Wriggle coastalmanagement

Whareama Estuary

Fine Scale Monitoring 2009/10

Prepared for **Greater Wellington Regional Council**
May 2010

Cover Photo: Whareama Estuary - Site WhaB - upper estuary 22 January 2010. Inside Photo: Overview of Site WhaB 22 January 2010.

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By

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WHAREAMA ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the first three years (2008-2010) of fine scale monitoring 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. An outline of the process used for estuary monitoring and management in GWRC is presented in the margin flow diagram, and the following table summarises fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

FINE SCALE MONITORING RESULTS

- Sediment Oxygenation: Redox Potential Discontinuity (RPD) was 1cm deep indicating "poor" oxygenation.
- The benthic invertebrate organic enrichment rating indicated a slightly polluted or "good" condition.
- The indicator of organic enrichment (Total Organic Carbon) was at low concentrations in all years.
- The benthic invertebrate mud tolerance rating was "moderate" - dominated by mud tolerant species.
- Nutrient enrichment indicators (TN and TP) were at low-moderate concentrations in all years.
- Sediment plates indicate high sedimentation at key sites since 2008.
- Mud dominated the sediments in 2008 but sand content increased at the lower site (A) in 2010.
- Heavy metals were well below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity).
- Macroalgal cover was low at most sites.

CONDITION RATINGS

	Site A			Site B		
	2008	2009	2010	2008	2009	2010
Sedimentation Rate	High			High		
Invertebrates (Mud tolerance)	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
RPD Profile (Sediment oxygenation)	Fair	Poor	Poor	Fair	Fair	Poor
TOC (Total Organic Carbon)	Good	Very Good	Very Good	Good	Very Good	Very Good
Total Nitrogen (TN)	Good	Good	Very Good	Good	Good	Good
Total Phosphorus (TP)	Good	Good	Good	Good	Good	Good
Metals (Cd, Cu, Cr, Pb, Zn)	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Metals (Ni)	Good	Good	Good	Good	Good	Good
DDT	Very Good			Very Good		
Invertebrates (Organic enrichment)	Moderate	Moderate	Good	Good	Good	Good

ESTUARY CONDITION AND ISSUES

Overall, the first three years of baseline monitoring show that the dominant intertidal habitat (i.e. unvegetated tidal-flat) in the Whareama Estuary was generally in a good to fair condition. The presence of elevated mud contents, high sedimentation rates, poorly oxygenated sediments and a benthic invertebrate community dominated by high numbers of a few mud and organic enrichment tolerant species, suggests that the estuary is currently experiencing problems - particularly related to excessive muddiness and poor sediment oxygenation.

RECOMMENDED MONITORING AND MANAGEMENT

Baseline conditions have now been clearly established. The results indicate problems associated with excessive muddiness and a "poor RPD" rating. In order to address these issues it is recommended that monitoring of sedimentation rate, RPD depth and grain size be undertaken annually until the situation improves and that a "complete" fine scale monitoring (including sedimentation rate and macroalgal mapping) be undertaken at 5 yearly intervals (next scheduled for Jan-Feb 2015), and broad scale habitat mapping at 10 yearly intervals (next scheduled for 2016-17).

The fine scale monitoring results reinforce the need for management of fine sediment and nutrient sources entering the estuary. It is recommended that sources of elevated loads in the catchment be identified and management be undertaken to minimise their adverse effects on estuary uses and values.

Whareama Estuary

Vulnerability Assessment
Identifies issues and recommends monitoring and management. Completed in 2007a (Robertson and Stevens 2007)

Whareama Estuary Issues
Moderate eutrophication
Excessive sedimentation
Habitat Loss (terrestrial margin)

Monitoring

Broad Scale Mapping
Sediment type
Saltmarsh
Seagrass
Macroalgae
Land margin

5 -10 yearly
First undertaken in 2007. Next due 2017. Macroalgae not yet undertaken.

Fine Scale Monitoring
Grain size, RPD, Organic Content Nutrients, Metals, Invertebrates, Macroalgae, Sedimentation,

3yr Baseline then 5 yearly
Baseline complete. Next survey 2015.

Condition Ratings
Area soft mud, Area saltmarsh, Area seagrass, Area terrestrial margin, RPD depth, Benthic Community, Organic content, N and P, Toxicity, Sedimentation rate.

Other Information
Previous reports, Observations, Expert opinion

ESTUARY CONDITION
Moderate Eutrophication
Excessive Sedimentation
Low Toxicity
Habitat Degraded (terrestrial margin)

Recommended Management
- Limit intensive landuse.
- Set nutrient, sediment guidelines.
- Margin vegetation enhancement..
- Manage weeds and pests.

1. INTRODUCTION

OVERVIEW

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. Recently, Greater Wellington Regional Council (GWRC) undertook vulnerability assessments of its region's coastlines to establish priorities for a long-term monitoring programme for the region (Robertson and Stevens 2007a, 2007b and 2007c). These assessments identified the following estuaries as immediate priorities for monitoring: Porirua Harbour, Whareama Estuary, Lake Onoke, Hutt Estuary and Waikanae Estuary.

GWRC began monitoring Whareama Estuary in January 2008, with the work being undertaken by Wriggle Coastal Management using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002), plus recent extensions.

The Whareama Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** of the estuary to major issues (Table 1) and appropriate monitoring design. This component has been completed for Whareama Estuary and is reported on in Robertson and Stevens (2007a).
2. **Broad scale habitat mapping** (EMP approach). This component, which documents the key habitats within each estuary and changes to these habitats over time, has been completed for the Whareama Estuary (Robertson and Stevens 2007a).
3. **Fine Scale Monitoring** (EMP approach). Monitoring of physical, chemical and biological indicators (Table 2) including sedimentation plate monitoring. This component, which provides detailed information on the condition of the Whareama Estuary, was first undertaken in 2008 and was repeated in 2009 (Robertson and Stevens 2008, 2009). The third year of monitoring (January 2010) is the subject of the current report.

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.

1. Introduction (Continued)

Table 1. Summary of the major issues affecting most NZ estuaries.

Major Estuary Issues	
Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. 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. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, 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. 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.
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. 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. 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. Diseases linked to pathogens include gastroenteritis, salmonellosis, hepatitis A, and noroviruses.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to estuaries through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Loss	Estuaries have many different types of habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), 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 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 commonplace with the major causes cited as 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.

Table 2. Summary of the broad and fine scale EMP indicators.

Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Eutrophication	Nuisance Macroalgal Cover	Broad scale mapping - estimates the change in the area of nuisance macroalgal growth (e.g. sea lettuce (*Ulva*), *Gracilaria* and *Enteromorpha*) over time.
Eutrophication	Organic and Nutrient Enrichment	Chemical analysis of total nitrogen, total phosphorus, and total organic carbon in replicate samples from the upper 2cm of sediment.
Eutrophication	Redox Profile	Measurement of depth of redox potential discontinuity profile (RPD) in sediment estimates likely presence of deoxygenated, reducing conditions.
Toxins	Contamination in Bottom Sediments	Chemical analysis of indicator metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) in replicate samples from the upper 2cm of sediment.
Toxins, Eutrophication, Sedimentation	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).
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Habitat Loss	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
Habitat Loss	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.

2. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the EMP (Robertson et al. 2002) and provides detailed information on the condition of the estuary. Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary) are selected and samples collected and analysed for physical, chemical and biological variables.

For the Whareama Estuary, two fine scale sampling sites (Figure 1, Appendix 1), were selected in mid-low water mudflats (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 and photographed alongside a ruler and a corresponding label. Colour and texture were described and average redox potential discontinuity (RPD) depth recorded.
- At each site, three samples (each a composite from four plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. All samples were kept in a chillybin in the field.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details in Appendix 1):
    * Grain size/Particle size distribution (% mud, sand, gravel).
    * Nutrients- total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC).
    * Trace metal contaminants (total recoverable Cd, Cr, Cu, Ni, Pb, Zn). Analyses were based on whole (sub 2mm) sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results are 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)

Epifauna were assessed from one random 0.25m^2 quadrat within each of ten plots. All animals observed on the sediment surface were identified and counted, and any visible microalgal mat development noted. The species, abundance and related descriptive information were recorded on specifically designed waterproof field sheets containing a checklist of expected species. Photographs of quadrats were taken and archived for future reference.

Infauna (animals within sediments)

- One sediment core was taken from each of ten sampling locations using a 130mm diameter (area = 0.0133m^2) PVC tube.
- 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 commercial laboratory (Gary Stephenson, Coastal Marine Ecology Consultants, see Appendix 1) for sieving, counting and identification. Each core was washed through a 0.5mm nylon mesh bag or sieve with the infauna retained and preserved in 70% isopropyl alcohol.

2. Methods (Continued)

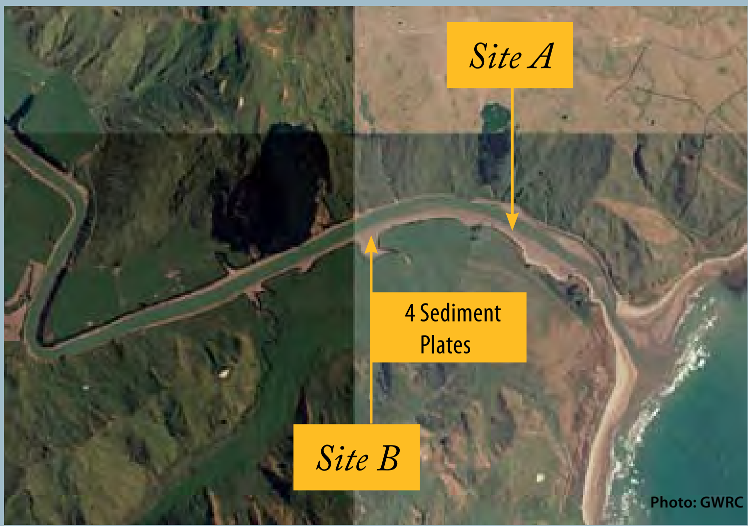


Figure 1. Location of sediment plates and fine scale monitoring sites in Whareama Estuary.

