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Freshwater Estuary

Fine Scale Monitoring 2008/09

Prepared for

Environment Southland

June 2009

Cover Photo: Seagrass (*Zostera muelleri*) in firm sands, Freshwater Estuary. **Inside Photo: Mid-tide in Freshwater Estuary.**

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By

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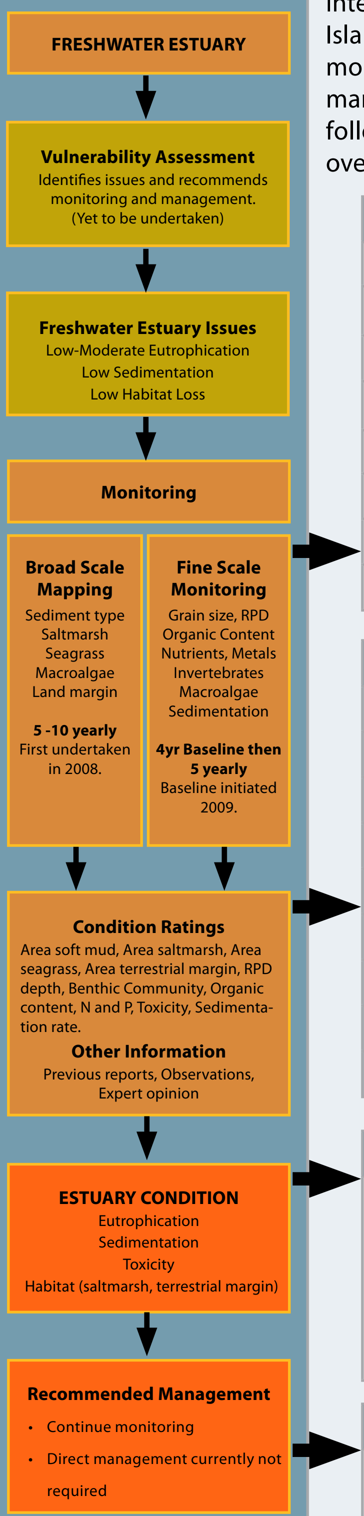
All photos by Wriggle except where noted otherwise.

FRESHWATER ESTUARY - EXECUTIVE SUMMARY



This report summarises the results of the first year of fine scale monitoring of two intertidal sites within Freshwater Estuary, a 812ha 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. An outline of the process used for estuary monitoring and management in Freshwater Estuary is presented in the margin flow diagram. The following tables summarise the 2009 fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

Fine Scale Monitoring Results

- Sediment Oxygenation: RPD was 1-10cm deep indicating moderate oxygenation.
- The benthic invertebrate community condition rating indicated a slightly enriched or "good" condition.
- The indicator of organic enrichment (Total Organic Carbon) was at very low concentrations.
- Nutrient enrichment indicators (total nitrogen and total phosphorus) were at low concentrations.
- Sedimentation rate was very low.
- Sand dominated the sediments and mud contents were extremely low.
- Heavy metals were well below the ANZECC (2000) ISQG-Low trigger values (i.e. very low toxicity).
- Nuisance macroalgal cover (measured in 2008) was moderate - a condition rating of "fair".

2009 Condition Ratings

Indicator	Site A	Site B
RPD Depth	Good	Good
Macrofauna	Good	Good
Organic Matter (TOC)	Very Good	Very Good
Nutrients (TN and TP)	Very Good	Very Good
Sedimentation Rate	Very Low	Baseline Year
Grain Size	Low Mud	Low Mud
Metals	Very Good	Very Good
Macroalgal % Cover (2008)	Fair	

Estuary Condition

Overall, the first year of fine scale monitoring showed that the dominant intertidal habitat (seagrass) in Freshwater Estuary was in good condition. The intertidal flats had very low sedimentation, absence of muds, and low sediment nutrient and heavy metal concentrations. The benthic community indicated slightly enriched conditions and, in conjunction with the macroalgal results, show that the estuary is in a moderately enriched (mesotrophic) state.

Recommended Monitoring and Management

Annual fine scale monitoring (including sedimentation rate) for the next three years. Following completion of the four year baseline, at five yearly intervals. The next monitoring is programmed for February 2010.
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

OVERVIEW

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. In 2000, Environment Southland (ES) identified a number of estuaries in it's region as immediate priorities for long term monitoring and in 2002 began monitoring in a staged manner. The estuaries currently included in the monitoring programme are New River, Jacobs River, Fortrose, Waikawa, Haldane, Waiau, Waituna and Freshwater. Risk assessments have been undertaken for a number of other estuaries in order to establish priorities for their management.

Broad scale monitoring of Freshwater Estuary was undertaken in April 2008, with the first year of fine scale baseline monitoring undertaken in February 2009. Wriggle Coastal Management and ES currently undertake the work using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions (e.g. Robertson and Stevens 2007).

The Freshwater Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment**. Assessment of the vulnerability of the estuary to major issues (Table 1) and appropriate monitoring design. This component has been 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 estuary condition, is the subject of the current report. This report presents the findings of the February 2009 monitoring, including condition ratings for the estuary.

Freshwater Estuary is a relatively large (812ha) "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, 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 (<1%).

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

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

Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Eutrophication	Nuisance Macroalgal Cover	Broad scale mapping - estimates the change in the area of nuisance macroalgal growth (e.g. sea lettuce (*Ulva*), *Gracilaria* and *Enteromorpha*) over time.
Eutrophication	Organic and Nutrient Enrichment	Chemical analysis of total nitrogen, total phosphorus, and total organic carbon in replicate samples from the upper 2cm of sediment.
Eutrophication	Redox Profile	Measurement of depth of redox potential discontinuity profile (RPD) in sediment estimates likely presence of deoxygenated, reducing conditions.
Toxins	Contamination in Bottom Sediments	Chemical analysis of indicator metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) in replicate samples from the upper 2cm of sediment.
Toxins, Eutrophication, Sedimentation	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Habitat Loss	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
Habitat Loss	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.

2. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the EMP (Robertson et al. 2002) and provides detailed information on the condition of the estuary. Using the outputs of 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, two fine scale sampling sites (Sites A and B, Figure 1), were selected in low-mid water seagrass, 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).

