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Freshwater Estuary

Fine Scale Monitoring 2012/13

Prepared for

Environment Southland

October 2013

Cover Photo: Seagrass beds flanked by native forest near Fred's Camp, Freshwater Estuary, 2013.


Barry and Ben Robertson (Wriggle) crossing extensive seagrass beds in the southwest of Freshwater Estuary, 2013.

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By

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Contents

List of Tables

List of Figures

All photos by Wriggle except where noted otherwise.

EXECUTIVE SUMMARY

This report summarises the results of four years (2009, 2010, 2011 and 2013) of baseline fine scale monitoring of two intertidal sites within Freshwater Estuary, an 818ha pristine, tidal river plus intertidal delta estuary 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

- Sediments were dominated by sand, with mud content very low (<1.3%) at both sites.
- Sediment oxygenation was good (Redox Potential Discontinuity (RPD) depth 1-10cm).
- Sediment nutrient enrichment indicators (Organic Carbon, Nitrogen and Phosphorus) were at very low concentrations.
- Extensive intertidal seagrass beds were present (60% of the estuary).
- Macroalgal cover was elevated (e.g. 26% of estuary with >50% cover in 2008), but nuisance conditions were not apparent.
- The benthic invertebrate organic enrichment rating was "good" at both sites (dominated by organisms intolerant of elevated organic enrichment or mud content).
- Heavy metals, used as an indicator of toxicity, were at very low concentrations and were well below the ANZECC (2000) ISQG-Low trigger values.

CONDITION RATINGS

Key To Ratings	High/Poor	Good	Site A				Site B			
	Fair	Very Good	2009	2010	2011	2013	2009	2010	2011	2013
Macro-invertebrates: Mud and Enrichment Tolerance			Good				Good			
Sediment Mud Content			Very low				Very low			
Sedimentation Rate			Very low				Very low			
Sediment Oxygenation (RPD)			Good				Good			
TOC (Total Organic Carbon)			Very low				Very low			
Total Nitrogen			Very low				Very low			
Total Phosphorus			Very low				Very low			
Metals (Cd, Cu, Cr, Ni, Pb, Zn)			Very low				Very low			

ESTUARY CONDITION AND ISSUES

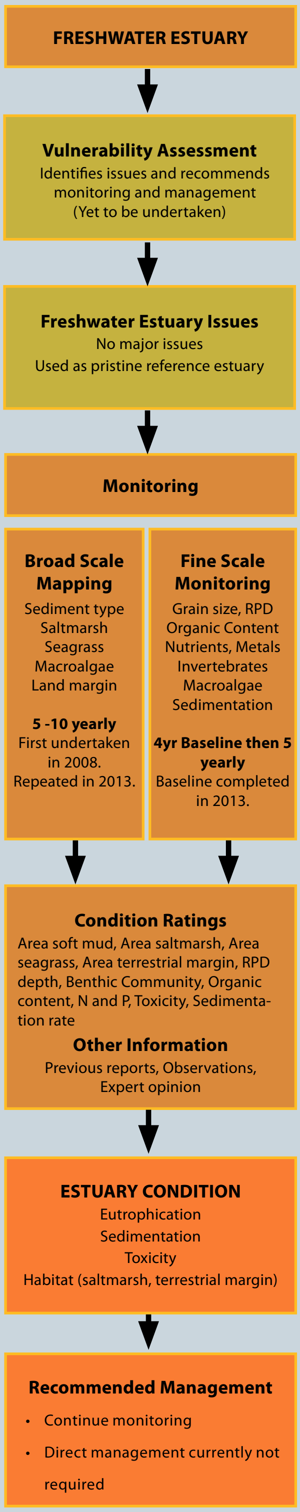
The results from the 2013 monitoring show that the intertidal sandy habitat that dominates the two sites at Freshwater Estuary was generally in very good condition and had not changed since 2009. The very low mud content, low nutrients and a benthic invertebrate community dominated by species with a preference for sand and low organic enrichment, indicates that this estuary is generally in a pristine state. In a national context, it is of interest that the estuary remains pristine (i.e. low sediment organic matter, RPD, and nutrients), despite an extensive macroalgal cover.

RECOMMENDED MONITORING AND MANAGEMENT

This was the final year of baseline monitoring and it is recommended that the fine scale monitoring should be repeated at 5 yearly intervals, next scheduled for February 2018. Five yearly broad scale habitat mapping is also scheduled for 2018. Sedimentation rate should be measured annually if the estuary is being monitored for other reasons, otherwise five yearly in conjunction with broad and fine scale monitoring.

In addition, identifying the key processes that maintain Freshwater Estuary in such good condition, despite its high macroalgal cover, would provide valuable information for future estuary management in Southland, and elsewhere in New Zealand.

