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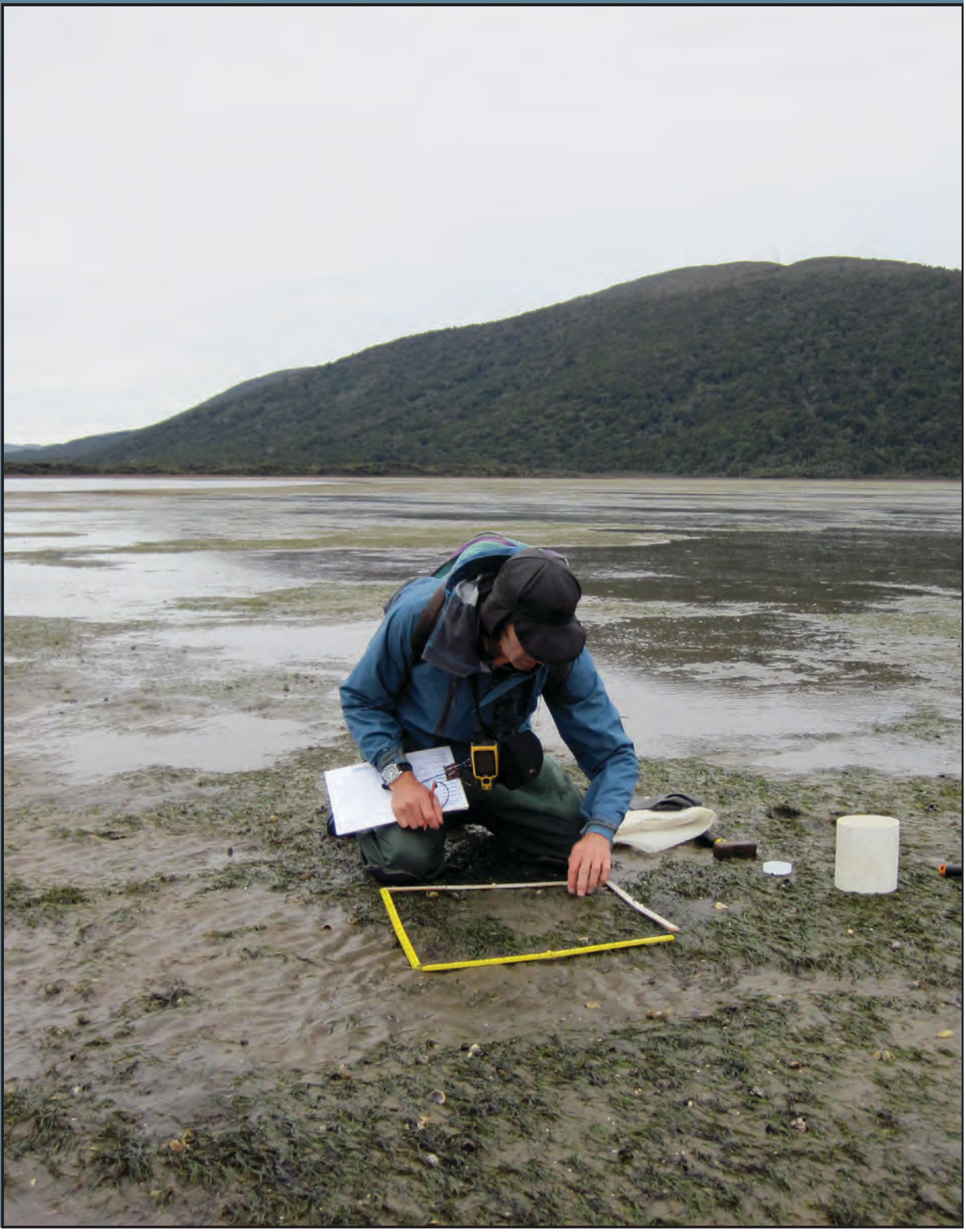
Freshwater Estuary

Intertidal Fine Scale Monitoring 2010/11



Prepared for **Environment Southland**
August 2011

Cover Photo: Leigh Stevens monitoring at Freshwater Estuary, February 2011

Freshwater Estuary February 2011.

Freshwater Estuary

Fine Scale Monitoring 2010/11

Prepared for
Environment Southland

By

Barry Robertson and Leigh Stevens

Wriggle Limited, PO Box 1622, Nelson 7040, Ph 03 545 1550, 021 417 936, www.wriggle.co.nz

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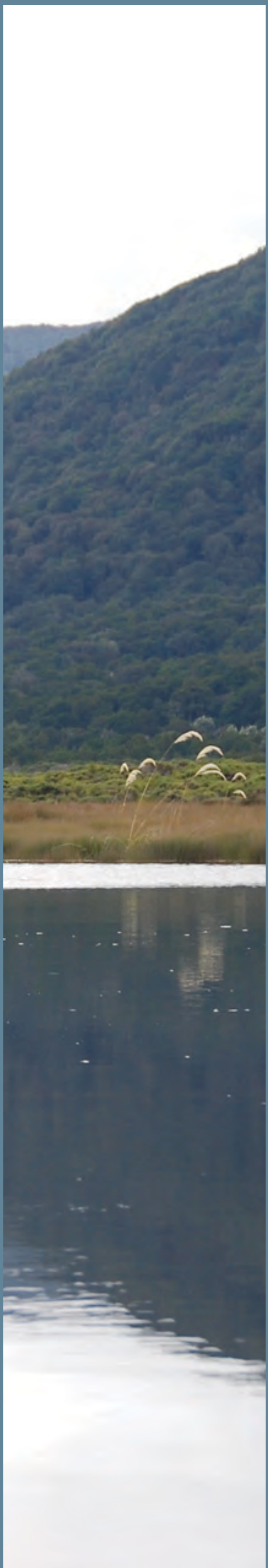
FRESHWATER ESTUARY - EXECUTIVE SUMMARY



This report summarises the results of the first three years (2009, 2010 and 2011) of fine scale monitoring of two intertidal sites within Freshwater Estuary, an 812ha pristine, tidal river mouth estuary and intertidal delta located at the sheltered western end of Paterson Inlet on Stewart Island. It is one of the key estuaries in Environment Southland's long-term coastal monitoring programme. The following sections summarise the fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

FINE SCALE MONITORING RESULTS

The third year of fine scale monitoring results for the condition of Freshwater Estuary showed the following.

In terms of sedimentation, the grain size results indicated sandy sediments, with very low mud contents and, a healthy benthic invertebrate community dominated by species that prefer sands. In combination with the 2008 broad scale mapping results, which showed that the intertidal area was dominated by firm sands and seagrass, there was no indication of a sedimentation problem (i.e. extensive areas of soft muds and low clarity waters were not present).

In terms of eutrophication, the results suggest that the estuary has a "moderate" level of enrichment.

This rating is based on the combined ratings for the following indicators:

- "poor" macroalgal rating (in 2008, 25% of the estuary had greater than 50% macroalgal cover),
- "low" benthic invertebrate organic enrichment tolerance rating,,
- low-moderate sediment nutrient and TOC concentrations,
- a variable RPD depth, indicating well-oxygenated sediments.
- low sediment mud content and,
- widespread seagrass cover (based on 2008 broadscale mapping).

Unlike some other Southland estuaries (e.g. New River and Jacobs River Estuaries), large areas of highly eutrophic conditions were not present in Freshwater Estuary (i.e. areas where the sediments exhibit all of the following; high macroalgal growth (>50% cover), are soft and muddy, have a shallow RPD, elevated nutrient and TOC concentrations and very high macroinvertebrate organic enrichment tolerance ratings).

In terms of toxicity, heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations.

ESTUARY CONDITION AND ISSUES

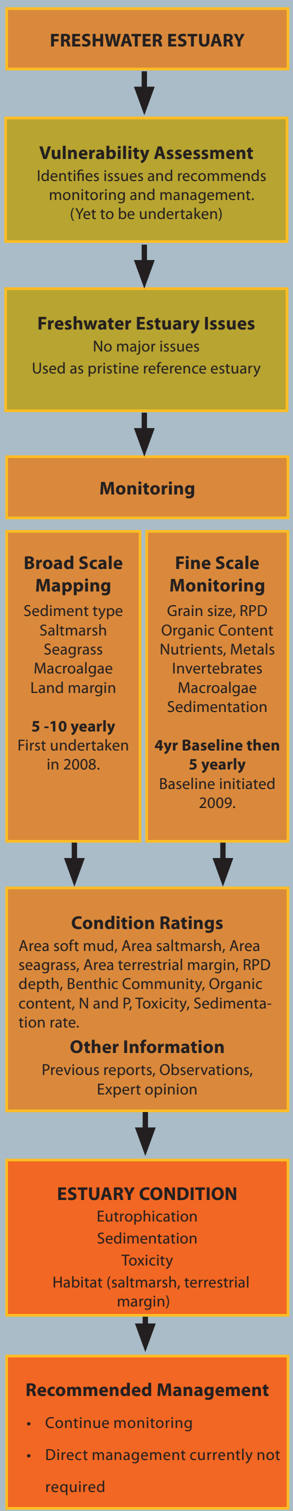
Overall, the results showed that Freshwater Estuary was in very good condition, reflecting the pristine nature of this estuary, and that conditions were similar to those measured in 2009 and 2010. The good condition can be attributed to the very low inputs of fine sediments, toxicants and disease causing microbes to the estuary, which, when combined with the moderate inputs of nutrients (estimated at 200tN/yr - NIWA WRENZ model) sourced from the native bush catchment, results in a thriving, healthy and productive seagrass-dominated estuarine environment.

RECOMMENDED MONITORING AND MANAGEMENT

One more year of baseline monitoring is recommended. The next fine scale monitoring (including sedimentation rate) should be undertaken in February 2012 and subsequently at 5 yearly intervals.

Because Freshwater Estuary is relatively unmodified and the surrounding land is protected within Rakiura National Park, direct management action by Environment Southland is currently considered unnecessary.

1. INTRODUCTION



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. In order to provide information on more pristine estuaries in the region, Freshwater Estuary, Stewart Island was included in ES's estuary monitoring priorities.

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

The Freshwater Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** of the estuary to major issues (Table 1) and appropriate monitoring design. Because of its low priority for assessment compared with other estuaries in the region, this component has not yet been undertaken for Freshwater Estuary.
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 April 2008. It is reported separately in Stevens and Robertson (2008).
3. **Fine Scale Monitoring** (EMP approach). Monitoring of physical, chemical and biological indicators (Table 2) including sedimentation plate monitoring. This component, which provides detailed information on the condition of the Freshwater Estuary, has been undertaken in 2009 and 2010 (Robertson and Stevens 2009, 2010). The February 2011 monitoring is the subject of the current report.

Freshwater Estuary is a relatively large (812ha), pristine "tidal river mouth" type estuary with intertidal delta that has established within the confines of Paterson Inlet. Fed by the largest river on Stewart Island, Freshwater River, it drains the native forest catchment of the Mt Anglem highlands and Ruggedy Mountain area. Its lower reaches meander across Freshwater Valley, the largest area of flat land on Stewart Island. The estuary itself is relatively shallow (mean depth approximately 2m), has an extensive intertidal area (77% of the estuary is exposed at low tide), and supports very large areas of seagrass. The combination of a hard-rock, native bush catchment and clear waters, good flushing and wave resuspension means that the majority of the delta sediments are sandy and homogeneous, and muddy sediments are a very minor component (<3%). Because of the pristine nature of the estuary, including its high value seagrass and saltmarsh habitats and natural vegetated margin and catchment, Freshwater Estuary serves as a valuable reference estuary for the rest of New Zealand.

