

Whareama Estuary

Fine Scale Monitoring 2015/16



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Whareama Estuary Fine Scale Site B

Whareama Estuary

Fine Scale Monitoring 2015/16

Prepared for
Greater Wellington Regional Council

by

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All photos by Wriggle except where noted otherwise.

WHAREAMA ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the fine scale baseline (2008-2010) and the first year of impact monitoring (2016) of two intertidal sites within Whareama Estuary, a 12km long, tidal river estuary on the Wairarapa coast. It is one of the key estuaries in Greater Wellington Regional Council's (GWRC's) long-term coastal monitoring programme. The following table summarises fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

FINE SCALE MONITORING RESULTS

- Sediment mud content was high (48-93% mud).
- Sediment oxygenation was moderate to poor [redox potential discontinuity (RPD) 1-2cm] with a declining trend at Site B.
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations, with an increasing trend at Site B.
- The benthic invertebrate mud and organic enrichment rating (NZ AMBI) indicated a moderate-high risk of mud and organic enrichment impacts both in 2016 as well as in the period 2008-2010.
- The mud and organic enrichment biotic index (NZ AMBI) showed no significant change at either site from the 2008-10 "baseline" compared to the 2016 "post baseline". However, the macroinvertebrate results for the whole community (PCO analysis) showed significant differences in the communities at each site in 2016 compared to all of the "baseline" 2008-10 data and, at Wha A only, differences in taxa abundance, diversity and richness (no differences at Site Wha B).
- Comparison of the infauna results with abiotic factors indicated that at Wha B, TOC, mud, TN, TP and RPD were all moderately correlated with the macrofaunal community, but at Wha A (the downstream site), no single or combination of measured environmental factors was well correlated with infauna results.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Low	Moderate
Very Low	High

Whareama Estuary	Site Wha A (downstream)				Site Wha B (upstream)			
	2008	2009	2010	2016	2008	2009	2010	2016
Sediment Mud Content	High	High	High	High	High	High	High	High
aRPD (Sediment Oxygenation)	Low	Moderate	Moderate	Moderate	Low	Low	Low	Moderate
TOC (Total Organic Carbon)	Low	Low	Low	Low	Low	Low	Low	Low
Total Nitrogen	Low	Low	Low	Low	Low	Low	Low	Low
Invertebrate Mud/Org Enrichment	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Metals (Cd, Cu, Cr, Hg, Ni, Pb, Zn) & As	Low	Low	Low	Not Measured	Low	Low	Low	Not Measured

ESTUARY CONDITION AND ISSUES

In summary, the results showed that in 2016, as in the baseline years 2008-10, the fine scale intertidal sediments had high mud concentrations (>25% mud), low levels of organic enrichment, moderate to poor sediment oxygenation and a typical, mud-tolerant mixed macroinvertebrate community with low species richness. In terms of changes since the 2008-2010 baseline, results showed that: mud, nutrient and organic carbon concentrations had increased at the upper muddier site, significant small changes in the structure of the macroinvertebrate community were apparent at both sites, but there was no change in the mud and organic enrichment biotic index (NZ AMBI) ratings at either site.

Overall, the findings reinforce that muddiness is an issue in this estuary.

RECOMMENDED MONITORING AND MANAGEMENT

Because Whareama Estuary is a large tidal river estuary with high ecological and human use values, situated in a developed and erosion-prone catchment, and vulnerable to excessive sedimentation and eutrophication, it has been identified by GWRC as a priority for monitoring. Baseline fine scale intertidal conditions were established from 2008-2010, and one year of post baseline sampling has been completed (2016). It is recommended that the next fine scale monitoring of intertidal sites be undertaken at the scheduled 5 yearly monitoring interval (i.e. 2021). Fine scale monitoring, in conjunction with sedimentation and broad scale monitoring, provides valuable information on current estuary condition and trends over time, particularly in relation to the widely acknowledged sedimentation issue in the estuary.

In addition to this monitoring it is recommended that additional targeted investigations be undertaken to more fully assess muddiness throughout the estuary (not just the lower estuary), identify the catchment mud sources and develop appropriate sediment load limits that recognise the erosion-prone nature of much of the catchment, its existing land use, and the limitations of the estuary to assimilate high sediment loads.

To date, the Wellington Regional Erosion Control Initiative (WRECI) has identified ~50% of the catchment as erosion-prone with high rates of sediment discharge, and therefore included under farm erosion plans.

1. INTRODUCTION

OVERVIEW



Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. In 2007 Greater Wellington Regional Council (GWRC) identified a number of estuaries in its region as immediate priorities for long term monitoring and in late 2007 began the monitoring programme in a staged manner. The estuaries currently included in the programme are; Porirua Harbour [Onepoto (Porirua) and Pauatahanui Arms], Whareama Estuary, Lake Onoke, Hutt Estuary and Waikanae Estuary. Risk assessments have been undertaken for a number of other estuaries in order to establish priorities for their management.

Monitoring of Whareama Estuary began with the first year of fine scale baseline monitoring undertaken in January 2008. The estuary monitoring process consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) as follows:

- 1. Ecological Vulnerability Assessment (EVA)** of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has been completed for Whareama Estuary and is reported in Robertson and Stevens (2007).
- 2. Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. Broad scale intertidal mapping of Whareama Estuary was undertaken in 2007 (Robertson and Stevens 2007).
- 3. Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Whareama Estuary, was undertaken in 2008, 2009 and 2010 to establish a baseline (Robertson and Stevens 2008, 2009 and 2010). The first year of post baseline monitoring was undertaken on 26 January 2016 and is the subject of this report. Sedimentation rates in the estuary have been monitored annually in the estuary since 2008 (e.g. Stevens and Robertson 2016).

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of condition ratings are presented and described in Section 2. The current report describes the 2016 fine scale results and compares them to the previous findings.

Whareama Estuary is a long, narrow, "tidal river" type estuary on the Wairarapa coast. It is enclosed within a steep valley and is relatively shallow (1-3m deep). The estuary margin is dominated by grassland and is generally devoid of saltmarsh vegetation except for a narrow strip in the lower section.

The catchment landuse is dominated by sheep and beef grazing but it also includes significant areas of native and exotic forest. However, because of the hilly nature, dominant soft rock type, and primarily grazed catchment, the suspended sediment yield is elevated. As a consequence, the estuary receives excessive inputs of fine sediments and the water is turbid, and the bed muddy except for the very lowest reaches where firm sands dominate.

Saltwater extends up to 12km inland and the water column is often stratified (freshwater overlying denser saline bottom water). There is an indication of moderate macroalgal growth at times and a distinctive green colouration from high phytoplankton growth in the water column. However, frequent floods flush these growths from the estuary into the surrounding ocean before they become a problem.

Fine scale monitoring (Robertson and Stevens 2008-2010) showed the intertidal flats had high sedimentation rates, poorly oxygenated sediments with a high mud content, and a benthic invertebrate community dominated by mud and organic enrichment tolerant species. In response to these indicators of excessive muddiness and poor sediment oxygenation, annual monitoring of sedimentation rate, grain size, and redox potential discontinuity (RPD) depth has been undertaken.

Table 1. Summary of the major environmental issues affecting most New Zealand estuaries.

1. Sedimentation

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand’s estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abraham 2005, Gibb and Cox 2009, Robertson and Stevens 2007a, 2010b, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sedimentation	Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
	Seagrass Area/Biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Mud Content	Grain size - estimates the % mud content of sediment.
	Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
	Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
	Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m ² replicate cores), and on the sediment surface (epifauna in 0.25m ² replicate quadrats).	

2. Eutrophication

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora*, *Ulva*, and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll <i>a</i> concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m ² replicate cores), and on the sediment surface (epifauna in 0.25m ² replicate quadrats).

Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural storm-water runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m ² replicate cores), and on the sediment surface (epifauna in 0.25m ² replicate quadrats).

5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
	Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
	Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity, and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, “risk indicator ratings” have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ and overseas estuary data and presented in the NZ estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
 1. Statistical measures be used to refine indicator ratings where information is lacking.
 2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
 3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

The indicators and condition thresholds or ratings used for the Whareama Estuary fine scale monitoring programme are summarised in Table 2, with detailed background notes explaining the use and justifications for each indicator presented in the NZ ETI (Robertson et al. 2016a and 2016b). The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of estuaries throughout NZ. Work to refine and document these relationships is ongoing.

Table 2. Summary of relevant estuary condition risk indicator ratings used in the present report.

INDICATOR	RISK RATING				Source
	Very Low	Low	Moderate	High	
Apparent Redox Potential Discontinuity (aRPD)	Unreliable	Unreliable	0.5-2cm	<0.5cm	Hargrave et al. (2008)
Redox Potential (mV) (representative sites at 1cm depth)	>+100	-50 to +100	-50 to -150	>-150	Robertson (in prep) Keeley et al. (2012)
Sediment Mud Content (%mud)	<5%	5-10%	>10-25%	>25%	NZ ETI (Robertson et al. 2016b)
Macroinvertebrate Enrichment Index (NZ AMBI)	0-1.0 None to minor stress on benthic fauna	>1.0-2.5 Minor to moderate stress on fauna	>2.5-4.0 Moderate to high stress on fauna.	>4.0 Persistent, high stress on benthic fauna	
Total Organic Carbon (TOC)	<0.5%	0.5-<1%	1-<2%	>2%	
Total Nitrogen (TN)	<250mg/kg	250-1000mg/kg	>1000-2000mg/kg	>2000mg/kg	

3. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary, but varies with estuary size) are selected and samples collected and analysed for the following variables.