Sedimentation Plate Deployment

Determining the sedimentation rate from now and into the future involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried, levelled, and the elevation measured, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. Locations (Figure 1) and methods for deployment are presented in the 2008 report (Robertson and Stevens 2008). In the future, these depths will be measured every 1-5 years and, over the long term, will provide a measure of rate of sedimentation in representative parts of the estuary.

CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented below) have been proposed for Whareama Estuary (based on the ratings developed for Southland's estuaries - e.g. Robertson & Stevens 2006). The ratings are based on a review of estuary monitoring data, guideline criteria, and expert opinion. They are designed to be used in combination with each other (usually involving expert input) when evaluating overall estuary condition and deciding on appropriate management. The condition ratings include an "early warning trigger" to highlight rapid or unexpected change, and each rating has a recommended monitoring and management response. In most cases initial management is to further assess an issue and consider what response actions may be appropriate (e.g. develop an Evaluation and Response Plan - ERP).

Total Nitrogen

In shallow estuaries like Whareama, the sediment compartment is often the largest nutrient pool in the system, and nitrogen exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL NITROGEN CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<500mg/kg	Monitor at 5 year intervals after baseline established
Good	500-2000mg/kg	Monitor at 5 year intervals after baseline established
Fair	2000-4000mg/kg	Monitor at 2 year intervals and manage source
Poor	>4000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Total Phosphorus

In shallow estuaries like Whareama the sediment compartment is often the largest nutrient pool in the system, and phosphorus exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL PHOSPHORUS CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<200mg/kg	Monitor at 5 year intervals after baseline established
Good	200-500mg/kg	Monitor at 5 year intervals after baseline established
Fair	500-1000mg/kg	Monitor at 2 year intervals and manage source
Poor	>1000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

2. Methods (Continued)

Total Organic Carbon

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, release of excessive nutrients, and adverse impacts to biota - all symptoms of eutrophication.

TOTAL ORGANIC CARBON CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<1%	Monitor at 5 year intervals after baseline established
Good	1-2%	Monitor at 5 year intervals after baseline established
Fair	2-5%	Monitor at 2 year intervals and manage source
Poor	>5%	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Benthic Community Index (Organic Enrichment)

Soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). The AZTI (AZTI-Tecnalia Marine Research Division, Spain) Marine Benthic Index (AMBI) (Borja et al. 2000) has been verified successfully in relation to a large set of environmental impact sources (Borja, 2005) and geographical areas (in both northern and southern hemispheres) and so is used here. However, although the AMBI is particularly useful in detecting temporal and spatial impact gradients care must be taken in its interpretation in some situations. In particular, its robustness can be reduced when only a very low number of taxa (1–3) and/or individuals (<3 per replicate) are found in a sample. The same can occur when studying low-salinity locations (e.g. the inner parts of estuaries), some naturally-stressed locations (e.g. naturally organic matter enriched bottoms; *Zostera* beds producing dead leaves; etc.), or some particular impacts (e.g. sand extraction, for some locations under dredged sediment dumping, or some physical impacts, such as fish trawling).

The equation to calculate the AMBI Biotic Coefficient (BC) is as follows;

$$BC = \{(0 \times \%GI) + (1.5 \times \%GII) + (3 \times \%GIII) + (4.5 \times \%GIV) + (6 \times \%GV)\}/100.$$

The characteristics of the above-mentioned ecological groups (GI, GII, GIII, GIV and GV) are summarised in Appendix 3.

BENTHIC COMMUNITY ORGANIC ENRICHMENT RATING			
ECOLOGICAL RATING	DEFINITION	BC	RECOMMENDED RESPONSE
High	Unpolluted	0-1.2	Monitor at 5 year intervals after baseline established
Good	Slightly polluted	1.2-3.3	Monitor 5 yearly after baseline established
Moderate	Moderately polluted	3.3-5.0	Monitor 5 yearly after baseline est. Initiate ERP
Poor	Heavily polluted	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Bad	Azoic (devoid of life)	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend to slightly polluted	>1.2	Initiate Evaluation and Response Plan

Benthic Community Index (Mud Tolerance)

Soft sediment macrofauna can also be used to represent benthic community health in relation to the extent of mud tolerant organisms compared with those that prefer sands. Using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) a "mud tolerance" rating has been developed similar to the "organic enrichment" rating identified above.

The equation to calculate the Mud Tolerance Biotic Coefficient (MTBC) is as follows;

$$MTBC = \{(0 \times \%SS) + (1.5 \times \%S) + (3 \times \%I) + (4.5 \times \%M) + (6 \times \%MM\}/100.$$

The characteristics of the above-mentioned mud tolerance groups (SS, S, I, M and MM) are summarised in Appendix 3.

BENTHIC COMMUNITY MUD TOLERANCE RATING			
MUD TOLERANCE RATING	DEFINITION	MTBC	RECOMMENDED RESPONSE
Very Low	Strong sand preference dominant	0-1.2	Monitor at 5 year intervals after baseline established
Low	Sand preference dominant	1.2-3.3	Monitor 5 yearly after baseline established
Moderate	Some mud preference	3.3-5.0	Monitor 5 yearly after baseline established. Initiate ERP
High	Mud preferred	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very High	Strong mud preference	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Some mud preference	>1.2	Initiate Evaluation and Response Plan

2. Methods (Continued)

Metals

Heavy metals provide a low-cost preliminary assessment of toxic contamination in sediments, and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for the presence of other major contaminant classes: pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

METALS CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<0.2 x ISQG-Low	Monitor at 5 year intervals after baseline established
Good	<ISQG-Low	Monitor at 5 year intervals after baseline established
Fair	<ISQG-High but >ISQG-Low	Monitor at 2 year intervals and manage source
Poor	>ISQG-High	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Sedimentation Rate

Elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse, and indicate where changes in land use management may be needed.

SEDIMENTATION RATE CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Low	0-1mm/yr (typical pre-European rate)	Monitor at 5 year intervals after baseline established
Low	1-2mm/yr	Monitor at 5 year intervals after baseline established
Moderate	2-5mm/yr	Monitor at 5 year intervals after baseline established
High	5-10mm/yr	Monitor yearly. Initiate ERP
Very High	>10mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

Redox Potential Discontinuity

The RPD is the grey layer between the oxygenated yellow-brown sediments near the surface and the deeper anoxic black sediments. It is an effective ecological barrier for most but not all sediment-dwelling species. A rising RPD will force most macrofauna towards the sediment surface to where oxygen is available. The depth of the RPD layer is a critical estuary condition indicator in that it provides a measure of whether nutrient enrichment in the estuary exceeds levels causing nuisance anoxic conditions in the surface sediments. The majority of the other indicators (e.g. macroalgal blooms, soft muds, sediment organic carbon, TP, and TN) are less critical, in that they can be elevated, but not necessarily causing sediment anoxia and adverse impacts on aquatic life. Knowing if the surface sediments are moving towards anoxia (i.e. RPD close to the surface) is important for two main reasons:

1. As the RPD layer gets close to the surface, a "tipping point" is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and to worsen sediment conditions.
2. Anoxic sediments contain toxic sulphides and very little aquatic life.

The tendency for sediments to become anoxic is much greater if the sediments are muddy. In sandy porous sediments, the RPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1 cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

RPD CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	>10cm depth below surface	Monitor at 5 year intervals after baseline established
Good	3-10cm depth below sediment surface	Monitor at 5 year intervals after baseline established
Fair	1-3cm depth below sediment surface	Monitor at 5 year intervals. Initiate ERP
Poor	<1cm depth below sediment surface	Monitor at 2 year intervals. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

3. RESULTS AND DISCUSSION

OUTLINE

A summary of the results of the 22 January 2010 fine scale monitoring of Whareama Estuary is presented in Table 3, with detailed results presented in Appendices 2 and 3. The results and discussion section is divided into three subsections based on the key estuary problems that the fine scale monitoring is addressing: sedimentation, eutrophication, and toxicity. Within each subsection, the results for each of the relevant fine scale indicators are presented. A summary of the condition ratings for each of the two sites is presented in the accompanying figures.

Table 3. Physical, chemical and macrofauna results (means) for Whareama Estuary (2008-2010).

	Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. of Species
		cm	ppt	%				mg/kg								No./m²	Mean No./core
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

SEDIMENTATION

Soil erosion is a major issue in New Zealand and the resulting suspended sediment impacts are of particular concern in estuaries because they act as a sink for fine sediments or muds. Sediments containing high mud content (i.e. around 30% with a grain size <63µm) are now typical in NZ estuaries that drain developed catchments. In such mud-impacted estuaries, the muds generally occur in the areas that experience low energy tidal currents and waves [i.e. the intertidal margins of the upper reaches of estuaries (e.g. Waikanae Estuary), and in the deeper subtidal areas at the mouth of estuaries (e.g. Hutt Estuary)] (Figure 2). In contrast, the main intertidal flats of developed estuaries (e.g. Porirua Harbour) are usually characterised by sandy sediments reflecting their exposure to wind-wave disturbance and are hence low in mud content (2-10% mud). In estuaries where there are no large intertidal flats, then the presence of mud along the narrow channel banks in the lower estuary can also be elevated (e.g. Hutt Estuary and Whareama Estuary). In estuaries with undeveloped catchments the mud content is extremely low (e.g. Freshwater Estuary, Stewart Island where the mud content is <1%).

