Coastal Sediment Monitoring Programme

Whāngārei Harbour and Bay of Islands

2016 Results

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Table of contents

Figures

Tables

Executive Summary

Northland Regional Council (council) monitored sediment metal and nutrient concentrations in surficial sediments at 32 sites in the Whāngārei Harbour and Bay of Islands in 2016. The same sites have previously been sampled by council in 2010, 2012 and 2014. The aim of this programme is to assess the contaminant and enrichment status of the sediment, identify environmental issues and track changes in the quality of the sediment over time. This information can then be used to evaluate the effectiveness of Regional Plans, to inform decision makers and to help develop policy initiatives and strategies.

Sediment Metals

Concentrations of copper and zinc exceeded the ANZECC ISQG-Low effect trigger values at the Upper Hātea River site. The ANZECC ISQG-Low effect trigger values for zinc were also exceeded at the Waiarohia Canal. The concentration of lead surpassed the threshold effects level (TEL) developed by MacDonald et al. (1996) at both of these sites. Zinc levels at Limeburners Creek exceeded the TEL in addition to copper readings at Waiarohia Canal, Limeburners Creek, Awaroa Creek and Waimahanga Creek. Metal concentrations at two sites (Upper Hātea River and Waiarohia Canal) in the Upper Whāngārei Harbour are therefore at levels which have the potential to cause adverse effects on marine ecosystems. Beyond the Upper Hātea River sites, concentrations of metal contaminants were below ANZECC ISQG-Low effect trigger values and the TEL, with concentrations of metals generally decreasing towards the entrance of the harbour. In the Bay of Islands all metal concentrations were below the ANZECC ISQG-Low effect trigger values and the TEL.

Comparisons with surveys conducted by council in 2010, 2012 and 2014 indicate that metal concentrations have remained relatively stable at most sites. The main exceptions to this were decreases in the concentrations of copper at Waiarohia Canal and zinc at the Upper Hātea River and the Waiarohia Canal. Comparisons of mud % (<63µm) and 2016 metal results correlated weak, to moderately within the Bay of Islands. The converse applied within the Whangarei Harbour where there was strong to very strong correlation at all sites.

Sediment Nutrients

The phosphorus concentrations at the Upper Hātea River, Waiarohia and Limeburners Creek were ‘very enriched’ using criteria developed by Robertson and Stevens (2007). At Limeburners Creek and the Upper Hātea River, nitrogen and total organic carbon (TOC) concentrations were defined as ‘enriched’ using the same criteria. TOC concentrations were ‘very enriched’ at Waiarohia Canal. However, concentrations were defined as ‘enriched’ at Awaroa, Waimahanga, Otaika Creeks and Mangapai River. Measurements generally improved with proximity to the harbour entrance where results were classified as ‘low to moderately enriched’ or ‘good’.

In the Bay of Islands, elevated nutrient concentrations were more widespread, although higher concentrations were generally found in more sheltered estuarine environments compared to exposed sites in the outer bay. In total, 13 sites where classified as ‘enriched’ for phosphorus and eight sites for TOC. Comparisons of mud % (<63µm) and 2016 nutrient results were strong to very strongly correlated at the Whangarei Harbour sites. Conversely, correlation within the Bay of Islands was weak to moderate.

1 Introduction

Metal contaminants can have lethal and sub lethal effects on marine organisms and in a contaminated environment the species diversity and species richness may decrease. 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). Metal contaminants are generally not subject to bacterial attack or other breakdown so are permanent additions to the marine environment. Although plants and animals can usually regulate metal contaminants within a certain range, metals that cannot be excreted remain within the organisms and accumulate over time. As metals accumulate in an organism they can interfere with biological processes. The contaminants can also move progressively up the food chain as organisms are consumed by other animals including humans and this may ultimately pose a risk to human health.

While nutrients are essential for all forms of life, nutrients that enter the environment from human sources, such as fertilizer, stormwater and treated wastewater may exceed the needs of an ecosystem. Initially surplus nutrients may stimulate algal growth and subsequently benthic communities and fish populations because there is an increase in food via additional plant material and organic detritus. However, large increases in algae can disturb the ecosystem, as algal growth can decrease light levels, and as the algae dies they are decomposed by bacteria which consume oxygen and can cause the water to become anoxic (hypoxia). Nutrient enrichment can also cause algal blooms including toxic algal blooms.

Since 2010 council has monitored sediment metal concentrations in surficial sediments at 32 sites in the Whāngārei Harbour and Bay of Islands. Surveys have been conducted every two years in 2010, 2012 and 2014. In 2012, 2014 and 2016 sediment nutrient concentrations and TOC were also monitored.

The main objectives of this programme are to:

- Assess contaminant and nutrient status in sediments;
- Compare sediment metal levels with sediment quality guidelines; and
- Examine spatial and temporal trends in metal and nutrient concentrations.

The results from this programme will also enable council to assess the performance and effectiveness of Regional Plans, inform decision makers and help with the development of policy initiatives and strategies. The results also provide a background data set with which to compare contaminant levels from point source discharges (e.g. industrial stormwater discharges).

The programme addresses council's responsibilities under the Resource Management Act (1991) in relation to sustainable management principals set out in Part II (Section 5) and directives to monitor the state of the environment as set out in Part IV (Section 35; 1 & 2a Section 30; 1a). The programme also satisfies the Regional Community Outcomes of the Long Term Council Community Plan 2009-2019 (LTCCP).

This report presents the results of the 2016 sediment survey. A comparison of this data with surveys conducted in 2010, 2012 and 2014 is also presented.

2 Methods

2.1 Sampling Sites

2.1.1 Whāngārei Harbour

Sediment samples were collected from 16 subtidal sites distributed throughout the Whāngārei Harbour. Sites were located in order to capture the inputs from the harbour's main tributaries and to ensure a good geographical spread through the harbour (Figure 1). Five sites were located in the Hātea River arm of the harbour, as a significant proportion of the harbour's catchment drains into this arm, with sites also located in the Otaika Creek, Mangapai River, Takahiwai Creek and Marsden Bay.

2.1.2 Bay of Islands

Sediment samples were collected from 16 subtidal sites located throughout the Bay of Islands. Sites were located in order to capture the main freshwater inputs to the bay and to ensure a good geographical spread throughout the outer bay (Figure 2). All site co-ordinates can be found in Appendix 1.

2.2 Sample Collection and Analysis

Sediment was collected with a Van Veen grab sampler, from which the surface sediment (top 2cm) was collected, with a sterilised plastic scoop. Separate samples were collected for grain size analysis and geochemical analysis. In the field, samples were stored on ice in zip-lock bags. The samples were transported to council's office, frozen and sent to external laboratories for chemical analysis. Sediment samples were analysed externally by Water Care Laboratory Services to determine ash free dry weight (AFDW), total nitrogen, total phosphorus, total cadmium, total chromium, total copper, total zinc, total nickel and total lead. Total organic carbon (TOC) was calculated from ash free dry-weight (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. In 2010, only cadmium, chromium, copper, lead and zinc, and sediment grain size were monitored. Nickel, nitrogen, phosphorus and ash free dry weight were added to the programme in 2012.

2.3 Data Analysis and Guideline Values

The sediment metal concentrations were assessed against ANZECC ISQG-Low Trigger values (Australian New Zealand Environment Conservation Council 2000) and threshold effect levels (TEL) developed by MacDonald *et al*. (1996) (Table 1).

Table 1. Sediment quality guidelines (all units are mg/kg).

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

ANZECC guidelines do not include trigger values for nutrients or TOC in sediments and there are currently no nationally accepted guideline values. Instead sediment nutrient concentrations and TOC were assessed against a classification developed by Robertson and Stevens (2007) (Table 2).

Table 2. Sediment nutrient guidelines (nitrogen and phosphorus units are mg/kg).

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

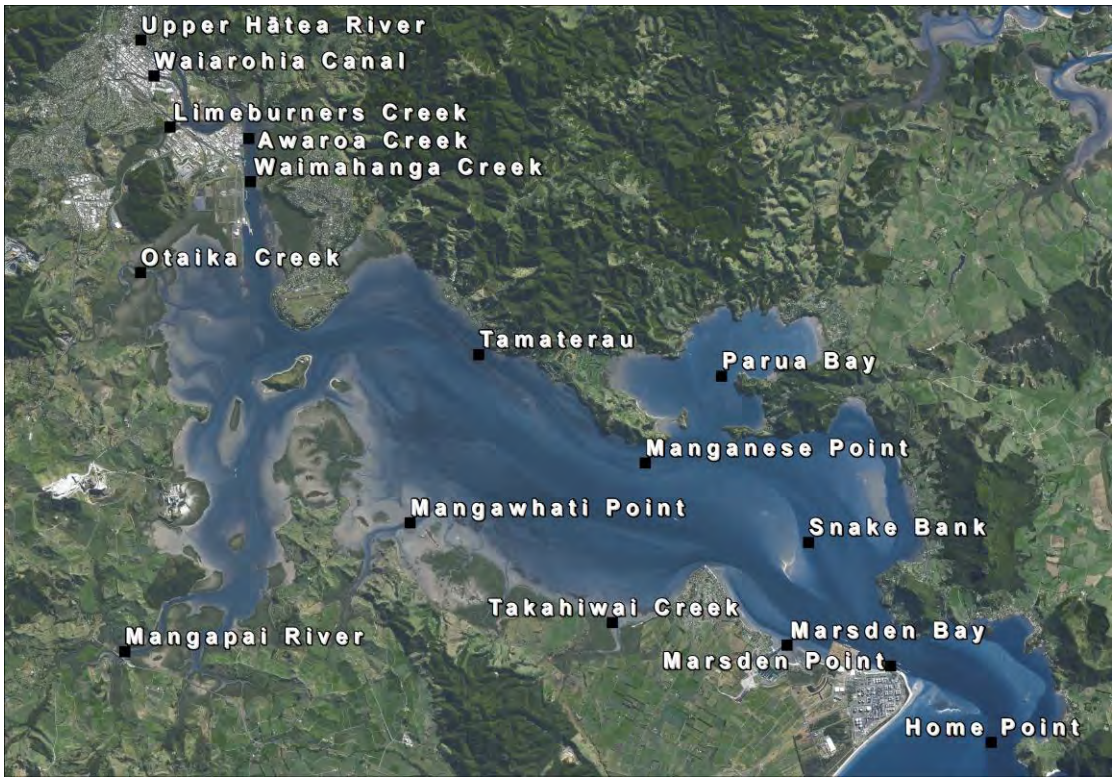

Figure 1. Location of sampling sites in Whāngārei Harbour.

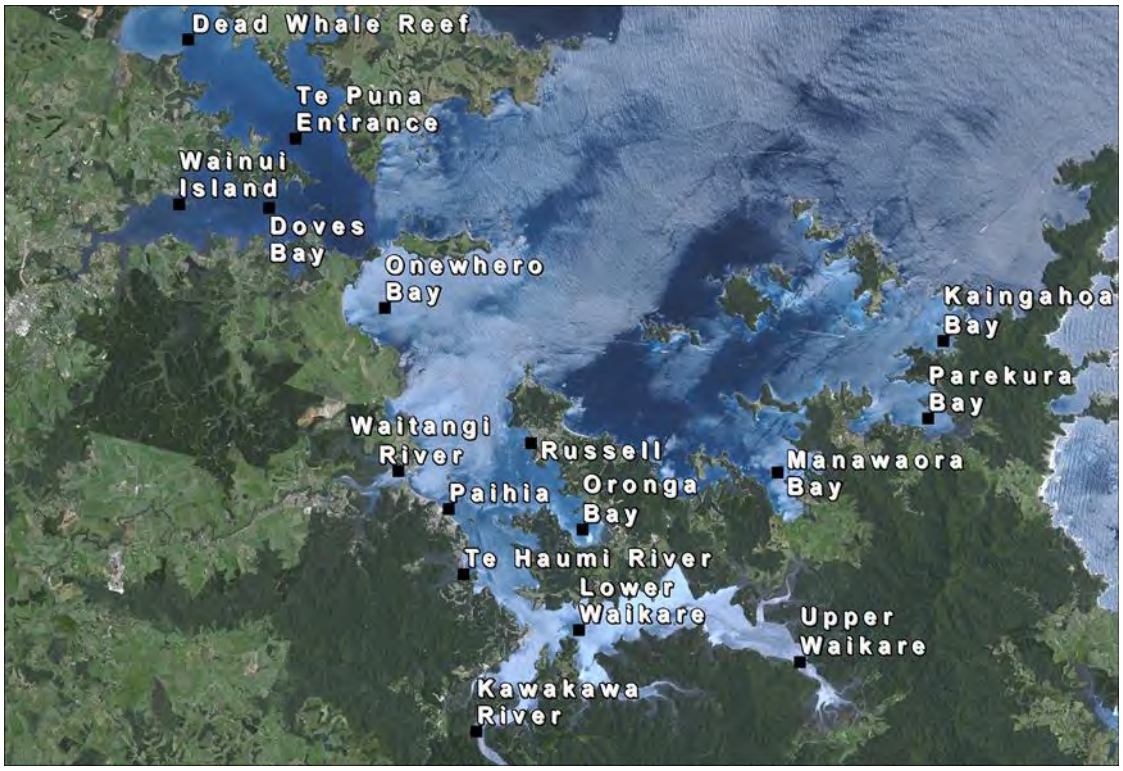

Figure 2. Location of sampling sites in Bay of Islands.

3 Results

3.1 Copper

Whāngārei Harbour

The highest total copper concentrations were recorded at the Upper Hātea River and the Waiarohia Canal. The concentrations at these two sites exceeded the ANZECC ISQG-Low effect trigger value of 65 mg/kg (Figure 3). These two sites have consistently held the highest concentrations of copper since the sediment monitoring programme commenced in 2010 (Table 3). All of the other copper concentrations measured were below the ANZECC ISQG-Low effect trigger value. However, copper concentration results exceeded the TEL of 18.7 mg/kg developed by MacDonald et al. (1996) at Limeburners Creek, Awaroa Creek, and Waimahanga (Figure 3 and Table 3). Concentrations of copper tended to decrease from the Hātea River to the entrance of the harbour. At Home Point and Marsden Point, near the harbour entrance, the concentrations of copper were 0.44 mg/kg and 0.46mg/kg respectively. The copper concentration detection limit is <0.45 mg/kg.

Similar spatial patterns were observed in 2010, 2012 and 2014 with the highest concentrations recorded at sites in the Upper Hātea River and lowest concentrations towards the harbour entrance (Table 3). Collectively the Upper harbour sites of; Upper Hātea River, Waiarohia Canal, Limeburners Creek, Awaroa Creek and Waimahanga Creek have exceeded either the TEL or the ANZECC ISQG-Low effect trigger value since sampling started in 2010. The Upper Hātea River and Waiarohia Canal have exceeded both values on two occasions whereas Limeburners Creek (2012 & 2016), Awaroa Creek (2014 & 2016) and Waimahanga Creek (2014 & 2016) have exceeded the TEL value. Conversely, in 2010 the copper concentration at Otaika Creek (29 mg/kg) exceeded the TEL but in subsequent years (2012, 2014, and 2016) the concentrations were well below the TEL (6.8 mg/kg, 8.5 mg/kg and 8.8 mg/kg respectively).

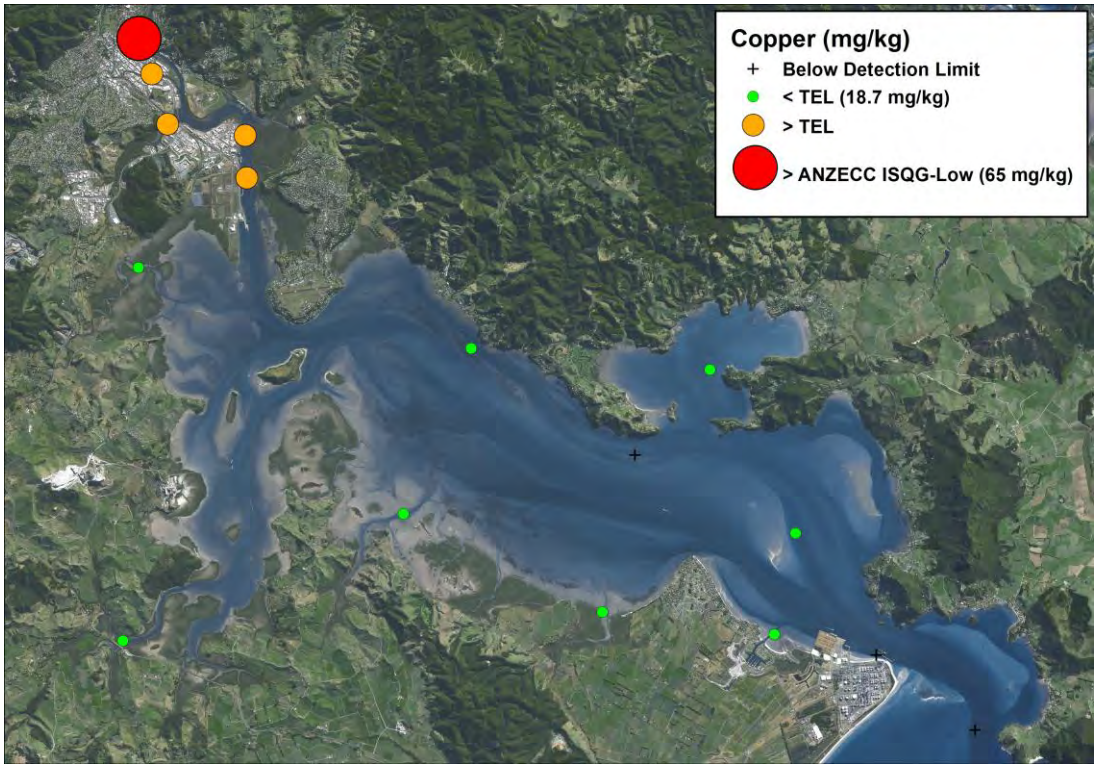

Figure 3. Sediment copper concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

In the Bay of Islands all the copper concentrations measured were below the ANZECC ISQG-Low effect trigger value of 65 mg/kg and the TEL of 18.7 mg/kg (Figure 4). The highest values were recorded at Lower Waikare (15 mg/kg), Wainui Island, Doves Bay and Te Puna entrance with the previous three sites all recording 12 mg/kg. The lowest value was recorded at Onewhero Bay (1.7 mg/kg) (Figure 4).

