coastalmanagement

Porirua Harbour

Intertidal Fine Scale Monitoring 2009/10

Prepared for Greater Wellington Regional Council
July 2010

Harvesting shellfish near the entrance to the Onepoto Arm, Porirua Harbour.

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Prepared for
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By

Barry Robertson and Leigh Stevens

Wriggle Limited, PO Box 1622, Nelson 7040, Ph 0275 417 935, 021 417 936, www.wriggle.co.nz

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PORIRUA HARBOUR - EXECUTIVE SUMMARY

Porirua Harbour Estuary

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

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Porirua Estuary Issues
Moderate eutrophication
Excessive sedimentation
Habitat Loss (saltmarsh, dune and terrestrial margin)

↓

Monitoring

Broad Scale Mapping
Sediment type
Saltmarsh
Seagrass
Macroalgae
Land margin

5 -10 yearly
First undertaken in 2008.

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

4yr Baseline then 5 yearly
Baseline yet to be completed.
Next survey 2011.

↓

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 (saltmarsh, terrestrial margin)

↓

Recommended Management

- Limit intensive landuse.
- Set nutrient, sediment guidelines.
- Margin vegetation enhancement.
- Manage for sea level rise.
- Enhance saltmarsh.
- Manage weeds and pests.

This report summarises the results of the first three years of fine scale monitoring of four intertidal sites (2008-2010) within Porirua Harbour, an 807ha tidal lagoon estuary. 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 outlined 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 was 1-2cm deep indicating poor oxygenation.
- The benthic invertebrate community condition rating indicated a slightly polluted or "good" condition.
- The indicator of organic enrichment (Total Organic Carbon) was at low concentrations in all years.
- Nutrient enrichment indicators (total nitrogen and phosphorus) were at low-moderate concentrations in all years.
- Sediment plates indicate low-moderate sedimentation at key sites since 2008.
- Sand dominated the sediments, but mud contents were relatively high.
- Heavy metals and DDT were well below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity).
- Macroalgal cover was elevated at most sites.

CONDITION RATINGS

Key To Ratings: Baseline est. | High/Poor | Fair | Good | Good-Very Good | Very good | Not measured

	Porirua (Onepoto) Arm						Pauatahanui Arm					
	Site A Railway			Site B Polytech			Site A Boatshed			Site B Upper		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Sedimentation Rate	Baseline est.	Low		Baseline est.	Moderate		Baseline est.	Very Low		Baseline est.	Moderate	
Invertebrates (Mud Tolerance)	Good	Good	Good	Good	Very good	Very good	Good	Good	Good	Good	Good	Good
RPD Profile (Sediment Oxygenation)	Fair	Fair	Fair	Good	Fair	Fair	Good	Fair	Fair	Good	Good	Fair
TOC (Total Organic Carbon)	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good
Total Nitrogen	Good	Good	Good	Very good	Very good	Very good	Good	Good	Good	Very good	Very good	Very good
Total Phosphorus	Good	Good	Good	Very good	Very good	Very good	Good	Good	Good	Very good	Very good	Very good
Invertebrates (Organic Enrichment)	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Metals (Cd, Cu, Cr, Ni, Pb, Zn)	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good
DDT	Not measured	Not measured	Very good	Not measured	Not measured	Very good	Not measured	Not measured	Very good	Not measured	Not measured	Very good

ESTUARY CONDITION AND ISSUES

Overall, the first three years of monitoring show the dominant intertidal habitat (i.e. unvegetated tidal-flat) in the Porirua Harbour is generally in good to moderate condition. Despite the good to moderate condition, the estuary shows signs of increasing mud contents, moderate sedimentation rates, moderate macroalgal growth, declining sediment oxygenation and a benthic invertebrate community dominated by sensitive species. This suggests that the estuary is on the borderline of a shift towards excessive muddiness and nutrient enrichment or eutrophication.

RECOMMENDED MONITORING AND MANAGEMENT

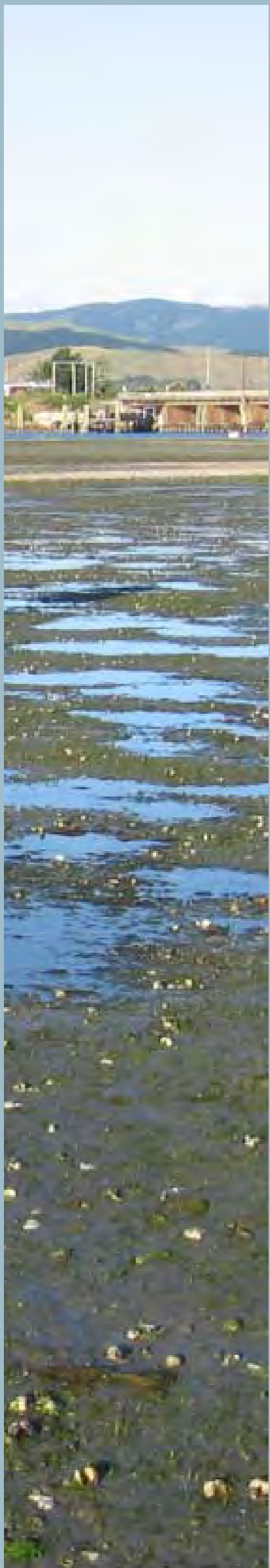
Baseline conditions have now nearly been established, with one more year of fine scale monitoring (including sedimentation rate and macroalgal mapping) recommended for January 2011. It is also recommended that additional sediment plates be deployed in the upper Porirua Arm (Polytech site) in 2011 to better account for the patchiness of sediment deposition at this site.

In order to develop sediment and nutrient budgets, nutrient and suspended sediment inputs from major sources during both baseflow and flood conditions should also be monitored. Nutrient and chlorophyll a concentrations in the water column of Porirua Harbour should also be monitored in order to assess potential for nuisance conditions. The following specific management actions are recommended:

- Limit nitrogen inputs to the estuary to levels that will not cause nuisance algal blooms i.e. limit estuary areal loading to 50mgN.m^{-2}.d^{-1} (Heggie 2006) which equates to mean catchment yields of 50 and 100 tonnes N/yr for the Porirua and Pauatahanui Arm catchments respectively (approximately 7-9 kgN/ha/yr). Currently the estuary areal N load is unknown and consequently there is a recommendation above to undertake input monitoring to rectify this.
- Limit suspended sediment catchment inputs to the estuary to levels that will not cause excessive estuary infilling i.e. limit sedimentation rates to 2 mm/yr (Gibbs and Cox 2009). The catchment SS input load required to meet this limit is currently unknown and therefore sediment budget monitoring/modelling is recommended to rectify this.

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 Porirua Harbour began in late 2007, but the first year of fine scale baseline monitoring began in January 2008. Wriggle Coastal Management and GWRC currently undertake the work using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions.

The Porirua Harbour monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment.** Assessment of the vulnerability of the estuary to major issues (Table 1) and appropriate monitoring design. This component has been completed for Porirua Harbour and is reported on in Robertson and Stevens (2007).
2. **Broad Scale Habitat Mapping** (EMP approach). This component, which documents the key habitats within the estuary, and changes to these habitats over time, was undertaken in 2008, and is reported separately in Stevens and Robertson (2008).
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 estuary condition, began in January 2008 (Robertson and Stevens 2008 and 2009). The third year of monitoring was undertaken in January 2010 and is the subject of the current report.

Porirua Harbour, fed by a number of small streams, is a large, well flushed "tidal lagoon" type estuary consisting of two arms, Onepoto (herewith referred to as Porirua) Inlet and Pauatahanui Inlet. Catchment landuse is dominated by urban use in the Porirua Inlet and by grazing in the steeper Pauatahanui Inlet catchment, although urban (residential) development is significant in some areas. The estuary itself is relatively shallow (mean depth approximately 1m), has an extensive intertidal area (35% of estuary exposed at low tide), and supports extensive areas of seagrass growing in firm mud sands. It has high uses and ecological values and provides a natural focal point for the thousands of people that live near, or visit, its shores.

The harbour has been extensively modified over the years, particularly the Porirua Inlet where the once vegetated arms have been reclaimed, and now most of the inlet is lined with rockwalls. The Pauatahanui Inlet is much less modified and has extensive areas of saltmarsh, a large percentage of which have been improved through local community efforts.

A recent report (Gibbs and Cox 2009) identifies sedimentation as a major problem in the estuary and indicates that both estuary arms are highly likely to rapidly infill and change from tidal estuaries to brackish swamps within 145-195 years. The dominant sources contributing to increasing sedimentation rates in the estuary were identified as discharges of both bedload and suspended load from the various input streams (e.g. Pauatahanui and Porirua Streams). Elevated inputs of nutrients from the same streams are also causing symptoms of moderate eutrophication (i.e. poor sediment oxygenation and moderate nuisance macroalgal cover) in the estuary (Stevens and Robertson 2009, Robertson and Stevens 2009).

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


Quadrat for epifauna sampling.

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 Porirua Harbour, four 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 each site, a 60m x 30m area in the lower intertidal was 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 3):
  - Grain size/Particle size distribution (% mud, sand, gravel).
  - Nutrients- total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC).
  - DDT isomers and trace metal contaminants (total recoverable Cd, Cr, Cu, Ni, Pb, Zn). Analyses were based on whole 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 randomly placed sediment core was taken from each of ten plots 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 to a commercial laboratory (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1) for sieving, counting, and identification. Each core was washed through a 0.5mm nylon bag or sieve with the infauna retained and preserved in 70% isopropyl alcohol - seawater solution.

2. Methods (Continued)

Figure 1. Location of sedimentation and fine scale monitoring sites in Porirua Harbour.

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 the 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 Porirua Harbour (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).

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 Evaluation & Response Plan
Very High	>10mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

2. Methods (Continued)

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 below.

The equation to calculate the Mud Tolerance Biotic Coefficient (MTBC) is a s 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 est. Initiate ERP
High	Mud preferred	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very High	Strong muds preference	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Some mud preference	>1.2	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 <1cm (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 Evaluation & Response Plan
Poor	<1cm depth below sediment surface	Monitor at 2 year intervals. Initiate Evaluation & Response Plan
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

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

2. Methods (Continued)

Total Phosphorus

In shallow estuaries like Freshwater 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

Total Nitrogen

In shallow estuaries like Freshwater, 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

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

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

3. RESULTS AND DISCUSSION

OUTLINE

A summary of the results of the 18-19 January 2010 fine scale monitoring of Porirua Harbour 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 Porirua Harbour (2008-2010).

	Site	Reps	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. of Species
			cm	ppt	%				mg/kg								No./m2	No./core
2008	Por A	10	2-3	30	1.33	9.96	88.13	1.90	0.028	11.3	5.1	6.1	8.4	39.4	685	442	9833	20.5
	Por B	10	5	27	0.60	4.03	94.42	1.57	0.041	5.1	3.6	9.5	3.6	59.9	504	158	10410	17.7
	Pau A	3	4	30	1.32	12.23	81.60	6.20	0.029	10.7	4.9	6.5	8.8	36.7	823	447	8175	18.8
	Pau B	3	3	30	0.58	4.50	90.17	5.33	0.020	4.7	2.3	4.7	3.9	23.0	546	150	9405	21.6
2009	Por A	3	2-3	30	0.39	9.23	89.30	1.47	0.034	12.3	5.0	8.5	6.7	41.0	643	397	10103	22.1
	Por B	3	2	28	0.21	5.73	85.80	8.43	0.046	5.6	3.9	3.7	8.9	57.7	<500	147	7455	13.3
	Pau A	3	2	30	0.38	9.93	81.47	8.57	0.025	11.0	4.6	7.7	6.1	35.0	700	437	7388	20.7
	Pau B	3	4	30	0.23	4.43	87.43	8.17	0.019	4.5	2.0	3.4	4.5	21.0	<553	137	9788	17.8
2010	Por A	3	1.5	31	0.26	9.97	88.10	1.93	0.029	10.6	3.8	7.1	5.3	35.7	<500	393	10650	21.8
	Por B	3	1	30	0.19	9.40	88.97	1.67	0.044	5.2	3.4	3.4	9.1	62.3	555	163	10853	15.1
	Pau A	3	1	31	0.35	15.13	80.37	4.50	0.025	10.7	4.8	7.4	6.8	37.3	673	470	10605	24.7
	Pau B	3	1	31	0.23	7.53	88.97	3.53	0.019	4.1	1.8	3.0	4.2	19.3	597	120	11873	23.8
2010	2010 DDT results for all four sites were below detection limits as follows: 2,4'-DDD,< 0.0050; 4,4'-DDD,< 0.0050;2,4'-DDE,< 0.0050; 4,4'-DDE,< 0.0050; 2,4'-DDT,< 0.0050; 4,4'-DDT,< 0.0050; Total DDT Isomers,< 0.030 mg/kg.																	

Note: Macrofauna abundance and species numbers are based on10 replicates per site.

SEDIMENTATION

Soil erosion is a major issue for tidal lagoon estuaries in NZ as they form a sink for fine suspended sediments. Porirua Harbour is particularly at risk because the main subtidal basins are rapidly infilling (Gibbs and Cox 2009).

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. Waihopai Arm, New River Estuary, Invercargill), 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, Wairarapa Coast). In estuaries with undeveloped catchments, like Freshwater Estuary, Stewart Island, the mud content is usually low (<2% mud).

