Wriggle coastalmanagement

New River Estuary

Intertidal Fine Scale Monitoring 2009/10

Prepared for
Environment Southland
August 2010

Cover Photo: Local recreational fisherman netting for flounders near Whalers Bay, New River Estuary.

Cover Photo: Leigh Stevens returning from sediment plate monitoring, Waihopai Arm, New River Estuary.

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Prepared for
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By

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All photos by Wriggle except where noted otherwise.

NEW RIVER ESTUARY - EXECUTIVE SUMMARY

New River Estuary

↓

Vulnerability Assessment
Identifies issues and recommends monitoring and management. Preliminary assessment completed in 2008 (Robertson and Stevens 2008)

↓

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

↓

Monitoring

Broad Scale Mapping
Sediment type
Saltmarsh
Seagrass
Macroalgae
Land margin

5 -10 yearly
Undertaken in 2002, 2007. Next 2012.
Macroalgae undertaken annually.

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

4yr Baseline then 5 yearly
Baseline complete. Next survey 2015.

↓

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

Other Information
Previous reports, Observations, Expert opinion

↓

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

↓

Recommended Management

- Identify/reduce sediment sources.
- 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 baseline 2001-2005 and the 2010 fine scale monitoring of three intertidal sites within New River Estuary, a large (4,100ha) tidal lagoon estuary near Invercargill. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. An outline of the process used for estuary monitoring and management by ES 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 AND SEDIMENTATION RATE RESULTS

- Sedimentation rate (infilling with mud) was very high for the 3 sites in the Waihopai Arm.
- Although sand dominates the fine scale sites, they have become much muddier, less oxygenated (shallower RPD) since 2001, and some mud intolerant species have been lost.
- Sediment nutrients and organic carbon have remained at low-moderate levels, and heavy metals were well below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity).
- The benthic invertebrate community showed only a slight tendency towards dominance by organic enrichment tolerant species.

CONDITION RATINGS

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

	Middle Site B					Daffodil Bay Site C					Bushy Pt Site D				
	2001	2003	2004	2005	2010	2001	2003	2004	2005	2010	2001	2003	2004	2005	2010
Sediment Oxygenation RPD	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	High/Poor	Fair	Fair	Fair	Fair	Fair
Invertebrates Mud Tolerance	Good	Good	Very good	Good	Good	Good	Good	Good	Good	Good	Fair	Fair	Fair	Fair	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	Very good	Very good	Very good
Total Nitrogen	Very good	Very good	Very good	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 Phosphorus	Good	Good	Good	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	Good-Very Good	Good-Very Good	Good-Very Good
Invertebrates Org. Enrichment	Good	Good	Good	Good	Good	Very good	Very good	Very good	Good	Good	Good	Good	Good	Good	Good

Sedimentation Rate	Waihopai Arm Upper			Waihopai Arm Centre			Waihopai Arm Bushy Pt			Remaining Estuary
	2008	2009	2010	2008	2009	2010	2008	2009	2010	
Sedimentation Rate	High/Poor	High/Poor	High/Poor	High/Poor	High/Poor	High/Poor	High/Poor	High/Poor	High/Poor	Not Yet Measured

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the fine scale monitoring, that is sedimentation, eutrophication and toxicity, the 2010 results indicate that the main body of the estuary is rapidly getting muddier, as is the Waihopai Arm, and that sediment oxygenation is deteriorating. As a result, some mud intolerant species, for example pipis, have been lost from the fine scale sites. However, concentrations of nutrients and organic matter in the sediments remained at the same low-moderate levels as were measured in 2002-2005 and the benthic invertebrate organic enrichment rating for the New River Estuary was in the "low to very low" category, indicating slight to moderate organic enrichment. Concentrations of sediment toxicants (heavy metals) were also low and similar to those measured in the baseline years.

Issues identified in other monitoring studies include; loss of high value habitat, excessive muddiness in some arms, disease risk associated with shellfish consumption and bathing, and toxicity near urban stormwater drains.

RECOMMENDED MONITORING AND MANAGEMENT

To rectify these problems, restoration of high value habitat and reduction of inputs of fine sediment, nutrients, faecal bacteria and toxicants to levels that the estuary can easily assimilate is recommended. However, because of the complex nature of the estuary and the wide range of inputs (both point and non-point source), effective management is unlikely without the aid of additional information. In particular the following short term studies are recommended; develop contaminant input budgets, characterise the condition of poorly flushed areas and the water column, identify the fate of contaminants, and assess the impacts of sea level rise.

In order to assess ongoing trends in the fine scale condition of the estuary it is recommended that fine scale monitoring should continue at 5 yearly intervals, and sedimentation rate monitoring annually.

1. INTRODUCTION

OVERVIEW

Estuary Type/Area	Tidal Lagoon
Catchment	1527 km^2
Dairy cows	64,611 cows
Nitrogen loading	Low-Mod: 7 kg/ha/yr
Catchment geology	Gravel, sandstone/siltstone, igneous
Saltmarsh (ha)	70 ha primarily jointed wire rush
Salinity	Well mixed, sea water dominated
Mean depth (m)	1-2m
Tidal flats	High
Uses/Values	Walking, shellfish collection, birds, scenic, fishing, duckshooting, whitebaiting, bathing.

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. Recently, Environment Southland (ES) undertook vulnerability assessments of its region's coastlines to establish priorities for a long-term monitoring programme for the region (Robertson and Stevens 2008). These assessments identified the following estuaries as immediate priorities for monitoring: Waikawa, Haldane, Fortrose (Toetoes), New River, Waimatuku, Jacobs River, Waituna Lagoon and Waiau Lagoon and Lake Brunton.

ES began monitoring New River Estuary in February 2001, with the work being undertaken by Cawthron Institute using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002).

The New River Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (Table 1) and appropriate monitoring design. A preliminary EVA has been completed for New River Estuary and is reported on in Robertson and Stevens (2008).
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 2002 (Robertson et al. 2002).
3. **Fine Scale Monitoring** (EMP approach). Monitoring of physical, chemical and biological indicators (Table 2) including sedimentation plate monitoring. This component, which provides detailed information on the condition of the New River Estuary, has been undertaken in 2001, 2003, 2004, 2005 (Robertson and Stevens 2006) and 2010. The February 2010 monitoring is the subject of the current report.

New River Estuary is a large "tidal lagoon" type estuary (area 4,100ha), discharging to the east end of Oreti Beach. Situated at the confluence of the Oreti and Waihopai Rivers, it drains a primarily agricultural catchment.

This shallow estuary (mean depth ~2m) is bordered by a mix of vegetation and landuses (urban, bush and grazed pasture). It has a wide range of habitats (extensive mudflats, seagrass and saltmarsh areas) but has also lost large areas through drainage and reclamation in the Waihopai Arm. Invercargill City is located adjacent to the Waihopai Arm and discharges its treated wastewater to the estuary. Nuisance blooms of macroalgae (*Enteromorpha* and *Gracilaria*), exceedance of bathing and shellfish faecal bacterial guidelines and sedimentation problems are common within the estuary.

As a consequence of the much reduced saltmarsh area, the estuary is expected to be more vulnerable to such issues as eutrophication and sedimentation (given that saltmarsh acts to reduce nutrient and sediment impacts).

Despite the presence of these issues, human use and ecological values of large parts of the estuary are high. However, it has been recommended that management actions be taken to improve the situation in areas where the condition is poor.

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 (shading signifies indicators used in the fine scale monitoring assessments).

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.
Sedimentation	Grain Size	Fine scale measurement of sediment type.
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 one or two per estuary, or three or four for larger estuaries) are selected and samples collected and analysed for physical, chemical and biological variables.

For the New River Estuary, three fine scale sampling sites (Figure 1, Appendix 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 (i.e. depth to light grey/black anoxic layer) 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).
    - * 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 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 nearby source of seawater and the contents of the core were washed through a 0.5mm nylon mesh bag. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.
- The samples were then transported to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).

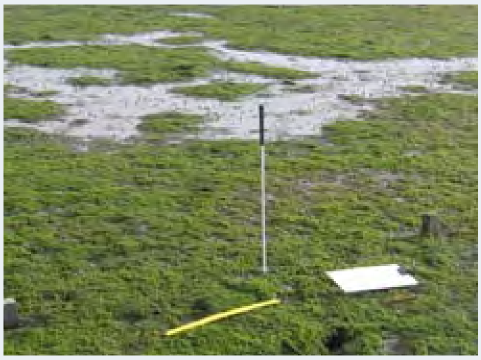
Figure 1. Location of sedimentation and fine scale monitoring sites in New River Estuary (Photo LINZ).

2. Methods (Continued)

Waihopai Arm sedimentation rate site in 2008.

Sedimentation Rate

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



Waihopai Arm sedimentation rate site in 2010.

CONDITION RATINGS

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

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 x %SS) + (1.5 x %S) + (3 x %I) + (4.5 x %M) + (6 x %MM}/100. The characteristics of the above-mentioned mud tolerance groups (SS, S, I, M and MM) are summarised in Appendix 2.

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
Fair	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 <1 cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

RPD CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	>10cm depth below surface	Monitor at 5 year intervals after baseline established
Good	3-10cm depth below sediment surface	Monitor at 5 year intervals after baseline established
Fair	1-3cm depth below sediment surface	Monitor at 5 year intervals. Initiate 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 New River 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 New River, 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
Fair	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 9-10 February 2010 fine scale monitoring results of New River Estuary is presented alongside the 2001-2005 baseline results 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: eutrophication, sedimentation, 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 three sites is presented in the accompanying figures.

Table 3. Physical, chemical and macrofauna results (means) for New River Estuary (2001-2010).

Site		RPD	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. of Species
		cm		%						mg/kg					No./m2	No./core
2001	NR B	3	0.30	1.2	98.8	0.1	0.100	8.4	3.6	0.7	4.3	15.4	<250	216	4131	7.7
	NR C	2	0.60	2.2	97.6	0.2	0.100	14.9	4.6	0.6	6.0	20.0	<250	365	3156	10.9
	NR D	3	0.28	1.2	98.2	0.6	0.100	12.3	3.6	0.5	5.2	17.4	<250	232	9594	8.8
2003	NR B	3	0.40	1.0	99.0	0.1	0.110	7.4	3.2	3.0	3.5	12.6	140	205	5085	10.3
	NR C	2	0.48	2.6	97.4	0.1	0.180	15.9	4.6	4.3	8.2	19.6	122	393	2888	12.0
	NR D	3	0.40	1.3	97.9	0.8	0.120	10.1	3.4	3.9	5.2	15.0	127	231	6338	8.9
2004	NR B	3	0.45	0.8	99.2	0.1	1.000	5.5	2.5	1.1	3.9	47.1	128	208	1343	6.6
	NR C	2	0.55	2.5	97.0	0.5	1.000	9.7	3.9	1.8	6.5	54.4	164	397	3548	10.7
	NR D	3	0.43	0.8	98.8	0.4	1.000	6.6	2.6	1.4	4.6	57.2	158	233	6143	10.6
2005	NR B	3	0.48	4.1	95.9	0.1	0.050	8.1	3.4	5.8	1.7	15.4	286	260	13598	9.5
	NR C	2	0.54	5.7	94.2	0.1	0.050	11.4	4.5	7.8	2.3	22.0	263	415	6750	12.2
	NR D	3	0.29	1.9	98.0	0.1	0.050	8.2	3.0	5.8	1.8	24.7	166	256	3293	6.4
2010	NR B	2	0.17	2.5	97.5	<0.1	0.018	7.6	3.6	5.5	1.5	16.7	<500	250	1800	8.3
	NR C	1	0.24	6.1	93.5	0.5	0.023	10.5	4.6	7.4	2.0	21.0	<500	380	2962	11.8
	NR D	2	0.22	4.6	94.9	0.5	0.028	10.3	4.3	7.1	2.1	21.0	<500	330	8175	9.9

SEDIMENTATION

Accelerated soil erosion from developed catchments is a major issue for tidal lagoon estuaries in New Zealand as they form a sink for fine suspended sediments. NZ estuaries are particularly sensitive to increased muddiness given the facts that they are generally sand dominated, have a diverse and healthy biology and a short history of catchment development. Increased muddiness results in reduced sediment oxygenation, production of toxic sulphides, increased nuisance macroalgal growth and a shift towards a degraded invertebrate and plant community. Such a change reduces feeding grounds and habitat for bird and fish species. Unless the input of fine sediment is reduced to a level below the assimilative capacity of the estuary then they will rapidly infill, high value habitat will be lost and their value for fish, birdlife and humans greatly reduced.