Recreational use of the estuary is moderate, mainly for walking, bird study, scenic values, fishing and shellfish collection. Commercially, the estuary is used for access to the Stewart Island walkway. Ecologically, habitat diversity is high, given the benefits of extensive sandy intertidal flats and seagrass beds, clear seawater, saltmarsh, and a native forest catchment.

The presence of stressors or threats is expected to be low. The estuary is surrounded by native forest protected within Rakiura National Park, while the waters of Paterson Inlet are managed under a mataitai (Te Whaka a Te Wera Mataitai Reserve). The main threats to the estuary are weed and pest invasions, climate change, and sea level rise.

1. Introduction (Continued)

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

Major Estuary Issues	
Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there.
Disease Risk	Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time. Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds. Diseases linked to pathogens include gastroenteritis, salmonellosis, hepatitis A, and noroviruses.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to estuaries through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Loss	Estuaries have many different types of habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is commonplace with the major causes cited as sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff and wastewater discharges.

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

Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
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.

Note: Yellow shading signifies fine scale indicators used in the Freshwater fine scale monitoring assessments.

2. METHODS

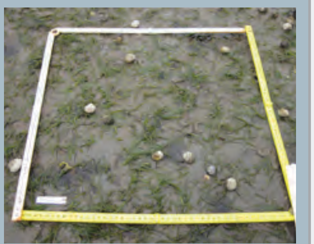
FINE SCALE MONITORING

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

In 2009, 2010 and 2011, two fine scale sampling sites (Sites A and B, Figure 1), were selected in low-mid tide seagrass habitat, the dominant intertidal habitat in Freshwater Estuary. At each site, a 60m x 30m area in the lower intertidal was marked out and divided into 12 equal sized plots. Within each site, ten plots were selected, a random position defined within each, and the following sampling and analysis undertaken:

Physical and chemical analyses:

- Within each plot, one randomly positioned core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average redox potential discontinuity (RPD) depth recorded.
- At each site, three samples (each a composite from four plots) of the top 20mm of sediment (each approx. 250gms) were collected. All samples were kept in a chillybin in the field.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details in Appendix 1):
  - Grain size/Particle size distribution (% mud, sand, gravel).
  - Nutrients - total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC).
  - Trace metal contaminants (Cd, Cr, Cu, Ni, Pb, Zn). Analyses were based on whole sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results are checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide at each site.



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 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).

2. Methods (Continued)

Figure 1. Freshwater Estuary - location of fine scale monitoring sites.

FINE SCALE SITE BOUNDARIES		
SITE	NZMG EAST	NZMG NORTH
A	2127177	5355174
A	2127167	5355145
A	2127112	5355169
A	2127121	5355197
B	2128013	5355384
B	2128036	5355402
B	2128077	5355362
B	2128055	5355340

SEDIMENT PLATE SITES		
No.	NZMG EAST	NZMG NORTH
A1	2127174	5355217
A2	2127167	5355236
A3	2127181	5355249
A4	2127192	5355234
B1	2128017	5355387
B2	2128020	5355391
B3	2128027	5355394
B4	2128031	5355397

2. Methods (Continued)

Sedimentation Rate

Determining the future sedimentation rate involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried and levelled, 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.

Two sites, each with four plates (20cm square concrete blocks) have been established in Freshwater Estuary with locations shown in Figure 1. Site A, established on 10 April 2008 has four plates buried approximately 20m apart in a square configuration deep in the sediments where substrate was stable. Site B was added on 27 February 2009 with the four plates buried at 5m, 10m, 20m, and 25m from the south eastern corner peg of the fine scale monitoring site.

Both sites were located in firm sand where sediment from Freshwater River was considered likely to deposit. The GPS positions of each plate were logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded (Appendix 2). In the future, these depths will be measured annually and, over the long term, will provide a measure of the rate of sedimentation in the estuary.

CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented below) have been proposed for Freshwater 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;

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

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

BENTHIC COMMUNITY MUD TOLERANCE RATING

MUD TOLERANCE RATING	DEFINITION	MTBC	RECOMMENDED RESPONSE
Very Low	Strong sand preference dominant	0-1.2	Monitor at 5 year intervals after baseline established
Low	Sand preference dominant	1.2-3.3	Monitor 5 yearly after baseline established
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 Freshwater the sediment compartment is often the largest nutrient pool in the system, and phosphorus exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

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

Total Nitrogen

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

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

Benthic Community Index (Organic Enrichment)

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

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

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

BENTHIC COMMUNITY ORGANIC ENRICHMENT RATING			
ECOLOGICAL RATING	DEFINITION	BC	RECOMMENDED RESPONSE
Very Low	Intolerant of enriched conditions	0-1.2	Monitor at 5 year intervals after baseline established
Low	Tolerant of slight enrichment	1.2-3.3	Monitor 5 yearly after baseline established
Moderate	Tolerant of moderate enrichment	3.3-5.0	Monitor 5 yearly after baseline est. Initiate ERP
High	Tolerant of high enrichment	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very High	Azoic (devoid of invertebrate life)	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend to slight enrichment	>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 12 February 2011 fine scale monitoring results of Freshwater Estuary is presented alongside the 2009 and 2010 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 Freshwater Estuary 2009 - 2011.

Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. Species
	cm	ppt	%				mg/kg								No./m^2	No./core
A 2009	1-5	32	0.20	0.80	98.71	0.50	<0.01	3	1.4	2.4	0.60	5.8	<500	153	2152	10.7
B 2009	1-10	32	0.17	0.30	99.21	0.49	0.012	4.0	1.6	3.1	0.78	7.6	<500	177	7545	16.8
A 2010	1-5	32	0.23	2.4	93.5	4.1	<0.01	2.6	1.2	2.4	0.59	5.6	<500	167	2152	9.1
B 2010	1-10	32	0.20	1.6	98.1	0.4	0.01	3.5	1.5	2.9	0.73	7.2	<500	193	4635	12.4
A 2011	1-6	32	0.18	1.4	97.97	0.63	<0.01	2.93	1.33	2.57	0.63	5.7	< 510	153	3390	11.3
B 2011	1-6	32	0.18	0.87	99.03	0.10	0.01	3.9	1.57	2.97	0.75	7.1	< 510	180	5985	15.6

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 maintained at 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 <63 μm) 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). However, in estuaries with undeveloped catchments, like Freshwater Estuary, Stewart Island, the mud content is usually low (<3% mud).

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

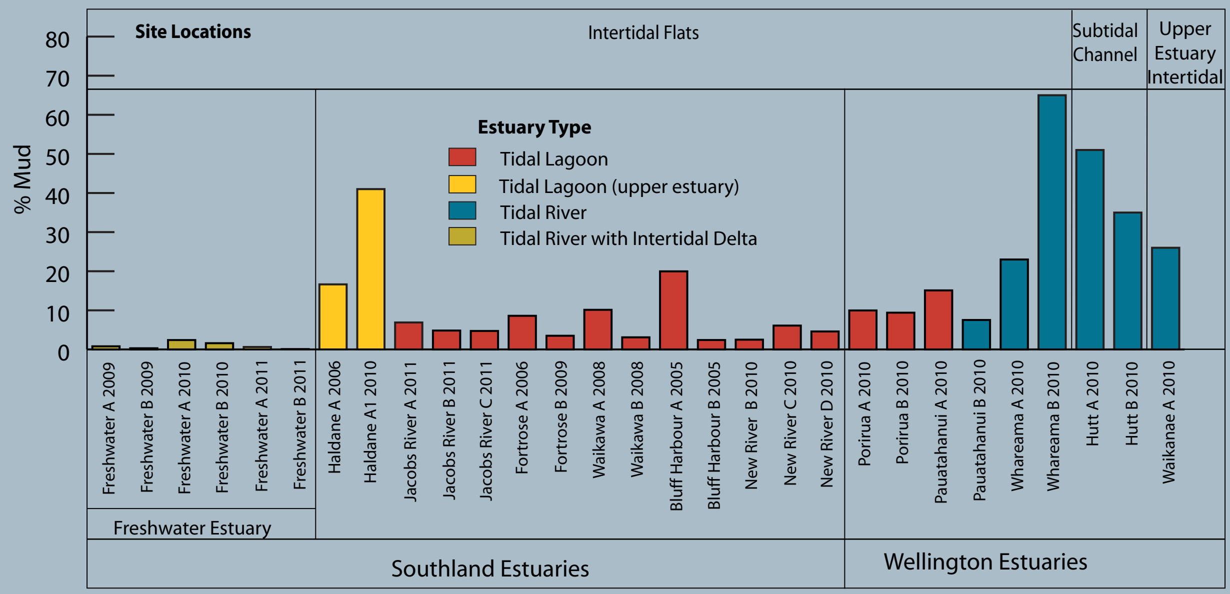


Figure 2. Percent mud content at fine scale monitoring sites, Southland and Wellington estuaries.

GRAIN SIZE

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results (Figures 3 and 4) show that mud content increased from the very low level of <1% mud at both sites in 2009 to 1.6-2.4% mud in 2010 and then dropped back to low levels again in 2011 (0.1-0.63%). Such a mud content is low compared with the dominant habitat in fine scale sites in other Southland estuaries (Figure 2).

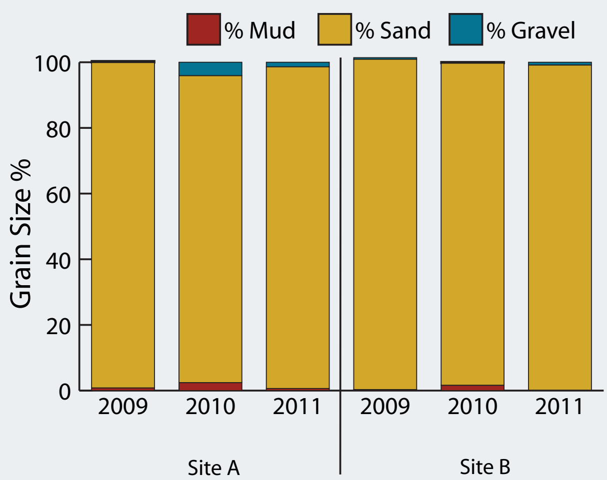


Figure 3. Grain size, Freshwater Estuary.

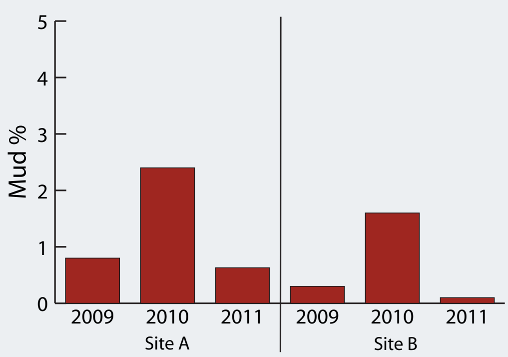


Figure 4. Percentage mud, Freshwater Estuary.