3. Results and Discussion (Continued)

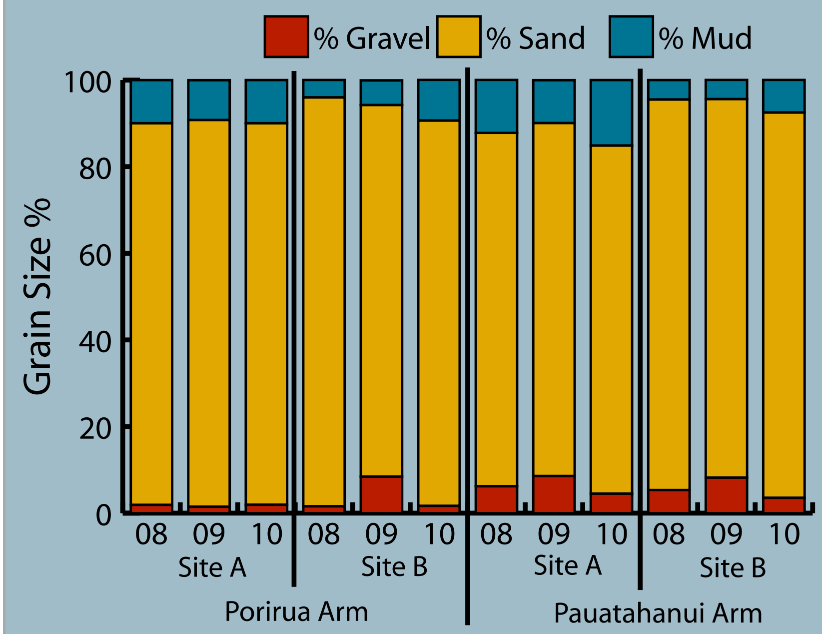


Figure 2. Grain size, Porirua Harbour, Jan 2008, 2009 and 2010.

In order to assess sedimentation in Porirua Harbour, a number of indicators have been used: grain size, sedimentation rate and presence of mud tolerant invertebrates and sedimentation rate.

Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results (Figure 2) show that although the sites were dominated by sandy sediments (80-89% sand in 2010), the mud content was also significant (7-15% mud). Also significant are the facts that;

- the highest mud content at each site between 2008 and 2010 was measured in 2010, and
- the mud content at each site was moderately high compared with fine scale sites in other tidal lagoon type estuaries in the Greater Wellington and Southland regions (Figure 3).

The source of these muds is almost certainly from the surrounding catchment. To address the potential for ongoing sedimentation within the estuary and to measure its magnitude, sediment plates were deployed at the fine scale monitoring sites.

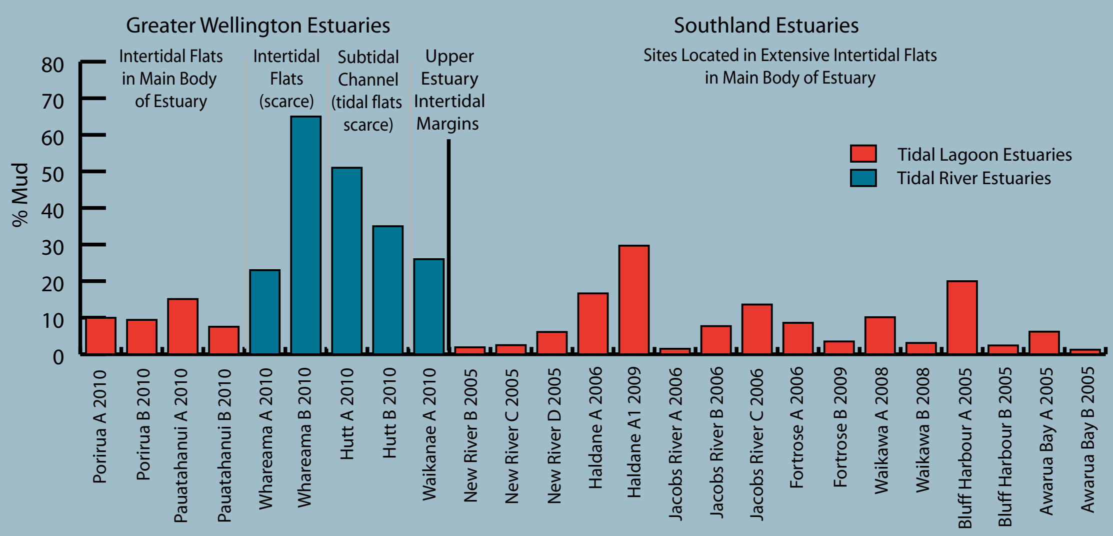


Figure 3. Percent mud content at fine scale monitoring sites, Greater Wellington and Southland estuaries.

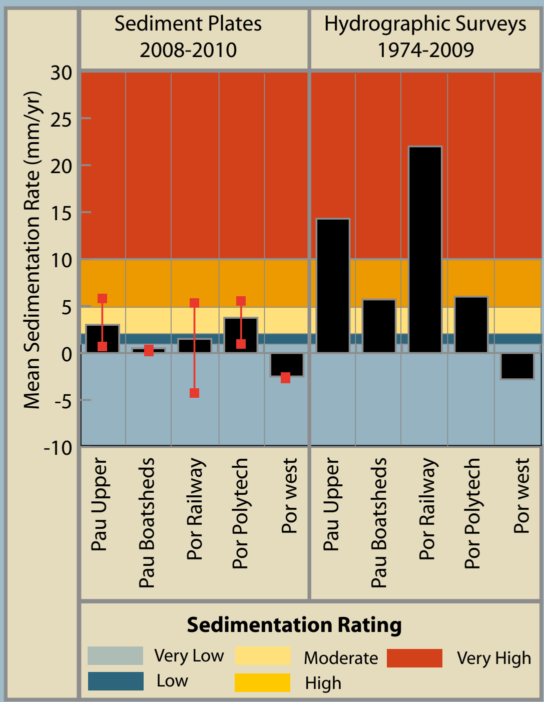


Figure 4. Porirua Harbour mean sedimentation rate (and range) from plate data (2007-2010) and hydrographic surveys 1974-2009 (Gibbs and Cox 2009).

Rate of Sedimentation

Fifteen sedimentation plates were deployed in the estuary in December 2007 and January 2008 to enable long term monitoring of sedimentation rates (Figure 1). Monitoring of the overlying sediment depth above each plate after approximately 2 years of burial was undertaken in the period 18-20 January 2010. The sediment plate results (Figure 4 left) indicated a mean sedimentation rate of -2.5 to 3.75mm/yr. Such rates fit within the "very low to moderate" categories. The highest rate (3.75mm/yr) was recorded in the upper estuary of the Porirua Arm (opposite the Polytech). However, within this site (which is represented by 2 sediment plates), the variability was high (0-14mm) which indicates a need for deployment of additional sedimentation plates to more adequately represent this patchiness. The lowest rate (-2.5mm/yr) was recorded in the western subtidal area of the western Porirua Arm.

Overall, these rates are low compared with the estimated mean sedimentation rate recorded over the 1974-2009 period using hydrographic survey data at these sites (Figure 4 right, Gibbs and Cox 2009). Such differences, however, can be explained if it is assumed that over the 35 year period of 1974-2009 there have been occasional years with very high pulses of sediment input interspersed with long periods of low input. Within this scenario, the 2008-2010 period when the sedimentation plate data was collected would coincide with the period of low input. Under current landuse patterns in NZ, such an assumption is considered highly likely. Very high rates of catchment sediment export have been measured during large floods, exotic forest harvesting, and exposure of large areas of soil during farm cultivation or property development. A recent study in the Motueka sub-catchments found that sediment yields doubled or tripled during exotic forest harvesting periods and high rainfall years (Clapp 2009). Such findings are typical, or in some cases, much lower than results from other catchment studies (Hicks and Harmsworth 1989, O'Loughlin et al. 1980). In order to preserve both arms of the Porirua Harbour as estuaries, Gibbs and Cox (2009) have recently recommended that the current average sedimentation rate of 5-10mm/year be reduced closer to the geologic rate of 1.0-2.0mm/year.

Macro-invertebrate Tolerance to Muds

Sediment mud content is a major determinant of the structure of the benthic invertebrate community. This section examines this relationship in Porirua Harbour in three steps:

1. Comparing the mean abundance and species diversity data with other NZ estuaries to see if there are any major differences (Figures 5 and 6).
2. Using multivariate techniques to explore whether the macro-invertebrate communities at each of the 4 sites differ between each of the three years of monitoring (Figure 7).
3. Using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) to assess the mud tolerance of the Porirua Harbour macro-invertebrate community over the three years of monitoring (Figures 8 and 9).

3. Results and Discussion (Continued)

The first step showed that the macro-invertebrate community at all four sites in Porirua Harbour included a wide range of species (33-42 species recorded in the 10 cores taken at each site in 2008, 27-42 species in 2009 and 27-46 species in 2010). Compared with the intertidal mudflats in other NZ estuaries that drain developed catchments, the community diversity was relatively high (Figure 5). Similarly, the overall community abundance at all four sites in Porirua Harbour was moderate at 7,000-12,000m^2 for all three years of monitoring (Figure 6) compared with other NZ estuaries.

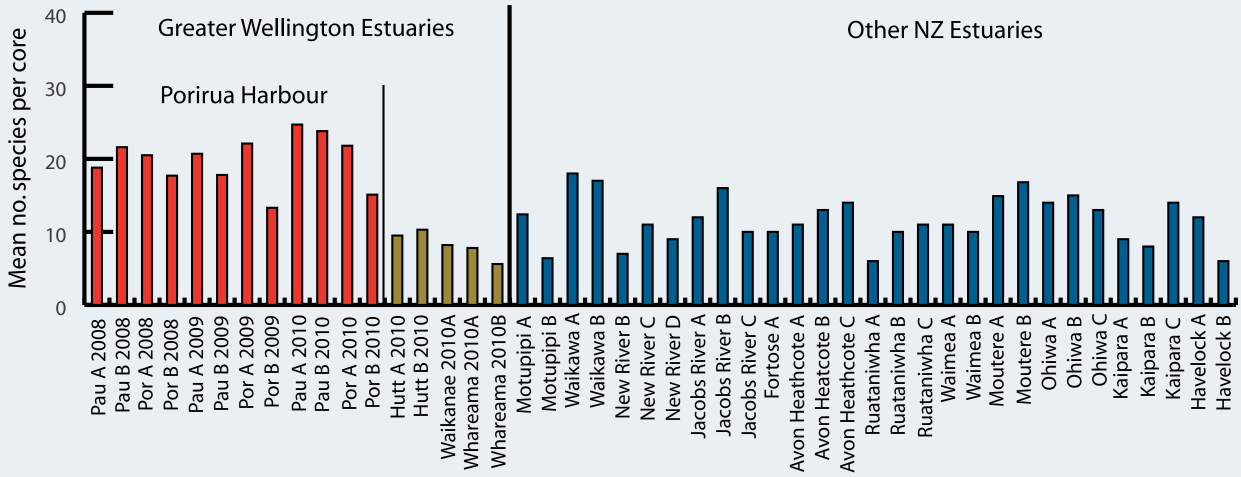


Figure 5. Mean number of infauna species, Porirua Harbour compared with other NZ estuaries.
(Source Robertson et al. 2002, Robertson and Stevens 2006, Robertson and Stevens 2008a, Robertson and Stevens 2010a, b and c).

