Mangonui Estuary Monitoring Programme

2016

Date: 6/10/2016

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Report Number: 2016098HN

Putting Northland first

NORTHLAND REGIONAL COUNCIL

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Executive summary

The Doubtless Bay catchment has been identified by Northland Regional Council (Council) as a priority catchment for the implementation of the National Freshwater Policy. The estuary drains a catchment of 26,079 ha and the land-use in the catchment has been heavily modified, with a considerable proportion of the catchment cleared for agricultural land-use. Catchment analysis using the land-use classification from the New Zealand Land Cover Database (LCDB2) indicated that in 2012, 42% of the catchment was covered by high producing exotic grassland, 20% with indigenous forest, 11% with exotic forest and 17% with manuka and kanuka shrubland.

In 2016, Council sampled 17 sites throughout the estuary in order to assess sediment quality and ecological status. This survey also provided baseline data to track changes in the health of the estuary over time. The survey methods were adapted from the Estuary Monitoring Protocol, which was developed by Cawthron for use by Regional Councils, and are consistent with other surveys conducted by Council.

Sediment grain size

Within the estuary, the highest proportions of mud were generally found at sites in sheltered tidal creek environments (Mng6 and 22) and along the eastern shore (Mng21, 20, 19, 17). However, the proportion of mud observed at the Mangonui sites was much smaller than those measured in other Northland estuaries such as Waitangi and the Whangarei Harbour. In contrast, the highest proportions of coarse sand and medium sand were found near the entrance of the estuary, at sites Mng14, Mng15 and Mng13.

Sediment nutrients

Land-use changes in catchments modifies the amount of run off estuaries receive. This runoff is often sediment laden, with elevated levels of organic matter and nutrients from anthropogenic sources (fertilizer, storm water and treated wastewater). While nutrients (e.g., nitrogen and phosphorus) are essential for all ecosystems, when nutrient concentrations exceed those required by the receiving ecosystem they can modify community structure and cause the system to degrade.

Using the criteria developed by Robertson and Stevens (2007), sediments at all sites, except Mng7 showed some level of enrichment for total phosphorus, whilst Mng5, 15, 17, 19, 20 and 22 were low to moderately enriched for nitrogen. For total organic carbon (sediment TOC), two sites in Mangonui Estuary scored ‘very good’, 11 were low to moderately enriched, and four sites were ‘enriched’ The only similarity between nutrient and TOC concentrations was that of high vales of TOC and TP at Mng5. Generally, highest levels of nutrients and TOC are observed at sites with high proportions of mud, as fine grains have a greater surface area to volume ratio, providing greater adsorption of organic carbon, and organic and remineralised inorganic nutrients. However, Mng5 did not have high concentrations of mud, rather this site had relatively high densities of adult cockles.

The mean nitrogen concentration measured in Mangonui Estuary was generally lower than means recorded in other Northland estuaries, athough the mean concentrations of phosphorus and TOC were higher. In particular, the average nitrogen to phosphorus ratio was lowest in Mangonui (0.75 with the next lowest being 1.24 in Waitangi). The marked differences in this ratio between the northern, east coast estuaries (e.g., Houhora, Ranganui and Parengarenga ratios 2.6 to 5.3) and the northern, west coast estuaries (Kaipara and Hokianga 2.2 and 2.6 respectively) is likely to be a reflection of underlying geology. High TOC values can reflect a number of factors, for example, biodeposits created by suspension feeding bivalves. The sites classified as ‘enriched’ by their TOC levels did not generally exhibit low diversity or high abundances of a limited number of macrofaunal species that typically reflects enriched conditions.

Sediment metals

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

The metal concentrations recorded in the Mangonui Estuary were slightly elevated for chromium, nickel and zinc compared to values reported in recent sediment surveys conducted by NRC for the Bay of Islands and Whangarei in 2016. The range of lead concentrations measured was similar to that measured in Whangarei but much larger compared to Waitangi. Concentrations of copper in the Mangonui Estuary were more similar to those found within Waitangi in 2016, and lower than levels observed in the Whangarei harbour.

Some exceedances of ANZECC ISQG-Low effect trigger values and the threshold effect levels (TEL) developed by MacDonald, Carr, Calder, Long and Ingersoll (1996) were observed at sites in Mangonui: Nickel concentration at Mng4 exceeded the TEL and Mng5 and Mng21 exceeded the ANZECC guidelines. Both Mng4 and 5 are located close to a busy road and storm water discharge points. Mng14 was within the ANZECC guidelines for copper, lead and zinc but exceeded the TEL guidelines; this is likely related to boating activity as Mng14 is located close to the entrance of the estuary, near a main channel and is within a mooring zone and adjacent to a historical slipway.

Ecological communities

The sites sampled in the Mangonui Estuary covered a range of intertidal habitats including; sheltered soft mud flats, sandy beaches, sand banks, shell banks and gravel/pebble shoreline. The taxa identified in the Mangonui estuary are similar to those in other estuarine environments surveyed in Northland. The most abundant taxa were polychaete worms (*Prionospio* sp., *Prionospio aucklandica*, *Aonides trifida*, and juvenile Nereididae) and bivalves (mainly the cockle *Austrovenus stutchburyi*). Five groups of sites occurred: Mng22; Mng5; Mng13 and 14; Mng6, Mng17, Mng19 and Mng20; and all others. Generally sites in the middle of the estuary and on the western side of the estuary tended to differ from the sites located in the south and east of the estuary.

Cockles (*Austrovenus stutchburyi*) were found at most sites, but only in high densities at Mng5, 14, 15 and 21. The highest densities of adults were found at sites Mng7 and Mng15. Pipis (*Paphies australis*) were only found at site Mng13 and 14, of which the majority fell into the <4 mm and 4-16 mm size classes. The wedge shell (*Macomona liliana*) was found throughout the estuary but in low numbers.

Use of health indices derived for Auckland Region estuaries suggested that macrofaunal communities of Mangonui generally had good health, with 5 sites having moderate health and resilience and eight with good health and resilience. However, Mng6 and 19 were suggested to be unhealthy with low resilience and Mng17 and 20 showed poor health and resilience.

Relating ecological communities to sediment data

The most important predictors of intertidal community structure were mud and fine sand content (together explaining 36% of the variability in community composition), with cadmium, nickel, total phosphorus and lead each contributing an extra 6%. Interestingly, TOC was not an important driver of community structure despite sites being classified across the range from 'low enrichment' to 'enriched'. There were very few strong correlations (> 0.85 Pearsons R) between the concentrations of potential stressors across the sites (only for chromium with copper, nickel and total phosphorus). Even stressors that are usually strongly correlated, for example, mud with TOC, copper with zinc and lead, did not exhibit strong correlations suggesting that sources of the stressors differ and that there is little overall spatial pattern in stress across the estuary.

1. Introduction

1.1 Background

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

NRC identified the Mangonui Estuary catchment as a priority catchment for the implementation of the freshwater National Policy Statement, and a catchment plan with specific rules and water quality limits has been developed. NRC subsequently undertook a survey of 17 sites throughout the Mangonui Estuary in order to provide baseline data to track changes in the health of the estuary over time.

The Mangonui Estuary monitoring programme has been adapted from the Estuary Monitoring Protocol by 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. This protocol has been adopted by a number of Regional Councils and there are now similar estuarine monitoring programmes throughout New Zealand (Bolton-Ritchie, 2007; Robertson & Stevens, 2007). In addition, Auckland Regional Council and Waikato Regional Council have long established marine monitoring programmes, which use similar methodologies (Ford & Anderson, 2005; Halliday, Hewitt and Lundquist, 2006; Kim, 2007; Nicholls, Hewitt and Hatton, 2002; Thrush, Pridmore, Hewitt, and Roper, 1988). The adoption of this standardised method ensures that the results are scientifically credible and comparable to those collected across New Zealand. This survey's methods are consistent with NRC's surveys for Whangarei Harbour (Griffiths, 2013), Kaipara Harbour (Griffiths, 2014a), and Waitangi Estuary (Griffiths, 2014b).

1.2 Study Area

1.2.1. The estuary

Mangonui Estuary is located in the south-eastern corner of Doubtless Bay, a large coastal embayment, on the east coast of the North Island. The estuary is 868.6 ha, 68% of which is intertidal, and at the inlet is 356 m wide. The largest freshwater source is the Oruaiti River, the largest river in the doubtless bay catchment, which enters the estuary in the southern part of the estuary. The Oruaiti River drains from Otangaroa on the northern edge of the Omahuta Forest; an area that is prone to erosion due to its geology and high rainfalls. As a result the river is often laden with terrigenous sediment that is deposited in the Mangonui Estuary.

1.2.2. The catchment

The estuary drains a catchment of 26,079 ha and the land-use in the catchment has been heavily modified, with a considerable proportion of the catchment cleared for agricultural land-use. Catchment analysis using the land-use classification from the New Zealand Land Cover Database (LCDB2) indicated that in 2012, 42% of the catchment was covered by high producing exotic grassland, 20% with indigenous forest, 11% with exotic forest and 17% with manuka and kanuka shrubland (Table 1 & Figure !).

Table 1: Land-use in Mangonui Catchment, from the New Zealand Land Cover Database (2012)

1st Order Class	2nd Order Class	Area (ha)	Percentage
Artificial Surfaces (< 1%)	Built-up Area (settlement)	62	< 1
	Surface Mine or Dump	5	< 1
	Transport Infrastructure	3	< 1
	Urban Parkland/Open Space	50	< 1
Bare or lightly vegetated surfaces (< 1%)	Landslide	1	< 1
	Sand or Gravel	1	< 1
Cropland (< 1 %)	Orchard, Vineyard or Other Perennial Crop	210	< 1
Forest (32%)	Deciduous Hardwoods	41	< 1
	Exotic Forest	2918	11
	Forest - Harvested	206	< 1
	Indigenous Forest	5124	20
	Mangrove	15	< 1
Grassland (44 %)	Herbaceous Freshwater Vegetation	13	< 1
	Herbaceous Saline Vegetation	37	< 1
	High Producing Exotic Grassland	11026	42
	Low Producing Grassland	487	2
Scrub and shrubland (22 %)	Broadleaved Indigenous Hardwoods	1085	4
	Gorse and/or Broom	286	1
	Matagouri or Grey Scrub	12	< 1
	Mixed Exotic Shrubland	80	< 1
	Manuka and/or Kanuka	4382	17
Water Bodies (< 1%)	Estuarine Open Water	21	< 1
	Lake or Pond	<1	< 1
	River	15	< 1
Total		26,079	100.0

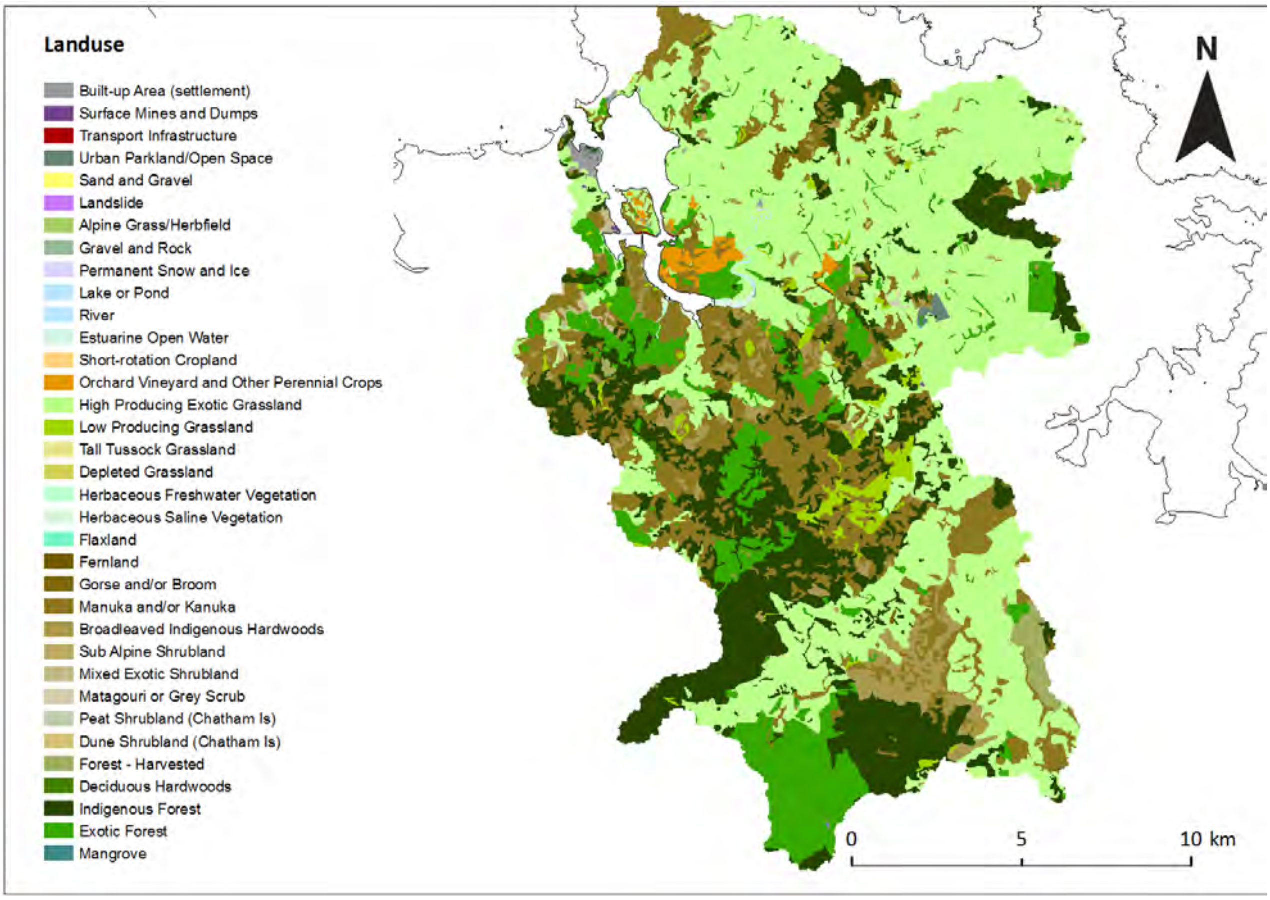

Figure 1: Land-use in the Mangonui Estuary, from the New Zealand Land Cover Database (2012).

