Ngunguru Estuary Monitoring Programme

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Putting Northland first

NORTHLAND REGIONAL COUNCIL

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Executive summary

The Ngunguru Estuary catchment has been identified by Northland Regional Council (Council) as a priority catchment. The estuary drains a catchment of 8,502 ha and the land-use in the catchment has been heavily modified, with a considerable proportion cleared for forestry blocks and agriculture. Catchment analysis using the land use classification from the New Zealand Land Cover Database (LCDB2) indicated that in 2012, 35% of the catchment was covered with indigenous forest, 29% with high producing exotic grassland, 15% with exotic forest and 8% with harvested forest.

In 2016, Council sampled 21 sites throughout the estuary in order to assess the sediment quality and ecological status. This survey also provides baseline data to track changes in the health of the estuary over time. The survey methods were adapted from the Estuary Monitoring Protocol (Robertson et al., 2002), which was developed by Cawthron for use by regional councils, and are consistent with other surveys conducted by Council.

Sediment grain size

The highest proportions of mud were generally found at sites in the upper reaches of the estuary around sheltered tidal creek environments (Ngu3, 2 and 5). In contrast, the highest proportions of coarse sand and medium sand were found near the entrance of the estuary at Ngu20, 21 and 22. The proportion of mud observed at the Ngunguru sites was generally smaller than that measured in other Northland estuaries such as Whangarei Harbour and Waitangi.

Sediment nutrients

Land-use changes in catchments can alter the amount of runoff estuaries receive. In Ngunguru the combination of steep hill country, highly erodible soils, and periodic high intensity rainfall events lead to accelerated soil erosion and downstream flooding (Baker, 2014). This sediment-laden runoff often contains 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 were classified as “low to moderately enriched” for total phosphorus, whilst Ngu2, 3, 5, 7 and 10 were “low to moderately enriched” for nitrogen. For total organic carbon (sediment TOC) 10 sites were classified as “low to moderately enriched” and the remaining 11 sites were classified as “very good”. There were no strong correlations between high levels of nutrients, TOC or mud.

Average nitrogen and phosphorus concentrations measured in Ngunguru Estuary were similar to means recorded in sediment surveys of other Northland estuaries, whilst the mean TOC was towards the low end of average values from other estuaries surveyed.

Sediment metals

Heavy metals can have lethal and sub-lethal effects on benthic invertebrates. In a contaminated environment the species diversity and richness may decrease as the community becomes dominated by a smaller number of more tolerant species.

The metal concentrations recorded in Ngunguru Estuary were all below the ANZECC ISQG-Low effect trigger values and the threshold effect levels developed by MacDonald et al. (1996). In addition to this, the average metal concentrations were lower than those values reported in recent sediment surveys conducted by NRC for Waitangi in 2013, and the Bay of Islands, Whangarei and Mangonui in 2016.

Ecological communities

The sites sampled in Ngunguru Estuary covered a range of intertidal habitats including; sandy beaches, sand banks, shell banks, sheltered soft mud flats, and seagrass. The taxa identified in Ngunguru Estuary are similar to those in other estuarine environments surveyed in Northland. The most abundant taxa were polychaete worms (*Aonides trifida, Heteromastus filiformis and Prionospio aucklandica*) and bivalves (mainly the cockle *Austrovenus stutchburyi*). Four groups of sites occurred: Ngu6, Ngu10 and 14, Ngu17, and all others. The site located within the seagrass patch (Ngu11) did not differ in community structure or biodiversity from the majority of the sites.

Cockles (*Austrovenus stutchburyi*) were found at all sites, although densities were variable (total counts from the three cores ranging from five individuals at Ngu2 to 700 at Ngu10). The highest densities were found at Ngu10, 14 and 19. Pipis (*Paphies australis*) were found at sites Ngu4, 10, 16, 17 and 22. 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 Ngunguru generally have good health, with 12 sites classified as having “good” health and resilience, and 8 sites having “moderate” health and resilience. Ngu1 was the only community to be classified as having “poor” health and resilience.

Relating ecological communities to sediment data

The most important variables determining the intertidal ecological community structure were zinc, fine sand, lead and total phosphorus. The two heavy metals are important despite concentrations of these at all sites being below present guidelines, similar to findings in another study.

1. Introduction

1.1 Background

Northland Regional Council (NRC) has implemented estuarine 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. 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 Ngunguru Estuary catchment as a priority catchment with a working group formed with a focus on mitigating sediment erosion. NRC subsequently undertook a survey of 21 sites throughout Ngunguru Estuary in order to provide baseline data to track changes in the health of the estuary over time.

The Ngunguru Estuary monitoring programme has been adapted from the Estuary Monitoring Protocol (Robertson et al., 2002), which was developed by Cawthron for use by regional councils. It 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 Environment Waikato have long established marine monitoring programmes, which use similar methodologies (Nicholls et al., 2002; Ford & Anderson, 2005; Halliday et al., 2006; Kim, 2007). The adoption of standardised methods ensures that the results are scientifically credible and comparable to those collected across New Zealand. The survey methods are consistent with other NRC surveys including Kaipara Harbour (Griffiths, 2014a), and Waitangi Estuary (Griffiths, 2014b). The full methodology is described within the Whangarei Harbour report (Griffiths, 2012).

1.2 Study Area

1.2.1. The estuary

Ngunguru Estuary is a small estuary located on the east coast of the North Island, just north of Whangarei. It is a shallow estuarine system with the majority of the water volume of the estuary emptying out of the system with each tide. Ngunguru Estuary has a full range of interconnecting marine habitat types, which include saltmarshes, mangroves, intertidal flats and extensive channels, and entrance sand spit. Each of these habitats contains distinctive plant and animal communities that contribute to the ecological values (Kerr, 2015). The largest freshwater source is the Ngunguru River, which enters the estuary from the East. The combination of steep hill country, highly erodible soils, and periodic high intensity rainfall events lead to accelerated soil erosion and downstream flooding. These events contribute sediment to the Ngunguru River and its tributaries, into the estuary, and out to the coast.

1.2.2. The catchment

Ngunguru Estuary drains a catchment of 8,502 ha and the land-use in the catchment has been heavily modified, with a considerable proportion of the catchment cleared for forestry and agriculture. Catchment analysis using the land use classification from the New Zealand Land Cover Database (LCDB2) indicated that in 2012, 35% of the catchment was covered with indigenous forest, 29% with high producing exotic grassland, 15% with exotic forest and 8% with harvested forest (Table 1 & Figure 1).

Table 1: Land-use in Ngunguru 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)	65	1
	Surface Mine or Dump	2	< 1
	Transport Infrastructure	1	< 1
	Urban Parkland/Open Space	3	< 1
Bare or lightly vegetated surfaces (< 1%)	Sand or Gravel	12	< 1
Cropland (< 1%)	Orchard, Vineyard or Other Perennial Crop	14	< 1
	Short-rotation Cropland	< 1	< 1
Forest (58%)	Exotic Forest	1270	15
	Forest - Harvested	647	8
	Indigenous Forest	3003	35
	Mangrove	23	< 1
Grassland (31%)	Herbaceous Freshwater Vegetation	11	< 1
	Herbaceous Saline Vegetation	53	1
	High Producing Exotic Grassland	2481	29
	Low Producing Grassland	124	1
Scrub and shrubland (9%)	Broadleaved Indigenous Hardwoods	150	2
	Gorse and/or Broom	15	< 1
	Manuka and/or Kanuka	608	7
	Matagouri or Grey Scrub	6	< 1
Water Bodies (< 1%)	Estuarine Open Water	12	< 1
	Lake or Pond	1	< 1
Total		8,502	100