1. Introduction (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)

FINE SCALE MONITORING (CONTINUED)

Sedimentation Plate Deployment:
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).

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)

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 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

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

2. Methods (Continued)

Metals

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

METALS CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<0.2 x ANZECC (2000) ISQG-Low	Monitor at 5 year intervals after baseline established
Good	< ANZECC (2000) ISQG-Low	Monitor at 5 year intervals after baseline established
Fair	< ANZECC (2000) ISQG-High but >ISQG-Low	Monitor at 2 year intervals and manage source
Poor	> ANZECC (2000) ISQG-High	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Sedimentation Rate

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

SEDIMENTATION RATE CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Low	<1mm/yr (typical pre-European rate)	Monitor at 5 year intervals after baseline established
Low	1-5mm/yr	Monitor at 5 year intervals after baseline established
Moderate	5-10mm/yr	Monitor at 5 year intervals after baseline established
High	10-20mm/yr	Monitor yearly. Initiate Evaluation & Response Plan
Very High	>20mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

Benthic Community Index

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

3. RESULTS AND DISCUSSION

OUTLINE

Tables 3 and 4 summarise the results of the 27 February 2009 fine scale monitoring of Freshwater Estuary, with detailed results presented in Appendices 2 and 3. In order to help place the results into context, they are discussed in three subsections: sedimentation, eutrophication, and toxicity, which are the key estuary problems that the fine scale monitoring is addressing. Within each subsection, the results for each of the relevant fine scale indicators are presented (e.g. total nitrogen is presented under the issue of eutrophication). A summary of the condition ratings for each of the two sites is presented in the figures accompanying the results.

Table 3. Physical and chemical results (means) for Freshwater Estuary.

Site and Year	Reps	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg							
Freshwater A 2009	3	1 to 5	30	0.20	0.8	99.1	0.50	<0.010	3.0	1.4	2.4	0.60	5.8	<500	153
Freshwater B 2009	3	1 to >10	30	0.17	0.3	100.6	0.50	0.012	4.0	1.6	3.1	0.78	7.6	<500	177

Table 4. Macrofauna results (means) for Freshwater Estuary.

Site and Year	Mean Total Abundance/m^2	Mean Number of Species/Core
Freshwater A 2009	2,175	10.7
Freshwater B 2009	7,575	16.8

SEDIMENTATION

2009 SEDIMENT RATING	Very Low

In order to assess sedimentation in Freshwater Estuary, three main indicators are measured; the area of soft mud, sedimentation rate, and grain size. The results are:

- **The area of soft mud**. Showed a "very good" rating (0.3% of the estuary area was soft mud) when measured using broad scale habitat mapping techniques (Stevens and Robertson 2008).
- **Sedimentation rate.** The results of the first years monitoring of sedimentation over four buried plates at Site A indicated a "very low" mean sedimentation rate of 0.25mm/yr (Figure 2).
- **Grain Size (% mud, sand, gravel)**. Fine scale monitoring in 2009 showed that both sites were dominated by sandy sediments (>99% sand), with little mud content (<1% mud) (Figure 3).

Where elevated catchment sediment loads discharge to deltas within large sheltered embayments (like Freshwater Estuary) there is a high risk of them becoming too muddy. Fortunately, the unmodified native bush and hard-rock catchment of Freshwater Estuary has a very low estimated suspended solid yield (600 tonnes/yr). As a consequence, sediment mud concentrations in the estuary are also low. Such a pristine estuary provides a valuable reference against which others can be compared.

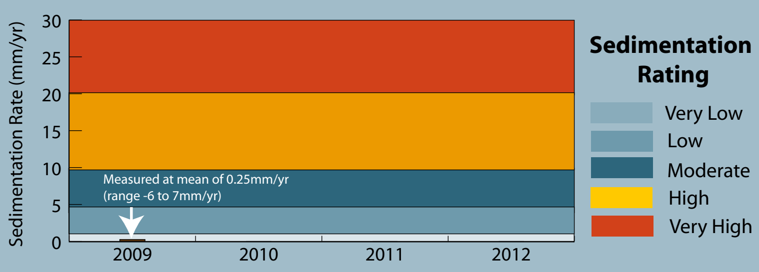


Figure 2. Sedimentation rate, Freshwater Estuary.

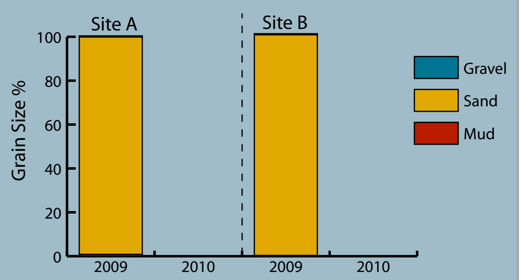


Figure 3. Grain size, Freshwater Estuary.