1.2.3. Estuarine sediment characteristics

There is limited information available about estuarine sediment characteristics in the Mangonui Estuary. In 2013 Taipa/Mangonui Estuary sediment was sampled for grain size and nutrient concentrations as a part of the Far North Harbours water and sediment quality investigation (Northland Regional Council, 2013a). This study was a repeat of a previous study (unreported) from 2004. The harbour entrance had almost 100% mud (site not sampled in 2016) and the largest profile of coarse sand was found in the upper harbour at Oruaiti River. A sample collected near the northern end of Paewhenua Island contained a large percentage of grains sized 63-250μm (fine sand) (Northland Regional Council, 2013a).

1.2.4. Estuarine sediment nutrients

There is limited information available about estuarine sediment nutrient concentrations in the Mangonui Estuary. In 2013 the levels of TOC, nitrogen and phosphorus were measured as a part of the Far North Harbours water and sediment quality investigation (Northland Regional Council, 2013a). Concentrations were within the range of other Northland Harbours, but TOC and total phosphorus were slightly elevated compared to Rangaunu and Parengarenga Harbour. The concentrations of phosphorus (490 mg/kg) and TOC (1.9 %) were at levels which suggested that the Mangonui Estuary was low to moderately enriched, using criteria developed by Robertson and Stevens (2007). The level of nitrogen (530 mg/kg) was classified as 'very good' using this criteria.

Table 2: Sediment nutrient concentrations previously recorded by NRC at the Taipa/Mangonui Estuary.

Year	Number of sites	Total Organic Carbon (%)	Total Nitrogen (g/m^3)	Total Phosphorus (g/m^3)
2013	6	1.9 (1.2 – 2.5)	354 (59 – 900)	490 (280 – 710)

1.2.5. Estuarine sediment metals

Resource consent monitoring around Mill Bay and Mangonui township shows concentrations away from the consented point sources to be comparable with the current study.

1.2.6. Ecology

There is limited information on the ecology of the Mangonui Estuary.

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 NRC's previous ecological survey of the Whangarei Harbour in 2012 (Griffiths, 2013).

2.1.1. Sampling sites

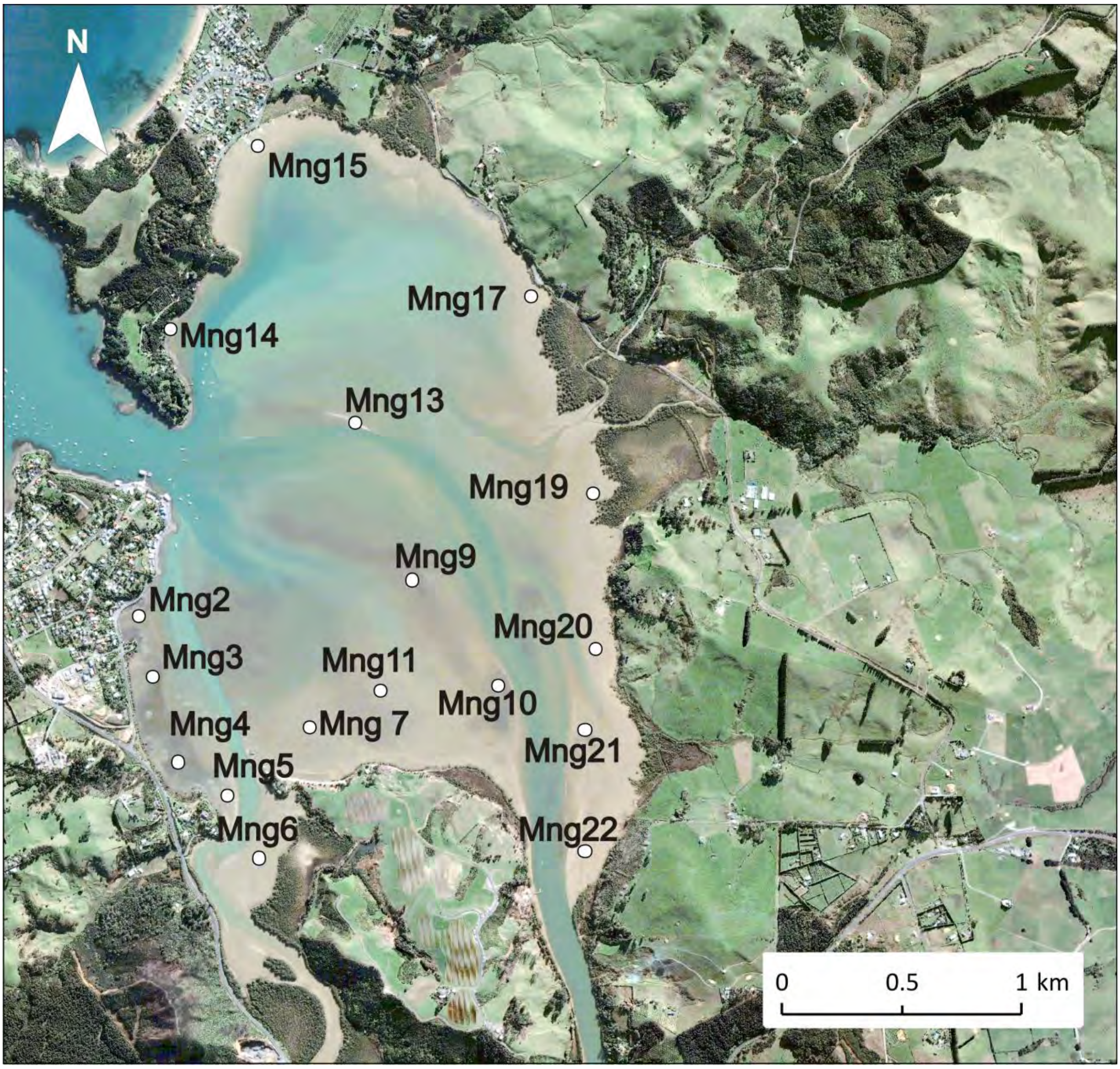

Figure 2: Location of sampling sites in Mangonui Estuary.

2.1.2. Timing of sampling

The survey of the Mangonui Estuary was conducted over three days from the 17^{th} - 19^{th} February 2016. Prior to the survey there had been 65 mm of rain in early February and over the survey period the area received a further 111 mm (measurements taken from the Oruru Bowling Club rain gauge).

2.1.3. Ecological sampling

The ecology was sampled using a Perspex core (with a diameter of 150 mm and 150 mm deep). Three replicates were collected at 15m intervals along a 30m transect positioned parallel to the shoreline. All core samples were sieved through a 500 µm mesh on site and the material retained in the sieve brought back to NRC's laboratory. All organisms retained were preserved with 70% ethanol and stained with rose bengal. Sorting and identification of all organisms was conducted by Cawthron Institute.

At the position of each replicate, a 0.25 m^2 quadrat was also sampled and the epifaunal benthic organisms quantified. The results from this are not discussed in this report.

Insect larvae (Insecta) identified from the samples were excluded from analysis as these are not marine benthic invertebrates. Unidentified decapod larvae were also excluded from the analysis this lifestage is not considered to have recruited to (become a part of) benthic populations yet.

2.1.4. Sediment Characteristics

One surface sediment sample of approximately 200 grams wet weight (consisting of the surface 2 cm) was collected at each site. The sample was collected from the middle of the 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 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.

2.2 State of the Environment Indicators

2.2.1. Traits-Based Index

Organisms can be categorised according to characteristics (traits) that are likely to reflect ecosystem function (i.e., their feeding mode, degree of mobility, position in the sediment column, body size, body shape, capacity to create tubes/pits/mounds, etc.). During 2010 and 2011, an index based on these biological traits was created (van Houte-Howes and Lohrer, 2010) and improved (Lohrer and Rodil, 2011). The index is based on seven broad trait categories (living position, sediment topography feature created, direction of sediment particle movement, degree of mobility, feeding behaviour, body size, body shape and body hardness). Specifically the richness of taxa exhibiting seven particular traits: living in the top 2 cm of sediment, having an erect structure or tube, moving sediment around within the top 2 cm, being sedentary or only moving within a fixed tube, being a suspension feeder, being of medium size, or being worm shaped. Values of this index range from 0-1, with values close to 0 indicating low levels of functional redundancy and highly degraded sites (see Table 3 for suggested groupings). Values closest to 1 indicate high levels of functional redundancy, which is indicative of healthy areas (high functional redundancy tends to increase the inherent resistance and resilience in the face of environmental changes) (Hewitt, Lohrer and Townsend, 2012). The index has been further refined by Hewitt et al. (2012) with the SUMmax parameter modified to allow the metric to be applied to a wider range of sites and those sampled with differing numbers of replicates (Lohrer and Rodil, 2011).

2.2.2. Benthic health models

The original benthic health model (BHMmetals) was developed by Auckland Regional Council, Marti Anderson (then Auckland University) and Simon Thrush and Judi Hewitt (NIWA), to determine the health of macrofaunal communities relative to storm-water contaminants. The model is based on a multivariate analysis of the variation in macrofaunal community composition related to total sediment copper, lead and zinc concentrations, extracted from the 500 µm fraction of the sediment (Anderson, Hewitt, Ford and Thrush, 2006).

In 2010-2011, another model was developed, this time to determine health relative to sediment mud content (BHMmud, Hewitt & Ellis, 2011). At the time of the development of this model it was determined that, while there was some crossover between community compositions found in response to high mud and high contaminants, the two effects could still be separated.
Both models are based on the community composition observed at 84 intertidal sites in the Auckland Region between 2002 and 2005. The sites are within tidal creeks, estuaries or

harbours, but do not include exposed beaches. They cover a range of contaminant concentrations and mud content. The models use Canonical Analysis of Principal Coordinates (CAP, Anderson & Willis, 2003) of square root transformed Bray-Curtis dissimilarities to extract variation related to a single environmental variable and produce a score of community composition related to that variable. For the metal model, the concentrations of the three metals have been used in a Principle Component Analysis to create a single axis (PC1) that explains <90% of the variability in contaminant differences between the sites. For the mud model, the % mud content of sediment at the time of sampling was used.

The macrofaunal community composition of sites and sampling times not in the models are compared to model data (using the ‘*add new samples*’ routine in *CAP, PermANOVA addon,* Primer E). The samples are then allotted to five different groups related to health (see Table 3). It is worth noting that BHM values are usually calculated from 10 to 12 replicates per site for state of the environment reporting and other council reports, here they were calculated from only three samples. While the TBI calculation has an adjustment for number of replicates, the BHM models do not yet (although this is in development).

2.2.3. Combined indices

Hewitt et al. (2012) recommended the use of the three indices above (TBI index, BHMmud score (CAPmud) and BHMmetals score (CAPmetals)) to provide a complementary assessment of health. Average health values are determined for each site in the following way:

a. If the CAPmud score is ≤ -0.12, the site is allocated to Mud group 1 (Table 3), and the combined Health score is calculated as the average CAPmetals and CAPmud group values. The TBI is not used in the combined score in this case, as it does not work well when mud content is extremely low (Hewitt et al. 2012).
b. If the CAPmetals score is ≥0.10, the site is allocated to group 4 or 5, and the combined Health score is equal to the TBI group value. At this level of contaminants, the TBI score itself fully reflects health.
c. Otherwise, Health is the average of the CAPmetals, CAPmud and TBI group values. Health scores, ‘x’, are then translated as x ≤ 0.2 ‘extremely good’; 0.2 <x≤ 0.4 ‘good’; 0.4 <x≤ 0.6 ‘moderate’; 0.6 <x≤ 0.8 ‘poor’ and x < 0.8 ‘unhealthy with low resilience’. It is important to recognise that the health scores are from particular sites within each estuary, and do not necessarily represent the health status of the estuary as a whole. There may be locations in each estuary that are significantly healthier, or less healthy, than the monitored sites.