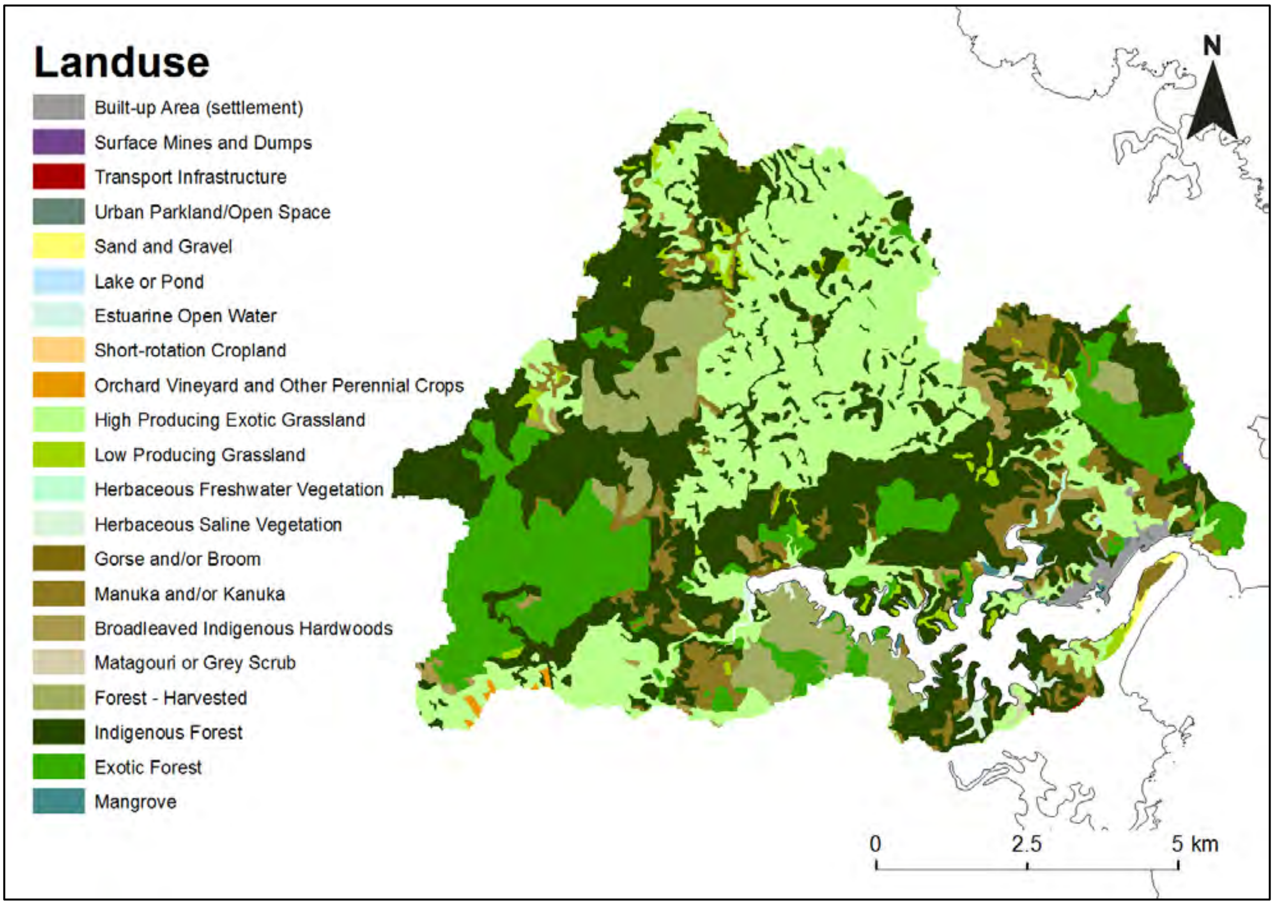

Figure 1: Land-use in the Ngunguru Catchment, from the New Zealand Land Cover Database (2012).

1.2.3. Estuarine sediment characteristics

Ngunguru Estuary was included as part of a survey of intertidal bivalve populations at a number of sheltered coastal sites around Northland in 2014 – 2015 (Berkenbusch & Neubauer, 2015). Sediment samples were collected from sites across the estuary between the township and the sandspit, corresponding to the area where sites Ngu11, 14, 16, 19 and 20 are located (Figure 2). Sediment grain size collected during the bivalve survey was dominated by fine sand (125 – 250 μm) , with smaller proportions of medium sand (250 – 500 μm) and coarse sand / gravel (> 500 μm), and traces of mud and very fine sand (< 125 μm). These findings complement the sediment grain size results from the current study.

1.2.4. Estuarine sediment nutrients

There is limited information available about estuarine sediment nutrient concentrations in Ngunguru Estuary. Sediment sampling in the estuary, as part of a Northland intertdal bivalve survey, found that organic content ranged between 1.2 - 2.5% (Berkenbusch & Neubauer, 2015).

1.2.5. Estuarine sediment metals

There is limited information on the sediment metal concentrations in Ngunguru Estuary. Resource consent monitoring of the township's stormwater has annually occurred from 2010. This involves sampling the sediments of six stormwater outlets for copper, lead, and zinc. The results from this sampling have not identified any issues, with all results well below relevant guidelines (Australian New Zealand Environment Conservation Council [ANZECC] 2000; MacDonald et al., 1996).

1.2.6. Ecology

The survey of intertidal bivalve populations at a number of sheltered coastal sites around Northland in 2014 – 2015 (Berkenbusch & Neubauer, 2015) found the local cockle (*Austrovenus stutchburyi*) population to be very healthy, with an estimated population density of 814 cockles per m^2 (up from 554 cockles per m^2 in the 2004 – 2005 survey). There was, however, a noted decline in the number of large (> 30 mm) cockles when compared to the survey in 2004 – 2005 (25 per m^2 to only 4 per m^2).

In contrast to the marked increase in the cockle population there was a noticeable decline in the number of pipis (*Paphies australis*). The population estimate dropped from 124 individuals per m^2 in the 2004 – 2005 survey to only 30 per m^2 in the 2014 – 2015 survey. Another very noticeable difference from previous surveys was the total absence of large (≥ 50 mm shell length) pipis. In the 2004 – 2005 survey large pipi made up 43% of the total count (Berkenbusch & Neubauer, 2015).

Following the overall decline in pipi and decline of large individuals in both specices the Ministry of Primary Industries issued a closure of the recreational harvest (Notice No. MPI 566).

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 Whangarei Harbour in 2012 (Griffiths, 2012).

2.1.1. Sampling sites

Figure 2: Location of sampling sites in Ngunguru Estuary.

2.1.2. Timing of sampling

The survey of Ngunguru Estuary was conducted over three days from the 8th – 10th March 2016 with 21 sites being sampled. Prior to the survey (1st – 2nd March) there had been 58 mm of rainfall recorded. However, from the 3rd – 10th March the area did not receive any rainfall (measurements taken from the Ngunguru rain gauge at Dugmores Rock).

2.1.3. Ecological sampling

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

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 Watercare 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 & Lohrer, 2010) and improved (Lohrer & 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 2 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 et al. (2012). The index has been refined over the last couple of years (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 & 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 et al., 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 is used. 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).

There is also a BHM - type model for responses to nutrients (nutrient canonical analysis of principal coordinates model, Ellis et al., 2015). This was derived from 75 sites with 3 replicates each in Tauranga Harbour. Total nitrogen, total phosphorus and chlorophyll a content at the sites were reduced to a single axis using principal component analysis (as for the contaminant model above). Community composition responses to this axis were then drawn out using CAP of square root transformed Bray-Curtis dissimilarities and a score of community composition related to nutrients produced. As the range of total nitrogen and total phosphorus concentrations observed in Ngunguru were within the ranges observed in Tauranga Harbour (140 – 1900 and 51 – 580 mg/kg respectively), we also did a comparative analysis of the Ngunguru community composition related to nutrients. We determined the fit of the model by comparing where the Ngunguru sites community composition and nutrient scores plotted relative to the model regression; a good fit would have all the Ngunguru sites lying within the confidence limits of the model regression.

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 2).

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 2), 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.

We have not included the BHMnutrient results in this overall analysis.

Table 2: Conversion of CAPmetals and CAPmud scores into health groups (1 is least healthy).

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 threshold effect levels (TEL) developed by MacDonald et al. (1996) (see Table 3). 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 3: Sediment quality guidelines.

Source	TEL (mg.kg^{-1})	ANZECC 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); the Shannon-Wiener diversity index and Pielou"s evenness index (J") for each core sample. Mean values were then calculated for each site. An expression of within-site variability was also calculated by determining the Bray-Curtis similarity between individual site replicates.

The species abundance data was also examined with cluster analysis and multidimensional scaling (MDS) using a Bray-Curtis similarity matrix. This analysis was performed on the mean species abundance for each site. A squareroot transformation was performed on the benthic infauna abundance data in order to downplay the influence of numerically dominant taxa (Clark & 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 square root transformed ecological data and the physical and sediment chemical properties (McArdle & Anderson, 2001). Prior to this analysis the sediment data was log 10 transformed. Mean abundance data was used for the DISTLM.

3. Results

3.1 Sediment physical properties

All of the sediment samples collected from Ngunguru Estuary were comprised of greater than 50% fine sand, with the exception of sites Ngu20, 4, 21 and 22 (47%, 43%, 37% and 24% respectively). The highest proportions of coarse sand were found at the northern sites near the estuary mouth (site Ngu20: 26%, Ngu21: 25% and Ngu22: 17%). Medium sand was detected throughout the estuary, with the highest proportion (59%) being detected at site Ngu22. Mud was most common in the upper reaches of the estuary, with the highest proportion (23%) being detected at site Ngu3 (Figure 3).