3. Results and Discussion (Continued)

EUTROPHICATION

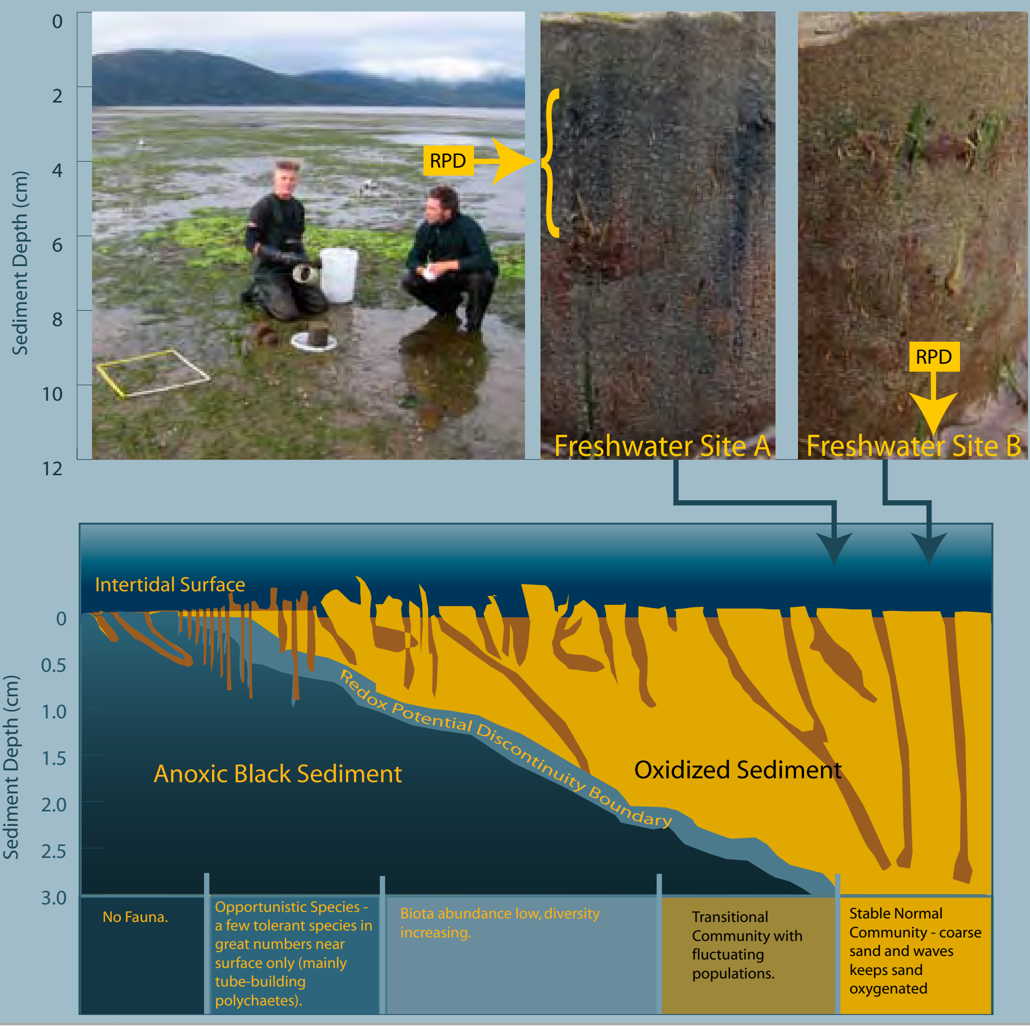
2009 RPD RATING
GOOD

The primary fine scale indicators of eutrophication are grain size, the RPD boundary, sediment organic matter, nitrogen and phosphorus concentrations, and the composition of the sediment-dwelling animal community. The broad scale indicators (reported in Stevens and Robertson 2008) are the percentages of the estuary covered by macroalgae (given a "fair" rating) and soft muds (given a "very good" rating).

The Redox Potential Discontinuity (RPD)
Figure 4 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, while the results showed that the RPD depth in Freshwater Estuary was variable (1 to 5cm at Site A and 1 to greater than 10cm at Site B). Seagrass (*Zostera muelleri*) was considered likely to be responsible for this variation. 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.

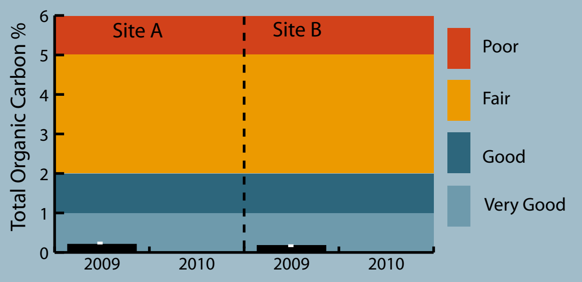
These moderately deep RPD values (a "good" condition rating) indicate that the benthic invertebrate community was likely to be in a "normal to transitional" state.

Figure 4. Sediment profiles, depths of RPD and predicted benthic community type, Freshwater Estuary, 27 February 2009. Arrows below cores relate to the type of community likely to be found in each core.



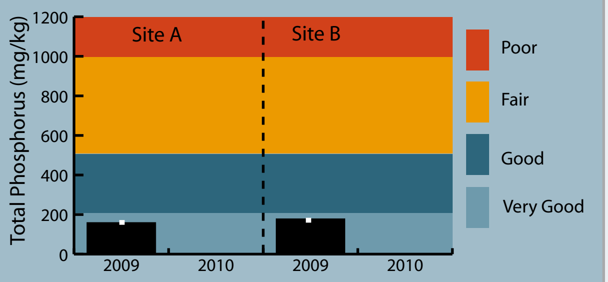
3. Results and Discussion (Continued)

Figure 5. Total organic carbon, (mean and range) Freshwater Estuary.



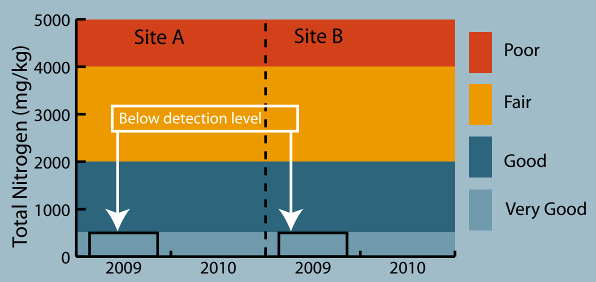
2009 TOC RATING	Very Good

Figure 6. Total phosphorus, (mean and range) Freshwater Estuary.



2009 TP RATING	Very Good

Figure 7. Total nitrogen, (mean and range) Freshwater Estuary.



2009 TN RATING	Very Good

TOTAL ORGANIC CARBON (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 was at very low concentrations (mean 0.17 and 0.2% for Sites A and B respectively) and met the “very good” condition rating (Figure 5).

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 at very low concentrations (mean 158mg/kg and 177mg/kg for Sites A and B respectively), and met the “very good” condition rating (Figure 6).

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)

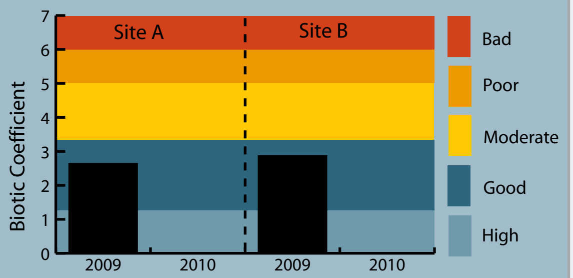
Like phosphorus, total nitrogen (the other key nutrient in the eutrophication process) was present at both sites at very low concentrations (mean <500mg/kg at both sites) and met the “very good” condition rating (Figure 7).

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.