Sediments containing high mud content (i.e. around 30% mud 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), 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. New River Estuary and 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).

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

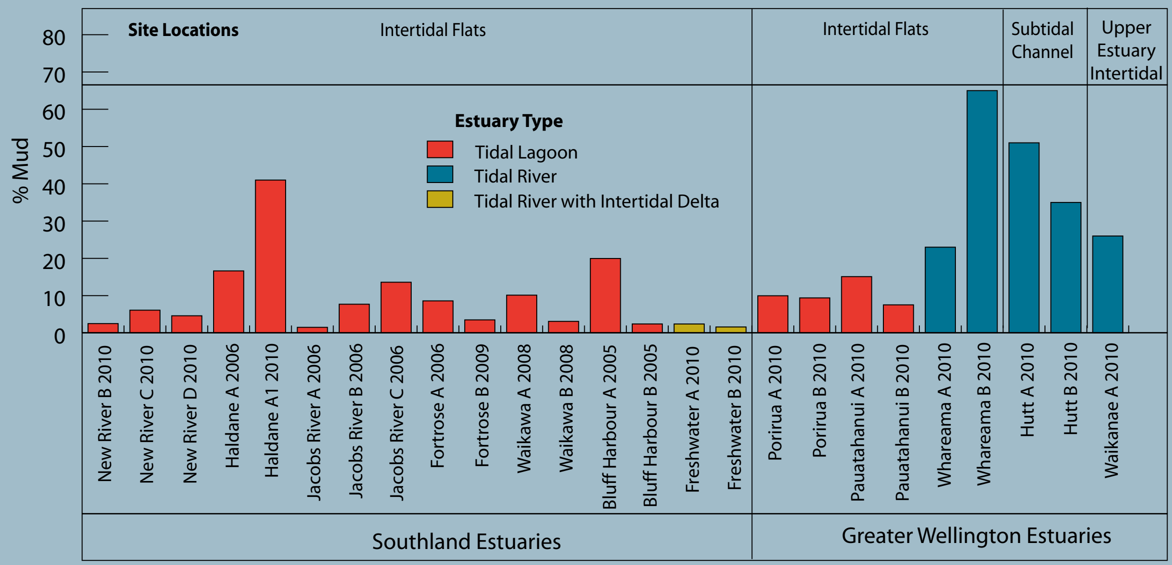


Figure 2. Percent mud content at fine scale monitoring sites, Southland and Greater Wellington estuaries.

GRAIN SIZE

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results (Figure 3) show that all three New River Estuary sites were dominated by sandy sediments (>93% sand in all years) and a relatively low mud content (<6.1% mud) compared with fine scale sites in other tidal lagoon type estuaries in the Greater Wellington and Southland regions (Figure 2).

However, the results show a major trend of increasing muddiness over the last 6 years (Figure 3a), particularly at the Bushy Point Site D and Daffodil Bay Site C. Such findings are not unexpected given the very high rates of infilling with muds in the Waihopai Arm (see next section).

The source of these fine muds is almost certainly from the surrounding Oreti and Waihopai catchments rather than the sea (Blakely 1971, Thoms 1981). To address the potential for ongoing sedimentation within the estuary and to measure its magnitude, sediment plates have been deployed in the Waihopai Arm of the estuary.

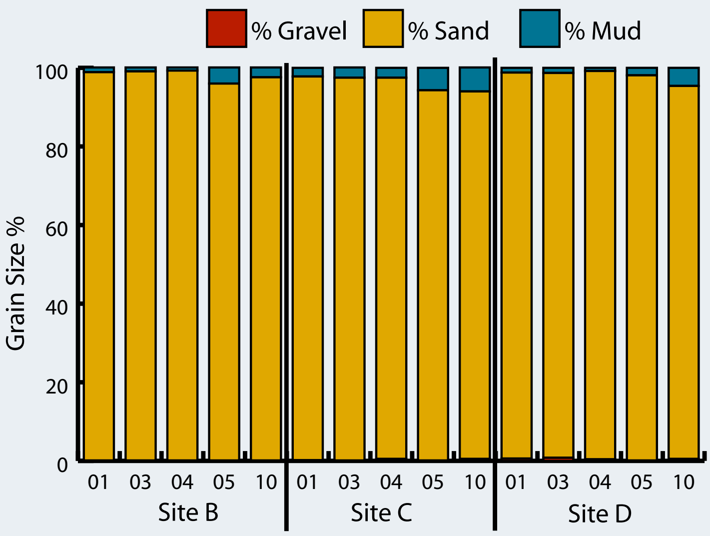


Figure 3. Grain size, New River Estuary.

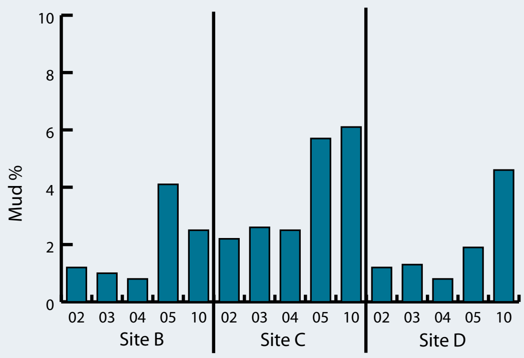


Figure 3a. Percentage mud, New River Estuary.

RATE OF SEDIMENTATION (WAIHOPAI ARM)

The sedimentation rate results for the Waihopai Arm indicate that this area is rapidly infilling. Twelve sedimentation plates were deployed in the Waihopai Arm in December 2007 to enable long term monitoring of sedimentation rates (Figure 1). Monitoring of the overlying sediment depth above each plate after approximately 3 years of burial was undertaken in February 2010. The sediment plate results for each of the 3 locations in the arm (Figure 4) indicated a mean sedimentation rate of 20-27mm/yr which fits within the "very high" category. The highest rates (50-60mm/yr) were recorded in the upper and central parts of the Waihopai Arm (opposite the Rifle Range) during the period February 2009 to February 2010. The lowest rates were recorded in the lower Waihopai Arm near Bushy Point (12-20mm/yr), but were still in the "very high" category. These rates show an increase over the mean rate measured for the Waihopai Arm between 1967 and 2007 of 13-17mm/yr using historical core aging techniques (Robertson and Stevens 2007). In relation to other NZ estuaries, the recent rate of infilling of the Waihopai Arm of the New River Estuary is extremely high (Figure 5).

Although the sedimentation rate for the whole estuary has not been measured, the facts that muddiness is increasing in the main body of the estuary and the extremely high rate of infilling in the Waihopai Arm, indicate that the sedimentation rate for the whole estuary is likely to be excessive. This means that the capacity of the estuary to assimilate fine sediment without detrimentally affecting the healthy functioning of the estuary has been exceeded.

In order to address excessive sedimentation in the Porirua Estuary, Gibbs and Cox (2009) have recently recommended that the current high sedimentation rate of 5-10mm/yr be reduced to the geologic or long term equilibrium rate of 1-2mm/year. Such a management recommendation is applicable to most NZ estuaries if high value habitats, sand-dominated tidal flats, and presence of sensitive plants and animals are to be maintained.

In order to provide interim management guidance for the New River Estuary, estimation procedures have been used (Table 4) to predict likely target suspended sediment (SS) inputs to meet an upper limit sedimentation rate of 2mm/yr. The results show that a one third reduction in the current input load is required to meet this target rate.

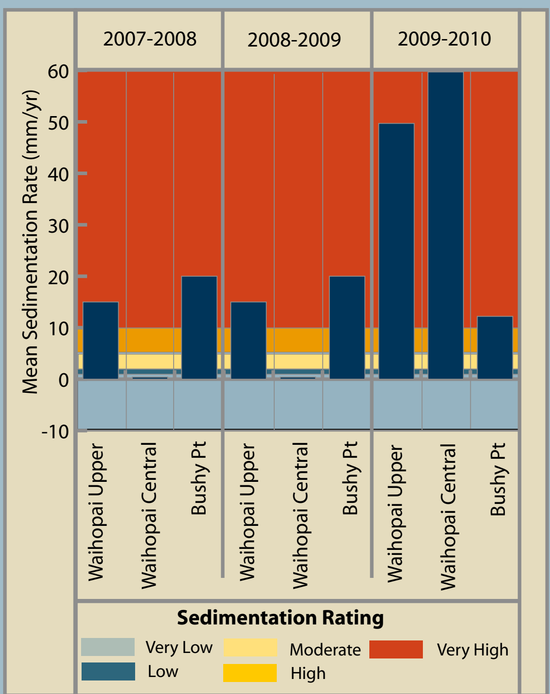


Figure 4. New River Estuary sedimentation rate from plate data (2007-2010).

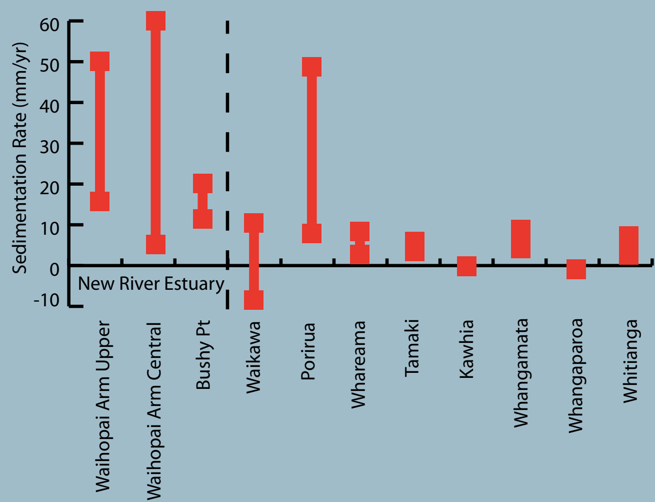


Figure 5. Sedimentation rate from New River Estuary and other NZ estuaries (Mead and Moores 2004, Abrahim 2005, Robertson and Stevens 2008, 2008a, 2010, 2010a).

3. Results and Discussion (Continued)

Table 4. Preliminary Suspended Sediment Input Target New River Estuary

	Result	Background
Current Estimated SS Input Load to Estuary	278,000 tonnes/yr	NIWA - WRENZ Model output. http://wrenz.niwa.co.nz/webmodel/
Current Estuary Sedimentation Rate	Mean Rate Unknown, but Waihopai Arm 5-60mm/yr	Waihopai data from historical sediment cores and recent sediment plate data (see earlier information in this section). Historical core data for Waihopai Arm shows average sedimentation rates over the past 40-47 years were 12.7-16.4mm/year based on lead and caesium dating respectively. Between 1906 to 1967 sedimentation rates based on lead dating were in the low range at 3.0mm/year. The upper New River Estuary was historically sandy, with pipis and cockles common in areas now covered by deep soft muds.
Target Sedimentation Rate for Healthy Estuary	1-2mm/yr	Likely long term equilibrium rate based on findings for other NZ estuaries (Gibbs and Cox 2009).
Target SS Input Load to New River Estuary	**200,000 t/yr or two thirds of the current input.**	Estuary area = 4,000ha = 40,000,000m^2 At a target sed. rate of 2mm/yr (i.e. 0.002m/yr) then: Annual SS Input = 40,000,000 x 0.002 = 80,000 m3/yr (or 80,000 x 1.3t/m3 = 104,000 tonnes/yr) if it all settled in the estuary. According to Martin and Whitfield (1983) more than 90% of the riverine suspended sediment settles out with the colloidal material in estuaries, where river water mixes with sea water. However, Viersa et al (2009) in a recent review of suspended sediment in world rivers indicated that the mechanisms controlling these processes are still poorly understood and attempts to quantify the fluxes remain very hazardous. Taking a conservative stance and assuming that greater than 50% of the input load does settle within the New River Estuary, then the SS input load would need to be less than 200,000 tonnes SS/yr (i.e. approximately two thirds of the estimated current input load of 300,000 tonnes SS/yr).