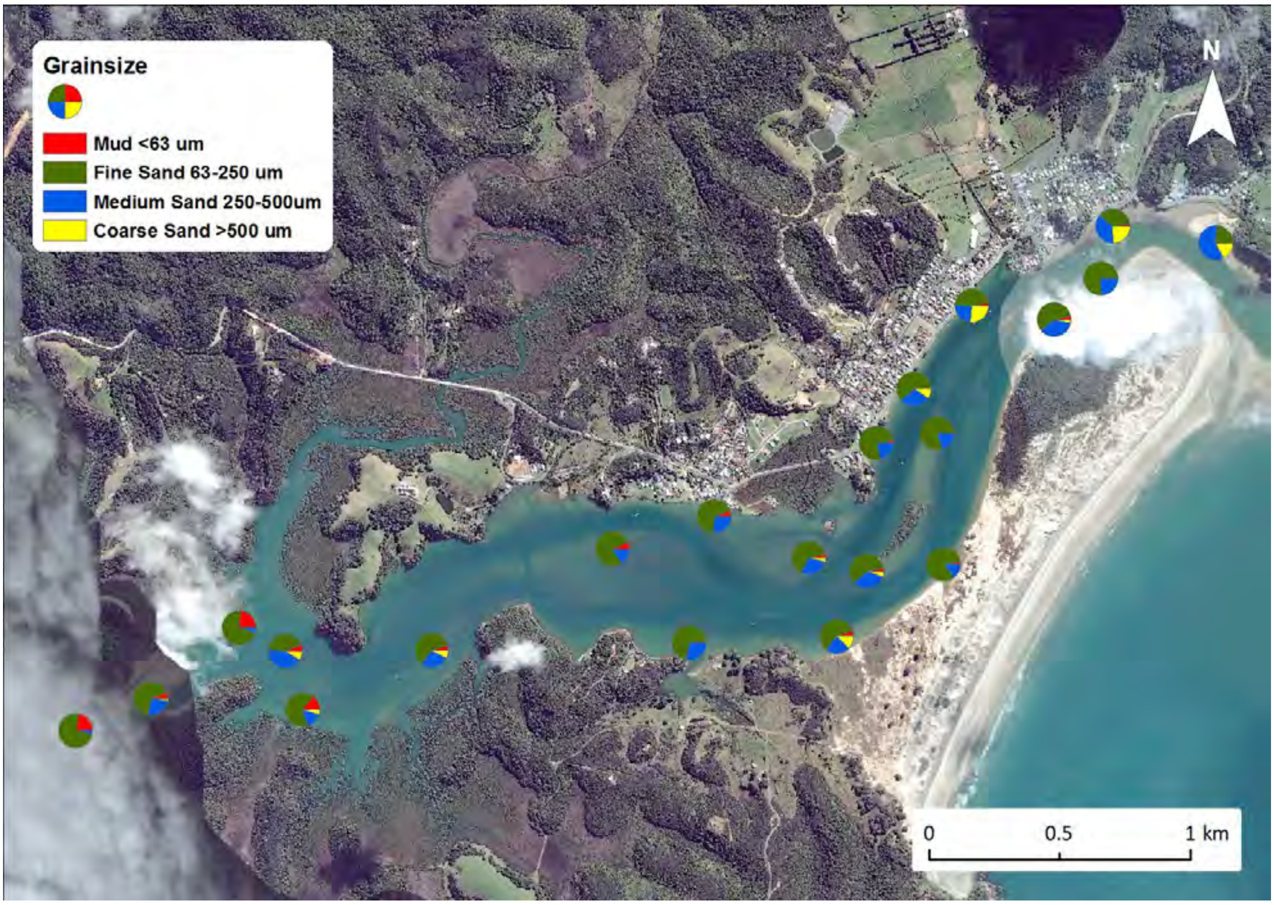

Figure 3: Sediment grain size characteristics in Ngunguru Estuary 2016.

3.2 Sediment Total Organic Carbon and nutrient concentrations

3.2.1. Total Organic Carbon

The highest levels of TOC were found at Ngu3 (1.6% w/w), Ngu2 and 4 (1.5% w/w). The lowest values were recorded at Ngu22 and 16 (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, 11 sites were classified as "very good" and 10 as "low to moderately enriched" (Figure 4).

Figure 4: TOC concentration in Ngunguru Estuary 2016.

3.2.2. Total Nitrogen

The highest concentrations of sediment nitrogen were recorded at Ngu5 (960 mg/kg) and Ngu2 (940 mg/kg) (Figure 5). The lowest concentration observed was 140 mg/kg at Ngu22. 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) 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 mg/kg as “very enriched”. Using this criteria the concentrations of 16 sites were classified as “very good” and five sites as “low to moderately enriched” (Figure 5).

Figure 5: Sediment total nitrogen concentrations in Ngunguru Estuary 2016.

3.2.3. Total Phosphorus

The highest concentration of sediment phosphorus was recorded at Ngu6 (470 mg/kg) with the lowest concentrations found at Ngu15 (220 mg/kg) (Figure 6). ANZECC guidelines do not include trigger values for phosphorus in sediments and there are currently no nationally accepted guideline values but Robertson and Stevens (2007) have also developed a 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 mg/kg as “very enriched”. Under this classification all 21 sites were considered “low to moderately enriched” (Figure 6).

Figure 6: Sediment total phosphorus concentrations in Nguguru Estuary 2016.

3.2.4. Comparisons with other Northland estuaries

The mean TOC from Ngunguru is towards the low end of average values from other Northland estuaries surveyed. The range of TOC measured at Ngunguru sits well within the ranges of all other estuaries (Table 4) (Bamford, 2016; McCartain & Hewitt, 2016; Northland Regional Council, 2013; Griffiths, 2014b). The range of nitrogen concentrations (minimum – maximum) in Ngunguru

Estuary was smaller than those recorded in sediment surveys of other estuaries in Northland, with the exception of Parengarenga South (Table 4). While the mean nitrogen concentration at Ngunguru sits around the middle of the range of means from all the other estuaries surveyed, the maximum is lower than in many of the other estuaries. The range of phosphorus concentrations recorded at Ngunguru was also smaller than most other estuaries surveyed recently by NRC, with the exception of Parengarenga North, Parengarenga South and Houhora. The mean phosphorus concentration at Ngunguru sits around the middle of the range of means from all the other estuaries surveyed (Table 4).

Table 4: Mean sediment TOC and nutrient concentrations in Northland estuaries.

	Year	N	TOC (%w/w)	Nitrogen (mg/kg)	Phosphorus (mg/kg)
Ngunguru	2016	21	1.0 (0.6 – 1.6)	487 (140 – 960)	328 (220 – 470)
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)
Waitangi	2013	10	2.6 (1.0 – 4.2)	803 (220 – 2600)	647 (410 – 850)
Bay of Islands	2016	16	2.2 (0.9 – 4.4)	904 (280 – 1700)	603 (380 – 980)
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 limits at all 21 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 Ngu2 (10 mg/kg) (Figure 7).

Figure 7: Sediment chromium concentrations in Ngunguru 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 the TEL of 18.7 mg/kg developed by MacDonald et al. (1996). The highest concentration of copper was at Ngu2 (6.2 mg/kg) (Figure 8).

Figure 8: Sediment copper concentrations in Ngunguru Estuary 2016.

3.3.4. Nickel

All of the nickel concentrations were well below the ANZECC ISQG-Low effect trigger value of 21 mg/kg and the TEL of 15.9 mg/kg developed by MacDonald et al. (1996). The highest concentration of nickel was at Ngu22 (5.4 mg/kg) (Figure 9).

Figure 9: Sediment nickel concentrations in Ngunguru Estuary 2016.

3.3.5. Lead

All of the lead concentrations were below the ANZECC ISQG-Low effect trigger value of 50 mg/kg and the TEL of 30.2 mg/kg developed by MacDonald et al. (1996). The highest concentration of lead was at Ngu2 (7.6 mg/kg) (Figure 10). This site also had the highest concentrations of chromium and copper.

Figure 10: Sediment lead concentrations in Ngunguru Estuary 2016.

3.3.6. Zinc

All of the zinc concentrations were below the ANZECC ISQG-Low effect trigger value of 200 mg/kg and the TEL of 124 mg/kg developed by MacDonald et al. (1996). The highest concentration of zinc was at Ngu4 (62 mg/kg) (Figure 11).

Figure 11: Sediment zinc concentrations in Ngunguru Estuary 2016.

3.3.7. Comparison of metal concentrations in Northland estuaries

The average metal concentrations recorded in Ngunguru Estuary were lower than those values reported in recent sediment surveys conducted by NRC for Waitangi in 2013, and the Bay of Islands, Whangarei and Mangonui in 2016 (Bamford, 2016; McCartain & Hewitt, 2016; Northland Regional Council, 2013; Griffiths, 2014b). The ranges reported for Ngunguru metals were also all lower than those for the other estuaries (Table 5).

Table 5: Mean metal concentrations recorded in Northland estuaries with range in brackets.

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

3.4 Ecology

3.4.1. Biodiversity

A total of 23,109 individuals belonging to 91 different taxa were identified from the samples collected in Ngunguru Estuary. The mean number of taxa varied from 14 at Ngu1 to 38 at Ngu20 (Table 6). The highest mean number of individuals was found at Ngu7 (654) (Table 6), which can be attributed to high densities of two polychaete worms, *Heteromastus filiformis* and *Aonides trifida* (Table 7). The lowest number of individuals was found at Ngu6 (99). Ngu16 had the highest Shannon-Wiener diversity, and also the highest Pielou"s evenness score. The lowest diversity score was found at Ngu1, which also had the second lowest evenness score. The lowest evenness score was found at Ngu17 (Table 6). Ngu11, located within a seagrass patch, does not have a higher diversity than the other sites.