- Salinity, Oxygenation (Redox Potential Discontinuity depth - aRPD or RPDmV), Grain size (% mud, sand, gravel).
- Organic Matter and Nutrients: Total organic carbon (TOC), Total nitrogen (TN), Total phosphorus (TP).
- Heavy metals and metalloids: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn) plus mercury (Hg) and arsenic (As).
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: these are measured in certain estuaries where a risk has been identified.

For the Whareama Estuary, two fine scale sampling sites (Figure 1), were selected in unvegetated, mid-low water habitat of the dominant substrate type (avoiding areas of significant vegetation and channels). At the upper site a 60m x 21m area, and at the lower site a 60m x 15m area, in the lower intertidal were marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and the following sampling undertaken:

Physical and chemical analyses.

- Within each plot, one random core was collected to a depth of at least 100mm, labelled and photographed alongside a ruler. Colour and texture were described and average apparent redox potential discontinuity (aRPD) depth recorded. In addition, at one plot redox potential was measured at 0, 1, 3, 6 and 10cm depths.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. All samples were kept in a chilly bin in the field.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details of lab methods and detection limits in Appendix 1):
 - * Grain size/Particle size distribution (% mud, sand, gravel).
 - * Nutrients - total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC).

Metals measured during the 2008-10 baseline identified a low risk and were consequently not measured in 2016.

- Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Epifauna (surface-dwelling animals).

Visually conspicuous epifauna within the sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species were identified and allocated a SACFOR abundance category based on percentage cover (Appendix 1, Table A), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Appendix 1, Table B). Species size determined both the quadrat size and SACFOR density rating applied, while photographs were taken and archived. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal/microalgal cover.

Infauna (animals within sediments).

- One randomly placed sediment core (130mm diameter (area = 0.0133m²) PVC tube) was taken from each of ten plots.
- The core tube was manually driven 150mm into the sediments, removed with the core intact, and inverted into a labelled plastic bag.
- Once all replicates had been collected at a site, the plastic bags were transported to a nearby source of seawater and the contents of the core were washed through a 0.5mm nylon mesh bag. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.
- The samples were sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).

2. Methods (continued)



Figure 1. Location of sediment plates and fine scale monitoring sites in Whareama Estuary.



4. RESULTS AND DISCUSSION

A summary of the results of the 26 January 2016 fine scale intertidal monitoring of Whareama Estuary, together with the 2008-10 baseline results, is presented in Table 3, with detailed results in Appendices 2 and 3. Analysis and discussion of the results are presented as two main steps; firstly, exploring the primary environmental variables that are most likely to be driving the ecological response in relation to the key issues of sedimentation, eutrophication, and toxicity, and secondly, investigating the biological response using the macroinvertebrate community.

Table 3. Summary of physical, chemical^a and macrofauna results (means) for 2 fine scale sites (2008-10 and 2016) in Whareama Estuary.

	Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	TS	Abundance	Richness
		cm	ppt	%				mg/kg										No./m ²
2008	Wha A	1.5	30	1.4	67.8	32.1	0.2	0.048	9.2	8.0	6.9	9.9	42.7	780	417	-	6,400	5.6
	Wha B	2.5	30	1.2	73.4	26.5	0.2	0.050	10.0	8.7	7.7	10.3	47.0	817	430	-	4,300	4.7
2009	Wha A	1.0	30	0.4	43.2	56.5	0.5	0.037	9.0	6.9	9.1	6.5	38.3	613	363	-	7,282	8.1
	Wha B	3.0	30	0.5	59.6	40.3	0.3	0.041	10.3	8.8	10.3	7.7	43.7	760	410	-	4,365	6.0
2010	Wha A	1.0	30	0.3	23.4	76.1	0.5	0.019	6.7	3.5	6.3	4.6	25.7	<500	343	-	7,567	8.2
	Wha B	1.0	30	0.6	64.9	35.1	< 0.1	0.044	9.2	7.4	9.1	7.1	40.0	677	363	-	4,710	5.8
2016	Wha A	2.0	29	0.49	52.6	47.2	0.2	-	-	-	-	-	-	600	400	1200	2,193	4.4
	Wha B	1.0	29	0.73	89.6	10.4	0.1	-	-	-	-	-	-	900	540	1500	2,909	4.7

PRIMARY ENVIRONMENTAL VARIABLES

The primary environmental variables that are most likely to be driving the ecological response in relation to the key issues of sedimentation, eutrophication and toxicity are as follows:

- For sedimentation or sediment muddiness, the variables are sediment mud content (often the primary controlling factor) and sedimentation rate.
- For eutrophication, the variables are organic matter (measured as TOC), nutrients and sediment aRPD depth (a qualitative measure of both available oxygen and the presence of eutrophication related toxicants such as ammonia and sulphide) (Dauer et al. 2000, Magni et al. 2009, Robertson 2013).
- The influence of non-eutrophication related toxicity is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs generally only assessed where inputs are likely, or metal concentrations are found to be elevated. For Whareama Estuary, baseline monitoring indicated low potential for toxicity so these indicators have not been assessed in the 2016 post baseline assessment.

The relationships between environmental factors and spatio-temporal influences in Whareama Estuary have been examined in two steps:

- One way ANOVA ($p=0.05$) was used to assess if there was a significant difference between means for any two years at each site, for each environmental factor.
- The ANOVA analysis was followed by a Tukey post hoc test to determine if there was a significant difference between 2016 data (i.e. "post baseline" data) and all of the baseline years 2008-10 and, if there was a significant difference between all of the years, whether the 2016 data was outside of the baseline data range. If the latter was true, then it was concluded that there had been a significant change between the baseline years and the post baseline year for that particular variable.

The results of these analyses are summarised in Table 4.

In summary, the results indicate a significant difference at the upstream Site B, between the baseline years (2008-10) and the post baseline year (2016), in all the key physical indicators of eutrophication and sedimentation, i.e. mud content, TOC, RPD, TN and TP. There was no significant difference detected at the downstream Site A.

4. Results and Discussion (continued)

Table 4. Summary of one way ANOVA (p=0.05) and Tukey post hoc tests for physical and chemical data for two fine scale sites in Whareama Estuary (2008-10 and 2016).

Site	Variable	ANOVA F and P value. Is there a significant difference between at least two of the years means? (p=0.05)	Post hoc test (Tukey P=0.05). Is there a significant difference between 2016 data and all of the baseline years 2008-2010? Also is 2016 data outside of the baseline data range?
Wha A	TOC*	F = 22.7, P < 0.001. Significant	Significant, but still within the range of baseline data.
	Mud	F = 89, P < 0.001. Significant	Significant, but still within the range of baseline data.
	RPD	F = 81, P < 0.001. Significant	Significant, but still within the range of baseline data.
	TN	F = 33, P < 0.001. Significant	Not Significant
	TP	F = 36, P < 0.001. Significant	Not Significant
Wha B	TOC*	F = 17, P < 0.001. Significant	Significant (increase)
	Mud	F = 105, P < 0.001. Significant	Significant (large increase)
	RPD	F = 41, P < 0.001. Significant	Significant (large reduction in depth of RPD)
	TN	F = 20, P < 0.001. Significant	Significant (small increase)
	TP	F = 107, P < 0.001. Significant	Significant (large increase)

* Note; TOC in 2008 was estimated based on TOC:TN relationship for Whareama as follows $TOC = 0.001(TN) - 0.1745$ ($R^2 = 0.854$)

SEDIMENT INDICATORS

Sediment Mud Content

Sediment mud content (i.e. % grain size <63µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments, unless naturally erosion-prone with few wetland filters (e.g. Whareama Estuary), are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island). In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >25% mud) in the primary sediment settlement areas e.g. where salinity driven flocculation occurs, or in areas that experience low energy tidal currents and waves (i.e. upper estuary intertidal margins and deeper subtidal basins). Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

The 2016 monitoring results showed Whareama Estuary had relatively high (48-93% mud) sediment mud contents (Table 3, Figure 2). Mud content was relatively variable across the 2008-2010 monitoring baseline at both sites (Figure 2). Site A (downstream) showed the largest variation, primarily because marine sands intermittently mix with catchment derived muds at this site. The 2016 Site A results were within the reported baseline data range, and not significantly different from the baseline (Table 4). The 2016 Site B (upstream) results were outside (above) the baseline range and significantly different from the baseline. These results indicate significantly increased muddiness at the upstream fine scale site. The overall high mud content fit the Band D rating, (which has been the same since monitoring began in 2008) and indicates the following ecological conditions are likely (Robertson et al. 2016b):

- Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity, especially if nutrient loads excessive.

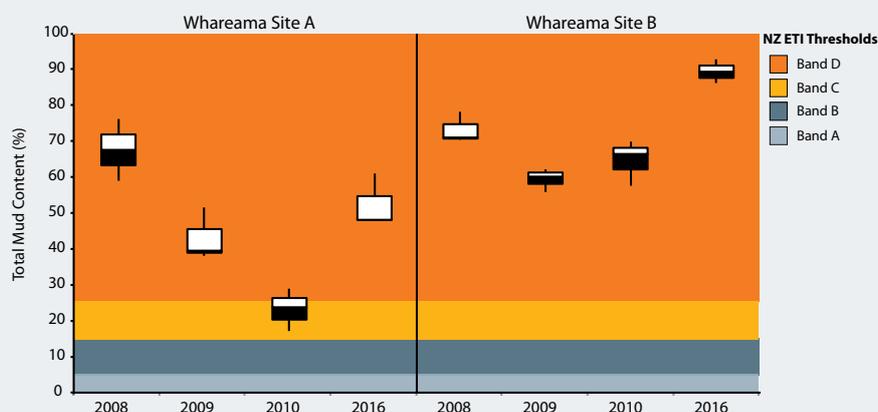


Figure 2. Mean mud content (median, interquartile range, total range, n=3) 2008, 2009, 2010 and 2016.