3. Results and Discussion (Continued)

Figure 8. Macroinvertebrate rating (Biotic Coefficient), Freshwater Estuary.



2009 BENTHIC COMMUNITY RATING	Good

SEDIMENT BIOTA

A key indicator of response to both man-made and natural stressors is the benthic invertebrate community condition. In Freshwater Estuary it was in the "good" category indicating slight enrichment at both sites (Figure 8). The rating reflects the very low mud and sediment nutrient concentrations of this estuary, combined with the presence of extensive seagrass beds.

As found in many well-flushed sandy NZ estuaries, the benthic invertebrate community in Freshwater Estuary included:

- Organisms with a strong sand preference (e.g. polychaete *Aonides* sp., pipi *Paphies australis*, and gastropods *Notoacmea helmsi* , *Diloma subrostrata*, and *Cominella glandiformis* - Norkko et al. 2001, Thrush et al. 2003).
- Very low abundance or absence of organisms that have a strong mud preference (e.g. polychaete *Scolecolepides* sp. and amphipod *Paracorophium excavatum*).

Compared with the intertidal mudflats in other NZ estuaries, the community diversity was moderate-high (mean 10-17 species per core - Figure 9), reflecting the presence of seagrass and the general absence of muds.

Mean abundance at each site was typical of good condition sandy estuaries at 2,000-7,500m^2 (Figure 10).

Figure 9. Mean number of infauna species, Freshwater Estuary compared with other NZ estuaries (Source Robertson et al. 2002, Robertson and Stevens 2009).

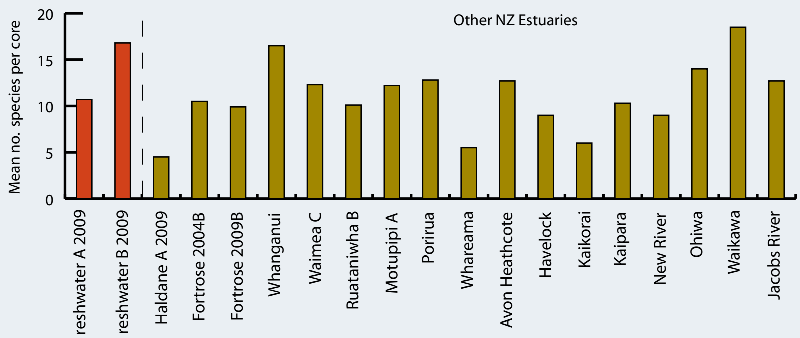
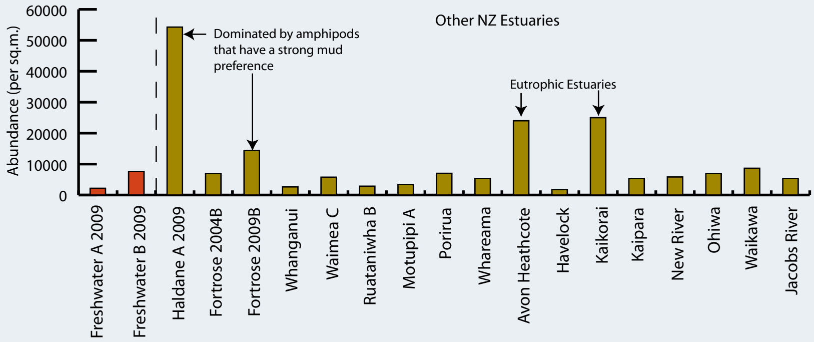
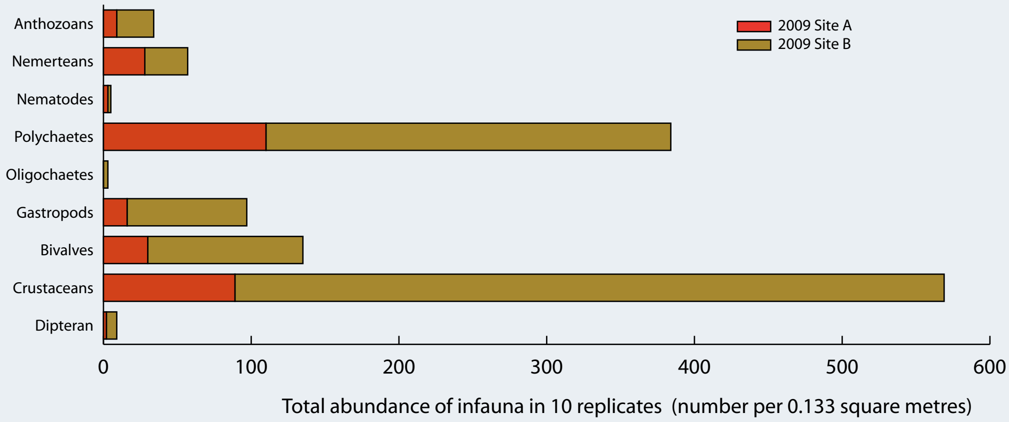


Figure 10. Mean total abundance of macrofauna, Freshwater Estuary compared with other NZ estuaries.



Like other NZ estuaries the intertidal community was dominated by polychaetes, crustacea, bivalves and gastropods (Figure 11).

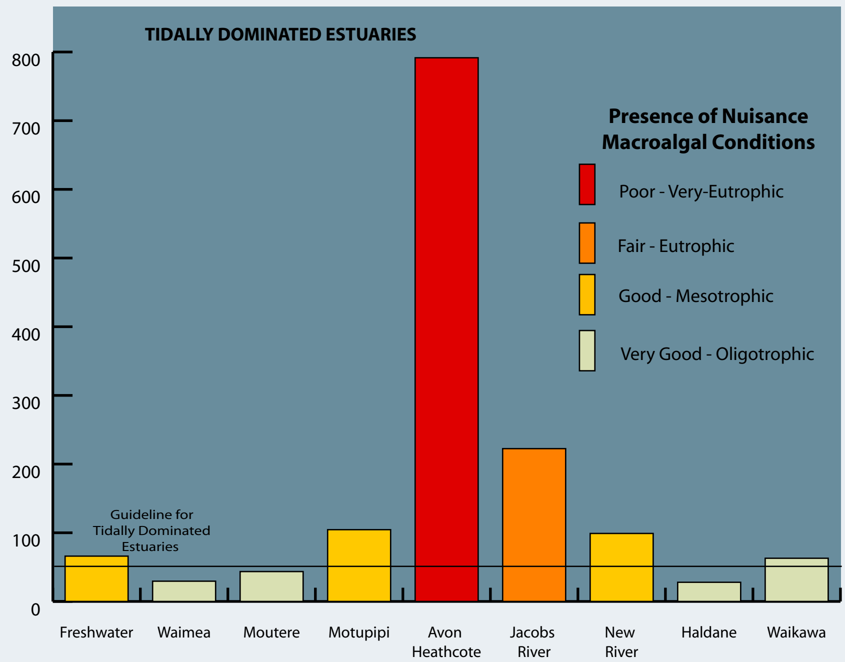
Figure 11. Abundance of major macrofauna groups, Freshwater Estuary.