Since 2010 all copper concentrations measured were also below the ANZECC ISQG-Low effect trigger value and the TEL (Table 5). Results from 2010 to 2016 show copper concentrations have slightly decreased at Wainui Island and Kawakawa, remained steady at Doves Bay, and slightly increased at Te Puna entrance and Lower Waikare. Onewhero Bay has consistently recorded the lowest copper concentration over all four sampling years.

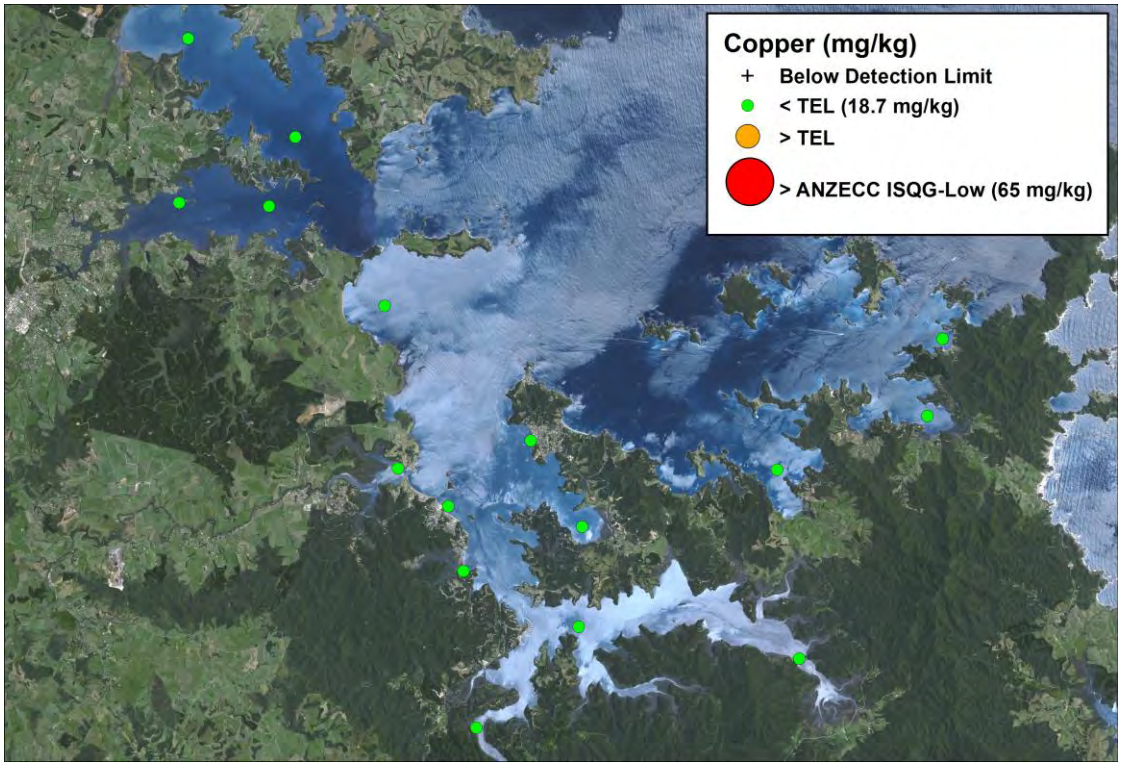

Figure 4. Sediment copper concentrations in the Bay of Islands in 2016.

3.2 Zinc

Whāngārei Harbour

The Upper Hātea River and the Waiarohia Canal shared the highest total zinc concentrations of 210 mg/kg (Figure 5 and Table 3). The concentration of zinc at these two sites exceeded the ANZECC ISQG-Low effect trigger value of 200mg/kg. All other sites zinc concentrations were below the ANZECC ISQG-Low effect trigger value with only Limeburners Creek (140 mg/kg) exceeding the TEL of 124 mg/kg. The highest concentrations were recorded at sites within the Upper harbour with concentrations decreasing towards the entrance of the harbour (Figure 5).

Home Point (6.6 mg/kg) recorded the lowest zinc concentration and was slightly below the detection limit of <6.7 mg/kg. This was followed closely by Takahiwai Creek (6.7 mg/kg), Marsden Bay (6.8 mg/kg) and Marsden Point (6.9 mg/kg).

Similar spatial patterns were found in 2010, 2012, and 2014 with the highest concentrations recorded at sites in the Upper Hātea River and lowest concentrations towards the harbour entrance (Table 3). Since 2012, the Upper Hātea River zinc concentrations have exceeded TEL twice (2012 & 2014) and the ANZECC ISQG-Low effect trigger value in 2016. The Waiarohia Canal zinc concentration has exceeded the ANZECC ISQG-Low effect trigger value on three out of four occasions (2010, 2014 & 2016). The TEL was also exceeded in 2012 at the Waiarohia Canal.

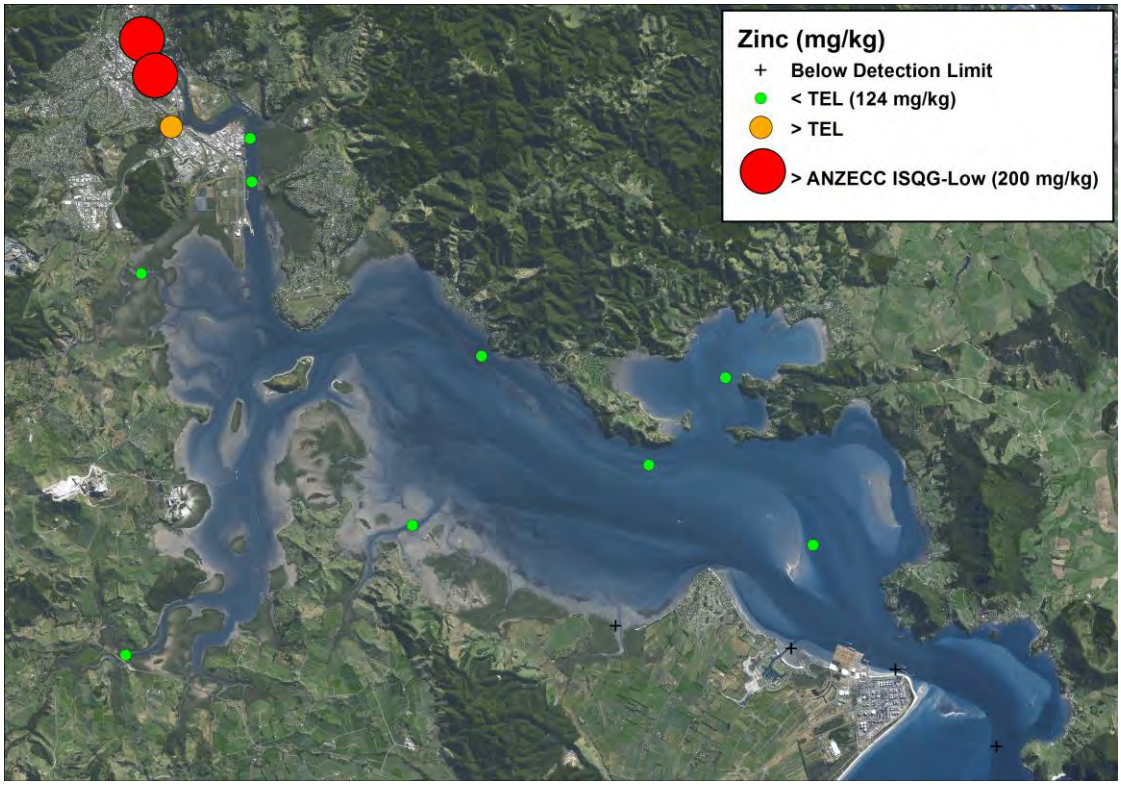

Figure 5. Sediment zinc concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

In the Bay of Islands all of the zinc concentrations measured were below the ANZECC ISQG-Low effect trigger value of 200 mg/kg and the TEL (Figure 6 and Table 5). The highest values were recorded at the Wainui Island (82 mg/kg) and the two sites in the Waikare Inlet (Upper Waikare Inlet 66 mg/kg and Lower Waikare Inlet 69 mg/kg). The lowest concentration was recorded at Onewhero Bay (23 mg/kg) (Figure 6).

Since sediment monitoring started in 2010 all of the zinc concentrations measured was below the ANZECC ISQG-Low effect trigger value and the TEL (Table 5).

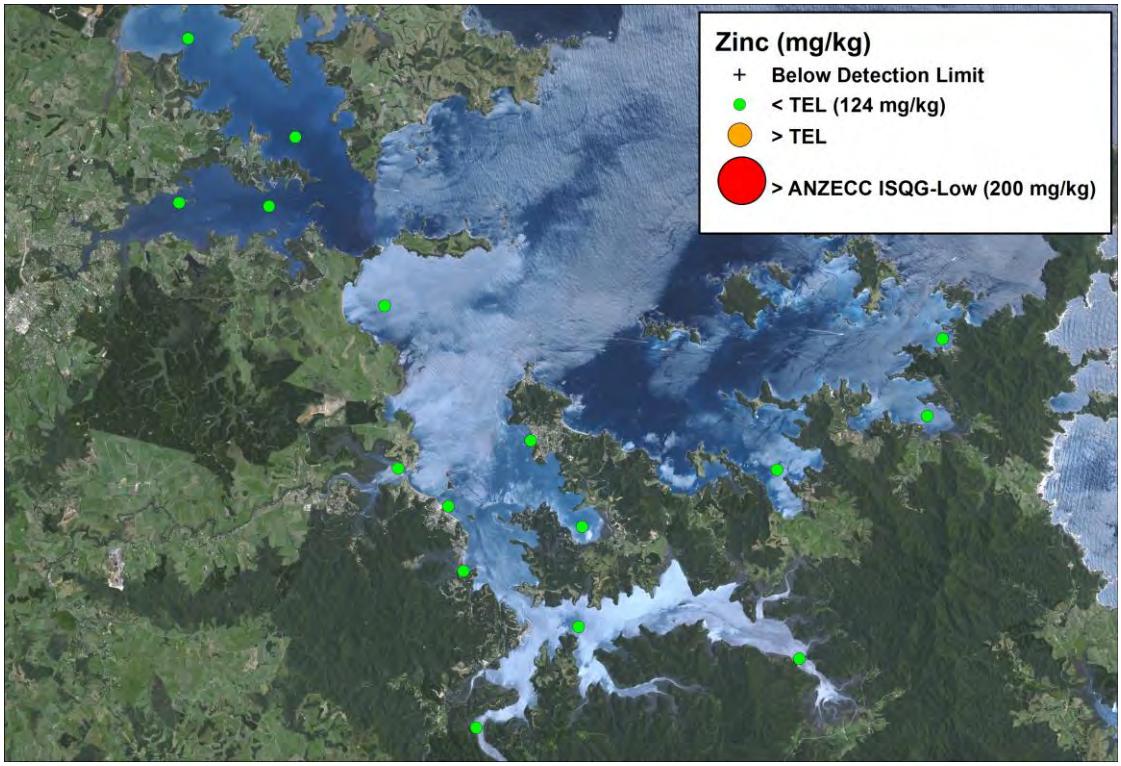

Figure 6. Sediment zinc concentrations in the Bay of Islands in 2016.

3.3 Lead

Whāngārei Harbour

All of the lead concentrations measured were below the ANZECC ISQG-Low effect trigger value of 50 mg/kg. However, concentrations at the Upper Hātea River (33 mg/kg) and the Waiarohia Canal (31 mg/kg) exceeded the TEL of 30.2 mg/kg (Figure 7 and Table 3). The highest total lead concentrations were recorded at sites in the Upper harbour (Upper Hātea River sites) with concentrations decreasing towards the harbour entrance. The lowest concentrations were found at Takahiwai Creek (0.7 mg/kg), Home Point (0.77 mg/kg), Marsden Bay and Marsden Point both recording 0.72 mg/kg.

Similar patterns were found in 2010, 2012 and 2014 with the highest concentrations recorded at the Upper Hātea River and Waiarohia Canal sites over the same period (Table 3). Results from the Upper Hātea River show that the TEL was surpassed twice (2014 & 2016). However, at the Waiarohia Canal site the TEL was exceeded on three occasions (2010, 2014 & 2016). Additionally, the ANZECC ISQG-Low effect trigger value was surpassed once in 2012 with a reading of 51 mg/kg.

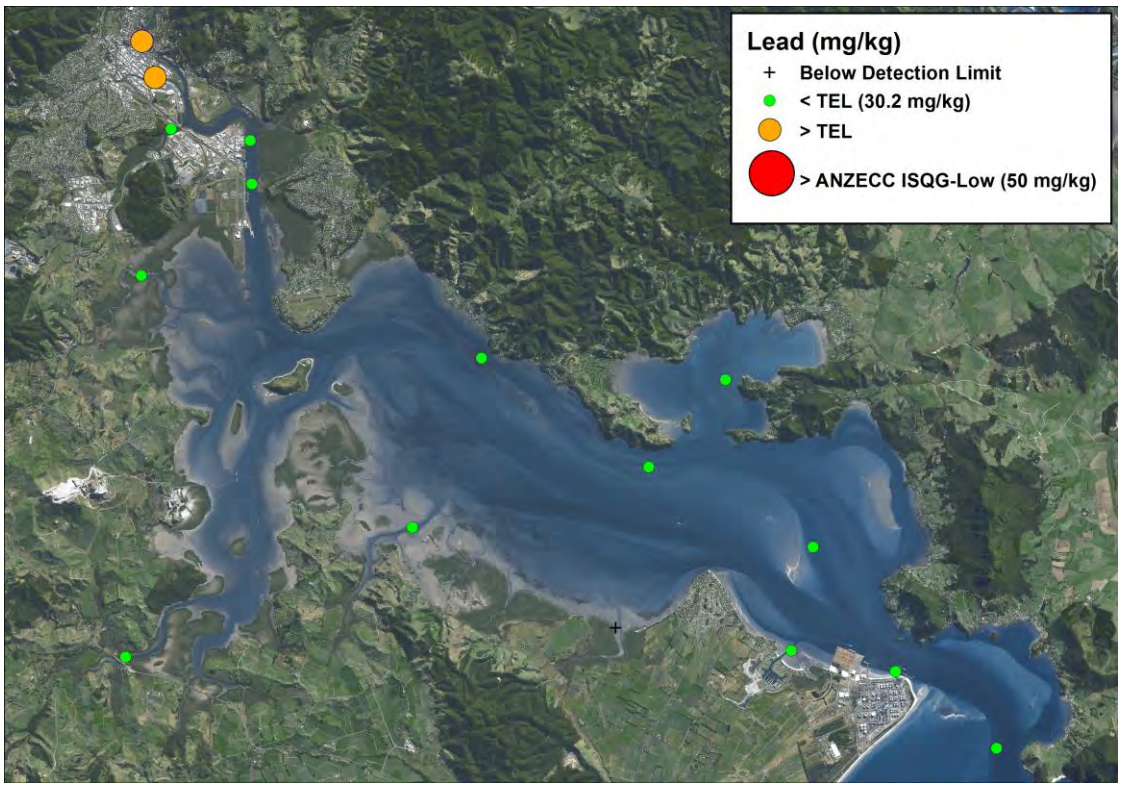

Figure 7. Sediment lead concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

All lead concentrations were below the ANZECC ISQG-Low effect trigger value of 50 mg/kg and the TEL of 30.2 mg/kg (Figure 8 and Table 5). The highest values were recorded at Dead Whale Reef (15 mg/kg), Bay of Islands (15 mg/kg) and Lower Waikare Inlet (14 mg/kg). The lowest concentration was recorded at Kaingahoa Bay (3.9 mg/kg).

Since sediment monitoring commenced in 2010 lead concentrations results have been below both the ANZECC ISQG-Low effect trigger value and the TEL (Table 5). In 2010, the highest value was recorded at the Lower Waikare Inlet, 2012 at Russell and 2014 at Kawakawa River. The lowest value was recorded at Kaingahoa Bay over all four sampling years.