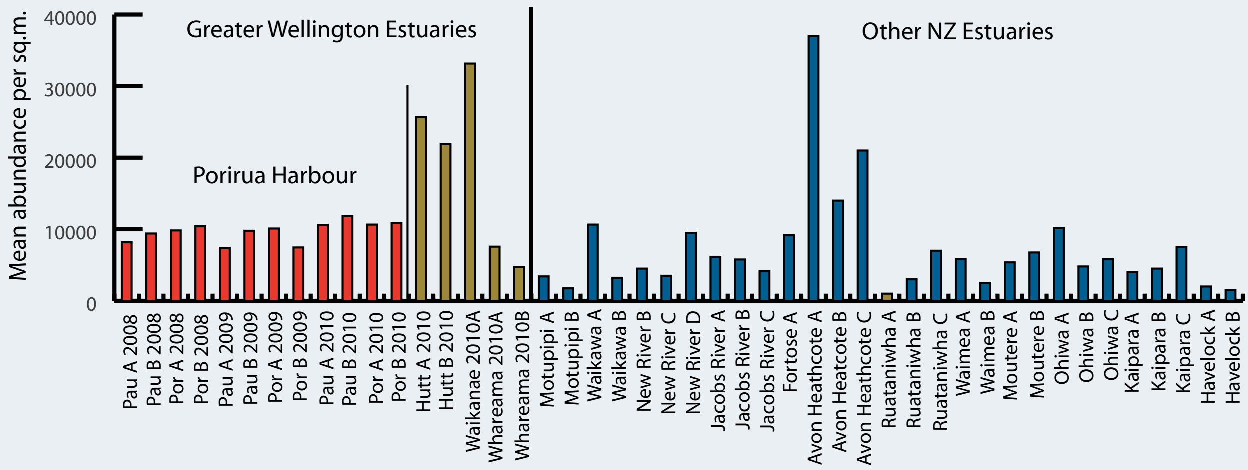
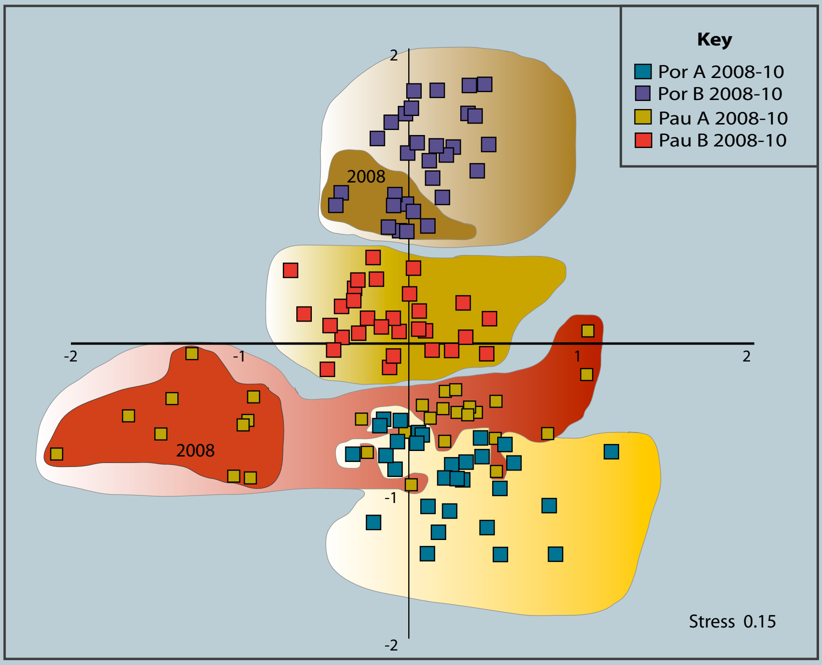


Figure 6. Mean total abundance of macrofauna, Porirua Harbour compared with other NZ estuaries.
(Source Robertson et al. 2002, Robertson and Stevens 2006, Robertson and Stevens 2008a, Robertson and Stevens 2010a, b and c).

In the second step, the results of the multivariate analysis (NMDS Plot, Figure 7) show that there was a difference in benthic invertebrate community structure between each of the sites for all the three years of monitoring. In addition, the plot shows that the communities at Por B and Pau B in 2008 differed from those in 2009 and 2010. Such differences are consistent with the steadily increasing mud content at these sites during this period, although natural variation could also account for such changes as the baseline is still being established.

3. Results and Discussion (Continued)



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 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.

Figure 7. NMDS plot showing the relationship among samples in terms of similarity in macro-invertebrate community composition for Sites Pau A and B, and Por A and B, for 2008, 2009 and 2010.

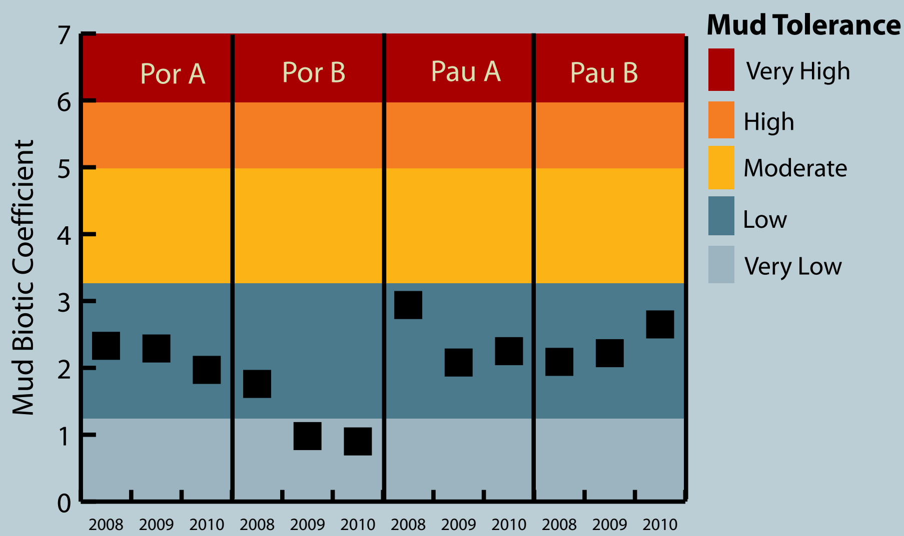


Figure 8. Mud tolerance macro-invertebrate rating.

In the third step, the results show that the Porirua Harbour macro-invertebrate mud tolerance rating was in the "low to very low" category which indicates that the community was dominated by species that prefer sand or a little mud rather than those with a strong mud preference (Figure 8).

These results are explored in more detail in Figure 9. This plot shows that, for each of the three years of monitoring, the benthic invertebrate community was dominated by a variety of polychaete and bivalve species, both of which were intolerant of high mud concentrations. The dominant species included:

Strong Sand Preference Organisms

The small surface deposit-feeding spionid polychaete *Aonides* sp. which has a very strong sand preference and lives throughout the sediment to a depth of 10cm. This species was present in elevated numbers only at the upper Porirua Inlet Site Por B (opposite Porirua Polytech), where mud contents averaged 9.4%. *Aonides* is free-living, not very mobile and is very sensitive to changes in the silt/clay content of the sediment. Its optimum or preferred mud content is in the 0-5% range as is its recorded distribution range (Norkko et al. 2001). Because the measured mud content at Site Por B has increased to a level that is double what the organism is expected to survive in, then it is likely that *Aonides* will disappear from this site unless mud content declines.

Sand Preference Organisms

"Sand preference" organisms were also found at all the sites in 2008-2010, including:

- Cockles - *Austrovenus stutchburyi* and the adult wedge shell - *Macomona liliana*. Both these species are particularly important in that they are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macro-invertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). Cockles are suspension feeders who prefer sand environments with an optimum range of 5-10% mud, but can be also be found sub-optimally in 0-60% mud. *Macomona* is a deposit feeding wedge shell that 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. It is rarely found beneath the RPD layer and is adversely affected at elevated suspended sediment concentrations (optimum range of 0-5% mud but can be also be found sub-optimally in 0-40% mud). Currently, the mud concentrations at the Porirua Harbour intertidal sites (7-15%) are expected to provide favourable habitat for these species.
- The small, deposit feeding, endemic nut clam *Nucula hartvigiana*. Is often abundant intertidally and in shallow water, especially in *Zostera* seagrass flats. It is often found together with cockles, but is not as abundant. This species feeds on organic particles within the sediment and is intolerant of organic enrichment. The highest abundances in Porirua Harbour were found near the sea (Railway and Boatshed sites).
- The small surface deposit-feeding spionid, *Boccardia* sp. which prefers low-moderate mud content but is 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. It is very sensitive to organic enrichment and is usually only present under unenriched conditions.
- The native orbiniid polychaete, *Orbinia papillosa,* which is a long, slender, unselective deposit feeder was also found at the sites in lower numbers. It prefers sand environments with an optimum range of 5-10% mud but can be also be found sub-optimally in 0-40% mud.

Low Mud Preference Organisms (but not high percentages of mud)

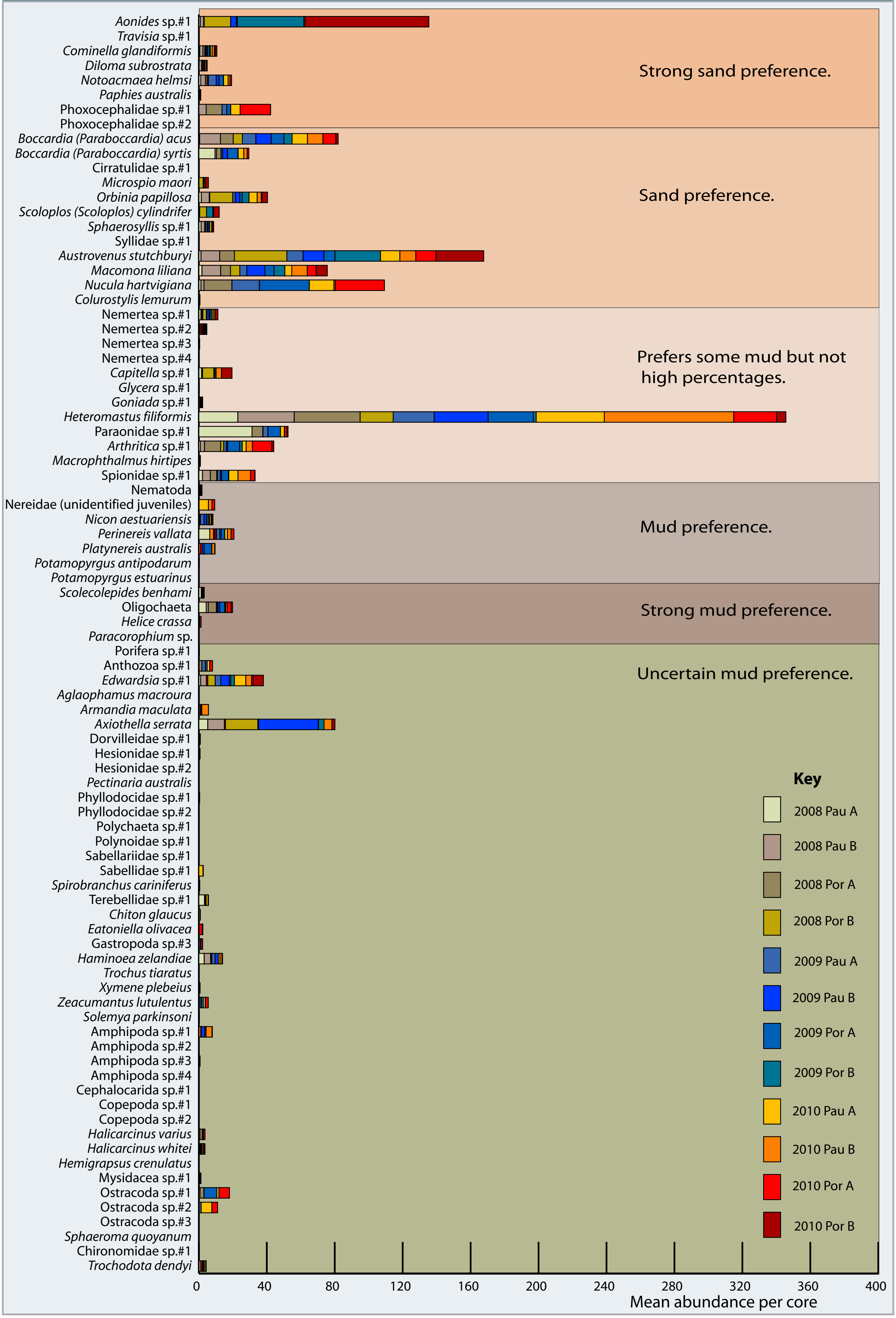
- Organisms that prefer "some mud but not high percentages" were also found at all the sites in 2008-2010, including the ubiquitous capitellid polychaete *Heteromastus filiformis*. This sub-surface, deposit-feeder lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. It also shows a preference for areas of moderate to high organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation has been demonstrated in this species which allows it to survive in elevated concentrations of sulfide and cyanide.

Mud Preference and Strong Mud Preference Organisms

Organisms that prefer "moderate or high mud contents" were also found at the sites but their numbers were low, for example:

- The very active and omnivorous, nereid polychaetes *Perinereis vallata* and *Platynereis australis*.
- The surface deposit feeding spionid polychaete *Scolecolepides benhami*. This spionid is very tolerant of mud, fluctuating salinities, organic enrichment and toxicants (e.g. heavy metals). It 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.

Figure 9. Porirua Harbour 2008-2010 - mud sensitivity of macro-invertebrates at four sites (see Appendix 3 for sensitivity details).



3. Results and Discussion (Continued)

EUTROPHICATION

2010 RPD RATING	Fair

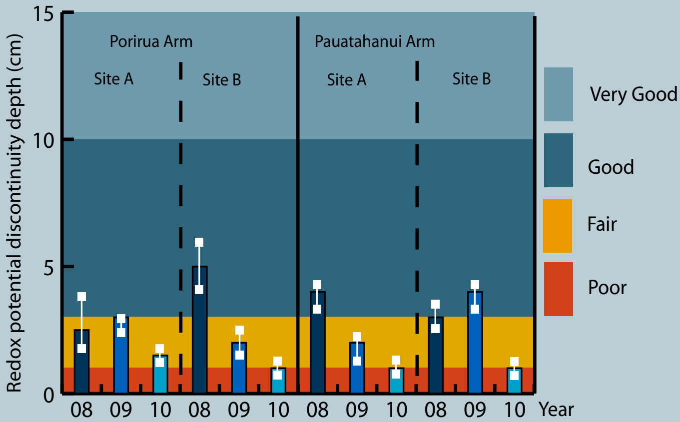


Figure 10. RPD depth (mean and range), Porirua Harbour, Jan 2008, 2009 and 2010.

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 (reported in Stevens and Robertson 2008 and 2009) are the percentages of the estuary covered by macroalgae and soft muds.