3. Results and Discussion (Continued)

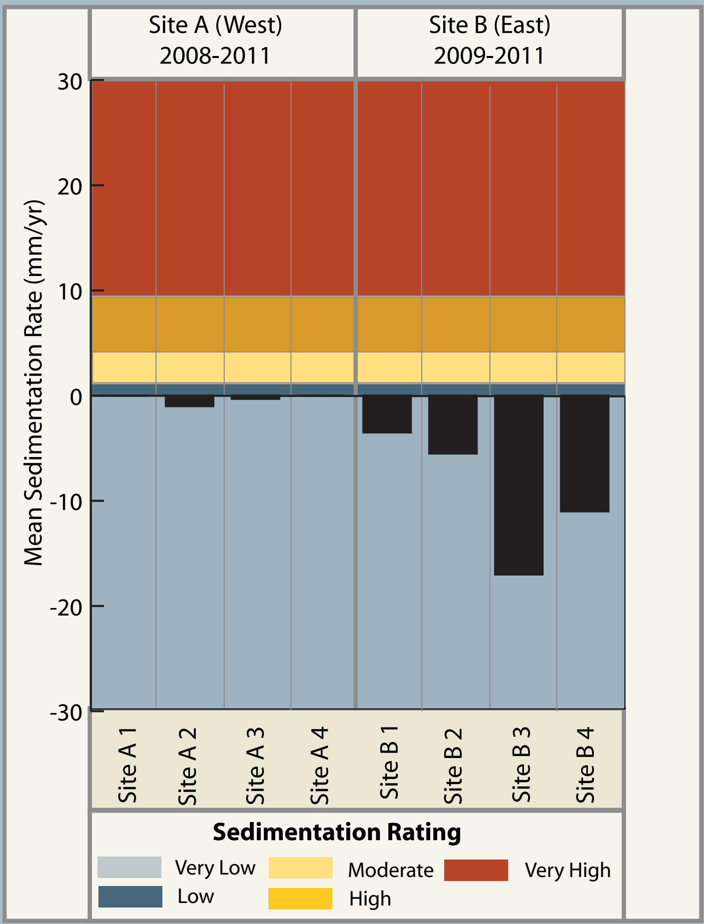


Figure 5. Sedimentation rate from plate data Freshwater Estuary (2008-2011).

RATE OF SEDIMENTATION

Four sedimentation plates were deployed in the estuary in April 2008 at Site A and another four in February 2009 at Site B (Figure 1) to enable long term monitoring of sedimentation rates. Monitoring of the overlying sediment depth above each plate after 2-3 years of burial indicated a mean sedimentation rate of -0.3 mm/yr at Site A and -9.3mm/yr at Site B (range -3.5 to -17mm/yr) (Figure 5).

These preliminary findings indicate variability in sedimentation rates within the main intertidal flats of Freshwater Estuary. At the more seaward Site B, which was closer to the main channel and the sea, the sediment was eroding at a higher rate compared to the more stable Site A. The erosion at Site B was likely to be the result of natural variation in substrate height as a result of flood and wind disturbances in this dynamic area of the estuary.

In relation to other NZ estuaries, the rate of sedimentation of Freshwater Estuary was extremely low (Figure 6).

Such low sedimentation rates confirm the pristine nature of Freshwater Estuary and its value as a reference estuary for New Zealand.

2011 Sedimentation Rate RATING	**Very Low**

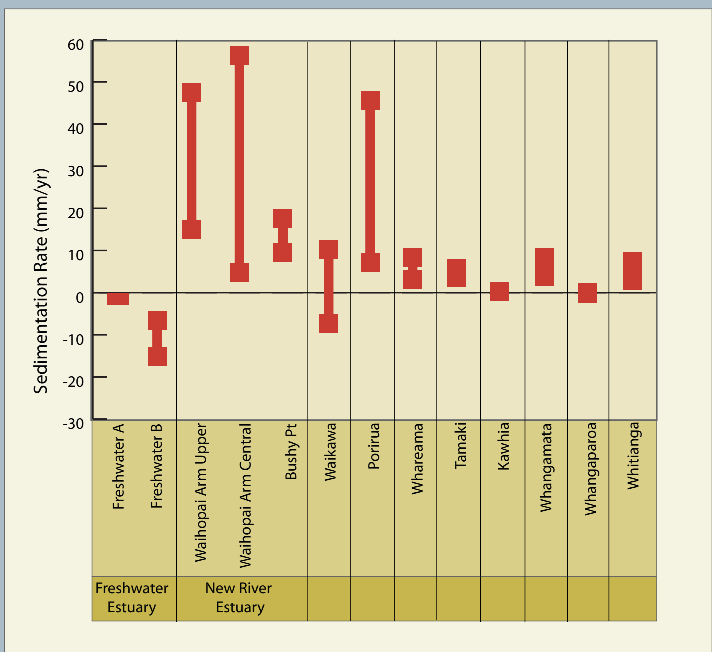


Figure 6. Sedimentation rate in Freshwater Estuary and other NZ estuaries (Mead and Moores 2004, Abrahim 2005, Robertson and Stevens 2008, 2008a, 2010, 2010a).

3. Results and Discussion (Continued)

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 the Freshwater 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 7 and 8).
2. Using multivariate techniques to explore whether the macro-invertebrate communities at Sites A and B differs between each of the three years of monitoring (Figure 9).
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 Freshwater Estuary macro-invertebrate community over the three years of monitoring (Figures 10 and 11).

The first step showed that the macro-invertebrate community at both sites in Freshwater Estuary in the baseline monitoring period (2009-2011) included a moderate range of species (9-17 species/core) compared with results from the intertidal mudflats in other NZ estuaries (Figure 7). Similarly, the overall community abundance at both sites in Freshwater Estuary in 2009-2011 was low to moderate at 2,100 to 7,500m^{-2} (Figure 8) compared with other NZ estuaries.

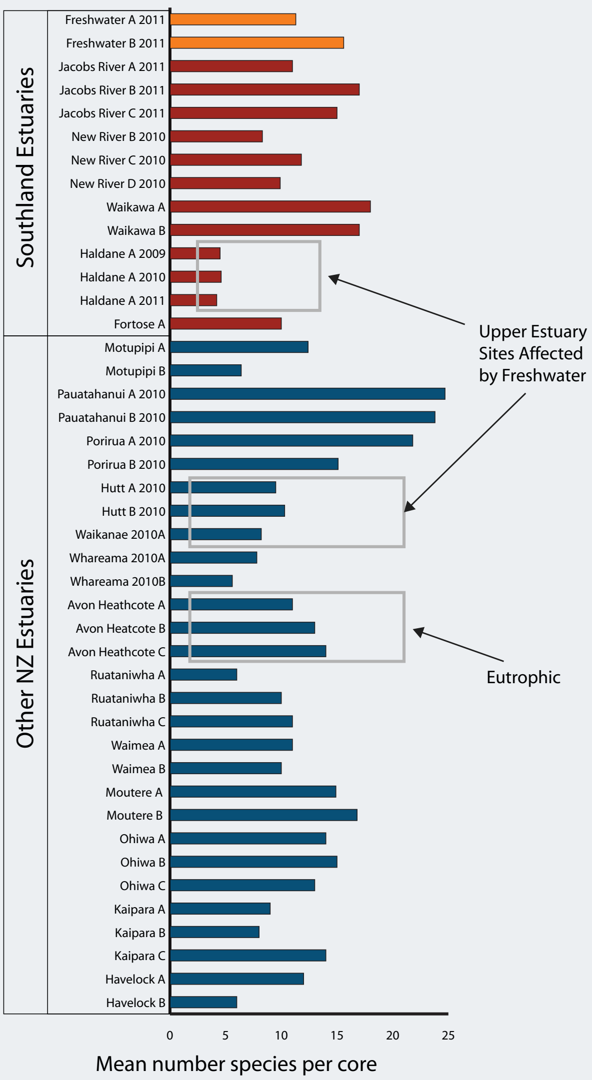


Figure 7. Mean number species of per core in Freshwater Estuary compared with other NZ estuaries.

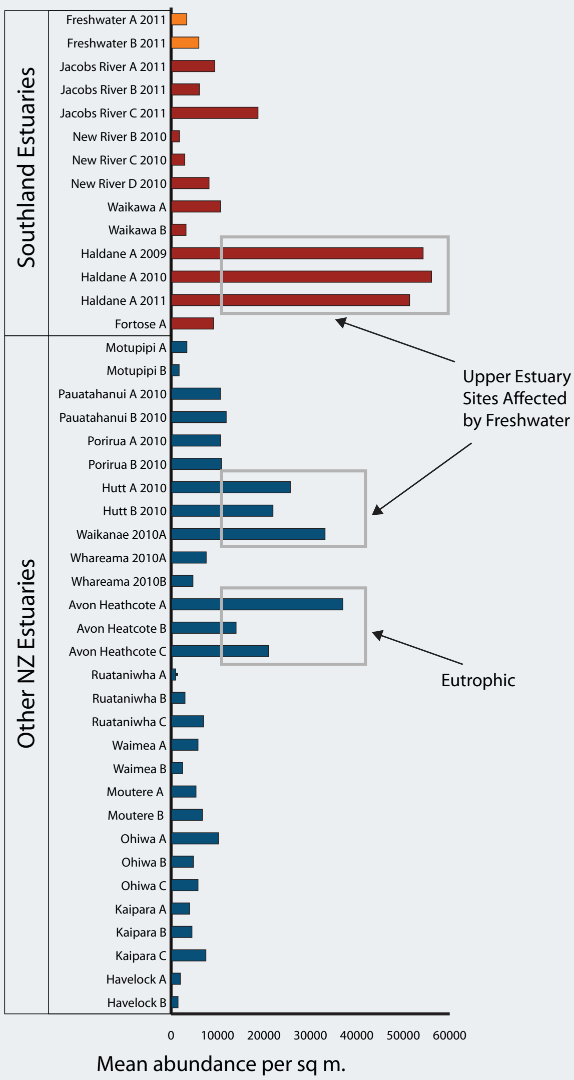


Figure 8. Mean total abundance of macro-fauna, Freshwater Estuary compared with other NZ estuaries.

3. Results and Discussion (Continued)

In the second step, the results of the multivariate analysis (NMDS Plot, Figure 9) show that there was a difference in the benthic invertebrate communities between each of the two sites for the three years of monitoring, but not at a highly sigificant level. In addition, the plot shows that there were small year to year differences at each site.

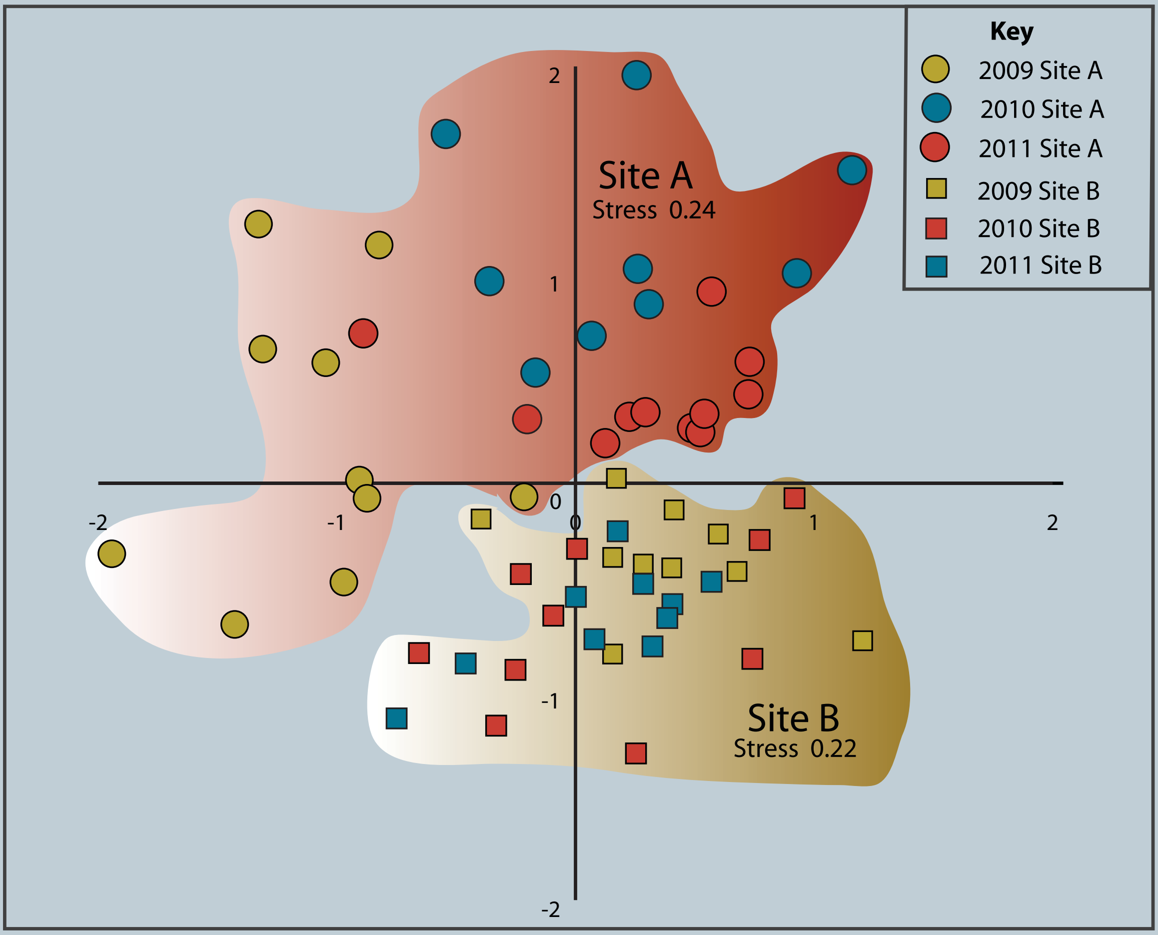


Figure 9. NMDS plot showing the relationship among samples in terms of similarity in macro-invertebrate community composition for Freshwater Estuary Sites A and B, for 2009, 2010 and 2011. The plot shows each of the 10 replicate samples for each site and is based on Bray Curtis dissimilarity and square root transformed data.