In terms of eutrophication, the results suggest that the estuary has a moderate level of enrichment. This rating is based on the "good" benthic invertebrate community rating in 2009 indicating slight enrichment, combined with the widespread macroalgal cover in 2008, where 25% of the estuary had greater than 50% macroalgal cover, indicating moderate enrichment.

Although the catchment is dominated by unmodified native bush, such a level of enrichment is not unexpected given the moderate nitrogen input to the estuary (estimated at 200tN/yr - NIWA WRENZ model). This areal N loading (i.e. $66mg.m^{-2}.d^{-1}$) is at the lower limit of the range where nuisance macroalgal conditions are expected in tidally dominated estuaries (Figure 12). Also it is close to the $50mg.m^{-2}.d^{-1}$ upper limit suggested by Heggie (2006) for ensuring no eutrophication of temperate tidally dominated estuaries.

Figure 12. Areal N loads and presence of nuisance macroalgal conditions, NZ estuaries.



3. Results and Discussion (Continued)

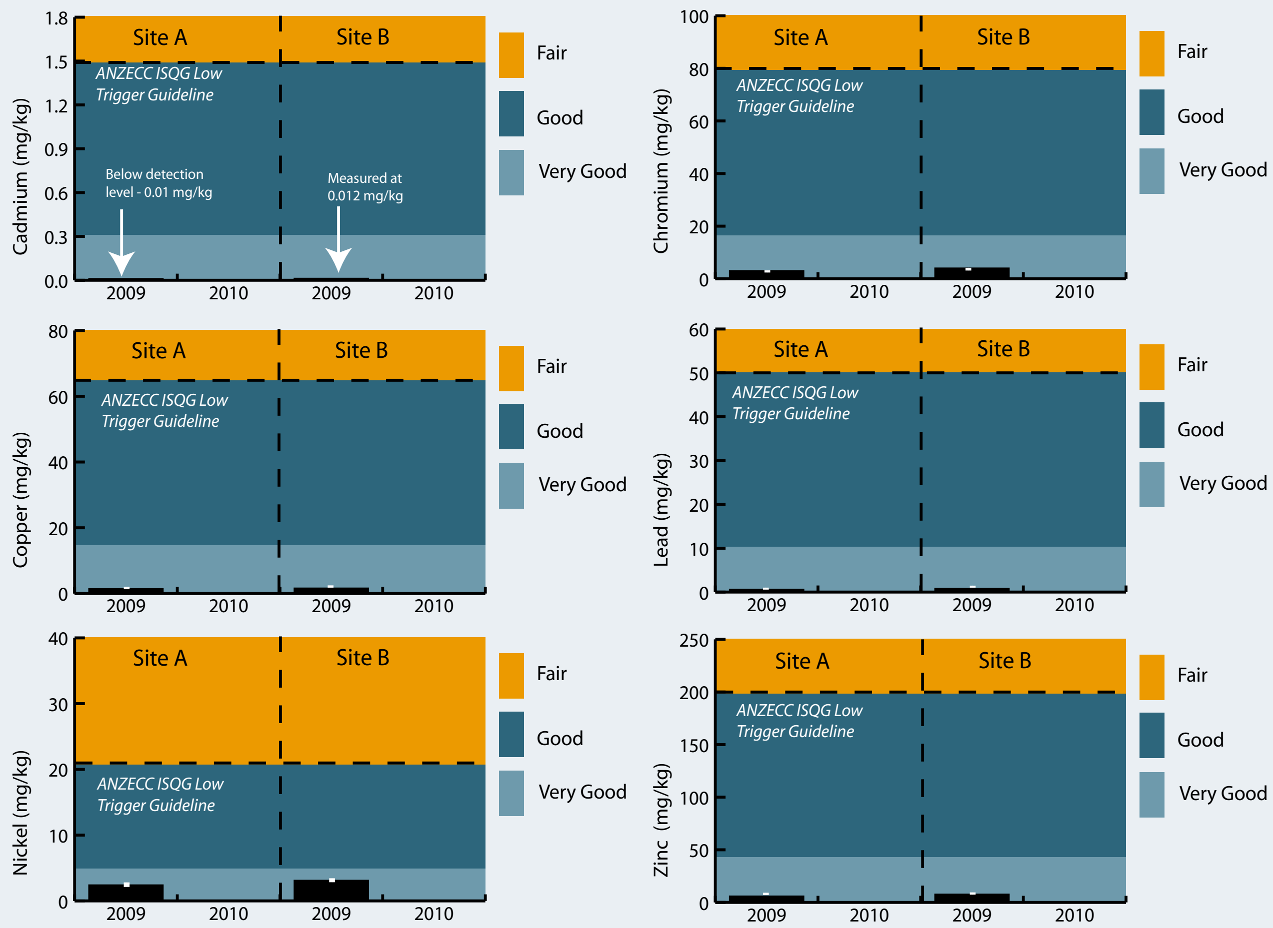
TOXICITY

2009 TOXICITY RATING	Very Good

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 13).

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 13. Sediment metal concentrations, (mean and range) Freshwater Estuary.