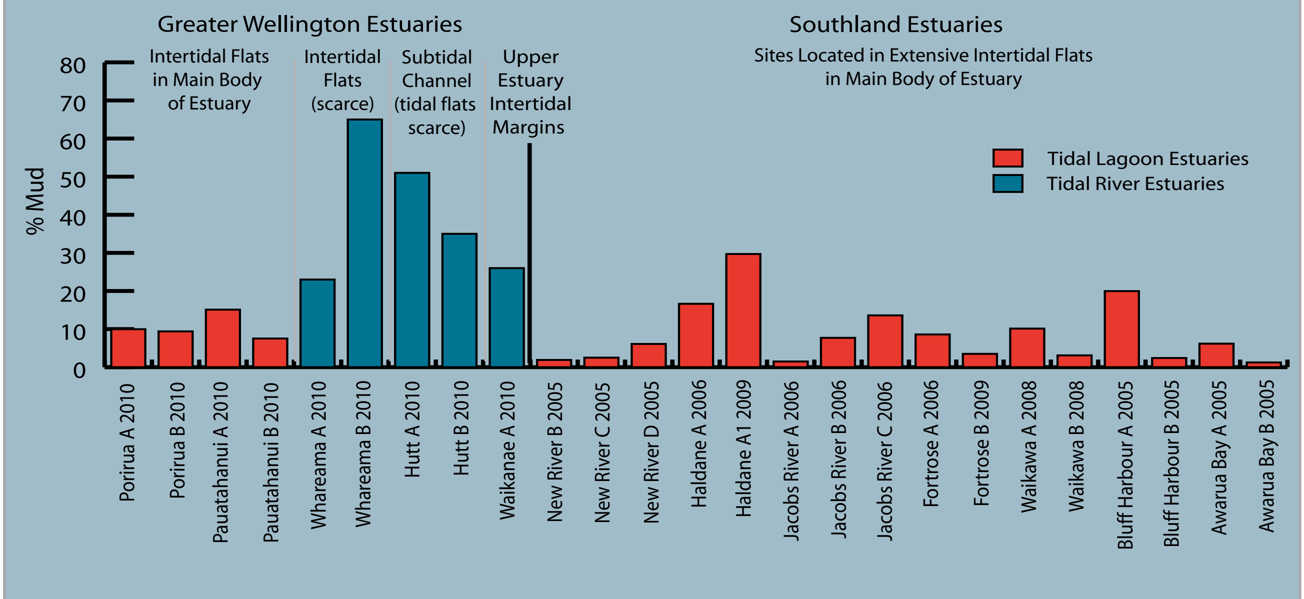


Figure 2. Percentage of mud at fine scale sites in NZ estuaries. Location of fine scale sites within each estuary type are also shown.

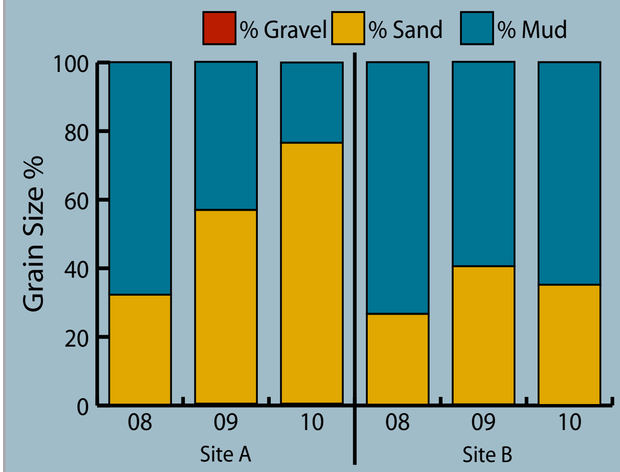


Figure 3. Grain size, Whareama Estuary (2008-2010).

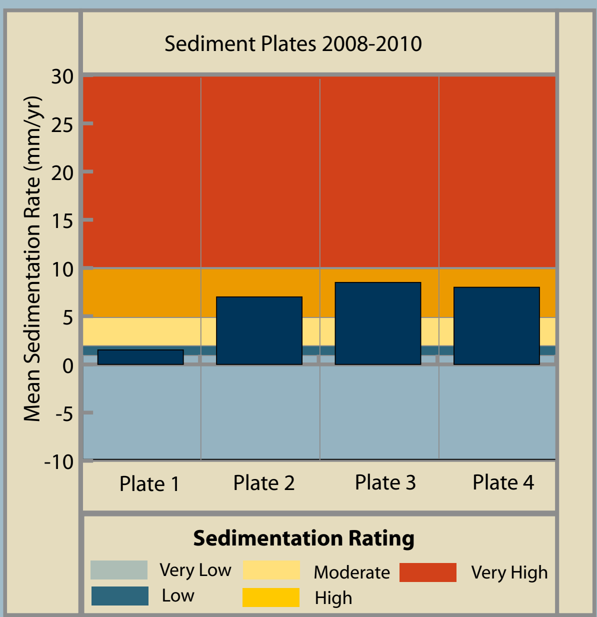


Figure 4. Sedimentation rate from plate data, Whareama Estuary (2008-2010).

2010 SEDIMENTATION RATE RATING	High

In order to assess sedimentation in the Whareama Estuary, a number of indicators have been used: grain size, the presence of mud tolerant macro-invertebrates and sedimentation rate.

Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. In 2008 all sites were dominated by muddy sediments (approximately 70% mud) (Figure 3). In 2009, a decline in mud content at both sites was reported and in 2010 results show a continuing decrease in mud content at Site A (now down to 23% mud) and a return to more elevated levels at Site B (65% mud). The variability in grain size between years is likely a reflection of the naturally dynamic nature of fine sediments in large, well-flushed, tidal river estuaries. Such variability is particularly evident at Site A as it is located at the boundary between sandy sediments (towards the sea) and finer muddy sediments (inland).

Compared with other tidal river estuaries, the mud content in the Whareama was similar, but as expected is high compared with fine scale sites in tidal lagoon type estuaries in the Wellington and Southland regions (Figure 2). The source of these muds is almost certainly from the surrounding catchment.

Rate of Sedimentation

To address the potential for ongoing sedimentation within the estuary, and to measure its magnitude, four sedimentation plates were deployed in January 2008 (Figure 1). The plates were located in a line at right angles to the river channel. Plate 1 was located 6m from the channel at low water, Plate 2@8m, Plate 3 @10m and Plate 4 @12m. Monitoring of the overlying sediment depth above each plate after one year of burial indicated a mean sedimentation rate of 14.5mm/yr. In January 2010, after two years of sedimentation, the mean sedimentation rate had dropped to 6-7mm/yr (Figure 4 - Plates 2, 3 and 4 were 7-8.5mm/yr) and Plate 1 was 1.5mm/yr).

Such findings indicate that the intertidal flat in the mid Whareama Estuary is currently infilling at a variable, but high rate. However, it will remain to be seen if such high rates are maintained in the longer term.

Macro-invertebrate Tolerance to Muds

The macro-invertebrate community in the Whareama Estuary was found to have a low number of species compared with other NZ estuaries (mean 5-8 species/core - Figure 5), a moderate mean abundance at 4700 - 7560/m^2 (Figure 6), and showed inter-site differences (see NMDS plot, Figure 7). The influence of mud content as a key variable causing these differences was then examined using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Norkko et al. 2001, Gibbs and Hewitt 2004) (Figures 8 and 9 and Appendices 2 and 3).

3. Results and Discussion (Continued)

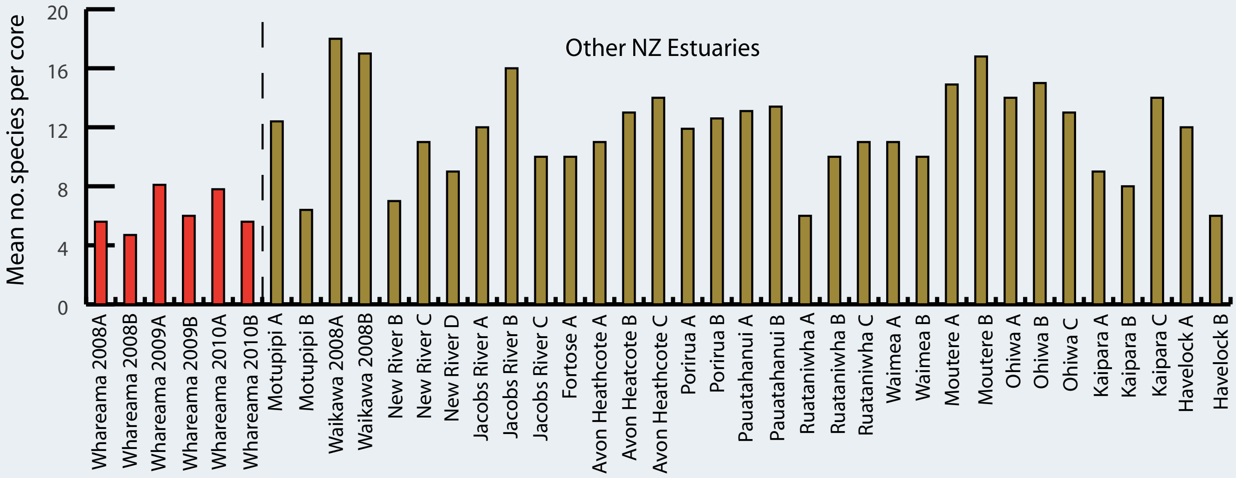


Figure 5. Mean number of infauna species, Whareama Estuary (2008-2010) compared with other NZ estuaries (Source Robertson et al. 2002, Robertson and Stevens 2006).