Redox Potential Discontinuity (RPD)

Figures 10 and 11 show the sediment profile and RPD depths for the Porirua Harbour and the likely benthic community that is supported at each site based on the measured RPD depth (adapted from Pearson and Rosenberg 1978). The results showed that the 2010 RPD depth in Porirua Harbour fine scale sites was at a relatively shallow depth (1-2cm) and therefore likely to be poorly oxygenated. These RPD ratings were at the shallowest they have been since recordings began in 2008. Such moderately shallow RPD values fit the "fair-poor" condition rating and indicate that the benthic invertebrate community was likely to be in a transitional state.

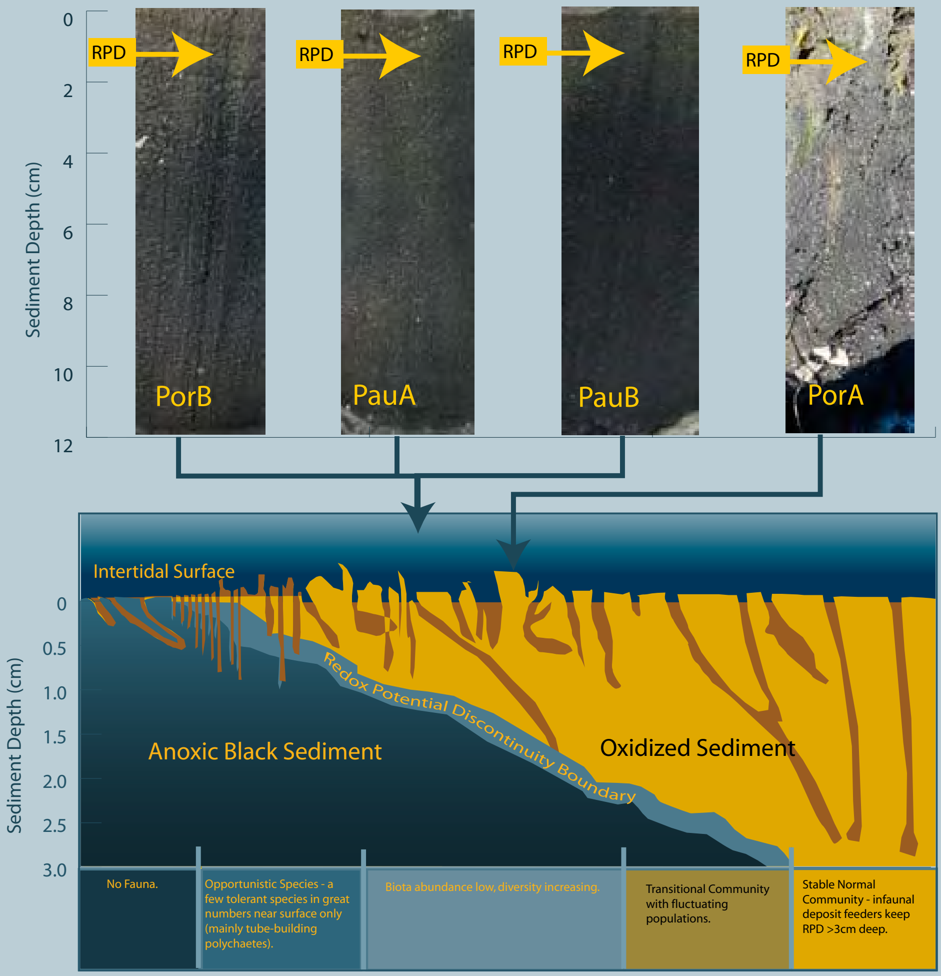


Figure 11. Sediment profiles, depths of RPD and predicted benthic community type, Porirua Harbour, 18-19 January 2010. Arrow below core relates to the type of community likely to be found in the core.

3. Results and Discussion (Continued)

2010 TOC RATING | **Very Good**

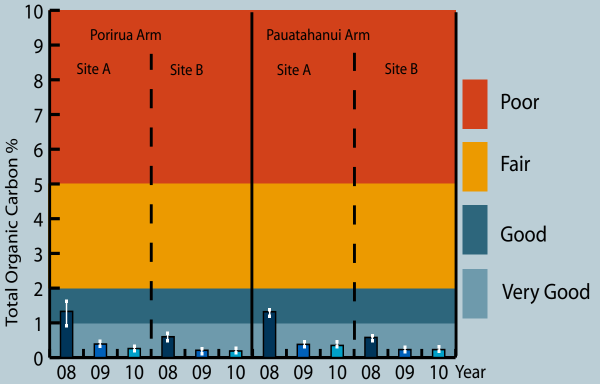


Figure 12. Total organic carbon (mean and range) at 4 intertidal sites, Jan 2008, 2009 and 2010.

2010 TP RATING | **Good-Very Good**

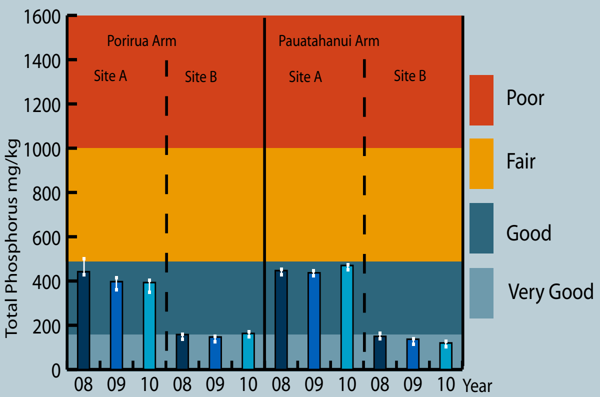


Figure 14. Total phosphorus (mean and range) at 4 intertidal sites, Jan 2008, 2009 and 2010.

2010 TN RATING | **Good**

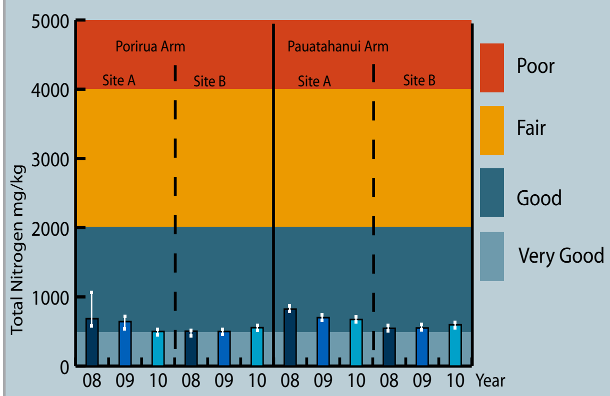


Figure 15. Total nitrogen (mean and range) at 4 intertidal sites, Jan 2008, 2009 and 2010.

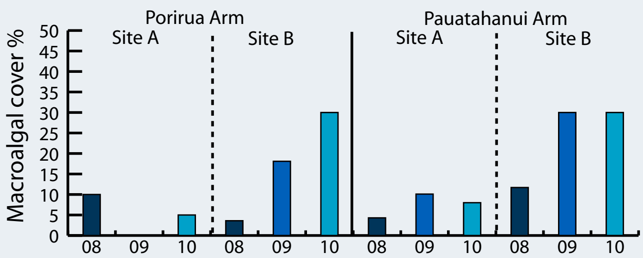
ORGANIC MATTER (TOC)

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 all four 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. Since 2009, TOC has been measured directly.

Also of interest in relation to the potential for increased sediment organic matter in the future, was the continuing elevated cover of surface macroalgae (*Enteromorpha* and *Gracilaria* sp.) at the fine scale sites in the upper areas of both estuary arms in 2010 (Figure 13).

Figure 13. Percentage macroalgal cover at 4 intertidal sites, Jan 2008, 2009 and 2010.



TOTAL PHOSPHORUS

Total phosphorus (a key nutrient in the eutrophication process) was present in the "low to moderate enrichment" or "very good to good" categories (Figure 14) at the two muddier sites in each arm (mean 393 and 470mg/kg at Por A and Pau A), but at the two sandier sites (Por B and Pau B), it was in the "very good" category (mean 163 and 120mg/kg respectively). These 2010 results were similar to those measured in 2008 and 2009.

TOTAL NITROGEN

Total nitrogen (the other key nutrient in the eutrophication process) was in the "low to moderate enrichment" or "good" category (Figure 15) at all 4 sites (mean <500 to 673mg/kg). Like phosphorus, these 2010 nitrogen results were similar to those measured in 2008 and 2009.

3. Results and Discussion (Continued)

Macro-invertebrate Organic Enrichment Index

The benthic invertebrate organic enrichment rating for the Porirua Harbour was in the "good" or "low" category, indicating slight to moderate organic enrichment for 2008, 2009 and 2010 (Figure 16). Such a rating likely reflects the low-moderate sediment nutrient concentrations in this estuary. As in previous years, the 2010 conditions resulted in a community dominated by a broad range of species sensitivities (Figure 17) including:

- Large numbers and elevated abundances of species that are very sensitive to organic enrichment (e.g. cockles *Austrovenus stutchburyi*, the wedge shell *Macomona liliana*, and the polychaetes *Boccardia* sp., *Orbinia papillosa* and the deep burrowing *Axiothella serrata*).
- Large numbers, but low abundances, of species that are indifferent to organic enrichment (slightly unbalanced) for example, the burrowing anemone *Edwardsia* sp. and various polychaetes.
- Large numbers and elevated abundances of species that are tolerant of excess organic enrichment (unbalanced situation) for example, the endemic nut clam *Nucula hartvigiana*, the small bivalve *Arthritica* sp, and various polychaetes including *Aonides* sp., and the nereids *Perinereis vallata* and *Platynereis australis*.
- High abundances of one particular species (the polychaete *Heteromastus filiformis*) that is a 2nd order opportunistic species and therefore very tolerant of organic enrichment (slight to pronounced unbalanced situations).
- Low abundances of one particular species (the polychaete *Capitella* sp.) that is a 1st order opportunistic species and therefore highly tolerant of organic enrichment (pronounced unbalanced situations).

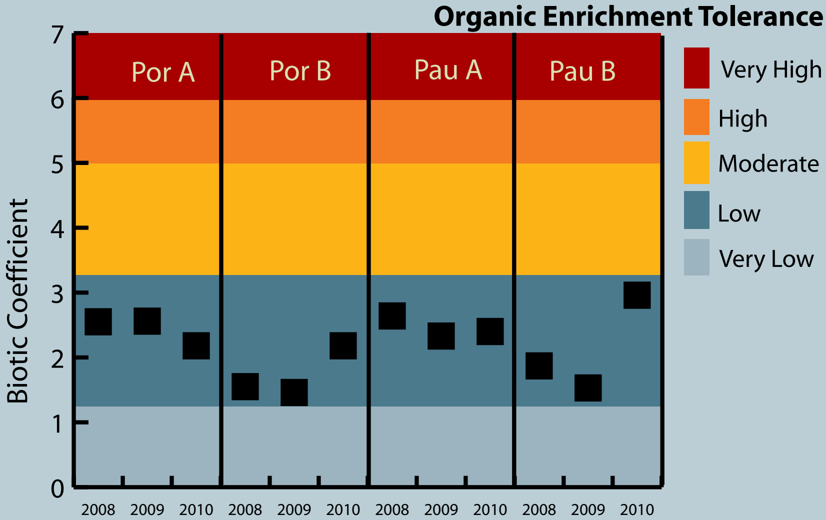
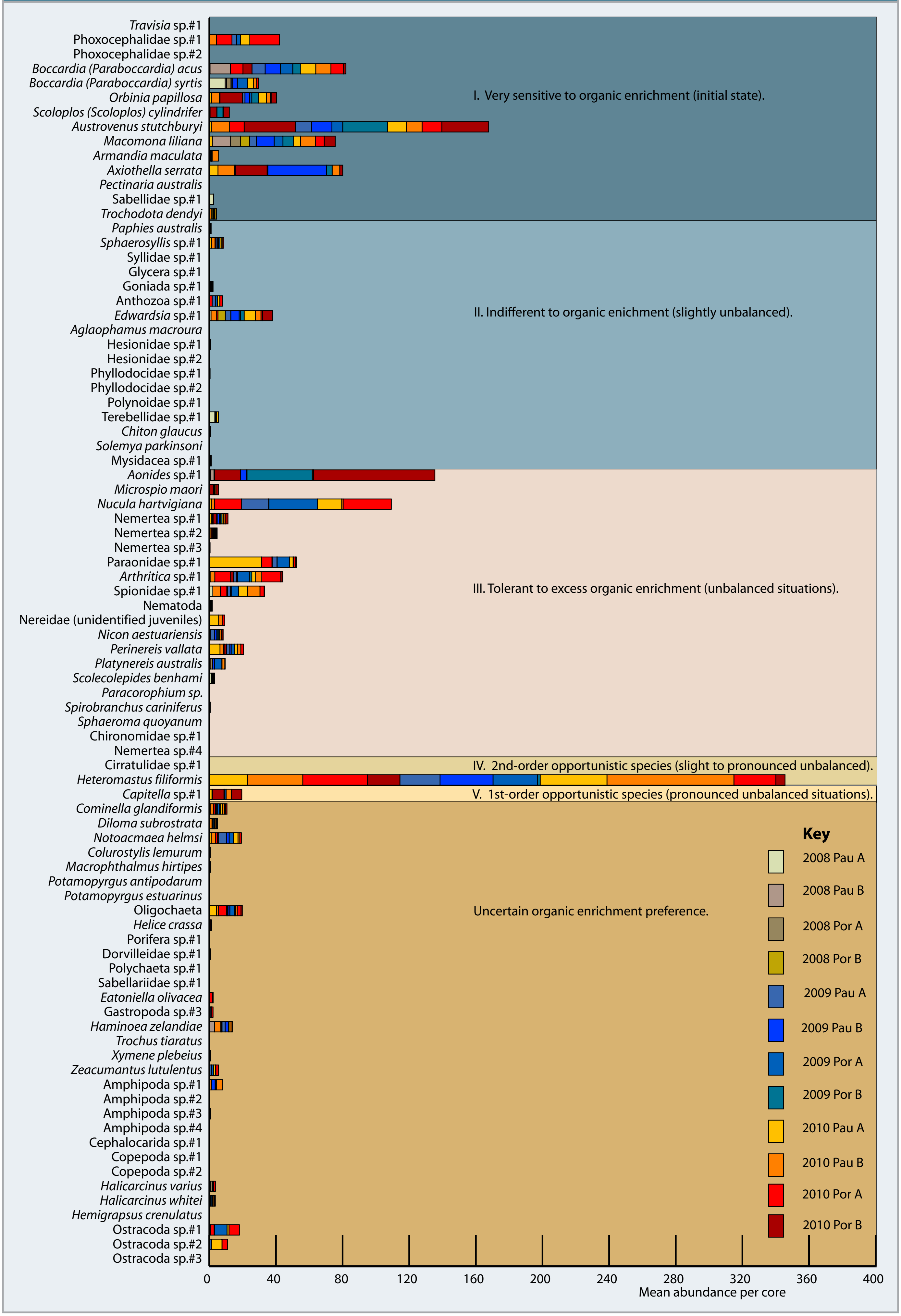


Figure 16. Benthic invertebrate organic enrichment rating, Porirua Harbour, Jan 2008, 2009 and 2010.