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 New River Estuary 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 6 and 7).
2. Using multivariate techniques to explore whether the macro-invertebrate communities at each of the 3 sites differ between each of the five years of monitoring (Figure 8).
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 New River Estuary macro-invertebrate community over the five years of monitoring (Figures 9 and 11).

3. Results and Discussion (Continued)

The first step showed that the macro-invertebrate community at all three sites in New River Estuary in the baseline monitoring period (2001-2005) which in 2010 ranged from 4-16 species/core, and reflected a moderate range of species when compared with mean results from intertidal mudflats in other NZ estuaries (Figure 6). Similarly, the overall community abundance at all three sites in New River Estuary in 2001-2005 and in 2010 was low to moderate compared with other NZ estuaries (Figure 7), total abundance of individual replicates ranging from 600 to 32,000m^{-2} .

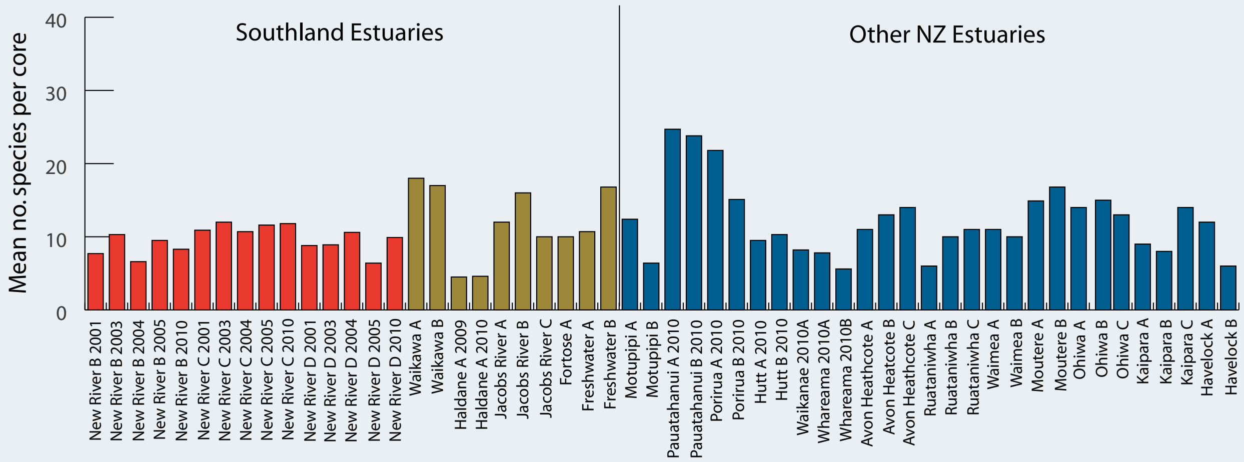


Figure 6. Mean number of infauna species, New River Estuary compared with other NZ estuaries (Source Robertson et al. 2002, Robertson and Stevens 2006, Robertson and Stevens 2008a, Robertson and Stevens 2010, 2010a, b and c).

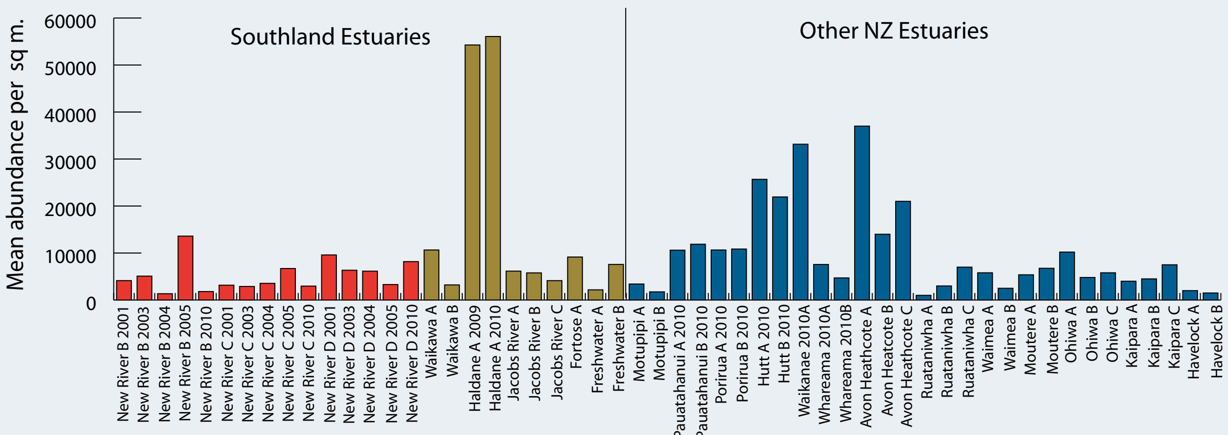


Figure 7. Mean total abundance of macrofauna, New River Estuary compared with other NZ estuaries.

3. Results and Discussion (Continued)

In the second step, the results of the multivariate analysis (NMDS Plot, Figure 8) show that there was a difference in the benthic invertebrate communities between each of the sites for all the five years of monitoring. In addition, the plot shows that there were year to year differences at each site, with the most pronounced difference being at Site D (Bushy Point) in 2010. Figure 8 shows that for this site the 2010 results were well separated and therefore significantly different from the 2001-2005 results. Such a difference is likely to be explained by the increasing mud content at this site in 2010 (1.9% mud in 2005 and 4.6% mud in 2010). The following section examines this conclusion in more detail.

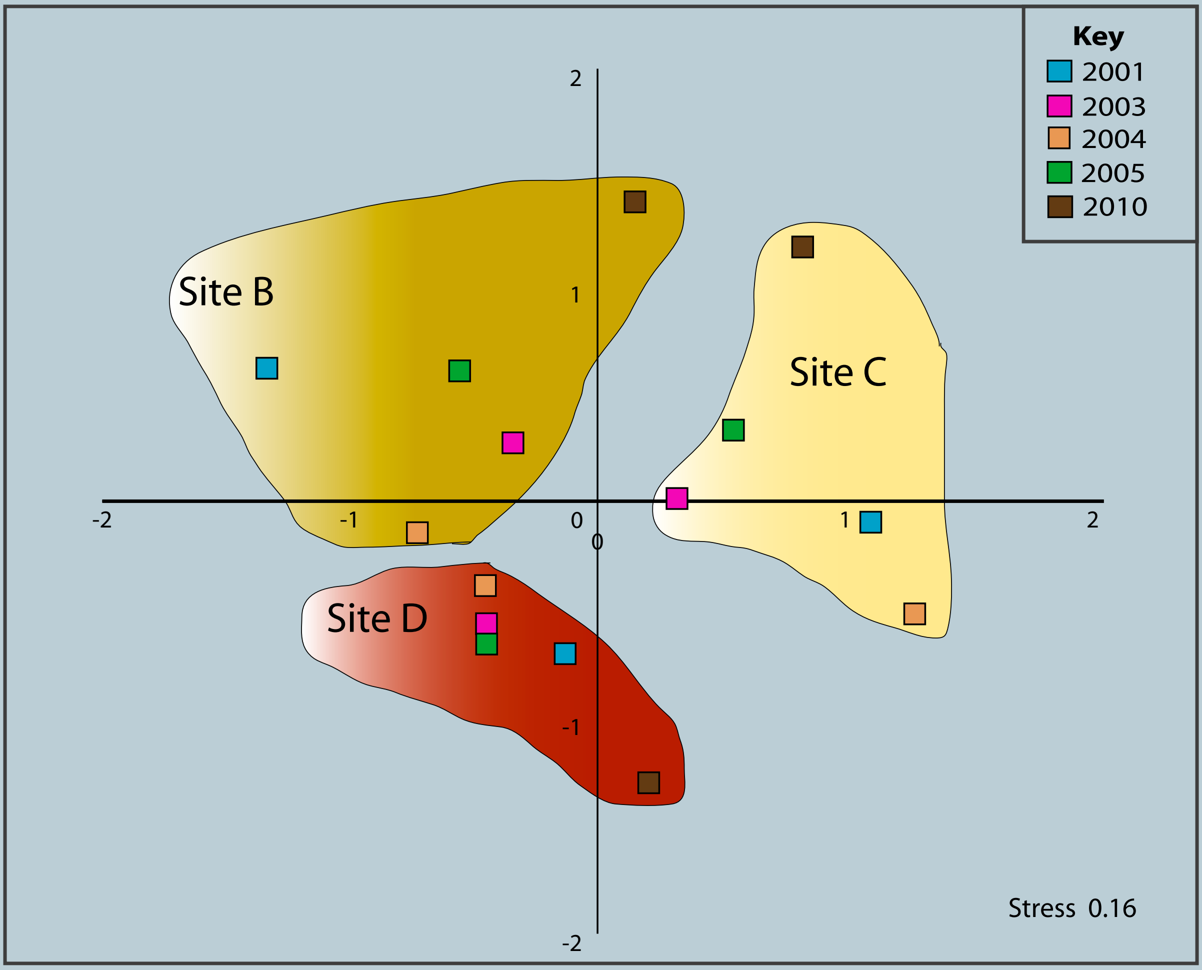


Figure 8. NMDS plot showing the relationship among mean samples in terms of similarity in macro-invertebrate community composition for New River Estuary Sites B, C and D, for 2001, 2003, 2004, 2005 and 2010. The plot shows the mean of each of the 10 (or 12 in 2001) replicate samples for each site and is based on Bray Curtis dissimilarity and fouth root transformed data.

The approach involves multivariate data analysis methods, in this case non-metric multidimensional scaling (NMDS) using PRIMER version 6.1.10. The analysis basically plots the site, year and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities i.e. how low the calculated stress value is. Stress values greater than 0.3 indicate that the configuration is no better than arbitrary, and we should not try and interpret configurations unless stress values are less than 0.2.

3. Results and Discussion (Continued)

In the third step, the species present at each site were divided into 6 groups based on their tolerance to mud and the results used to calculate a mud tolerance rating for each year and site. The results show that Sites B (Middle) and C (Daffodil Bay) were in the "low" or "very low" category for each of the 5 years of monitoring which indicates that the communities at these sites were dominated by species that prefer sand or a little mud rather than those with a mud or strong mud preference (Figure 9). However, at the more upstream Site D (Bushy Point), the rating was in the "fair" category for each of the 5 years of monitoring which indicates a community dominated by species that prefer mud at this site. These results are explored in more detail in Figure 11.