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

3. Results and Discussion (Continued)

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 A and B were in the "low" or "very low" category for each of the 3 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 10). The 2011 results show a small decrease in the mud biotic coefficient at both sites compared with the 2010 figures, indicating a shift towards a community that prefer lower mud contents. These findings reflect the lower mud content found at both sites in 2011 (Figure 4).

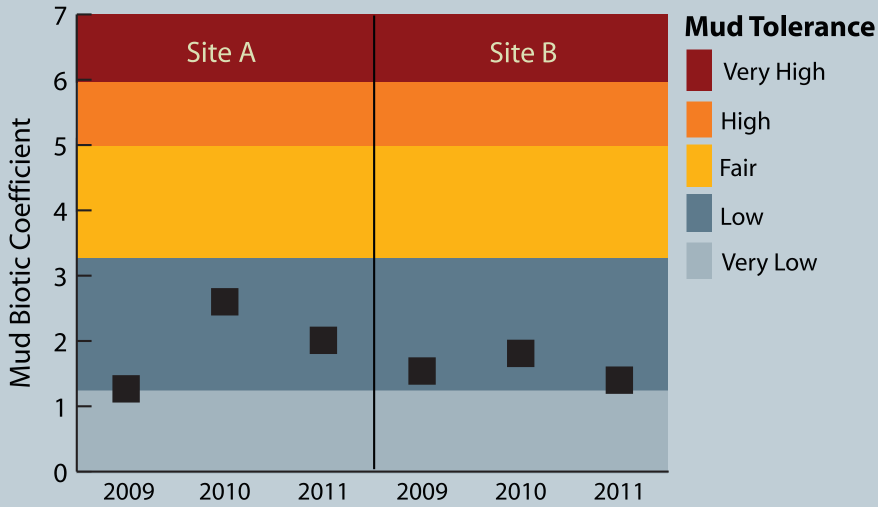


Figure 10. Mud tolerance macroinvertebrate rating at 2 sites in Freshwater Estuary 2009-2011.

These results are explored in more detail in Figure 11. This plot shows that, for each of the three 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:

Relatively High Numbers of "Strong Sand Preference" Species. Strong sand preference, or highly mud intolerant species, were present at both sites and in relatively high numbers. They included: the small surface deposit-feeding spionid polychaete *Aonides* sp. that lives throughout the sediment to a depth of 10cm; the native NZ bivalve *Paphies australis* or pipi; the mudflat top shell *Diloma subrostrata*; and *Notoacmea helmsii*, the small native limpet that attaches to shell and stone surfaces. Also, as might be expected from such a pristine estuary, the number of "strong sand preference" species was high compared with other Southland estuaries (Robertson and Stevens, 2010). The only other Southland estuary with similar high numbers of species was Waikawa Estuary in the Catlins.

Moderate Numbers of "Sand Preference" Organisms. "Sand preference" organisms were also found at the sites in 2009-2011 in moderate numbers. In particular, they included the following;

- Cockles (*Austrovenus stutchburyi*) and the small estuarine barnacle (*Austrominius modestus*). Cockles are a 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. Currently, the mud concentrations at the Freshwater Estuary sites of 0.1-2.4%, are expected to provide favourable habitat for these species.

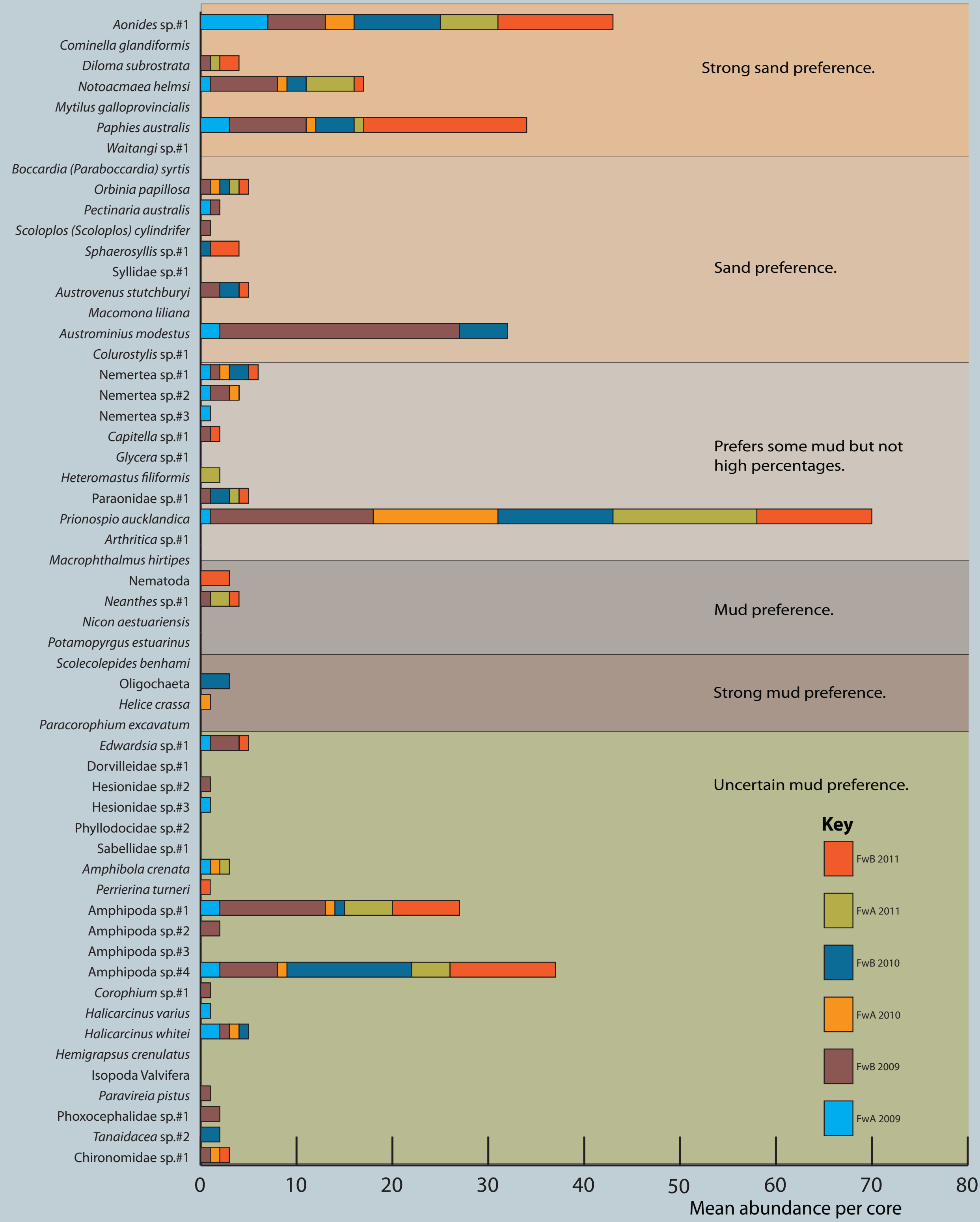


Figure 11. Macro-invertebrates at Sites A and B grouped by sensitivity to mud (see Appendix 3) Freshwater Estuary 2009-2011.

- The native orbiniid polychaete, *Orbinia papillosa,* which is a long, slender, unselective deposit feeder was also found at the site in very low numbers. It prefers sand environments with an optimum range of 5-10% mud but can be also be found sub-optimally in 0-40% mud.
- The delicate and colourful syllid *Sphaerosyllis*, which is often hidden amongst the epifauna.
- The subsurface deposit-feeding herbivore *Pectinaria australis* which lives in a cemented sand grain cone-shaped tube and feeds head down with the tube tip near the surface.

High Numbers of Some Species That "Prefer Some Mud But Not High Percentages". In particular, there were high numbers of *Prionospio aucklandica*, a small, common, intertidal spionid which can handle moderately enriched situations. A number of other species were present in this category including nemertean worms and a small sub-surface, deposit-feeding paraonid worm usually found in muddy-sands.

Low Numbers of "Mud and Strong Mud Preference" Species. Organisms that prefer "moderate or high mud contents" were also found at the sites but their numbers were low. They included deposit-feeding oligochaete and nematode worms; *Neanthes* which is a large nereid worm that is active and omnivorous, usually green or brown in colour; and *Helica crassa* the burrowing mud crab.

EUTROPHICATION

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. For short residence time estuaries, like Freshwater, highly eutrophic conditions only occur when sediments from large areas of the estuary exhibit all of the following symptoms; high macroalgal growth (>50% cover), are soft and muddy, have a shallow RPD, elevated nutrient and TOC concentrations and very high invertebrate organic enrichment tolerance ratings.

Redox Potential Discontinuity (RPD)

The 2011 results show a shallow, dark layer (1-6cm deep) indicating low oxygen and the presence of sulphides in the upper sediments. However, below this thin layer, a more oxygenated profile is present. Seagrasses requires oxygen to grow, so have adapted efficient strategies to maintain oxygen in their root systems via an interconnected system of gas spaces transporting oxygen from the leaves down to the roots (Larkum et al. 1989). They also release oxygen from the roots which shields plants against harmful toxins such as sulfides, and provides a source of oxygen to the surrounding sediment. As a consequence, the sediments were moderately oxygenated, consistent with the presence of infauna feeding voids and burrows below the RPD.

2011 RPD RATING
GOOD

Figure 12 shows the sediment profile, RPD depths, and the benthic community expected at each site based on the RPD depth (adapted from Pearson and Rosenberg 1978). Because the sediments were dominated by sands it is inferred that sediment aeration was relatively good, which is supported by the RPD results. These moderately deep RPD values (a "good" condition rating) indicate that the benthic invertebrate community was likely to be in a "normal to transitional" state.