Figure 17. Porirua Harbour 2008-2010 - macroinvertebrate organic enrichment sensitivity (see Appendix 3 for sensitivity details).



EPIFAUNA

Visible surface dwelling organisms (epifauna) were also recorded using quadrats rather than the much smaller cores used to sample the whole benthic community (i.e. infauna and epifauna). These results, although not used in the benthic community index, demonstrate the typical highly variable nature of epifauna communities. In all three years of monitoring, epifauna were both more abundant and more diverse in the Pauatahanui Arm and the seaward end of the Porirua Arm - Site Por A opposite Mana Railway (Figures 18 and 19) than compared with the upper end of the Porirua Arm adjacent to Porirua City. In terms of composition, the epifaunal communities in the Pauatahanui Arm included a typical array of shellfish including cockles, whelks, topshells, limpets, spire shells and bubble shells, as well as the mudflat anemone. In the Porirua Arm, the epifauna was less diverse and included cockles, whelks, topshells, limpets and spire shells.

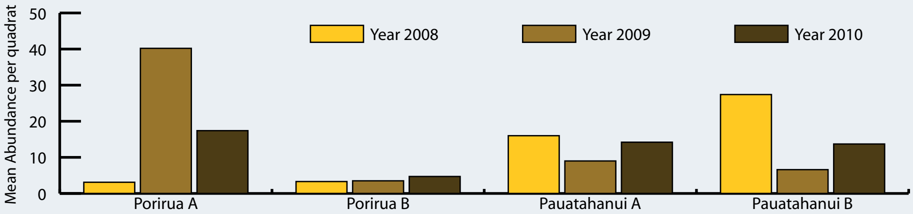


Figure 18. Mean abundance of epifauna per quadrat - Porirua Harbour and other NZ estuaries (source Robertson et al. 2002, Robertson and Stevens 2006).

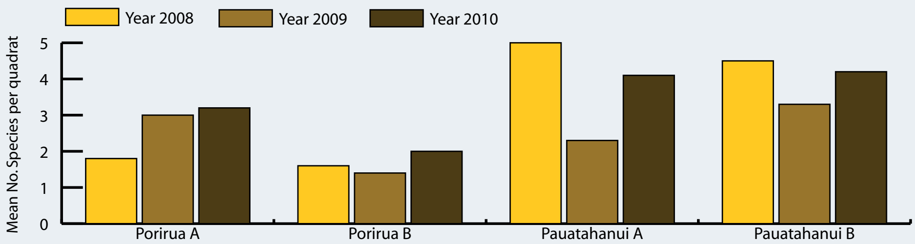


Figure 19. Mean number of epifauna species per quadrat - Porirua Harbour and other NZ estuaries (source Robertson et al. 2002, Robertson and Stevens 2006).

TOXICITY

METALS 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 20). In 2010 metals met the "very good" condition rating for cadmium, chromium, copper, and lead at all sites, zinc in the two Pauatahanui sites and at Por A, and nickel at the two upper estuary sites (Por B and Pau B). Metals met the "good" rating for nickel at the two lower estuary sites (Por A and Pau A) and zinc (Por B).

DDT The organochloride pesticide DDT and its various isomers were also measured at each site in 2010. The results confirmed that total DDT concentrations in all samples were below detection limits (<0.03 ug/kg dry weight) and therefore well below the ANZECC ISQG-Low trigger criteria of 1.6 ug/kg dry weight (Appendix 2).

It is important to note that the National Estuary Monitoring Protocol targets representative broad intertidal areas of the estuary, not localised areas of potential enrichment around stormwater outfalls and stream inputs. Other studies of the Harbour (e.g. Sorensen and Milne 2009) that target these latter areas, or subtidal muds (e.g. Milne et al. 2009), report more elevated concentrations of potential toxicants.

3. Results and Discussion (Continued)

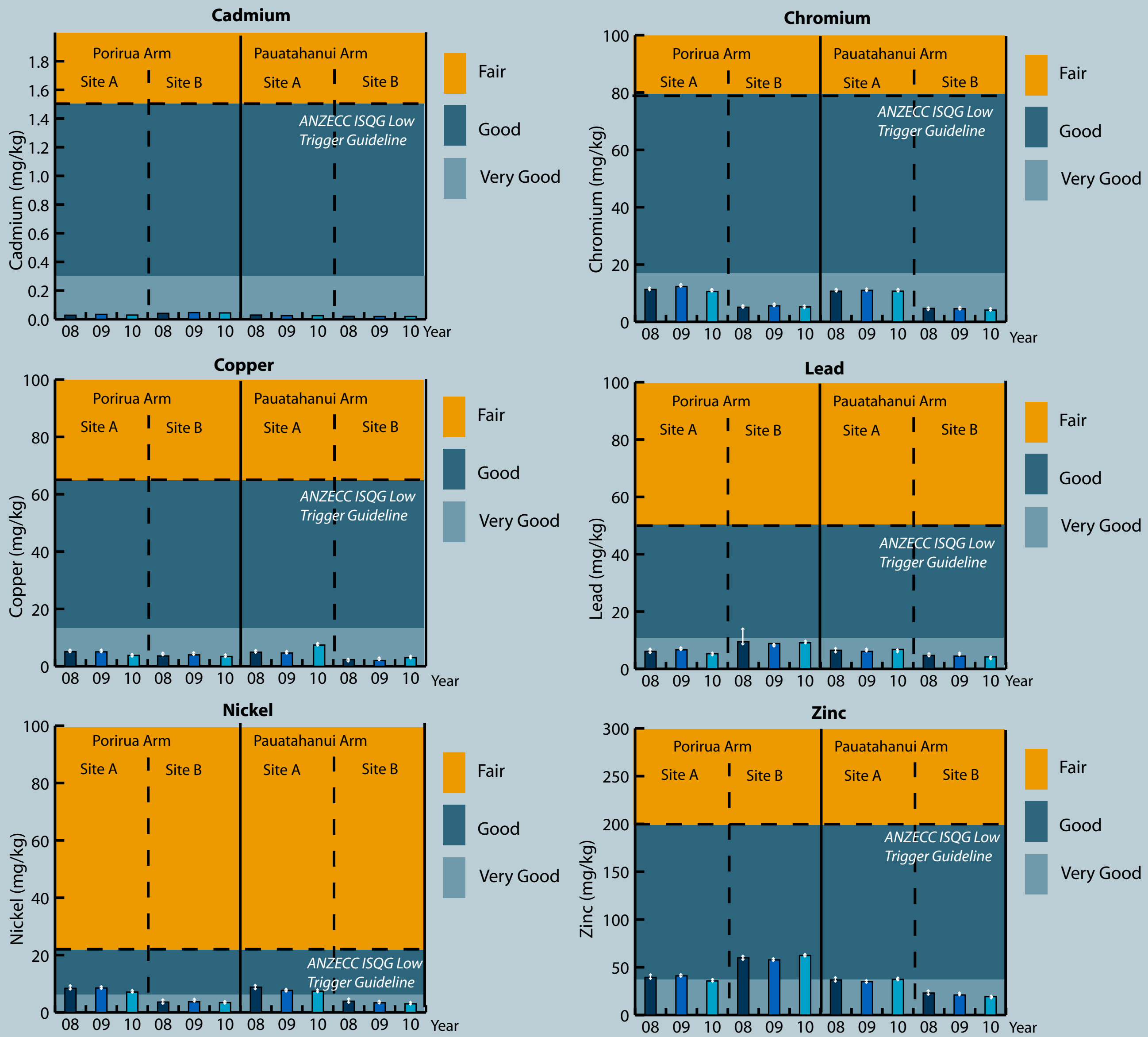


Figure 20. Total recoverable metals (mean and range) at 4 intertidal sites, Porirua Harbour Jan 2008, 2009 and 2010.

4. CONCLUSIONS

In conclusion, the third year of intertidal fine scale monitoring results for a range of physical, chemical and biological indicators of estuary condition show that the dominant intertidal habitat in Porirua Harbour was unvegetated muddy sand and was generally in "good" to "moderate" condition with a diverse and healthy invertebrate community. In relation to the key issues addressed by the fine scale monitoring: sedimentation, eutrophication and toxicity, the results are similar to those found in the first year of the baseline (2008). That is:

- A moderately eutrophic estuary, with low-moderate nutrients (TN and TP) and organic content, and a relatively shallow RPD layer at all sites.
- Low-moderate sedimentation in the intertidal zone and a general trend of increasing muddiness.

4. Conclusions (Continued)

- A macro-invertebrate community that shows a preference for organisms that prefer low mud content and low organic enrichment, but also includes some that can withstand high mud contents and organic enrichment. Such a community is relatively healthy and diverse but is prone to loss of sensitive species if there is a shift towards increased muddiness and/or nutrient enrichment.
- Low intertidal sediment toxicity (based on heavy metal data). Other studies targeting stormwater outfalls and stream inputs have shown more elevated sediment toxicity is present in localised areas, with sediment metal concentrations generally highest in the mud-enriched subtidal basins.

5. MONITORING

The monitoring to date shows that the Porirua Harbour has a high priority for ongoing monitoring. This arises because the estuary is large, has high ecological and human use vales and is very vulnerable to excessive sedimentation, eutrophication and disease risk. For example, although the estuary still supports extensive populations of mud intolerant species, if sedimentation continues at the current high rates then such populations are likely to be lost in the near future. Establishing a comprehensive monitoring baseline is therefore more important in such estuaries compared with smaller, less vulnerable, estuaries in the region. The National Estuary Monitoring Protocol (Robertson et al. 2002) recommends four years of baseline monitoring for such estuaries.

Because fine scale monitoring of Porirua Harbour has now been undertaken for three years, it is recommended that one more year of fine scale monitoring (including sedimentation rate and macroalgal mapping) be undertaken in January 2011. As suggested but not initiated last year, it is recommended that additional sediment plates be deployed in upper Porirua Arm (Polytech site) in 2011 to better account for the patchiness of sediment deposition at this important site (i.e. a site that is both vulnerable to urban rural runoff and representative of upper Porirua Arm estuary conditions).

Nutrient Monitoring (Catchment Inputs and Estuary Water Column). In order to develop sediment and nutrient budgets, nutrient and suspended sediment inputs from major sources during both baseflow and flood conditions should also be monitored. Nutrient and chlorophyll a concentrations in the water column of Porirua Harbour should also be monitored in order to assess the potential for nuisance conditions.

6. MANAGEMENT

The combined results of the 2008 to 2010 fine scale monitoring reinforce the need for management of fine sediment, nutrients, and toxicant inputs to the estuary.

In particular the following specific management actions are recommended:

- Limit nitrogen inputs to the estuary to levels that will not cause nuisance algal blooms i.e. limit estuary areal loading to $50mgN.m^{-2}.d^{-1}$ (Heggie 2006) which equates to mean catchment yields of 50 and 100 tonnes N/yr for the Porirua and Pauatahanui Arm catchments respectively (approximately 7-9 kgN/ha/yr). Currently the estuary areal N load is unknown and consequently there is a recommendation above to undertake input monitoring to rectify this.
- Limit suspended sediment catchment inputs to the estuary to levels that will not cause excessive estuary infilling i.e. limit sedimentation rates to 2 mm/yr (Gibbs and Cox 2009). The catchment SS input load required to meet this limit is currently unknown and therefore sediment budget monitoring/modelling is recommended to rectify this.

7. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMEC	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
DDT Isomers	R.J Hill	Sonication extraction, Florasil cleanup, GC-ECD analysis	see results

* 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. 2010 DETAILED RESULTS

Physical and chemical results for Porirua Harbour, 18-19 January 2010.

	Site	Rep.*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
			cm	ppt@15^{0}C	%				mg/kg							
Porirua Arm	Por A	1-4	2.0	31	0.31	12.2	86.3	1.5	0.032	11	4	7.3	5.5	37	< 510	380
	Por A	5-8	1.2	31	0.25	9.8	88.4	1.8	0.029	11	3.9	7	5.4	36	< 500	410
	Por A	9-10	1	31	0.21	7.9	89.6	2.5	0.026	9.9	3.5	7	4.9	34	<500	390
	Por B	1-4	1	30	0.21	8.3	90.8	0.9	0.046	5.2	3.8	3.3	9.1	63	510	170
	Por B	5-8	1	30	0.19	9.9	88.8	1.3	0.047	5.1	3.3	3.5	9.1	61	< 500	170
	Por B	9-10	1	30	0.18	10	87.3	2.8	0.039	5.2	3.1	3.5	9.1	63	600	150
Pautahanui Arm	Pau A	1-4	1	31	0.31	13.9	80.4	5.7	0.025	11	4.8	7.3	6.5	37	590	470
	Pau A	5-8	1	31	0.34	14.1	83.7	2.2	0.026	11	4.9	7.7	7	38	690	500
	Pau A	9-10	1	31	0.4	17.4	77	5.6	0.024	10	4.8	7.3	7	37	740	440
	Pau B	1-4	1	31	0.21	6.7	90.2	3.1	0.016	3.7	1.6	2.7	3.8	18	570	110
	Pau B	5-8	1	31	0.26	8.3	86.7	5	0.021	4.2	1.9	3.1	4.6	20	680	140
	Pau B	9-10	1	31	0.21	7.6	90	2.5	0.019	4.3	1.8	3.1	4.2	20	540	110

* composite samples

Site		2,4'-DDD	4,4'-DDD	2,4'-DDE	4,4'-DDE	2,4'-DDT	4,4'-DDT	Total DDT Isomers
		mg/kg						
Porirua Arm	Por A	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.030
	Por B	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.030
Pauatahanui Arm	Pau A	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.030
	Pau B	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.030

Sediment Plate Depths (mm).

Estuary Arm	Site	13/12/07	15/1/09	19-20/1/10	2007-2010 Mean Sed. Rate (mm/yr)	Site Mean (mm/yr)
Porirua	Lower (Railway)	168	164	159	-4.5	1.5
	Lower (Railway)	150	152	158	4	
	Lower (Railway)	152	155	163	5.5	
	Lower (Railway)	93	95	95	1	
	Upper (Polytech d/s)	237	237	240	1.5	3.75
	Upper (Polytech u/s)	230	244	242	6	
	Western Subtidal	120	Not measured	115	-2.5	-2.5
Pauatahanui	Upper East Arm	181	182	186	2.5	3
	Upper East Arm	215	218	228	6.5	
	Upper East Arm	182	186	183	0.5	
	Upper East Arm	176	177	181	2.5	
	Paremata Boatsheds	Not measured	171	172	1	0.5
	Paremata Boatsheds	Not measured	213	213	0	
	Paremata Boatsheds	Not measured	232	232	0	
	Paremata Boatsheds	Not measured	234	235	1	

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

Station Locations

Porirua A	PorA-01	PorA-02	PorA-03	PorA-04	PorA-05	PorA-06	PorA-07	PorA-08	PorA-09	PorA-10
NZTM EAST	1756457	1756462	1756461	1756472	1756480	1756477	1756477	1756469	1756478	1756494
NZTM NORTH	5447774	5447786	5447804	5447820	5447819	5447804	5447791	5447770	5447774	5447811

Porirua B	PorB-01	PorB-02	PorB-03	PorB-04	PorB-05	PorB-06	PorB-07	PorB-08	PorB-09	PorB-10
NZTM EAST	1754615	1754560	1754554	1754545	1754558	1754562	1754568	1754575	1754580	1754587
NZTM NORTH	5445422	5445483	5445498	5445508	5445513	5445505	5445493	5445484	5445486	5445503

Pauatahanui A	PauA-01	PauA-02	PauA-03	PauA-04	PauA-05	PauA-06	PauA-07	PauA-08	PauA-09	PauA-10
NZTM EAST	1757243	1757246	1757245	1757246	1757241	1757241	1757219	1757230	1757235	1757246
NZTM NORTH	5448644	5448669	5448602	5448613	5448627	5448640	5448644	5448620	5448613	5448601

Pauatahanui B	PauB-01	PauB-02	PauB-03	PauB-04	PauB-05	PauB-06	PauB-07	PauB-08	PauB-09	PauB-10
NZTM EAST	1760358	1760357	1760360	1760362	1760366	1760364	1760364	1760366	1760377	1760378
NZTM NORTH	5448343	5448308	5448318	5448300	5448303	5448311	5448329	5448351	5448349	5448341

Epifauna (numbers per 0.25m^2 quadrat) - 18-19 January 2010

Porirua A

Scientific name	Common name	PorA-01	PorA-02	PorA-03	PorA-04	PorA-05	PorA-06	PorA-07	PorA-08	PorA-09	PorA-10
Austrovenus stutchburyi	Cockle	0	10	16	3	12	13	8	11	11	8
Haminoea zelandiae	Bubble shell										1
Cominella glandiformis	Mudflat whelk	1	1	2	4	1	2	2	5	4	2
Diloma subrostrata	Mudflat topshell		2		6	8	14	4	5	2	9
Zeacumantus lutulentus	Spire shell				1	2	4				

Porirua B

Scientific name	Common name	PorB-01	PorB-02	PorB-03	PorB-04	PorB-05	PorB-06	PorB-07	PorB-08	PorB-09	PorB-10
Austrovenus stutchburyi	Cockle	1					3	2	6		1
Cominella glandiformis	Mudflat whelk		1					1			1
Zeacumantus lutulentus	Spire shell	2		5	4	1	3	3	1	5	1
Diloma subrostrata	Mudflat topshell	*2*			*2*	*2*					

Pauatahanui A

Scientific name	Common name	PauA-01	PauA-02	PauA-03	PauA-04	PauA-05	PauA-06	PauA-07	PauA-08	PauA-09	PauA-10
Austrovenus stutchburyi	Cockle			3	3	2	3		2	4	
Haminoea zelandiae	Bubble shell		1				1	1	3	1	
Cominella glandiformis	Mudflat whelk		2		1	1	3	1	4	6	3
Diloma subrostrata	Mudflat topshell	9	2		5	1	1	4	4	2	
Notoacmea helmsii	Estuarine limpet	7	3		2		4	10	2	1	
Zeacumantus lutulentus	Spire shell	*1*	*6*	*5*	*18*	*6*		*3*		*1*	

Pauatahanui B

Scientific name	Common name	PauB-01	PauB-02	PauB-03	PauB-04	PauB-05	PauB-06	PauB-07	PauB-08	PauB-09	PauB-10
Austrovenus stutchburyi	Cockle	1	1	2				6	8	6	4
Haminoea zelandiae	Bubble shell	5			4	7	2	6	3	2	3
Cominella glandiformis	Mudflat whelk	4	5	5	4	5	4	2	1	1	2
Diloma subrostrata	Mudflat topshell		1	2	1	1	1				4
Notoacmea helmsi	Estuarine limpet		1	2							
Zeacumantus lutulentus	Spire shell	1	4	1	1	5	10	3	3	3	

Infauna (numbers per 0.0133m^2 core) - 15-16 January 2009: See following pages

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Por A-01	Por A-02	Por A-03	Por A-04	Por A-05	Por A-06	Por A-07	Por A-08	Por A-09	Por A-10
ANTHOZOA	Anthozoa sp.#1	II	2		2	2	3		1	3		4
	Edwardsia sp.#1	II			2	3						4
NEMERTEA	Nemertea sp.#1	III	1									
	Nemertea sp.#2	III			1							1
	Nemertea sp.#3	III										
NEMATODA	Nematoda	III		1								
POLYCHAETA	*Aglaophamus macroura*	II										
	Aonides sp.#1	III										
	Armandia maculata	I										
	Axiothella serrata	I										
	Boccardia (Paraboccardia) acus	I	9	4	8	15	5	2	3	6		24
	Boccardia (Paraboccardia) syrtis	I			3	1	1	1	2	1		1
	Capitella sp.#1	V										
	Cirratulidae sp.#1	IV										
	Dorvilleidae sp.#1	NA		1								
	Glycera sp.#1	II			1		1					
	Goniada sp.#1	II									1	
	Hesionidae sp.#1	II										
	Hesionidae sp.#2	II			1							
	Heteromastus filiformis	IV	75	22	36	21	6	12	21	29	10	20
	Microspio maori	III										
	Nereidae (unidentified juveniles)	III	1		1	6	3		3		1	1
	Nicon aestuariensis	III		2								1
	Orbinia papillosa	I			1		2					1
	Paraonidae sp.#1	III	1		1		1		1	1	4	5
	Perinereis vallata	III	3	5	2	3	1		3			
	Phyllodocidae sp.#1	II										
	Phyllodocidae sp.#2	II										
	Platynereis australis	III						1	1			
	Polynoidae sp.#1	II										
	Sabellidae sp.#1	I										
	Scolecolepides benhami	III								1		
	Scoloplos (Scoloplos) cylindrifer	I										
	Sphaerosyllis sp.#1	II			1	1			1			3
	Spionidae sp.#1	III	2	2	7	3	2	1		1	1	6
	Spirobranchus cariniferus	III										
	Syllidae sp.#1	II										
	Terebellidae sp.#1	II							2			
	Travisia sp.#1	I										
OLIGOCHAETA	Oligochaeta	NA	2	2	2	1	1	3		4	4	4
POLYPLACOPHORA	*Chiton glaucus*	II									1	

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Por A-01	Por A-02	Por A-03	Por A-04	Por A-05	Por A-06	Por A-07	Por A-08	Por A-09	Por A-10
GASTROPODA	*Cominella glandiformis*	NA		1		1	2	1		1		
	Diloma subrostrata	NA				3			1	2		
	Eatoniella olivacea	NA	1				1					
	Gastropoda sp.#3	NA	4			1		2		2		1
	Haminoea zelandiae	NA	2				1					
	Notoacmaea helmsi	NA		1		2	1		4			1
	Potamopyrgus antipodarum	NA										
	Potamopyrgus estuarinus	NA										
	Trochus tiaratus	NA										
	Xymene plebeius	NA	2			1			1			
	Zeacumantus lutulentus	NA		1	2	2	3	1	3		2	2
BIVALVIA	*Arthritica sp.#1*	III	33	8	12	10	1	1	21	12	1	15
	Austrovenus stutchburyi	I	6	13	17	11	15	8	9	13	6	21
	Macomona liliana	I	2	5	6	5	7	5	8	4	4	6
	Nucula hartvigiana	III	27	15	46	36	36	35	27	25	17	25
	Paphies australis	II										
	Solemya parkinsoni	II										
CRUSTACEA	Amphipoda sp.#1	NA	1									
	Amphipoda sp.#2	NA										
	Amphipoda sp.#3	NA	3					1			1	
	Amphipoda sp.#4	NA										
	Colurostylis lemurum	NA	1									
	Copepoda sp.#1	NA										
	Copepoda sp.#2	NA				1						
	Halicarcinus varius	NA	2		3		1		1		2	
	Halicarcinus whitei	NA					1				1	1
	Helice crassa	NA	1			1	1	2	1		2	
	Macrophthalmus hirtipes	NA										
	Mysidacea sp.#1	II										
	Ostracoda sp.#1	NA	18	1	3	2	8	3	20	4	2	1
	Ostracoda sp.#2	NA	16	1	4			2	4	5	1	1
	Ostracoda sp.#3	NA										
	Paracorophium sp.	III										
	Phoxocephalidae sp.#1	I	45	11	15	1	10	24	20	15	22	16
	Phoxocephalidae sp.#2	I										
	Sphaeroma quoyanum	III										
INSECTA	Chironomidae sp.#1	III										
HOLOTHUROIDEA	*Trochodota dendyi*	I										
Total species in sample			25	18	24	24	25	18	23	18	19	24
Total individuals in sample			260	96	177	133	114	105	158	129	83	165