Table 3: Conversion of CAPmetals and CAPmud scores into health groups (1 is least healthy). Cut off point is equal or less than. These groups are then converted (along with TBI scores) into values of similar scale (0-1) that run in the same direction (higher values indicating more degraded conditions), to facilitate their combination into overall health scores.

Group	CAPmetals		CAPmud		TBI	
	Cutoff	value	Cutoff	value	Cutoff	value
1	-0.164	0.2	-0.12	0.2	0.4	0.33
2	-0.0667	0.4	-0.05	0.4	0.3	0.67
3	0.0234	0.6	0.02	0.6		1.0
4	0.10	0.8	0.10	0.8		
5		1.0		1.0		

2.3 Data 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 TEL developed by MacDonald et al. (1996) (see Table 4). These TEL levels are used by Auckland Council to assess metal contamination levels in Auckland Region estuaries. Sediment TOC and nutrient concentrations were assessed against a classification developed by Robertson and Stevens (2007).

Table 4: Sediment quality guidelines for cadmium, chromium, copper, nickel, lead and zinc. Units are mg/kg on a dry weight basis (<500 μm sediment fraction). Comparison thresholds TEL (MacDonald et *al.* 1996) and the interim sediment quality guidelines (ISQG) of ANZECC (2000).

Source	TEL (mg.kg^{-1})	ISQG-Low (mg.kg^{-1})
Cadmium	0.68	1.5
Chromium	52.3	80
Copper	18.7	65
Nickel	15.9	21
Lead	30.2	50
Zinc	124	200

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); Pielou's evenness index (J') and the Shannon-Wiener diversity index for each core sample. Mean values were then calculated for each site. An expression of within-site variability was also calculated by determining the Bray-Curtis similarity between individual site replicates.

The species abundance data was also examined with cluster analysis and multidimensional scaling (MDS) using a Bray-Curtis similarity matrix. This analysis was performed on the mean species abundance for each site. A log (X+1) transformation was performed on the benthic infauna abundance data in order to downplay the influence of numerically dominant taxa (Clark and Warwick, 2001). Cluster analysis and MDS ordination are visual displays of the species similarity matrix which can help to identify groups of samples. Samples located close to each on the plots are more similar to each other.

A distance-based linear model (DISTLM) was then used to model the relationship between the squar root transformed ecological data and the physical and sediment chemical properties (McArdle and Anderson, 2001). Prior to this analysis the sediment data was log 10 transformed. Mean abundance data was used for the DISTLM.

3. Results

3.1 Sediment physical properties

Most sites within the Mangonui Estuary had a high proportion of fine sand (Figure 3). However, sites to the north were largely composed of coarse to medium sand with smaller amounts of fine sand. Further away from the mouth sediment was composed mostly of medium to fine sand with small amounts of mud (< 5%). Mud was more common along the eastern shoreline and in the upper reaches of the estuary. The highest proportion of mud (47%) was found at site Mng22 which is located in a sheltered tidal creek (Figure 3).

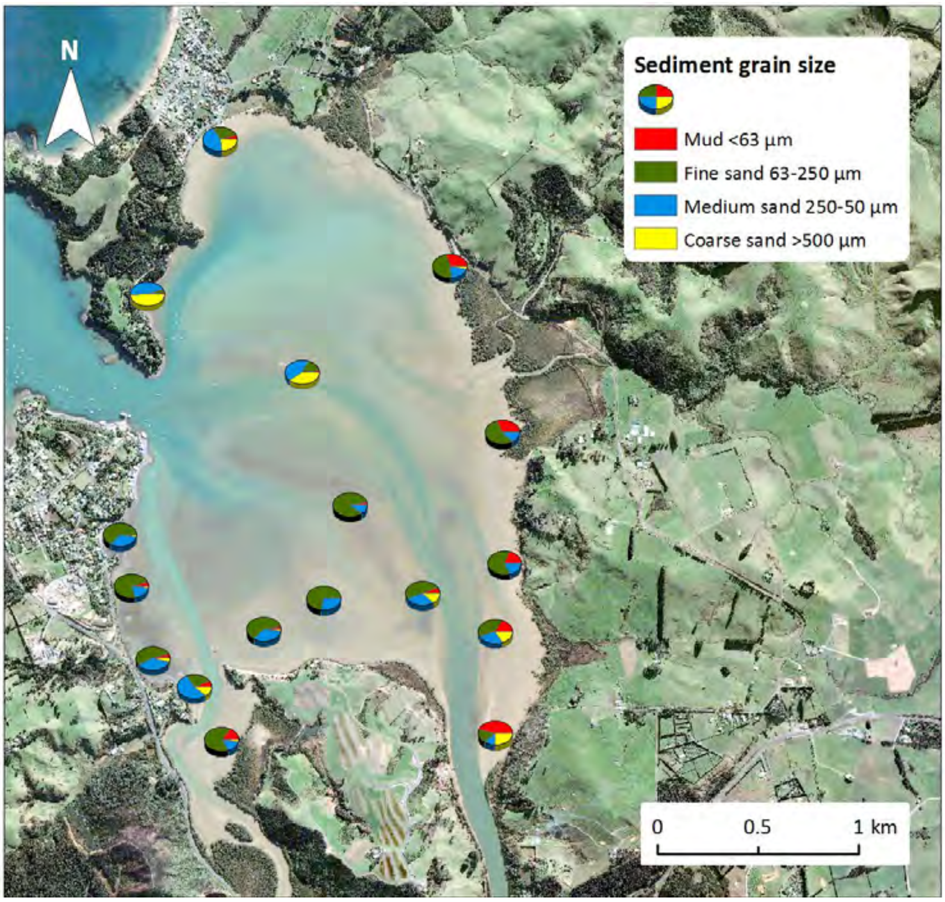

Figure 3: Sediment grain size characteristics in the Mangonui Estuary 2016.

3.2 Sediment Total Organic Carbon and nutrient concentrations

3.2.1. Total Organic Carbon

The highest levels of TOC were found at Mng22 (3.7 %w/w), Mng19 and 21 (2.2 %w/w) and Mng5 (2.1 %w/w). The lowest values were recorded at Mng7 and 11 (0.6 %w/w) (Figure 4). ANZECC guidelines do not include trigger values for TOC in marine sediments and there are currently no nationally accepted guideline values. Robertson and Stevens (2007) have developed their own classifications for TOC, where levels below 1% are classified as 'very good', levels between 1-2% are classified as 'low to moderately enriched', levels between 2-5% are classified as 'enriched' and levels above 5% as 'very enriched'. Using this criteria Mng7 and 11 are considered 'very good', 11 sites are 'low to moderately enriched' and four sites are 'enriched' (Figure 4).

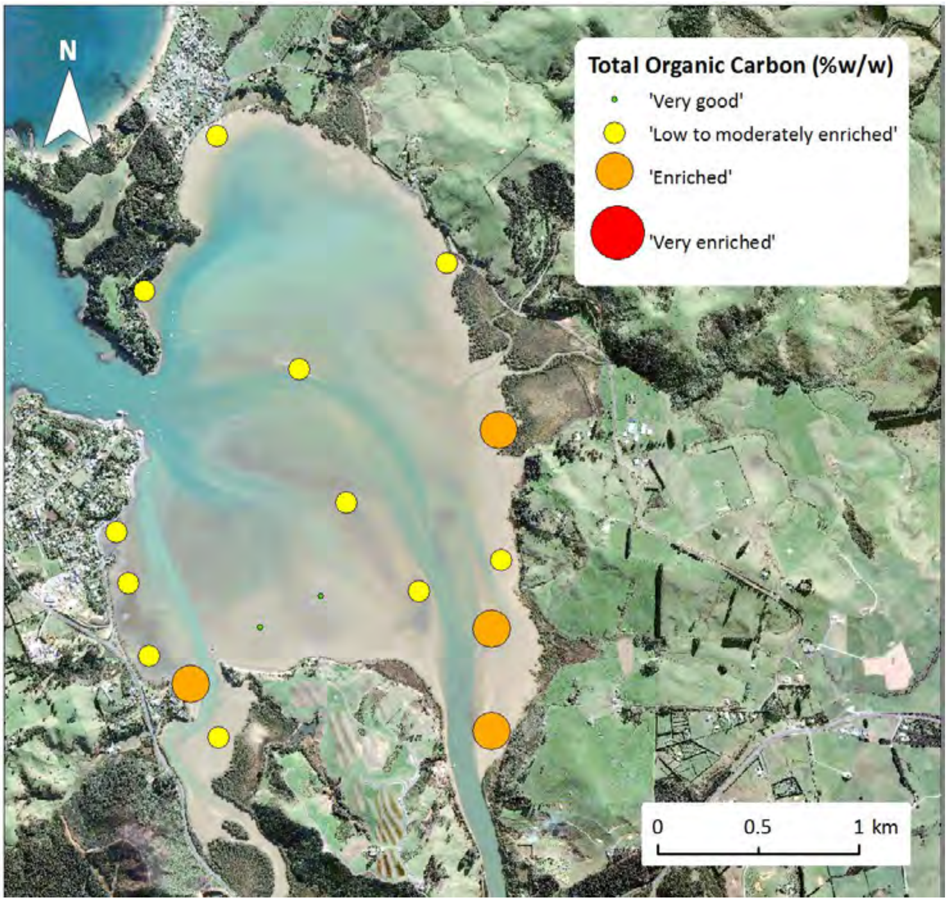

Figure 4: TOC concentration in the Mangonui Estuary 2016.

3.2.2. Total Nitrogen

The highest concentration of sediment nitrogen was recorded at Mng22 (1,300 mg/kg), which was almost double the next highest concentration (Figure 5). The lowest concentration observed was 150 mg/kg at Mng7. ANZECC guidelines do not include trigger values for nitrogen in marine sediments and there are currently no nationally accepted guideline values. Again, Robertson and Stevens (2007) have developed their own classifications for sediment nitrogen concentrations, where 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 this criteria the concentrations of 11 sites were classified as 'very good' and six sites as 'low to moderately enriched' (Figure 5).

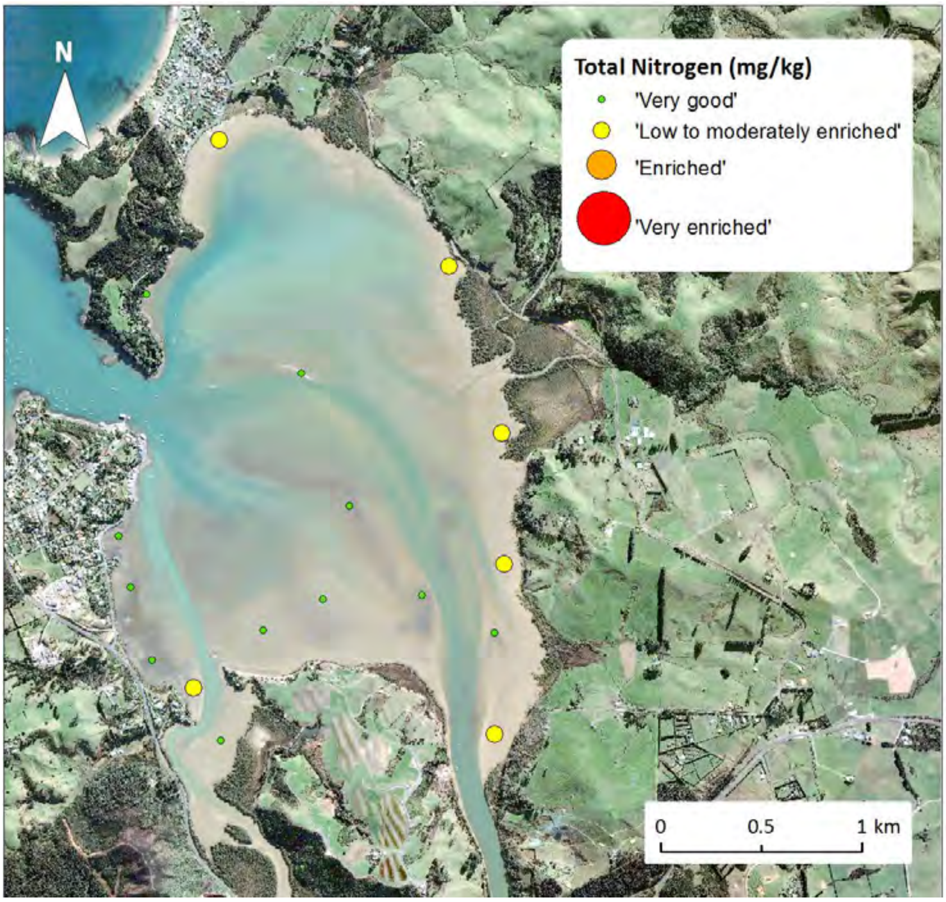

Figure 5: Sediment total nitrogen concentrations in the Mangonui Estuary 2016.