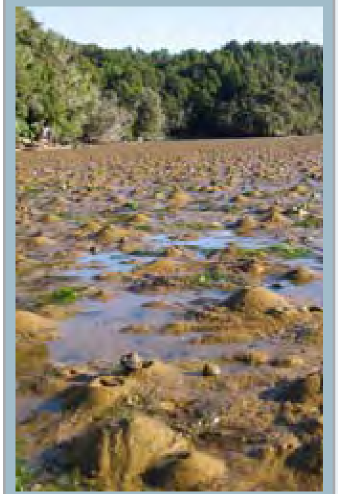


4. SUMMARY AND CONCLUSIONS

The fine scale monitoring results for a range of physical, chemical and biological indicators of estuary condition show that Freshwater Estuary was in good condition. The key findings were;

- The sediments were dominated by sands, with mud concentrations very low compared with other Southland estuary monitoring sites.
- The intertidal habitat was dominated by seagrass beds.
- Sediment levels of organic carbon, nitrogen and phosphorus were very low.

4. Summary and Conclusions (Continued)



- The benthic invertebrate community condition index was in the upper range of the "good" category, indicating slightly enriched conditions.
- Species diversity was high compared with other NZ estuaries and included organisms with a strong sand preference. As expected, there was a very low abundance of organisms that have a strong mud preference.
- Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations.

In terms of eutrophication, the results suggest that the estuary is moderately enriched or mesotrophic. The cause of this enrichment is expected to be driven by the moderate-high nitrogen inflow from the native bush dominated catchment (estimated mean 0.8 mgN/l), as well as the nutrient cycling mediation role played by the extensive seagrass beds in the estuary.

In terms of sedimentation, Freshwater Estuary has a low risk of excessive inputs of fine sediments, and consequently will provide valuable reference site information for estuaries in the Southland region.

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 monitoring results and condition ratings, it is recommended that monitoring continue as outlined below:

Fine Scale Monitoring (including sedimentation rate).
Undertake baseline monitoring (at Sites A and B) annually for three more years and subsequently at five yearly intervals or as deemed necessary based on the condition ratings. The next fine scale monitoring is scheduled for February 2010.

Sedimentation Rate Monitoring.
Monitor the depths of the existing eight sediment plates during the fine scale monitoring scheduled for 2010. Following the 2010 monitoring, it is recommended that the depth of all plates be measured whenever fine scale monitoring is undertaken.

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) for editing.

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APPENDICES

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. 2009 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), 27 February 2009.

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 5	30	0.19	1.6	97.6	0.7	< 0.010	2.8	1.3	2.3	0.57	5.6	<500	150
Freshwater A	5-8	1 to 5	30	0.18	< 0.1	101	0.3	< 0.010	3	1.4	2.5	0.61	6	<500	150
Freshwater A	9-10	1	30	0.22	0.6	98.8	0.6	< 0.010	3.2	1.4	2.4	0.63	5.9	<500	160
Freshwater B	1-4	1 to 10	30	0.18	< 0.1	100	0.5	0.011	4.3	1.8	3.3	0.83	7.9	<500	180
Freshwater B	5-8	4 to >10	30	0.17	< 0.1	103	0.3	0.012	3.7	1.6	3	0.78	7.3	<500	170
Freshwater B	9-10	1 to >10	30	0.15	0.6	98.7	0.7	0.012	4	1.5	3.1	0.74	7.5	<500	180

* 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	1-5	1-5	1-5	1-5	1-5	1-5	1	1-5	1	1
Freshwater B	2-3	1-10	>10	2	>10	>10	>10	1-4	1-10	>10

APPENDIX 2. 2008 DETAILED RESULTS (CONTINUED)

Epifauna (numbers per 0.25m² quadrat)

Freshwater Estuary Site A, 27 February 2009										
	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)	12	10	11	16	6	3	9	14	10	2
Mytilus galloprovincialis (blue mussel)				1		1				
No. species/quadrat	1	1	1	2	1	2	1	1	1	1
No. individuals/quadrat	12	10	11	17	6	4	9	14	10	2

Epifauna (numbers per 0.25m² quadrat)

Freshwater Estuary Site B, 27 February 2009										
	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)			1			4				
Austrominius modestus (estuarine barnacle)		10		25						
Austrovenus stutchburyi (cockle)	1	3	1	7		4			1	
Diloma subrostrata (mudflat topshell)	1	3	7	5	2		2		1	4
Mytilus galloprovincialis (blue mussel)						1				
Notoacmea helmsi (estuarine limpet)										1
Paphies australis (pipi)			1	4	3					1
No. species/quadrat	2	3	3	4	1	3	1	0	2	2
No. individuals/quadrat	2	16	9	41	2	9	2	0	2	5

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

Site A (west)	No	Date	NZMG East	NZMG North	depth
	1	10-Apr-08	2127174	5355217	235
	2	10-Apr-08	2127167	5355236	250
	3	10-Apr-08	2127181	5355249	286
	4	10-Apr-08	2127192	5355234	278
Site B (east)	**No**	**Date**	**NZMG East**	**NZMG North**	**depth**
	5	27-Feb-09	2128017	5355387	125
	6	27-Feb-09	2128020	5355391	127
	7	27-Feb-09	2128027	5355394	144
	8	27-Feb-09	2128031	5355397	162

Site A - First Year Sedimentation				
Site A (West)	**No**	**4/10/08**	**2/27/09**	**change (mm)**
	1	235	240	5
	2	250	244	-6
	3	286	281	-5
	4	278	285	7
sum all depths		**1049**	**1050**	**1**
average change				**0.25**

Freshwater Estuary: Percentage Cover of *Zostera* sp. (seagrass) at each site, 27 February 2009.