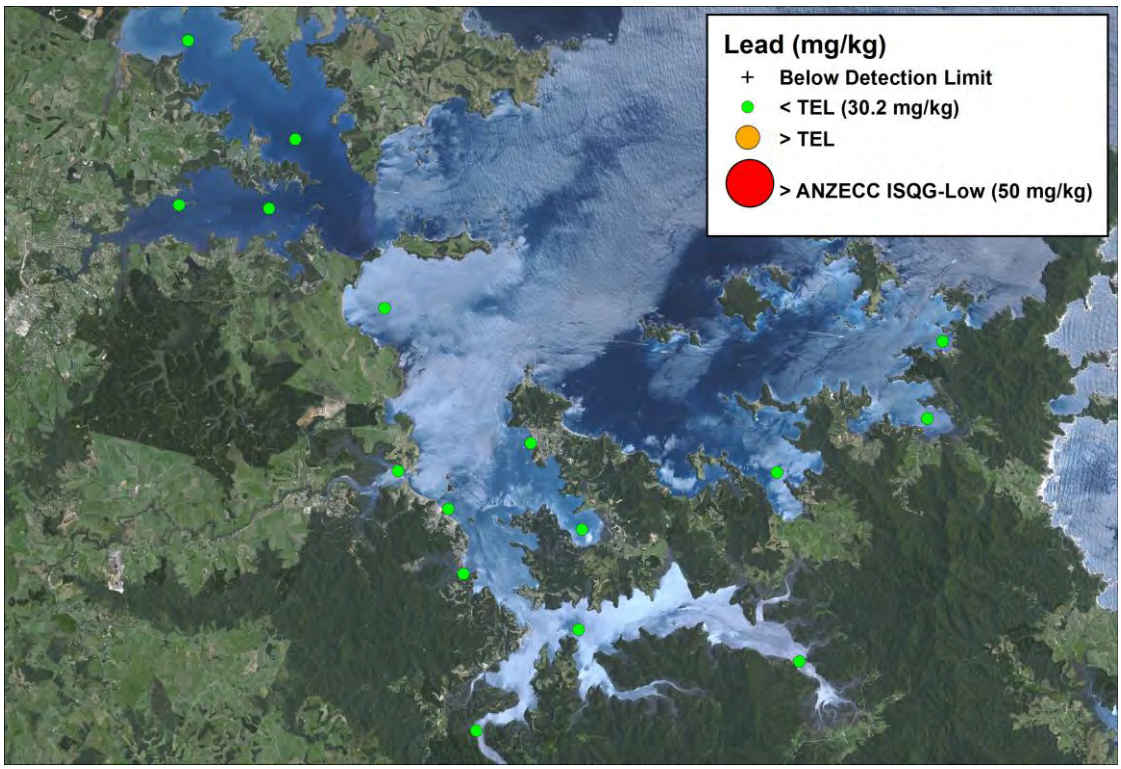

Figure 8. Sediment lead concentrations in the Bay of Islands in 2016.

3.4 Chromium

Whāngārei Harbour

All chromium concentrations measured were below the ANZECC ISQG-Low effect trigger value of 80 mg/kg and the TEL value of 52.3 mg/kg (Figure 9 and Table 3). The highest concentrations were recorded at the Upper Hātea River, Waiarohia Canal, and Waimahanga Creek (25 mg/kg, 19 mg/kg and 16 mg/kg respectively). Chromium concentrations were lower towards the harbour entrance with the lowest values found at Takahiwai Creek (3 mg/kg), Marsden Bay (3.6 mg/kg) and Marsden Point (3.8 mg/kg) (Figure 9).

Since sediment monitoring commenced in 2010, all chromium concentrations have been below the ANZECC ISQG-Low effect trigger value and the TEL (Table 3). The highest concentrations were found at the Upper Hātea River and Waiarohia Canal during the same period. The lowest chromium concentrations levels have consistently been recorded near the entrance of the harbour with Takahiwai Creek receiving the lowest ever result of 3 mg/kg.

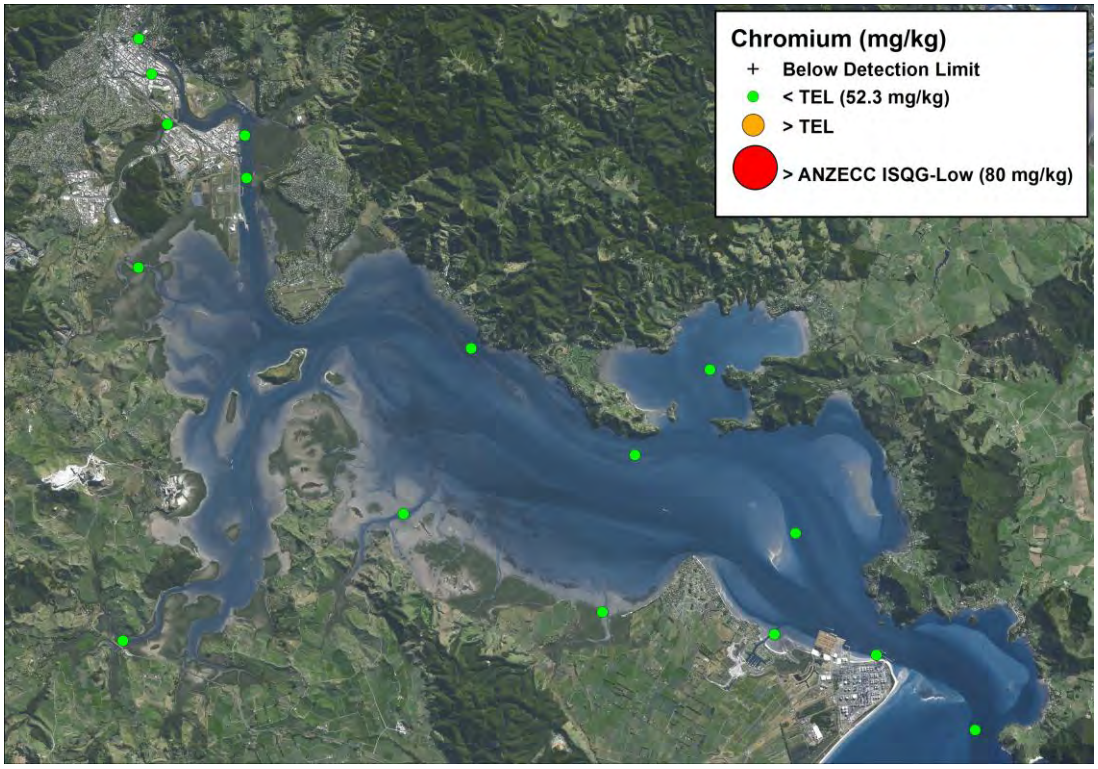

Figure 9. Sediment chromium concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

All chromium concentrations were below both the ANZECC ISQG-Low effect trigger value of 80 mg/kg and the TEL of 52.3 mg/kg (Figure 10 and Table 5). The highest values were recorded at Wainui Island (48 mg/kg), Doves Bay (38 mg/kg) and Te Puna entrance (35 mg/kg). The lowest concentration was found at Te Haumi River (7.2 mg/kg).

Since 2010, all of the chromium concentrations measured was also below the ANZECC ISQG-Low effect trigger value and the TEL (Table 5). From 2010 to date, the highest values have been recorded at Wainui Island, Doves Bay and Te Puna entrance. The lowest value, over the same period, has regularly been recorded at Te Haumi River.

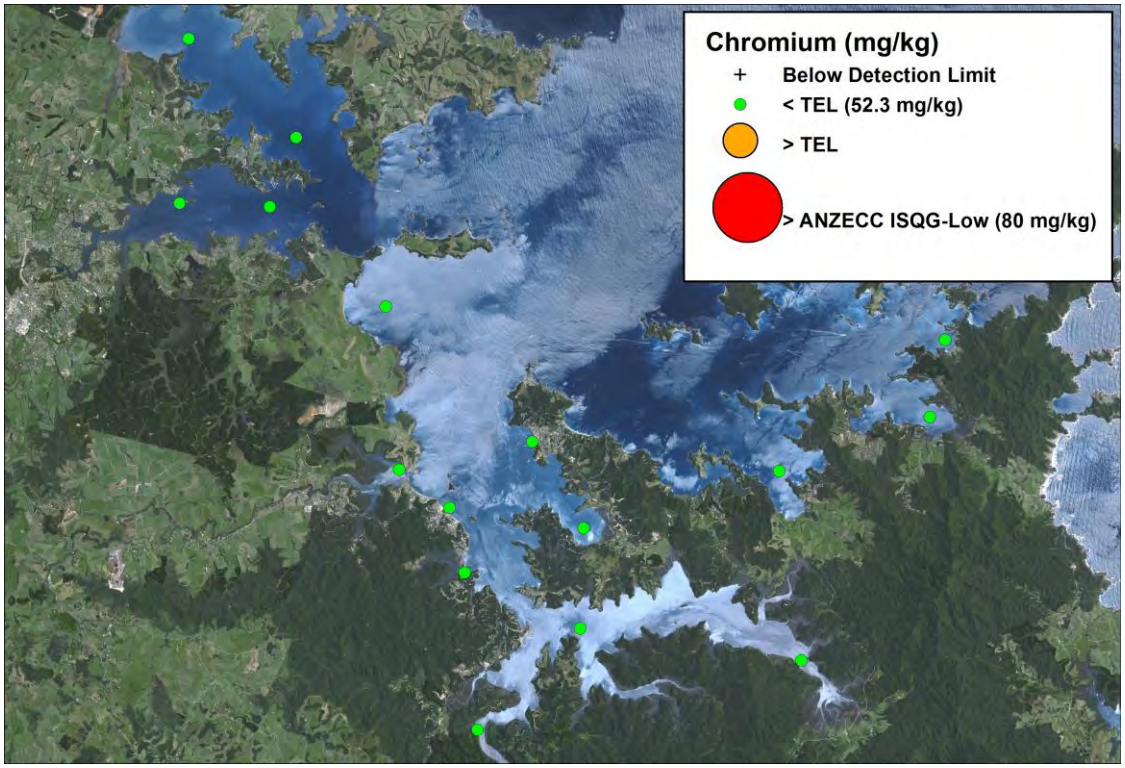

Figure 10. Sediment chromium concentrations in the Bay of Islands in 2016.

3.5 Nickel

Whāngārei Harbour

Since nickel sampling started in 2012, concentrations have been below the ANZECC ISQG-Low effect trigger value of 21 mg/kg and the TEL of 15.9 mg/kg (Figure 11 and Table 3). The highest concentrations were recorded at the Upper Hātea River (12 mg/kg) and Waiarohia Canal (11 mg/kg) sites (Figure 11). Lower concentrations were found towards the harbour entrance with the lowest value recorded at Marsden Point (0.8 mg/kg).

In 2012 and 2014 the highest concentrations were also recorded at the Upper Hātea River and Waiarohia Canal. In 2012 the nickel concentration at Waiarohia Canal exceeded the TEL (Table 3). The lowest value was recorded at Marsden Bay (0.83 mg/kg) in 2012. In 2014 the lowest nickel result was 1.0 mg/kg which was recorded at Marsden Bay and Marsden Point.

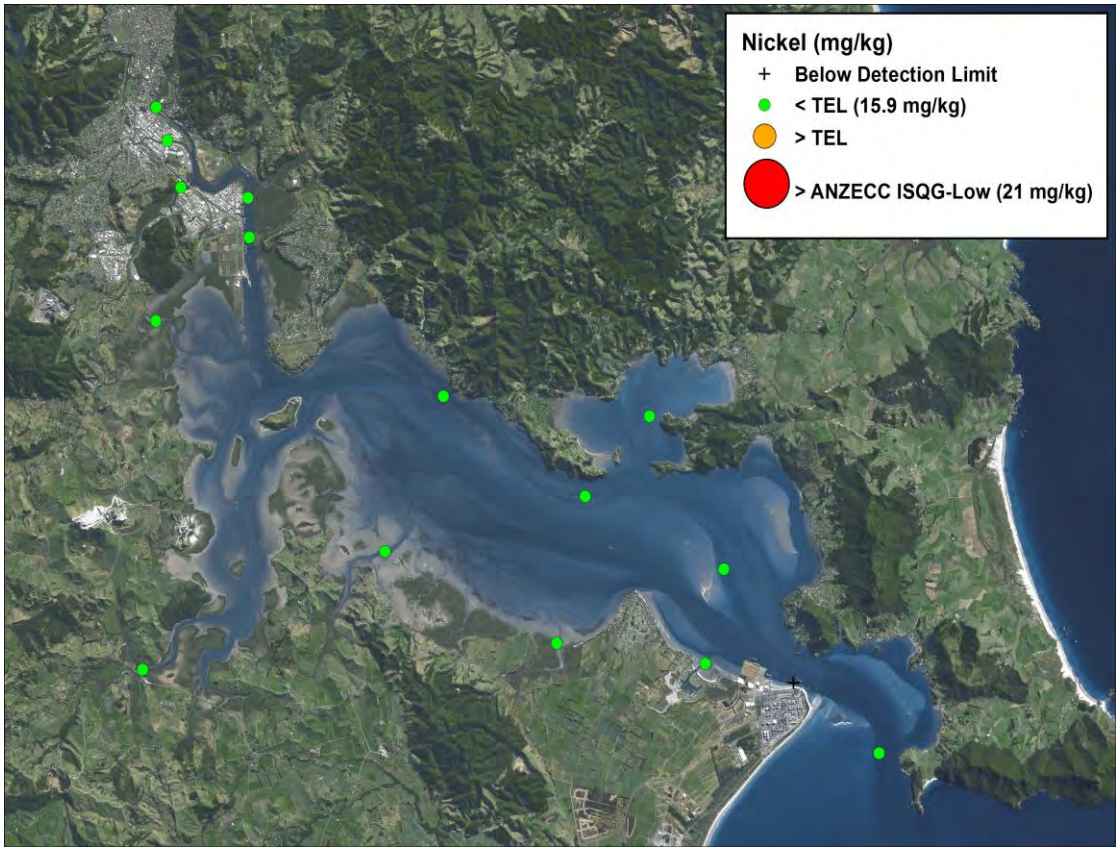

Figure 11. Sediment nickel concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

Sampling for nickel concentrations in the Bay of Islands started in 2014. In 2014 and 2016 nickel concentrations were below the ANZECC ISQG-Low effect trigger value of 21 mg/kg and the TEL of 15.9 mg/kg. The highest recorded levels were at Doves Bay 15 mg/kg (both years), Wainui Island 14 mg/kg (both years) and Te Puna entrance 13 mg/kg and 15 mg/kg respectively. This collective of sites were close to exceeding the TEL (Figure 12 & Table 5). The lowest concentrations were recorded at Kaingahoa Bay 2.8 mg/kg and 3.4 mg/kg and Te Hamui River 3.2 mg/kg and 4.5 mg/kg.

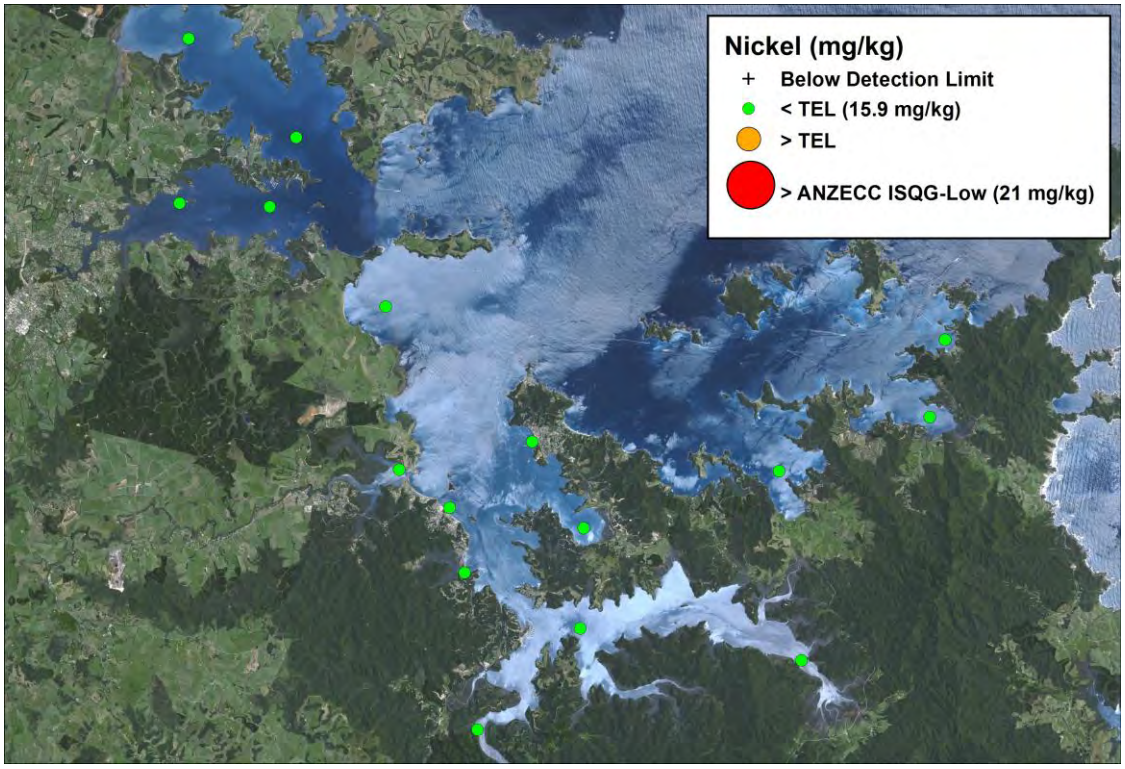

Figure 12. Sediment nickel concentrations in the Bay of Islands in 2016.