4. Results and Discussion (continued)

EUTROPHICATION INDICATORS

The primary variables indicating eutrophication impacts are sediment mud content, aRPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal cover.

Sediment Grain Size (% Mud)

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, the high mud contents at all sites indicate sediment oxygenation is likely to be relatively poor, given the associated lower porosities.

Apparent Redox Potential Discontinuity (aRPD)

The depth of the aRPD boundary indicates the extent of oxygenation within sediments. Currently, the condition rating for redox potential is under development (Robertson et al. 2016b) pending the results of a PhD study in which aRPD, and redox potential (measured with an ORP electrode and meter) are being assessed for a gradient eutrophication symptoms. Initial findings indicate that the recommended NZ estuary aRPD and redox potential thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Table 2 and Figure 3).

Figure 3 shows the aRPD depths for the two Whareama sampling sites for the period 2008-2010 and 2016, and redox potentials for the two sites (5 depths at each site) measured in 2016.

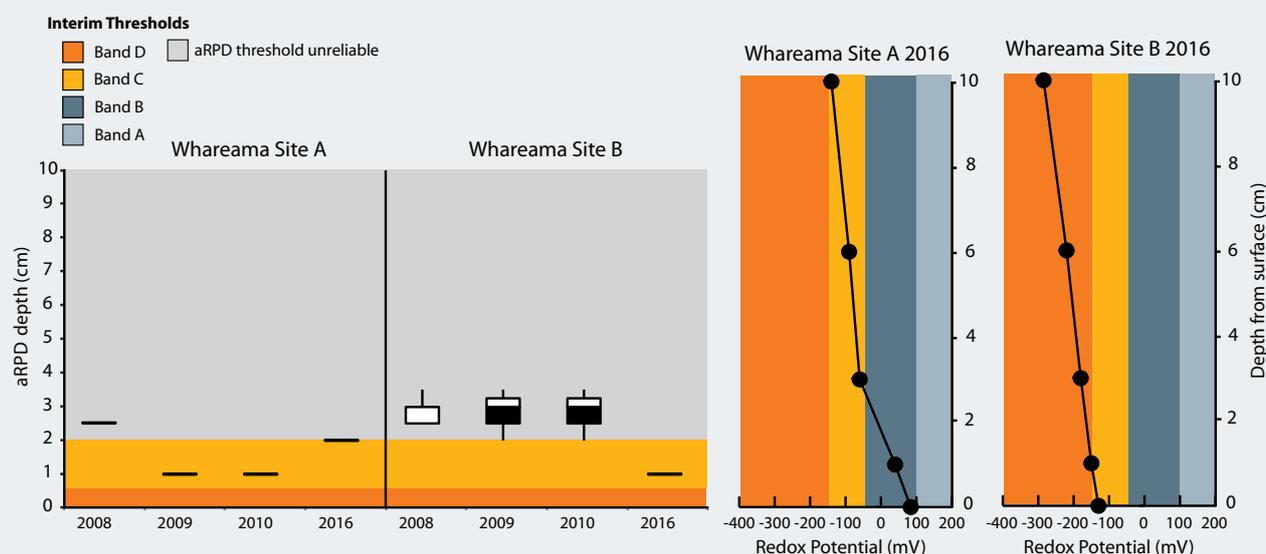


Figure 3. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3) 2008, 2009, 2010 and 2016, and redox potential (mV) at 5 depths in 2016.

The results show that in 2016, the aRPD depth was 2cm at the downstream Site A and shallower at 1cm at the upstream Site B, indicating a higher risk of ecological impacts at the upstream site, i.e. approaching the trigger of >0.5cm that indicates very poor conditions for macrofauna. The redox potential data for the sites in 2016 (Figure 3) confirmed the poor status for the upstream Site B, with Band D or anoxic conditions below 1cm depth, and more transitory conditions with no anoxia at the downstream Site A.

The data for all years (i.e. 2008-10 and 2016) showed that mean aRPD was similar between all baseline years (Table 4 ANOVA results), but the results for 2016 were significantly less than the baseline years (Tukey post-hoc test, $p=0.05$). These results indicate a significant decline in aRPD at the upstream fine scale Site B, but no significant change at the downstream Site A.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow aRPD, excessive algal growth, high NZ AMBI biotic coefficient (see the following macroinvertebrate condition section), then TN, TP and TOC concentrations provide a good indication that loadings are exceeding the assimilative capacity of the estuary.

4. Results and Discussion (continued)

However, a low TOC, TN, or TP concentration does not in itself indicate an absence of eutrophication symptoms. It may be that the estuary, or part of an estuary, may have reached a eutrophic condition and simply exhausted the available nutrient supply. Obviously, the latter case is likely to better respond to input load reduction than the former.

The 2008-10 and 2016 results for both sites showed TOC (<0.8%) and TN (<1000mg/kg) were in the “very low-low” risk indicator rating, while TP was unrated but relatively low at <600 mg/kg. The low ratings for TOC, TN and TP concentrations reflect the high potential of this tidal river estuary to flush nutrients to the ocean (Robertson et al 2016a) despite elevated nutrient loads from the catchment. The data for all years (i.e. 2008-10 and 2016) showed that mean TOC, TN and TP concentrations were significantly different between all baseline years at both sites (Table 4 ANOVA results). The 2016 TOC, TN and TP concentrations were found to be significantly greater than the baseline years for Site B (Tukey post-hoc test, $p=0.05$), with no significant difference detected at Site A. In addition, chlorophyll a concentration was measured in the water column adjacent to Site B (1.5-4.3ug/l), and macroalgal biomass on the sediments over the lower intertidal flats ($0g.m^{-2}$). Using the NZ ETI thresholds (Robertson et al. 2016b), each of these indicators rated in the “low” category (see Section 5 for overall eutrophication score).

Overall, the results for the sediment and eutrophication environmental variables indicate that the sediment conditions at the two sites over the period 2008-10 and 2016 have been variable, but included a significant change at Site B in 2016 to a more degraded state in relation to muddiness, sediment oxygenation, organic carbon and nutrients.

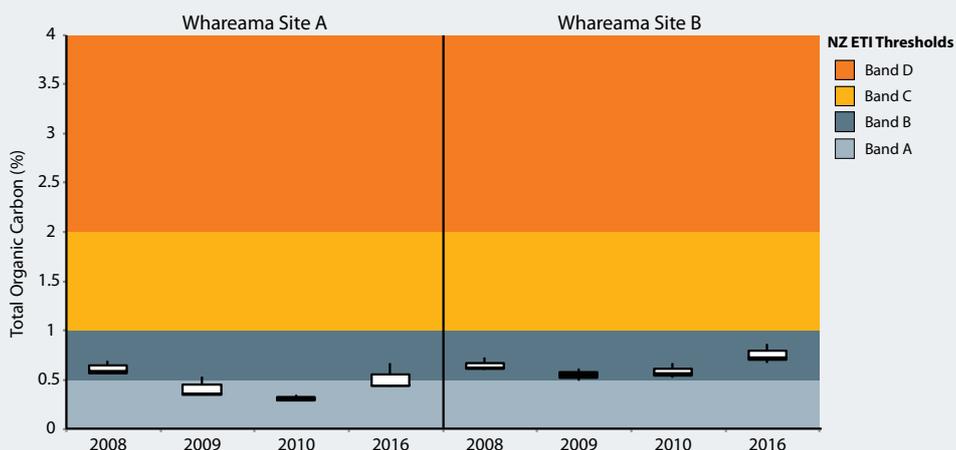


Figure 4. Mean total organic carbon (median, interquartile range, total range, n=3) 2008, 2009, 2010 and 2016.

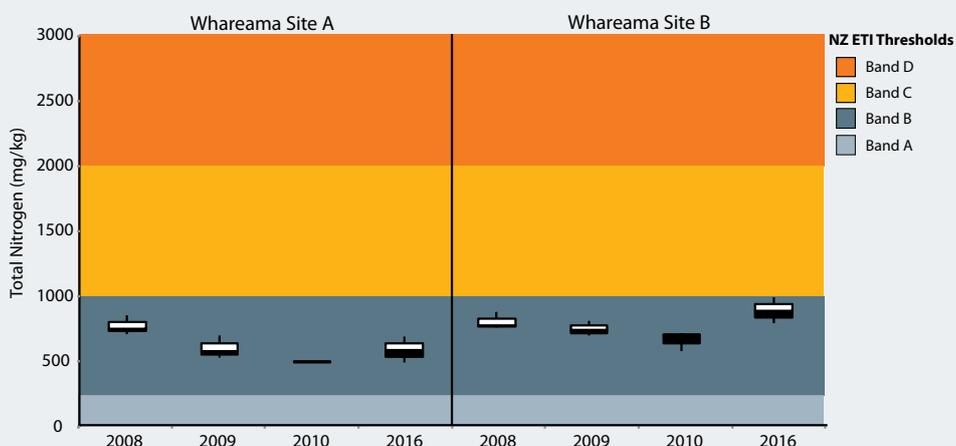


Figure 5. Mean total nitrogen (median, interquartile range, total range, n=3) 2008, 2009, 2010 and 2016.