Bray-Curtis similarity gives an indication of within-site similarity. A high value similarity indicates that the taxa (and their abundances) in the three replicates are similar to each other, whereas a low value similarity indicates that the species (and their abundances) found in the three replicates are dissimilar to each other. The highest similarity was found at Ngu3, and the lowest similarity was found at Ngu10 (Table 6). The major species contributing to within site similarity at the majority of sites were either polychaete worms (*Aonides trifida*: 8 sites, *Heteromastus filiformis*: 4 sites, and *Prionospio aucklandica*: 3 sites) or the bivalve *Austovenus stutchburyi* (3 sites). The exceptions to this were Ngu17, Ngu22 and Ngu2 where the major contributing species were *Austrominius modestus* (barnacles), *Exosphaeroma chilensis* (an isopod) and oligochaetes.

Table 6: Mean diversity indices and Bray-Curtis similarity at sites in Ngunguru Estuary 2016.

Site	Total number of species	Number of individuals	Shannon Diversity	Pielou"s Evenness	Bray-Curtis Similarity
Ngu1	14	496	1.04	0.39	81.28
Ngu2	21	308	1.75	0.57	72.06
Ngu3	17	449	1.47	0.52	81.41
Ngu4	26	152	2.27	0.70	54.05
Ngu5	30	306	2.06	0.61	72.42
Ngu6	22	99	2.01	0.65	61.81
Ngu7	27	654	1.97	0.60	62.27
Ngu8	27	361	1.84	0.56	80.24
Ngu9	20	464	1.45	0.48	71.49
Ngu10	28	350	1.98	0.59	49.20
Ngu11	28	223	2.10	0.63	67.59
Ngu12	34	437	1.83	0.52	73.03
Ngu13	31	547	1.92	0.56	71.59
Ngu14	24	190	1.85	0.58	62.41
Ngu15	30	561	1.47	0.43	70.91
Ngu16	31	124	2.63	0.77	54.63
Ngu17	29	377	1.08	0.32	74.98
Ngu19	36	548	2.30	0.64	69.07
Ngu20	38	328	2.14	0.59	80.93
Ngu21	36	497	2.37	0.66	62.18
Ngu22	37	267	2.30	0.64	58.98

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 4 groups of sites of greater than 39% selfsimilarity. The majority of the sites have grouped together. However, Ngu6 (located near the top of the estuary), Ngu10 and 14 (located near the middle of the estuary) and Ngu17 (located near the mouth of the estuary) appear to have separated into their own groups. Ngu11 (the site within a seagrass patch) does not have a community composition that differs from the majority of the sites.

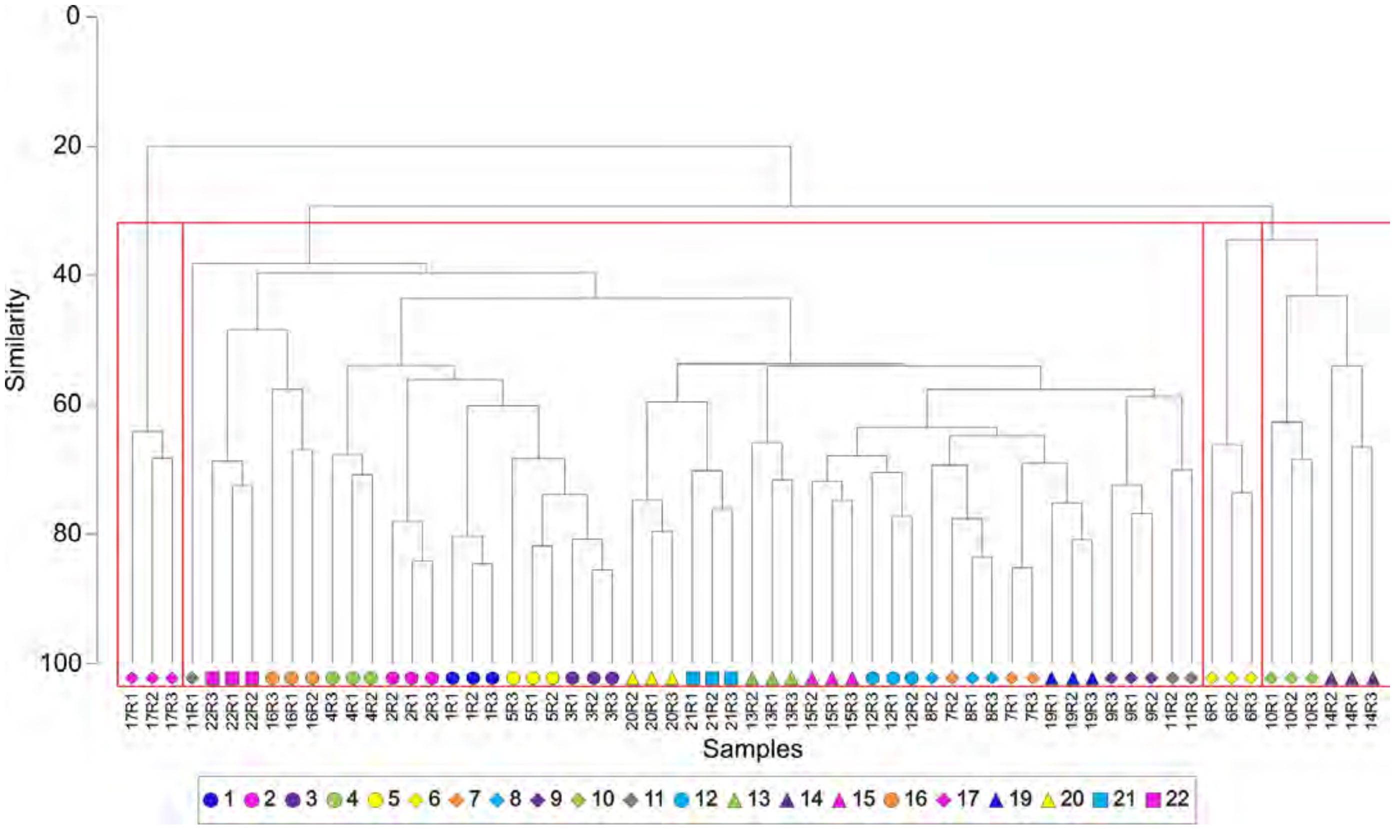

Figure 12: Group average linkage cluster of Bray-Curtis similarities from squareroot transformed infauna abundance data collected from 21 sites in Ngunguru Estuary 2016.