3.6 Cadmium

Whāngārei Harbour

All of the cadmium concentrations were below the ANZECC ISQG-Low effect trigger value of 1.5 mg/kg and the TEL of 0.68 mg/kg (Figure 13 and Table 3). In total, 12 of the sites had concentrations below the detection limit (<0.09 mg/kg). The sites with the highest concentrations were the Upper Hātea River and Limeburners Creek (both 0.15 mg/kg).

In 2010 and 2012 all cadmium concentrations were also below the ANZECC ISQG low effect trigger value and the TEL (Table 3). The highest concentrations were recorded at the Upper Hātea River, Otaika Creek and Waiarohia Canal in 2010, Upper Hātea River and Waiarohia Canal in 2012. In 2014 Upper Hātea River and Limeburners Creek recorded the highest concentrations. The remaining sites were close to or below detection limits.

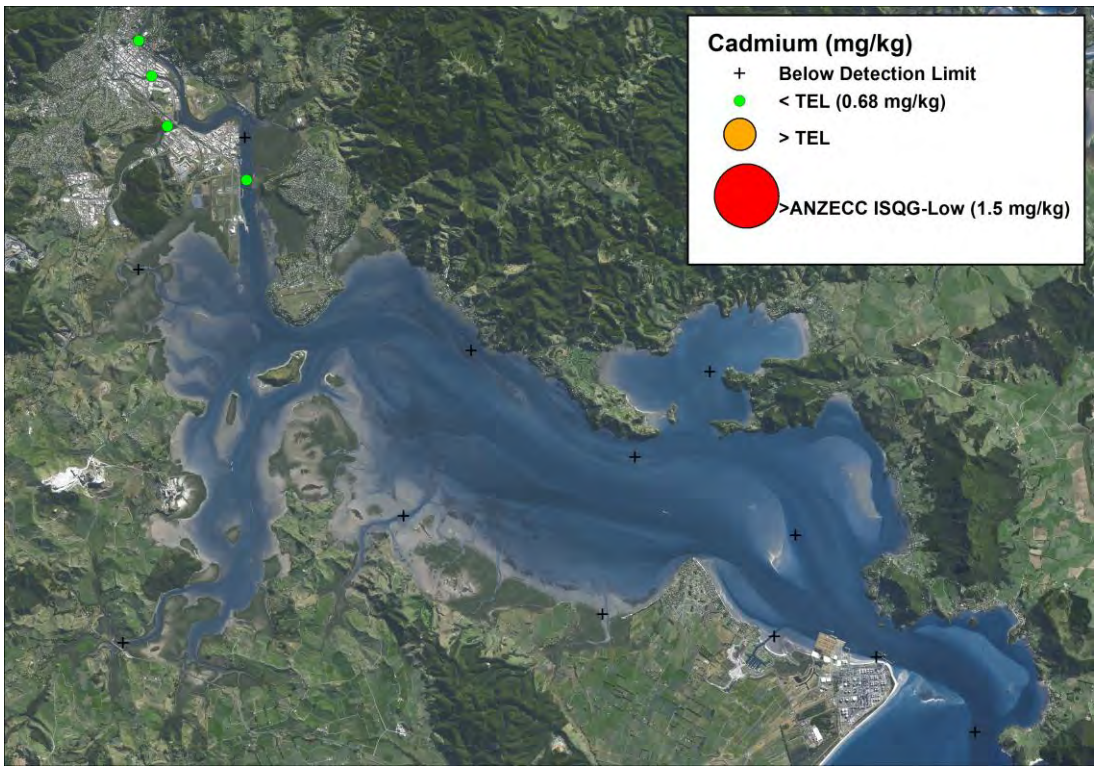

Figure 13. Sediment cadmium concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

All of the cadmium concentrations were below the detection limits of <0.09 mg/kg at all 16 sites (Figure 14).

To date the Doves Bay; Lower Waikare, Te Haumi, Oronga Bay and Onewhero sites have yet to exceed the cadmium detection limit.

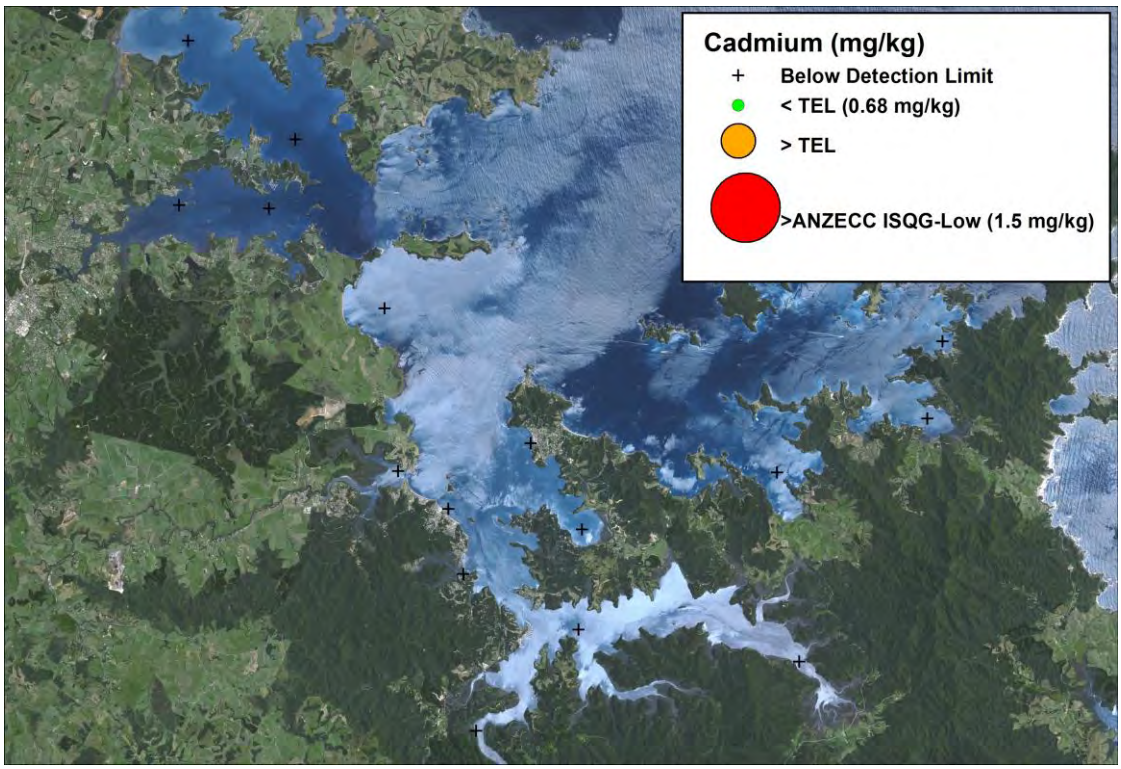

Figure 14. Sediment cadmium concentrations in the Bay of Islands in 2016.

3.7 Total Organic Carbon (TOC)

Whāngārei Harbour

The highest levels of TOC were found at the Waiarohia Canal (5.21 %w/w), Upper Hātea River (4.98 %w/w) and Limeburners Creek (4.57 %w/w) sites (Figure 15 and Table 4). The lowest values were recorded near the harbour entrance at Home Point (0.28 %w/w), Mangawhati Point (0.32 %w/w), Manganese Point and Marsden Bay (both 0.36 %w/w). ANZECC guidelines do not include trigger values for TOC in marine sediments. However, Robertson and Stevens (2007) have developed an enrichment classification for TOC. Robertson and Stevens (2007) classify TOC levels as follows; below 1% 'good', between 1-2% 'low to moderately enriched', between 2-5% 'enriched' and levels above 5% as 'very enriched'. Under these criteria, seven of 16 sites were classified as 'good', two sites were 'low to moderately enriched', six sites as 'enriched' and one 'very enriched' (Figure 15). The level for TOC at the Waiarohia Canal site (4.85 %w/w) was close to the threshold for 'very enriched'.

In 2012, five sites were classified as 'good', nine sites were 'low to moderately enriched' and two sites were 'enriched'. In 2014, results showed that five sites were 'enriched', two 'low to moderately enriched' and nine 'good' (Table 4).

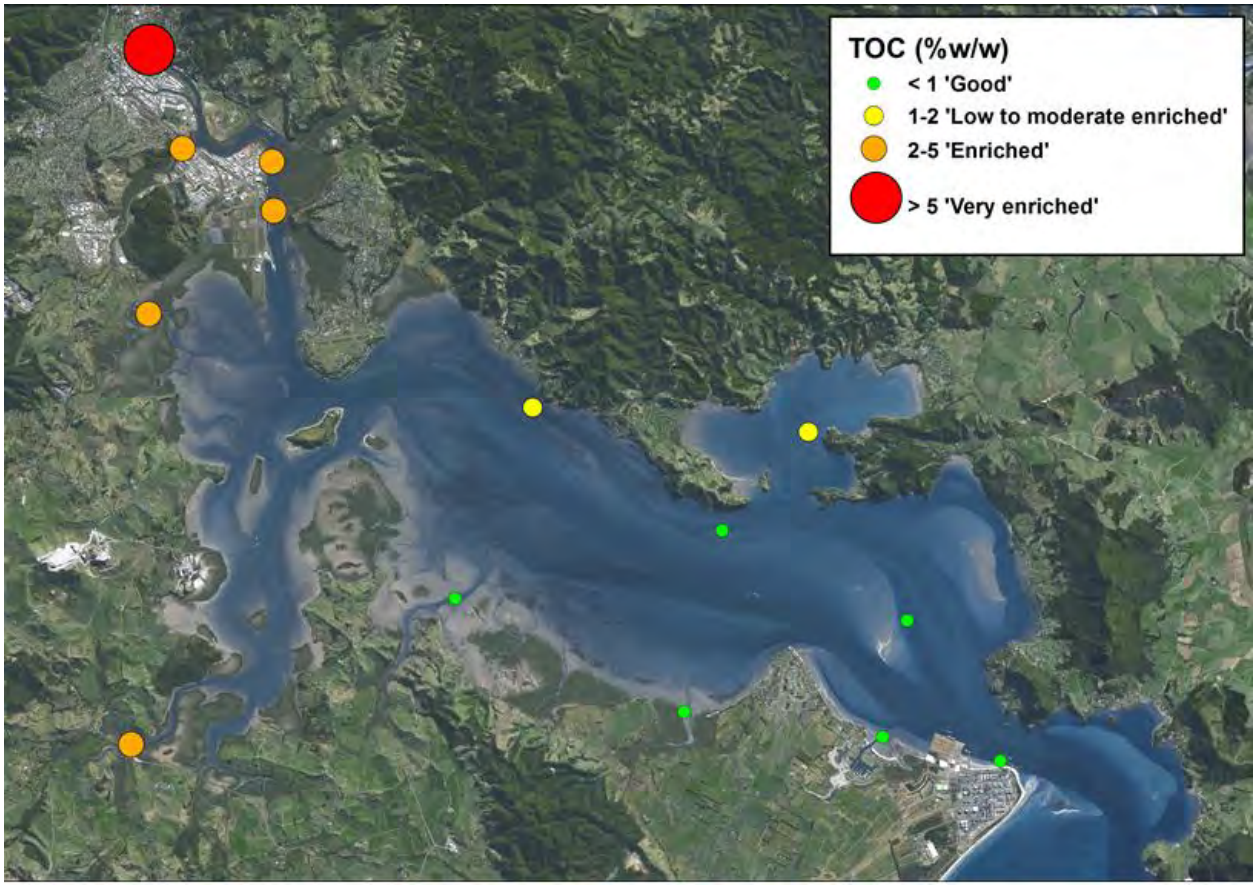

Figure 15. Sediment TOC concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

The highest levels of TOC were found at Doves Bay (4.39 %w/w) and Te Puna entrance (3.89 %w/w) (Figure 16 and Table 6). The lowest values were at the Kawakawa River (0.85 %w/w) and Te Haumi River (1.06 %w/w). Using the classification developed by Robertson and Stevens (2007) eight sites were classified as 'low to moderately enriched' and eight sites as 'enriched' (Figure 16 & Table 6). In both 2012 and 2014, eight sites were classified as 'low to moderately enriched' and eight sites as 'enriched' (Table 6).

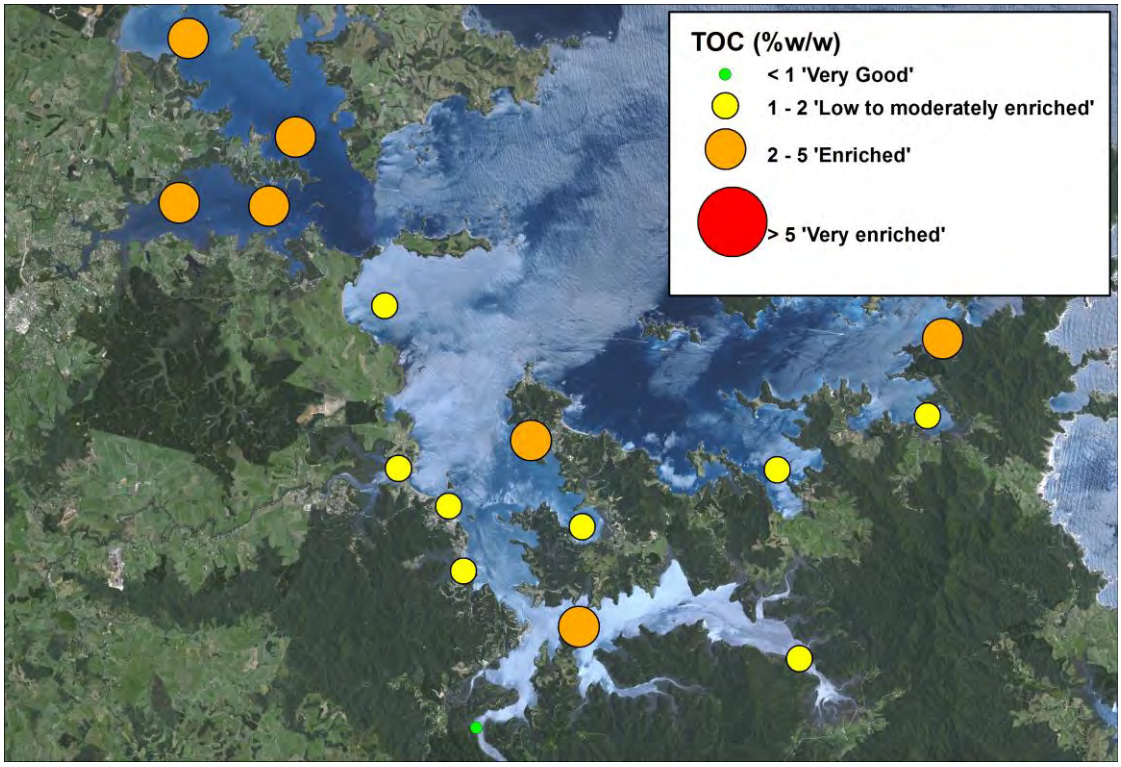

Figure 16. Sediment TOC concentrations in the Bay of Islands in 2016.

3.8 Nitrogen

Whāngārei Harbour

The highest concentration of nitrogen was recorded at the Waiarohia Canal (3500 mg/kg), with the lowest value recorded at Tamaterau (110 mg/kg) (Figure 17 and Table 4). ANZECC guidelines do not include trigger values for nitrogen in marine sediments but Robertson and Stevens (2007) developed a classification for sediment nitrogen concentrations. Using this classification concentrations below 500 mg/kg are classified as 'good', concentrations between 500-2000 mg/kg are classified as 'low to moderately enriched', concentrations between 2000-4000 mg/kg are classified as 'enriched' and concentrations above 4000 mg/kg as 'very enriched'. Using this classification system the concentrations of nitrogen at nine of 16 sites were classified as 'good', four sites as 'low to moderately enriched' and three sites 'enriched' (Figure 17 & Table 4).

In 2012 Limeburners Creek was classified as 'very enriched', six sites were 'low to moderately enriched' and nine sites were 'good'. Results from 2014 indicated that seven sites were 'good', six were 'low to moderately enriched' and three 'enriched' (Table 4).