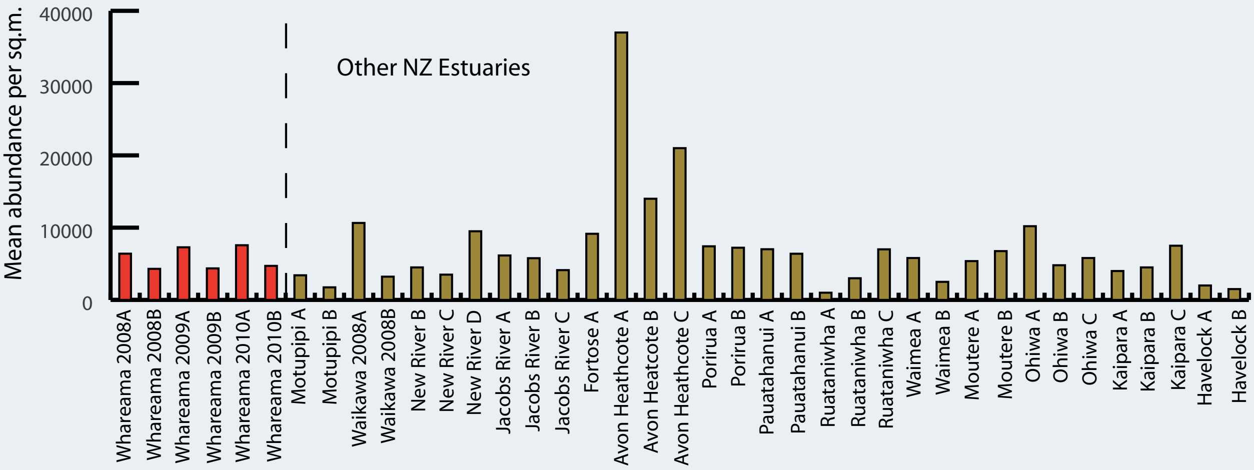
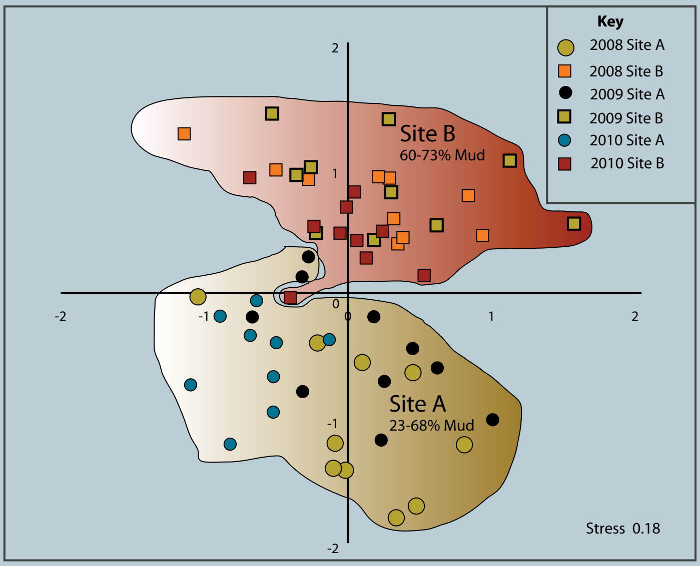


Figure 6. Mean total abundance of macrofauna, Whareama Estuary (2008-2010) compared with other NZ estuaries (Source Robertson et al. 2002, Robertson and Stevens 2006).

Figure 7. NMDS plot showing the relationship among samples in terms of similarity in macro-invertebrate community composition for Sites A and B, for 2008, 2009 and 2010. The plot shows each of the 10 replicate samples for each site and is based on Bray Curtis dissimilarity and square root transformed data.

The approach involves multivariate data analysis methods, in this case non-metric multidimensional scaling (NMDS) using PRIMER version 6.1.10. The analysis basically plots the site, year 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 depends on how good a representation it is of actual dissimilarities i.e. how low the calculated stress value is. Stress values greater than 0.3 indicate that the configuration is no better than arbitrary, and we should not try and interpret configurations unless stress values are less than 0.2.



3. Results and Discussion (Continued)

The results show that the Whareama Estuary was dominated by mud-tolerant organisms at both sites (Figure 9), and that the macro-invertebrate mud tolerance rating was in the “moderate” category and had increased in 2010 (Figure 8).

The dominant “mud tolerant” species were:

- The small sedentary deposit feeding bivalve, *Arthritica* sp. which lives greater than 2cm deep in the muddy sands at both sites. It prefers 20-60% mud content but can be found in mud contents from 5-70%.
- The small subsurface deposit feeding capitellid polychaete *Heteromastus filiformis*. It lives throughout the sediment to depths of 15cm, and prefers 10-15% mud content but can be found in mud contents from 0-95%. It shows a preference for areas of moderate to high 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 (Grieshaber and Völkel 1998).
- The ubiquitous surface deposit feeding spionid polychaete *Scolecolepides benhami* which often occurs in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. It has a strong mud preference and its optimum range is 25-30% mud content but can be found in mud contents from 0-100%. It is a prey item for fish and birds.

The increasing shift towards mud-tolerant organisms in 2010 was likely a response to the high levels of mud and high sedimentation rates at these sites. This trend towards “mud preference” species is likely to continue given the very elevated mud content and the fact that “sand-preference” species (i.e. species that are not expected to survive long-term in mud-dominated sediment) still exist at both sites.

In particular, the cockle (*Austrovenus stutchburyi)* prefers sand environments with an optimum range of 5-10% mud but can also be found sub-optimally (i.e. lower numbers) in 0-60% mud. In 2010, a small number of cockles were present in patches at each of the two Whareama sites (in 23% mud at Site A and 65% at Site B). The small size of the patches relative to what was observed nearer the sandy mouth of the estuary suggest that the populations at these two sites may be remnants, already under pressure from high mud concentrations and sediment runoff.

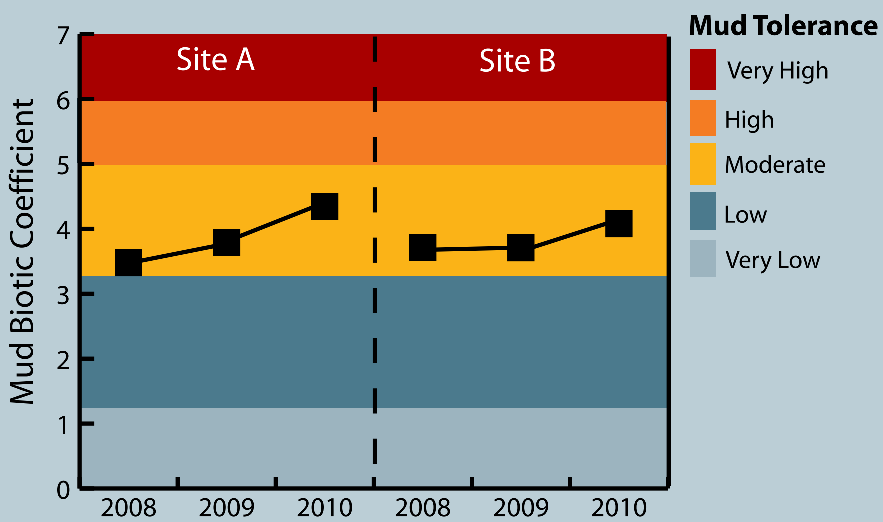


Figure 8. Mud tolerance macro-invertebrate rating, Sites A and B, Whareama Estuary (2008-2010).

In the future, it is likely that the cockle population will be lost from this site unless mud concentrations decline. Such a loss will have a negative influence on estuary condition and values because of the role cockles play in improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macro-invertebrate species present in an estuary (Lohrer et al. 2004, Thrush et al. 2006). In addition, cockles are an important part of the diet of some wading bird species (particularly oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns) and sand flounder and other predatory fish.

Overall this indicates that macro-invertebrate community in the Whareama Estuary is strongly affected by the elevated sediment mud content, and that levels of fine sediment have reached levels where all sites, and nearly all sensitive species, are affected.

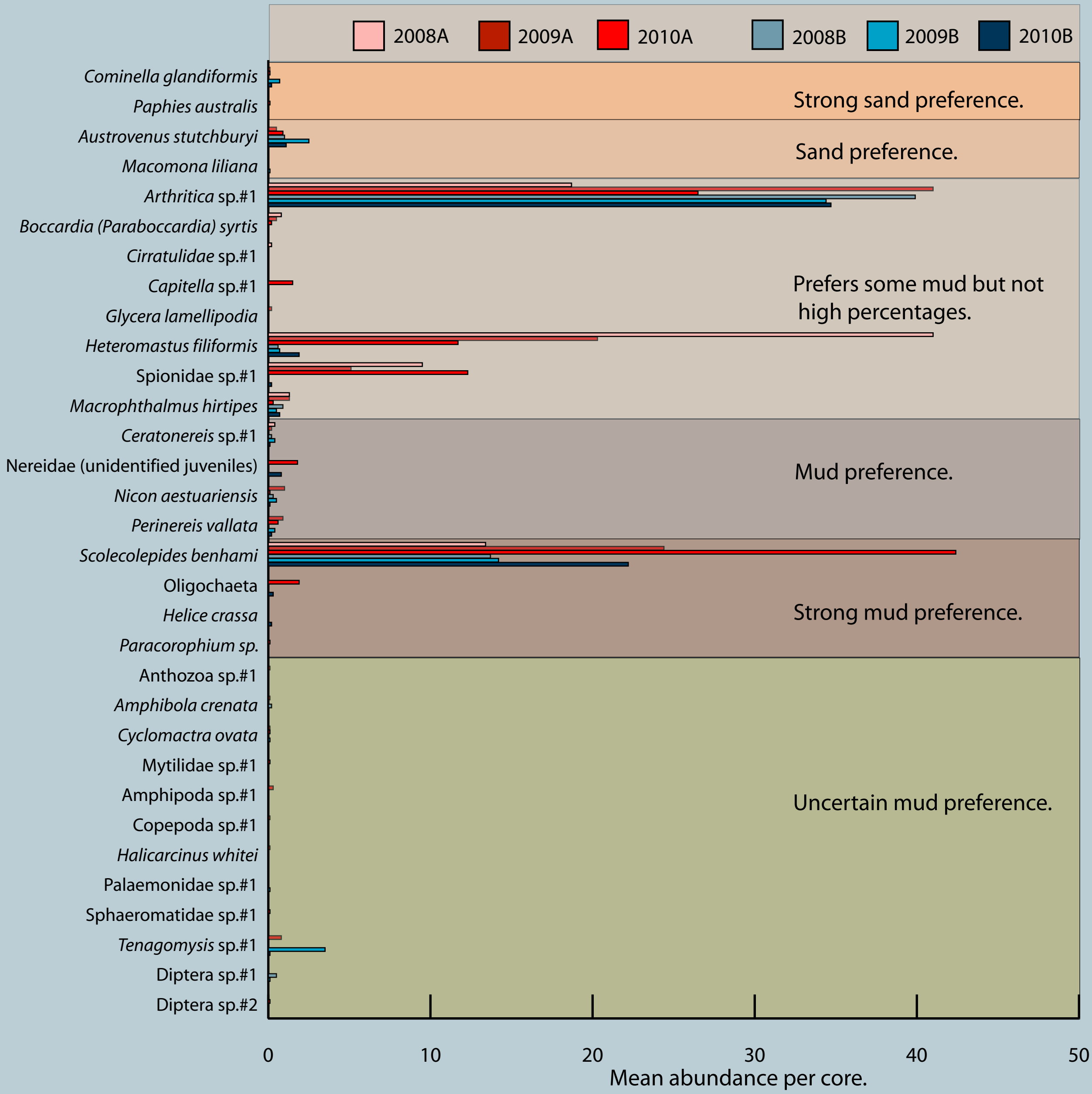


Figure 9. Mud tolerance of macro-invertebrates at Sites A and B, Whareama Estuary (2008-2010). See Appendix 3 for tolerance details.