3. Results and Discussion (Continued)

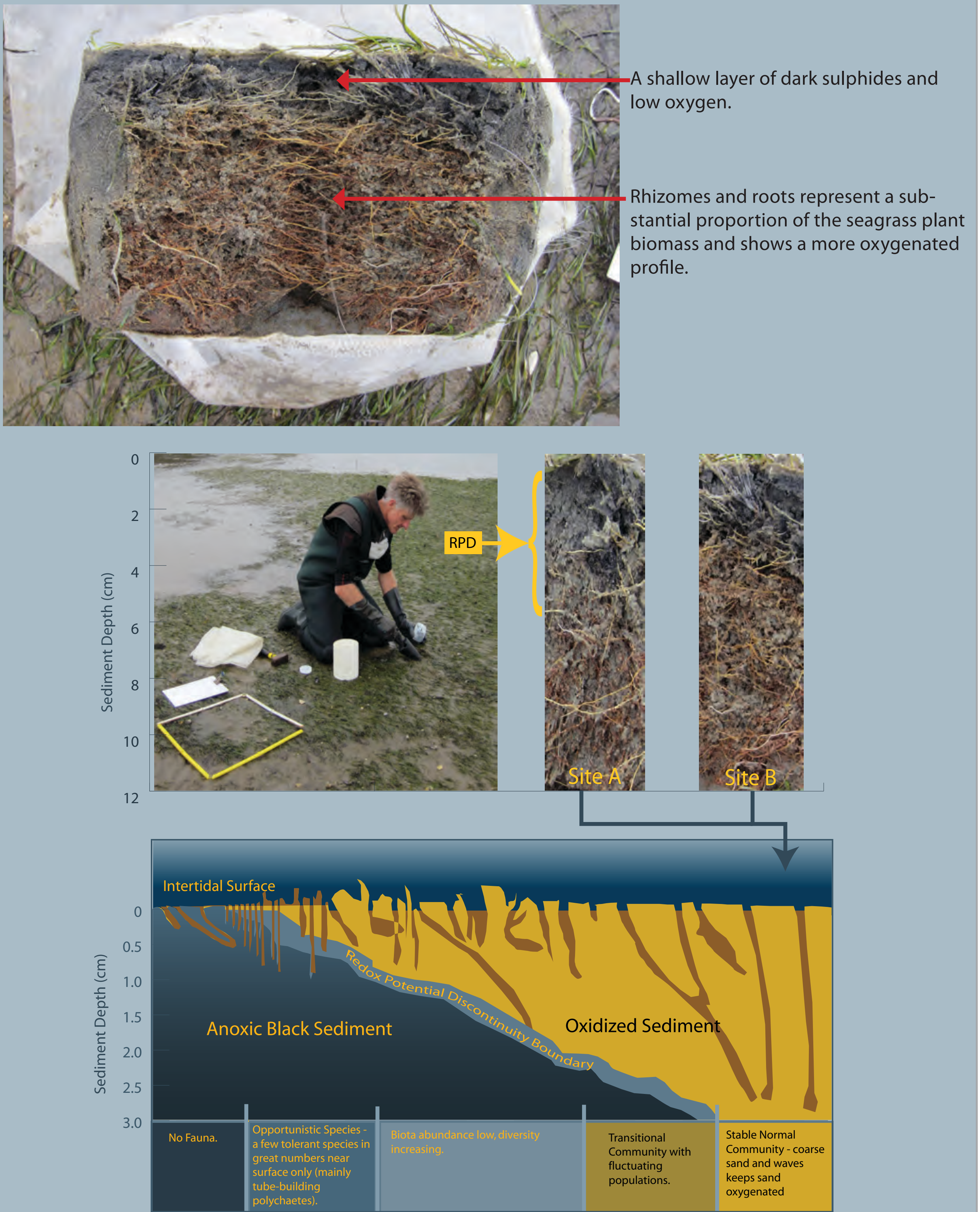
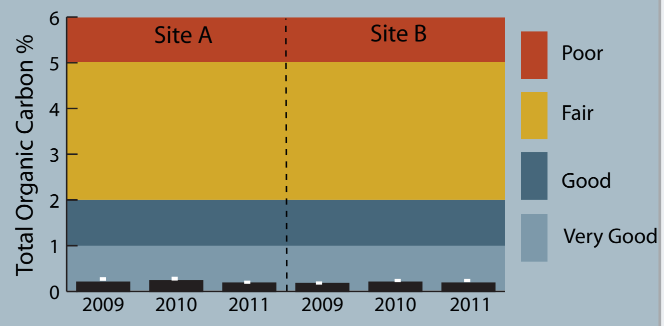
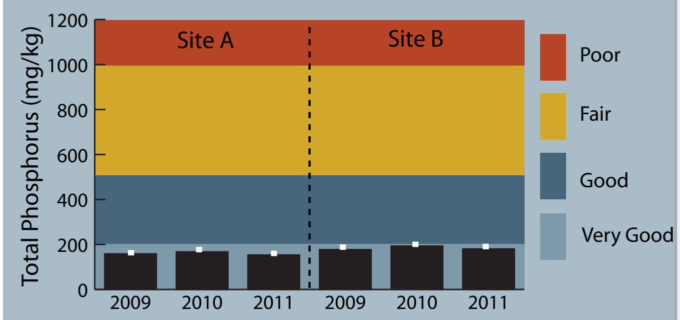


Figure 12. Sediment profiles, depths of RPD and predicted benthic community type, Freshwater Estuary 12 February 2011. Arrow below core relates to the type of community likely to be found in the core.



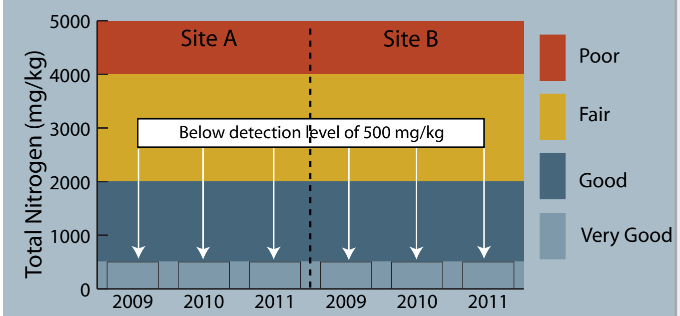
2011 TOC RATING	Very Good

Figure 13. Total organic carbon, (mean and range) Freshwater Estuary.



2011 TP RATING	Very Good

Figure 14. Total phosphorus, (mean and range) Freshwater Estuary.



2011 TN RATING	Very Good

Figure 15. Total nitrogen, (mean and range) Freshwater Estuary.

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 numbers of suspension-feeders (e.g. bivalves and certain polychaetes) decline, and deposit-feeders (e.g. opportunistic polychaetes) increase, as organic input to the sediment increases (Pearson and Rosenburg 1978).

The indicator of organic enrichment (TOC) at both sites in 2011 was at very low concentrations (mean 0.18%) and met the "very good" condition rating (Figure 13). These TOC concentrations were similar to those measured in 2009 and 2010.

The low TOC levels reflect the generally well-flushed nature of much of the estuary area and a likely low load of organic matter (sourced primarily from phytoplankton and macroalgae) depositing on the sediments.

TOTAL PHOSPHORUS (TP)

Total phosphorus, a key nutrient in the eutrophication process, was present at both sites in 2011 at very low concentrations (mean 153mg/kg and 180mg/kg for Sites A and B respectively), and met the "very good" condition rating (Figure 14). These TP concentrations were similar to those measured in 2009 and 2010.

This means that the Freshwater Estuary sediments have a low store of P in the sediments. In addition, this store of P is primarily unavailable for fertilising nuisance algal growth, given the absence of extensive anoxic conditions under which P release is favoured.

TOTAL NITROGEN (TN)

Like phosphorus, total nitrogen (the other key nutrient in the eutrophication process) was present at both sites at very low concentrations (mean <500mg/kg at both sites) in 2011 and met the "very good" condition rating (Figure 15). As in 2009 and 2010, these TN concentrations were below the analytical detection limit of 500 mg/kg.

This means that the Freshwater sediments have a low store of N in the sediments (sourced from both recent and historical catchment inputs).

As with phosphorus, this store of N is also primarily unavailable for fertilising nuisance algal growth, because of the absence of extensive anoxic conditions which favours the release of bioavailable nitrogen sources to the water column.

Macro-invertebrate Organic Enrichment Index

The benthic invertebrate organic enrichment rating for Freshwater Estuary at Site B was in the "low" category, indicating a community slightly tolerant of organic enrichment for 2009, 2010 and 2011 (Figure 16). At Site A, the 2010 and 2011 results showed the presence of species with a moderate tolerance of organic enrichment. This increase was likely related to higher numbers of the dominant spionid, *Prionospio aucklandica* (relatively enrichment tolerant) in 2010 and 2011 compared to 2009, and the slight increase in the rating may reflect the impact, and subsequent community response, of the increased mud detected in 2010. Overall the enrichment rating is consistent with the low-moderate sediment nutrient concentrations originating in runoff from the native bush catchment. As in 2009 and 2010, the 2011 conditions resulted in a community dominated by a broad range of species sensitivities (Figure 17) including:

- Low-moderate abundances and numbers of species that are very sensitive to organic enrichment and many of which are often present in *Zostera* beds (e.g. the native orbiniid polychaete, *Orbinia papillosa;* the small, subsurface deposit-feeding/herbivore, *Pectinaria australis* which lives in a cemented sand grain cone-shaped tube and feeds head down with the tube tip near the surface; the cockle, *Austrovenus stutchburyi*; the surface deposit feeder, *Scoloplos cylindrifer;* the gammarid amphipod, Phoxocephalidae sp. and the spionid polychaete *Boccardia* sp.).
- Low-moderate abundances and numbers of species that are indifferent to organic enrichment (slightly unbalanced), particularly pipis (*Paphies australis*), the acorn barnacle *Austrominius modestus* and the burrowing anemone *Edwardsia* sp.
- Moderate numbers of species and elevated abundances of some species that are tolerant to excess organic enrichment (unbalanced situation) for example, the small deposit-feeding spionid polychaete *Aonides sp.*, and nemertean worms.
- Low numbers of species that are very tolerant to organic enrichment (slight to pronounced unbalanced situations), for example the polychaetes *Prionospio aucklandica* and *Heteromastus filiformis*. High abundances of *Prionospio* at both sites was likely related to the presence of seagrass (*Zostera*) beds and associated increased organic material.
- Low diversity and abundance of species highly tolerant to organic enrichment (pronounced unbalanced situations), e.g. the polychaete *Capitella* sp.

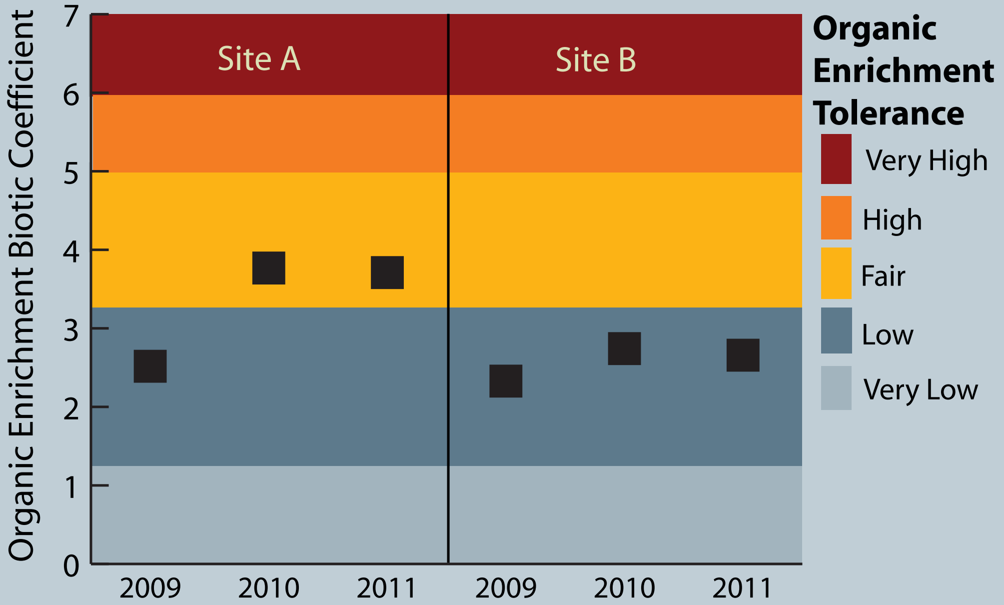


Figure 16. Benthic invertebrate organic enrichment rating at 2 sites in Freshwater Estuary 2009-2011.