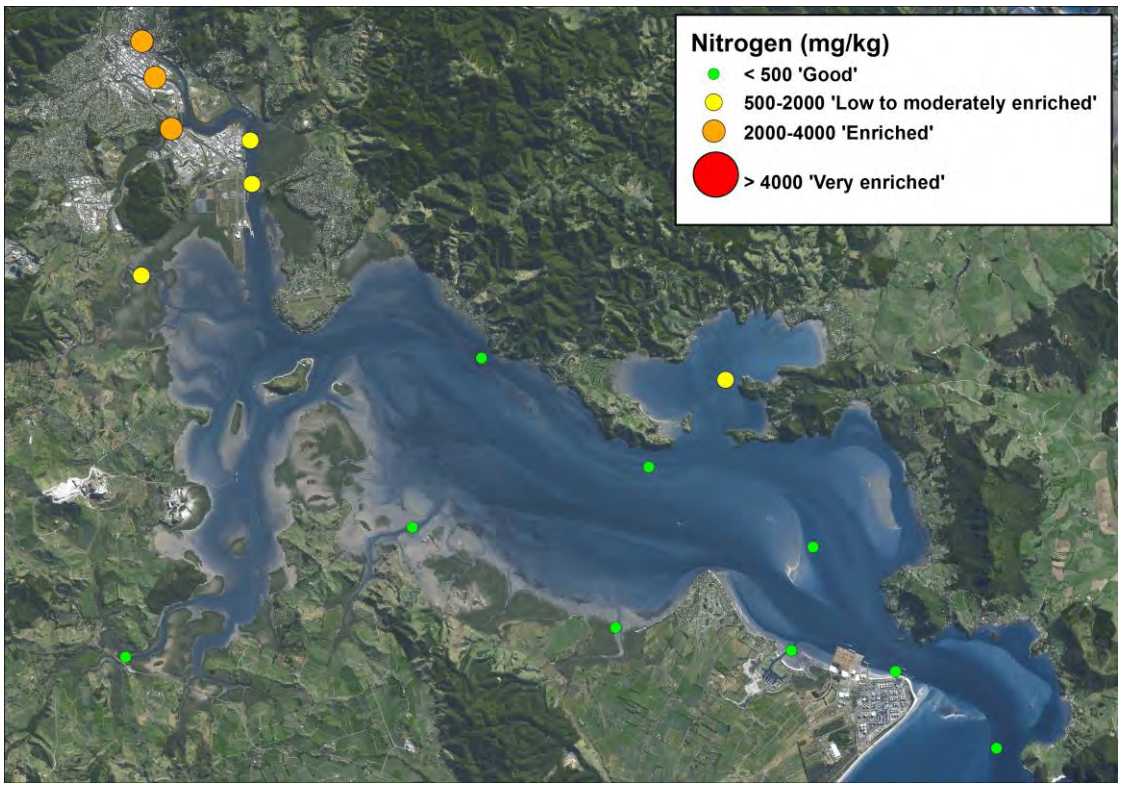

Figure 17. Sediment nitrogen concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

The highest concentration of nitrogen was recorded at Te Puna entrance and Doves Bay (both 1700 mg/kg) and the lowest value was at Onewhero Bay (280 mg/kg) (Figure 18 and Table 6). Under the classification developed by Robertson and Stevens (2007) three sites were classified as 'good' and 13 as 'low to moderately enriched'.

In 2012, four sites were 'good' and 12 sites were 'low to moderately enriched'. Results from 2014 indicated that four sites were 'good', 11 were 'low to moderately enriched' and one 'enriched' (Table 6).

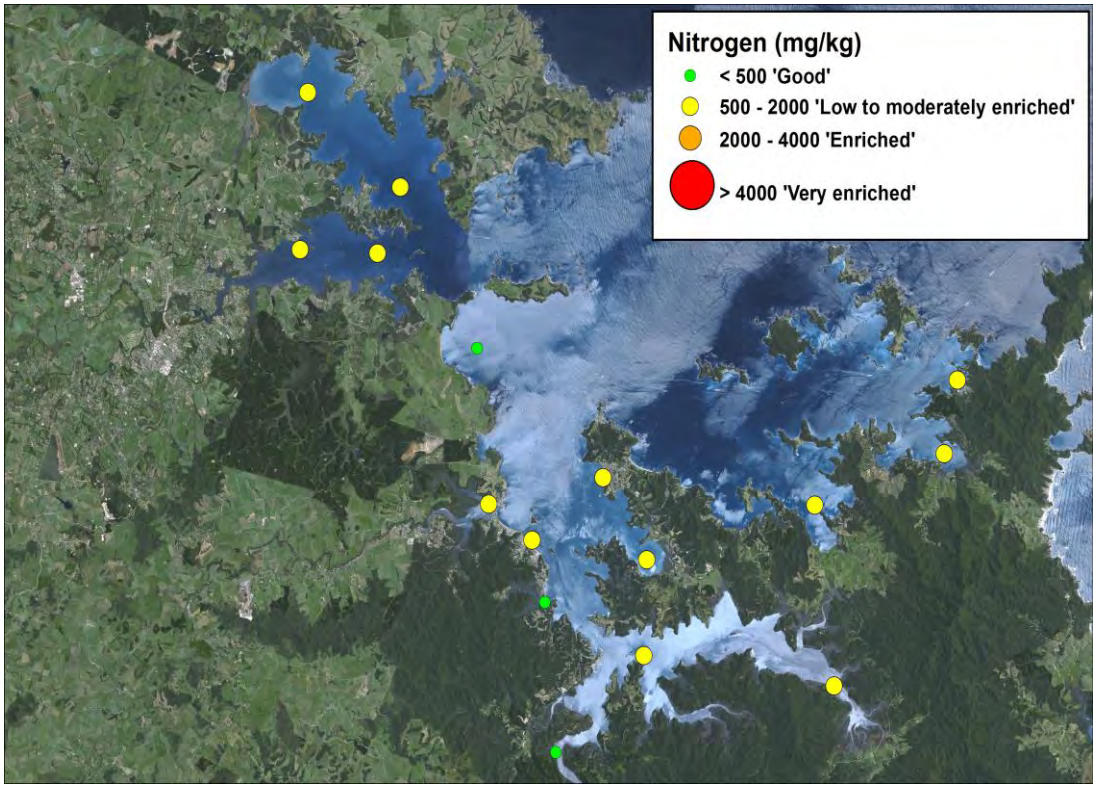

Figure 18. Sediment nitrogen concentrations in the Bay of Islands in 2016.

3.9 Phosphorus

Whāngārei Harbour

The highest concentrations of phosphorus were recorded at the Upper Hātea River (1500 mg/kg), Waiarohia Canal (1100 mg/kg) and Limeburners Creek (1400 mg/kg) with the lowest concentrations found at Takahiwai Creek (52 mg/kg) (Figure 19 and Table 4). ANZECC guidelines do not include trigger values for phosphorus in sediments but Robertson and Stevens (2007) also developed a classification for sediment phosphorus concentrations. In their classification concentrations below 200 mg/kg are classified as '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 seven sites were classified as 'good', four sites as 'low to moderately enriched', two sites as 'enriched' and three as 'very enriched' (Figure 19 and Table 4).

In 2012, eight sites were 'good', three sites were 'low to moderately enriched', four sites were 'enriched and one site (Limeburners Creek) was 'very enriched'. Results from 2014 indicated that seven sites were 'good', four 'low to moderately enriched', three 'enriched', and two 'very enriched' (Table 4).

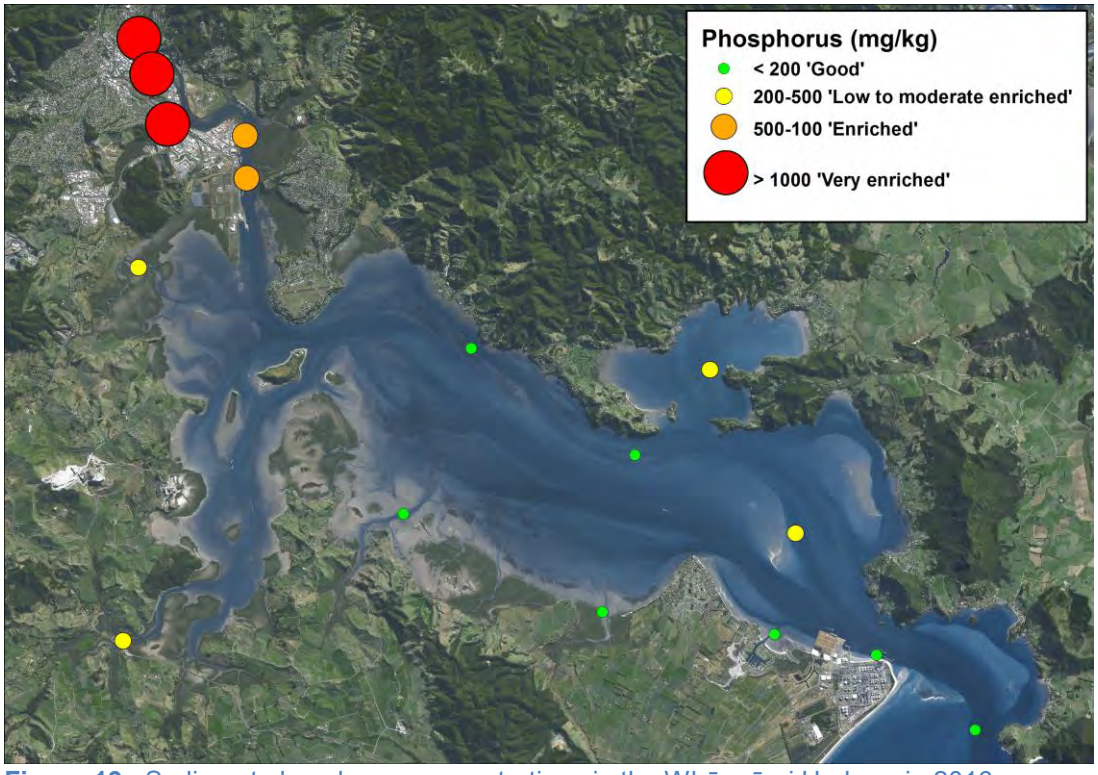

Figure 19. Sediment phosphorus concentrations in the Whāngārei Harbour in 2016.

Bay of Islands

The highest phosphorus concentration was at Wainui Island (980 mg/kg) and the lowest value was at Orongo Bay (380 mg/kg) (Figure 20 and Table 6). Under the classification developed by Robertson and Stevens (2007) three sites were classified as 'low to moderately enriched' and 13 sites as 'enriched' (Figure 20). In 2012, 13 sites were 'enriched' and one site was 'very enriched' and two were low to moderately enriched.

Results from 2014 indicated that three sites were 'low to moderately enriched' with the remaining 13 classified as 'enriched' (Table 6).

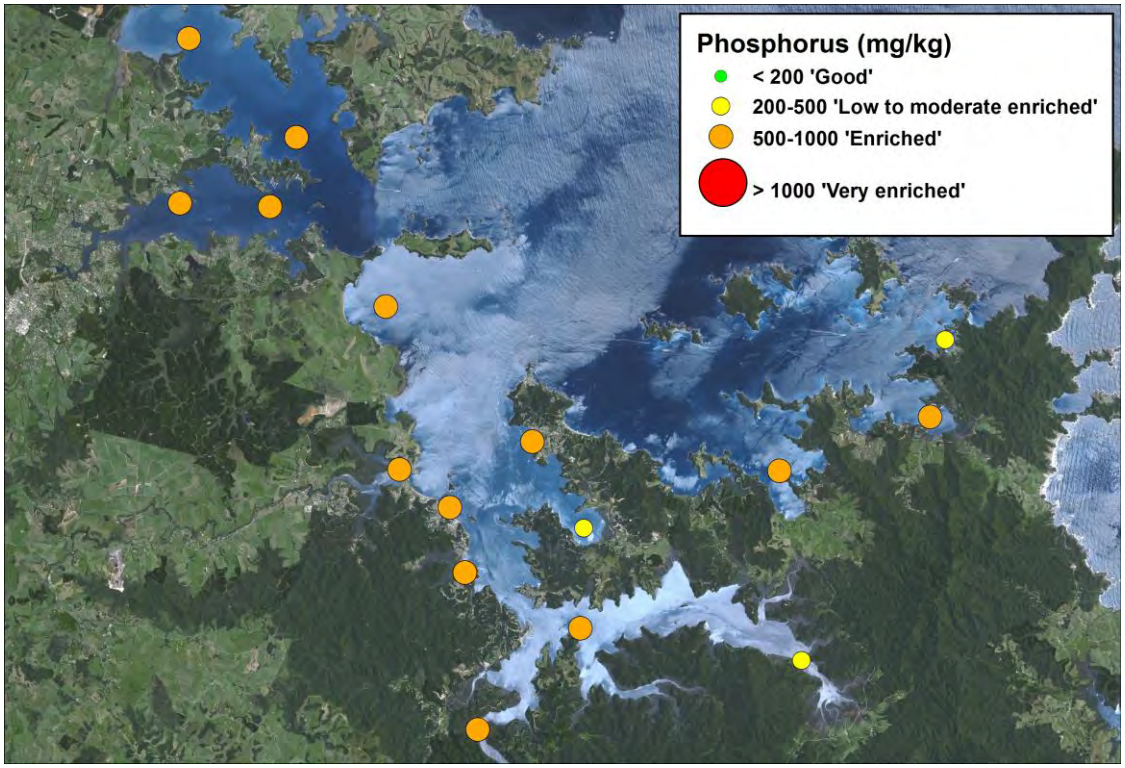

Figure 20. Sediment phosphorus concentrations in the Bay of Islands in 2016.

3.10 Grain Size

Whāngārei Harbour

Sites in the tidal creek environments of the Upper Hātea River and Waiarohia Canal contained a high proportion of mud. Limeburners Creek contained a high rate of mud and fine sand. The remainder of the Upper Harbour sites (Awaroa, Waimahanga, Otaika Creeks and Mangapai River) tended to have combinations of fine sand/mud or medium sand/mud/fine sand respectively (Figure 21). Sites in the outer harbour tended to comprised of mainly medium sand and fine sand with little or no mud.

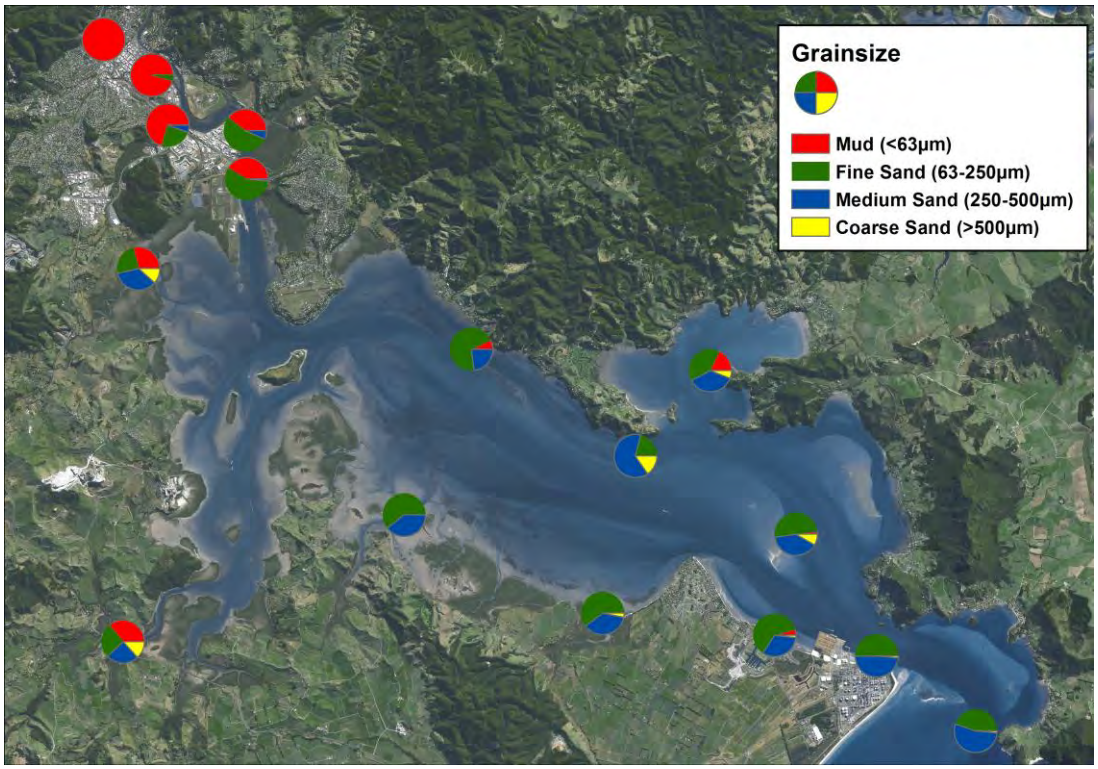

Figure 21. Sediment grain size characteristics in the Whāngārei Harbour in 2016.

Bay of Islands

Sites within the Kerikeri Inlet (Wainui Island and Doves Bay), Te Puna entrance and Dead Whale Reef contained a majority of mud and fine sand. Sheltered bays such as Oronga Bay and Manawaora Bay had high proportions of mud. However, the sediment composition at two estuarine sites (Waitangi Estuary and Kawakawa River) contained a majority of coarse and medium sand (Figure 22). At more exposed sites such as Paihia, Russell, Kaingahoa, Parekura and Onewhero Bay the sediment had low proportions of mud and higher proportions of fine sand, medium sand and coarse sand.