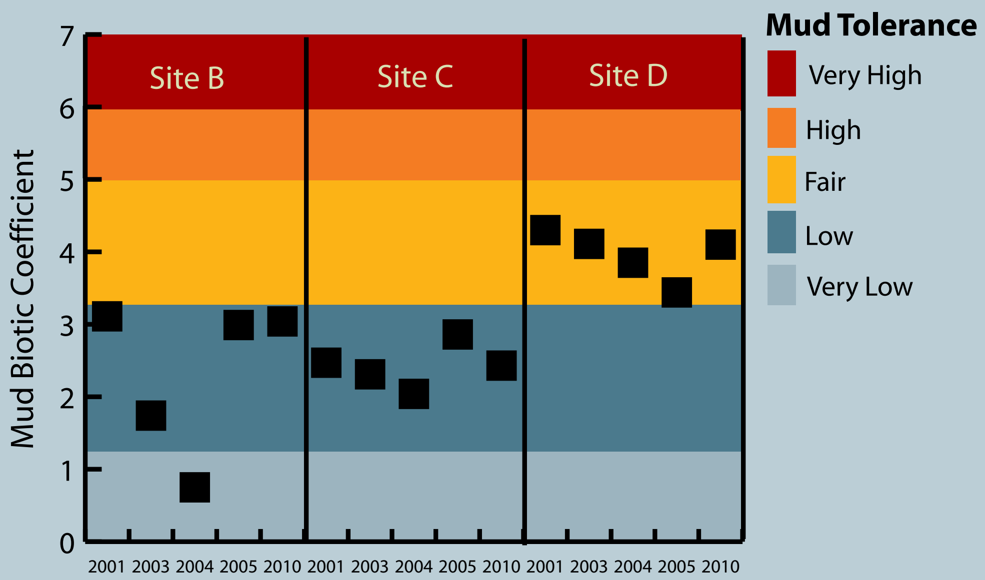
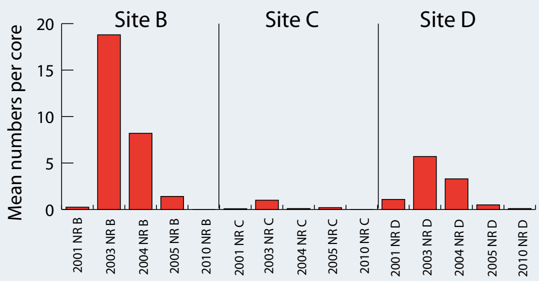


Figure 9. Mud tolerance macroinvertebrate rating.

Figure 11 shows that for each of the five years of monitoring, the benthic invertebrate community was dominated by a variety of polychaete, gastropod, nemertean, crustacean and bivalve species with varying tolerances to mud. The important findings were as follows:

- **Low Numbers of Strong Sand Preference Species.** Although strong sand preference, or highly mud intolerant species were present at some of the sites, their numbers were low.
- **Pipis Virtually Absent.** Pipis (*Paphies australis*) are a strong sand preference species with optimum distribution ranges for adults of 0-5% mud (Norkko et al. 2001). They were present at all three sites during the baseline monitoring in 2001, 2003, 2004 and 2005 (Figure 10). However, in 2010, the first year of trend monitoring, they had disappeared from all sites except for one small individual at Site D. A possible explanation for their absence in 2010 was the trend of increasing muddiness at the sites over the last 6 years, and the fact that it is getting closer to, and in some cases exceeding, the upper limit optimal for pipis of 5% mud at some of the sites. Such findings indicate that if mud content continues to increase in the main body of the estuary then pipis may be permanently lost.

Figure 10. Pipi abundance at 3 sites in New River Estuary 2001-2010.



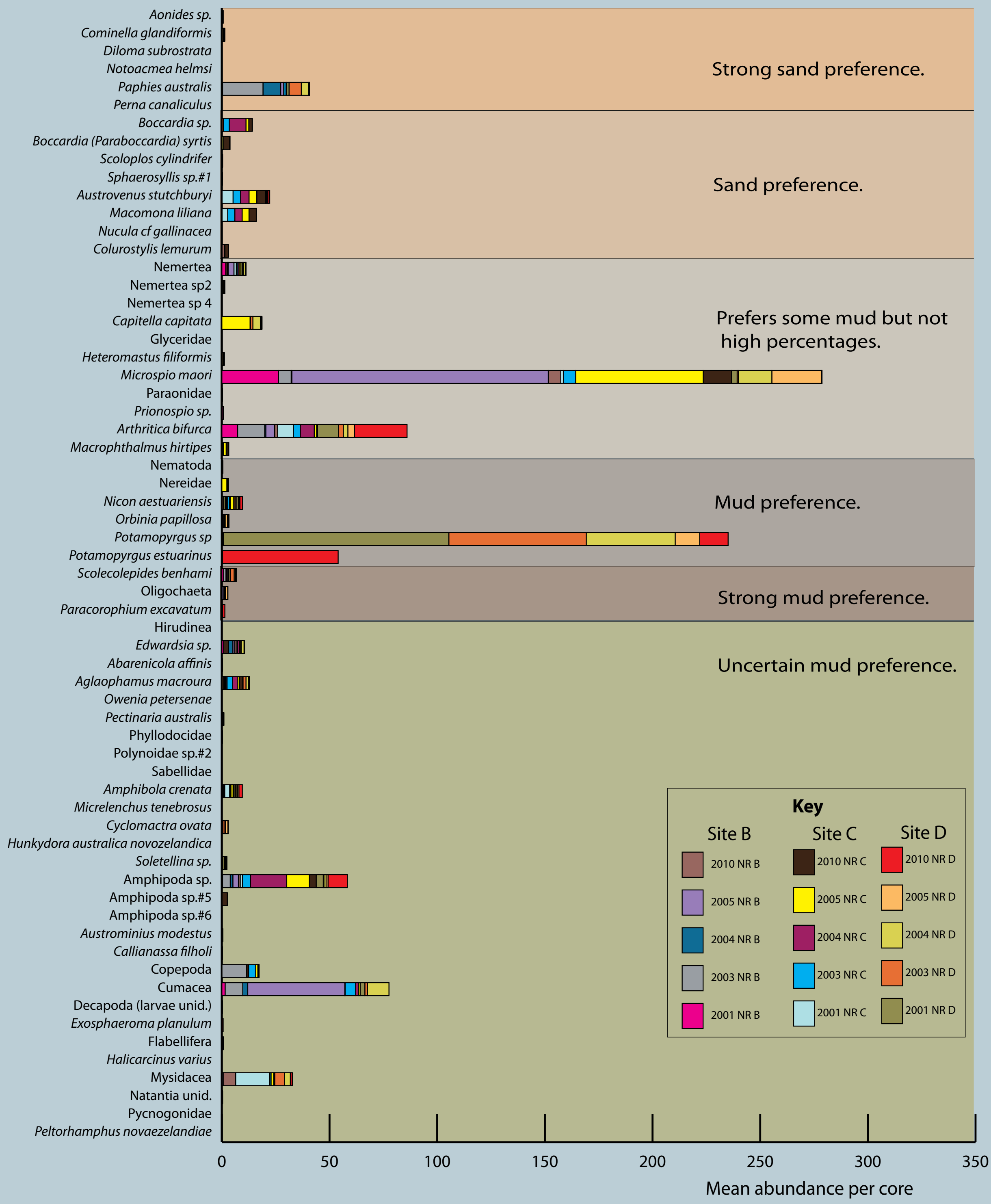
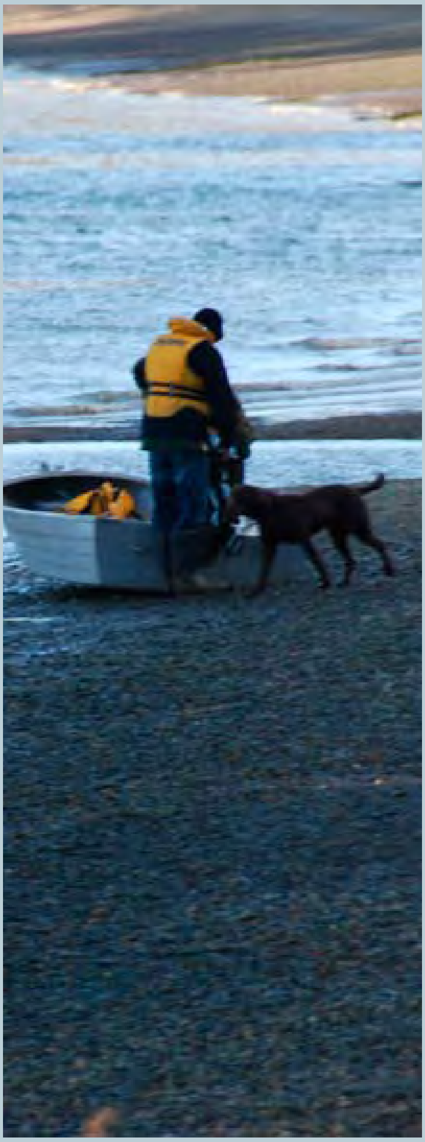


Figure 11. New River Estuary 2001-2010 - mud sensitivity of macro-invertebrates at three sites (see Appendix 3 for sensitivity details).



- **Low Numbers of Sand Preference Organisms.** Although "sand preference" organisms were also found at all the sites in 2001-2010, they were also present in low numbers.
    - Cockles (*Austrovenus stutchburyi*) and the adult wedge shell (*Macomona liliana*) are particularly important species in that they 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). 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 New River Estuary sites of 2.1-7.3%, are expected to provide favourable habitat for these species.
    - The small surface deposit-feeding spionid, *Boccardia* sp. 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 present under unenriched conditions.

- **High Numbers of Two Species That Prefer Some Mud But Not High Percentages.** In particular, there were high numbers of *Microspio maori*, a small, common, intertidal spionid which prefers 0-20% mud and can handle moderately enriched situations, and the small, sedentary deposit feeding bivalve, *Arthritica bifurca* which prefers 20-40% mud is also found at lower mud contents. It lives greater than 2cm deep in the sediment.

- **High Numbers of a Mud-Loving Snail.** Organisms that prefer "moderate or high mud contents" were also found at the sites but their numbers were low, except for the small native estuarine snails *Potamopyrgus estuarinus* and *P. antipodarum* which were common at Site D (Bushy Point). They feed on decomposing animal and plant matter, bacteria and algae, and are intolerant of anoxic surface muds but are tolerant of muds. Their absence from the more downstream sites B and C was likely related to their requirement to have brackish water for their survival. The presence of high numbers of snails at Site D was also likely to be the explanation for the "fair" mud tolerance rating for this site (Figure 9). Also present at all the sites was 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.

EUTROPHICATION

2010 RPD RATING	Fair

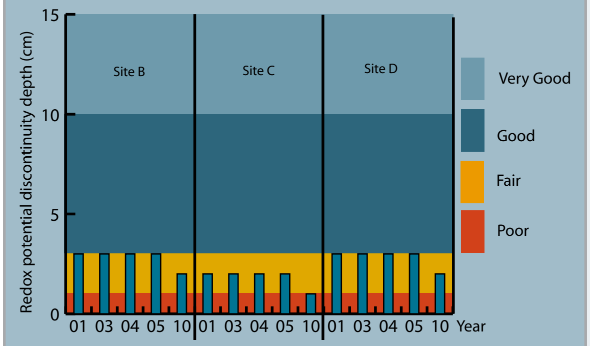


Figure 12. RPD depth (mean and range) New River Estuary.

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

Redox Potential Discontinuity (RPD)

Figures 12 and 13 show the sediment profile and RPD depths for the New River Estuary 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 New River Estuary fine scale sites was relatively shallow (1-2cm) and therefore sediments are likely to be poorly oxygenated. These RPD ratings were shallower than those measured at the sites during baseline monitoring period. 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 or skewed towards pollution-tolerant species (Figure 13).