3.2.3. Total Phosphorus

The highest concentration of sediment phosphorus was recorded at Mng5 (1,200 mg/kg) with the lowest concentrations found at Mng7 (180 mg/kg) (Figure 6), which was also the site with the lowest concentration of nitrogen. ANZECC guidelines do not include trigger values for phosphorus in sediments and there are currently no nationally accepted guideline values but Robertson and Stevens (2007) have also developed a classifications 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 one site was classified as 'very good', six sites were 'low to moderately enriched', nine sites were classified as 'enriched' and one site (Mng5) was 'very enriched' (Figure 6).

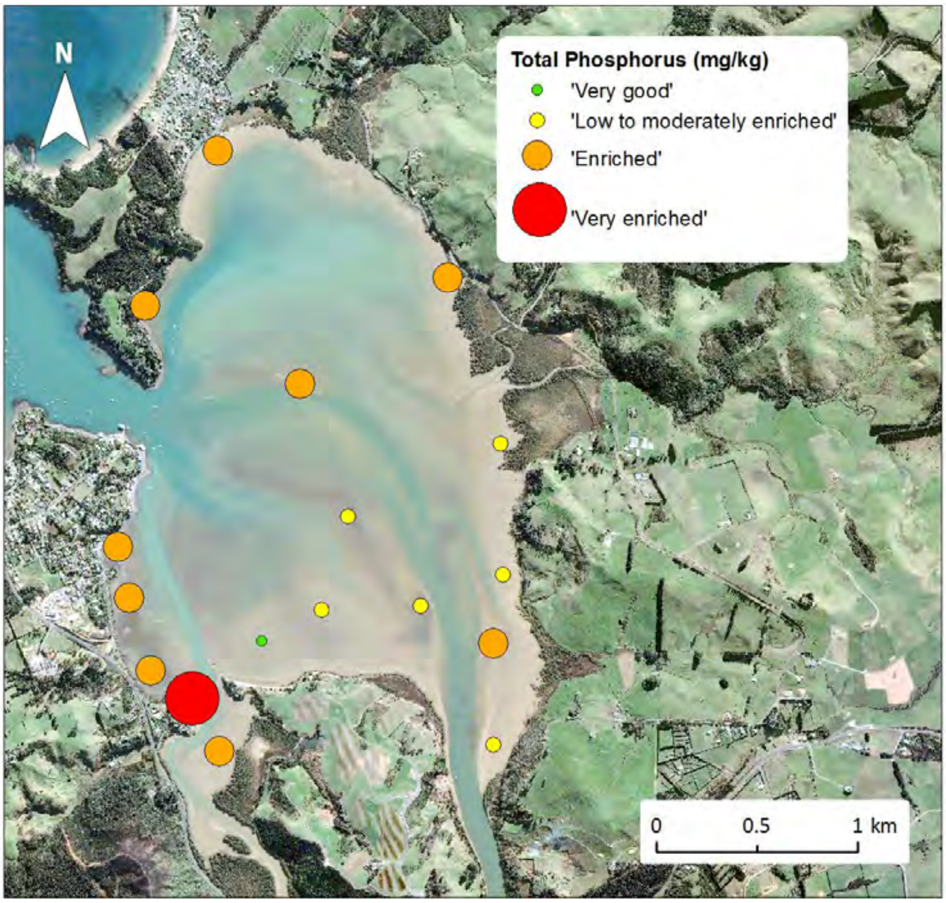

Figure 6: Sediment total phosphorus concentrations in the Mangonui Estuary 2016.

3.2.4. Comparisons with other Northland estuaries

The minimum, mean and maximum TOC concentrations in Mangonui were average compared to those recorded in other estuaries and similar to those observed in Taipa/Mangonui in 2013 (Table 5). The range of nitrogen concentrations in the Mangonui Estuary were generally smaller than the those recorded in sediment surveys of other estuaries in Northland (Bamford, 2016; Northland Regional Council, 2013a; Parkes, Hewitt and McCartain, 2016,), with the exception of Ngunuguru, Parengarenga, Houhora and Rangaunu (Table 5). The mean concentration measured in 2016 was slightly higher than that measured in 2013 (Taipa/Mangonui), however the sites sampled were different. The nitrogen concentration recorded at Mng22 was particularly high in comparison to the other Mangonui sites, but was within the ranges measured in most other estuaries. The range of phosphorus concentration recorded at Mangonui was larger, with a higher maximum concentration, than all other estuaries surveyed recently by NRC with the exception of Bay of Islands and Waitangi, both of which had a higer average but smaller range, and Whangarei, which had a lower maximum but much larger range (Table 5).

Table 5: Sediment TOC and nutrient concentrations in Northland estuaries. Number of samples (N) mean nitrogen, phosphorus and TOC with range presented in brackets.

	Year	N	TOC (%w/w)	Nitrogen (mg/kg)	Phosphorus (mg/kg)
Mangonui	2016	17	1.7 (0.6 – 3.7)	413 (150 – 1300)	549 (180 – 1200)
Whangarei	2016	16	2.0 (0.3 – 5.2)	931 (110 – 3500)	468 (52 – 1500)
Ngunguru	2016	21	1.0 (0.6 – 1.6)	487 (140 – 960)	328 (220 – 470)
Bay of Islands	2016	16	2.2 (0.9 – 4.4)	904 (280 – 1700)	603 (380– 980)
Kaipara	2014	44	1.5 (0.2 -3.9)	804 (33 – 3900)	313 (27 – 700)
Waitangi	2013	10	2.6 (1.0 – 4.2)	803 (220 – 2600)	647 (410 – 850)
Parengarenga North	2013	12	0.9 (0.3 - 2.5)	263 (62-1300)	102 (28-180)
Parengarenga South	2013	10	0.4 (0.1 – 1.0)	218 (25-500)	60 (18-200)
Houhora	2013	6	1.3 (0.6 - 1.9)	688 (270 – 1100)	129 (52 – 220)
Rangaunu	2013	10	0.8 (0.2 -2.2)	318 (64-920)	122 (24 -360)
Taipa/Mangonui	2013	6	1.9 (1.2 – 2.5)	354 (59 – 990)	490 (280 – 710)
Whangaroa	2013	7	3.3 (1.3 - 6.0)	800 (130 – 1600)	518 (390 – 710)
Hokianga	2013	11	3.3 (0.2 - 5.2)	1102 (43-2700)	512 (54 -800)

3.3 Sediment metal Concentrations

3.3.1. Cadmium

The concentrations of cadmium were below the laboratory detection at all of the 17 sites.

3.3.2. Chromium

All of the chromium concentrations were well below the ANZECC ISQG-Low effect trigger value of 80 mg/kg and the TEL of 52.3 mg/kg developed by MacDonald et al. (1996). The highest concentration of chromium was at Mng5 (47 mg/kg) (Figure 7).

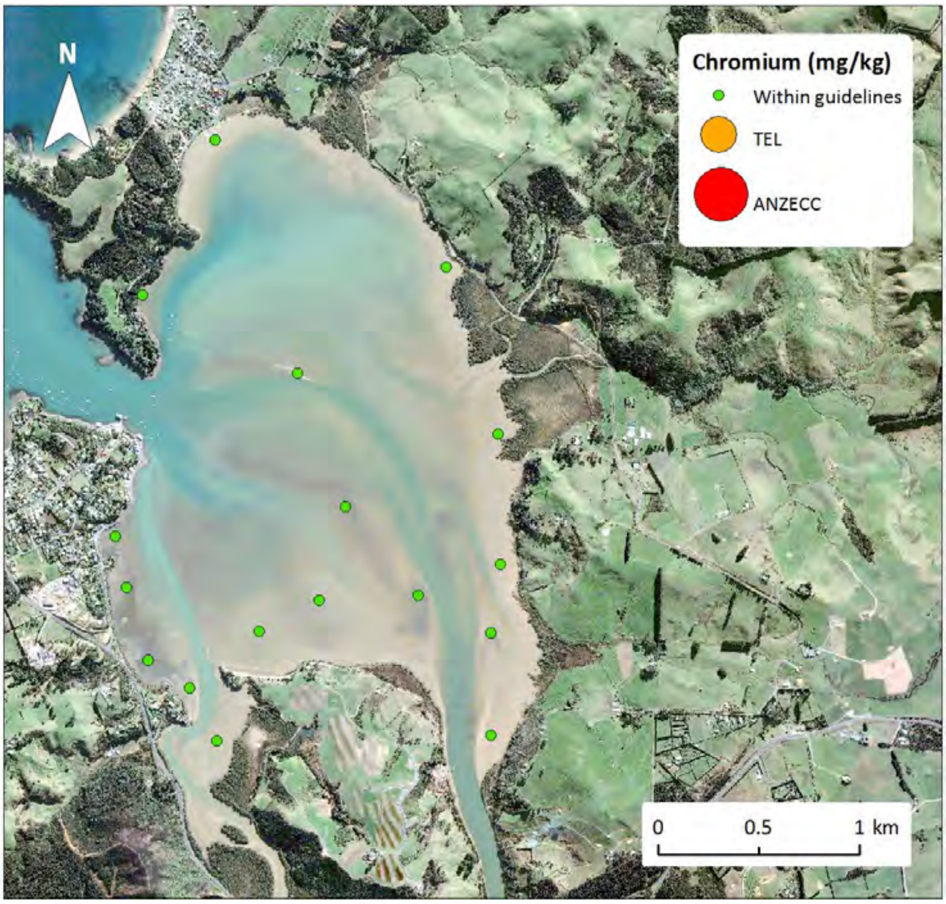

Figure 7: Sediment chromium concentrations in the Mangonui Estuary 2016.

3.3.3. Copper

All of the copper concentrations were well below the ANZECC ISQG-Low effect trigger value of 65 mg/kg and all except for Mng14 (23 mg/kg) were below the TEL of 18.7 mg/kg developed by MacDonald et al. (1996) (Figure 8).

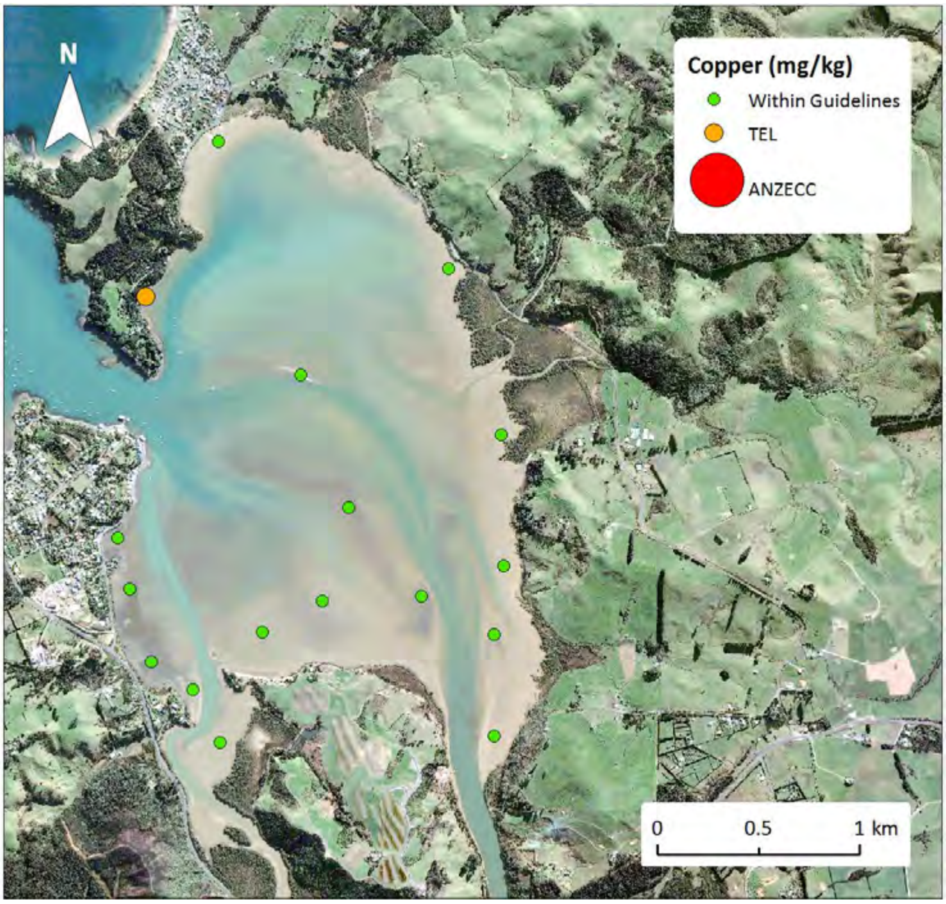

Figure 8: Sediment copper concentrations in the Mangonui Estuary 2016.