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Por B-01	Por B-02	Por B-03	Por B-04	Por B-05	Por B-06	Por B-07	Por B-08	Por B-09	Por B-10
ANTHOZOA	Anthozoa sp.#1	II										
	Edwardsia sp.#1	II	3	5	8	7	6	4	4	10	9	5
NEMERTEA	Nemertea sp.#1	III	1	1	4		1	1	1	2	3	3
	Nemertea sp.#2	III								1	1	1
	Nemertea sp.#3	III										
NEMATODA	Nematoda	III								1		
POLYCHAETA	*Aglaophamus macroura*	II										
	Aonides sp.#1	III	123	70	84	97	110	83	93	36	13	20
	Armandia maculata	I										
	Axiothella serrata	I	2	3		2	2	2	1	1	4	1
	Boccardia (Paraboccardia) acus	I	2	1	2	4		3		1		1
	Boccardia (Paraboccardia) syrtis	I										
	Capitella sp.#1	V	6	5	5	12	5	5	4	11	4	5
	Cirratulidae sp.#1	IV										
	Dorvilleidae sp.#1	NA										
	Glycera sp.#1	II										
	Goniada sp.#1	II										
	Hesionidae sp.#1	II										
	Hesionidae sp.#2	II										
	Heteromastus filiformis	IV	3	3	7	12	8	9	3		6	4
	Microspio maori	III	1	3	2	1	3	2	2	1	1	1
	Nereidae (unidentified juveniles)	III										
	Nicon aestuariensis	III		3		1			2			1
	Orbinia papillosa	I	2	4	3	1	3		3	9	4	4
	Paraonidae sp.#1	III	1	4		1						
	Perinereis vallata	III										
	Phyllodocidae sp.#1	II										
	Phyllodocidae sp.#2	II										
	Platynereis australis	III										
	Polynoidae sp.#1	II										
	Sabellidae sp.#1	I										
	Scolecolepides benhami	III										
	Scoloplos (Scoloplos) cylindrifer	I	2	3	1	4	3	4	2	6	2	6
	Sphaerosyllis sp.#1	II										
	Spionidae sp.#1	III		1		1						
	Spirobranchus cariniferus	III										
	Syllidae sp.#1	II										
	Terebellidae sp.#1	II										
	Travisia sp.#1	I										
OLIGOCHAETA	Oligochaeta	NA				5	2	1				
POLYPLACOPHORA	*Chiton glaucus*	II										

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Por B-01	Por B-02	Por B-03	Por B-04	Por B-05	Por B-06	Por B-07	Por B-08	Por B-09	Por B-10
GASTROPODA	*Cominella glandiformis*	NA			1	2		1		1	3	1
	Diloma subrostrata	NA										
	Eatoniella olivacea	NA										
	Gastropoda sp.#3	NA										
	Haminoea zelandiae	NA										
	Notoacmaea helmsi	NA										
	Potamopyrgus antipodarum	NA										
	Potamopyrgus estuarinus	NA										
	Trochus tiaratus	NA										
	Xymene plebeius	NA										
	Zeacumantus lutulentus	NA										
BIVALVIA	*Arthritica sp.#1*	III	1	3	4			3	1			
	Austrovenus stutchburyi	I	38	25	34	34	20	30	16	28	20	36
	Macomona liliana	I	3	3	8	7	7	9	7	10	4	8
	Nucula hartvigiana	III										
	Paphies australis	II			1						1	
	Solemya parkinsoni	II										
CRUSTACEA	Amphipoda sp.#1	NA					1					
	Amphipoda sp.#2	NA										
	Amphipoda sp.#3	NA										
	Amphipoda sp.#4	NA										
	Colurostylis lemurum	NA										
	Copepoda sp.#1	NA							1			
	Copepoda sp.#2	NA										
	Halicarcinus varius	NA										
	Halicarcinus whitei	NA		1	1		2					2
	Helice crassa	NA										
	Macrophthalmus hirtipes	NA										
	Mysidacea sp.#1	II								1		
	Ostracoda sp.#1	NA										
	Ostracoda sp.#2	NA										
	Ostracoda sp.#3	NA										
	Paracorophium sp.	III										
	Phoxocephalidae sp.#1	I										
	Phoxocephalidae sp.#2	I										
	Sphaeroma quoyanum	III										
INSECTA	Chironomidae sp.#1	III	1									
HOLOTHUROIDEA	*Trochodota dendyi*	I										1
Total species in sample			15	17	15	16	14	14	14	15	14	17
Total individuals in sample			189	138	165	191	173	157	140	119	75	100

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Paua A-01	Paua A-02	Paua A-03	Paua A-04	Paua A-05	Paua A-06	Paua A-07	Paua A-08	Paua A-09	Paua A-10
ANTHOZOA	Anthozoa sp.#1	II	2	6				2			2	3
	Edwardsia sp.#1	II	5	5	12	6		5	6	14	12	2
NEMERTEA	Nemertea sp.#1	III				1	3	1	2		1	
	Nemertea sp.#2	III	2						1		1	
	Nemertea sp.#3	III										
NEMATODA	Nematoda	III										
POLYCHAETA	*Aglaophamus macroura*	II										
	Aonides sp.#1	III										
	Armandia maculata	I		1	1				1			
	Axiothella serrata	I										
	Boccardia (Paraboccardia) acus	I	14	9	1	13	5	11	5	22	7	3
	Boccardia (Paraboccardia) syrtis	I		3	4	7	2	12	1	1		3
	Capitella sp.#1	V					1					
	Cirratulidae sp.#1	IV										1
	Dorvilleidae sp.#1	NA								1	1	
	Glycera sp.#1	II										
	Goniada sp.#1	II				1		1				
	Hesionidae sp.#1	II										
	Hesionidae sp.#2	II										
	Heteromastus filiformis	IV	41	46	44	51	39	26	26	31	54	43
	Microspio maori	III										
	Nereidae (unidentified juveniles)	III	8	6	1	8		7	11	4	6	5
	Nicon aestuariensis	III		1	1		1			1	1	1
	Orbinia papillosa	I	9	6	6	8	10	4	1	1	2	1
	Paraonidae sp.#1	III	4	2	6	1		1	2	1	1	5
	Perinereis vallata	III	2	2	1	1		1	2	3		4
	Phyllodocidae sp.#1	II										
	Phyllodocidae sp.#2	II							1			
	Platynereis australis	III					1					
	Polynoidae sp.#1	II							1			
	Sabellidae sp.#1	I										
	Scolecolepides benhami	III										
	Scoloplos (Scoloplos) cylindrifer	I	1	1								
	Sphaerosyllis sp.#1	II	3		2	2		1		3		
	Spionidae sp.#1	III	8	3	6	3	7		4	7	5	11
	Spirobranchus cariniferus	III							4			
	Syllidae sp.#1	II								1		
	Terebellidae sp.#1	II			1	1	1		2	2	1	4
	Travisia sp.#1	I										
OLIGOCHAETA	Oligochaeta	NA									2	2
POLYPLACOPHORA	*Chiton glaucus*	II		2	1						1	3

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Paua A-01	Paua A-02	Paua A-03	Paua A-04	Paua A-05	Paua A-06	Paua A-07	Paua A-08	Paua A-09	Paua A-10
GASTROPODA	*Cominella glandiformis*	NA	1	1			1	3	1		3	
	Diloma subrostrata	NA		1		1		1		1		
	Eatoniella olivacea	NA										
	Gastropoda sp.#3	NA				1						
	Haminoea zelandiae	NA	1		1	1	1			1	2	3
	Notoacmaea helmsi	NA	7	1	3		1		7	1	5	2
	Potamopyrgus antipodarum	NA										
	Potamopyrgus estuarinus	NA										
	Trochus tiaratus	NA										
	Xymene plebeius	NA										
	Zeacumantus lutulentus	NA	1					1	4	1	1	3
BIVALVIA	*Arthritica sp.#1*	III	8	1	1	2	2	2	4		1	2
	Austrovenus stutchburyi	I	13	15	4	15	4	13	9	18	14	9
	Macomona liliana	I	2	6	4	5	3	7	3	3	4	4
	Nucula hartvigiana	III	20	9	9	6	19	14	19	13	13	23
	Paphies australis	II										
	Solemya parkinsoni	II										
CRUSTACEA	Amphipoda sp.#1	NA							1	2	2	1
	Amphipoda sp.#2	NA										
	Amphipoda sp.#3	NA										2
	Amphipoda sp.#4	NA										
	Colurostylis lemurum	NA				1			1			1
	Copepoda sp.#1	NA										
	Copepoda sp.#2	NA										
	Halicarcinus varius	NA										
	Halicarcinus whitei	NA		1								1
	Helice crassa	NA										
	Macrophthalmus hirtipes	NA				1			1			
	Mysidacea sp.#1	II										
	Ostracoda sp.#1	NA			1	2	4	4			1	
	Ostracoda sp.#2	NA	6	7	14	1	8	5	11		3	8
	Ostracoda sp.#3	NA										
	Paracorophium sp.	III										
	Phoxocephalidae sp.#1	I	1	4	3	4	5	5	5	2	10	17
	Phoxocephalidae sp.#2	I										
	Sphaeroma quoyanum	III										
INSECTA	Chironomidae sp.#1	III										
HOLOTHUROIDEA	*Trochodota dendyi*	I	1				4	1	1	1		
Total species in sample			23	24	23	25	21	23	29	24	27	28
Total individuals in sample			160	139	127	143	122	128	137	135	156	167

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Paua B-01	Paua B-02	Paua B-03	Paua B-04	Paua B-05	Paua B-06	Paua B-07	Paua B-08	Paua B-09	Paua B-10
ANTHOZOA	Anthozoa sp.#1	II										
	Edwardsia sp.#1	II	2	5	1	3	1	5	5	2	7	3
NEMERTEA	Nemertea sp.#1	III		1		1	2	4		1	1	
	Nemertea sp.#2	III		1							2	2
	Nemertea sp.#3	III			1			1				
NEMATODA	Nematoda	III								1		
POLYCHAETA	*Aglaophamus macroura*	II										
	Aonides sp.#1	III		1		1	2	3				
	Armandia maculata	I	1	7	5	2	5	6	9	2	1	1
	Axiothella serrata	I	2	15	2		1	8	6	3	7	2
	Boccardia (Paraboccardia) acus	I	6	14	8	8	11	5	8	16	10	5
	Boccardia (Paraboccardia) syrtis	I	1	2		2	1	4	5			5
	Capitella sp.#1	V	2	3	5	1	4	5	1			11
	Cirratulidae sp.#1	IV										
	Dorvilleidae sp.#1	NA										
	Glycera sp.#1	II										
	Goniada sp.#1	II	1			1					1	
	Hesionidae sp.#1	II										
	Hesionidae sp.#2	II										
	Heteromastus filiformis	IV	48	91	88	54	88	80	110	49	55	99
	Microspio maori	III	1		1			4	1			
	Nereidae (unidentified juveniles)	III	2	4	2	1		1	3	4	2	2
	Nicon aestuariensis	III		2	1		3	1			2	1
	Orbinia papillosa	I	2	4	4	2				5	3	4
	Paraonidae sp.#1	III							2			
	Perinereis vallata	III	1	5	5		1	1	1	1	3	3
	Phyllodocidae sp.#1	II					1					
	Phyllodocidae sp.#2	II										
	Platynereis australis	III		6	2	1	3	4		1		
	Polynoidae sp.#1	II										
	Sabellidae sp.#1	I										
	Scolecolepides benhami	III						1	1			
	Scoloplos (Scoloplos) cylindrifer	I		1						1	1	
	Sphaerosyllis sp.#1	II		1				1	2	1	1	
	Spionidae sp.#1	III	1	6	9		2	17	12	10	2	15
	Spirobranchus cariniferus	III										
	Syllidae sp.#1	II										
	Terebellidae sp.#1	II										
	Travisia sp.#1	I										
OLIGOCHAETA	Oligochaeta	NA		1		1	2	1	3			1
POLYPLACOPHORA	*Chiton glaucus*	II										

APPENDIX 2. 2009 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES		Paua B-01	Paua B-02	Paua B-03	Paua B-04	Paua B-05	Paua B-06	Paua B-07	Paua B-08	Paua B-09	Paua B-10
GASTROPODA	*Cominella glandiformis*	NA		3	1	3		1	1		2	2
	Diloma subrostrata	NA	1				2		1	2		2
	Eatoniella olivacea	NA										
	Gastropoda sp.#3	NA	1									
	Haminoea zelandiae	NA		1	2		2		1	1	3	2
	Notoacmaea helmsi	NA	1	5	1		1		1	1		1
	Potamopyrgus antipodarum	NA							1	1		
	Potamopyrgus estuarinus	NA				1						
	Trochus tiaratus	NA								1		
	Xymene plebeius	NA										1
	Zeacumantus lutulentus	NA		1							1	
BIVALVIA	*Arthritica sp.#1*	III	1	1	2	3	1			22	1	6
	Austrovenus stutchburyi	I	8	10	11	6	9	7	12	10	14	7
	Macomona liliana	I	6	10	11	11	9	6	11	10	10	7
	Nucula hartvigiana	III		1	1			1	1		4	
	Paphies australis	II										
	Solemya parkinsoni	II										
CRUSTACEA	Amphipoda sp.#1	NA		19	6		1	4			1	4
	Amphipoda sp.#2	NA										
	Amphipoda sp.#3	NA										
	Amphipoda sp.#4	NA			1							
	Colurostylis lemurum	NA										
	Copepoda sp.#1	NA										
	Copepoda sp.#2	NA										
	Halicarcinus varius	NA		1						1	1	
	Halicarcinus whitei	NA				2	2		2	1		1
	Helice crassa	NA										
	Macrophthalmus hirtipes	NA										
	Mysidacea sp.#1	II		1			1					
	Ostracoda sp.#1	NA										
	Ostracoda sp.#2	NA										
	Ostracoda sp.#3	NA										
	Paracorophium sp.	III				1						
	Phoxocephalidae sp.#1	I										
	Phoxocephalidae sp.#2	I										
	Sphaeroma quoyanum	III										
INSECTA	Chironomidae sp.#1	III										
HOLOTHUROIDEA	*Trochodota dendyi*	I		1					1			
Total species in sample			19	31	23	20	24	24	25	24	24	24
Total individuals in sample			88	224	170	105	155	171	201	147	135	187