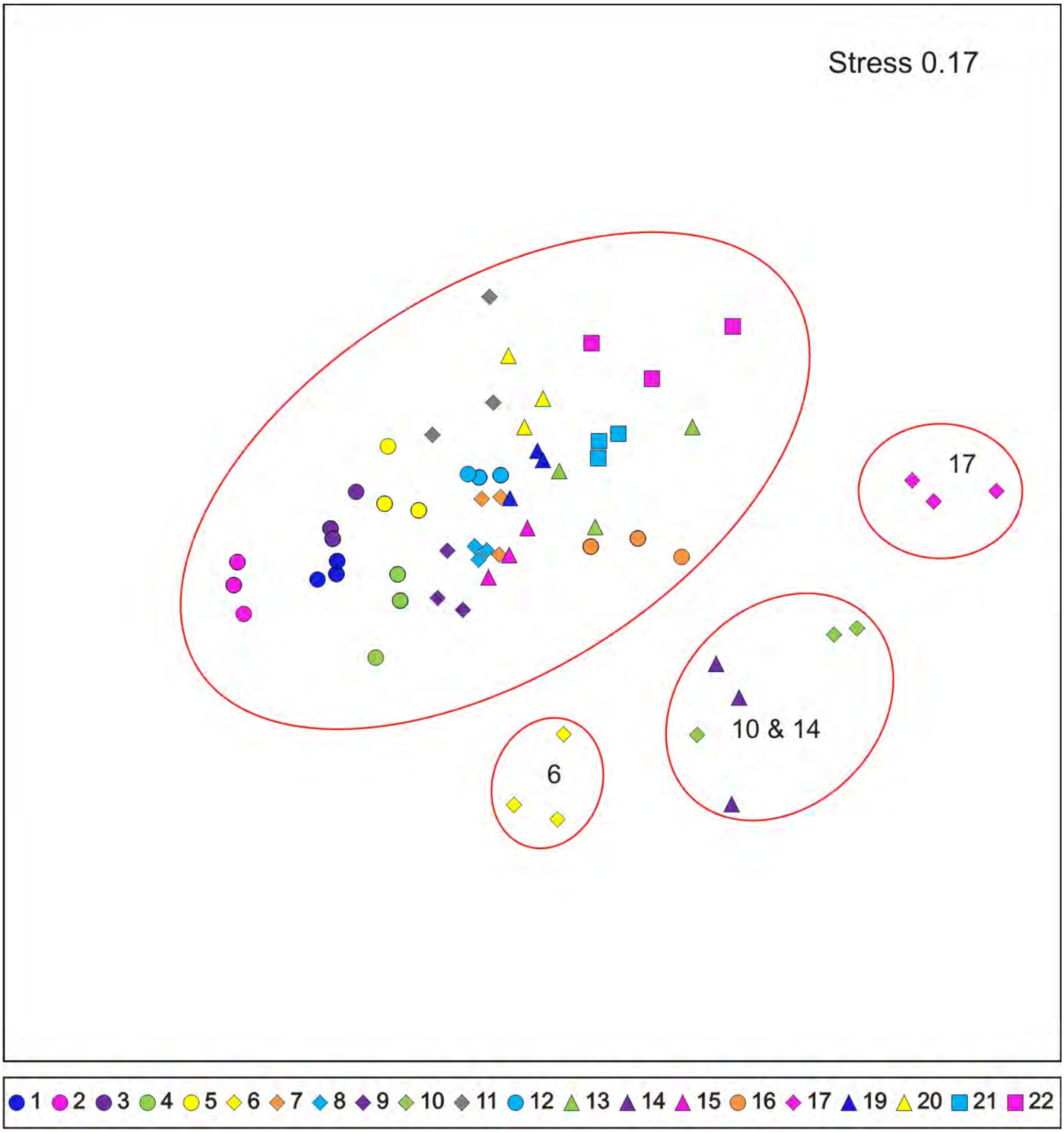

Figure 13: Non-metric multidimensional scaling (MDS) ordination of Bray-Curtis similarities from squareroot transformed infauna abundance data collected from 21 sites in Ngunguru Estuary 2016.

3.5 Species abundance

3.5.1. Species abundance

Communities at the majority of sites were dominated by polychaetes (including *Aonides trifida, Heteromastus filiformis and Prionospio aucklandica*) and bivalves (including *Austrovenus stutchburyi*, *Paphies australis* and *Macomona liliana*). Overall, these two taxonomic groups accounted for 59% and 17% of all individuals identified respectively. Polychaetes dominated the communities at most sites (40% - 88%), with the exception of Ngu6,10 and 14, which were dominated by bivalves, and Ngu17, which was dominated by “Others” (e.g. *Austrominius modestus* and *Notoacmea* sp.- see full list in Appendix 6-1).

Aonides trifida was the most common polychaete across all of the sites (ranked in the top five most abundant taxa at 7 sites and present at 15 / 21 sites in total), followed by *Heteromastus filiformis* (ranked in the top five most abundant taxa at 4 sites and present at 14 / 21 sites in total) and *Prionospio aucklandica* (ranked in the top five most abundant taxa at 2 sites and present at 10 / 21 sites in total). A*ustrovenus stutchburyi* was the most abundant bivalve across all of the sites (ranking within the top 5 species at all 21 sites). Other bivalves that also ranked in the top five most abundant taxa included *Macomona liliana* (Ngu1, 12 and 15), *Paphies australis* (Ngu4, 16, 17 and 22) and *Linucula hartvigiana* (Ngu11, 13 and 20). Also common within the top ranking taxa were oligochaetes (7 / 21 sites), the anemone *Anthopleura aureoradiata* (7 / 21 sites) and the barnacle *Austrominius modestus* (5 / 21 sites).

Table 7: Top five most abundant taxa found at the sampling sites in Ngunguru Estuary 2016.

Site	Most abundant				Less abundant
Ngu1	*Aonides trifida* (339.0)	Oligochaeta (78.3)	*Heteromastus filiformis* (53.0)	*Macomona liliana* (7)	*Austrovenus stutchburyi* (6.3)
Ngu2	Oligochaeta (140.0)	*Heteromastus filiformis* (70.7)	*Scolelepis* sp. (31)	*Aricidea* sp. (17.0)	Nereididae (14.0)
Ngu3	*Heteromastus filiformis* (232.7)	*Aricidea* sp. (103.3)	*Aonides trifida* (43.0)	Oligochaeta (32.7)	*Prionospio aucklandica* (8.0)
Ngu4	*Aonides trifida* (50.7)	*Heteromastus filiformis* (21.3)	Nereididae (17.0)	Oligochaeta (16.3)	*Paphies australis* (8.0)
Ngu5	*Heteromastus filiformis* (115.3)	*Aricidea* sp. (70.7)	Oligochaeta (26.3)	*Austrovenus stutchburyi* (15.0)	*Prionospio* sp. (13.3)
Ngu6	*Austrovenus stutchburyi* (34.3)	Oligochaeta (26.7)	*Anthopleura aureoradiata* (13.7)	Sipuncula (6.3)	Syllidae (6.0)
Ngu7	*Heteromastus filiformis* (205.7)	*Aonides trifida* (149.3)	*Austrovenus stutchburyi* (80.7)	*Anthopleura aureoradiata* (69.0)	*Prionospio aucklandica* (62)
Ngu8	*Aonides trifida* (161.3)	*Austrovenus stutchburyi* (68.3)	*Anthopleura aureoradiata* (36.0)	*Heteromastus filiformis* (35.3)	Oligochaeta (14.3)
Ngu9	*Aonides trifida* (265.3)	*Heteromastus filiformis* (85.0)	*Austrovenus stutchburyi* (56.3)	*Lasaea parengaensis* (11.0)	*Capitella capitata* (9.7)
Ngu10	*Austrovenus stutchburyi* (148.3)	*Zeacumantus subcarinatus* (66.7)	Phoxocephalidae (36.7)	*Austrominius modestus* (26.0)	*Notoacmea* sp. (15.0)
Ngu11	*Heteromastus filiformis* (81.3)	*Aonides trifida* (49.3)	*Prionospio aucklandica* (30.3)	*Linucula hartvigiana* (11.0)	*Austrovenus stutchburyi* (6.3)
Ngu12	*Aonides trifida* (222)	*Prionospio aucklandica* (62.7)	*Austrovenus stutchburyi* (48.3)	*Heteromastus filiformis* (22.0)	*Macomona liliana* (15.0)
Ngu13	*Aonides trifida* (268.3)	*Austrominius modestus* (72.0)	*Anthopleura aureoradiata* (58.0)	*Linucula hartvigiana* (27.7)	*Austrovenus stutchburyi* (25.3)
Ngu14	*Austrovenus stutchburyi* (97.0)	*Austrominius modestus* (21.7)	*Notoacmea* sp. (17.3)	*Scoloplos cylindrifer* (13.0)	*Aonides trifida* (8.3)
Ngu15	*Aonides trifida* (351.3)	*Austrovenus stutchburyi* (67.3)	*Anthopleura aureoradiata* (43.0)	*Macomona liliana* (33.0)	*Heteromastus filiformis* (17.0)
Ngu16	*Prionospio aucklandica* (27.0)	*Anthopleura aureoradiata* (15.6)	*Paphies australis* (15.3)	*Austrovenus stutchburyi* (12.7)	*Heteromastus filiformis* (9.3)
Ngu17	*Austrominius modestus* (276.7)	*Paphies australis* (52.3)	*Notoacmea* sp. (11.7)	Amphipoda (11.0)	*Austrovenus stutchburyi* (5.3)
Ngu19	*Austrovenus stutchburyi* (101.3)	*Prionospio aucklandica* (84.7)	*Heteromastus filiformis* (81.7)	*Aonides trifida* (78.0)	*Sphaerosyllis* sp. (63.0)
Ngu20	*Prionospio aucklandica* (153.0)	*Sphaerosyllis* sp. (43.7)	*Heteromastus filiformis* (20.0)	*Linucula hartvigiana* (16.7)	*Aonides trifida* (13.7)
Ngu21	*Austrominius modestus* (103.3)	*Aonides trifida* (88.0)	*Austrovenus stutchburyi* (71.3)	*Prionospio aucklandica* (61.3)	*Anthopleura aureoradiata* (47.0)
Ngu22	*Exosphaeroma chilensis* (91.3)	Polydorid (48.3)	*Prionospio aucklandica* (28.0)	*Aonides trifida* (15.3)	*Paphies australis* (14.7)

3.6 Shellfish

Pipis (*Paphies australis*) were found at the following sites: Ngu4, 10, 16, 17 and 22. Those found at Ngu4, 10 and 22 fell into either the < 4 mm or 4 – 16 mm size classes, whereas those found at Ngu16 and 17 were mostly in the > 16 mm size class (Figure 14). As per the 2014 – 2015 Northland bivalve survey (Berkenbusch & Neubauer, 2015) there was a total absence of pipis with ≥ 50 mm shell length. The habitat at all of these sites was described as firm sand with varying amounts of overlying shell hash.