3.3.4. Nickel

The highest concentrations of nickel were recorded at Mng5 (22 mg/kg) and Mng21 (21 mg/kg) (Figure 6). These exceeded the TEL of 15.9 mg/kg developed by MacDonald et al. (1996) and the ANZECC ISQG-Low effect trigger value of 21 mg/kg. Mng4 (16 mg/kg) also exceeded the TEL (Figure 9). The remaining 14 sites were all below guideline levels.

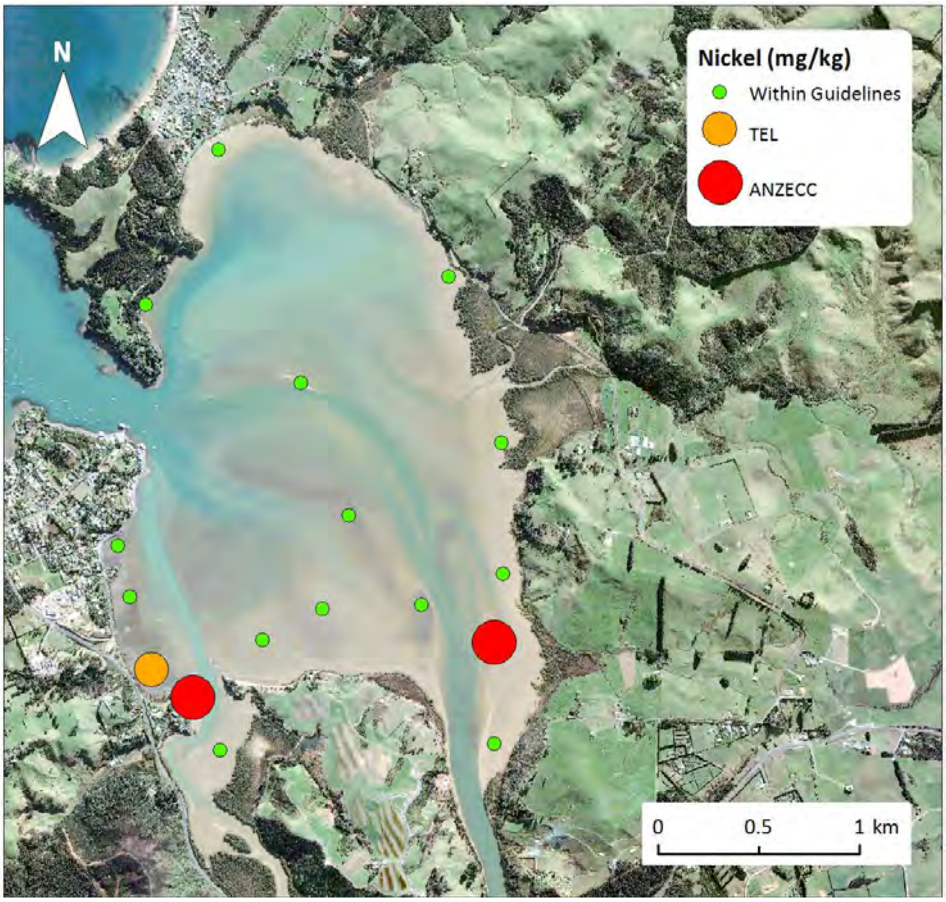

Figure 9: Sediment nickel concentrations in the Mangonui Estuary 2016.

3.3.5. Lead

All of the lead concentrations were below the ANZECC ISQG-Low effect trigger value of 50 mg/kg but Mng14 (41 mg/kg) exceeded the TEL of 30.2 mg/kg developed by MacDonald et al. (1996). The higher concentrations of lead were found towards the entrance of the estuary (Figure 10).

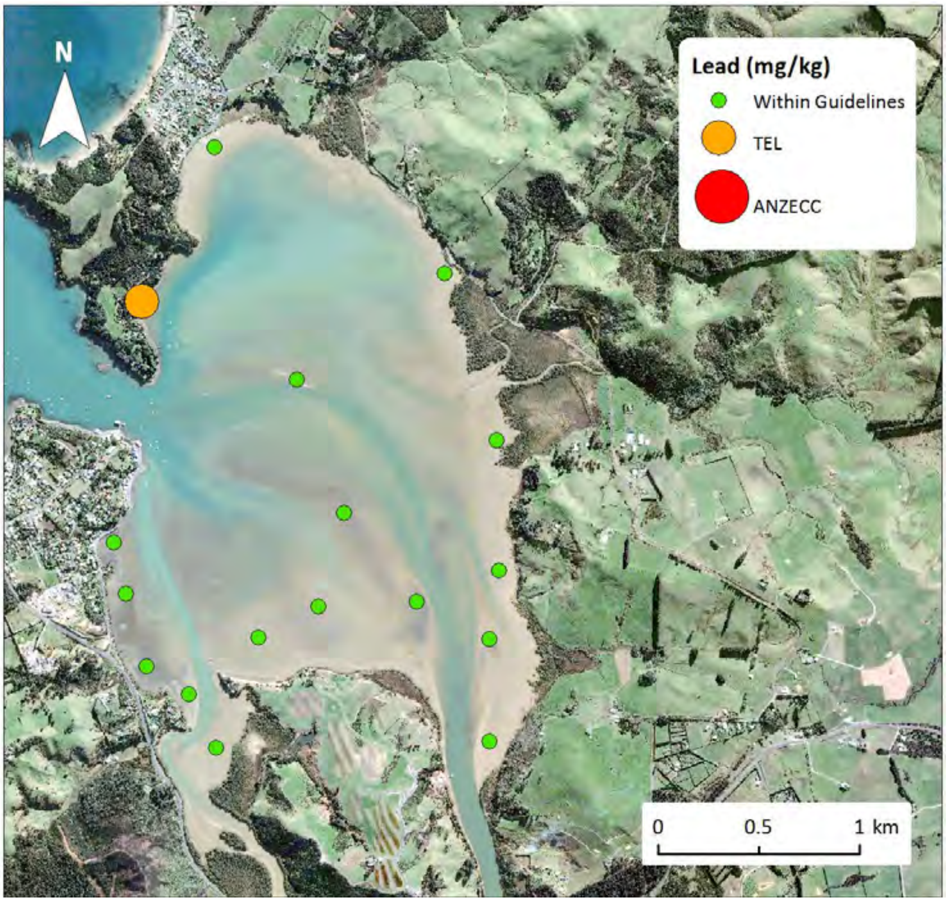

Figure 10: Sediment lead concentrations in the Mangonui Estuary 2016.

3.3.6. Zinc

All of the zinc concentrations were below the ANZECC ISQG-Low effect trigger value of 200 mg/kg but the TEL of 124 mg/kg developed by MacDonald et al. (1996) was exceeded at Mng14 (170 mg/kg) (Figure 11).

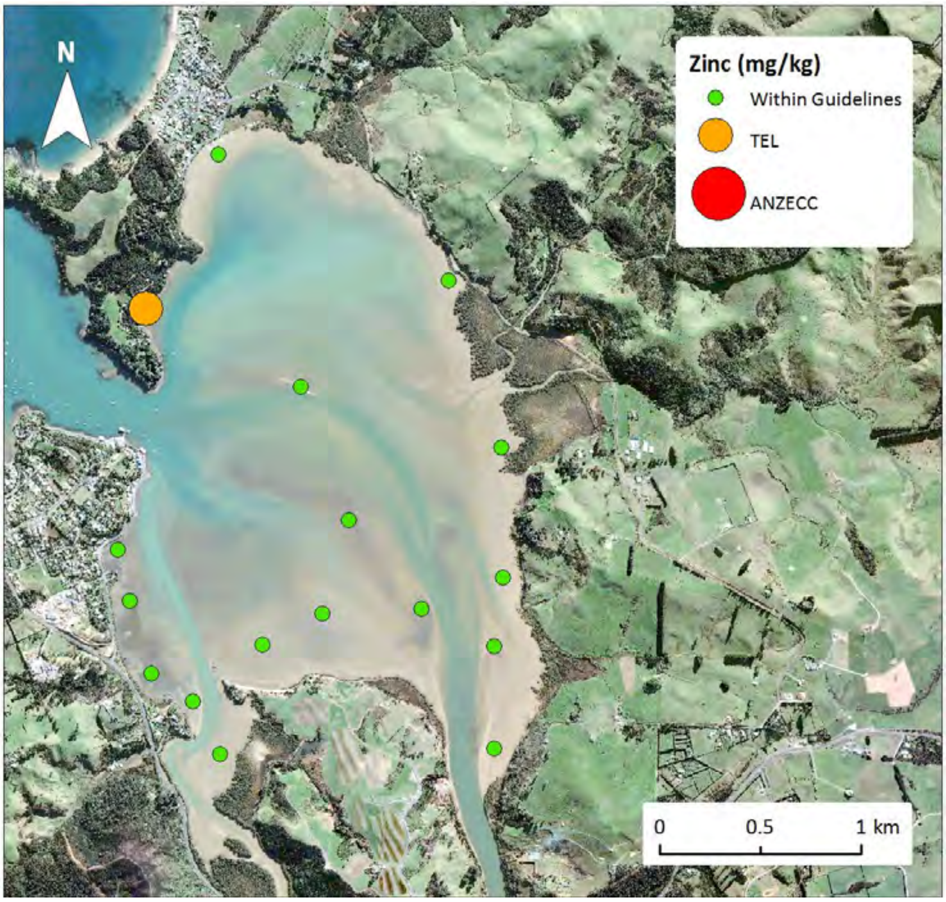

Figure 11: Sediment zinc concentrations in the Mangonui Estuary 2016.

3.3.7. Comparison of metal concentrations in Northland estuaries

The metal concentrations recorded in the Mangonui Estuary were slightly elevated for chromium, nickel and zinc compared to values reported in recent sediment surveys conducted by NRC for the Bay of Islands and Whangarei in 2016 (Bamford, 2016, Parkes et al. 2016). The range of lead concentrations was similar to Whangarei but was much larger compared to Bay of Islands Ngunguru and Waitangi (Table 6) (Griffiths, 2014b). Concentrations of copper in the Mangonui Estuary were more comparable to those found within Bay of Islands Ngunguru and Waitangi in 2016, and lower than levels in Whangarei Harbour (Table 6) (Griffiths, 2014b).

Table 6: Mean metal concentrations recorded in Northland estuaries with range in brackets. Number of samples (N) mean metal concentration, with range presented in brackets.

	Mangonui (2016)	Whangarei (2016)	Bay of Islands (2016)	Ngunguru (2016)	Waitangi (2013)
N	17	16	16	21	10
Cadmium	<0.09	<0.09 (<0.09 – 0.15)	<0.09	<0.09	<0.09 (<0.09 – 0.13)
Chromium	30 (9 – 47)	10 (3 – 25)	19 (7 – 48)	7 (3.5 – 10)	13 (5 – 17)
Copper	9 (2 – 23)	15 (0 – 79)	9 (2 – 15)	3 (0.9 – 6.2)	11 (4 – 17)
Nickel	12 (3- 22)	5 (1 – 12)	8 (3 – 15)	3 (1.4 – 5.4)	8 (5 – 10)
Lead	5 (0.7 – 41)	9 (1 – 33)	10 (4 – 15)	3 (1.1 – 7.6)	8 (4 – 10)
Zinc	76 (24 – 170)	58 (0 – 210)	51 (23 – 82)	26 (11 – 62)	56 (33 – 84)

3.4 Ecology

3.4.1. Biodiversity

A total of 15,932 individuals belonging to 102 different taxa were identified in Mangonui Estuary. The mean number of taxa varied from 15 at Mng19 to 45 at Mng21 (Table 7). The highest mean number of individuals was found at Mng13 (1,097) which can be attributed to high densities of Oligochaeta and the small spionid *Aonides trifida* (Table 8). The lowest number of individuals was found at Mng6, this site is located on the western side of Paewhenua Island. Mng11 had the highest Shannon-Wiener diversity and the third highest Pielou's evenness. The lowest diversity score was found at Mng5, which also had the second lowest evenness score. The highest evenness score was at Mng19 and the lowest at Mng13 (Table 7).

Bray-Curtis similarity indicated that the within site similarity at Mng14 was low (41%) compared to other sites within the estuary. A low Bray-Curtis similarity indicates that the species (and their abundances) found in the three replicates are dissimilar to each other. The highest Bray-Curtis similarity was at Mng4 (74%). A high Bray-Curtis similarity indicates that the taxa (and their abundance) in the three replicates are similar to each other (Table 7).

Table 7: Mean diversity indices and Bray-Curtis similarity at sites in Mangonui Estuary 2016.