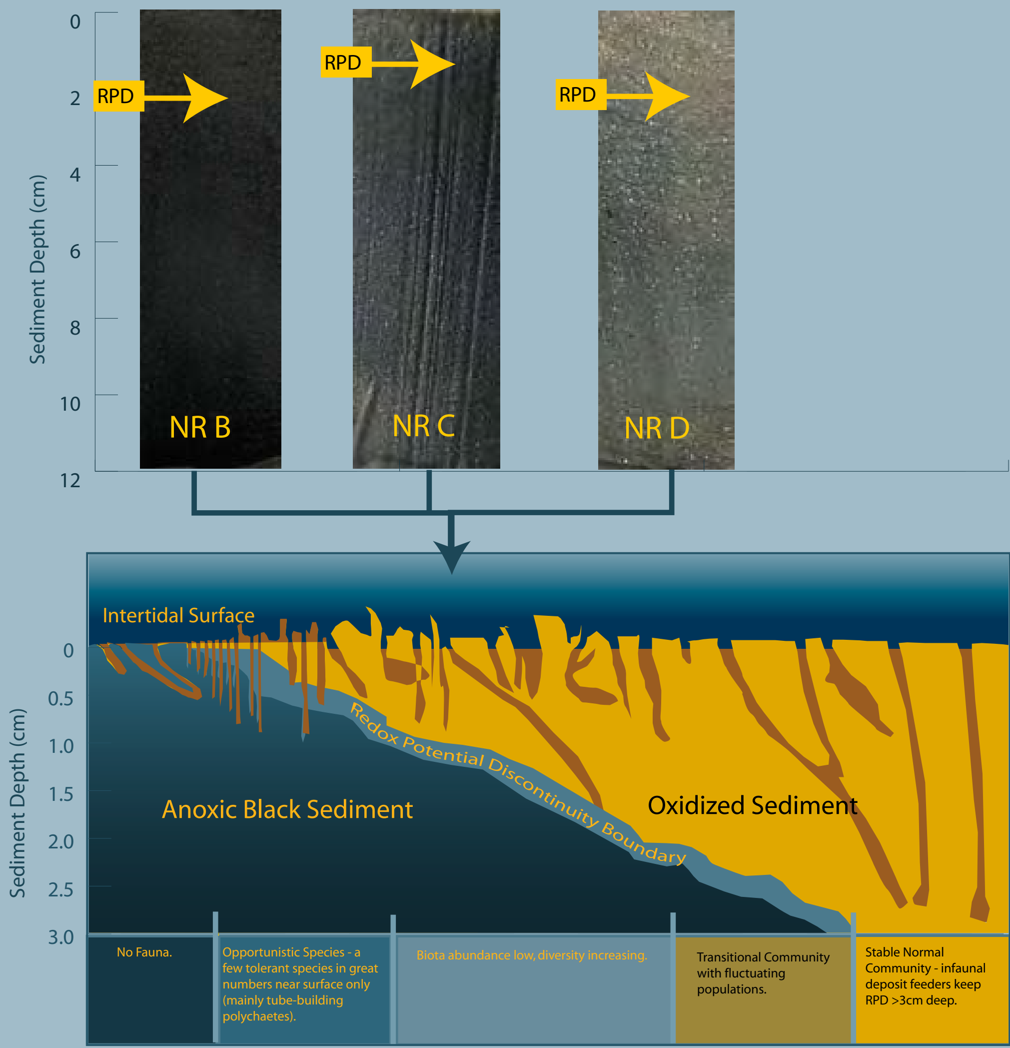
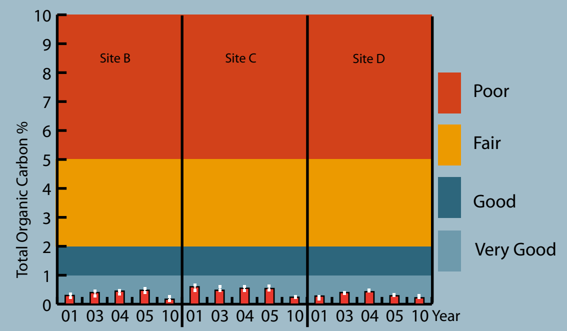


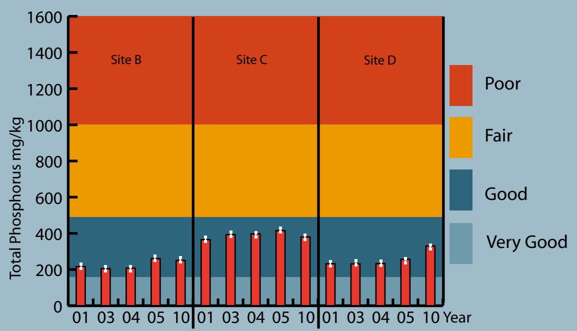
Figure 13. Sediment profiles, depths of RPD and predicted benthic community type, New River Estuary, 9-10 February 2010. Arrow below core relates to the type of community likely to be found in the core.

Figure 14. Total organic carbon (mean and range) at 3 intertidal sites, 2001-2010.



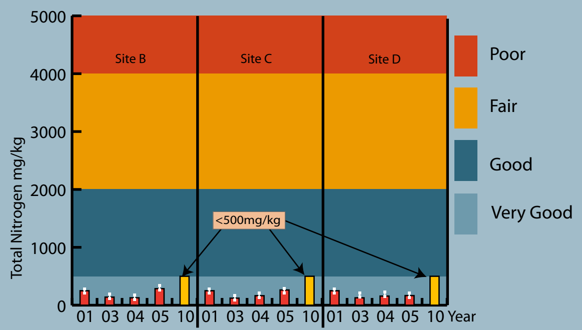
2010 TOC RATING	Very Good

Figure 15. Total phosphorus (mean and range) at 3 intertidal sites, 2001-2010.



2010 TP RATING	Good

Figure 16. Total nitrogen (mean and range) at 3 intertidal sites, 2001-2010.



2010 TN RATING	Very Good

ORGANIC MATTER (TOC)

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

The indicator of organic enrichment (TOC) at all three sites in 2010 (Figure 14) was at low concentrations (<1%) at all sites and met the "very good" condition rating. These conditions were similar to those measured during the four year baseline monitoring period 2002-2005. Such conditions indicate a low extent of accumulation of organic matter in the sediments of the main body of the estuary. This is supported by measured low levels of macroalgal growth in this section of the estuary (Stevens and Robertson 2010). However, in localised areas of the estuary where mud and macroalgal accumulation is common (e.g. Waihopai Arm and Daffodil Bay), much more elevated concentrations are expected.

TOTAL PHOSPHORUS

Total phosphorus (a key nutrient in the eutrophication process) was present in the "low to moderate enrichment" category (Figure 15) at all three sites in 2010 and met the "good" condition rating. These 2010 results were similar to those measured during the four year baseline monitoring period 2002-2005.

Such conditions indicate a moderate to low extent of accumulation of phosphorus in the sediments of the main body of the estuary. However, like TOC, in localised areas of the estuary where mud and macroalgal accumulation is common (e.g. Waihopai Arm and Daffodil Bay), much more elevated concentrations are expected.

TOTAL NITROGEN

Total nitrogen (the other key nutrient in the eutrophication process) was in the "low enrichment" category (Figure 16) at all 3 sites in 2010 and met the "very good" condition rating. These 2010 results were similar to those measured during the four year baseline monitoring period 2002-2005.

Such conditions indicate a low extent of accumulation of nitrogen in the sediments of the main body of the estuary. However, like TOC and TP, in localised areas of the estuary where mud and macroalgal accumulation is common (e.g. Waihopai Arm and Daffodil Bay), much more elevated concentrations are expected.

Macro-invertebrate Organic Enrichment Index

The benthic invertebrate organic enrichment rating for the New River Estuary was in the "low to very low" category, indicating slight to moderate organic enrichment for 2001-2005 and 2010 (Figure 17). Such a rating likely reflects the moderate sediment nutrient concentrations, and the exposed nature of this central part of the estuary. As in previous years, the 2010 conditions resulted in a community dominated by a broad range of species sensitivities (Figure 18) including:

- Low-moderate abundances and numbers of species that are very sensitive to organic enrichment (e.g. the small, sedentary deposit feeding bivalve, *Arthritica bifurca*, cockles *Austrovenus stutchburyi*, the wedge shell *Macomona liliana*, and the polychaete *Boccardia* sp.).
- Low-moderate abundances and numbers of species that are indifferent to organic enrichment (slightly unbalanced) for example, pipis (*Paphies australis*), the burrowing anemone *Edwardsii* sp., mysid shrimps and various polychaetes.
- Moderate numbers of species and elevated abundances of species that are tolerant to excess organic enrichment (unbalanced situation) for example, the spionid polychaete *Microspio maori*, and at Site D (Bushy Point) the small native estuarine snails *Potamopyrgus estuarinus* and *P. antipodarum*.
- Low abundances and diversity of species that are very tolerant to organic enrichment (slight to pronounced unbalanced situations), for example the polychaete *Heteromastus filiformis*.
- 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).

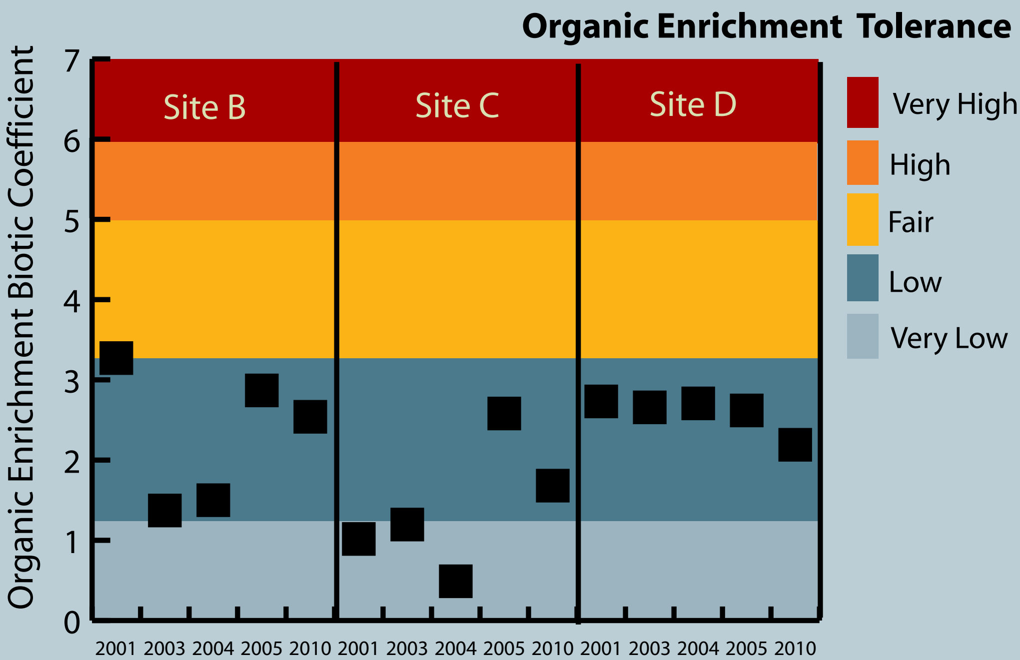


Figure 17. Benthic invertebrate organic enrichment rating, New River Estuary.