EUTROPHICATION

2010 RPD RATING	Fair

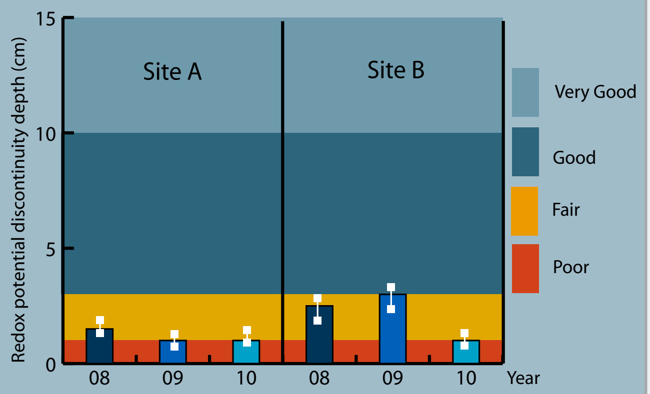


Figure 10. RPD depth (mean and range), Whareama Estuary (2008-2010).

The primary fine scale indicators of eutrophication are grain size, RPD boundary, sediment organic matter, nitrogen and phosphorus concentrations, and the community structure of certain sediment-dwelling animals. The broad scale indicators are the percentages of the estuary covered by macroalgae and soft muds.

Redox Potential Discontinuity (RPD)

Figures 10 and 11 (also Table 4) show the RPD depths and sediment profiles for each of the two Whareama sampling sites, and indicates the likely benthic community that is supported at the site based on the measured RPD depth (adapted from Pearson and Rosenberg 1978).

The RPD depth in 2010 was relatively shallow (1cm at both sites), the shallowest since recordings began in 2008. Such RPD values fit the "poor" condition rating and indicate sediments are likely to be poorly oxygenated and the benthic invertebrate community is likely to be in a transitional state.

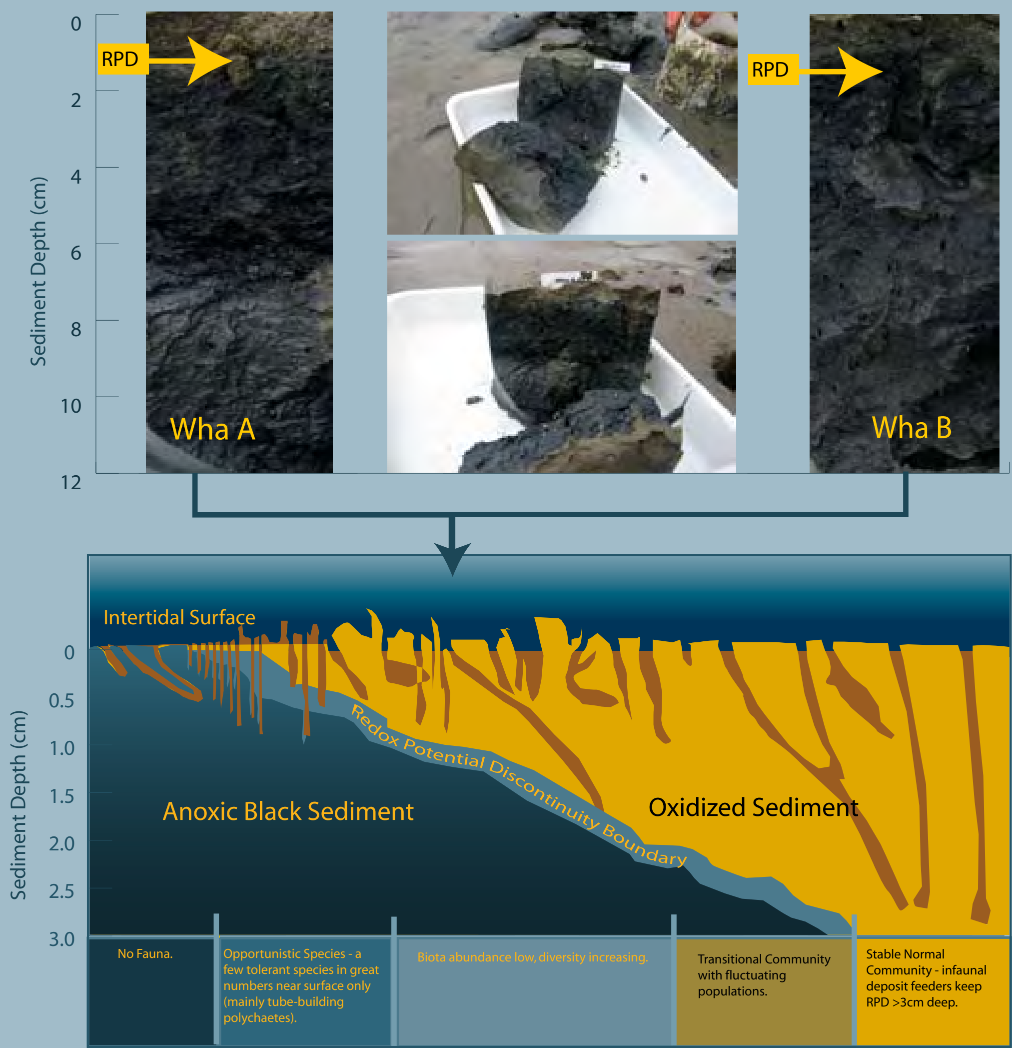


Figure 11. Sediment profiles, depths of RPD and predicted benthic community type, Whareama Estuary, 22 January 2010. Arrow below cores relates to the type of community likely to be found in the cores.

3. Results and Discussion (Continued)

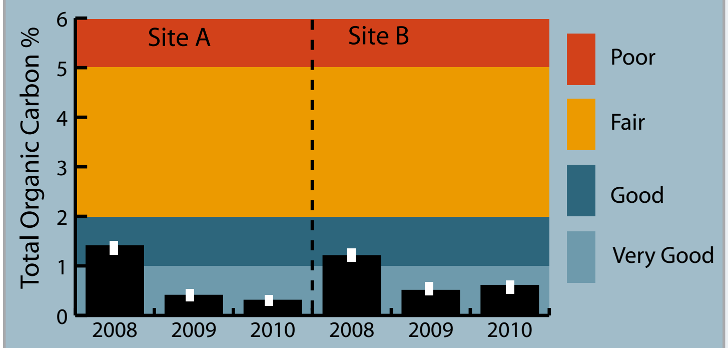


Figure 12. Total organic carbon (mean and range) at 2 intertidal sites, Jan 2008, 2009 and 2010.

2010 TOC RATING	**Very Good**

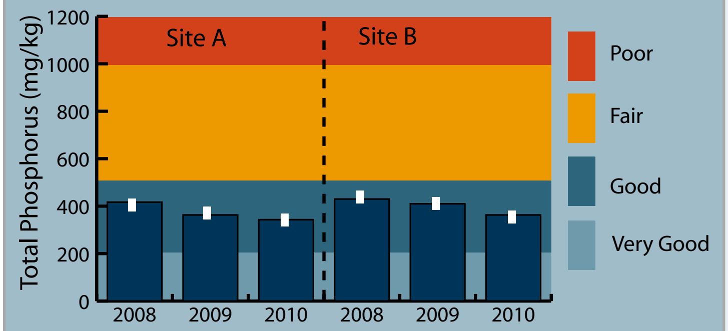


Figure 13. Total phosphorus (mean and range) at 2 intertidal sites, Jan 2008, 2009 and 2010.

2010 TP RATING	**Good**

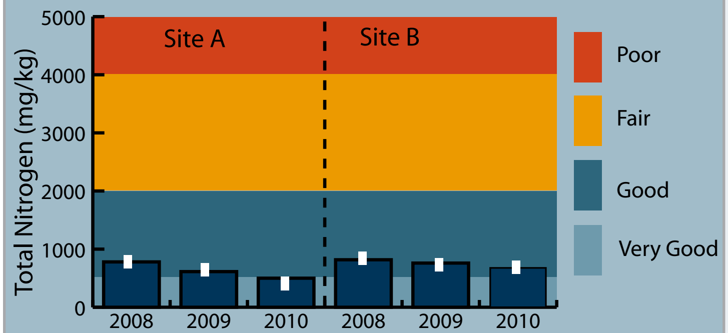


Figure 14. Total nitrogen (mean and range) at 2 intertidal sites, Jan 2008, 2009 and 2010.

2010 TN RATING	**Good**

ORGANIC MATTER (TOC)

Fluctuations in organic input are considered to be one of the principal causes of faunal change in estuarine and near-shore benthic environments. Increased organic enrichment results in changes in physical and biological parameters, which in turn have effects on the sedimentary and biological structure of an area. The number of suspension-feeders (e.g. bivalves and certain polychaetes) declines and deposit-feeders (e.g. opportunistic polychaetes) increase as organic input to the sediment increases (Pearson and Rosenberg 1978).