Site	Species richness	Number of individuals	Shannon Diversity	Pielou's Evenness	Bray-Curtis Similarity
Mng2	33	142	2.13	0.61	57.92
Mng3	33	373	1.95	0.56	64.88
Mng4	33	274	1.86	0.53	74.50
Mng5	28	692	1.39	0.42	60.96
Mng6	18	39	2.30	0.79	48.04
Mng7	38	172	2.51	0.69	64.93
Mng9	33	174	2.10	0.60	55.14
Mng10	31	412	1.51	0.44	66.80
Mng11	39	219	2.75	0.75	61.99
Mng13	39	1097	1.45	0.39	51.83
Mng14	27	392	1.98	0.60	41.12
Mng15	31	274	2.47	0.72	48.52
Mng17	28	84	2.32	0.70	69.63
Mng19	15	54	2.32	0.86	50.62
Mng20	28	101	2.40	0.72	69.33
Mng21	45	389	2.59	0.68	52.83
Mng22	28	424	1.52	0.46	56.21

3.4.2. Multivariate analysis of ecological data

Analysis of the average linkage clustering and MDS ordination (Figure 12 & Figure 13) of the species abundance data indicate the existence of 5 groups of sites of greater than 40% self-similarity, with sites in the middle of the estuary and on the western side of the estuary tending to group separately from the sites located in the south and east of the estuary.

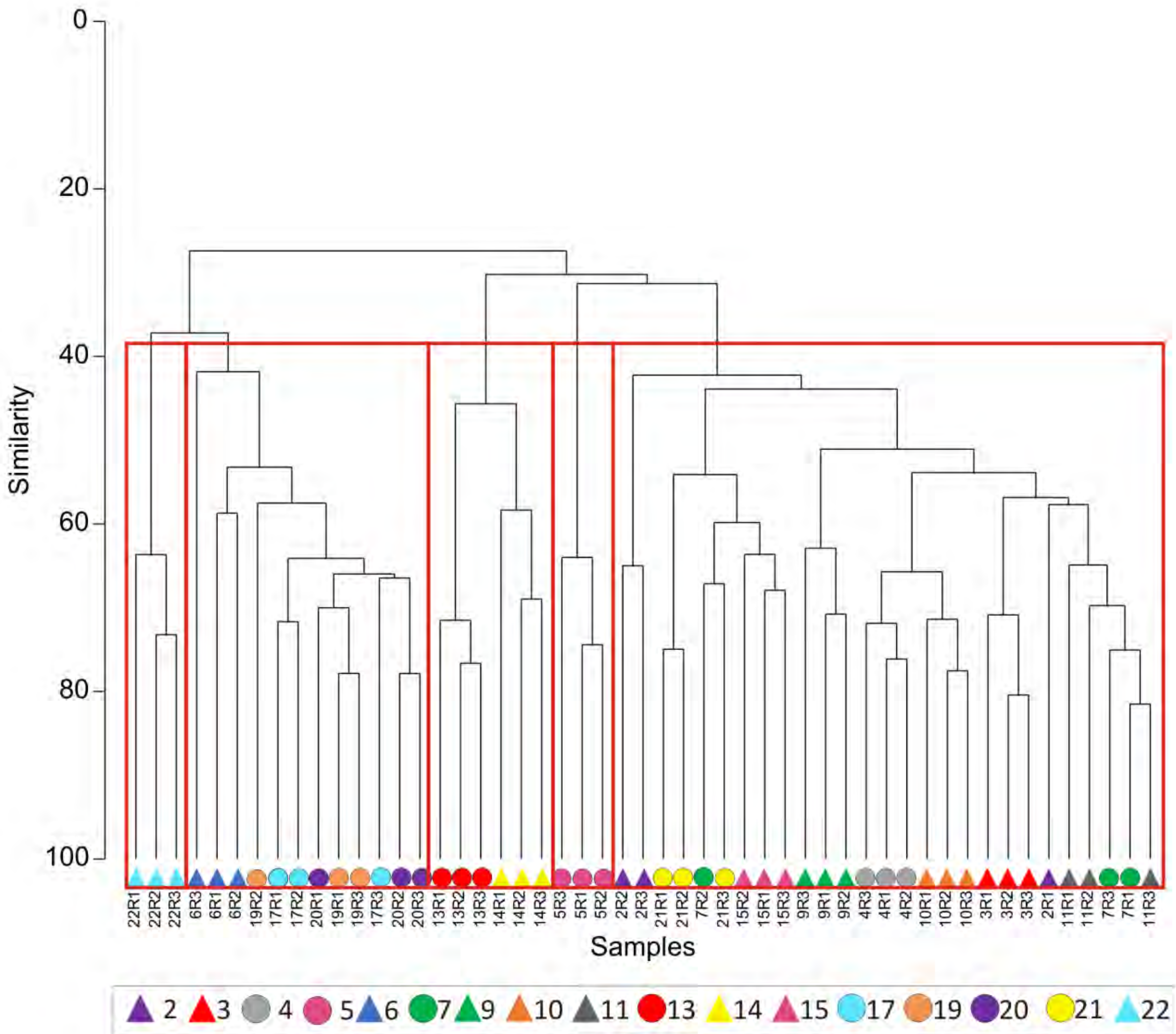

Figure 12: Group average linkage cluster of Bray-Curtis similarities from Log (X +1) transformed infauna abundance data collected from 17 sites in Mangonui Estuary 2016.The red boxes indicate groupings of sites with similar communities.

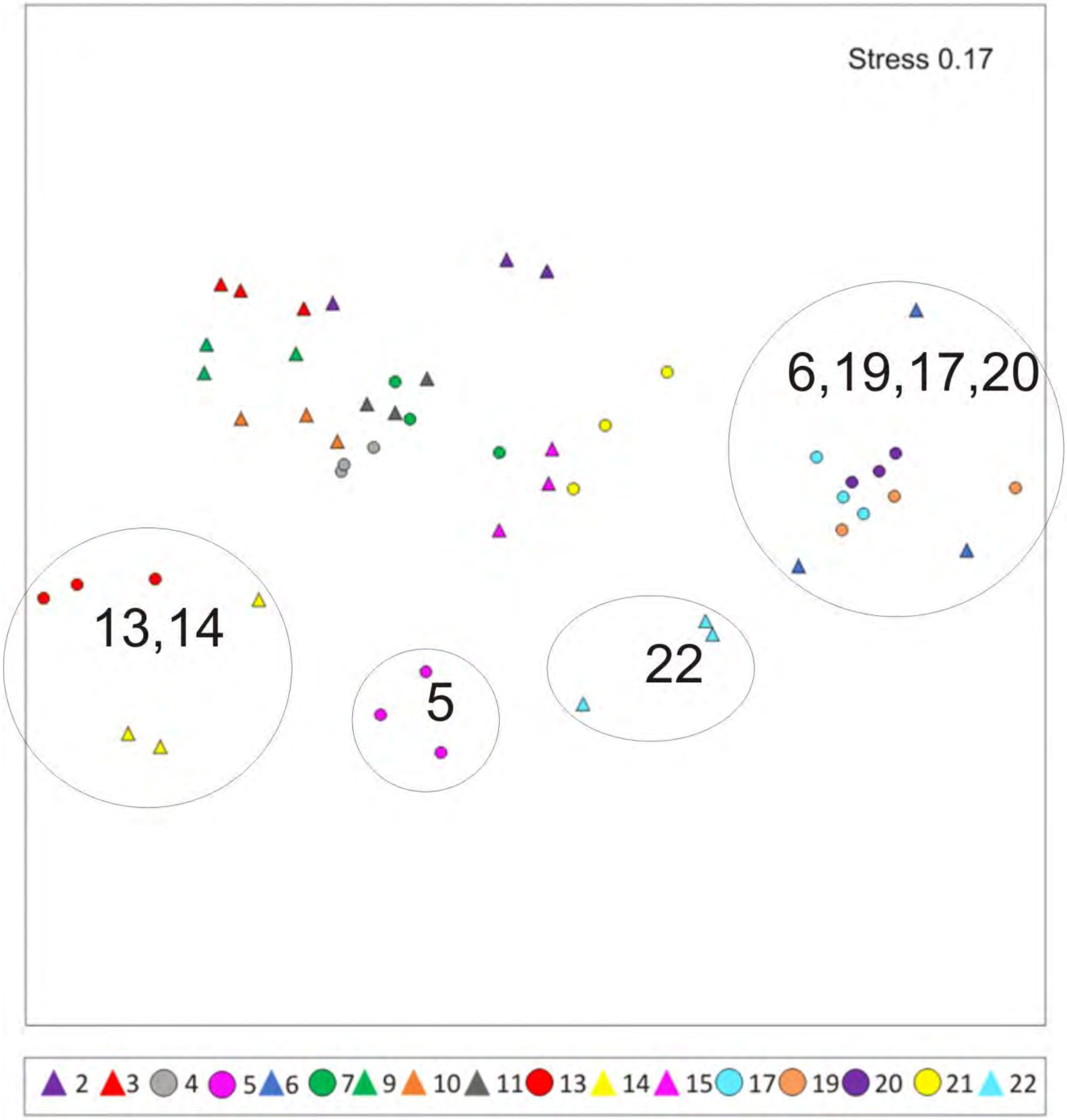

Figure 13: Non-metric multidimensional scaling (MDS) ordination of Bray-Curtis similarities from Log (X +1) transformed infauna abundance data collected from 17 sites in Mangonui Estuary 2016. Sites closest together are more similar and the red circles or box indicates groupings of sites with similar communities.

3.5 Species abundance

Communities at most sites were dominated by polychaete (including Spionidae, Polydoridae and Neriedidae) and oligochaete worms. Overall, these two taxonomic groups accounted for 49% and 20% of all individuals identified. Bivalves (including *Austrovenus stutchburyi*, *Paphies australis* and *Macomona liliana*) were the other main group accounting for 10% of individuals. The communities at Mng3, 4, 6, 10,15,17,19, 20 were composed of polychaete worms (72-91%). Mng2, 7, 13 and 21 were dominated by both polychaetes (58% - 69%) and bivalves (14% - 32%), whereas Mng9 and 11 were dominated by polychaetes (39% - 68%) and 'others' (14% - 51%) (including Nematodes and *Anthopleura aureoradiata*, see full list in Appendix 6-1). The community at Mng5 was composed mostly of others (60%) and Oligochaeta (24%), whilst Mng22 was composed mostly of Oligochaeta (60%) and Polychaeta (34%).

Prionospio spp (*Prionospio sp* and *Prionospio aucklandica*) was the most common polychaete to be ranked in the top five most abundant taxa across all of the sites, followed by *Aonides trifida* and juvenile Nereididae. *Austrovenus stutchburyi* was the most abundant bivalve across all of the sites. Other bivalves that ranked in the top five most abundant species included *Macomona liliana* (Mng2 and 9), *Paphies australis* (Mng13 and 14) and *Diplodonta zelandica* (Mng2 and 3).

Table 8: Top five most abundant taxa found at the sampling sites in the Mangonui Estuary 2016. Numbers in brackets are the mean abundance (n=3) of the taxa per core.

Site	Most abundant				Less abundant
2	*Prionospio sp*. (68.0)	*Austrovenus stutchburyi* (15.7)	*Ostracoda* (9.0)	*Diplodonta zelandica, Macomona liliana,* Nematoda, Nereididae (juvenile) (6.0)	*Heteromastus filiformis* (4.3)
3	Polydorid (156.7)	*Prionospio sp*. (75.7)	*Aonides trifida* (48.3)	*Sphaerosyllis sp*. (21.7)	*Diplodonta zelandica* (11.3)
4	*Aonides trifida* (126.7)	Nematoda (66.3)	*Austrovenus stutchburyi* (16.3)	Nereididae (juvenile) (14.3)	*Magelona sp*. (8.0)
5	*Austrominius modestus* (363.3)	Oligochaeta (149.7)	*Austrovenus stutchburyi* (79.3)	Nematoda (73.7)	*Prionospio sp*. (6)
6	*Prionospio sp*. (11.0)	Oligochaeta (5.0)	Copepoda, Nereididae (juvenile) (4.0)	*Aricidea sp.*, *Cossura consimilis* (3.3)	Paraonidae (3)
7	*Prionospio sp*. (59.3)	*Austrovenus stutchburyi* (18.7)	Nematoda (16.3)	*Sphaerosyllis sp*. (13.3)	Polydorid (7.7)
9	Nematoda (87.0)	*Prionospio sp*. (19.0)	*Anthopleura aureoradiata* (11.7)	*Magelona sp*. (8.3)	*Macomona liliana* (5.3)
10	*Aonides trifida* (277.0)	Cumacea (24.0)	Nematoda (22.3)	*Prionospio sp*. (15.0)	*Austrovenus stutchburyi* (9.7)
11	Prionospio sp. (57.3)	Nematoda (25.0)	Sphaerosyllis sp. (23.0)	Oligochaeta(16.0)	Polydorid (12.7)
13	Oligochaeta (552.3)	*Aonides trifida* (339.7)	*Paphies australis* (78.7)	*Paravireia sp*. (33.0)	Syllidae (17.3)
14	*Aonides trifida* (144.7)	Nereididae (juvenile) (100.3)	*Austrovenus stutchburyi* (36.3)	*Paphies australis* (27.3)	*Paravireia sp*. (17.0)
15	*Austrovenus stutchburyi* (52.0)	*Aonides trifida* (43.0)	*Prionospio sp*. (36.7)	*Sphaerosyllis sp*. (27.0)	*Prionospio aucklandica* (24.3)
17	*Aricidea sp*. (26.3)	*Prionospio sp*. (16.0)	Paraonidae (8.3)	Nereididae (juvenile) (7.0)	*Prionospio aucklandica* (5.0)
19	Paraonidae (14.3)	*Prionospio sp.* (5.7)	*Prionospio aucklandica* (5.3)	*Aricidea sp.*, Oligochaeta (5.0)	Nereididae (juvenile) (4.7)
20	Paraonidae (28.7)	*Prionospio sp*. (16.3)	*Aricidea sp*.(11.7)	*Heteromastus filiformis* (10.0)	*Prionospio aucklandica* (5.7)
21	*Aonides sp*. (103.7)	*Prionospio sp*. (68.3)	*Austrominius modestus* (48.7)	*Austrovenus stutchburyi* (29.7)	*Prionospio aucklandica* (19.7)
22	Oligochaeta (277.7)	*Prionospio sp*. (28.3)	Polydorid (19.0)	*Heteromastus filiformis* (15.3)	*Capitella capitata* (12.7)

3.6 Shellfish

Pipis (*Paphies australis*) were only found at site Mng13 and 14, of which the majority fell into the <4 mm and 4-16 mm size classes. Mng13 is situated on a shell ridge, composed of shell hash and coarse/medium sand, located in the middle of the entrance next to a main channel. Mng14 is located in a small embayment next to the entrance of the estuary where the sediment is mostly gravel and course sand.