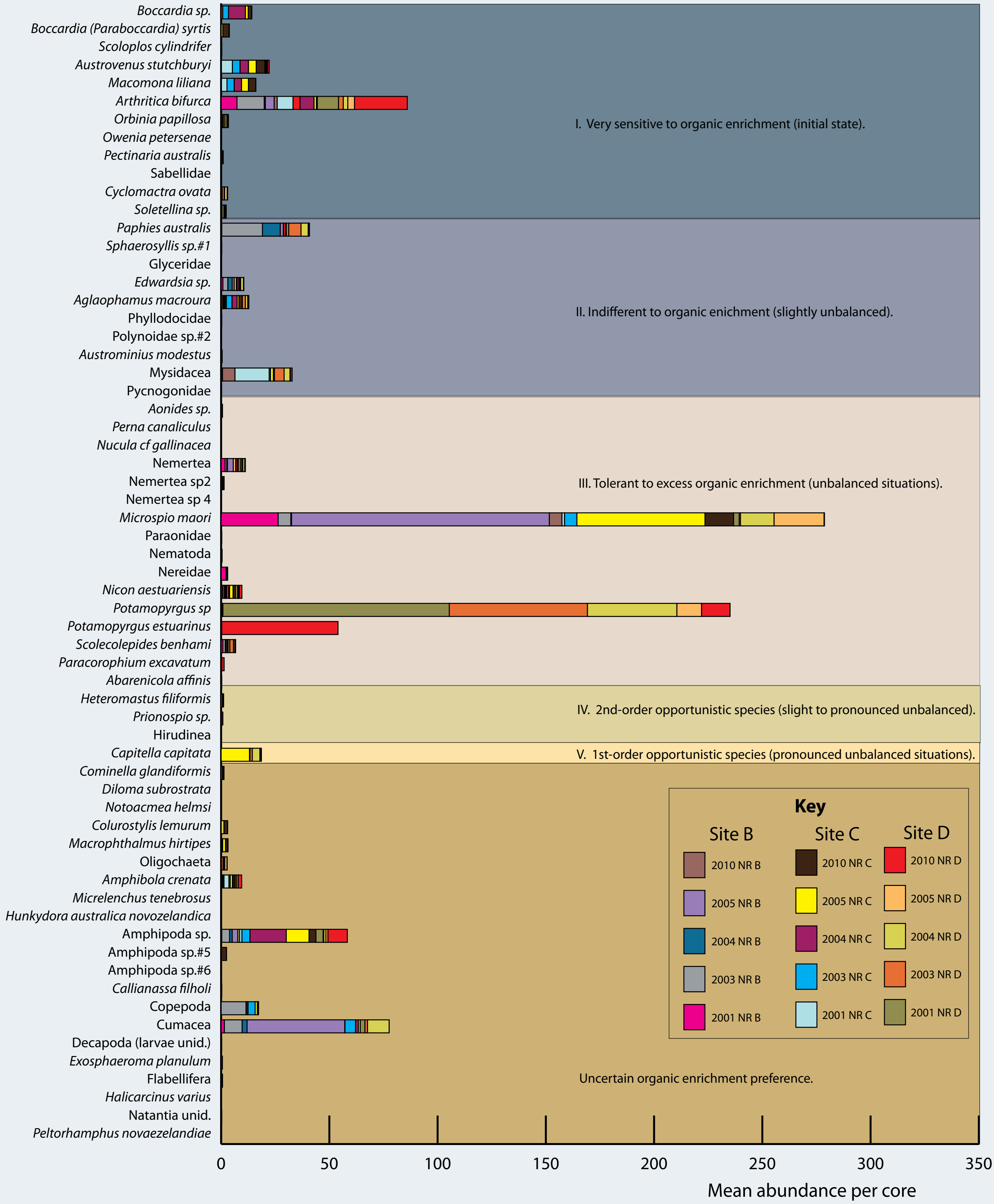


Figure 18. New River Estuary 2001-2010 - macroinvertebrate organic enrichment sensitivity (see Appendix 3 for sensitivity details).

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 all years including the recent monitoring undertaken in 2010, with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 19). In 2010 metals met the "very good" condition rating for all the metals at all of the sites. Such ratings indicate that toxicity in the main body of the New River Estuary is not a problem.

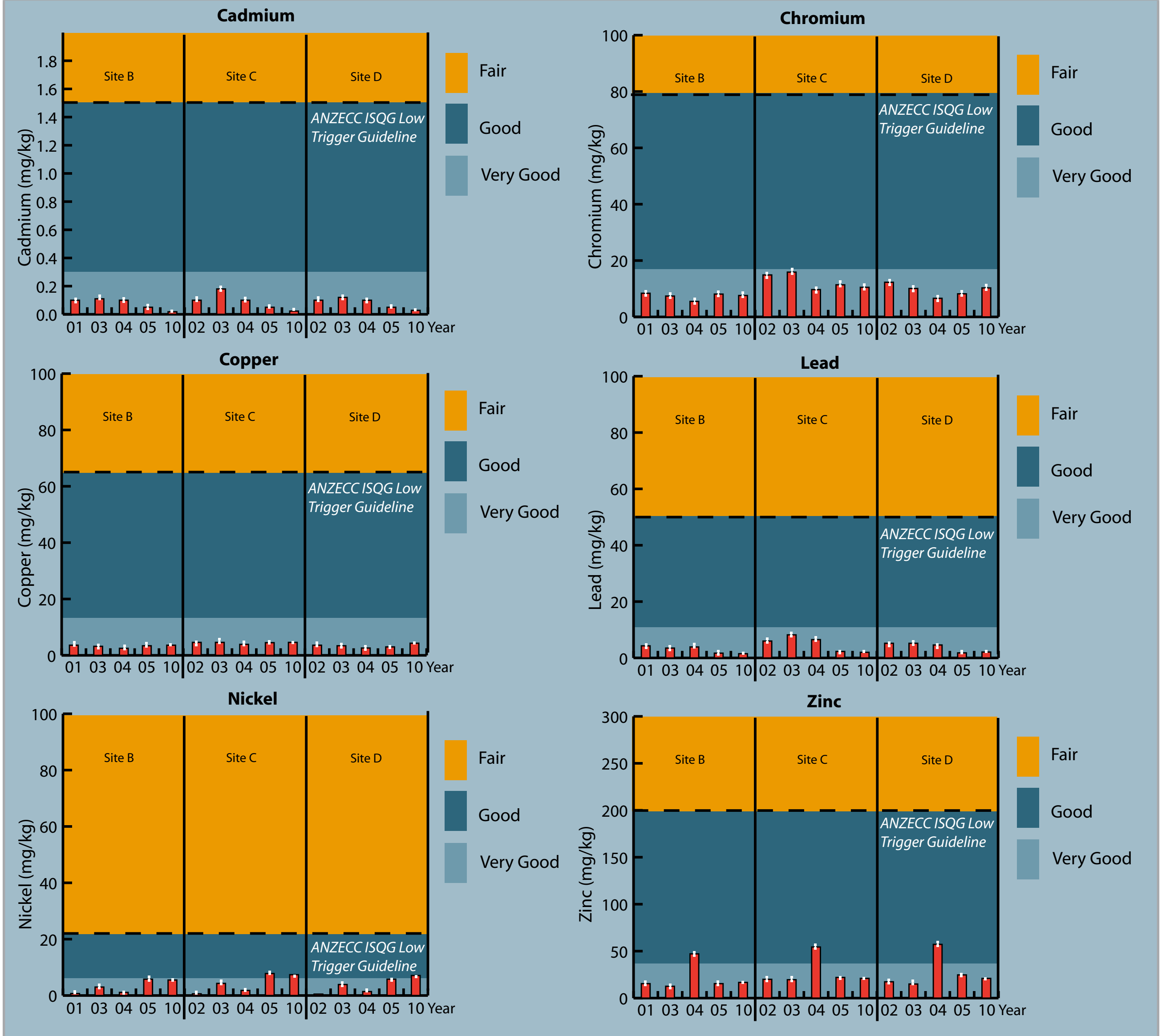


Figure 19. Total recoverable metals (mean and range) at 3 intertidal sites, New River Estuary.

4. CONCLUSIONS

Main Intertidal Flats	**Sedimentation** The 2010 monitoring results indicate that since 2004 there has been a shift towards increased muddiness in the main intertidal flats of the estuary as follows: • The mud content at the three sampling sites has at least doubled. • Sediment oxygenation, as indicated by the depth of the RPD layer, has declined. • There has been a shift towards more mud-tolerant organisms at one of the sites, and the loss of the mud intolerant pipis from all of the sites. **Eutrophication** The 2010 monitoring results also showed that concentrations of nutrients and organic matter in the sediments remained at the same low-moderate levels as were measured in 2002-2005 and the benthic invertebrate organic enrichment rating for the New River Estuary was in the "low to very low" category, indicating slight to moderate organic enrichment. **Toxicants** Concentrations of sediment toxicants (heavy metals) were low and similar to those measured in the baseline years.
Waihopai Arm	**Sedimentation Rate** The sedimentation rate results for the Waihopai Arm indicate that this area of the New River Estuary is rapidly infilling with mud as indicated by a mean sedimentation rate of 20-27mm/yr which fits within the "very high" category. Macroalgal mapping results (Stevens and Robertson 20101) also indicate severe eutrophication of this section of the estuary.
Other Issues	In determining the overall condition of the estuary, the results discussed above must be considered alongside results from other areas of the estuary and other parameters [e.g. broad scale mapping (Robertson and Stevens 2007), macroalgal mapping (Stevens and Robertson 2008, 2009, 2010), bathing and shellfish risk monitoring (Environment Southland and Invercargill City Council monitoring results)]. In summary, these other studies indicate the following: • Historically, the New River Estuary has lost large areas of high value habitat (particularly saltmarsh and seagrass) which means that the estuary has a much lowered capacity to assimilate inputs of sediment, nutrients, faecal bacteria and toxicants and has lowered ecological values. • In the more poorly flushed estuary arms and embayments (especially the Waihopai Arm and Daffodil Bay), there has been an excessive rate of sedimentation or infilling, poor sediment oxygenation, and nuisance algal growths. • Shellfish health and human disease risk problems are common throughout the estuary. • Localised toxicity problems exist around some sources of urban stormwater.

5. FUTURE MONITORING

New River Estuary has been identified by Environment Southland as a high priority for monitoring, and is a key part of their coastal monitoring programme being undertaken in a staged manner throughout the Southland region. The future monitoring recommendations are outlined as follows:

Fine Scale Monitoring.

Continue with the programme of 5 yearly fine scale trend monitoring at three sites. Next monitoring scheduled for February 2015.

Macroalgal Monitoring.

Continue with the programme of annual broad scale mapping of macroalgae. Next monitoring scheduled for February 2011.

Broad Scale Habitat Mapping.

Continue with the programme of 5 yearly broad scale habitat mapping. Next monitoring scheduled for February/March 2012.

Sedimentation Rate Monitoring.

Because sedimentation is a priority issue in the estuary it is recommended that all sediment plate depths be measured annually and that additional sediment plates be deployed at representative locations so that the sedimentation rate over much larger parts of the estuary can be determined. These plates will also be used to gauge the success of actions taken to reduce sediment inputs.

In addition, it is recommended that accurate elevation maps of the estuary be undertaken at regular intervals (5-10 years) in order to provide a measure of sedimentation rates throughout the estuary. In order to obtain an accurate measure of sedimentation over the estuary with time, an elevation map would be required with a vertical height accuracy of <1cm (ideally 2-5mm). There are a variety of methods that could be used to produce such a map but most of them would be incapable of providing sufficient accuracy to be valuable in the short term (Table 5). Table 5 shows that a ground survey approach using traditional surveying techniques, or widespread deployment of buried sedimentation plates, are the only methods likely to provide useful measures in estuaries where change in elevation is in the order of 1-15mm/yr. Airborne LIDAR, although an attractive method for broadscale elevation mapping given its broad horizontal spread, only has a vertical accuracy of 12-20cm.

Table 5. A comparison of techniques for estuary topography mapping (adapted from Mason et al. 2000).