Figure 14: Length frequency distribution of pipis (*Paphies australis*) in Ngunguru Estuary 2016.

The wedge shell (*Macomona liliana*) was found throughout the estuary, but in much lower numbers than the cockle *Austrovenus stutchburyi.* Ngu12 and 15 had the highest total counts (70 and 68 individuals from the three cores collected) (Figure 15). The majority of *Macomona* at these two sites were not adults (i.e. they were < 16mm). Both of these sites are located on the sheltered landward side of the entrance sand spit. Sites with the highest numbers of adults were Ngu1, 3, 5, 8 and 13.

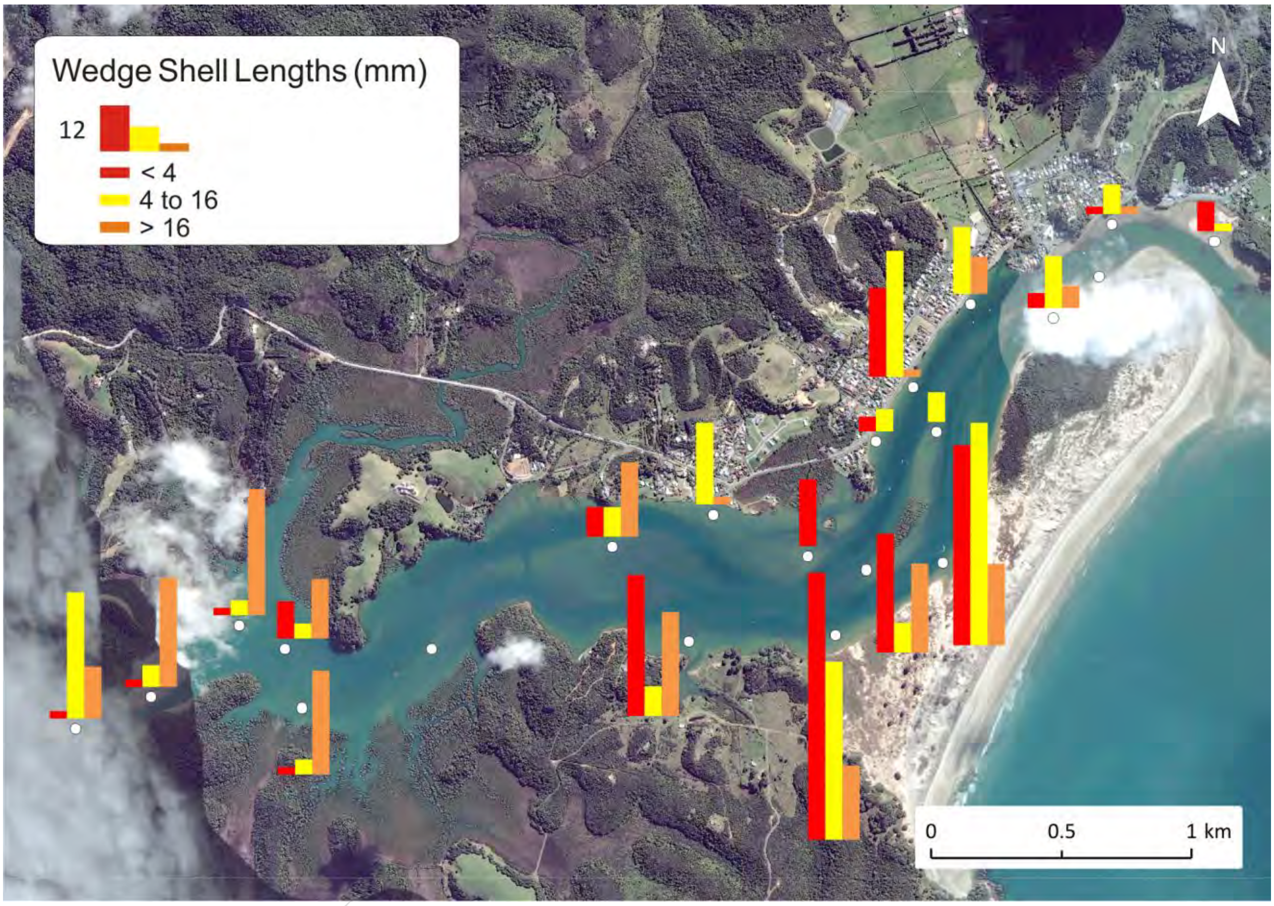

Figure 15: Length frequency distribution of wedge shells (*Macomona liliana*) in Ngunguru Estuary 2016.

Cockles (*Austrovenus stutchburyi*) were found at all sites, although there was considerable variation in densities (total counts from three cores ranging from five individuals at Ngu2 to 700 at Ngu10). The highest densities were found at Ngu10, 14 and 19 (Figure 16). Averages taken across all reps at all sites showed that the size class distributions were very evenly spread (< 4 mm: 16.5 individuals; 4 – 16 mm: 16.8 individuals; > 16 mm: 16.9 individuals). More adults (sized > 16mm) were found in the middle and towards the mouth of the estuary (sites Ngu7, 10, 13, 14, 19 and 21).

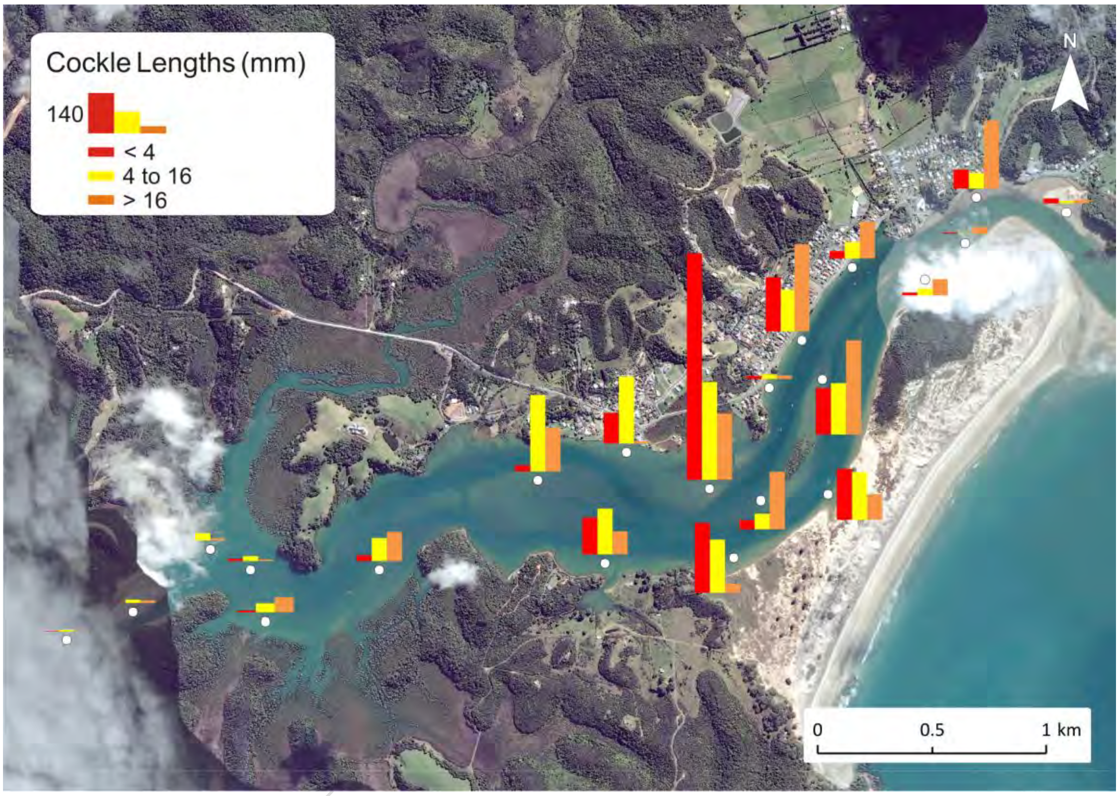

Figure 16: Length frequency distribution of cockles (*Austrovenus stutchburyi*) in Ngunguru Estuary 2016.

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, showed that zinc, lead, mud, medium sand, TOC, chromium and copper were all significantly correlated ($p < 0.05$) with the intertidal ecological community structure (Table 8). Forwards selection revealed that 29% of the variability in community composition could be explained by zinc and fine sand. A further 2 variables each contributed over 6% explained (lead, and total phosphorus), resulting in 42% explained.

Table 8: DISTLM marginal tests for log10 sediment properties and species abundance data from 21 sites in the Ngunguru Estuary 2016.