The indicator of organic enrichment (TOC) at both sites in 2010 (Figure 12) was at low concentrations (<1%) at all sites and met the "very good" condition rating. Significantly lower TOC concentrations were measured in 2009 and 2010 compared with 2008, which are likely to be the result of over-estimation in 2008. In 2008, ash free dry weight and a standard conversion factor were used to estimate TOC. In 2009, TOC was measured directly.

TOTAL PHOSPHORUS

Total phosphorus (a key nutrient in the eutrophication process) was present in 2010 at slightly lower concentrations than recorded in 2008 and 2009, but was still rated in the "low to moderate enrichment" category (Figure 13).

This means that the Whareama Estuary sediments have a low-moderate store of P in the sediments (sourced from both recent and historical catchment inputs).

TOTAL NITROGEN

Like phosphorus, total nitrogen (the other key nutrient in the eutrophication process) was present in 2010 at slightly lower concentrations than recorded in 2008 and 2009, but was still rated in the "low to moderate enrichment" category (Figure 14). This means that the Whareama sediments have a low-moderate store of N in the sediments (sourced from both recent and historical catchment inputs).

The combined 2010 results for Whareama Estuary indicate the following in relation to eutrophication symptoms. The first finding was that the sediments were muddy and therefore prone to poor oxygenation. In such situations, low levels of organic enrichment result in depletion of sediment oxygen and a shallow RPD depth. In other words, although the TOC and nutrient levels may be low in relation to other estuaries (as indicated by the ratings), they can still cause organic enrichment problems (i.e. shallow RPD) in muddy estuaries. This is reinforced by the findings in the following subsection.

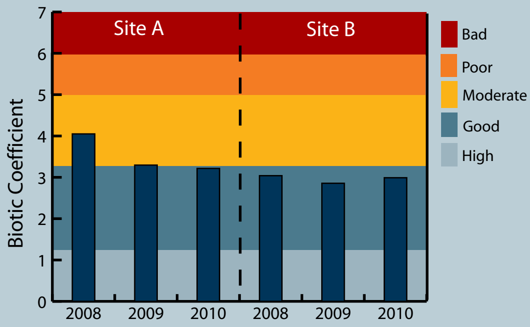


Figure 15. Organic enrichment macro-invertebrate rating, Whareama Estuary (2008-2010).

Macro-invertebrate Organic Enrichment Index

The benthic invertebrate organic enrichment index shows that the rating in the Whareama Estuary fitted the "good-moderate" category in 2008, 2009 and 2010 (Figure 15). Such a rating indicated that the organisms were dominated by enrichment tolerant species and that the sites were moderately enriched. This dominance is demonstrated more clearly in Figure 16 which shows very low numbers of Type I or "very sensitive" organisms, and Type II organisms which are "indifferent to organic enrichment"; and elevated numbers of Types III, IV and V tolerant organisms. The most abundant organisms, the small bivalve *Arthritica* sp., and the polychaetes *Scolecolepides benhami* and *Heteromastus filiformis*, were moderately tolerant of organic enrichment.

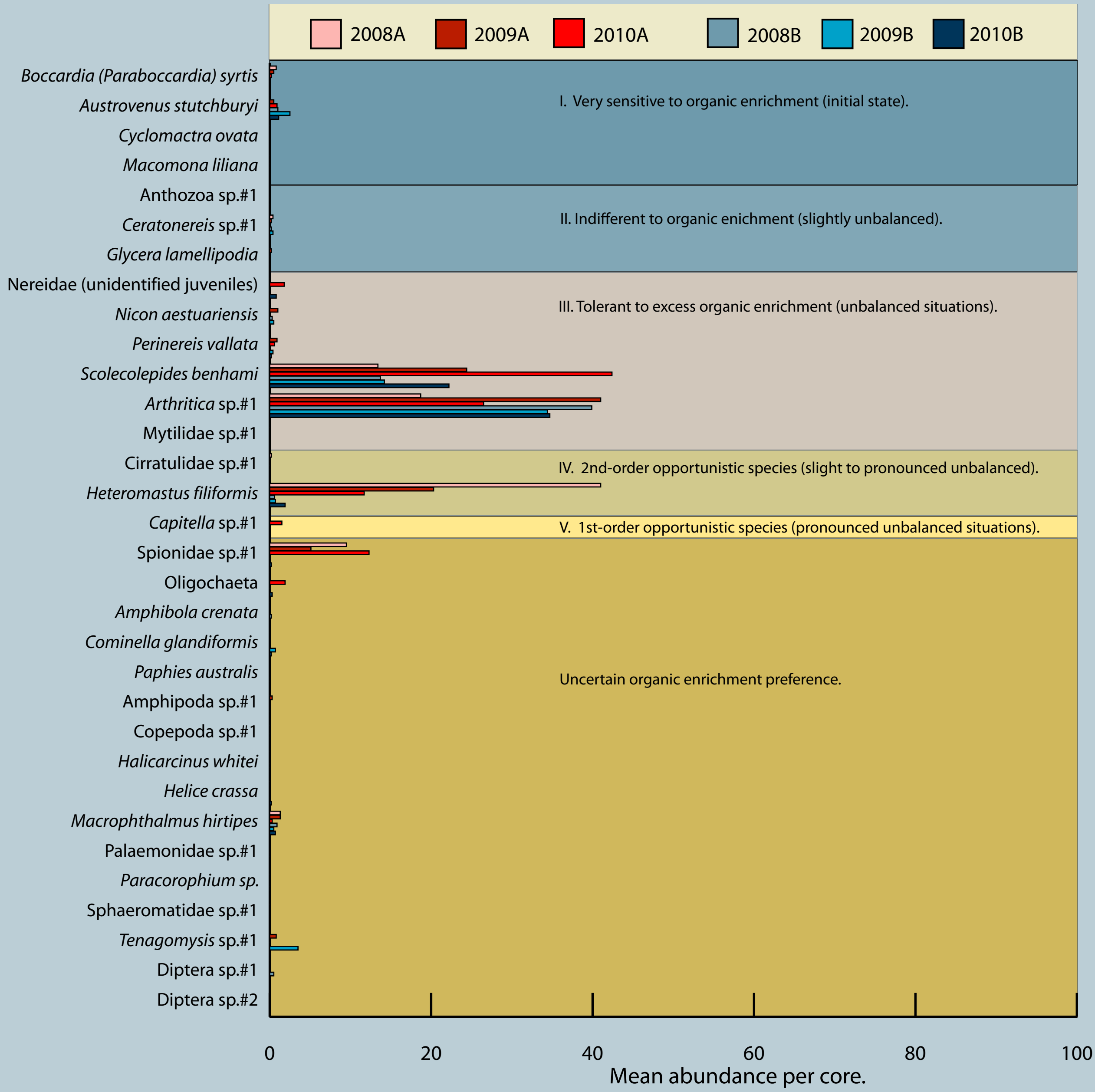


Figure 16. Organic enrichment sensitivity of macro-invertebrates at Sites A and B, Whareama Estuary (2008-2010). See Appendix 3 for sensitivity details.

TOXICITY

2010 TOXICITY RATING
Good
Very Good

METALS AND DDT

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at low to very low concentrations in 2008, 2009 and 2010, with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 17). In 2010 metals met the "good" condition rating for nickel and the "very good" condition rating for cadmium, chromium, copper, lead and zinc at both sites. Organochlorine pesticide and polychlorinated biphenyls (PCB's) were measured in 2008 and were all below detection limits and ANZECC (2000) criteria (Robertson and Stevens 2008).

These results indicate that there is no widespread contaminant-related toxicity in the Whareama Estuary.

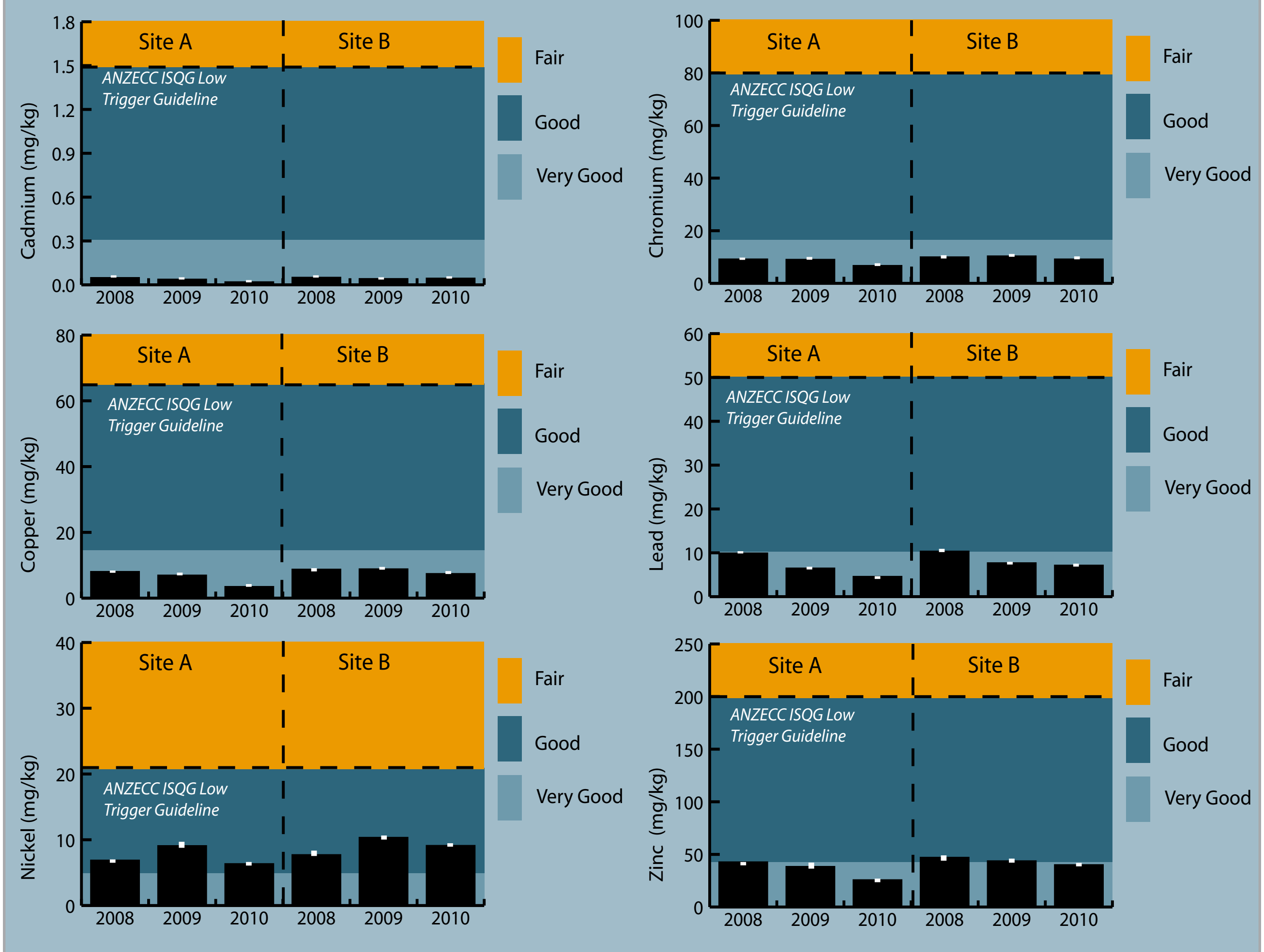


Figure 17. Total recoverable metals (mean and range) at 2 intertidal sites, Whareama Estuary Jan 2008, 2009 and 2010.