4. Results and Discussion (continued)

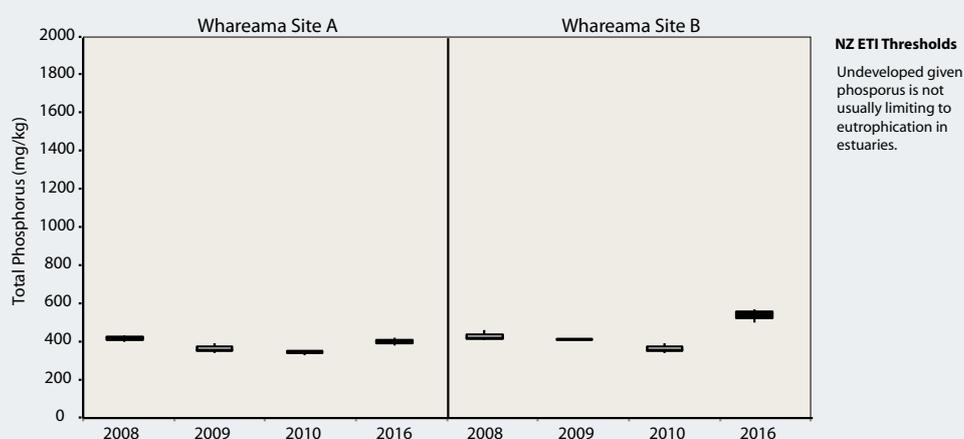


Figure 6. Mean total phosphorus (median, interquartile range, total range, n=3) 2008, 2009, 2010 and 2016.

BENTHIC MACROINVERTEBRATE COMMUNITY

Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong primary linkage to sediments and secondary linkage to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987, Robertson et al. 2016 in press). Because they integrate recent pollution history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macroinvertebrates to stressors in Whareama Estuary has been examined in four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among fine scale sites sampled in 2008, 2009, 2010 and 2016.
2. The BIO-ENV program in the PRIMER (v.6) package was used to evaluate and compare the relative importance of different environmental factors and their influence on the identified macrobenthic communities.
3. Assessment of species richness, abundance, diversity and major infauna groups.
4. Assessment of the response of the macroinvertebrate community to increasing mud and organic matter among fine scale sites sampled in 2008, 2009, 2010 and 2016, based on identified tolerance thresholds for NZ taxa (NZ AMBI, Robertson et al. 2015, Robertson et al. 2016 in press).

Macroinvertebrate Community Ordination

Principle Coordinates Analysis (PCO), based on between-year species abundance data collected in 2008-10 and 2016, showed that the invertebrate community at the two sites (Wha A and Wha B) in 2016 was significantly different from 2008, 2009 and 2010 (i.e. PERMANOVA $P < 0.0009$ for all sites, for between-year comparisons, Figure 7), indicating significant structural changes to the community over this period. Vector overlays of environmental variables (based on Pearson correlations) are also presented in order to provide preliminary exploratory information in relation to the potential influence of environmental factors at each of the four sites (a more detailed analysis is presented below).

Influence of Environmental Factors

Comparison of the faunal results with abiotic factors using the BIOENV procedure (correlates rank values of faunal similarities between sites with rank Euclidean distances based on environmental factors between sites) indicated that, although analyses of the faunal results showed differences between years at each of the four sites (Figure 9), the environmental variables provided only a partial explanation for these differences.

- At Wha A (i.e. the downstream site), no one or combination of the environmental factors measured was well correlated with the faunal results ($r=0.37$) (Table 5).
- At Wha B (i.e. the upstream site), TOC, mud, TN, TP and RPD were all identified as being moderately correlated with the macrobenthic faunal assemblages of the study area at different range of rank correlations ($r < 0.53-0.59$) (Table 5).

4. Results and Discussion (continued)

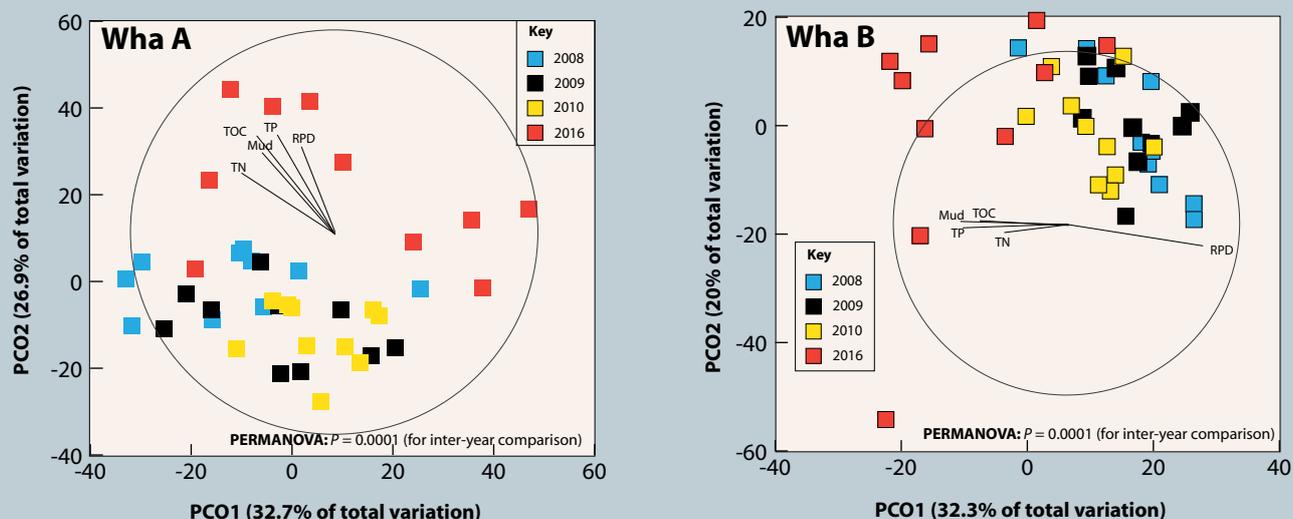


Figure 7. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at each site, Whareama Estuary, 2008, 2009, 2010 and 2016, and the environmental variables that possibly reflect the observed differences.

Figure 7 shows the relationship among samples in terms of similarity in macroinvertebrate community composition at Sites Wha A and Wha B, for the sampling period 2008, 2009, 2010 and 2016. The plot shows the 10 replicate samples for each site, and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves an unconstrained multivariate data analysis method, in this case principle coordinates analysis (PCO) using PERMANOVA version 1.0.5 (PRIMER-e v6.1.15). The analysis plots the site and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram(s) depends on how good a representation it is of actual dissimilarities (i.e. how much of the variation in the data matrix is explained by the first two PCO axes). For the present plots, the cumulative variation explained was >52-60% for all sites, indicating a relatively good representation of the abundance matrix.

PERMANOVA, testing for statistical significant differences in the invertebrate communities among samples, reflected highly significant ($P > 0.0001$) structural changes over the sampling period 2008, 2009, 2010 and 2016.

The environmental vector overlays, based on Pearson correlations, show preliminary exploratory information on the strength of environmental relationships with their length in relation to the circle boundary indicating the magnitude of the strength. In this case, the results indicate that the 2016 communities were likely separated from the 2008-2010 at each of the sites by mud, TOC, TN, TP and RPD.

Table 5. Combinations of factors with highest Spearman correlation coefficients between mean faunal and sediment abiotic similarity matrices (Primer's BIOENV routine) for each of two Whareama Estuary sites (2008-10 and 2016).

Site	Variables	Best Combination	2nd Combination	3rd Combination	4th Combination
Wha A	1	TOC 0.371	TP 0.285	TN 0.225	
	2	TOC, TN 0.358	TOC, TP 0.344	TOC, RPD 0.324	TOC, Mud 0.316
	3	TOC, TN, TP 0.353	TOC, Mud, TP 0.316	TN, TP 0.315	TOC, Mud, TN 0.310
	4	TOC, Mud, TN, TP 0.328			
Wha B	1	TP 0.579			
	2	TP, RPD 0.595	TN, TP, RPD 0.590	TN, RPD 0.531	
	3	TN, TP, RPD 0.590	TOC, TP, RPD 0.574	Mud, TN, TP 0.567	Mud, TP, RPD 0.548
	4	TOC, TN, TP, RPD 0.552			
	5	All 5 variables; 0.530			

4. Results and Discussion (continued)

Species Richness, Abundance, Diversity and Infauna Groups

The next step was to assess whether simple univariate whole community indices, i.e. species richness, abundance and diversity at each site (Figure 8), could explain the differences between years indicated by the PCO analysis. The data for all years (i.e. 2008-10 and 2016) showed that species richness, abundance and Shannon diversity significantly differed between at least two years for Wha A but not for Wha B (Table 6 ANOVA results). In addition, the Tukey post-hoc test ($p=0.05$) indicated a significant difference between the “post baseline” 2016 data and all of the “baseline” 2008-10 data at Wha A but no significant difference at Wha B. Another important point was that the number of taxa per core was very low at both sites, which is typical for estuaries where high mud contents predominate.

Figure 9 shows that although the community at all sites in 2008, 2009, 2010 and 2016 was dominated by polychaetes, bivalves and crustacea, there were obvious differences between years within most taxa groups. In particular, there was a clear reduction in bivalves at both sites in 2016.