Vertical Accuracy	Topography Mapping Technique							
	Ground Survey	Airborne Stereo	Airborne LIDAR	Airborne INSAR	Waterline	Wave Current	Satellite INSAR	Optical Satellite
1cm	Possible	Improbable	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible	Not Possible
10cm	Very Possible	Possible	Possible	Not Possible	Improbable	Improbable	Not Possible	Not Possible

6. MANAGEMENT

This report has highlighted several problems that require management in the New River Estuary including: widespread sedimentation and disease risk as well as localised toxicity and nutrient enrichment with associated algal blooms and poorly oxygenated sediments. To rectify these problems, restoration of high value habitat and reduction of inputs of fine sediment, nutrients, faecal bacteria and toxicants to levels that the estuary can easily assimilate, is recommended. However, because of the complex nature of the estuary and the wide range of inputs (both point and non-point source), effective management is unlikely without the aid of additional information. In particular;

1. **Contaminant Input Budgets.** In order to identify the major sources of contaminants to the estuary, suspended sediment, nutrient, toxicant, and faecal bacterial input budgets are required. To derive such budgets, monitoring data will be required for both point and non-point sources, including wet and dry weather flow data.
2. **Broad Scale Sedimentation Rate**. In order to assess sedimentation over the whole estuary, regular elevation mapping is required as indicated in previous section.
3. **Condition of Poorly Flushed Areas**. In order to better characterise areas of the estuary that are prone to problems it is recommended that the existing condition of sediments in poorly flushed areas in the estuary be synoptically monitored. Parameters should include; algal cover, RPD depth, macro-invertebrate abundance and diversity, TP, TN and TOC.
4. **Condition of Water Column.** In order to assess the potential for algal blooms, disease risk and low water clarity it is recommended that the existing condition of the water column throughout the estuary be synoptically monitored at low and high tide. Parameters should include; turbidity, nutrients, faecal coliforms, chlorophyll a, salinity, temperature, dissolved oxygen.
5. **Fate of Contaminants**. In order to assess the fate of contaminant inputs to the estuary, particularly sediment, nutrients and faecal coliforms, and the fate of macroalgal blooms, it is recommended that a modelling approach be used - either a simple desktop method or a more complex dilution/dispersion/settling/resuspension approach. It is recommended that the fate assessment be undertaken once components 1-3 above are completed and only if the results indicate that such an assessment is required.
6. **Sea Level Rise Impact**. In order to assess the impact to estuary habitat from accelerated sea level rise it is recommended that inundation scenarios be identified and mapped as GIS layers and, together with already existing habitat layers, used to identify habitat vulnerability.

Overall, if the approach is followed and the estuary and its surroundings are managed to ensure that the assimilative capacity is not breached, then the estuary will flourish and provide sustainable human use and ecological values in the long term.

7. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

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

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

APPENDIX 2. 2010 DETAILED RESULTS

Physical and chemical results for New River Estuary, 9-10 February 2010.

Site	Rep.*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt@15^{0}C	%				mg/kg							
NR B	1-4	2	31	0.20	2.1	97.9	< 0.1	0.018	7.8	3.7	5.7	1.5	17	<500	260
NR B	5-8	2	31	0.16	2.4	97.6	< 0.1	0.019	7.3	3.5	5.3	1.5	16	<500	240
NR B	9-10	2	31	0.16	2.9	97.1	< 0.1	0.016	7.6	3.5	5.5	1.5	17	<500	250
NR C	1-4	1	30	0.22	7.3	92.7	< 0.1	0.025	11.0	4.9	7.9	2.1	22	530	430
NR C	5-8	1	30	0.29	7.0	93.0	< 0.1	0.027	11.0	4.9	7.7	2.0	21	<500	390
NR C	9-10	1	30	0.20	4.1	94.7	1.2	0.018	9.6	4.0	6.6	2.0	20	<500	320
NR D	1-4	2	31	0.18	3.6	95.4	0.9	0.023	9.6	4.0	6.7	2.1	20	<500	300
NR D	5-8	2	31	0.17	3.4	96.1	0.5	0.025	9.4	3.9	6.6	2.0	20	<500	300
NR D	9-10	2	31	0.31	6.8	93.2	< 0.1	0.035	12.0	5.0	7.9	2.1	23	<500	390

* composite samples

Sediment Plate Depths (mm).

Location	Site	No	Sediment depth (mm)			Change (mm)		Mean		Mean Rate/Year
			2/27/07	2/19/09	2/10/10	2007-2009	2009-2010	2007-2009	2009-2010	2007-2010
Site - Rifle Range 1 (Nth)	Upper North Arm	1	403	445	496	42	51	30	49.75	26.6
	Upper North Arm	2	290	331	368	41	37			
	Upper North Arm	3	325	327	387	2	60			
	Upper North Arm	4	270	305	356	35	51			
Site - Rifle Range 2 (Sth)	Central North Arm	5	280	279	316	-1	37	0.75	59.75	20.1
	Central North Arm	6	382	395	458	13	63			
	Central North Arm	7	295	282	342	-13	60			
	Central North Arm	8	400	404	483	4	79			
Site - Bushy Point	Lower North Arm	9	226	253	270	27	17	59.5	12.25	23.9
	Lower North Arm	10	265	381	396	116	15			
	Lower North Arm	11	240	323	328	83	5			
	Lower North Arm	12	265	277	289	12	12			

APPENDIX 2. 2010 DETAILED RESULTS (CONTINUED)

Station Locations

Shellbank Site B	NRE-B01	NRE-B02	NRE-B03	NRE-B04	NRE-B05	NRE-B06	NRE-B07	NRE-B08	NRE-B09	NRE-B10
NZGD2000 NZTM EAST	1241954	1241952	1241948	1241948	1241951	1241957	1241964	1241969	1241977	1241976
NZGD2000 NZTM NORTH	4842378	4842366	4842345	4842332	4842327	4842340	4842356	4842375	4842377	4842365

Daffodil Bay Site C	NRE-C01	NRE-C02	NRE-C03	NRE-C04	NRE-C05	NRE-C06	NRE-C07	NRE-C08	NRE-C09	NRE-C10
NZGD2000 NZTM EAST	1239469	1239459	1239446	1239439	1239442	1239452	1239456	1239474	1239483	1239470
NZGD2000 NZTM NORTH	4842289	4842298	4842309	4842313	4842321	4842317	4842313	4842301	4842309	4842314

Bushy Point Site D	NRE-D01	NRE-D02	NRE-D03	NRE-D04	NRE-D05	NRE-D06	NRE-D07	NRE-D08	NRE-D09	NRE-D10
NZGD2000 NZTM EAST	1240383	1240398	1240408	1240425	1240447	1240418	1240402	1240384	1240385	1240396
NZGD2000 NZTM NORTH	4844276	4844272	4844268	4844267	4844248	4844256	4844258	4844260	4844255	4844251

Epifauna (numbers per 0.25m² quadrat) - 9-10 February

NRE B East side (Shellbank)

Scientific name	Common name	NRE-B01	NRE-B02	NRE-B03	NRE-B04	NRE-B05	NRE-B06	NRE-B07	NRE-B08	NRE-B09	NRE-B10
Amphibola crenata	Estuarine mud snail				1				1		
Potamopyrgus estuarinus	Estuarine snail										

NRE C Daffodil Bay

Scientific name	Common name	NRE-C01	NRE-C02	NRE-C03	NRE-C04	NRE-C05	NRE-C06	NRE-C07	NRE-C08	NRE-C09	NRE-C10
Amphibola crenata	Estuarine mud snail	1	1	7	4	4	5	4	4	1	8
Austrovenus stutchburyi	Cockle				1		1			1	
Cominella glandiformis	Mudflat whelk		1		1						

NRE D Bushy Point

Scientific name	Common name	NRE-D01	NRE-D02	NRE-D03	NRE-D04	NRE-D05	NRE-D06	NRE-D07	NRE-D08	NRE-D09	NRE-D10
Amphibola crenata	Estuarine mud snail	3	8	4	4	6	5	11	6	6	2
Austrovenus stutchburyi	Cockle									1	
Potamopyrgus estuarinus	Estuarine snail	500	400	400	500	450	350	300	450	500	350

Algae (Percent cover) - 9-10 February

Station:	NRE-B01	NRE-B02	NRE-B03	NRE-B04	NRE-B05	NRE-B06	NRE-B07	NRE-B08	NRE-B09	NRE-B10
Visible Microalgae	100	100	100	100	100	100	100	100	100	100

Station:	NRE-C01	NRE-C02	NRE-C03	NRE-C04	NRE-C05	NRE-C06	NRE-C07	NRE-C08	NRE-C09	NRE-C10
Gracilaria	10	20	10	0	10	20	10	0	0	10

Scientific name	NRE-D01	NRE-D02	NRE-D03	NRE-D04	NRE-D05	NRE-D06	NRE-D07	NRE-D08	NRE-D09	NRE-D10
Gracilaria	0	0	5	1	1	0	10	30	1	5

Infauna (numbers per 0.0133m² core) - 9-10 February

See following page.

APPENDIX 2. 2010 DETAILED RESULTS (CONTINUED)