4. SUMMARY AND CONCLUSIONS

The third year of fine scale monitoring results for estuary condition showed that Whareama Estuary was generally in good-fair condition. Conditions were similar to those measured in 2008 and 2009, with the key findings as follows;

- In 2010, the sediments were still dominated by muds at the upstream site, but the mud content had declined at the lower site (closer to the sea), and the site had become much sandier.
- Redox Potential Discontinuity (RPD) was 1cm deep indicating "poor" sediment oxygenation.
- Although, sediment levels of organic carbon, nitrogen and phosphorus were low in relation to other estuaries, they were causing organic enrichment problems in the Whareama because this estuary is muddy, and therefore prone to poor oxygenation.
- Sedimentation rates measured during the period 2008-2010 were high in the major area of intertidal mudflat in the estuary. Such high rates signify rapid infilling of this important area of the estuary.
- The benthic invertebrate community was dominated by mud-tolerant organisms at both sites and the macro-invertebrate mud tolerance rating was in the "moderate" category and had increased (i.e. more "mud tolerant" than "sand preference" species were present in 2010).
- The benthic invertebrate organic enrichment index was in the upper range of the "good" category, indicating slight to moderate organic enrichment.
- Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at low to very low concentrations.
- Nuisance macroalgal growth in the estuary, which has not yet been quantitatively monitored, was observed to be present but at very low concentrations (i.e. likely to meet the "very good" rating).
- In terms of eutrophication, the results suggest that the estuary has a low to moderate level of enrichment.

5. MONITORING

Whareama Estuary has been identified by GWRC as a priority for monitoring, and is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout the Greater Wellington region. Baseline conditions (2008-2010) have now been established and it is recommended that monitoring continue as outlined below:

Annual Monitoring. The results indicate problems associated with excessive muddiness and a "poor RPD" rating. In order to address these issues it is recommended that monitoring of sedimentation rate, RPD depth and grain size be undertaken annually until the situation improves.

Fine Scale Monitoring. It is recommended that a "complete" fine scale monitoring assessment (including sedimentation rate and macroalgal mapping) be undertaken at 5 yearly intervals (next scheduled for Jan-Feb 2015).

Broad Scale Habitat Mapping. It is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2016-17).

6. MANAGEMENT

The fine scale monitoring results reinforce the need for management of nutrient and, more particularly, fine sediment sources entering the estuary. It is recommended that sources of elevated loads in the catchment be identified and management undertaken to minimise their adverse effects on estuary uses and values.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from various people, local residents (particularly Glen and Angie Meredith from Orui Station) who provided access to the estuary, Maz Robertson for editing, and lastly the staff of Greater Wellington Regional Council who made it all happen. In particular, the support and feedback of Juliet Milne (GWRC) was much appreciated.

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Air dry (35 degC, sieved to pass 2mm and 63um sieves, gravimetric - (% sand, gravel, silt)	N/A
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt

* Coastal Marine Ecology Consultants (established in 1990) specialises in coastal soft-shore and inner continental shelf soft-bottom benthic ecology. Principal, Gary Stephenson (BSc Zoology) has worked as a marine biologist for more than 25 years, including 13 years with the former New Zealand Oceanographic Institute, DSIR. Coastal Marine Ecology Consultants holds an extensive reference collection of macroinvertebrates from estuaries and soft-shores throughout New Zealand. New material is compared with these to maintain consistency in identifications, and where necessary specimens are referred to taxonomists in organisations such as NIWA and Te Papa Tongarewa Museum of New Zealand for identification or cross-checking.

APPENDIX 2. DETAILED RESULTS

Station Locations

Whareama A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1860703	1860687	1860675	1860661	1860654	1860666	1860678	1860695	1860691	1860684
NZTM NORTH	5455343	5455351	5455357	5455359	5455358	5455353	5455347	5455340	5455335	5455338

Whareama B	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1860084	1860073	1860045	1860046	1860063	1860069	1860088	1860094	1860079	1860067
NZTM NORTH	5455318	5455314	5455300	5455289	5455299	5455305	5455315	5455308	5455300	5455294

Physical and chemical results for Whareama Estuary, 22 January 2010.

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg							
WhaA	1-4	1	30	0.33	17.2	81.8	1	0.02	6.7	3.4	6.3	4.4	25	< 500	330
WhaA	5-8	1	30	0.27	29.2	70.7	0.1	0.021	6.9	3.7	6.4	4.7	27	< 500	350
WhaA	9-10	1	30	0.28	23.9	75.8	0.3	0.017	6.5	3.3	6.3	4.6	25	< 500	350
WhaB	1-4	3.5	30	0.5	57.8	42.1	< 0.1	0.032	8.5	6.5	8.2	6.6	36	590	360
WhaB	5-8	3	30	0.65	70.1	29.9	< 0.1	0.054	10	8.4	10	7.7	44	730	390
WhaB	9-10	2	30	0.54	66.7	33.3	< 0.1	0.045	9	7.3	9.1	7.1	40	710	340

* composite samples

Sediment Plate Depths (mm)

Estuary	Site	18 Jan 2008	18 Jan 2009	22 Jan 2010	Mean Sed. Rate (mm/yr)
Whareama	Plate 1	182	188	185	1.5
	Plate 2	156	170	170	7
	Plate 3	215	234	232	8.5
	Plate 4	216	235	232	8

Whareama A - 22 Jan. 2010 Epifauna (numbers per 0.25m² quadrat)

Station	Wha A-01	Wha A-02	Wha A-03	Wha A-04	Wha A-05	Wha A-06	Wha A-07	Wha A-08	Wha A-09	Wha A-10
Austrovenus stutchburyi (cockle)	0	0	0	0	0	0	0	0	0	0
No. species/quadrat	0	0	0	0	0	0	0	0	0	0
No. individuals/quadrat	0	0	0	0	0	0	0	0	0	0

Whareama A - 22 Jan. 2010 Infauna (numbers per 0.01327m² core) (Note NA = Not Assigned)

Group	**Species**	AMBI Group	Mud Tolerance Group	Wha A-01	Wha A-02	Wha A-03	Wha A-04	Wha A-05	Wha A-06	Wha A-07	Wha A-08	Wha A-09	Wha A-10
ANTHOZOA	Anthozoa sp.#1	II	?										
POLYCHAETA	*Boccardia (Paraboccardia) syrtis*	I	2							1		1	
	Capitella sp.#1	V	3	2	3	3	2		2	1	2		
	Ceratonereis sp.#1	II	4										
	Cirratulidae sp.#1	IV	2										
	Glycera lamellipodia	II	3										
	Heteromastus filiformis	IV	3	36	20	17	18	3	5	9	5	1	3
	Nereidae (unidentified juveniles)	III	4	3	3	2	3	2	1	2	1	1	
	Nicon aestuariensis	III	4				1						
	Perinereis vallata	III	4		1					2	1		2
	Scolecolepides benhami	III	5	33	41	27	12	44	36	41	68	61	61
	Spionidae sp.#1	NA	3	21	22	8	6	4	19	4	3	5	31
OLIGOCHAETA	Oligochaeta	NA	5			1	17						1
GASTROPODA	*Amphibola crenata*	NA	?										
	Cominella glandiformis	NA	1		1								
BIVALVIA	Arthritica sp.#1	III	2	67	7	20	21	10	3	47	26	23	41
	Austrovenus stutchburyi	I	2			2	1	1	2	1		1	1
	Cyclomactra ovata	I	?	1									
	Macomona liliana	I	2										
	Mytilidae sp.#1	III	?			1							
	Paphies australis	NA	1						1				
CRUSTACEA	Amphipoda sp.#1	NA	?										
	Copepoda sp.#1	NA	?										
	Halicarcinus whitei	NA	?										
	Helice crassa	NA	5										
	Macrophthalmus hirtipes	NA	3				2		1				
	Palaemonidae sp.#1	NA	?										
	Paracorophium sp.	NA	5				1						
	Sphaeromatidae sp.#1	NA	?		1								
	Tenagomysis sp.#1	NA	?										
INSECTA	Diptera sp.#1	NA	?										
	Diptera sp.#2	NA	?					1					
	Total species in sample			7	9	9	11	7	9	9	7	7	7
	Total individuals in sample			163	99	81	84	65	70	108	106	93	140

AMBI and MUD Group details see page 24

Whareama B - 22 Jan. 2010 Epifauna (numbers per 0.25m² quadrat)