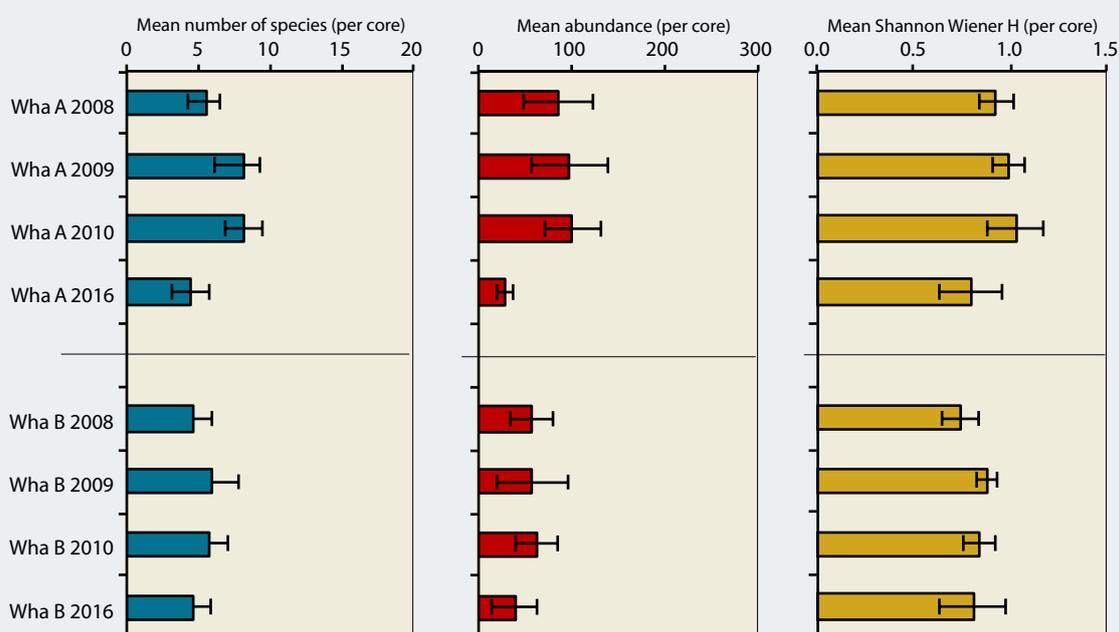


Figure 8. Mean number of species, abundance per core, and Shannon diversity index (\pm SE, $n=10$), Whareama Estuary, 2008, 2009, 2010 and 2016.

Table 6. Summary of one way ANOVA ($p=0.05$) and Tukey post hoc tests for macroinvertebrate data for two fine scale sites in Whareama Estuary (2008-10 and 2016).

Site	Variable	ANOVA F and P value. Is there a significant difference between at least two of the years means? ($p=0.05$)	Post hoc test (Tukey $P=0.05$). Is there a significant difference between 2016 data and all of the baseline years 2008-2010? Also is 2016 data outside of the baseline data range?
Wha A	Mean No Species	F = 21, P < 0.001. Significant	Significant, decline in species number
	Mean Abundance	F = 10.6, P < 0.001. Significant	Significant, decline in species abundance
	Shannon Wiener (H)	F = 6.8, P = 0.001. Significant	Significant, decline in H diversity
Wha B	Mean No Species	F = 2.31, P = 0.093. Not Significant	Not Significant
	Mean Abundance	F = 1.5, P = 0.23. Not Significant	Not Significant
	Shannon Wiener (H)	F = 2.8, P = 0.05. Not Significant	Not Significant

4. Results and Discussion (continued)

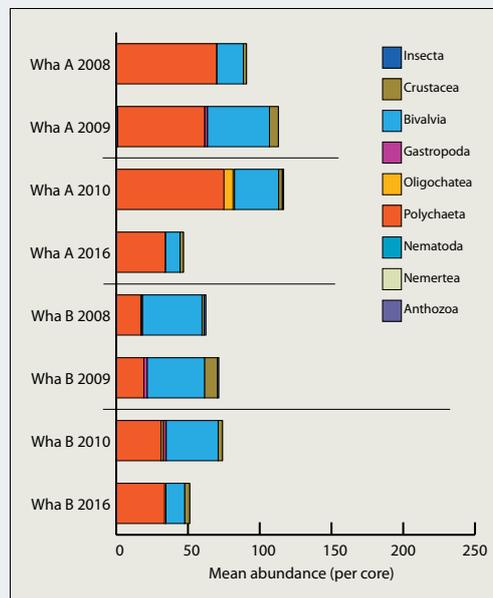


Figure 9. Mean abundance of major infauna groups (n=10), Whareama Estuary, 2008, 2009, 2010 and 2016.

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

In the Whareama Estuary, organic matter and mud are major determinants of the structure of the benthic invertebrate community. The previous section has already established the following:

- For the lower (more marine-dominated) Site Wha A, there were clear trends in the abundance, richness and diversity between the baseline years (2008-10), and post baseline 2016, but no trends for the upper Site B. In addition, the data showed that for both sites there were obvious differences between whole communities over this time.

The following analyses explore the macrofaunal results in greater detail using two steps as follows:

1. Mud and Organic Enrichment Index (NZ AMBI)

The first approach is undertaken by using the NZ AMBI (Robertson et al. 2016 in press), which is a benthic macroinvertebrate index, based on the international AMBI approach (Borja et al. 2000), that includes several modifications to strengthen its response to anthropogenic stressors, particularly mud and organic enrichment as follows:

- integration of previously established, quantitative ecological group classifications (Robertson et al. 2015),
- addition of a meaningful macrofaunal component (taxa richness), and
- derivation of classification- and breakpoint-based thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents). The latter was used to evaluate the applicability of existing AMBI condition bands, which were shown to accurately reflect benthic condition for the >100 intertidal NZ estuarine sites surveyed: 2% to ~30% mud reflected a 'normal' to 'impoverished' macrofauna community, or 'high' to 'good' status; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an 'unbalanced' to 'transitional to pollution' macrofauna community, or 'good' to 'moderate' status; and >3% to 4% TOC reflected a 'transitional to pollution' to 'polluted' macrofauna community, or 'moderate' to 'poor' status.

In addition, the AMBI was successfully validated (R^2 values >0.5 for mud, and >0.4 for total organic carbon) for use in shallow, intertidal dominated estuaries New Zealand-wide.

For the two fine scale sites in the Whareama Estuary, the NZ AMBI biotic coefficients ranged from 2.8-4.7, and were predominantly in the 'moderate' to 'poor' ecological condition category (i.e. a 'transitional' to 'impoverished' type community indicative of moderate levels of organic enrichment and high mud concentrations).

4. Results and Discussion (continued)

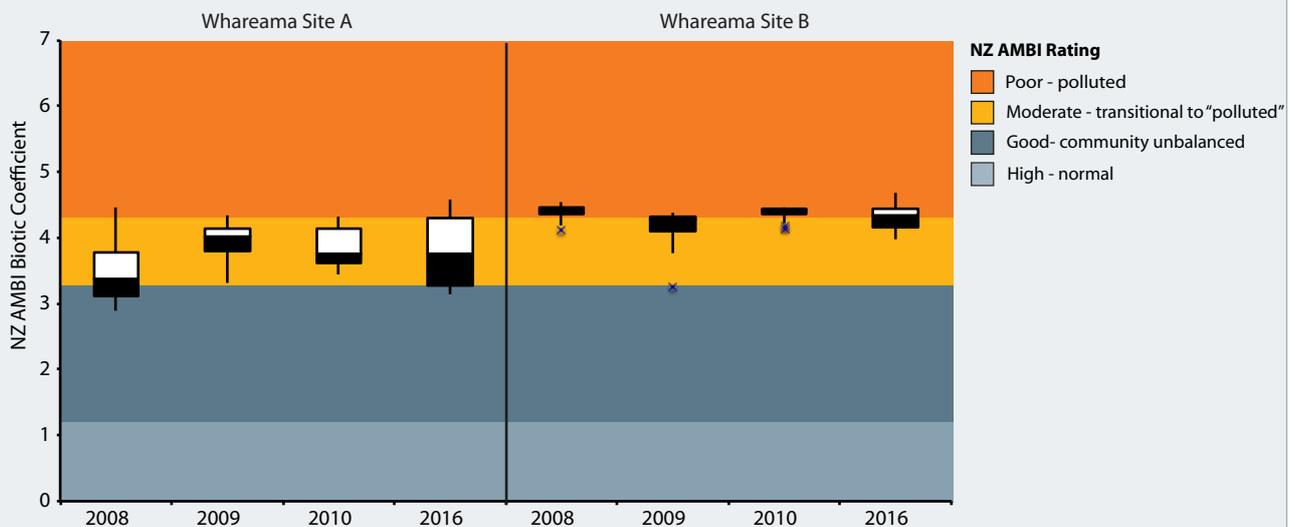


Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=3), Whareama Estuary, 2008-10 and 2016.

As expected, the muddier and more organically enriched upper Site Wha B, had consistently higher NZ AMBI biotic coefficients than the more marine influenced downstream site.

The data for all years (i.e. 2008-10 and 2016) showed that the NZ AMBI coefficient did not significantly differ between any of the years at either site (Table 7 ANOVA results), and therefore predictably the Tukey post-hoc test ($p=0.05$) indicated no significant difference between the “post baseline” 2016 data and all of the “baseline” 2008-10 data. These results indicate that, despite significant post-baseline differences in macroinvertebrate abundance, diversity and richness at Wha A, mud, TN and TOC contents at Wha B, and whole community structure (PCO/PERMANOVA, $P<0.05$), there was no corresponding significant difference in the abundance of individuals within each of the 5 taxa sensitivity groupings used in the NZ AMBI.

Table 7. Summary of one way ANOVA ($p=0.05$) and Tukey post hoc tests for macroinvertebrate NZ AMBI (Robertson et al, 2016) data for 2 fine scale sites (2008-10 and 2016) in Whareama Estuary.