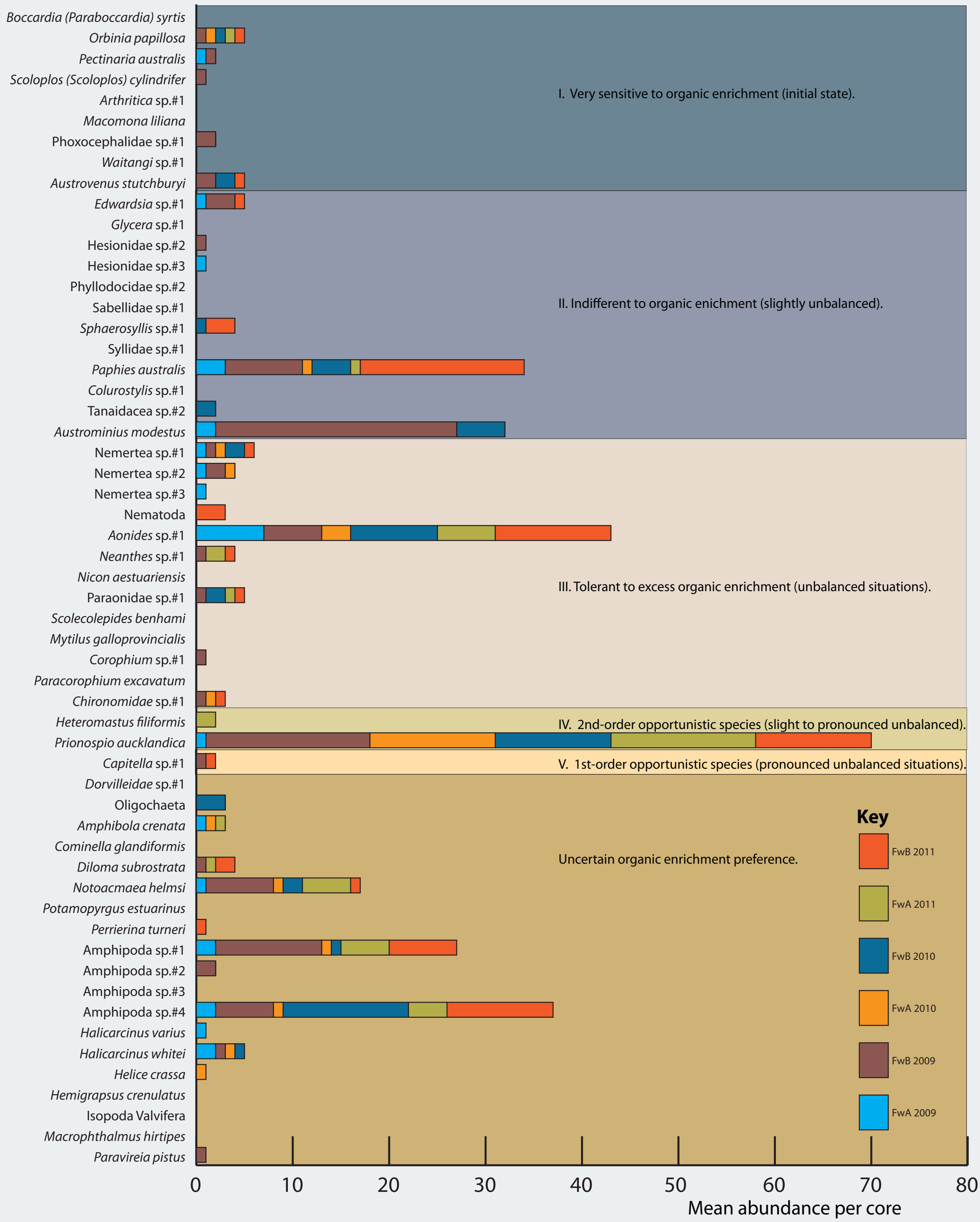


Figure 17. Organic enrichment sensitivity of macroinvertebrates, Freshwater Estuary, 2009-2011 (see Appendix 3 for sensitivity details).

3. Results and Discussion (Continued)

TOXICITY

2011 TOXICITY RATING	Very Good

METALS

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations at both intertidal sites, with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 18). These metal concentrations were similar to those measured in 2009 and 2010. Metals met the "very good" condition rating and indicated there is no widespread toxicity in Freshwater Estuary, which reflects the pristine nature of the catchment.

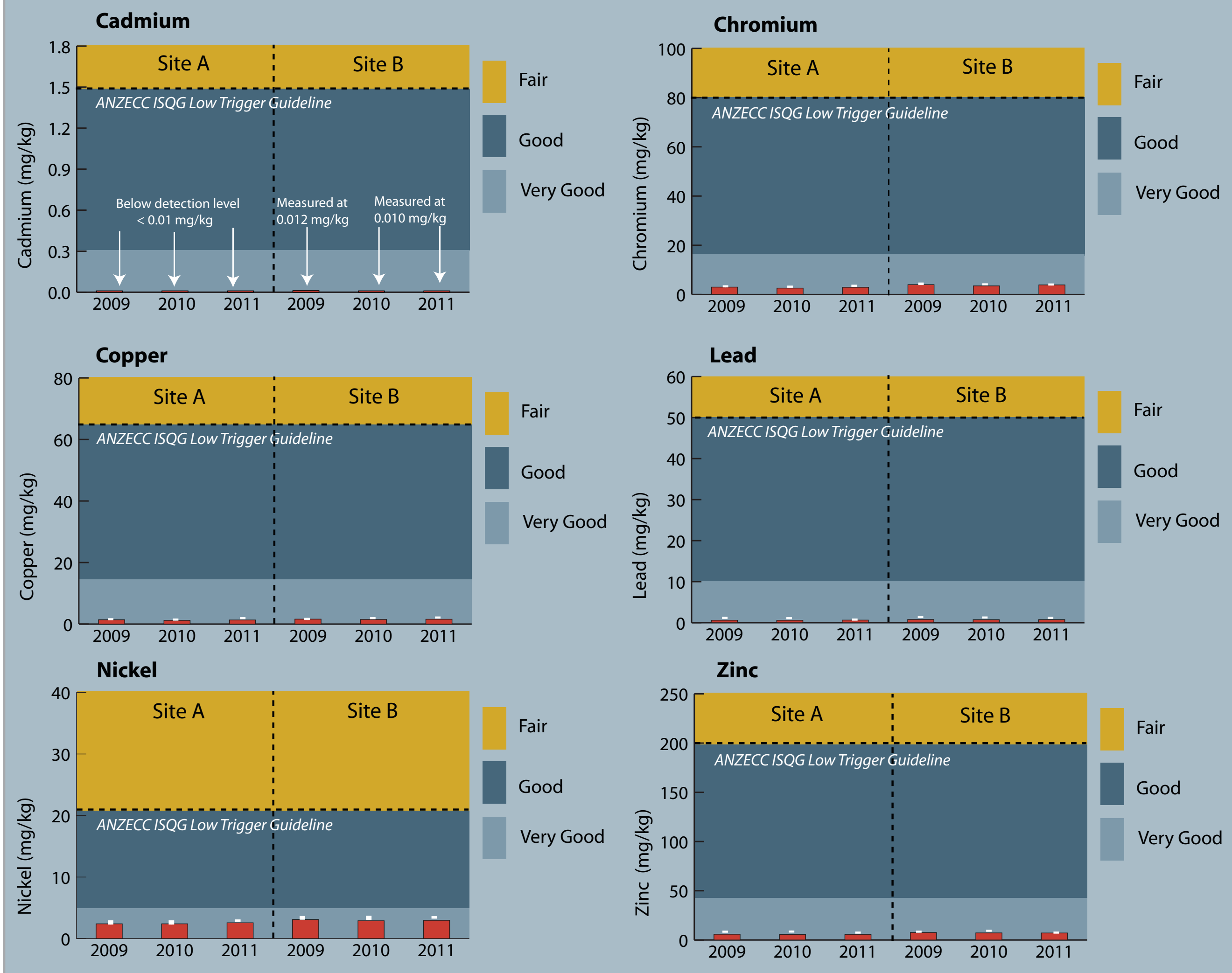


Figure 18. Sediment metal concentrations, (mean and range) Freshwater Estuary, 2009-2011.

4. SUMMARY AND CONCLUSIONS

The third year of fine scale monitoring results for the condition of Freshwater Estuary showed the following (see diagram below for summary of ratings).

In terms of sedimentation, the grain size results indicated sandy sediments, with very low mud contents and, a healthy benthic invertebrate community dominated by species that prefer sands. In combination with the 2008 broad scale mapping results, which showed that the intertidal area was dominated by firm sands and seagrass, there was no indication of a sedimentation problem (i.e. extensive areas of soft muds and low clarity waters were not present).

In terms of eutrophication, the results suggest that the estuary has a "moderate" level of enrichment.

This rating is based on the combined ratings for the following indicators:

- "poor" macroalgal rating (in 2008, 25% of the estuary had greater than 50% macroalgal cover),
- "low" benthic invertebrate organic enrichment tolerance rating,,
- low-moderate sediment nutrient and TOC concentrations,
- a variable RPD depth, indicating well-oxygenated sediments.
- low sediment mud content and,
- widespread seagrass cover (based on 2008 broadscale mapping).

Unlike some other Southland estuaries (e.g. New River and Jacobs River Estuaries), large areas of highly eutrophic conditions were not present in Freshwater Estuary (i.e. areas where the sediments exhibit all of the following; high macroalgal growth (>50% cover), are soft and muddy, have a shallow RPD, elevated nutrient and TOC concentrations and very high macroinvertebrate organic enrichment tolerance ratings).

In terms of toxicity, heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations.

Overall, the results showed that Freshwater Estuary was in very good condition, reflecting the pristine nature of this estuary, and that conditions were similar to those measured in 2009 and 2010. The good condition can be attributed to the very low inputs of fine sediments, toxicants and disease causing microbes to the estuary, which, when combined with the moderate inputs of nutrients (estimated at 200tN/yr - NIWA WRENZ model) sourced from the native bush catchment, results in a thriving, healthy and productive seagrass-dominated estuarine environment.

CONDITION RATINGS

	Site A 2009	Site B 2009	Site A 2010	Site B 2010	Site A 2011	Site B 2011
Sedimentation Rate	Very Low	Baseline Year	Very Low	Very Low	Very Low	Very Low
Invertebrates Mud Tolerance	Low	Low	Low	Low	Low	Low
RPD Profile (sed oxygenation)	Good	Good	Good	Good	Good	Good
TOC (Total Organic Carbon)	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Total Nitrogen (TN)	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Total Phosphorus (TP)	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Metals (Cd, Cu, Cr, Pb, Ni, Zn)	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Grain Size	Very Low Mud	Very Low Mud	Very Low Mud	Very Low Mud	Very Low Mud	Very Low Mud
Organic Enrichment (inverts)	Good	Good	Fair	Good	Fair	Good
Macroalgal % Cover (2008)	Fair (26% of estuary with >50% cover)					
Seagrass % Cover (2008)	Very Good (60% of estuary)					
Soft Mud % Cover (2008)	Very Good (0.3% of estuary)					
Saltmarsh % Cover (2008)	Moderate (5% of estuary)					

5. MONITORING

Freshwater Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's coastal monitoring programme being undertaken in a staged manner throughout the Southland region. Based on the 2009, 2010 and 2011 monitoring results and condition ratings, it is recommended that monitoring continue as outlined below:

Fine Scale Monitoring (including sedimentation rate).
Complete a fourth and final year of baseline monitoring and subsequently undertake monitoring at five yearly intervals or as deemed necessary based on the condition ratings. The next fine scale monitoring is scheduled for February 2012.