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 % cover	80-100	80-100	80-100	80-100	50-80	80-100	50-80	80-100	80-100	80-100
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 % cover	80-100	80-100	80-100	80-100	80-100	50-80	80-100	50-80	50-80	50-80

APPENDIX 2. 2008 DETAILED RESULTS (CONTINUED)

Infauna - Freshwater Estuary Site A, 27 February 2009 (numbers per 0.01327m² core) (Note NA = Not Assigned)

Group	Species	AMBI	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	4	0	3	1	0	1	0	0	0	0
NEMERTEA	Nemertea sp.1	III	3	2	1	2	2	0	0	2	1	1
	Nemertea sp.2	III	0	0	0	2	0	1	1	2	1	0
	Nemertea sp.3	III	0	0	0	0	2	1	0	2	1	1
NEMATODA	*Nematoda*	III	0	0	0	0	3	0	0	0	0	0
POLYCHAETA	*Aonides* sp.	III	0	3	2	4	21	5	13	10	3	7
	Boccardia (Paraboccardia) syrtis	I	0	0	0	0	0	0	0	0	0	0
	Capitella sp.	V	1	0	1	1	1	0	0	0	0	0
	Dorvilleidae sp.	NA	0	0	0	0	0	0	0	0	0	0
	Glycera sp.1	II	0	0	0	0	0	0	0	0	0	0
	Hesionidae sp.	II	0	0	0	0	0	0	0	0	0	0
	Hesionidae sp.	II	0	0	0	4	2	0	0	5	0	1
	Nicon aestuariensis	III	0	0	0	0	0	1	0	0	0	0
	Orbinia papillosa	I	0	0	1	0	0	1	0	1	0	0
	*Paraonidae*sp.	III	0	0	0	0	0	0	0	0	0	0
	Pectinaria australis	I	0	0	0	1	1	0	2	1	0	0
	Perinereis vallata	III	0	0	0	2	0	0	0	0	0	0
	Phyllodocidae sp.	II	0	0	0	0	0	0	0	0	0	0
	Prionospio aucklandica	IV	0	0	0	7	1	0	3	1	1	1
	Scolecolepides benhami	III	0	0	0	0	0	0	0	0	0	1
	Scoloplos (Scoloplos) cylindrifer	I	0	0	0	0	0	0	0	0	0	0
	Syllidae sp.1	II	0	0	0	0	0	0	0	0	0	0
OLIGOCHAETA	Oligochaeta	NA	0	0	0	0	0	0	0	0	0	0
GASTROPODA	*Amphibola crenata*	NA	0	0	0	1	0	1	0	0	7	1
	Cominella glandiformis	NA	0	0	0	0	0	0	0	0	0	0
	Diloma subrostrata	NA	0	0	0	0	0	0	0	1	0	0
	Notoacmaea helmsi	NA	1	0	0	0	1	1	1	0	1	0
BIVALVIA	*Arthritica* sp.	I	0	0	0	0	0	0	0	0	0	0
	Austrovenus stutchburyi	NA	0	0	0	0	1	0	0	0	0	0
	Mytilus galloprovincialis	III	1	0	0	0	0	0	0	0	0	0
	Paphies australis	II	1	5	1	9	1	0	0	10	1	0
CRUSTACEA	Amphipoda sp.1	NA	0	0	1	4	4	0	0	0	1	6
	Amphipoda sp.2	NA	0	0	0	0	0	0	0	0	1	2
	Amphipoda sp.3	NA	0	0	0	0	0	0	0	0	0	0
	Amphipoda sp.4	NA	0	1	8	5	0	0	0	2	0	0
	Austrominius modestus	NA	0	0	0	0	0	21	0	0	0	0
	Corophium sp.1	NA	0	0	0	0	0	0	0	0	0	0
	Halicarcinus varius	NA	0	0	1	0	1	0	2	2	2	2
	Halicarcinus whitei	NA	2	1	3	4	0	5	0	1	0	0
	Helice crassa	NA	0	1	0	0	0	0	0	1	0	0
	Hemigrapsus crenulatus	NA	0	0	0	0	0	0	1	0	0	0
	Isopoda Valvifera	NA	0	1	0	0	0	0	0	0	0	0
	Macrophthalmus hirtipes	NA	0	0	0	0	0	0	0	0	0	0
	Paracorophium excavatum	NA	0	1	0	0	0	0	1	0	0	0
	Paravireia pistus	NA	0	0	0	1	0	0	0	0	0	0
	Phoxocephalidae sp.	I	0	0	0	0	0	0	0	0	0	0
	Tanaidacea sp.	II	0	0	0	0	0	0	0	0	0	0
INSECTA	Chironomidae sp.	III	2	0	0	0	0	0	0	0	0	0
Total no. of species			8	8	10	15	13	10	8	14	11	10
Total abundance			15	15	22	48	41	38	24	41	20	23

Infauna - Freshwater Estuary Site B, 27 February 2009 (numbers per 0.01327m^2 core) (Note NA = Not Assigned)

Group	Species	AMBI	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	4	4	3	0	3	2	2	1	3	3
NEMERTEA	Nemertea sp.1	III	2	1	0	0	1	3	0	2	2	0
	Nemertea sp.2	III	0	0	1	2	0	6	5	1	1	2
	Nemertea sp.3	III	0	0	0	0	0	0	0	0	0	0
NEMATODA	*Nematoda*	III	0	0	1	0	1	0	0	0	0	0
POLYCHAETA	*Aonides* sp.	III	7	1	14	5	16	5	4	1	3	1
	Boccardia (Paraboccardia) syrtis	I	0	0	0	0	0	1	0	1	0	0
	Capitella sp.	V	0	1	1	0	0	0	1	2	0	0
	Dorvilleidae sp.	NA	0	0	1	0	0	0	0	0	0	0
	Glycera sp.1	II	0	0	0	1	0	0	0	0	0	0
	Hesionidae sp.	II	0	0	0	0	0	1	3	1	0	0
	Hesionidae sp.	II	0	0	0	0	0	0	0	0	0	0
	Nicon aestuariensis	III	0	0	0	0	0	0	0	0	0	0
	Orbinia papillosa	I	3	0	0	3	0	0	1	0	0	0
	Paraonidae sp.	III	1	1	5	0	0	1	0	0	0	0
	Pectinaria australis	I	1	0	1	0	1	1	0	1	0	1
	Perinereis vallata	III	1	0	2	0	1	1	0	0	0	0
	Phyllodocidae sp.	II	0	1	0	1	0	0	0	0	0	1
	Prionospio aucklandica	IV	2	15	32	8	16	52	10	17	7	8
	Scolecolepides benhami	III	0	0	0	0	0	0	0	0	0	0
	Scoloplos (Scoloplos) cylindrifer	I	0	0	0	4	2	0	0	0	0	0
	Syllidae sp.1	II	0	0	0	0	1	0	0	0	0	0
OLIGOCHAETA	Oligochaeta	NA	0	0	0	0	2	1	0	0	0	0
GASTROPODA	*Amphibola crenata*	NA	0	0	0	0	0	0	0	1	0	0
	Cominella glandiformis	NA	0	0	0	0	0	0	0	1	0	0
	Diloma subrostrata	NA	0	0	1	0	0	1	5	0	0	0
	Notoacmaea helmsi	NA	9	8	4	18	3	7	8	3	10	2
BIVALVIA	*Arthritica* sp.	I	0	0	0	0	1	2	0	0	0	0
	Austrovenus stutchburyi	NA	3	2	3	4	0	2	2	1	1	1
	Mytilus galloprovincialis	III	0	0	0	0	0	0	0	0	0	0
	Paphies australis	II	18	7	3	13	4	5	10	5	6	12
CRUSTACEA	Amphipoda sp.1	NA	12	7	2	11	23	1	18	7	27	1
	Amphipoda sp.2	NA	7	0	0	8	1	0	0	0	2	0
	Amphipoda sp.3	NA	0	0	0	0	0	0	0	0	0	1
	Amphipoda sp.4	NA	8	11	6	4	6	7	3	1	10	3
	Austrominius modestus	NA	0	0	0	229	0	0	18	0	0	1
	Corophium sp.1	NA	2	0	0	1	1	0	0	0	0	2
	Halicarcinus varius	NA	2	0	1	0	0	0	0	0	0	1
	Halicarcinus whitei	NA	0	0	0	3	0	0	2	0	0	0
	Helice crassa	NA	0	0	0	0	0	0	0	0	0	0
	Hemigrapsus crenulatus	NA	0	0	0	0	0	0	0	0	0	0
	Isopoda Valvifera	NA	0	0	0	0	0	0	0	0	0	0
	Macrophthalmus hirtipes	NA	0	0	0	0	0	1	0	0	0	0
	Paracorophium excavatum	NA	0	0	0	0	0	0	0	0	0	0
	Paravireia pistus	NA	4	0	0	0	0	0	1	0	0	0
	Phoxocephalidae sp.	I	6	2	0	1	1	9	1	1	2	0
	Tanaidacea sp.	II	0	0	1	0	0	0	0	0	0	0
INSECTA	Chironomidae sp.	III	0	0	0	1	1	0	0	0	0	5
Total no. of species			18	13	18	18	19	20	17	17	12	16
Total abundance			92	61	82	317	85	109	94	47	74	45