Site	Variable	ANOVA F and P value. Is there a significant difference between at least two of the years means? ($p=0.05$)	Post hoc test (Tukey $P=0.05$). Is there a significant difference between 2016 data and all of the baseline years 2008-2010? Also is 2016 data outside of the baseline data range?
Wha A	NZ AMBI	F = 2.1, P = 0.118. Not Significant	Not Significant
Wha B	NZ AMBI	F = 0.12, P = 0.079. Not Significant	Not Significant

2. Individual Species Changes

To further explore possible reasons for why the PCO community analysis shows differences at each site between the baseline and post baseline years but the NZ AMBI does not, it is appropriate to look at changes in the abundance of individual species over time using:

- Univariate SIMPER (PRIMER-e) analysis (Table 8 and details in Appendix 2).
- Comparisons of direct plots of mean abundances of the 5 major mud/enrichment tolerance groupings (i.e. “very sensitive to organic enrichment” group through to “1st-order opportunistic species” group) (Figure 11).

4. Results and Discussion (continued)

The SIMPER analysis (summarised in Table 8) shows which taxa are causing the greatest contribution (including the magnitude of each taxon - see Appendix 2 for details) to the difference between macroinvertebrate community structure between baseline years 2008-10 and post baseline 2016 changes. The results indicate the following:

- At Site Wha B, the taxa responsible for the greatest difference (48-58% reduction in abundance between baseline years and 2016) was the small sedentary deposit feeding and mud tolerant bivalve, *Arthritica* sp., which lives greater than 2cm deep in the muds at both sites.
- At Site Wha A, the taxa responsible for the greatest difference (37-43% reduction in abundance between baseline years and 2016) varied between each of the baseline years (in 2008 *Heteromastus filiformis*, 2009 *Arthritica* sp., and 2010 *Scolecopelides benhami*). Like *Arthritica*, the small capitellid polychaete *Heteromastus filiformis* is a subsurface deposit feeder, whereas the ubiquitous spionid polychaete *Scolecopelides benhami* is a surface deposit feeder. All three taxa are tolerant of muds.

These results, which show significant changes in species level abundances between years at each site, are illustrated in Figure 11, which shows a comparison between years of the mean abundances of each of the 5 major mud/enrichment tolerance groupings (i.e. “very sensitive to organic enrichment” group through to “1st-order opportunistic species” group, Robertson 2013, Robertson et al. 2015 in press).

Table 8. Species causing the greatest contribution to the difference between macroinvertebrate community structure between baseline years 2008-10 and post baseline 2016 at Whareama Estuary sites (SIMPER Analysis, details see Appendix 2).

Wha A (downstream site)	Wha B (upstream site)
<i>Heteromastus filiformis</i> (responsible for greatest difference in 2008)	<i>Arthritica bifurca</i> (responsible for greatest difference in 2008, 2009, and 2010)
<i>Arthritica bifurca</i> (responsible for greatest difference in 2009)	<i>Scolecopelides benhami</i>
<i>Scolecopelides benhami</i> (responsible for greatest difference in 2010)	<i>Heteromastus filiformis</i>
<i>Prionospio</i> sp.	<i>Austrovenus stutchburyi</i>
<i>Arthritica bifurca</i>	<i>Tenagomysis</i> sp.
<i>Hemiplax hirtipes</i>	
Oligochaeta	

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for two long term intertidal monitoring sites within Whareama Estuary in 2016, and supported by the baseline 2008, 2009 and 2010 results, showed the following key findings:

Physical and Chemical Condition

- Sediment mud content in 2016 was at relatively high levels (48-93% mud). The data for all years (i.e. 2008-10 and 2016) indicated a significant increase in mud content at the upstream Site Wha B between the “post baseline” 2016 data and all of the “baseline” 2008-10 data, and no change for Site Wha A.
- Sediment oxygenation (aRPD) in 2016 was shallow (1cm) at Site Wha B and moderately shallow (2cm) at Wha A. Redox potential data for the sites in 2016 confirmed the poor status for the upstream Site B, with Band D or anoxic conditions below 1cm depth, and more transitory conditions with no anoxia at the downstream Site A. The data showed that mean aRPD at each site was similar between all baseline years (i.e. 2008-10). The results for 2016 showed no significant change at Site A (downstream site) compared to baseline measurements, but detected a significant decline in aRPD at Site B, the upstream fine scale site.
- The 2008-10 and 2016 results for both sites, showed TOC (<0.8%) and TN (<1000mg/kg) were in the “very low-low” risk indicator rating, while TP was unrated but relatively low at <600 mg/kg. The data also showed that the 2016 TOC, TN and TP concentrations were significantly greater than the baseline years for Site B but not for Site A.

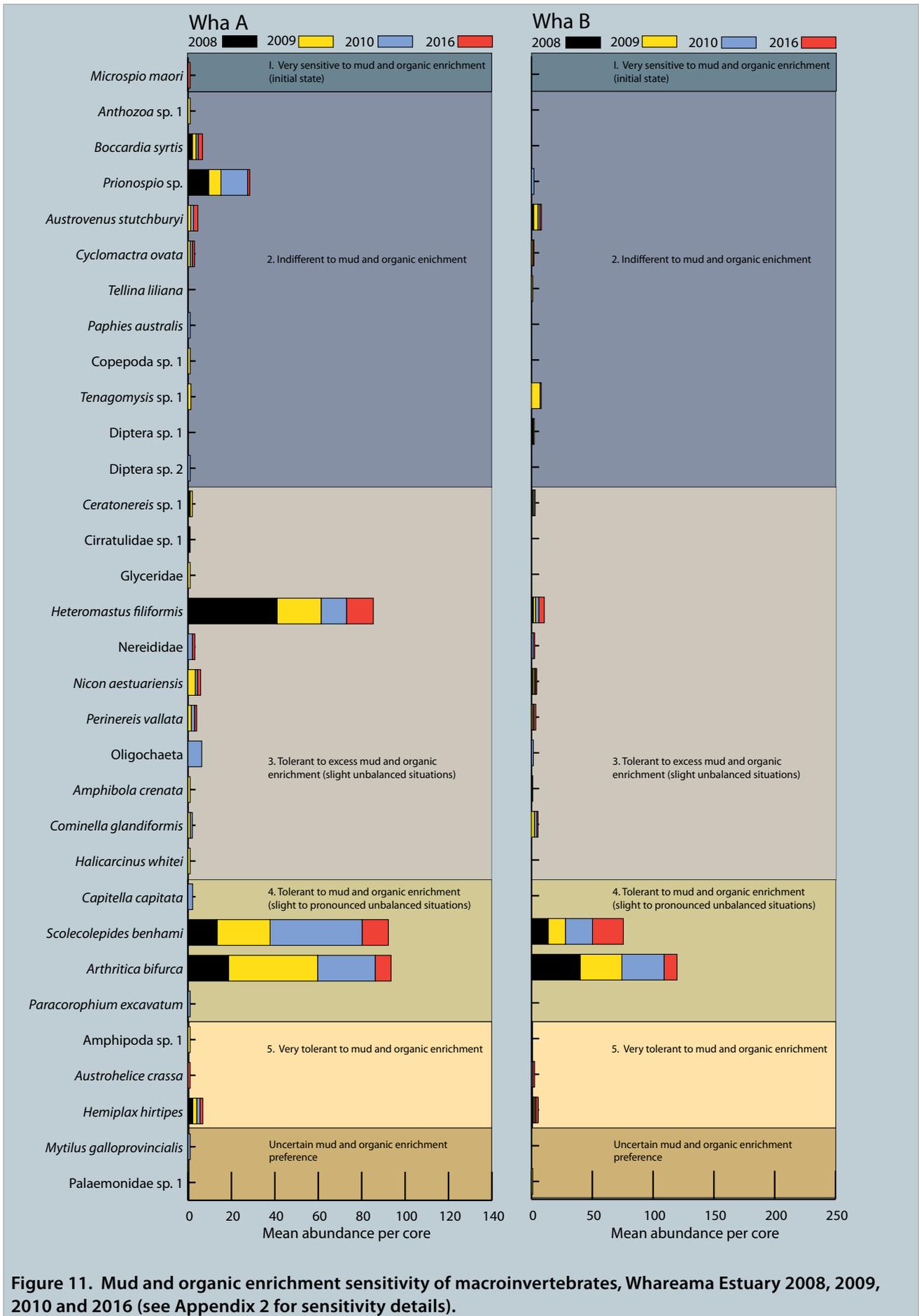


Figure 11. Mud and organic enrichment sensitivity of macroinvertebrates, Whareama Estuary 2008, 2009, 2010 and 2016 (see Appendix 2 for sensitivity details).

5. Summary and Conclusions (continued)

- Macroinvertebrates consisted of a mixed assemblage of species, dominated by mud tolerant polychaetes, bivalves and crustacea, spread across both sites between 2008-10 and 2016.
- The mud and organic enrichment biotic index (NZ AMBI) showed no significant change at either site from the 2008-10 “baseline” compared to the 2016 “post baseline”. However, statistical analysis of the macroinvertebrate results for the whole community (PCO analysis) showed significant differences in the communities at each site in 2016 compared to all of the “baseline” 2008-10 data and, at Wha A only, differences in taxa abundance, diversity and richness (no differences at Site Wha B).
- Comparison of the infauna results with abiotic factors indicated that at Wha B, TOC, mud, TN, TP and RPD were all moderately correlated with the macrofaunal community, but at Wha A (the downstream site), no single or combination of measured environmental factors was well correlated with infauna results.