Station	WhaB-01	WhaB-02	WhaB-03	WhaB-04	WhaB-05	WhaB-06	WhaB-07	WhaB-08	WhaB-09	WhaB-10
Amphibola crenata (Mud snail)	0	0	2	0	0	1	0	1	0	0
Cominella glandiformis (Mudflat whelk)	0	0	1	0	0	0	0	0	0	2
No. species/quadrat	0	0	2	0	0	1	0	1	0	1
No. individuals/quadrat	0	0	3	0	0	1	0	1	0	2

Whareama B - 22 Jan. 2010 Infauna (numbers per 0.01327m² core) (Note NA = Not Assigned

Group	**Species**	AMBI Group	Mud Tolerance Group	Wha B-01	Wha B-02	Wha B-03	Wha B-04	Wha B-05	Wha B-06	Wha B-07	Wha B-08	Wha B-09	Wha B-10
ANTHOZOA	Anthozoa sp.#1	II	?										
POLYCHAETA	*Boccardia (Paraboccardia) syrtis*	I	2										
	Capitella sp.#1	V	3										
	Ceratonereis sp.#1	II	4						1				
	Cirratulidae sp.#1	IV	2										
	Glycera lamellipodia	II	3										
	Heteromastus filiformis	IV	3	5	4	2	5	1	1				1
	Nereidae (unidentified juveniles)	III	4	1	1	1		1			3	1	
	Nicon aestuariensis	III	4									1	
	Perinereis vallata	III	4	1								1	
	Scolecolepides benhami	III	5	31	13	20	25	19	28	20	19	26	21
	Spionidae sp.#1	NA	3	2									
OLIGOCHAETA	Oligochaeta	NA	5		1		2						
GASTROPODA	*Amphibola crenata*	NA	?										
	Cominella glandiformis	NA	1					2					
BIVALVIA	Arthritica sp.#1	III	2	19	31	43	79	49	32	6	37	34	17
	Austrovenus stutchburyi	I	2	1	3	1		1		1	3		1
	Cyclomactra ovata	I	?										
	Macomona liliana	I	2										
	Mytilidae sp.#1	III	?										
	Paphies australis	NA	1										
CRUSTACEA	Amphipoda sp.#1	NA	?										
	Copepoda sp.#1	NA	?										
	Halicarcinus whitei	NA	?										
	Helice crassa	NA	5			1					1		
	Macrophthalmus hirtipes	NA	3		1		1	1		1	1	1	1
	Palaemonidae sp.#1	NA	?										
	Paracorophium sp.	NA	5										
	Sphaeromatidae sp.#1	NA	?										
	Tenagomysis sp.#1	NA	?		1								
INSECTA	Diptera sp.#1	NA	?										
	Diptera sp.#2	NA	?										
	Total species in sample			7	8	6	5	7	4	4	6	6	5
	Total individuals in sample			60	55	68	112	74	62	28	64	64	41

AMBI and MUD Group details see page 24

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
	Anthozoa sp.1	II	NA	Unidentified anemone.
Polychaeta	*Boccardia (Paraboccardia) syrtis*	I	S Optimum range 10-15% mud,* distribution range 0-50%*	A small surface deposit-feeding spionid. Prefers low-mod 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	*Capitella capitata*	V	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *Heteromastus filiformis*.	A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments.
Polychaeta	*Ceratonereis* sp.	II	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.	A nereid (ragworm) that has most likely been introduced to NZ.
Polychaeta	Cirratulidae sp.	IV	S Optimum range 10-15% mud,* distribution range 5-70%*	Subsurface deposit feeder that prefers sands. Small sized, tolerant of slight to unbalanced situations.
Polychaeta	*Glycera lamellipoda*	II	I Optimum range 10-15% mud,* distribution range 0-95%*	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. Often present in muddy conditions. Intolerant of low salinity.
Polychaeta	*Heteromastus filiformis*	IV	I Optimum range 10-15% mud,* distribution range 0-95%*	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 to high 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.
Polychaeta	Nereidae	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.	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.
Polychaeta	*Nicon aestuariensis*	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate to high mud content sediments.
Polychaeta	*Perinereis vallata*	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers sandy sediments.

APPENDIX 3. INFAUNA CHARACTERISTICS

	Group and Species	Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Polychaeta	*Scolecolepides benhami*	III	MM Optimum range 25-30% mud,* distribution range 0-100%*	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. **Strong Mud Preference.** Prey for fish and birds. Rare in Freshwater Estuary (<1% mud) and Porirua Estuary (5-10% mud). Common in Whareama (35-65% mud), Fortrose Estuary (5% mud), Waikanae Estuary 15-40% mud. Moderate numbers in Jacobs River Estuary (5-10% muds) and New River Estuary (5% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai arm, New River estuary.
Polychaeta	Spionidae (likely *Prionospio*)	IV	I Optimum range 65-70% mud* or 20- 50%**, distribution range 0-95%*. Sensitive to changes in sediment mud content.	Prionospio-group have many NZ species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was originally *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A suspension feeding spionid (also capable of detrital feeding) that **prefers living in muddy sands (65-70% mud) but doesn't like higher levels.** But animals found in 0-95% mud. **Commonly an indicator of increase in mud content. Tolerant of organically enriched conditions.** Common in Freshwater estuary (<1% mud). Present in Waikawa (10% mud), Jacobs River Estuary (5-10% muds).
Oligochaeta	Oligochaetes	IV	MM Optimum range 95-100% mud*, distribution range 0-100%**.	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Bivalvia	*Arthritica* sp.1	III	I Optimum range 55-60% mud*, or 20-40%***, distribution range 5-70%**.	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
Bivalvia	*Austrovenus stutchburyi*	II	S Prefers sand with some mud (optimum range 5-10% mud* or 0-10% mud**, distribution range 0-85% mud**).	Family Veneridae. 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. 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).

APPENDIX 3. INFAUNA CHARACTERISTICS

Group	Species	Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Bivalvia	*Cyclomactra ovata*	I	Uncertain	Trough shell of the family Mactridae, endemic to NZ. 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.
Bivalvia	*Mocomona liliana*	I	S Prefers sand with some mud (optimum range0-5% mud* distribution range 0-40% mud**).	**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. Thrush et al. (2006) show that this large deposit feeding bivalve is important in that it enhances nutrient and oxygen fluxes and its presence influences the types of other macroinvertebrate species present. These bivalves draw organic material and microphytes from the sediment surface with their inhalant siphon and defecate directly into the sediment around their shell, enhancing the concentration of organic matter at 5-10cm below the sediment surface. Sand Preference: **Prefers 0-5% mud (range 0-40% mud).**
Bivalvia	Mytilidae sp.	III	Uncertain	A small juvenile belong to the mussel group.
Bivalvia	*Paphies australis*	II	SS (adults) S or M (Juveniles) Strong sand preference (adults optimum range 0-5% mud*, distribution range 0-5% mud**). Juveniles often found in muddier sediments.	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. **Optimum mud range 0-5% mud and very restricted to this range. Juveniles more tolerant of mud.** Common at mouth of Motupipi Estuary (0-5% mud), Freshwater Estuary (<1% mud), a few at Porirua B (Polytech) 5% mud.
Crustacea	Amphipoda sp.	NA	Uncertain	An unidentified amphipod.
Crustacea	Copepoda	NA	Uncertain	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 (Harpactacoida) have worm-shaped bodies.
Crustacea	*Halicarcinus whitei*	NA	Uncertain	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
Crustacea	*Helice crassa*	NA	MM Optimum range 95-100% mud, distribution range 5-100%*.	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content. Optimum Range 95-100% mud (found in 5-100% mud).
Crustacea	*Macrophthalmus hirtipes*	NA	I Optimum range 45-50% mud, distribution range 0-95%*.	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 tunneling mud crab, it feeds from the nutritious mud.
Crustacea	Palaemonidae	I	Uncertain	Palaemonidae is a family of shrimp of the order Decapoda.

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Crustacea	*Paracorophium* sp.	III	MM Optimum Range 95-100% mud (found in 40-100% mud)*.	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Optimum Range 95-100% mud (found in 40-100% mud) in upper Nth. Is. estuaries. In Sth. Is. and lower Nth. Is. common in Waikanae Estuary (15-40% mud), Haldane Estuary (25-35% mud) and in Fortrose Estuary (4% mud). 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.
Crustacea	Sphaeromatidae	III	Uncertain	An isopod. Marine pill bugs are scavengers and browsers, feeding on living and rotting algae and other debris on the sea floor. Most species are less than 10mm long but some can be twice this length. They can swim but do so upside-down. They are brooders as are all isopods and females of some species develop deep cavities underneath to house the eggs and young.
Crustacea	*Tenagomysis* sp.	II	Uncertain	A mysid shrimp species.
Insecta	Diptera sp.	NA	Uncertain	Fly or midge larvae - species unknown.

* Preferred and distribution ranges based on findings from the Whitford Embayment in the Auckland Region (Norkko et al. 2001).
** Preferred and distribution ranges based on findings from 19 North Island estuaries (Gibbs and Hewitt 2004).
*** Preferred and distribution ranges based on findings from Thrush et al. (2003)

**** Tolerance to Mud Codes are as follows (from Gibbs and Hewitt, 2004, Norkko et al. 2001) :

1 = SS, strong sand preference.
2 = S, sand preference.
3 = I, prefers some mud but not high percentages.
4 = M, mud preference.
5 = MM, strong mud preference.

***** AMBI Sensitivity to Organic Enrichment Groupings (from Borja et al. 2000)

Group I. Species very sensitive to organic enrichment and present under unpolluted conditions (initial state). They include the specialist carnivores and some deposit-feeding tubicolous polychaetes.

Group II. Species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.

Group III. Species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations). They are surface deposit-feeding species, as tubicolous spionids.

Group IV. Second-order opportunistic species (slight to pronounced unbalanced situations). Mainly small sized polychaetes: subsurface deposit-feeders, such as cirratulids.

Group V. First-order opportunistic species (pronounced unbalanced situations). These are deposit-feeders, which proliferate in reduced sediments.

The distribution of these ecological groups, according to their sensitivity to pollution stress, provides a Biotic Index with 5 levels, from 0 to 6.