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
	Porifera sp.	NA	NA	Unidentified sponge
	Anthozoa sp.#1	II	NA	Unidentified anemone. An upright, stout, pale cream-coloured species.
Anthozoa	*Edwardsia* sp.#1	III	NA	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
Nematoda	Nemertea	III	I Optimum range 55-60% mud,* distribution range 0-95%*	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp.	III	M Mud tolerant.	Small unsegmented roundworms. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5mm mesh sieve. Generally reside in the upper 2.5cm of sediment. Intolerant of anoxic conditions.
Polychaeta	*Aglaophamous macroura*	II	NA	A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate (Beesley et al. 2000). Feeding type is carnivorous. Significant avoidance behaviour by other species. Feeds on *Heteromastus filiformis, Orbinia papillosa* and *Scoloplos cylindrifer* etc.
Polychaeta	*Aonides* sp.	III	SS Optimum range 0-5% mud,* distribution range 0-5%*	Small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. *Aonides* is free-living, not very mobile and strongly prefers to live in fine sands; also very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds.
Polychaeta	*Armandia maculata*	I	NA	Common subsurface deposit-feeding/herbivore. Belongs to Family Dpheliidae. Found intertidally as well as subtidal in bays and sheltered beaches. Prefers fine sand to sandy mud at low water. Does not live in a tube. Depth range: 0-1000m. A good coloniser and explorer. Pollution and mud intolerant.
Polychaeta	*Axiothella serrata*	I	NA	Subsurface deposit-feeder. Belongs to Family Maldanidae. Found intertidally in enclosed harbours/estuaries only. Prefers fine to very fine sands where it builds a loosely-cemented sand-grain tube or burrow shaped like a J to about 15cm depth. Pollution and mud intolerant.
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	Capitellidae	V or IV	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *Heteromastus filiformis*.	Subsurface deposit feeder, occurs down to about 10cm sediment depth. Common indicator of organic enrichment. Bio-turbator. Prey for fish and birds.
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	Dorvilleidae sp.	NA	NA	Active surface-dwelling omnivores with chitinous jaw elements consisting of four longitudinal rows of minute, toothed, black plates, and with two pairs of appendages on the rounded prostomium. Not generally common.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Polychaeta	Glyceridae	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.
	Goniada sp.1	II	I Optimum range 50-55% mud,* distribution range 0-60%*	Slender burrowing predators (of other smaller polychaetes) with proboscis tip with two ornamented fangs. The goniadids are often smaller, more slender worms than the glycerids. The small goniadid *Glycinde dorsalis* occurs low on the shore in fine sand in estuaries.
	Hesionidae sp.#1	II	NA	Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The NZ species are little known.
	Heteromastus filiformis	IV	I Optimum range 10-15%* or 20-40% 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. Prey items for fish and birds.
	Microspio maori	III	S Expect optimum range in 0-20% mud.	A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in low numbers in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary very abundant (5% mud, moderate organic enrichment). Prey items for fish and birds.
	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.
	Orbinia papillosa	I	S Optimum range 5-10% mud,* distribution range 0-40%*	Endemic orbiniid. Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.
	Paraonidae	III	Uncertain *Aricidea* sp. is an I Optimum range 35-40% mud,* distribution range 0-70%*	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15cm and appear to be sensitive to changes in the mud content of the sediment. Some species of *Aricidea* are associated with sediments with high organic content.
	Pectinaria australis	I	NA	Subsurface deposit-feeding/herbivore. Lives in a cemented sand grain cone-shaped tube. Feeds head down with tube tip near surface. Prefers fine sands to muddy sands. Mid tide to coastal shallows. Belongs to Family Pectinariidae. Often present in NZ estuaries. Density may increase around sources of organic pollution and eelgrass beds. Intolerant of anoxic conditions.
	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 mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Polychaeta	Phyllodocidae	II	NA	The phyllodocids are a colourful family of long, slender, and very active carnivorous worms characteristically possessing enlarged dorsal and ventral cirri which are often flattened and leaf-like (paddleworms). They are common intertidally and in shallow waters.
	Platynereis australis	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	An intertidal soft shore nereid (which are common and very active, omnivorous worms). Prefers mud/sand sediments.
	Polynoidae	II	NA	The polynoid scale worms are dorsoventrally flattened predators. Lower intertidal and subtidal to deep sea throughout NZ. Conspicuous, but never abundant.
	Sabellariidae sp.1	NA	NA	Sabellariids live in thick-walled sand and shell-fragment tubes cemented to rock or to any durable surface. As such they often modify the habitat. Some colonial species form conspicuous hummocks and substantial reefs. Sabellariids are filter feeders and detritus feeders. Pollution and mud intolerant.
	Sabellidae sp.#1	I	NA	Sabellids are not usually present in intertidal sands, though some minute forms do occur low on the shore. They are referred to as fan or feather-duster worms and are so-called from the appearance of the feeding appendages, which comprise a crown of two semicircular fans of stiff filaments projected from their tube.
	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 items 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.
	Scoloplos (Scoloplos) cylindrifer	I	S Optimum range 0-5% mud,* distribution range 0-60%*	A 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. Prefers low-moderate mud content (<50% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions.
	Sphaerosyllis sp.	II	S Optimum range 25-30% mud,* distribution range 0-40%*	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers sandy sediments.
	Spionidae sp.	NA	NA	An unknown spionid polychaete. Feed at the sediment-water interface - as either deposit or suspension feeders.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Polychaeta	*Spirobranchus cariniferus*	II	NA	Better known as *Pomatoceros caeruleus* this conspicuous serpulid was the first NZ polychaete to be given a name, and was described as a new species (with different names) at least 6 times! Currently in genus Spirobranchus but further study may place it back in *Pomatoceros*. *Spirobranchus cariniferus* is the common colonial serpulid of NZ shores. It is found mostly on the lower shore on shaded rock faces, becoming more prominent in the cooler south, where tube layers up to 30cm thick may occur. On soft shores small groups occur on top of any suitable hard object such as small stones and dead shell.
Polychaeta	Syllidae	II	S Optimum range 25-30% mud,* distribution range 0-40%*	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers mud/sand sediments (25-30% mud).
Polychaeta	Terebellidae	II	NA	Large tube or crevice dwellers with a confusion of constantly active head tentacles and a few pairs of anterior gills.
Polychaeta	*Travisia olens*	I	SS Optimum range 0-5% mud*, distribution range 0-5%**.	Belong to the Opheliids. Short-bodied, cigar-shaped, muscular sand burrowers. Opheliids are deposit feeders, but probably selective in their intake of particulate material. The large, fat, bad smelling, grey-white coloured scalibregmatid *Travisia olens* is found on open to semi-protected sand beaches.
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.
Polyplacophora	*Chiton glaucus*	II	NA	*Chiton glaucus*, or the green chiton, is a species of chiton, a marine polyplacophoran mollusc in the family Chitonidae, the typical chitons. It is the most common chiton species in NZ. The shell, consisting of eight valves surrounded by a girdle, is fairly large, up to 55mm in length.
Gastropoda	*Cominella glandiformis*	NA	SS Optimum range 5-10% mud*, distribution range 0-10%**.	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 30m away, even when the tide is out. Intolerant of anoxic surface muds. **Strong Sand Preference. Optimum mud range 5-10% mud.**
Gastropoda	*Diloma subrostrata*	NA	SS Optimum range 5-10% mud,* distribution range 0-15%*	The mudflat top shell, lives on sandflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ and feeds on the film of microscopic algae on top of the sand. Has a strong sand preference.
Gastropoda	*Eatoniella olivacea*	NA	NA	A small smooth conical gastropod, 2mm long and dark brown to black. It lives by scraping the detritus or diatomaceous film from the surfaces of algae.
Gastropoda	Gastropoda sp. #1 and #2.	NA	NA	Yet to be identified.
Gastropoda	*Haminoea zelandiae*	NA	NA	The white bubble shell, is a species of medium-sized sea snail or bubble snail, a marine opisthobranch gastropod mollusc in the family Haminoeidae. This bubble shell snail is common on intertidal mudflats in sheltered situations associated with eel grass. This species is endemic to NZ. It is found around the North Island and the northern part of the South Island.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Gastropoda	*Notoacmaea helmsi*	NA	SS Optimum range 0-5% mud*, distribution range 0-10%**.	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Has a strong sand preference.
Gastropoda	*Potamopyrgus antipodarum*	III	M Tolerant of muds.	Endemic to NZ. Small snail that can live in freshwater as well as brackish conditions. In estuaries *P. antipodarum* can tolerate up to 17-24% salinity. Shell varies in colour (gray, light to dark brown). Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds but can tolerate organically enriched conditions. Tolerant of muds. Populations in saline conditions produce fewer offspring, grow more slowly, and undergo longer gestation periods.
Gastropoda	*Potamopyrgus estuarinus*	III	M Tolerant of muds.	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
Gastropoda	*Trochus tiaratus*	NA	NA	A small top snail from the family Trochidae and is endemic to NZ.
Gastropoda	*Xymene plebeius*	NA	NA	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds.
Gastropoda	*Zeacumantus lutulentus*	NA	NA	Belongs to the Family Muricidae, or murex snails, which are a large and varied taxonomic family of small to large predatory sea snails
	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.
	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, 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 suggests 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).
	Macomona liliana	II	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. Sand Preference: **Prefers 0-5% mud (range 0-60% mud).**

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Bivalvia	*Nucula hartvigiana*	I	S Optimum range 0-5% mud,* distribution range 0-60%*	Small deposit feeder. Nut clam of the family Nuculidae (<5mm), is endemic to NZ. Often abundant in top few cm. It is found intertidally and in shallow water, especially in *Zostera* eel grass flats. It is often found together with the NZ cockle, *Austrovenus stutchburyi*, but is not as abundant. Like *Arthritica* this species feeds on organic particles within the sediment. Has a plug-like foot, which it uses for motion in mud deposits. **Intolerant of organic enrichment.** Prefers 0-5% mud (range 0-60%). High abundance in Porirua Harbour near sea (Railway and Boatshed sites). None in Freshwater Estuary.
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.** Common at the mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud.
Bivalvia	*Solemya parkinsoni*	II	NA	The razor mussel. The elongate cylindrical shell valves have the brown, smooth shining epidermis extending beyond the margin forming a characteristic and distinctive fringe; interior of the shell a dull grey-white; grows up to 5cm in length. A common species on sand banks at depths up to 25cm.
Crustacea	Amphipoda	NA	NA	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers sandy sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
Crustacea	Cephalocarida sp.1	NA	NA	Cephalocarida (horseshoe shrimps) is a class of only about nine shrimp-like benthic species. Discovered in 1955. Found from the intertidal zone down to a depth of 1500m, in all kinds of sediments. They feed on marine detritus.
Crustacea	*Colurostylis lemurum*	NA	S Optimum range 0-5% mud* distribution range 0-60% mud**.	A cumacean and a semi-pelagic detritus feeder. Cumacea is an order of small marine crustaceans, occasionally called hooded shrimps. Some species can survive in water with a lower salinity rate, like in brackish water (e.g. estuaries). Most species live only one year or less, and reproduce twice in their lifetime. Cumaceans feed mainly on microorganisms and organic material from the sediment. Species that live in the mud filter their food, while species that live in sand browse individual grains of sand.
Crustacea	Copepoda	NA	NA	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 varius*	NA	NA	Pillbox crabs are usually found on the sand and mudflats but may also be encountered under stones on the rocky shore. *Halicarcinus varius* (10mm) has a pear-shaped carapace, its upper half covered in small hairs. Males have hairy nippers. Its colour varies from white/green to yellow, found in sheltered areas on brown seaweeds or under stones.
Crustacea	*Halicarcinus whitei*	NA	NA	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
	Helice crassa	NA	MM Optimum Range 95-100% mud (found in 5-100% mud)*.	Endemic, burrowing mud crab. *Helice crassa* is concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
	Hemigrapsus crenulatus	NA	NA	The hairy-handed crab is commonly found on mud flats and sand flats, but it may also occur under boulders on the intertidal rocky shore. Is a very effective scavenger and tolerates brackish conditions.
	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 tunnelling mud crab, it feeds from the nutritious mud.
	Mysidacea sp.#1	II	NA	Mysidacea is a group of small, shrimp-like creatures. They are sometimes referred to as opossum shrimps. Wherever mysids occur, whether in salt or fresh water, they are often very abundant and form an important part of the normal diet of many fishes
	Ostracoda sp.	NA	NA	Ostracods or seed shrimps, have a body which is encased by two valves.
	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.
	Phoxocephalidae sp.	I	SS Optimum range 0-5% mud*, distribution range 0-5%**.	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Sphaeroma quoyanum	III	NA	A marine boring isopod found in the estuarine waters of NZ, Australia and California. Forms burrows in a variety of substrates. Well known as an invader that forms burrows along marsh edges which encourages erosion.
Insecta	Chironomidae	III	NA	A member of this non-biting midge family.
Holothuroidea	*Trochodota dendyi*	I	NA	A sea cucumber, that is soft bodied and worm-like in appearance and burrows up to 20cm into sand - a deposit feeder and sediment disturber.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

* 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.