Overall, the results for the sediment and eutrophication environmental variables monitored indicate variable sediment conditions at the two sites over the 2008-10 baseline period, with a significant change at Wha B in 2016 to a more degraded state in relation to muddiness, sediment oxygenation, organic carbon and nutrients. Statistical analysis of macrofaunal data indicates that this decline in condition at Wha B did not result in a corresponding shift in the mud and organic enrichment biotic index (i.e. NZ AMBI) rating, but did manifest as a significant difference in the general community structure. Such findings are typical of sites where mud content is consistently high (i.e. >25%) and taxa are dominated by those indifferent or tolerant to mud. In such situations, a shift to a higher mud content does not greatly alter the general abundance of individuals within sensitivity groupings, but can cause changes in the taxa contributing to those abundances. In addition, the eutrophication score using the NZ ETI approach (Robertson et al. 2016b) was estimated to be at a “low” level based on the results for macroalgae (very low), chlorophyll a (very low), RPD (low-moderate), TOC (low) and NZ AMBI (moderate).

In summary, the results showed that in 2016, as in the baseline years 2008-10, the fine scale intertidal sediments had high mud concentrations (>25% mud), low levels of organic enrichment, moderate to poor sediment oxygenation and a typical, mud-tolerant mixed macroinvertebrate community with low species richness.

In terms of changes since the 2008-2010 baseline, results showed that:

- mud, nutrient and organic carbon concentrations had increased at the upper muddier site
- significant small changes in the structure of the macroinvertebrate community were apparent at both sites but there was no change in the mud and organic enrichment biotic index (i.e. NZ AMBI) ratings at either site.

In terms of the condition of the wider estuary (i.e. outside the fine scale sites) in relation to the key estuary ecological issues of sedimentation, eutrophication, toxicity and habitat modification, the findings of this report need to be viewed in conjunction with other reports that document the condition of other susceptible habitats in the estuary, particularly reports related to broad scale habitat mapping and monitoring (both subtidal and intertidal - see Stevens and Robertson 2007) and sedimentation rate monitoring (Stevens and Robertson 2016).

6. MONITORING AND MANAGEMENT

MONITORING

Because Whareama Estuary is a large tidal river estuary with high ecological and human use values, situated in a developed and erosion-prone catchment, and vulnerable to excessive sedimentation and eutrophication, this estuary has been identified by GWRC as a priority for monitoring. As a consequence, it is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout the Wellington region. This monitoring programme primarily consists of long term fine scale and broad scale elements. The present report addresses the fine scale intertidal component of the long term programme. The recommendation for ongoing monitoring for this component is as follows.

Fine Scale Monitoring.

Fine scale intertidal sampling of sites Wha A and Wha B has now been undertaken for three baseline years (2008-10) and one post baseline year (2016). It is recommended that the next fine scale monitoring of intertidal sites (including sedimentation rate measures and macroalgal mapping) be undertaken at the next scheduled 5 yearly monitoring interval (2021).

6. Monitoring and Management (continued)

Sediment Monitoring. As a robust baseline has now been established, monitor sedimentation rate, RPD depth and grain size in conjunction with 5 yearly fine scale monitoring (see previous).

Broad Scale Habitat Mapping. It is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals. Although next scheduled for Jan-Feb 2017, any decision regarding ongoing monitoring should be linked to a review of catchment land management and reflect region-wide priorities.

If initiated, it is recommended that broad scale mapping be expanded to include subtidal areas, considering the predominantly subtidal nature of Whareama River Estuary (see following recommendation).

Intensive Investigation. In order to defensibly support effective management decisions, further intensive investigations are recommended as follows:

- Assess the full extent of current sedimentation within this 10-11km long estuary (broad scale subtidal mapping is recommended as the first step to identifying fine sediment deposition areas).
- Subsequently develop a defensible monitoring programme to assess whole estuary sedimentation rates and the success of catchment erosion control initiatives.
- Identify appropriate fine sediment load limits for the estuary, that recognise the erosion-prone nature of much of the catchment, its existing landuse and the limitations of the estuary to assimilate high sediment loads.

MANAGEMENT

Fine scale monitoring, in conjunction with sedimentation and broad scale assessments, provide valuable information on current estuary condition and trends over time, particularly in relation to the sedimentation issue in the estuary. The sediment indicators monitored in 2016 reinforce the 2008-10 fine scale monitoring results and annual sedimentation rate data (Stevens and Robertson 2016), about the increasing muddiness of this estuary. To defensibly address this issue, it is recommended that the following management be considered:

- Identify the likely source and magnitude of fine sediment (mud) inputs at a subcatchment scale under both natural state conditions (i.e. forested catchment with natural wetlands), and current land cover.
- Determine the relative input of sediment from dominant catchment land uses and apply relevant sediment guideline criteria for the estuary (e.g. under development ANZECC guidelines) to determine the magnitude of any changes required to maintain health estuary functioning. This is usually undertaken using existing catchment models such as CLUES, and extensions incorporating refined sediment yields for specific land use activities e.g. Green et al. (2014), and validated by monitoring sediment loads carried in rivers draining major subcatchments. In some situations, forensic techniques are applied to estuary sediments to assess historical sedimentation rates (e.g. isotope based ageing of sediment cores) and to identify the primary sources contributing to sediment accumulating in the estuary (e.g. compound specific stable isotope source tracking).
- Through stakeholder involvement, identify an appropriate “target” estuary condition and determine any catchment management changes needed to achieve the target.
- Using the results of the above investigations, and other appropriate monitoring data, identify sediment input load guideline criteria that will reduce fine sediment infilling to the target state, and develop a plan to achieve such targets. For example, ensuring Best Management Practices (BMPs) are being implemented within the catchment. This step may require additional detailed investigation of fine sediment sources, transport, deposition and export within the estuary, to provide underpinning information upon which to base management decisions.

However, given that the Wellington Regional Erosion Control Initiative (WRECI) established in 2009 has already identified ~50% of the catchment as erosion-prone with high rates of sediment discharge, and with many of these included under farm erosion planning initiatives, it is likely many of these steps have already been partially or completely addressed.

Overall, the step-wise approach presented above is intended to cost effectively address the source of sediment, identify management targets, and guide management to help ensure that the assimilative capacity of the estuary is not exceeded so that the estuary can flourish and provide sustainable human use and ecological values in the long term.

7. ACKNOWLEDGEMENTS

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Appendix 2. 2016 Detailed results (continued)

Whareama Sites (Wha A and Wha B) 2016. Infauna (numbers per 0.01327m² core) (Note NA = Not Assigned)

Group	Species	NZ AMBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
Anthozoa	Anthozoa sp. 1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	<i>Boccardia syrtis</i>	2	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0
	<i>Capitella capitata</i>	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Ceratonereis</i> sp. 1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cirratulidae sp. 1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Glyceridae	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Heteromastus filiformis</i>	3	0	0	5	1	26	13	6	12	14	22	0	0	1	2	2	1	2	1	5	22
	<i>Microsio maori</i>	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Nereididae	3	0	0	2	1	1	0	1	1	0	1	1	1	0	0	0	0	0	0	2	1
	<i>Nicon aestuariensis</i>	3	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
	<i>Perinereis vallata</i>	3	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	2	0	0	0	0
	<i>Prionospio</i> sp.	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Scolecopides benhami</i>	4	24	19	27	23	5	5	10	5	1	2	3	38	25	48	37	29	25	7	11	31	
Oligochaeta	Oligochaeta	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	<i>Amphibola crenata</i>	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Cominella glandiformis</i>	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Bivalvia	<i>Arthritica bifurca</i>	4	4	0	7	3	0	0	2	0	21	7	0	1	0	33	10	1	4	0	0	15
	<i>Austrovenus stutchburyi</i>	2	0	0	0	1	0	0	0	3	0	0	0	1	1	1	0	1	3	0	1	0
	<i>Cyclomactra ovata</i>	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	<i>Tellina liliana</i>	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Mytilus galloprovincialis</i>	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Paphies australis</i>	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crustacea	Amphipoda sp. 1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Copepoda sp. 1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Halicarcinus whitei</i>	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Austrohelice crassa</i>	5	1	0	0	0	0	0	0	0	0	0	1	3	1	0	0	1	0	0	0	0
	<i>Hemiplax hirtipes</i>	5	2	1	1	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	3	0
	Palaemonidae sp. 1	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Paracorophium excavatum</i>	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>Tenagomysis</i> sp. 1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Insecta	Diptera sp. 1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diptera sp. 2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total species in sample			5	2	5	5	3	3	5	4	5	7	5	5	5	4	3	6	6	3	6	4
Total individuals in sample			33	20	42	29	32	19	21	21	38	36	8	44	29	84	49	35	36	9	23	69

Epifauna results for Whareama Estuary, 26 January 2016.

Wha A	No epifauna present	
Wha B	<i>Amphibola crenata</i> (Mud snail)	6-10 per m2

Physical and chemical results for Whareama Estuary, 26 January 2016.