The wedge shell (*Macomona liliana*) was found throughout the estuary but in low numbers at most sites. Mng2, Mng4 and Mng21 had the highest abundances (mean 5 – 8 in total). Individuals found at Mng2 and 4 fell into the 4-16 mm and <16 mm size classes whereas at Mng21 most were juveniles (<4 mm). All three sites were composed mostly of fine sand.

High densities of cockles (*Austrovenus stutchburyi*) were found at Mng5 and Mng15; both sites are sheltered and were composed of mostly firm, medium sand. Across the entire estuary the number of juvenile cockles (<4 mm) was much higher than those in large size classes (4-16 mm and <16 mm) (Figure 14).

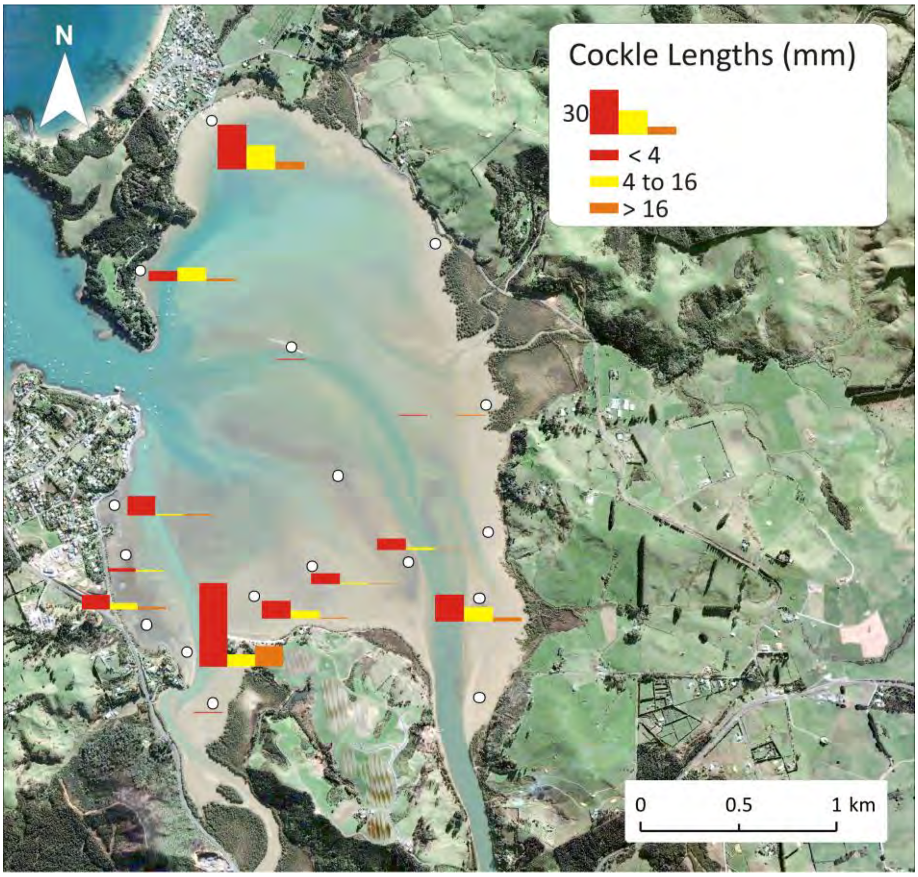

Figure 14: Length frequency distribution of cockles (*Austrovenus stutchburyi*) in Mangonui Estuary 2016.

3.7 Relating intertidal community structure and sediment properties

A distance-based linear model (DISTLM) using the Bray-Curtis similarity matrix and the log10 transformed sediment data similarity matrix, showed that mud, nitrogen, fine sand and medium sand were all related to the intertidal ecological community structure (Table 9). Mud (18.4%) explained the highest proportion of variation in the community structure followed by nitrogen concentration (16.9%).

Table 9: DISTLM marginal tests for log10 sediment properties and species abundance data from 17 sites in the Mangonui Estuary 2016.

Sediment properties	Pseudo-F	P-value	Proportion of variation explained
Mud	3.21	0.002	18.4
Nitrogen	3.05	0.003	16.9
Fine sand	2.79	0.004	15.7
Medium sand	2.55	0.012	14.5
Coarse sand	2.05	0.040	12.0
TOC	1.91	0.052	11.3
Phosphorus	1.63	0.111	9.8
Cadmium	1.21	0.251	7.4
Zinc	1.11	0.328	6.9
Copper	1.08	0.363	6.7
Chromium	1.04	0.394	6.5
Lead	0.99	0.447	6.2
Nickel	0.78	0.635	4.9

DISTLM conducted using a forward selection procedure showed that the combination of mud and fine sand explained 33% of the variation in the community structure (Pseudo-F = 3.25, P-value = 0.001). While not significant ($p < 0.05$), another 4 variables each added an extra 6 % explained (cadmium, nickel, total phosphorus, lead (in the order they were selected)) resulting in 58% explained.

3.8 State of the Environment Indicators

3.8.1. Benthic Health Models (BHMmetals and BHMmud)

The BHMmetals model was developed to determine the health of communities relative to storm water contaminants (total sediment copper, lead and zinc concentrations). Soon after, the BHMmud model was developed to determine health relative to sediment mud content. The majority of the sites sampled within the Mangonui Estuary indicate extremely good to good health for BHMmetals, with scores falling into groups 1 or 2 (blue and green colouring, respectively). The score at Mng22 was within the group 3 (yellow colour – moderate health) and Mng6, 17, 19 and 20 scores all fell within group 4 (golden - poor health) for BHMmetals. For BHMmud, none of the sites scored in group one (blue - extremely good), eight of the 17 sites had scores in group 2 (green – good health), four sites were within group 3 (yellow -moderate health) and five within group 4 (golden - poor health) (Table 10).

Table 10: Benthic Health Model values (metals and mud) for the 17 sites in Mangonui Estuary sampled in 2016. The colouration means extremely good (blue); good (green); moderate (yellow); poor (golden) and unhealthy with low resilience (red).

Site	BHMmetal	BHMmud
Mng2	-0.07	-0.06
Mng3	-0.11	-0.06
Mng4	-0.09	-0.07
Mng5	-0.12	-0.04
Mng6	0.03	0.04
Mng7	-0.10	-0.06
Mng9	-0.20	-0.12
Mng10	-0.12	-0.09
Mng11	-0.11	-0.05
Mng13	-0.10	-0.04
Mng14	-0.12	-0.08
Mng15	-0.08	-0.04
Mng17	0.04	0.04
Mng19	0.05	0.06
Mng20	0.03	0.06
Mng21	-0.10	-0.06
Mng22	0.01	0.08

3.8.2. Traits Based Index (TBI)

The Traits Based Index (TBI) was developed to assess the functional redundancy of benthic communities as an indicator of resilience (van Houte-Howes & Lohrer 2010; Lohrer & Rodil 2011). TBI is based on seven broad trait categories and generates a value between 0 and 1. Values close to 0 indicate low levels of functional redundancy (and possibly an indication of site degradation), whereas, values closest to 1 indicate high levels of functional redundancy (increased resilience in the face of environmental change) and health. All of the sites sampled scored in group 1 (blue - good) for levels of functional redundancy/resilience except for Mng5, 6, 19 and 20. Mng5 and Mng20 were on the upper border of group 2 (yellow – intermediate), whilst Mng6 and 19 scores were within group 3 (red – poor) (
Table 11).

Table 11: Traits Based Index (TBI) values for the 17 sites sampled in Mangonui Estuary 2016. The colouration, blue, yellow and red denote good, intermediate and poor levels of functional redundancy/resilience, respectively.

Site	TBI
Mng2	0.67
Mng3	0.61
Mng4	0.67
Mng5	0.40
Mng6	0.24
Mng7	0.67
Mng9	0.67
Mng10	0.64
Mng11	0.76
Mng13	0.56
Mng14	0.50
Mng15	0.54
Mng17	0.43
Mng19	0.24
Mng20	0.40
Mng21	0.77
Mng22	0.52

3.8.3. Combined Indices

Combining the BHMmetal, BHMmud and TBI values provides an indication of the overall health of the Mangonui Estuary. Results show that there are some sites that did not score well; Mng6 and 19 are unhealthy with low resilience (red), Mng17 and 20 show poor health and resilience. Of the remaining sites, five show moderate and eight show good health and resilience (Table 12 and Figure 15).

Table 12: Combined health values for the 17 sites sampled in Mangonui Estuary. The colouration denotes extremely good (blue); good (green); moderate (yellow); poor (golden) and unhealthy with low resilience (red).

Site	Combined health score
Mng2	0.38
Mng3	0.38
Mng4	0.38
Mng5	0.44
Mng6	0.87
Mng7	0.38
Mng9	0.31
Mng10	0.38
Mng11	0.44
Mng13	0.44
Mng14	0.38
Mng15	0.44
Mng17	0.64
Mng19	0.87
Mng20	0.76
Mng21	0.38
Mng22	0.58

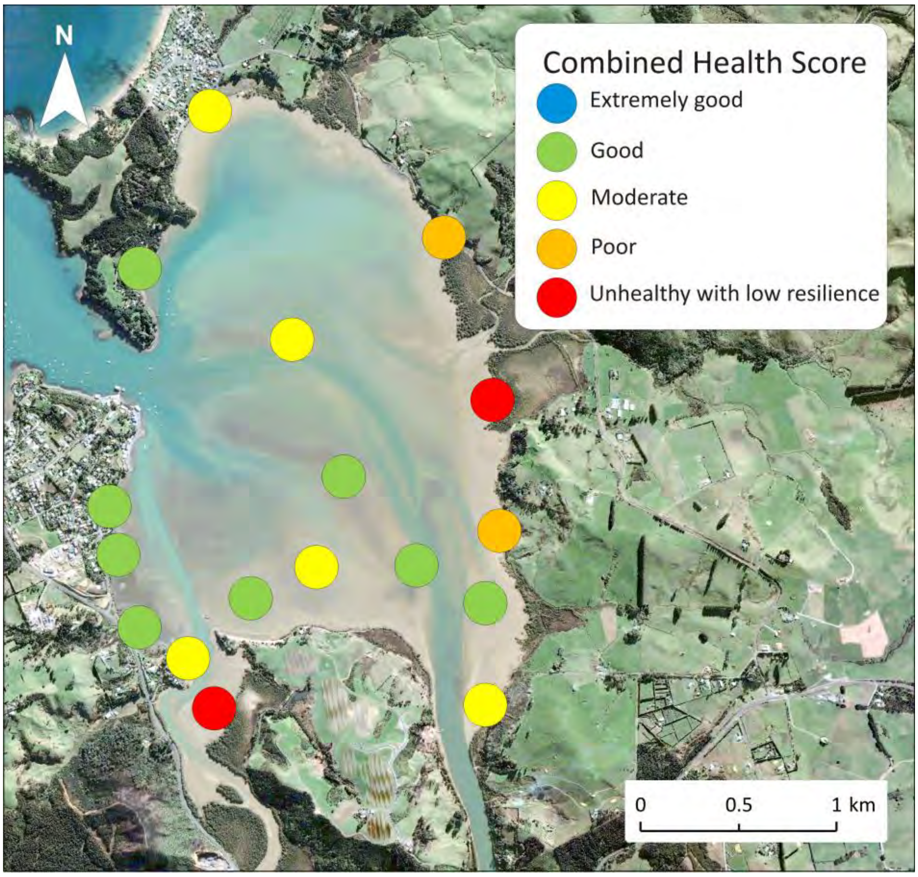

Figure 15: Combined health models and TBI scores for sampled sites in Mangonui Estuary 2016.