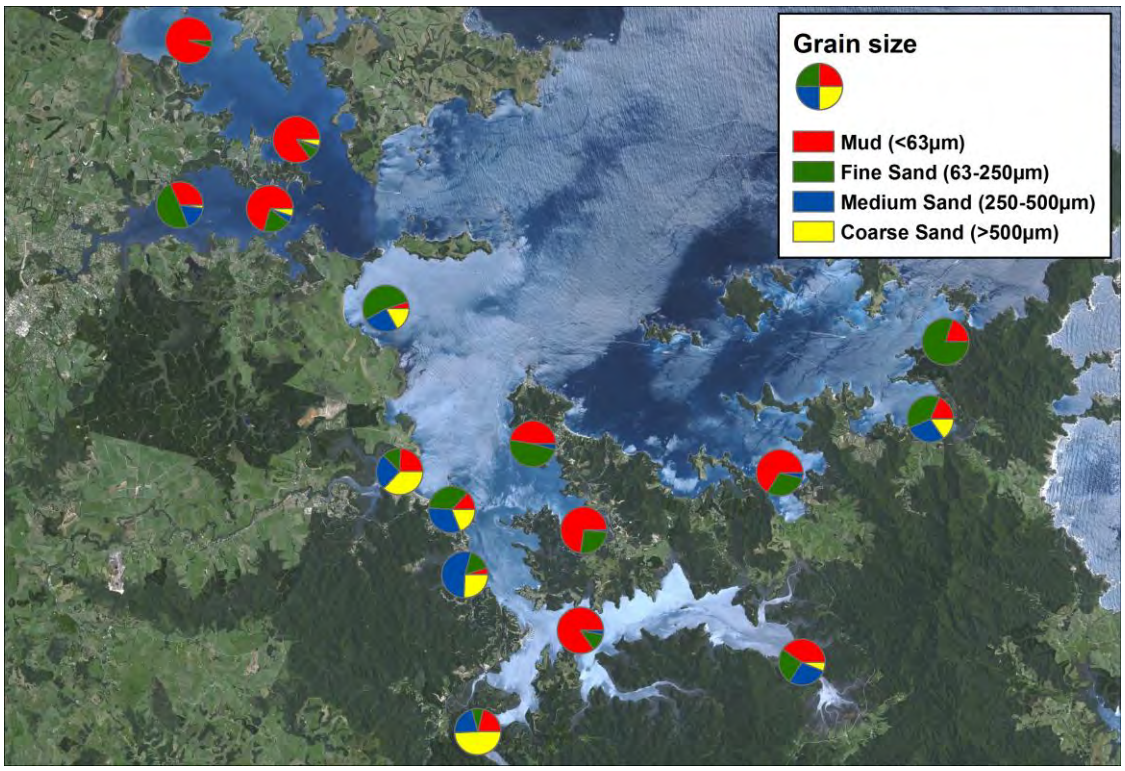

Figure 22. Sediment grain size characteristics in the Bay of Islands in 2016.

3.11 Correlation of concentrations of heavy metals and nutrients in relation to mud (< 63µm)

Heavy metals

Correlations between % mud (<63µm) and copper concentrations were significant in the Whangarei Harbour (R^2 0.90). This relationship was weaker in Bay of Islands (R^2 0.29) (Figure 23).

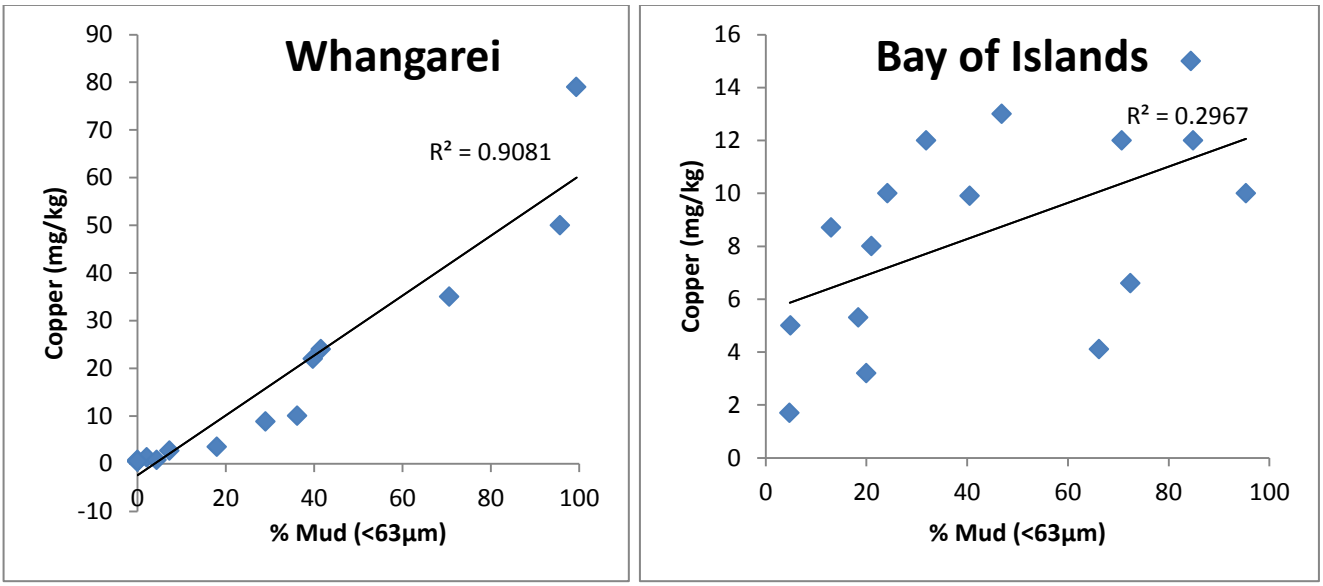

Figure 23. R^2 values, sediment copper concentrations and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

Associations between mud and zinc concentrations was very strongly correlated in the Whangarei Harbour (R^2 0.96). However, this relationship was considerably weaker in Bay of Islands, (R^2 0.08) (Figure 24).

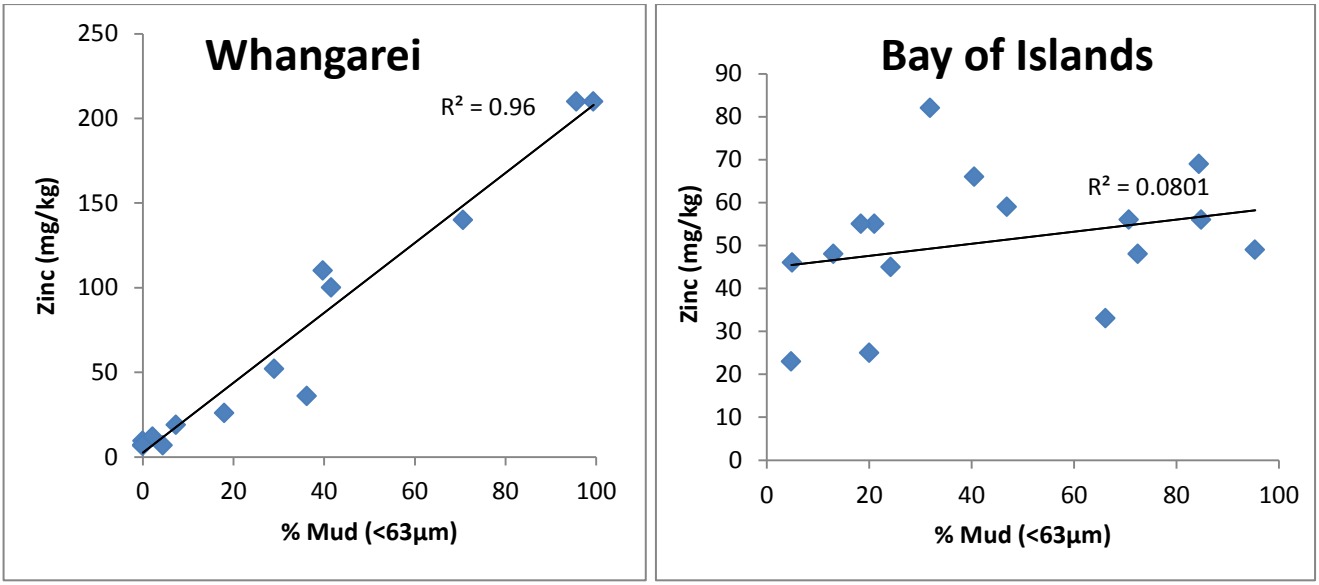

Figure 24. R^2 values, sediment zinc concentrations and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

Relationships between mud and lead concentrations was very strongly correlated in the Whangarei Harbour (R^2 0.96). This relationship correlated moderately in Bay of Islands, (R^2 0.43) (Figure 25).

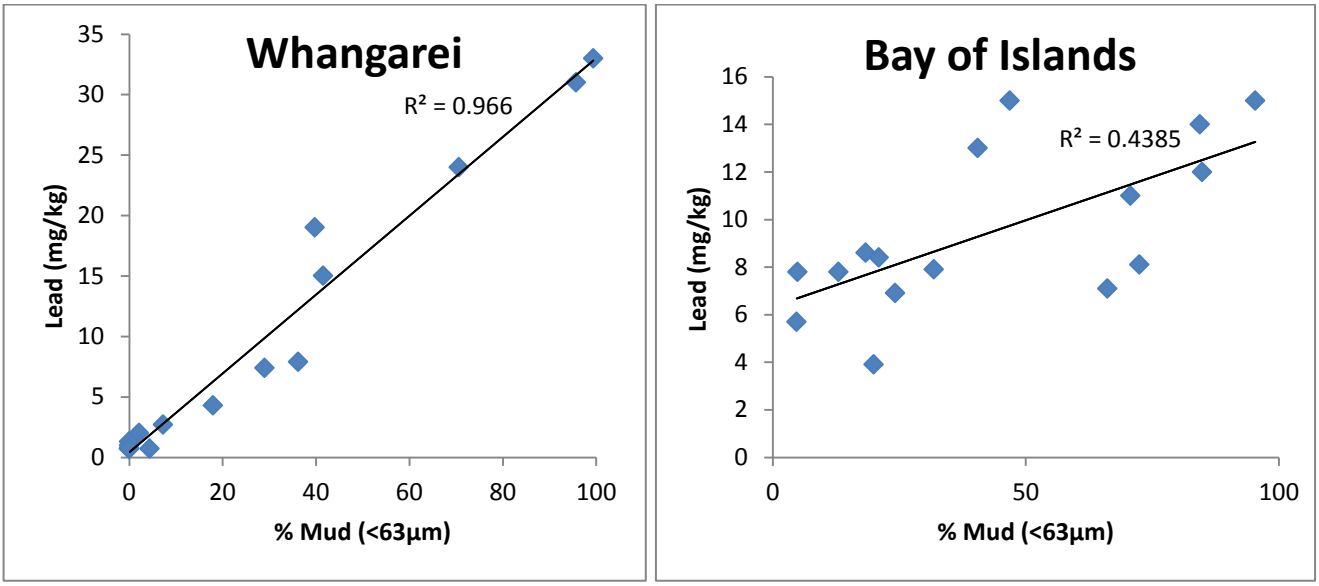

Figure 25. R^2 values, sediment lead concentrations and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

Mud and chromium concentrations were modestly correlated in the Whangarei Harbour (R^2 0.85) and weakly correlated in the Bay of Islands (R^2 0.23) (Figure 26).

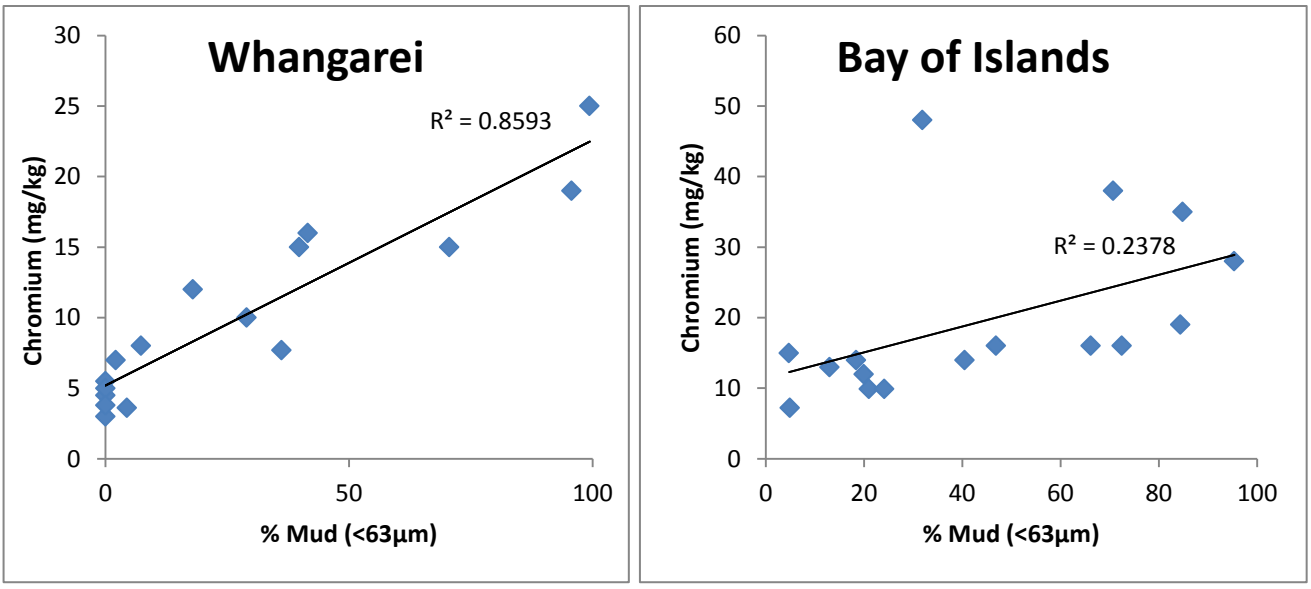

Figure 26. R^2 values, sediment chromium concentrations and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

Nickel concentrations and mud were modestly correlated in the Whangarei Harbour (R^2 0.88) and weakly correlated in the Bay of Islands (R^2 0.23) (Figure 26).

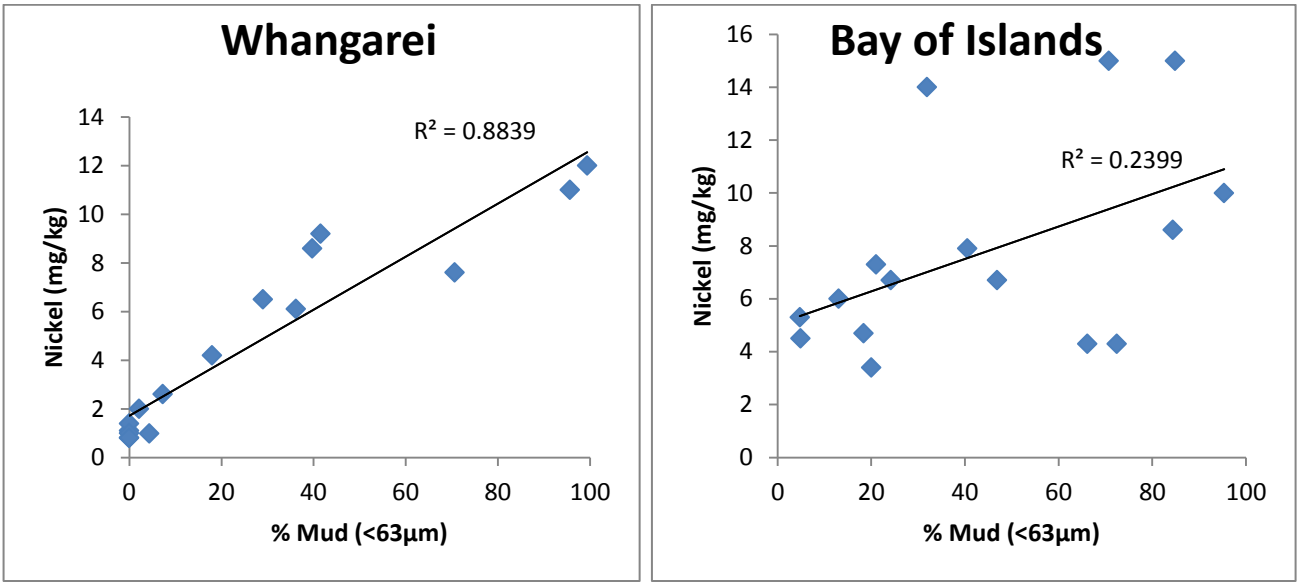

Figure 27. R^2 values, sediment nickel concentrations and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

Cadmium could not be compared in the above manner as the Bay of Islands results were all below detection limits.

Nutrients

Nitrogen concentrations and mud were moderate to strongly correlated in the Whangarei Harbour (R^2 0.87) and moderately correlated in the Bay of Islands (R^2 0.57) (Figure 28).