Site/Rep/Date	RPD	Salinity	TOC	Mud	Sand	Gravel	TN	TP	TS
	cm	ppt		%			mg/kg		
WHA A-01 26-Jan-2016	2	31.5	0.41	48.3	51.5	0.3	600	380	0.11
WHA A-02 26-Jan-2016	2	31.5	0.65	61.3	38.7	0.1	700	420	0.14
WHA A-03 26-Jan-2016	2	31.5	0.42	48.2	51.5	0.3	500	400	0.11
WHA B-01 26-Jan-2016	1	31	0.65	86.3	13.7	0.1	800	500	0.2
WHA B-02 26-Jan-2016	1	31	0.71	89.5	10.5	0.1	900	550	0.12
WHA B-03 26-Jan-2016	1	31	0.84	93	7	0.1	1000	570	0.13

Condition Thresholds (from NZ ETI (Robertson et al. 2016a and 2016b))

^a Band A Very Low Risk	NA	NA	<0.5	<5	NA	NA	<250	<100	NA
^a Band B Low Risk	NA	NA	0.5-1.0	5-15	NA	NA	250-1000	100-300	NA
^a Band C Moderate Risk	NA	NA	1-2	15-25	NA	NA	1000-2000	300-500	NA
^a Band D High Risk	0cm	NA	>2	>25	NA	NA	>2000	>500	NA

^a NZ ETI (Robertson et al. 2016a and 2016b)

Appendix 2. 2016 Detailed results (continued)

SIMPER (Primer analysis) - Whareama Estuary Site. Wha A

Groups 2008 & 2016 - Average dissimilarity = 63.13

	Group 2008	Group 2016				
Taxa	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
<i>Heteromastus filiformis</i>	41	9.9	27.05	1.69	42.85	42.85
<i>Arthritica bifurca</i>	18.7	4.4	12.88	1.13	20.4	63.25
<i>Scolecopides benhami</i>	13.4	12.1	10.6	1.16	16.8	80.05
<i>Prionospio</i> sp.	9.5	0.1	8.34	1.68	13.2	93.26

Groups 2009 & 2016 - Average dissimilarity = 63.99

	Group 2009	Group 2016				
Taxa	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
<i>Arthritica bifurca</i>	41	4.4	25.75	1.64	40.24	40.24
<i>Scolecopides benhami</i>	24.4	12.1	14.86	1.39	23.23	63.47
<i>Heteromastus filiformis</i>	20.3	9.9	13.28	1.19	20.76	84.23
<i>Prionospio</i> sp.	5.1	0.1	3.53	1.04	5.52	89.75
<i>Hemiplax hirtipes</i>	1.3	0.4	1.02	1.09	1.6	91.35

Groups 2010 & 2016 - Average dissimilarity = 65.44

	Group 2010	Group 2016				
Taxa	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
<i>Scolecopides benhami</i>	42.4	12.1	24.61	1.8	37.61	37.61
<i>Arthritica bifurca</i>	26.5	4.4	16.4	1.54	25.06	62.67
<i>Prionospio</i> sp.	12.3	0.1	9.14	1.4	13.97	76.65
<i>Heteromastus filiformis</i>	11.7	9.9	8.17	1.41	12.48	89.13
Oligochaeta	1.9	0	1.66	0.37	2.54	91.67

SIMPER (Primer analysis) - Whareama Estuary Site. Wha B

Groups 2008 & 2016 - Average dissimilarity = 62.76

	Group 2008	Group 2016				
Taxa	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
<i>Arthritica bifurca</i>	39.9	6.4	36.5	1.72	58.16	58.16
<i>Scolecopides benhami</i>	13.7	25.4	16.93	1.89	26.97	85.13
<i>Heteromastus filiformis</i>	0.6	3.6	3.26	0.62	5.2	90.33

Groups 2009 & 2016 - Average dissimilarity = 62.36

	Group 2009	Group 2016				
Taxa	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
<i>Arthritica bifurca</i>	34.4	6.4	29.96	1.81	48.04	48.04
<i>Scolecopides benhami</i>	14.2	25.4	17.7	1.77	28.39	76.43
<i>Heteromastus filiformis</i>	0.7	3.6	3.36	0.63	5.39	81.82
<i>Austrovenus stutchburyi</i>	2.5	0.8	2.99	0.46	4.8	86.62
<i>Tenagomysis</i> sp. 1	3.5	0	2.54	0.64	4.07	90.69

Groups 2010 & 2016 - Average dissimilarity = 52.62

	Group 2010	Group 2016				
Taxa	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
<i>Arthritica bifurca</i>	34.7	6.4	29.86	1.78	56.75	56.75
<i>Scolecopides benhami</i>	22.2	25.4	13.86	1.42	26.33	83.08
<i>Heteromastus filiformis</i>	1.9	3.6	3.36	0.72	6.39	89.47
<i>Austrovenus stutchburyi</i>	1.1	0.8	1.08	0.91	2.04	91.52

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		NZ AMBI Group	Details
Anthozoa	Anthozoa sp.#1	2	Unidentified anemone. An upright, stout, pale cream-coloured species.
	<i>Boccardia</i> sp.	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
Polychaeta	<i>Capitella</i> sp.	4	A blood red capitellid polychaete which is very pollution tolerant. Common in sulphide rich anoxic sediments. Commonly <i>Capitella capitata</i> .
	<i>Ceratonereis</i> sp.1	3	A nereid (ragworm) that has most likely been introduced to NZ.
	Cirratulidae sp.	3	Small subsurface deposit feeder, prefers sands, tolerant of slight to unbalanced situations.
	Glyceridae	3	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions and low salinity.
	<i>Heteromastus filiformis</i>	3	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	<i>Microspio maori</i>	1	A small, common, intertidal spionid. Can handle moderately enriched situations. Prey items for fish and birds.
	Nereididae	3	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete <i>Nereis diversicolor</i> is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of elevated sulphide concentrations.
	<i>Nicon aestuariensis</i>	3	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate mud content sediments.
	<i>Perinereis vallata</i>	3	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
	<i>Prionospio</i> sp.	2	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is <i>Prionospio aucklandica</i> which was renamed to <i>Aquilaspio aucklandica</i> . Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that is common at low water mark in harbours and estuaries.
	<i>Scolecopides benhami</i>	4	A spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. A close relative, the larger <i>Scolecopides freemani</i> occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary.
Oligochaeta	Oligochaetes	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.

Appendix 3. Infauna Characteristics (Continued)

Group and Species		NZ AMBI Group	Details
Gastropoda	<i>Amphibola crenata</i>	3	A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria.
	<i>Cominella glandiformis</i>	3	<i>Cominella glandiformis</i> , or the mud whelk or mud-flat whelk is a species of predatory sea snail, a marine gastropod mollusc in the family Buccinidae, the true whelks. Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds.
Bivalvia	<i>Arthritica bifurca</i>	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
	<i>Austrovenus stutchburyi</i>	2	Family Veneridae which is a family of bivalves which are very sensitive to organic enrichment. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects. Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community who are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).
	<i>Cyclomactra ovata</i>	2	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water.
	<i>Tellina liliana</i>	2	A deposit feeding wedge shell. This species lives at depths of 5–10cm in the sediment and uses a long inhalant siphon to feed on surface deposits and/or particles in the water column. Rarely found beneath the RPD layer. Adversely affected at elevated suspended sediment concentrations.
	<i>Mytilus galloprovincialis</i>	NA	<i>Mytilus galloprovincialis</i> (blue mussel) is an invasive species, is now common throughout NZ. It is dark blue or brown to almost black. Common in estuaries, often on rocks but also can be found on sands. It is known that <i>M. galloprovincialis</i> is able to outcompete and displace native mussels and become the dominant mussel species in certain localities. This is because it may grow faster than native mussels, be more tolerant to air exposure and have a reproductive output of between 20% and 200% greater than that of indigenous species.
	<i>Paphies australis</i>	2	The pipi is endemic to NZ. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7m.

Appendix 3. Infauna Characteristics (Continued)

Group and Species		NZ AMBI Group	Details
Crustacea	Amphipoda	Sp 1 = 5 Sp 2 = 4 Sp 3 = 1 Sp 4 = 2	Amphipoda is an order of malacostracan crustaceans with no carapace and generally with laterally compressed bodies. The name amphipoda means “different-footed”, and refers to the different forms of appendages, unlike isopods, where all the legs are alike. Of the 7,000 species, 5,500 are classified into one suborder, Gammaridea. The remainder are divided into two or three further suborders. Amphipods range in size from 1 to 340 millimetres (0.039 to 13 in) and are mostly detritivores or scavengers. They live in almost all aquatic environments. Amphipods are difficult to identify, due to their small size, and the fact that they must be dissected. As a result, ecological studies and environmental surveys often lump all amphipods together. Species sensitivities to muds and organic enrichment differs.
	<i>Austrohelice crassa</i>	5	Endemic, burrowing mud crab. <i>Helice crassa</i> concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
	Copepoda	2	Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat and they constitute the biggest source of protein in the oceans. Usually having six pairs of limbs on the thorax. The benthic group of copepods (Harpacticoida) have worm-shaped bodies.
	<i>Halicarcinus whitei</i>	3	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	<i>Hemiplax hirtipes</i>	5	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. Previously <i>Macrophthalmus hirtipes</i> .
	Palaemonidae	NA	Palaemonidae is a family of shrimp of the order Decapoda.
	<i>Paracorophium</i> spp.	4	A tube-dwelling corophioid amphipod. Two species in NZ, <i>Paracorophium excavatum</i> and <i>Paracorophium lucasi</i> and both are endemic to NZ. <i>P. lucasi</i> occurs on both sides of the North Island, but also in the Nelson area of the South Island. <i>P. excavatum</i> has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites like Whareama A and B (30-70% mud) we get very few.
	<i>Tenagomysis</i> sp. 1	2	A mysid shrimp species.
	Diptera sp.	2	Fly or midge larvae - species unknown.

* NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al. (2015).

1 = highly sensitive to (intolerant of) mud and organic enrichment;

2 = sensitive to mud and organic enrichment;

3 = widely tolerant of mud and organic enrichment;

4 = prefers muddy, organic enriched sediments;

5 = very strong preference for muddy, organic enriched sediments.