Broad Scale Habitat Mapping.

Continue with the programme of 5 yearly broad scale habitat mapping. Next monitoring February/March 2013.

Sedimentation Rate Monitoring.
Because sedimentation is a priority issue in Southland estuaries and Freshwater Estuary is an important example of a pristine estuary, it is recommended that sedimentation rate monitoring continues. The next sedimentation rate monitoring is scheduled for February 2012.

Macroalgal Mapping.
Macroalgal cover was not observed to be causing conditions unsuitable for estuarine animals (i.e. sediment oxygen not being reduced to low levels from rotting algae), nor were nuisance effects from smells evident. Consequently it is recommended that macroalgae be monitored five yearly in the absence of obvious changes in the estuary. The next macroalgal mapping is scheduled to take place in 2013.

6. MANAGEMENT

Because Freshwater Estuary is relatively unmodified, and the surrounding land is protected within Rakiura National Park, no direct management action by Environment Southland is currently considered necessary.

7. ACKNOWLEDGEMENTS

Many thanks to Greg Larkin (Coastal Scientist, Environment Southland) for his help undertaking and organizing the field survey and for his comments on the draft report. Thanks also to Maz Robertson (Wriggle Ltd) for editing assistance.

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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. 2011 DETAILED RESULTS

Station Locations

Freshwater A	FW A-01	FW A-02	FW A-03	FW A-04	FW A-05	FW A-06	FW A-07	FW A-08	FW A-09	FW A-10
NZMG260 East	2127170	2127158	2127139	2127126	2127122	2127136	2127151	2127165	2127160	2127152
NZMG260 North	5355175	5355178	5355188	5355195	5355182	5355176	5355169	5355163	5355157	5355159
Freshwater B	**FW B-01**	**FW B-02**	**FW B-03**	**FW B-04**	**FW B-05**	**FW B-06**	**FW B-07**	**FW B-08**	**FW B-09**	**FW B-10**
NZMG260 East	2128024	2128030	2128040	2128048	2128060	2128052	2128040	2128029	2128035	2128050
NZMG260 North	5355380	5355371	5355367	5355352	5355358	5355365	5355374	5355385	5355392	5355381

Physical and Chemical Results for Freshwater Estuary (Sites A and B), 12 February 2011.

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg							
Freshwater A	1-4	1 to 6	32	0.17	1.1	98.4	0.5	< 0.010	2.7	1.3	2.5	0.64	5.5	< 510	149
Freshwater A	5-8	1 to 6	32	0.19	1.6	97.7	0.7	< 0.010	3	1.3	2.5	0.63	5.4	< 510	154
Freshwater A	9-10	1 to 6	32	0.18	1.5	97.8	0.7	< 0.010	3.1	1.4	2.7	0.63	6.2	< 510	157
Freshwater B	1-4	1 to 6	32	0.23	1.1	98.8	0.1	0.013	5	1.8	3.5	0.94	8.1	< 510	200
Freshwater B	5-8	1 to 6	32	0.15	0.7	99.2	< 0.1	< 0.010	3.3	1.4	2.6	0.61	6.4	< 510	168
Freshwater B	9-10	1 to 6	32	0.17	0.8	99.1	0.1	< 0.010	3.4	1.5	2.8	0.69	6.8	< 510	173

* composite samples

RPD depths (cm)

Site	FW 01	FW 02	FW 03	FW 04	FW 05	FW 06	FW 07	FW 08	FW 09	FW 10
Freshwater A (v=variable)	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v
Freshwater B (v=variable)	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v	1-6v

APPENDIX 2. 2011 DETAILED RESULTS (CONTINUED)

Epifauna (numbers per 0.25m² quadrat) 12 February 2011

Freshwater Estuary Site A	FW A-01	FW A-02	FW A-03	FW A-04	FW A-05	FW A-06	FW A-07	FW A-08	FW A-09	FW A-10
Amphibola crenata Estuary mud snail	8	8	15	6	14	10	11	11	4	4
Austrominius modestus Estuarine barnacle	40	26	56	77	12	25	15	35	16	25
Diloma subrostrata Mudflat topshell										1
Mytilus galloprovincalis Blue mussel	2	1				1	2	2	2	5
Paphies australis Pipi		1								
No. species/quadrat	3	4	2	2	2	3	3	3	3	4
No. individuals/quadrat	50	36	71	83	26	36	28	48	22	35

Freshwater Estuary Site B	FW B-01	FW B-02	FW B-03	FW B-04	FW B-05	FW B-06	FW B-07	FW B-08	FW B-09	FW B-10
Amphibola crenata Estuary mud snail							5			
Austrominius modestus Estuarine barnacle	10		10	19	18		70			
Austrovenus stutchburyi Cockle				4		1				
Cellana strigilus redmiculum					1					
Diloma subrostrata Mudflat topshell	1			2						
Mytilus galloprovincalis Blue mussel					3		1			
Paphies australis Pipi			3				1			
Xenostrobus pulex Black mussel			1							
No. species/quadrat	2	0	3	3	3	1	4	0	0	0
No. individuals/quadrat	11	0	14	25	22	1	77	0	0	0

Freshwater Estuary: Sediment Plate Baseline and First Year Sedimentation Details (depths in mm).

	No	Date	NZMG East	NZMG North	10/4/08	27/2/09	14/2/10	12/2/11	Change from baseline (mm)	Mean Sedimentation Rate (mm/yr)
Site A (west)	1	10-Apr-08	2127174	5355217	235	240	236	235	0	-1mm/yr
	2	10-Apr-08	2127167	5355236	250	244	245	247	-3	
	3	10-Apr-08	2127181	5355249	286	281	284	285	-1	
	4	10-Apr-08	2127192	5355234	278	285	284	278	0	
	No	Date	NZMG East	NZMG North		27/2/09	14/2/10	12/2/11	Change from baseline (mm)	Mean Sedimentation Rate (mm/yr)
Site B (east)	5	27-Feb-09	2128017	5355387		125	115	118	-7	-18.5mm/yr
	6	27-Feb-09	2128020	5355391		127	119	116	-11	
	7	27-Feb-09	2128027	5355394		144	116	110	-34	
	8	27-Feb-09	2128031	5355397		162	140	140	-22	

Freshwater Estuary: Percentage Cover of Macroalgae at each site, 12 February 2011.

Freshwater A	FW A-01	FW A-02	FW A-03	FW A-04	FW A-05	FW A-06	FW A-07	FW A-08	FW A-09	FW A-10
Zostera (seagrass) % cover	80-100	80-100	80-100	80-100	80-100	80-100	50-80	80-100	80-100	80-100
Ulva lactuca % cover									1-05	
Freshwater B	**FW B-01**	**FW B-02**	**FW B-03**	**FW B-04**	**FW B-05**	**FW B-06**	**FW B-07**	**FW B-08**	**FW B-09**	**FW B-10**
Zostera (seagrass) % cover	50-80	05-10	20-50	20-50	20-50	10-20	20-50	20-50	1-5	20-50
Gracillaria chilensis % cover		1-5								

APPENDIX 2. 2011 DETAILED RESULTS (CONTINUED)

Infauna - Freshwater Estuary Site A, 12 February 2011 (numbers per 0.01327m^2 core) (Note NA = Not Assigned)

Group	Species	AMBI	MUD	Fw A-01	Fw A-02	Fw A-03	Fw A-04	Fw A-05	Fw A-06	Fw A-07	Fw A-08	Fw A-09	Fw A-10
ANTHOZOA	*Edwardsia* sp.#1	II	NA			1						1	1
NEMERTEA	Nemertea sp.#1	III	3			1				1	2		
	Nemertea sp.#2	III	3					1				2	1
	Nemertea sp.#3	III	3										
NEMATODA	Nematoda	III	4										
POLYCHAETA	*Aonides* sp.#1	III	1	5	5	4			11	5	12	10	8
	Boccardia (Paraboccardia) syrtis	I	2										
	Capitella sp.#1	V	3			1				1			
	Dorvilleidae sp.#1	NA	NA										
	Glycera sp.#1	II	3										
	Hesionidae sp.#2	II	NA										
	Hesionidae sp.#3	II	NA										
	Heteromastus filiformis	IV	3	1	5	1		1	1	1	5	1	2
	Neanthes sp.#1	III	4		3	4	3	2		2	1	2	
	Nicon aestuariensis	III	4										
	Orbinia papillosa	I	2									4	3
	Paraonidae sp.#1	III	3		3	1				1	1	3	
	Pectinaria australis	I	2		1				1				
	Phyllodocidae sp.#2	II	NA										
	Prionospio aucklandica	IV	3		13	8	9	7	24	29	22	30	12
	Sabellidae sp.#1	II	NA							1	1		
	Scolecolepides benhami	III	5										
	Scoloplos (Scoloplos) cylindrifer	I	2										
	Sphaerosyllis sp.#1	II	2										
	Syllidae sp.#1	II	2										
OLIGOCHAETA	*Oligochaeta*	NA	5										
GASTROPODA	*Amphibola crenata*	NA	NA	2	1	2	1	1	1	1	1	2	1
	Cominella glandiformis	NA	1										
	Diloma subrostrata	NA	1	1				1	1	1		4	
	Notoacmaea helmsi	NA	1	2	7	4	2	7	3	10	6	3	3
	Potamopyrgus estuarinus	NA	4										
BIVALVIA	*Arthritica* sp.#1	I	3								1		
	Austrovenus stutchburyi	I	2										1
	Macomona liliana	I	2										
	Mytilus galloprovincialis	III	1										
	Paphies australis	II	1	1				3	1				
	Perrierina turneri	NA	NA										
CRUSTACEA	Amphipoda sp.#1	NA	NA	1	15	1	2		5	1	17	4	
	Amphipoda sp.#2	NA	NA										
	Amphipoda sp.#3	NA	NA										
	Amphipoda sp.#4	NA	NA	1	1	6	3	3	4	4	3	3	7
	Austrominius modestus	II	2	2									
	Colurostylis sp.#1	NA	2										
	Corophium sp.#1	III	NA										
	Halicarcinus varius	NA	NA								1		
	Halicarcinus whitei	NA	NA				1		1				
	Helice crassa	NA	5				1					1	
	Hemigrapsus crenulatus	NA	NA										
	Isopoda Valvifera	NA	NA										
	Macrophthalmus hirtipes	NA	3										
	Paracorophium excavatum	NA	5	1					1				
	Paravireia pistus	NA	NA										
	Phoxocephalidae sp.#1	I	NA										
	Tanaidacea sp.#2	II	NA						1				
	Waitangi sp.#1	I	1										
INSECTA	Chironomidae sp.#1	III	NA	4									
Total no. of species				11	10	12	8	9	13	13	13	14	10
Total abundance				21	54	34	22	26	55	58	73	70	39

APPENDIX 2. 2011 DETAILED RESULTS (CONTINUED)

Infauna - Freshwater Estuary Site B, 12 February 2011 (numbers per 0.01327m^2 core) (Note NA = Not Assigned)