Sediment properties	Pseudo-F	P-value	Proportion of variation explained
Zinc	4.68	0.001	19.77
Lead	4.51	0.001	19.19
Mud	3.90	0.001	17.03
Medium Sand	2.69	0.011	12.40
TOC	2.33	0.019	10.92
Chromium	2.17	0.027	10.24
Copper	2.02	0.036	9.60
Total Nitrogen	1.89	0.055	9.05
Nickel	1.67	0.101	8.09
Total Phosphorus	1.55	0.133	7.54
Fine Sand	1.50	0.144	7.30
Cadmium	1.02	0.410	5.10
Course Sand	0.83	0.594	4.17

3.8 State of the Environment Indicators

3.8.1. Benthic Health Models

The BHMmetals model was developed to determine the health of communities relative to stormwater contaminants (total sediment copper, lead and zinc concentrations). Soon after, the BHMmud model was developed to determine health relative to sediment mud content. The BHMnutrients model is derived from Tauranga Harbour data and has not previously been used elsewhere.

The majority of the sites sampled within Ngunguru Estuary indicate “good” to “moderate” health of the macrofaunal community composition as related to these heavy metals, with most scores falling into groups 2 or 3 (green and yellow colouring, respectively) (Table 9). Sites Ngu6 and Ngu16 both scored extremely good (blue colouring, group 1).

For BHMmud, only site Ngu14 scored “extremely good” (blue colouring, group 1), with the majority of the sites scoring “good” to “moderate” health. However, community composition at two sites (Ngu1 and Ngu2), both exhibited poor health related to mud content of the sediment (Table 9).

The data from Ngunguru generally fitted the BHMnutrient model well. Most sites plotted well within the model regression 95% confidence limits for the individual points. However, three sites were not well predicted by the model. Sites Ngu6 and 10 had better health than we would have expected from their nutrient values, scoring “extremely good” (blue colouring). One site had lower health than expected from its nutrient values (Ngu1) scoring “poor” (golden colouring). Of the remaining sites, which all fitted the model well, four sites scored “good” (green colouring), three sites scored “poor”, and the rest were scored as “moderate” (yellow colouring) (Table 9). The four poor sites (Ngu1, 3, 7 and 9) were located in the upper to mid estuary.

Table 9: Benthic Health Model values (metals, mud and nutrients) for the 21 sites in Ngunguru Estuary sampled in 2016.

Site	BHMmetal	BHMmud	BHMnutrients
Ngu1	-0.059	0.032	0.13
Ngu2	-0.035	0.052	0.09
Ngu3	-0.068	0.019	0.12
Ngu4	-0.101	-0.039	0.03
Ngu5	-0.047	0.002	0.11
Ngu6	-0.166	-0.078	-0.07
Ngu7	-0.102	-0.037	0.14
Ngu8	-0.125	-0.058	0.11
Ngu9	-0.074	-0.009	0.12
Ngu10	-0.091	-0.079	-0.07
Ngu11	-0.056	0.001	0.11
Ngu12	-0.113	-0.094	0.05
Ngu13	-0.123	-0.116	0.06
Ngu14	-0.154	-0.121	-0.03
Ngu15	-0.124	-0.087	0.04
Ngu16	-0.171	-0.113	0.01
Ngu17	-0.077	-0.072	0.02
Ngu19	-0.114	-0.075	0.08
Ngu20	-0.097	-0.076	0.04
Ngu21	-0.120	-0.089	0.07
Ngu22	-0.148	-0.101	-0.01

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 colour - good) for levels of functional redundancy/resilience except for Ngu1, 3 and 6. Ngu3 and 6 TBI values fell within group 2 (yellow – intermediate) and Ngu1 value was within group 3 (red – poor), indicating poor levels of functional redundancy / resilience (Table 10).

Table 10: Traits Based Index (TBI) values for the 21 sites sampled in Ngunguru Estuary 2016.

Site	TBI
Ngu1	0.25
Ngu2	0.41
Ngu3	0.32
Ngu4	0.54
Ngu5	0.55
Ngu6	0.38
Ngu7	0.48
Ngu8	0.53
Ngu9	0.42
Ngu10	0.49
Ngu11	0.52
Ngu12	0.63
Ngu13	0.59
Ngu14	0.42
Ngu15	0.55
Ngu16	0.58
Ngu17	0.43
Ngu19	0.65
Ngu20	0.79
Ngu21	0.64
Ngu22	0.66

3.8.3. Combined Indices

Combining the BHMmetal, BHMmud and TBI values provides an indication of the overall health of the Ngunguru estuary. Results show that the majority of sites have good (green colouring) and moderate (yellow colouring) levels of health and resilience (Table 11 and Figure 17). Site Ngu1 is the only community to have poor (golden colouring) health and resilience.

Table 11: Combined health values for the 21 sites sampled in Ngunguru Estuary.

Site	Combined health score
Ngu1	0.80
Ngu2	0.58
Ngu3	0.56
Ngu4	0.44
Ngu5	0.51
Ngu6	0.42
Ngu7	0.44
Ngu8	0.38
Ngu9	0.44
Ngu10	0.38
Ngu11	0.51
Ngu12	0.38
Ngu13	0.38
Ngu14	0.31
Ngu15	0.38
Ngu16	0.31
Ngu17	0.38
Ngu19	0.38
Ngu20	0.38
Ngu21	0.38
Ngu22	0.38

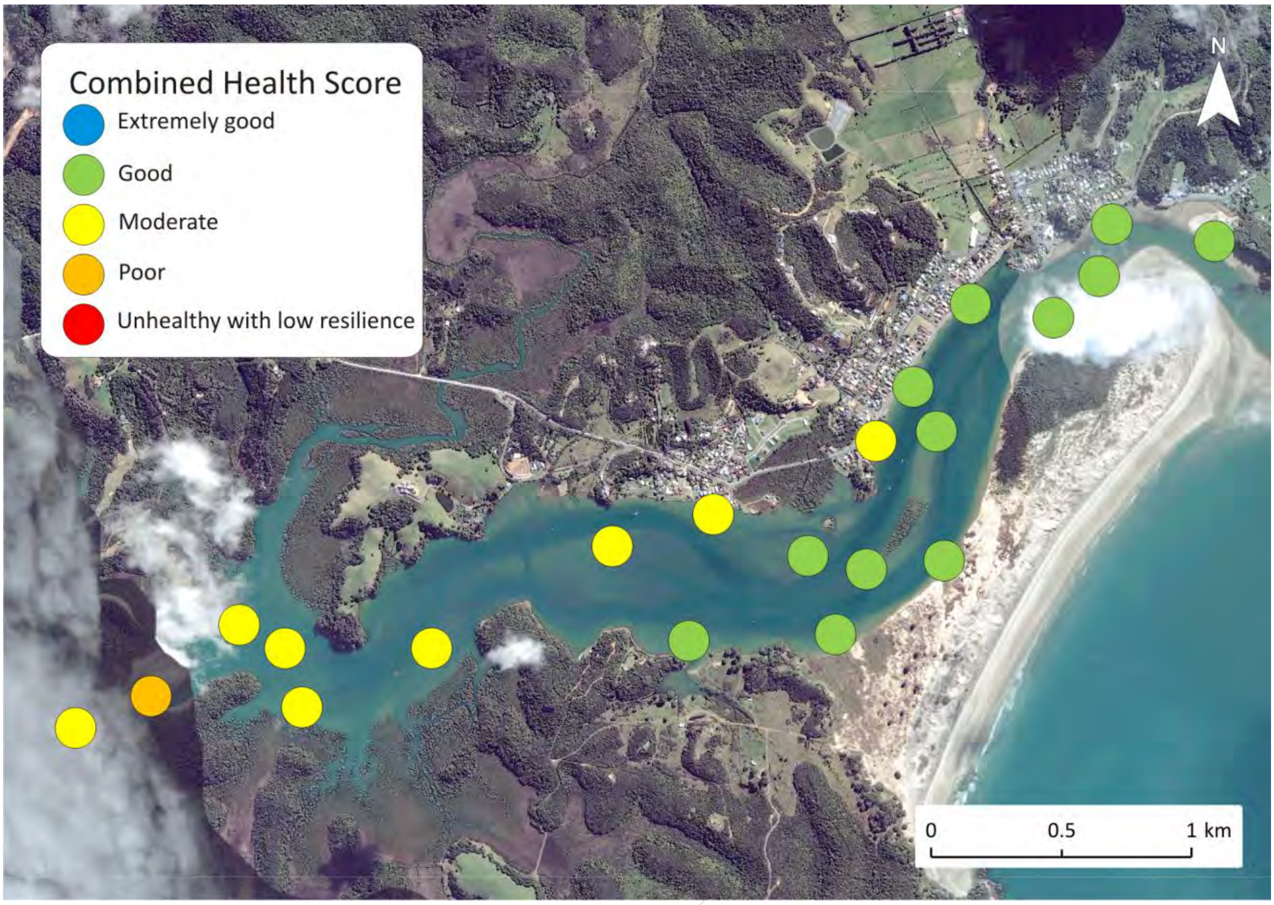

Figure 17: Combined BHMmetals, BHMmud and TBI score for sampled sites in Ngunguru Estuary 2016.