Taxa	AMBI	AMBI	MUD	Nre B-01	Nre B-02	Nre B-03	Nre B-04	Nre B-05	Nre B-06	Nre B-07	Nre B-08	Nre B-09	Nre B-10	Nre C-01	Nre C-02	Nre C-03	Nre C-04	Nre C-05	Nre C-06	Nre C-07	Nre C-08	Nre C-09	Nre C-10	Nre D-01	Nre D-02	Nre D-03	Nre D-04	Nre D-05	Nre D-06	Nre D-07	Nre D-08	Nre D-09	Nre D-10
Anthozoa	*Edwardsia* sp.	II	NA	1		1	1	1	1	1	1		3	2	1	1				1	1							1					
Nemertea	NEMERTEA	III	3																												1		
	Nemertea sp2	III	3		1	1	1	1					1				1		1	1		2					1	1				1	1
	Nemertea sp 4	III	3										1																				
Polychaeta	*Aglaophamus macroura*	II	NA		2	1			1					2	2	1	3		1	3	1		2		1					1			
	Aonides sp.	III	1																														
	Boccardia sp.	I	2											1		2	1	1		6	2	3											
	Boccardia (Paraboccardia) syrtis	I	2	1	1		5	1						3	4	5	4		1	2	3	1	5	1				1					
	Capitella capitata	V	3		4	2		2		3		2	22		1			1		2													
	Microspio maori	III	3	2	40	2	8	1	3	1			1	24	12	16	9	11	5	17	5	17	16	1								1	
	Nicon aestuariensis	III	4		1		1		2					1	2	1	1	2	1		2		1	3	1	1	1		1		1	2	2
	Orbinia papillosa	I	4			2	1	1			1	1		1	1			2															
	Polynoidae sp.#2	II	NA																													1	
	Sabellidae	I	NA																														
	Scolecolepides benhami	III	5			1	2				1	1	1							1							2						1
	Sphaerosyllis sp.#1	II	2													1																	
Oligochaeta	Oligochaeta	NA	5																			1					1						
Gastropoda	*Amphibola crenata*	NA	NA				1			1							2			1				1		1	1	1	4	1	2	3	2
	Cominella glandiformis	NA	1												1																		
	Potamopyrgus antipodarum	III	4																					9	12	22	13	12	7	15	21	14	7
	Potamopyrgus estuarinus	III	4															1			1			26	44	61	52	59	34	77	96	54	35
Bivalvia	*Arthritica bifurca*	I	3	2			1	1	1	1	1	4	3	1			1				2			17	33	21	9	23	30	5	22	29	55
	Austrovenus stutchburyi	I	2			1								2	1	6	5	2	2	9	4	5	4	1	1		1	4			1		
	Cyclomactra ovata	I	NA																								2						
	Macomona liliana	I	2											4	5	3	3	3	2	3	2	6	3										
	Paphies australis	II	1																												1		
	Soletellina sp.	I	NA	1								2																					
Crustacea	Amphipoda sp.	NA	NA			1	3		1		2		1	2	5	4	2	1		1	2	13	2	4	1	2	5	8	6	13	27	16	8
	Amphipoda sp.#5	NA	NA													6	4	3				12											
	Amphipoda sp.#6	NA	NA																												1		
	Colurostylis lemurum	NA	2	1		3	1	1		1	1	1	4	5	3			1	1	3		2	2										
	COPEPODA	NA	NA																					1								1	
	Exosphaeroma planulum	NA	NA																						1		1	1	2			1	
	Halicarcinus varius	NA	NA																			1											
	Macrophthalmus hirtipes	NA	3				2							1	1		1	3	1		1		1			1							
	Mysidacea	II	NA			29	19	1			1	1	7	2			1										3		1		3	1	
	Paracorophium excavatum	III	5				1	1																1	3	4		1			1	2	
Total species in sample				**6**	**6**	**11**	**14**	**10**	**6**	**6**	**7**	**7**	**10**	**14**	**13**	**11**	**14**	**12**	**9**	**13**	**12**	**11**	**9**	**11**	**9**	**8**	**13**	**11**	**8**	**6**	**12**	**13**	**8**
Total specimens in sample				**8**	**49**	**44**	**47**	**11**	**9**	**8**	**8**	**12**	**44**	**51**	**39**	**46**	**38**	**31**	**15**	**50**	**26**	**63**	**36**	**65**	**97**	**113**	**92**	**112**	**85**	**112**	**177**	**126**	**111**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Hirudinea	Hirudinea sp.1	NA	NA	Unidentified leech. Leeches are most common in warm, protected shallows where there is little disturbance from currents. Free-living leeches avoid light and generally hide and are active or inactive under stones or other inanimate objects, among aquatic plants, or in detritus. Some species are most active at night. Silted substrates are unsuitable for leeches because they cannot attach. Some species can tolerate mild pollution.
Anthozoa	*Anthopleura aureoradiata*	II	SS Optimum range 5-10% mud,* distribution range 0-15%*	Mud flat anemone, attaches to cockle shells and help reduce the rate at which cockles accumulate parasites. Grows up to 10mm, intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al., 2001). Very tolerant to a range of Polycyclic Aromatic Hydrocarbons (PAH's). *Anthopleura* are also tolerant to UV light, because they have mycosporine-like amino acids in their tissue which act like a biological sunscreen. It has green plant cells in its tissues that convert solar energy to food. Its column is rough with warts.
Anthozoa	*Edwardsia* sp.#1	II	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.
Nemertea	Nemertea sp.	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. Very common. 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.
Polychaetes	*Abarenicola affinis*	III	NA	An endemic species that belongs to Family Arenicolidae. Lower shore, burrowing in medium to fine, sheltered sands and discharging a pile of sandy coils on the surface. *Abarenicola affinis* thrives in organically enriched sediments. The once well-known *Abarenicola affinis* population of Wellington's Petone Beach has dwindled greatly in number since the closure of an abattoir outfall, and now Otago Harbour may have New Zealand's biggest population of lugworms.
Polychaetes	*Aglaophamous macroura.*	II	NA	A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate. Feeding type is carnivorous. Significant avoidance behaviour by other species. Feeds on *Heteromastus filiformis, Orbinia papillosa* and *Scoloplos cylindrifer* etc.
Polychaetes	*Aonides oxycephala*	III	SS Optimum range 0-5% mud*, distribution range 0-80%**.	A small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. Although Aonides is free-living, it is not very mobile and prefers to live in fine sands. Aonides is very sensitive to changes in the silt/clay content of the sediment. **But is generally tolerant of organically enriched situations.** In general, polychaetes are important prey items for fish and birds.
Polychaetes	*Boccardia (Paraboccardia) syrtis and acus*	I	S Optimum range 10-15% mud,* distribution range 0-50%*	Small surface suspension-feeding spionids (also capable of detrital feeding). Prefers sand with low-mod mud content but found in a wide range of sand/mud. **Prefers 10-15% mud but can live in 0-50% 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. When in dense beds, the community tends to encourage build-up of muds.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaetes	*Capitella capitata*	V	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *Heteromastus f.*	A blood red capitellid polychaete which is **very pollution tolerant.** Common in suphide rich anoxic sediments.
	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. Prefer 10-15% mud but found in wide range. Intolerant of low salinity.**
	Heteromastus filiformis	IV	I Optimum range 10-15% mud,* distribution range 0-95%*	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate to high organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	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.
	Nereidae	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of high sulphide concentrations.
	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 mud content sediments.**
	Orbinia papillosa	1	S Optimum range 5-10% mud,* distribution range 0-50%*	Family Orbiniidae. Live in sandy or fine sand sediments. Do not have a burrow. A large non selective deposit feeder. Endemic orbiniid. Without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant. Prefers 5-10% mud but found from 0-50% mud. Sensitive to changes in sedimentation rate. Low numbers in Bluff Harbour (2-20% mud), New River Estuary (1-6% mud).
	Owenia petersenae	II	NA	Oweniidae. Members of the Oweniidae have characteristic tubes which are considerable longer than the animal and are composed of shell fragments and sand grains which are stacked on top of each other. Oweniids often remain intact within their tubes and must be carefully removed for proper examination. *O. fusiformis* is currently thought to include a variety of species. Normally a suspension feeder, but is capable of detrital feeding. Is a cosmopolitan species frequently abundant on sandflats. **Are classified as intermediate type species along organic enrichment gradients (Pearson and Rosenberg 1978).**

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaetes	Paraonidae sp.#1	III	NA	Slender burrowing worms, 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 to a depth of 15cm. Sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content. **Aricidea prefer 35-40% mud (range 0-70% mud).**
Polychaetes	*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.**
Polychaetes	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.
Polychaetes	Polydora sp	I	S Optimum range 10-15% mud,* distribution range 0-50%*	A Spionid. Polydora-group have many NZ species. Difficult to identify unless complete and in good condition. The Polydora group of species specialise in boring into shells. *Boccardia acus* bores into the upper exposed shell of the cockle *Austrovenus stutchburyi*. Several other Polydora group species live free in tubes in the sand. The tubes of the most widely-occurring species, *Boccardia syrtis*, form a visible fine turf on sandstone reefs and on some sand flats.
Polychaetes	Polynoidae	II	NA	The polynoid scale worms are dorsoventrally flattened predators. Lower intertidal and subtidal to deep sea throughout New Zealand. Conspicuous but never abundant.
Polychaetes	*Prionospio aucklandica* originally *Aquilaspio aucklandica.*	IV	I Optimum range 65-70% mud* or 20- 50%**, distribution range 0-95%*. Sensitive to changes in sediment mud content.	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was originally *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A suspension feeding spionid (also capable of detrital feeding) that **prefers living in muddy sands (65-70% mud) but doesn't like higher levels.** But animals found in 0-95% mud. **Commonly an indicator of increase in mud content. Tolerant of organically enriched conditions.** Common in Freshwater estuary (<1% mud). Present in Waikawa (10% mud), Jacobs River Estuary (5-10% muds).
Polychaetes	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.
Polychaetes	*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 but prefers moderate mud content (25-30% mud).** But also found in 0-100% mud environments. 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 Rrm, New River Estuary.
Polychaetes	*Scolelepis (Microspio) sp*	III	NA	A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary (5% mud),

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group	Species	Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaetes	*Scoloplos cylindrifer*	I	S Optimum range 0-5% mud,* distribution range 0-60%*	Originally, *Haploscoloplos cylindrifer.* Belongs to Family Orbiniidae which are thread-like burrowers without head appendages. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. **Prefers 0-5% mud (range 0-60% mud).** **Pollution and mud intolerant**.
Polychaetes	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).
Gastropoda	*Amphibola crenata*	NA	NA	A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria.
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 30 metres 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 mudflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ. Feeds on the film of microscopic algae on top of the sand. **Strong Sand Preference . Optimum mud range 5-10% mud.**
Gastropoda	*Notoacmaea helmsi*	I	SS Optimum range 0-5% mud*, distribution range 0-10%**.	Endemic to NZ. Small grazing limpet attached to stones and shells in intertidal zone. **Intolerant of anoxic surface muds and sensitive to pollution.** **Strong sand preference 0-5% mud (range 0-10% mud).** Present in Porirua Harbour 4-5% mud, Freshwater estuary <1% mud. A few in Fortrose (5% mud).
Gastropoda	*Potamopyrgus estuarinus*	NA	M Tolerant of muds.	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feed on decomposing animal and plant matter, bacteria, and algae. **Intolerant of anoxic surface muds. Tolerant of muds.**
Bivalves	*Arthritica bifurca*	III	I Optimum range 55-60% mud*, or 20-40%***, distribution range 5-70%**.	A small sedentary deposit feeding bivalve, preferring a moderate mud content. Lives greater than 2cm deep in the muds. **Prefers 55-60% mud (range 5-70% mud).**
Bivalves	*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. **Can live in both mud and sand but is sensitive to increasing mud - prefers low mud content (5-10% but can be found in 0-60% mud). Rarely found below the RPD layer.** Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns.
Bivalves	*Hunkydora australica novozelandica*	NA	NA	Belongs to the Family Myochamidae, large marine bivalves of the Pholadomyoida order. The valves are unequal, the left valve flat, and the right convex, and overlapping the left. DOC threat classification 7 - range restricted.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group	Species	Organic Enrichment Tolerance- AMBI Group *****	Mud Tolerance ****	Details
Bivalves	*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).**
	Mactra Ovata (Cyclomactra ovata)	I	NA	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water. Mud Tolerance; prefers 0-10% mud (range 0-80%).
	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 New Zealand. Often abundant in top few cm. It is found intertidally and in shallow water, especially in *Zostera* sea grass flats. It is often found together with the New Zealand 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.
	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 New Zealand. 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 mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud.
	Solletellina	I	NA	*Soletellina* is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells.
Oligichaeta	Oligochaete sp.	I ?	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.
Crustacea	*Amphipoda sp.1*	NA	NA	An unidentified amphipod.
	Austrominius modestus	II	NA	Small acorn barnacle (also named *Elminius modestus*). Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones.

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Crustacea	*Callianassa filholi*	NA	NA	Ghost shrimp, Decapoda, endemic to NZ. Makes long, semi-permanent burrows between low water of neap and spring. Up to 5cm long it is pale milk white with coral pink. Can't walk on a firm surface. A male and a female normally occupy a burrow. When feeding the shrimp moves close to one of the entrances.
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	Cumacea	NA	NA	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	*Decapoda (larvae)*	NA	NA	Unidentified crab larvae.
Crustacea	*Exosphaeroma* sp.	NA	NA	Small seaweed dwelling isopod.
Crustacea	Flabellifera	NA	NA	Flabellifera is the second largest isopod suborder.
Crustacea	*Macrophthalmus hirtipes*	NA	I Optimum range 45-50% mud, distribution range 0-95%*.	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
Crustacea	*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
Osteichthyes	*Peltorhamhus novaezelandiae*	NA	NA	Juvenile common sole. The young of many adult flatfish species are strongly dependent on estuarine areas. In New River estuary many juvenile flatfish inhabit the small channels at low tide and are preyed on by other fish. Flatfish depend on benthic invertebrates as a food source with diet consisting of mainly small crabs, worms and crustaceans. Flatfish are fast growing and are a relatively dependable fishery from year to year.
Pycnogonidae	Pycnogonid sp.	I	NA	Sea spiders either walk along the bottom with their stilt-like legs or swim just above it using an umbrella pulsing motion.[1] Most are carnivorous and feed on cnidarians, sponges, polychaetes and bryozoans. Sea spiders are generally predators or scavengers. They will often insert their proboscis, a long appendage used for digestion and sucking food into its gut, into a sea anemone and suck out nourishment. The sea anemone, large in comparison to its predator, almost always survives this ordeal. Studies have shown that adult taste preferences depend on what the animals were fed as young

APPENDIX 3. INFAUNA CHARACTERISTICS

NA=Not Allocated

* 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.