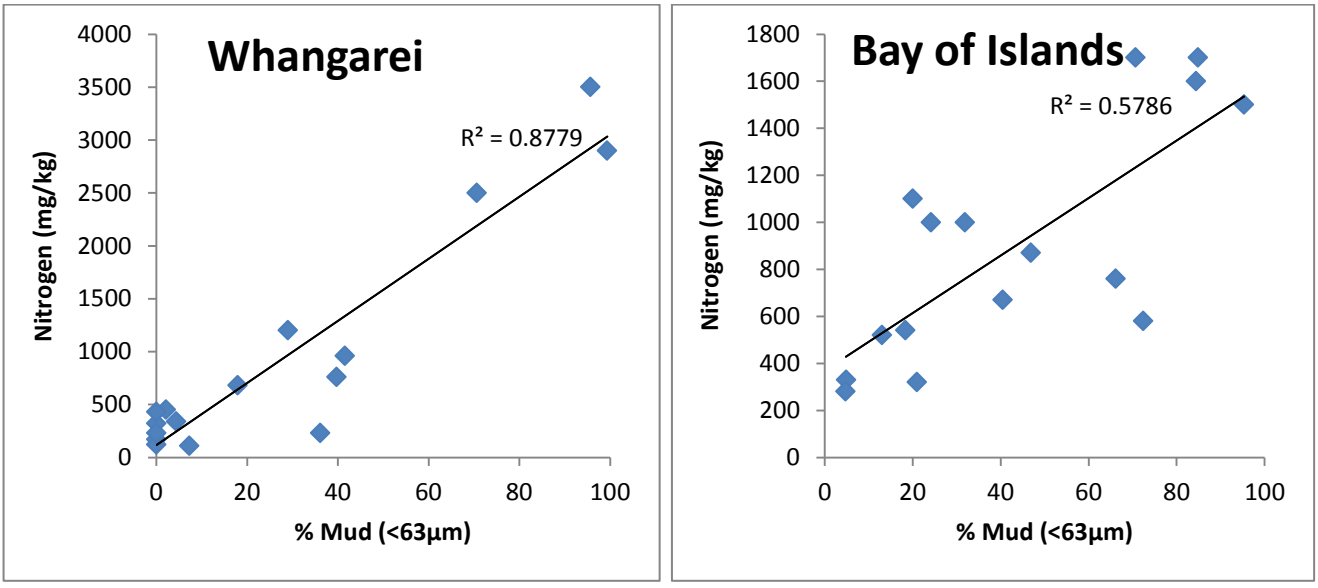

Figure 28. R^2 values, sediment nitrogen concentrations and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

Phosphorus concentrations and mud were strongly correlated in the Whangarei Harbour (R^2 0.91) and very weakly correlated in the Bay of Islands (R^2 0.0006) (Figure 29).

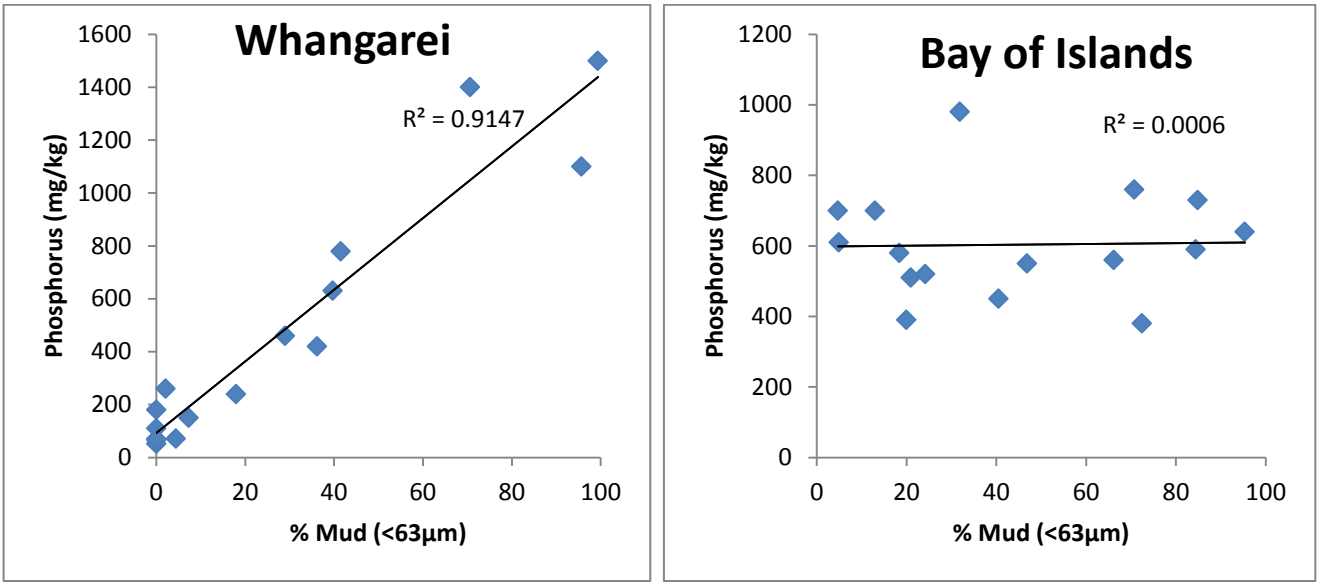

Figure 29. R^2 values, sediment phosphorus concentrations and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

TOC (%w/w) calculations and % mud (<63µm) correlated strongly in the Whangarei Harbour (R^2 0.93) whereas results showed much more variability in the Bay of Islands (R^2 0.36) (Figure 30).

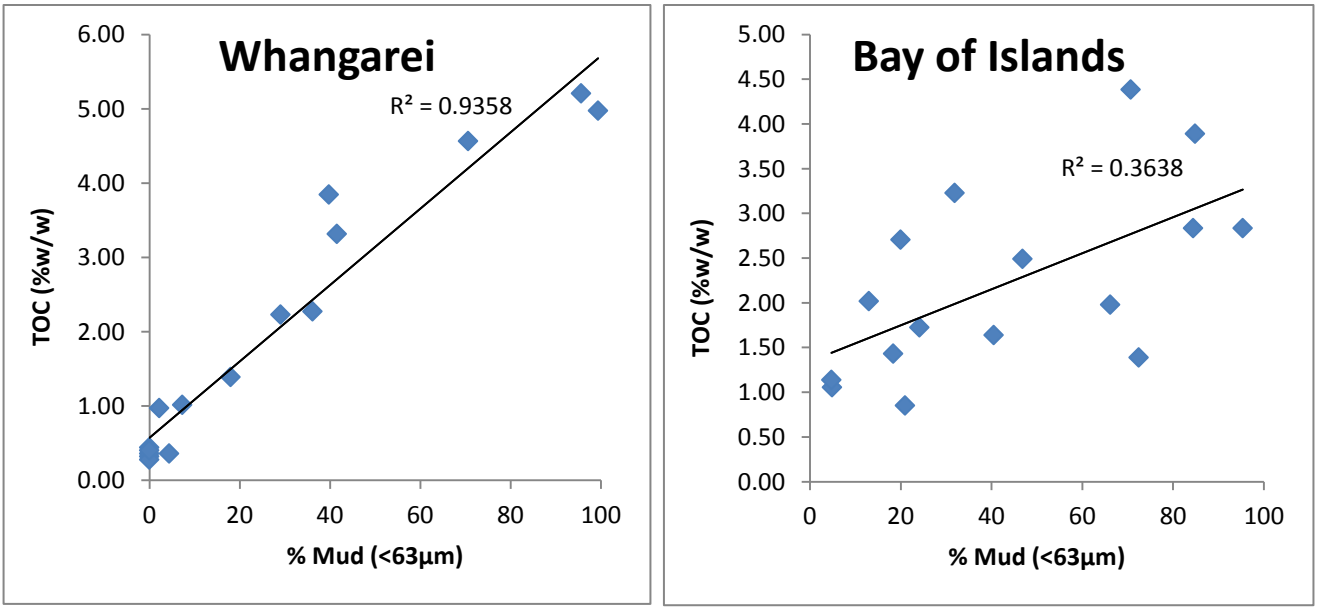

Figure 30. R^2 values, TOC (%w/w), and % mud (<63µm) comparisons between Whangarei and Bay of Islands in 2016.

3.12 Trends over time for Metal Concentrations

A key aim of council's sediment monitoring programme is to identify changes in contaminant concentration over time. However as the time series data is relatively limited, with only four data points, no formal statistical trend analysis was conducted. It is likely that at least another couple of sampling events will be required before meaningful statistical analysis could be conducted. Since nickel, nitrogen, phosphorus and TOC were only sampled in 2012, 2014 and 2016, more time would be required to identify purposeful trends for these parameters.

Whāngārei Harbour

Concentrations of metals were relatively stable at most sites in Whāngārei Harbour (Table 3). The Upper Harbour sites of Waiarohia Canal and Hātea River continue to retain the highest concentrations of copper, lead and zinc. However, since sampling of nickel started in 2012, concentrations have trended slightly downwards at Upper Harbour sites. Both cadmium and chromium results have remained below the TEL threshold over all four years of sampling.

The contaminant status has improved slightly since 2014 with three samples exceeding ANZECC ISQG-Low trigger values compared to one in 2010, two in 2012 and four in 2014 (Table 3). The contaminant status for zinc in the Upper Hātea River has improved slightly for zinc. Copper levels appear to be generally elevated at the Upper Harbour sites, with results exceeding the TEL or the ANZECC ISQG-Low, on all occasions, though results were highly variable. There is a general increase in copper levels at the Upper Hātea River site.

Concentrations of TOC and nutrients show more variation compared with concentrations of metals over the three years of sampling (2012, 2014 and 2016) (Table 4). TOC levels have increased noticeably at the Upper Harbour sites. Conversely, sites with closer proximately to the Harbour entrance have shown a slight decrease for TOC over the same period of time.

The nitrogen enrichment status has deteriorated slightly at the Upper Harbour sites of Hātea River, Waiarohia Canal, Limeburners Creek, Awaroa Creek, Waimahanga Creek and the Otaika Creek sites. Whereas phosphorous has remained relatively steady at these same sites (Table 4). Sites closer to the harbour entrance have improved slightly over the previous four years of sampling.

Increases in phosphorus were found at the Upper Hātea River, Waiarohia Canal and Limeburners Creek (Table 4). Results from these sites where 'very enriched'. The remainder of the Upper Harbour sites (Awaroa Creek, Waimahanga Creek, Otaika Creek, and Mangapai River) have remained consistent with phosphorus concentrations of 'enriched' (Awaroa Creek and Waimahanga Creek) and 'low to moderately enriched' at Otaika Creek, and Mangapai River (Table 4).

Comparisons with 2014 grain size results reveal variability in the proportion of mud at the Upper Hatea River, Waiarohia Canal, Limeburners Creek, Awaroa Creek, Waimahanga Creek and Otaika Creek sites. Mud proportions increased at the Upper Hātea River, Waiarohia Canal and Limeburners Creek sites. Fine sand proportions increased at the Awaroa Creek and Waimahanga Creek sites with a decrease in both mud and fine sand at Otaika Creek. Mud content at Mangapai River, Mangawhati Point and Takahiwai Creek declined slightly also.

Bay of Islands

Concentrations of metals remain relatively stable throughout the Bay of Islands. The contaminant status of sediment in the Bay of Islands has remained the same with all metal concentrations below ANZECC ISQG-Low and TEL at all sites over the course of all four sampling years (Table 5).

Concentrations of TOC and nutrients were more variable over the three years of sampling (2012, 2014 and 2016) than concentrations of metals (Table 6). Low to moderate enrichment concentrations of nitrogen were found at Lower Waikare, Te Puna entrance and Doves Bay in 2016. Low to moderate enrichment concentrations have also been recorded at Wainui Island, Dead Whale Reef, Kawakawa River and the Upper Waikare during the course of all three years of nutrient sampling (Table 6).

Phosphorus concentrations have persisted as 'enriched' at 13 sites over the past three sampling years. Orongo Bay and Kaingahoa Bay have continually returned 'low to moderate enrichment' over the same time period (Table 6). Onewhero Bay continues a reducing concentration trend with enrichment values fluctuating at Upper Waikare between 2014 and 2016.

A large decrease (1.31%) was observed in the level of TOC between 2014 and 2016 at Kawakawa River and a moderate decrease at Upper Waikare (0.88%). In 2012 and 2014 the same eight sites were classified as 'enriched' and the same eight sites 'low to moderately enriched' (Table 6). Results from 2016 indicate that seven sites were classified as 'enriched', Russell and Kaingahoa concentrations have increased slightly, with the balance of the sites remaining steady.

There was less variability in the proportion of mud at sites in the Bay of Islands compared to Whāngārei. Coarse sand proportions have increased slightly at Dead Whale Reef, Te Puna entrance, Doves Bay, Te Haumi River and Parekura Bay compared to results from 2014.

Table 3. Metal concentrations (mg/kg) of sediment in the Whāngārei Harbour.

2016	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Upper Hātea River	0.15	25	79	33	12	210
Waiarohia Canal	0.12	19	50	31	11	210
Limeburners Creek	0.15	15	35	24	7.6	140
Awaroa Creek	<0.091	15	22	19	8.6	110
Waimahanga Creek	0.12	16	24	15	9.2	100
Otaika Creek	<0.091	10	8.8	7.4	6.5	52
Mangapai River	<0.09	7.7	10	7.9	6.1	36
Mangawhati Point	<0.09	4.5	0.73	0.97	1.1	7.1
Tamaterau	<0.09	8	2.7	2.7	2.6	19
Manganese Point	<0.09	5.5	<0.45	1.3	1.4	9.5
Takahiwai Creek	<0.089	3	0.58	0.7	0.82	<6.7
Parua Bay	<0.09	12	3.5	4.3	4.2	26
Snake Bank	<0.089	7	1.3	2	2	12
Marsden Bay	<0.091	3.6	0.72	0.72	0.99	<6.8
Home Point	<0.088	5	<0.44	0.77	1	<6.6
Marsden Point	<0.092	3.8	<0.46	0.72	0.8	<6.9

2014	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Upper Hātea River	0.17	28	65	31	14	220
Waiarohia Canal	0.16	24	67	39	14	290
Limeburners Creek	0.16	10	14	10	4.5	100
Awaroa Creek	<0.09	21	30	18	11	120
Waimahanga Creek	<0.09	22	32	18	12	110
Otaika Creek	0.096	11	8.5	7	6.8	57
Mangapai River	<0.088	8.1	8.1	7	6.5	31
Mangawhati Point	<0.09	7	1.7	1.7	2.1	13
Tamaterau	<0.089	11	3.3	3.7	3.5	26
Manganese Point	<0.089	8.4	0.54	1.7	2	13
Takahiwai Creek	<0.090	4	0.6	0.77	1.1	<6.8
Parua Bay	<0.091	13	3.5	4	4.4	25
Snake Bank	<0.089	5.7	0.46	1.3	1.4	8.2
Marsden Bay	<0.09	3.8	0.5	0.66	1	<6.7
Home Point	<0.089	4.9	<0.45	0.7	1.1	<6.7
Marsden Point	<0.089	4.1	<0.45	0.66	1	<6.7
2012	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Upper Hātea River	0.16	27	38	39	14	160
Waiharohia Canal	0.16	31	79	51	16	150
Limeburners Creek	<0.1	15	26	17	8.6	110
Kissing Point	<0.1	17	19	18	9.5	110
Waimahanga Creek	0.11	16	16	20	7.3	73
Otaika Creek	<0.1	9.4	6.8	6.4	4.7	52
Mangapai River	<0.1	7.6	8.5	8.4	5	38
Mangawhati Point	<0.1	3.8	<0.5	0.66	0.93	<7.5
Tamaterau	<0.1	8.6	2.3	2.5	2.7	18
Manganese Point	<0.1	7.3	0.71	1.9	2	14
Takahiwai Creek	<0.1	2.4	<0.5	0.62	0.88	<7.5
Parua Bay	<0.1	11	3.2	3.9	3.9	22
Snake Bank	<0.1	4.4	<0.5	1.1	1.1	<7.5
Marsden Bay	<0.1	2.7	<0.5	0.53	0.83	<7.5
Home Point	<0.1	4.5	<0.5	0.67	1	<7.5
Marsden Point	<0.1	5.8	<0.5	1	1.2	<7.5
2010	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Upper Hātea River	0.15	30	42	27	N.S.	168
Waiharohia Canal	0.57	27	54	38	N.S.	210
Limeburners Creek	0.09	11.7	7.7	7.1	N.S.	49
Awaroa Creek	0.11	22	27	26	N.S.	109
Waimahanga Creek	0.2	17	16.4	15.5	N.S.	86
Otaika Creek	0.16	16.4	29	19.5	N.S.	139
Mangapai River	0.05	8.1	8.2	7.3	N.S.	35
Mangawhati Point	0.01	6.9	1	1.5	N.S.	10.6
Tamaterau	0.02	21	6.4	6	N.S.	45

Manganese Point	<0.01	8.9	1.6	2.7	N.S.	15.8
Takahiwai Creek	0.01	4.7	0.5	0.87	N.S.	7.5
Parua Bay	0.02	17.7	3.7	5.4	N.S.	39
Snake Bank	<0.01	7.1	0.6	1.58	N.S.	9.2
Marsden Bay	0.02	7.2	0.9	1.34	N.S.	10.3
Home Point	<0.01	3.4	<0.2	0.53	N.S.	4.4
Marsden Point	<0.01	6.1	0.3	0.9	N.S.	7.3

Green = below TEL, **Orange** = exceeded TEL, **Red** = exceeded ANZECC ISQG-Low effect trigger values, **N.S** = not sampled.