4. Discussion

4.1 Sediment physical properties

Within the estuary, the highest proportions of mud were generally found at sites in sheltered tidal creek environments (Mng6 and 22) and along the eastern shore (Mng21, 20, 19, 17). Tidal creeks are generally low energy depositional environments and tend to be more influenced by inputs of terrigenous sediment than marine sediment from the open coast. The eastern shoreline of the Mangonui Estuary is also relatively sheltered and receives runoff from surrounding grass and cropland, which may be laden with terrigenous sediment. There were small amounts of mud found at all these sites except Mng11. While there had been heavy rain in the area prior to sampling and on the 2nd day of sampling, there appears no correlation between the days the sites were sampled and the amount of mud found.

In contrast the highest proportions of coarse sand and medium sand were found near the entrance of the estuary, at Mng14, Mng15 and Mng13. The proximity of these sites to the entrance of the estuary means they are more exposed and are higher energy environments than the more sheltered tidal creeks, and are also more likely to receive more inputs of coarser grain marine sediment. It was also noted that there was a lot of shell hash at these sites.

The proportion of mud at the Mangonui sites was generally much smaller than proportions measured in other Northland estuaries such as Waitangi and the Whangarei Harbour (Northland Regional Council, 2013a). This is interesting given the high degree of sediment loading observed in the pictures taken of the harbour during the sampling period (see cover picture), but consistent with the Gibbs & Olsen (2016) report on sediment source tracing. This report also found low mud content on the intertidal sediments of the lower intertidal flats and attributed this to resuspension by wind waves.

4.2 Sediment total organic carbon and nutrient concentrations

Land-use changes in catchments can alter the amount of runoff estuaries receive. This runoff is often sediment laden, and can have elevated levels of organic matter and nutrients from anthropogenic sources (fertilizer, storm water and treated wastewater). While nutrients (nitrogen and phosphorus) are essential for all ecosystems, when nutrient concentrations exceed the requirements of the receiving ecosystem, they can modify community structure and cause the system to degrade. Initially increased nutrients may stimulate benthic communities. However, as sediment organic matter increases, the oxygenated portion of the sediment column can become limited to the upper few millimetres or may be eliminated altogether, and bottom water dissolved oxygen concentrations can drop to levels that are damaging or lethal to aerobic 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. However, many macrofauna mix sediment and irrigate deep sediments with oxygenated bottom water, ameliorating the effects of pervasive porewater hypoxia/anoxia. The movement and feeding activities of many macrofauna also affect TOC levels by adding proteins and carbon to the outside of sediment particles.

Using the criteria developed by Robertson and Stevens (2007) all of the sites, except for Mng7, showed some level of enrichment for total phosphorus with Mng5 being 'very enriched'. Sites Mng5, 15, 17, 19, 20 and 22 were low – moderately enriched for nitrogen. For TOC two sites in Mangonui Estuary scored 'very good', 11 were low to moderately enriched, and sites Mng5, 19, 21, 22 were classified as 'enriched'. The sites that recorded highest levels of nutrients and TOC were generally consistent with the sites that had the highest proportions of mud. This is expected as highest levels of nutrients and TOC are generally observed at sites with high proportions of mud. Fine grains have a greater surface area to volume ratio, providing more opportunities for attachment by microbes, which can result in higher organic carbon, organic and remineralised inorganic nutrients. Mng5, however, did not have a high proportion of mud yet was classified as 'enriched' (TOC), 'low to moderately enriched' (total nitrogen) and 'very enriched' (total phosphorus). Importantly, the sites classified as 'enriched' by their TOC levels did not generally exhibit the low diversity and high abundance of a few macrofaunal species that prefer, or are resistant to, enriched conditions. In particular, site Mgn5 had a high density of adult cockles and their biodeposits are likely to contribute to the TOC enrichment.

The mean nitrogen concentration measured in Mangonui Estuary was generally lower than means recorded in sediment surveys of other Northland estuaries, though the mean concentrations of phosphorus were higher (Northland Regional Council, 2013a). In particular, the average nitrogen to phosphorus ratio is lowest in Mangonui (0.75 with the next lowest being 1.24 in Waitangi). The marked differences in this ratio between the northern east coast estuaries (e.g., Houhora, Rangaunu and Parengarenga ratios 2.6 to 5.3) and the western estuaries (Kaipara and Hokianga 2.2 and 2.6 respectively) is likely to be a reflection of underlying geology as young volcanic soils are often high in phosphorus. TOC values observed at the Mangonui 2016 sites were around the middle of those observed at sites in other estuaries.

For TOC and nutrients, the concentrations observed in this survey were higher than those observed in 2013 (for TOC only the maximum observed concentration was higher). This may indicate degradation over time, however, there are two important points to consider in making this observation. Firstly, the sites sampled in 2013 are not the same as those sampled in 2016. Secondly, observations over time in east coast estuaries of the Auckland Region show both seasonal and annual variation in AFDW that would result in sites frequently changing TOC classifications by one or two levels, for example from 'very good' to 'low to moderately enriched' or from 'enriched' to 'very good'. Unfortunately no information on seasonal or long-term annual variation in nutrient concentrations is available to make a similar observation.

4.3 Sediment metal concentrations

Heavy metals can have lethal and sub lethal effects on benthic invertebrates and in a contaminated environment the species diversity and species richness may decrease as the community becomes dominated by a smaller number of more tolerant species, which are able to survive and reproduce in these conditions (Clarke and Warwick, 2001). A common source of heavy metals (e.g., cadmium, chromium, copper, nickel, lead and zinc) is storm water runoff and, as a result, sites located close to outfalls and roads can exhibit elevated levels of metals. Conversely, heavy metal concentrations can reflect underlying geology, with the geology of the surrounding Mangonui catchment generally high in copper (Christie and Barker, 2007). Concentrations of heavy metals tend to increase as sediment grain size decreases, which reflects the tendency for heavy metals to be preferentially adsorbed on the large surface area of fine grained sediments rich in clay minerals (Abrahim, Parker and Nichol, 2006).

All of the sites sampled in the Mangonui Estuary were well below the ANZECC ISQG-Low effect trigger values and the TEL developed by MacDonald et al. (1996) for cadmium, and chromium. Nickel concentration at Mng4 exceeded the TEL and at Mng5 and Mng21 exceeded the ANZECC guidelines. Both Mng4 and 5 are located close to a busy road and storm water discharge points (Northland Regional Council, 2013b). Mng14 was within the ANZECC guidelines for copper, lead and zinc but exceeded the TEL guidelines; this is likely related to boating activity as the site is within a mooring zone and adjacent to a historical slipway.

4.4 Ecology

No previous ecological sampling had been carried out in the Mangonui Estuary; the purpose of this report is to create a description of the estuary's ecology as a baseline for future monitoring. The sites sampled in the Mangonui Estuary covered a range of intertidal habitats including;

sheltered soft mud flats, sandy beaches, sand banks, shell banks and gravel/pebble shoreline. A total of 15,926 individuals belonging to 98 different taxa were identified and the communities were dominated by polychaete (48% of individuals) and Oligochaeta (20% of individuals) worms and bivalves (10% of individuals). The most abundant taxa were *Prionospio* (*Prionospio* sp. and *Prionospio aucklandica*), *Aonides trifida*, juvenile Nereididae and *Austrovenus stutchburyi*.

Analysis of the average linkage clustering and MDS ordination (Figure 12 & Figure 13) of the species abundance data indicate 5 groups of sites of greater than 40% self-similarity occur, with sites in the middle of the estuary and on the western side of the estuary tending to group out from the sites located in the south and east of the estuary.

Cluster analysis and MDS ordination of the ecological data showed that there is some geographical grouping of the sites sampled within the estuary, those on the western side and middle of the estuary and those on the eastern shoreline and in the tidal creeks. In particular, Mng17, 19 and 20 grouped together tightly, suggesting that these site were quite similar in community composition. At these sites, the top five most abundant species were made up of polychaete worms (*Aricidia*, *Prionospio* sp., *Prionospio aucklandica*, Paraonidae and Nereididae juv.). Mng6 grouped with these 3 sites although within-site similarity was much lower.

Cockles (*Austrovenus stutchburyi*) were found at most sites, but only in high densities at Mng5, 14, 15 and 21. Juveniles (<4 mm) were mostly found with highest densities of adults at sites Mng7 and Mng15.. Pipis (*Paphies australis*) were only found at site Mng13 and 14, of which the majority fell into the <4 mm and 4-16 mm size classes. Both these sites had predominantly coarse sediment. The wedge shell (*Macomona liliana*) was found throughout the estuary but at low numbers. Mng2, Mng4 and Mng21 had the highest abundances (mean 5 – 8 in total). Individuals found at Mng2 and 4 fell mostly into the 4-16 mm and <16 mm size class whereas at Mng21 individuals mostly fell into the <4 mm. Adult *Macomona* generally prefer to live separated from each other by a few centimetres, probably to prevent feeding interference.

Macrofaunal community health indices suggested that macrofaunal communities of Mangonui generally have good health, with 5 sites having moderate health and resilience and eight with good health and resilience. However, Mng6 and 19 were suggested to be unhealthy with low resilience and Mng17 and 20 showed poor health and resilience.

4.5 Relating ecology to sediment data

The most important predictors of intertidal community structure were mud content, total nitrogen, fine sand and medium sand content, ranging in their ability to predict variation in community structure from 21% (mud) down to 14% (medium sand content). Mud and fine sand content together were able to explain 36%, with cadmium, nickel, total phosphorus and lead all contributing an extra 6%. Interestingly, organic content (TOC) was not important despite 4 sites being classified as ‘enriched’.

There were very few strong correlations (< 0.85 Pearsons R) between the concentrations of these potential stressors across the sites (only for chromium with copper, nickel and total phosphorus). Even stressors that are usually strongly correlated (e.g., mud with TOC, copper with zinc and lead) did not exhibit strong correlations, suggesting that sources of these may differ (e.g., underlying geology controlling copper and total phosphorous) and that there is little apparent spatial patterning in terms of stress across the estuary.

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6. Appendix

Appendix 6-1: List of classes of taxa used in section 3.4.3

Amphipoda
Amphipoda
Amphipoda G
Corophiidae
Phoxocephalidae

Bivalve
Arthritica bifurca
Austrovenus stutchburyi
Bivalvia Unid. (juv)
Cyclomactra ovata
Diplodonta zelandica
Linucula hartvigiana
Macomona liliana
Mactridae
Musculista senhousia
Nucula sp.
Ostreidae (Juvenile)
Paphies australis
Soletellina sp.

Crabs / Shrimp
Alpheus sp.
Austrohelice crassa
Brachyura (juv.)
Halicarcinus whitei
Hemigrapsus edwardsi
Hemiplax hirtipes
Palaemon sp.

Isopoda
Exosphaeroma chilensis
Exosphaeroma planulum
Paravireia sp

Other
Acarina
Anthopleura aureoradiata
Anthozoa
Austrominius modestus
Caprellidae
Chironomid pupae
Chiton glaucus
Coleoptera indet. (larvae)
Collembola
Copepoda
Cumacea
Ephydridae
Gastropoda eggs Unid.
Mussel Spat
Nematoda
Notoacmea sp.
Osteichthyes
Ostracoda
Paradixa sp.
Parasterope australis
Ephydridae
Gastropoda eggs Unid.
Mussel Spat

Polychaete

Aglaophamus sp.

Aonides sp.

Aonides trifida

Aricidea sp.

Barantolla lepte

Capitella capitata

Ceratonereis sp.

Cirratulidae

Cossura consimilis

Dorvilleidae

Euchone sp.

Glyceridae

Goniadidae

Heteromastus filiformis

Leitoscoloplos kerguelensis

Magelona sp.

Nereididae

Nereididae (juvenile)

Nicon aestuariensis

Orbinia papillosa

Orbiniidae

Owenia petersenae

Oweniidae

Paraonidae

Perinereis nuntia

Perinereis nuntia var brevicirrus

Perinereis sp.

Polydorid

Prionospio aucklandica

Prionospio sp.

Sabellidae

Scolecolepides benhami

Scolelepis sp.

Sphaerosyllis sp.

Spionidae

Syllidae

Gastropoda

Cominella glandiformis

Diloma sp.

Diloma subrostrata

Haminoea zelandiae

Micrelenchus sp.

Philine auriformis

Relichna aupouria

Spio sp.

Zeacumantus lutulentus

Zeacumantus subcarinatus

Nemertea

Nemertea

Nemertea sp. 1

Nemertea sp. 2

Nemertea sp. 3

Nemertea sp. 4

Nemertea sp. 6

Nemertea sp. 7

Nemertea sp. 8

Oligochaeta

Oligochaeta

.

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