4. Discussion

4.1 Sediment physical properties

Within the estuary, the highest proportions of mud were generally found at sites in the upper reaches of the estuary near sheltered tidal creek environments (Ngu2, 3 and 5). Tidal creeks are typically low energy depositional environments and tend to be more influenced by inputs of terrigenous sediment than marine sediment from the open coast. Small amounts of mud were found at all outer sites except Ngu14, 17 and 22. The absence of mud at Ngu22 is most likely due to it being directly in the mouth of the estuary and therefore exposed to a high energy environment. Sites Ngu14 and 17 are both shell banks overlying dense packed sand in the lower reaches of the estuary. Also, Ngu14 is near the middle of the main channel, and Ngu17 is in a sub-channel, where high current flows could prevent settlement of very fine sediments.

The proportion of mud observed at the Ngunguru sites was generally much smaller than proportions measured in other Northland estuaries such as Whangarei Harbour and Waitangi (NRC, 2013). This is interesting given that the combination of steep hill country, highly erodible soils, and periodic high intensity rainfall events has been stated to lead to accelerated soil erosion. Either this sediment is staying in suspension and being exported to the open coast, is deposited upstream of the sites sampled, or much of the sediment load entering the estuary is composed of fine sands rather than silts and clays.

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, stormwater 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 surface of the sediment, or may be eliminated altogether. 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 opportunistic species that are tolerant of low oxygen conditions. However, many macrofauna mix sediment and irrigate deep sediments with oxygenated bottom water, alleviating the effects of pervasive porewater hypoxia/anoxia (Norkko et al., 2012). 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), sediments at all sites were classified as “low to moderately enriched” for total phosphorus, whilst Ngu2, 3, 5, 7 and 10 were low to moderately enriched for nitrogen. For total organic carbon (sediment TOC), 10 sites were classified as “low to moderately enriched” and the remaining 11 sites were classified as “very good”. There were no strong correlations between high levels of nutrients, TOC or mud with the highest correlation observed being between TOC and total nitrogen (Pearson’s R = 0.77).

Average nitrogen and phosphorus concentrations measured in Ngunguru Estuary were very similar to means recorded in sediment surveys of other Northland estuaries, whilst the mean TOC was towards the lower end of average values from other estuaries surveyed (NRC, 2013).

4.3 Sediment metal concentrations

Heavy metals can have lethal and sub-lethal effects on benthic invertebrates. In a contaminated environment species diversity and richness may decrease as the community becomes dominated by a smaller number of more tolerant species (Clarke & Warwick, 2001). A common source of heavy metals (e.g. cadmium, chromium, copper, nickel, lead and zinc) is stormwater runoff and, as a result, sites located close to outfalls and roads can exhibit elevated levels of metals. Concentrations of heavy metals tend to increase as sediment grain size decreases, which reflects the tendency for heavy metals to be preferentially adsorbed onto the collectively large surface area of fine grained sediments that are rich in clay minerals (Abrahim et al., 2006).

The metal concentrations recorded in Ngunguru Estuary were all below the ANZECC ISQG-Low effect trigger values and the threshold effect levels developed by MacDonald et al. (1996). In addition to this, the average metal concentrations were lower than those values reported in recent sediment surveys conducted by NRC for Waitangi in 2013 and the Bay of Islands, Whangarei and Mangonui in 2016.

4.4 Ecology

While shellfish have previously been surveyed in Ngunguru Estuary, sampling of the macrofaunal community structure has not been conducted. Thus, the purpose of this report is to create an ecological baseline for future monitoring. The sites sampled in Ngunguru Estuary covered a range of intertidal habitats including; sheltered soft mud flats, sandy beaches, sand banks, shell banks and a seagrass patch. A total of 23,109 individuals belonging to 91 different taxa were identified across 21 sites (three cores per site) and the communities were dominated by polychaetes (59% of individuals), bivalves (17% of individuals) and “Others” (e.g. *Austrominius modestus* and *Notoacmea* sp.). The most abundant taxa were *Aonides trifida, Heteromastus filiformis, Prionospio aucklandica, Austrovenus stutchburyi, Anthopleura aureoradiata* and oligochaetes.

Four groups of sites with different community composition were observed (Ngu6, Ngu 10 and 14, Ngu17 and the rest). These site groupings do not appear to have any geographical similarities. Polychaetes dominated the communities at most of the sites with the exception of Ngu6,10 and 14, which were dominated by bivalves, and Ngu17, which was dominated by “Others” (e.g. *Austrominius modestus* and *Notoacmea* sp.).

Pipis (*Paphies australis*) were found at sites Ngu4, 10, 16, 17 and 22. Larger sized pipis were mainly found at Ngu16 and 17; the greatest shell length recorded was 46mm. The wedge shell (*Macomona liliana*) was found throughout the estuary, but in much lower numbers than the cockle *Austrovenus stutchburyi.* Ngu12 and 15 had the highest total counts of *Macomona* (70 and 68 individuals from three cores), the majority of which fell into either the < 4 mm or 4 – 16mm size classes. Both of these sites are located on the sheltered landward side of the entrance sand spit, which would provide a good environment for juvenille conspecifics to settle. Sites with the highest numbers of adults were Ngu1, 3, 5, 8 and 13. Cockles (*Austrovenus stutchburyi*) were found at all sites, although there was high variation in densities (total counts from three cores ranging from five individuals at Ngu2 to 700 at Ngu10). The highest densities were found at Ngu10, 14 and 19. Averages taken across all reps at all sites showed that the size class distributions were very evenly spread (< 4 mm: 16.5 individuals; 4 – 16 mm: 16.8 individuals; > 16 mm: 16.9 individuals). More adults (sized > 16mm) were found in the middle and towards the mouth of the estuary (sites Ngu7, 10, 13, 14, 19 and 21).The habitat at all bivalve - dominated sites was described as firm sand.

Macrofaunal community health indices suggested that communities of Ngunguru generally have good health, with 8 sites having moderate health and resilience and 12 with good health and resilience. Ngu1 was the only community to have poor health and resilience, reflecting the lower numbers of species and low biodiversity observed at this site.

4.5 Relating ecology to sediment data

The most important variables determining the intertidal ecological community structure were zinc and fine sand, which explained 29% of variation in the community structure. A further 2 variables each contributed over 6% (lead and total phosphorus). These results are of interest because two heavy metals appear to be important drivers of the community composition, despite none of them exceeding the TEL guidelines. This supports results from a study of Auckland estuaries which found changes in community composition below TEL guidelines for copper, lead and zinc and suggested lower limits would be more protective of the majority of species (Hewitt et al., 2009).

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6. Appendix

Appendix 6-1: List of classes of taxa used in section 3.5.1

Amphipoda

Amphipoda

Phoxocephalidae

Bivalve

Arthritica bifurca

Austrovenus stutchburyi

Bivalvia Unid. (juv)

Crassostrea gigas

Diplodonta zelandica

Lasaea parengaensis

Limnoperna pulex

Linucula hartvigiana

Macomona liliana

Musculista senhousia

Mytilidae (Juvenile)

Ostreidae (Juvenile)

Paphies australis

Crabs / Shrimp

Alpheus socialis

Alpheus sp.

Austrohelice crassa

Brachyura (juv.)

Decapoda (Juvenile)

Halicarcinus cookii

Halicarcinus whitei

Hemigrapsus edwardsi

Hemiplax hirtipes

Heterosquilla sp.

Tanaidacea

Isopoda

Cirolanidae

Exosphaeroma chilensis

Exosphaeroma sp.

Isocladus sp.

Lysianassidae

Natatolana sp.

Paravireia sp.

Others

Acarina

Aglajidae

Algae (red filamentous)

Anthopleura aureoradiata

Anthozoa

Austrominius modestus

Bryozoa (encrusting)

Copepoda

Cumacea

Diptera indet. (pupae)

Edwardsia sp.

Holothuroidea

Insecta

Ischnochiton maorianus

Nematoda

Notoacmea sp.

Osteichthyes

Ostracoda

Platyhelminthes

Sipuncula

Polychaete

Aonides trifida

Aricidea sp.

Armandia maculata

Capitella capitata

Capitellidae

Ceratonereis sp.

Cirratulidae

Dorvilleidae

Glyceridae

Heteromastus filiformis

Leitoscoloplos sp.

Magelona sp.

Maldanidae

Nereididae

Nicon aestuariensis

Oenonidae

Orbinia papillosa

Orbiniidae

Pectinaria australis

Perinereis nuntia

Polydorid

Polynoidae

Prionospio aucklandica

Prionospio sp.

Scalibregmatidae

Scolecolepides benhami

Scolelepis sp.

Scoloplos cylindrifer

Sphaerosyllis sp.

Spionidae

Syllidae

Gastropod

Cominella glandiformis

Diloma subrostrata

Duplicaria tristis

Epitoniidae

Gastropoda (rissoid like)

Gastropoda (micro snails)

Haminoea zelandiae

Neoguraleus sinclairi

Philine auriformis

Philine sp.

Potamopyrgus estuarinus

Spio sp.

Zeacumantus subcarinatus

Nemertea

Nemertea

Oligochaeta

Oligochaeta

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