Group	Species	AMBI	MUD	Fw B-01	Fw B-02	Fw B-03	Fw B-04	Fw B-05	Fw B-06	Fw B-07	Fw B-08	Fw B-09	Fw B-10
ANTHOZOA	*Edwardsia* sp.#1	II	NA			4		3		1	1	1	1
NEMERTEA	Nemertea sp.#1	III	3	1	2	1	1	1	2	4		1	1
	Nemertea sp.#2	III	3		1								1
	Nemertea sp.#3	III	3										
NEMATODA	Nematoda	III	4		1	4	5	2	2	8	1		7
POLYCHAETA	*Aonides* sp.#1	III	1	2	9	12	15	12	22	13	6	4	21
	Boccardia (Paraboccardia) syrtis	I	2			1		2			1		
	Capitella sp.#1	V	3		3			1	3	2	2	1	1
	Dorvilleidae sp.#1	NA	NA										
	Glycera sp.#1	II	3										
	Hesionidae sp.#2	II	NA										
	Hesionidae sp.#3	II	NA										
	Heteromastus filiformis	IV	3				1						
	Neanthes sp.#1	III	4	4	1	2					5	1	1
	Nicon aestuariensis	III	4			1					1		
	Orbinia papillosa	I	2		3		1	3		1			2
	Paraonidae sp.#1	III	3		2	3		2	1	2			
	Pectinaria australis	I	2					2					
	Phyllodocidae sp.#2	II	NA										
	Prionospio aucklandica	IV	3		17	19	6	8	13	15	22	1	14
	Sabellidae sp.#1	II	NA										
	Scolecolepides benhami	III	5		1								
	Scoloplos (Scoloplos) cylindrifer	I	2					1			1		1
	Sphaerosyllis sp.#1	II	2		3	13	1	1	1	7		1	3
	Syllidae sp.#1	II	2										
OLIGOCHAETA	*Oligochaeta*	NA	5				1					1	2
GASTROPODA	*Amphibola crenata*	NA	NA										
	Cominella glandiformis	NA	1										
	Diloma subrostrata	NA	1		1		1		8	2	3		
	Notoacmaea helmsi	NA	1	1	1	3			1	3	4		
	Potamopyrgus estuarinus	NA	4										
BIVALVIA	*Arthritica* sp.#1	I	3							1	1		1
	Austrovenus stutchburyi	NA	2		1				2	1	1		1
	Macomona liliana	I	2						2				
	Mytilus galloprovincialis	III	1			1							
	Paphies australis	II	1	27	5	18	8	15	21	12	18	34	9
	Perrierina turneri	NA	NA			3				1	1		2
CRUSTACEA	Amphipoda sp.#1	NA	NA		3	15	4	8	16	22	5	1	
	Amphipoda sp.#2	NA	NA				2						
	Amphipoda sp.#3	NA	NA					1					
	Amphipoda sp.#4	NA	NA	5	10	17	7	14	10	9	23	4	12
	Austrominius modestus	NA	2						1				1
	Colurostylis sp.#1	NA	2						1				
	Corophium sp.#1	III	NA										
	Halicarcinus varius	NA	NA										
	Halicarcinus whitei	NA	NA			1				2			
	Helice crassa	NA	5								1		
	Hemigrapsus crenulatus	NA	NA										
	Isopoda Valvifera	NA	NA										
	Macrophthalmus hirtipes	NA	3										
	Paracorophium excavatum	NA	5								1		
	Paravireia pistus	NA	NA					1					
	Phoxocephalidae sp.#1	I	NA										
	Tanaidacea sp.#2	II	NA										
	Waitangi sp.#1	I	1										
INSECTA	Chironomidae sp.#1	III	NA				1		2		1		1
Total no. of species				6	17	17	14	17	17	18	20	11	19
Total abundance				40	64	118	54	77	108	106	99	50	82

APPENDIX 3. INFAUNA CHARACTERISTICS

Group	Species	Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Anthozoa	*Edwardsia* sp.#1	III	S Prefers sandy sediments with low-moderate mud (0-20% mud)******.	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 (0-20% mud). Intolerant of anoxic conditions.
Nemertea	Nemertea	III	I Optimum range 55-60% mud,* distribution range 0-95%*	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp.	III	M Mud tolerant.	Small unsegmented roundworms. 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.
Polychaeta	*Aonides* sp.	III	SS Optimum range 0-5% mud,* distribution range 0-5%*	Small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. *Aonides* is free-living, not very mobile and strongly prefers to live in fine sands; also very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds.
Polychaeta	*Boccardia (Paraboccardia) syrtis*	I	S Optimum range 10-15% mud,* distribution range 0-50%*	A small surface deposit-feeding spionid. Prefers low-mod mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
Polychaeta	Capitellidae	V or IV	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *Heteromastus filiformis*.	Subsurface deposit feeder, occurs down to about 10cm sediment depth. Common indicator of organic enrichment. Bio-turbator. Prey for fish and birds.
Polychaeta	Dorvilleidae sp.	NA	NA	Active surface-dwelling omnivores with chitinous jaw elements consisting of four longitudinal rows of minute, toothed, black plates, and with two pairs of appendages on the rounded prostomium. Not generally common.
Polychaeta	Glyceridae	II	I Optimum range 10-15% mud,* distribution range 0-95%*	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions. Often present in muddy conditions. Intolerant of low salinity.
Polychaeta	*Hesionidae* sp.#1	II	NA	Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The New Zealand species are little known.
Polychaeta	*Heteromastus filiformis*	IV	I Optimum range 10-15% mud,* distribution range 0-95%*	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate to high organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
	Neanthes sp #1	III	M	A nereid worm that is active and omnivorous, 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. Mud Tolerance; Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.
Polychaeta	*Nicon aestuariensis*	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate to high mud content sediments.
Polychaeta	*Orbinia papillosa*	I	S Optimum range 5-10% mud,* distribution range 0-40%*	Endemic orbiniid. Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.
Polychaeta	Paraonidae	III	Uncertain *Aricidea* sp. is an I Optimum range 35-40% mud,* distribution range 0-70%*	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15cm and appear to be sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content.
Polychaeta	*Pectinaria australis*	I	S******	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 (0-20% mud). 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.
Polychaeta	*Perinereis vallata*	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers sandy sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
Polychaeta	Phyllodocidae	II	NA	The phyllodocids are a colourful family of long, slender, and very active carnivorous worms characteristically possessing enlarged dorsal and ventral cirri which are often flattened and leaf-like. They are common intertidally and in shallow waters.
Polychaeta	*Prionospio aucklandica*	IV	I Optimum range 65-70% mud,* distribution range 0-95%*	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was renamed to *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001).

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Polychaeta	*Scolecolepides benhami*	III	MM Optimum range 25-30% mud,* distribution range 0-100%*	A Spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. **Strong Mud Preference.** Prey items for fish and birds. Rare in Freshwater Estuary (<1% mud) and Porirua Estuary (5-10% mud). Common in Whareama (35-65% mud), Fortrose Estuary (5% mud), Waikanae Estuary 15-40% mud. Moderate numbers in Jacobs River Estuary (5-10% muds) and New River Estuary (5% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai arm, New River Estuary.
	Scoloplos (Scoloplos) cylindrifer	I	S Optimum range 0-5% mud,* distribution range 0-60%*	A surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. Prefers low-moderate mud content (<50% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions.
	Sphaerosyllis sp.	II	S Optimum range 25-30% mud,* distribution range 0-40%*	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers sandy sediments.
	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 sandy sediments. The largest and best-known New Zealand intertidal syllid is *Odontosyllis polycera*, notable for its thick, black-banded body and the large flap behind the head. Living on the surface and in crevices of algae, sponges, hydroids, ascidians, etc., on the undersides of unsilted boulders, and also surface-creeping in soft sediments.
Oligochaeta	Oligochaetes	IV	MM Optimum range 95-100% mud*, distribution range 0-100%**.	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
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.
	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.
	Diloma subrostrata	NA	SS Optimum range 5-10% mud,* distribution range 0-15%*	The mudflat top shell, lives on sandflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ and feeds on the film of microscopic algae on top of the sand. Has a strong sand preference.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Gastropoda	*Notoacmaea helmsi*	NA	SS Optimum range 0-5% mud*, distribution range 0-10%**.	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Has a strong sand preference.
Gastropoda	*Potamopyrgus 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.**
Bivalvia	*Arthritica* sp.1	III	I Optimum range 55-60% mud*, or 20-40%***, distribution range 5-70%**.	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
Bivalvia	*Austrovenus stutchburyi*	I	S Prefers sand with some mud (optimum range 5-10% mud* or 0-10% mud**, distribution range 0-85% mud**).	Family Veneridae. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects. Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community who are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).
Bivalvia	*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).**
Bivalvia	*Mytilus galloprovincialis*	III	NA	*Mytilus galloprovincialis* (blue mussel) is an invasive species, is now common throughout NZ. It is dark blue or brown to almost black. Common in estuaries, often on rocks but also can be found on sands. It is known that *M. galloprovincialis* is able to outcompete and displace native mussels and become the dominant mussel species in certain localities. This is because it may grow faster than native mussels, be more tolerant to air exposure and have a reproductive output of between 20% and 200% greater than that of indigenous species.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Bivalvia	*Paphies australis*	II	SS (adults) S or M (Juveniles) Strong sand preference (adults optimum range 0-5% mud*, distribution range 0-5% mud**). Juveniles often found in muddier sediments.	The pipi is endemic to 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.
	Corophium sp.	NA	NA	A species of amphipod in the Family Corophiidae.
	Perrierina turneri	NA	Uncertain.	A small bivalve - relatively uncommon.
Crustacea	Amphipoda	NA	Uncertain.	An unidentified amphipod.
	Austrominius modestus	II	S Prefers sandy habitat ******.	Small acorn barnacle (also known as *Elminius modestus*). Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones. A filter feeder that prefers sandy substrate.
	Colurostylis sp.#1	II	S	A cumacean that prefers sandy environments. Prefers 0-5% mud with range 0-60% mud**. Cumacea is an order of small marine crustaceans, occasionally called hooded shrimp. Their unique appearance and uniform body plan makes them easy to distinguish from other crustaceans.
	Halicarcinus varius	NA	NA	Pillbox crabs are usually found on the sand and mudflats but may also be encountered under stones on the rocky shore. *Halicarcinus varius* (10mm) has a pear-shaped carapace, its upper half covered in small hairs. Males have hairy nippers. Its colour varies from white/green to yellow, found in sheltered areas on brown seaweeds or under stones.
	Halicarcinus whitei	NA	NA	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Helice crassa	NA	MM Optimum Range 95-100% mud (found in 5-100% mud)*.	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
	Hemigrapsus crenulatus	NA	NA	The hairy-handed crab is commonly found, on mud flats and sand flats, but it may also occur under boulders on the rocky shore intertidal. Is a very effective scavenger and tolerates brackish conditions.
	Isopoda Valvifera	NA	NA	A species of isopod in the Suborder Valvifera.
	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.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

	Group and Species	Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Crustacea	*Paracorophium excavatum*	III	MM Optimum Range 95-100% mud (found in 40-100% mud)*.	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Optimum Range 95-100% mud (found in 40-100% mud) in upper Nth. Is. estuaries. In Sth. Is. and lower Nth. Is. common in Waikanae Estuary (15-40% mud), Haldane Estuary (25-35% mud) and in Fortrose Estuary (4% mud). Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites like Whareama A and B (30-70% mud) we get very few.
	Paravireia pistus	NA	NA	A new species of marine isopod in Family Spaeromatidae from Stewart Island (found in 1973 - in bottom mud from shallow water in Paterson Inlet).
	Phoxocephalidae sp.	I	NA	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Tanaidacea sp.	II	NA	Small, mostly marine-dwelling crustaceans that are diverse and abundant in some marine environments.
	Waitangi sp.	I	SS	An amphipod of the Phoxocephalidae Family with a strong sand preference.
Insecta	Chironomidae larvae	III	NA	Non-biting midges. Larvae are important as food items for fish and other aquatic organisms. They are also important as indicator organisms, generally they are pollution tolerant.

* 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.

****** Based on long term monitoring data from 100 low-mid tide sites in 22 South Island and lower North Island estuaries collected by Wriggle Ltd between 2001 and 2010 (mud concentrations range from 0.3-73% mud).