Table 4. Nutrient concentrations of sediment in the Whāngārei Harbour

2016	TOC (%w/w)	Nitrogen(mg/kg)	Phosphorus (mg/kg)
Upper Hātea River	4.98	2900	1500
Waiarohia Canal	5.21	3500	1100
Limeburners Creek	4.57	2500	1400
Awaroa Creek	3.85	760	630
Waimahanga Creek	3.32	960	780
Otaika Creek	2.23	1200	460
Mangapai River	2.28	230	420
Mangawhati Point	0.32	170	110
Tamaterau	1.02	110	150
Manganese Point	0.36	120	180
Takahiwai Creek	0.44	320	52
Parua Bay	1.39	680	240
Snake Bank	0.97	450	260
Marsden Bay	0.36	340	72
Home Point	0.28	230	66
Marsden Point	0.40	430	70
2014	TOC (%w/w)	Nitrogen(mg/kg)	Phosphorus (mg/kg)
Upper Hātea River	4.93	2400	1200
Waiarohia Canal	4.03	3400	1300
Limeburners Creek	2.36	600	940
Awaroa Creek	3.36	1400	850
Waimahanga Creek	3.8	2000	890
Otaika Creek	1.06	910	400
Mangapai River	0.97	1000	360
Mangawhati Point	0.65	760	120
Tamaterau	0.93	410	220
Manganese Point	0.32	30	120
Takahiwai Creek	0.56	470	80
Parua Bay	1.02	470	250
Snake Bank	0.52	160	120
Marsden Bay	0.32	560	58
Home Point	0.32	20	72
Marsden Point	0.24	33	62

Table 4. (Cont.) Nutrient concentrations of sediment in the Whāngārei Harbour

2012	TOC (%w/w)	Nitrogen(mg/kg)	Phosphorus (mg/kg)
Upper Hātea River	1.22	500	950
Waiarohia Canal	1.81	450	780
Limeburners Creek	1.22	4900	1200
Awaroa Creek	1.35	1200	580
Waimahanga Creek	4.79	1400	920
Otaika Creek	0.73	860	380
Mangapai River	1.6	1300	430
Mangawhati Point	0.97	100	50
Tamaterau	0.52	540	120
Manganese Point	0.32	87	140
Takahiwai Creek	2.02	320	83
Parua Bay	1.31	460	230
Snake Bank	1.68	190	83
Marsden Bay	1.47	140	54
Home Point	0.52	14	59
Marsden Point	1.31	110	75

Green = 'good', **Yellow** = 'low to moderate enrichment', **Orange** = 'enriched', **Red** = 'very enriched'

Table 5. Metal concentrations (mg/kg) of sediment in the Bay of Islands.

2016	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Wainui Island	0.09	48	12	7.9	14	82
Doves Bay	0.088	38	12	11	15	56
Te Puna Entrance	0.091	35	12	12	15	56
Dead Whale Reef	0.091	28	10	15	10	49
Kawakawa River	0.09	9.9	8	8.4	7.3	55
Lower Waikare	0.09	19	15	14	8.6	69
Upper Waikare	0.091	14	9.9	13	7.9	66
Te Haumi River	0.089	7.2	5	7.8	4.5	46
Paihia	0.088	13	8.7	7.8	6	48
Waitangi River	0.089	9.9	10	6.9	6.7	45
Oronga Bay	0.088	16	6.6	8.1	4.3	48
Russell	0.091	16	13	15	6.7	59
Manawaora Bay	0.091	16	4.1	7.1	4.3	33
Parekura Bay	0.091	14	5.3	8.6	4.7	55
Kaingahoa Bay	0.092	12	3.2	3.9	3.4	25
Onewhero Bay	0.09	15	1.7	5.7	5.3	23

Table 5. (Cont.) Metal concentrations (mg/kg) of sediment in the Bay of Islands.

2014	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Wainui Island	0.098	39	14	7.2	14	59
Doves Bay	<0.087	35	12	8.9	15	50
Te Puna Entrance	<0.091	31	11	10	13	48
Dead Whale Reef	<0.09	24	8.8	12	8.6	42
Kawakawa River	<0.091	13	15	13	9	86
Lower Waikare	<0.089	17	13	12	8	62
Upper Waikare	<0.09	15	9.7	12	7.5	63
Te Haumi River	<0.09	5	3.8	5.3	3.2	29
Paihia	<0.091	9.4	3.6	5.3	4.3	38
Waitangi River	<0.088	12	10	7	7.1	43
Oronga Bay	<0.09	15	6	6.8	4.3	43
Russell	<0.09	7.4	6.6	9.5	4	33
Manawaora Bay	<0.091	15	3.9	5.9	4.5	31
Parekura Bay	<0.089	12	4	6.7	4.2	48
Kaingahoa Bay	<0.09	10	2.5	3.2	2.8	20
Onewhero Bay	<0.09	10	1.7	4.1	6	14
2012	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Wainui Island	<0.09	42	15	8.3	N.S.	64
Doves Bay	<0.09	38	13	11	N.S.	51
Te Puna Entrance	<0.09	31	10	12	N.S.	50
Dead Whale Reef	<0.089	24	8	13	N.S.	42
Kawakawa River	<0.09	16	17	13	N.S.	69
Lower Waikare	<0.09	17	13	13	N.S.	60
Upper Waikare	<0.09	16	9.6	16	N.S.	71
Te Haumi River	<0.089	8.4	7.3	10	N.S.	47
Paihia	<0.089	11	6.9	7.2	N.S.	42
Waitangi River	0.099	12	13	7.8	N.S.	50
Oronga Bay	<0.089	16	6.2	8.2	N.S.	46
Russell	<0.091	15	10	17	N.S.	56
Manawaora Bay	<0.09	17	3.9	6.7	N.S.	33
Parekura Bay	<0.091	15	3.8	7.7	N.S.	58
Kaingahoa Bay	<0.089	12	2.7	3.9	N.S.	23
Onewhero Bay	0.09	16	1.6	5.7	N.S.	17
2010	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Wainui Island	0.05	47	15.1	10.3	N.S.	59
Doves Bay	0.05	40	12.9	10.6	N.S.	47
Te Puna Entrance	0.04	32	10.1	11.2	N.S.	45
Dead Whale Reef	0.03	27	8.6	13.4	N.S.	43
Kawakawa River	0.06	14.6	13.8	13	N.S.	82
Lower Waikare	0.03	19.6	13.3	13.8	N.S.	61
Upper Waikare	0.03	15.8	10.3	11.6	N.S.	55
Te Haumi River	0.02	8.9	5.1	7.7	N.S.	42
Paihia	0.03	9.6	2.7	5.7	N.S.	32
Waitangi River	0.13	9.5	6.3	6.1	N.S.	46
Oronga Bay	0.02	14.2	5	7.1	N.S.	42
Russell	0.03	12.5	7.9	13.7	N.S.	40
Manawaora Bay	0.03	14.9	3.2	6.2	N.S.	28
Parekura Bay	0.02	13.3	5.6	6.9	N.S.	41
Kaingahoa Bay	0.04	11.3	2.4	3.7	N.S.	19.8
Onewhero Bay	0.06	14.2	1.2	5.1	N.S.	12.7

Green = below TEL, **Orange** = exceeded TEL, **Red** = exceeded ANZECC ISQG-Low effect trigger values, **N.S**. = not sampled.

Table 6. Nutrient concentrations of sediment in the Bay of Islands

2016	TOC (%w/w)	Nitrogen(mg/kg)	Phosphorus (mg/kg)
Wainui Island	3.23	1000	980
Doves Bay	4.39	1700	760
Te Puna Entrance	3.89	1700	730
Dead Whale Reef	2.84	1500	640
Kawakawa River	0.85	320	510
Lower Waikare	2.84	1600	590
Upper Waikare	1.64	670	450
Te Haumi River	1.06	330	610
Paihia	2.02	520	700
Waitangi River	1.72	1000	520
Oronga Bay	1.39	580	380
Russell	2.49	870	550
Manawaora Bay	1.98	760	560
Parekura Bay	1.43	540	580
Kaingahoa Bay	2.71	1100	390
Onewhero Bay	1.14	280	700

2014	TOC (%w/w)	Nitrogen(mg/kg)	Phosphorus (mg/kg)
Wainui Island	4.16	1400	850
Doves Bay	4.75	1800	770
Te Puna Entrance	4.61	2100	740
Dead Whale Reef	2.75	1400	610
Kawakawa River	2.15	780	690
Lower Waikare	3.10	1900	630
Upper Waikare	2.49	1100	520
Te Haumi River	1.56	390	610
Paihia	1.22	370	640
Waitangi River	1.77	1200	520
Oronga Bay	1.06	530	360
Russell	1.64	450	440
Manawaora Bay	2.32	900	510
Parekura Bay	1.26	320	520
Kaingahoa Bay	1.22	610	320
Onewhero Bay	1.64	550	720

2012	TOC (%w/w)	Nitrogen(mg/kg)	Phosphorus (mg/kg)
Wainui Island	4.43	1300	950
Doves Bay	4.84	1600	800
Te Puna Entrance	4.34	1600	730
Dead Whale Reef	2.92	1200	570
Kawakawa River	3.36	1300	730
Lower Waikare	3.10	1300	630
Upper Waikare	2.79	1000	650
Te Haumi River	1.02	260	660
Paihia	1.94	480	650
Waitangi River	1.47	530	530
Oronga Bay	1.64	930	370
Russell	1.02	890	730
Manawaora Bay	2.06	770	520
Parekura Bay	1.35	360	530
Kaingahoa Bay	1.47	710	420
Onewhero Bay	1.31	400	1000

Green = 'very good', **Yellow** = 'low to moderate enrichment', **Orange** = 'enriched', **Red** = 'very enriched'

4 Discussion

4.1 Sediment Metal Concentrations

Metal concentrations at three sites in the Upper Hātea River area are at levels which have the potential to cause adverse effects on marine ecosystems. Concentrations of copper and zinc exceeded ANZECC ISQG-Low effect trigger values at the Upper Hātea River and the Waiarohia Canal. In addition, lead concentrations exceeded the TEL at these sites also. Copper TEL concentrations were also exceeded at Limeburners, Awaroa, Waimahanga Creeks and Waiarohia Canal. Council's surveys in 2010 and 2012 (Northland Regional Council 2011, Griffiths 2012) also found high levels of metal contaminants in the Hātea River and previous studies have reported elevated concentrations of metals in the sediment at the Upper Hātea River and the Waiarohia Canal (Venus 1984, Northland Regional Council 1990, Webster et al. 2000, Northland Regional Council 2003 and Griffiths 2011a).

The Hātea River, flows through the city of Whāngārei, the main urban centre in Northland, where the majority of the urban and industrial development in the catchment is centred. Road runoff, stormwater discharges, industrial discharges and leachates from landfills are all possible sources of metal contamination. The high 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. Correlation analyses of mud (<63μm) and metal concentrations, using R^2, showed contrasting results between Whāngārei Harbour and the Bay of Islands in 2016 (Figures 23 – 27). Results from Whāngārei Harbour indicated a strong correlation between mud and metal concentrations. Heavy metal absorption tends to increase as sediment grain size decreases, which reflects the tendency for heavy metals to be preferentially absorbed on the large surface area of fine grained sediments rich in clay minerals (Abrahim et al. 2007).

Relatively low concentrations of metal contaminants were recorded at Limeburners Creek, which is encouraging given that the Whāngārei wastewater treatment plant discharges into this catchment. Beyond the Hātea River sites, concentrations of metals were below ANZECC ISQG-Low effect trigger values and the TEL in 2016. Concentrations of metals tended to decrease towards the entrance of the harbour and this pattern has continued over the past four sampling events.

In the Bay of Islands all of the metal concentrations measured were below the ANZECC ISQG-Low effect trigger values and the TEL in all four years (2010, 2012, 2014 and 2016). The highest concentrations of copper, lead and zinc tended to be found at Wainui Island and Te Puna entrance. The highest concentrations of chromium and nickel were found at the two sites in the Kerikeri Inlet (Wainui Island and Doves Bay). Sediment monitoring conducted as part of the council's Estuary Monitoring Programme has also found elevated concentrations of chromium and nickel at sites located in the Kerikeri Inlet (Griffiths 2011b). The lowest concentrations of zinc, copper and lead were generally found at Kaingahoa Bay and Onewhero Bay over all four years, with the lowest levels of chromium found at Te Haumi River. Abrahim et al. (2007) suggests that sediment grain size is an important factor which influences the concentrations of heavy metals in estuarine sediments. Correlation analyses of mud and metal concentrations in the Bay of Islands revealed a weak relationship between these factors (Figures 23 – 27).

This may be explained by the smaller scale concentration of urban and industrial development across the whole of the Bay of Islands study area and/or underlying geology pertaining to sediment size.

Comparisons with surveys conducted by council in 2010, 2012 and 2014 indicate that metal concentrations have remained relatively stable at most sites, although there was a general increase in copper at the Upper Hātea River site. However, the converse applies at Otaika Creek where concentrations of copper, lead and zinc have decreased.

4.2 Sediment TOC and Nutrient Concentrations

The nutrient concentrations recorded in this study indicate that a number of sites in the Bay of Islands and the Upper Hātea River, in Whāngārei Harbour, were 'enriched' using criteria developed by Robertson and Stevens (2007).

In Whāngārei Harbour the Waiarohia Canal was classified as 'very enriched' for TOC. The Upper Hātea River and Limeburners Creek were classified as 'very enriched' for both phosphorus and nitrogen and 'enriched' for TOC. Awaroa and Waimahanga Creeks were classified 'enriched' for phosphorus and TOC. The potential sources of nutrients to the Upper Hātea River are discharges from the waste treatment plant, seepage from the wastewater network, discharges from boats, industrial discharges, stormwater and runoff from agricultural land.

Nutrients have been measured on three sampling occasions 2012, 2014 and 2016 but much higher variability was observed compared to concentrations of metal contaminants. Correlation analyses of mud (<63µm), TOC (%w/w) and nutrient concentrations, using R^2, showed contrasting results between Whāngarei Harbour and the Bay of Islands in 2016 (Figures 28 – 30). Overall, TOC and nutrients were strongly correlated to mud in the Whāngarei Harbour. In Whāngārei there were noticeable decreases in the nitrogen and phosphorus concentration at Limeburners Creek which is the receiving environment for discharges from the Whāngārei wastewater treatment plant. Field observations from 2014 indicated that the sediment collected in Limeburners Creek contained a lot of calcareous worm tube cases which made it difficult to collect a sample with the grab. It is possible that fine sediment escaped from the grab sample which may have affected the nutrient concentrations recorded. The opposite applied in 2016 where 70% of the sediment sample was 'mud' and 24% was 'fine sand'. This may explain the contrasting differences (increases) in TOC and nutrient measurements in 2016.

In the Bay of Islands, 13 sites were classified as 'enriched' for phosphorus and seven sites for TOC. Interestingly, the Kawakawa River site has shown a steady decrease in TOC since sampling started in 2012. The TOC value has decreased by 1.31 between 2014 and 2016 and 2.52 between 2012 and 2016. Coincidently, mud at this site has decreased whilst coarse sand has increased between 2014 and 2016. Correlation analyses of mud, TOC and nutrient concentrations were weakly correlated in the Bay of Islands (Figures 28 – 30). The potential sources of nutrients to the Bay of Islands include discharges from wastewater treatment plants, seepage from the wastewater network, septic tanks, discharges from boats, industrial discharges, runoff from agricultural land and discharges from farm dairy effluent systems. The geographical spread of these potential sources of nutrients may explain the weak relationship between mud, TOC and nutrients. Typically strongly correlated parameters, such as mud with TOC and metal concentrations, did not exhibit such relationships, suggesting that sources of phosphorus may be derived from underlying geology or possibly limited inputs of these contaminants.

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6 References

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.

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

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.

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*.

Resource Management Act, (1991). Retrieved from http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html

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 & Stevens 2007. *Waikawa Estuary 2007. Fine scale Monitoring and Historical sediment coring*. Prepared for Environment Southland.

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

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

Griffiths, R. (2012). *Whāngārei Harbour Estuary Monitoring Programme 2012.* Northland Regional Council technical report.

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

Appendix 1

Whāngārei Harbour site co-ordinates

Site ID	Site name	X	Y
110087	Upper Hātea River	1719787	6046046
110088	Waiarohia Canal	1720058	6045305
110089	Limeburners Creek	1720386	6044261
110090	Awaroa Creek	1722003	6044028
110091	Waimahanga Creek	1722034	6043143
110092	Otaika Creek	1719777	6041276
110093	Mangapai River	1719456	6033503
110094	Mangawhati Point	1725310	6036143
110095	Tamaterau	1726715	6039595
110096	Manganese Point	1730134	6037371
110097	Takahiwai Creek	1729451	6034096
110098	Parua Bay	1731692	6039152
110099	Snake Bank	1733480	6035744
110100	Marsden Bay	1733033	6033638
110101	Home Point	1737224	6031642
110102	Marsden Refinery	1735163	6033209

Bay of Islands site co-ordinates

Site ID	Site name	X	Y
110071	Wainui Is	1691353	6104383
110072	Doves Bay	1694063	6104274
110073	Te Puna entrance	1694858	6106356
110074	Dead Whale Reef	1691625	6109335
110075	Kawakawa River	1700310	6088551
110076	Lower Waikare	1703397	6091598
110077	Upper Waikare	1710058	6090643
110078	Te Haumi River	1699922	6093272
110079	Paihia	1699476	6095228
110080	Waitangi River	1697958	6096369
110081	Oronga Bay	1703499	6094615
110082	Russell	1701959	6097208
110083	Manawaora Bay	1709386	6096336
110084	Parekura Bay	1713920	6097953
110085	Kaingahoa Bay	1714378	6100278
110086	Onewhero Bay	1697547	6101273

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