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		AMBI Group	Details
Anthozoa	*Edwardsia* sp.#1	II	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	III	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp.	III	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	*Aonides* sp.	III	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.
	Boccardia (Paraboccardia) syrtis and acus	I	Small surface deposit-feeding spionids. Prefers low-mod mud content but found in a wide range of sand/mud. Lives in flexible tubes 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.
	Capitella sp.	V	A species of capitellid polychaete which is pollution tolerant. Common in sulphide rich anoxic sediments.
	Dorvilleidae sp.	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.
	Glyceridae	II	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15 cm. 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.
	Hesionidae sp.#1	II	Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The New Zealand species are little known.
	Nicon aestuariensis	III	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate to high mud content sediments.
	Orbinia papillosa	I	Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.
	Paraonidae sp.#1	III	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15cm and appear to be sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content.
	Pectinaria australis	I	Subsurface deposit-feeding/herbivore. Lives in a cemented sand grain cone-shaped tube. Feeds head down with tube tip near surface. Prefers fine sands to muddy sands. Mid tide to coastal shallows. Belongs to Family Pectinariidae. Often present in NZ estuaries. Density may increase around sources of organic pollution and eelgrass beds. Intolerant of anoxic conditions.
	Perinereis vallata	III	An intertidal soft shore nereid (which are common and very active, omnivorous worms). Prefers sandy sediments.
	Phyllodocidae	II	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.
	Prionospio aucklandica	IV	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	Species	AMBI Group	Details
Polychaetes	*Scolecolepides benhami*	III	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.
Polychaetes	*Scoloplos (Scoloplos) cylindrifer*	I	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.
Polychaetes	Syllidae	II	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	Oligochaete sp.	NA	Segmented worms - deposit feeders. Classified as very pollution tolerant by AMBI (Borja et al. 2000) but a review of literature suggests that there are some less tolerant species.
Gastropoda	*Amphibola crenata*	NA	A pulmonate gastropod endemic to New Zealand. 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	Endemic to NZ. A carnivore living on surface of sand 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. Has a strong sand preference.
Gastropoda	*Diloma subrostrata*	NA	The mudflat top shell, lives on sandflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ and feeds on the film of microscopic algae on top of the sand. Has a strong sand preference.
Gastropoda	*Notoacmaea helmsi*	NA	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Has a strong sand preference.
Bivalvia	*Arthritica* sp.#1	III	A small sedentary deposit feeding bivalve, preferring a moderate mud content. Lives greater than 2cm deep in the muds.
Bivalvia	*Austrovenus stutchburyi*	NA	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. Rarely found below the RPD layer.
Bivalvia	*Mytilus galloprovincialis*	III	*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.
Bivalvia	*Paphies australis*	II	Pipi (endemic) are tolerant of moderate wave action, 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. Have a strong sand preference.
	Amphipoda sp.	NA	An unidentified amphipod.
	Copepoda	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.
	Austrominius modestus	NA	Small acorn barnacle (also named *Elminius modestus*). Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones.
	Corophium sp.	NA	A species of amphipod in the Family Corophiidae.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		AMBI Group	Details
	Halicarcinus varius	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	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Helice crassa	NA	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level.
	Hemigrapsus crenulatus	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	A species of isopod in the Suborder Valvifera.
	Macrophthalmus hirtipes	NA	The stalk-eyed mud crab is endemic to New Zealand and prefers water-logged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunneling mud crab, it feeds from the nutritious mud.
	Paracorophium excavatum	NA	A species of amphipod in the Family Corophiidae.
	Paravireia pistus	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	A family of amphipods.
	Tanaidacea sp.	II	Small, mostly marine-dwelling crustaceans that are diverse and abundant in some marine environments.
Diptera	Chironomidae larvae	III	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.

AMBI Sensitivity to Stress Groupings (from Borja et. al 2000)

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

Group II. Species indifferent to enrichment, always present in low densities with non-signicant 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 anoxic sediments.

The distribution of these ecological groups, according to their sensitivity to pollution stress, provides a Biotic Coefficient from 0-7, divided into a Biotic Index with five levels.