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, 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 (NEMP) (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** (NEMP approach). This component, which documents the key habitats within the estuary, and changes to these habitats over time, was undertaken in 2008 and repeated in 2013. It is reported separately in Stevens and Robertson (2008) and Stevens and Robertson (2013).
3. **Fine Scale Monitoring** (NEMP 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, 2010 and 2011 (Robertson and Stevens 2009, 2010, 2011). The February 2013 final baseline monitoring is the subject of the current report.

Freshwater Estuary is a relatively large (812ha), unmodified "tidal river plus intertidal delta" type estuary 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 Mountains 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 undeveloped 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)

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

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 *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 NEMP indicators (shading signifies indicators used in this fine scale assessment).

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

For Freshwater Estuary, two fine scale sampling sites (Sites A and B, Figure 1, Appendix 2) 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 random core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average Redox Potential Discontinuity (RPD) depth recorded.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details in Appendix 3):
    - Grain size/Particle size distribution (% mud, sand, gravel).
    - Nutrients - total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC).
    - Trace metal contaminants (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 were checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Epifauna (surface-dwelling animals)

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

Infauna (animals within sediments)

- One randomly placed sediment core was taken from each of ten plots using a 130mm diameter (area = $0.0133m^2$) PVC tube.
- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled plastic bag.
- Once all replicates had been collected at a site, the plastic bags were transported to a nearby source of seawater and the contents of the core were washed through a 0.5mm nylon mesh bag. The infauna remaining were carefully emptied into a labelled plastic container 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).

Sedimentation Plate Deployment

Determining ongoing sedimentation rates involves measuring how much sediment builds up over a buried plate over time. Two sites, each with four plates (20cm square concrete blocks) have been established in Freshwater Estuary (Figure 1). In 2008 at Site A, four plates were buried approximately 20m apart in a square configuration deep in the sediments. In 2009, an additional four plates were buried at Site B, located 5m, 10m, 20m, and 25m from the north western corner peg of the fine scale monitoring site. Both sites were located in firm sand where sediment from Freshwater River was considered likely to be deposited. Each plate position was logged by GPS and marked with adjacent wooden stakes. Plate depths are measured by clearing away surface debris or macroalgae, placing a 2m straight-edge on the sediment surface above each plate (to average out small surface irregularities), pushing a probe through the sediment until it hits the buried plate, and recording the mean depth from the sediment surface to the top of the buried plate (see Appendix 2 for data). Buried plates, measured every 1-5 years, will provide a long-term measure of mean sedimentation rates in the estuary.

2. Methods (Continued)

CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented below) has been proposed for Freshwater Estuary (based on the ratings first developed for Southland's estuaries - e.g. Robertson & Stevens 2006). The ratings are based on relevant estuary monitoring data, guideline criteria, and expert opinion, and are regularly reviewed. They are screening tools 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).

Wriggle Estuary Benthic Index (WEBI)

When representative sites are surveyed, soft sediment macrofauna can be used to represent benthic community health and classify estuary condition. The AZTI (AZTI-Tecnalia Marine Research Division, Spain) Marine Benthic Index (AMBI) (Borja et al. 2000) has previously been used to classify NZ estuary macrofauna, but because the AMBI ratings include non-estuarine habitats, and are primarily drawn from overseas data, an index specific to NZ estuaries has been developed by Wriggle. Robertson (2013) produced mud and organic matter sensitivity ratings for 99 NZ estuary taxa from estuaries throughout NZ with funding from Wriggle and 3 NZ Regional Councils (Southland, Wellington and Waikato). Each taxa was allocated one of 5 sensitivity groupings (see Appendix 3) for use within a new index, the "Wriggle Estuary Benthic Index" (WEBI) that calculates an integrated mud and organic enrichment rating for a site. The equation to calculate the WEBI biotic coefficient (BC) is:

$$BC = \{(0 \times \%Rating1) + (1.5 \times \%Rating2) + (3 \times \%Rating3) + (4.5 \times \%Rating4) + (6 \times \%Rating5)\}/100.$$

The WEBI has been verified in relation to both mud content and total organic carbon for a wide range of NZ estuary types and regions, and is a valuable extension to the NZ National Estuary Monitoring Protocol (Robertson et al. 2002). The WEBI is particularly useful in detecting temporal and spatial impact gradients related to sediment and eutrophication stressors. However, if toxicity levels (apart from toxicity related to eutrophic conditions, i.e. elevated sulphide or ammonia) exceed levels that cause biotic stress, its robustness can be reduced and interpretation of results needs to account for this.

WRIGGLE ESTUARY BENTHIC INDEX - WEBI (Mud and Organic Enrichment)

RATING	DEFINITION	BC	RECOMMENDED RESPONSE
Very Good	Intolerant of mud and organic matter	0-1.2	Monitor 5 yearly after baseline established
Good	Tolerant of slight mud and organic matter	1.2-3.3	Monitor 5 yearly after baseline established
Fair	Tolerant of moderate mud and organic matter	3.3-5.0	Monitor 5 yearly after baseline est. Initiate ERP
Poor	Tolerant of high mud and organic matter	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very Poor	Very tolerant of high mud and organic matter	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend to more tolerant species	>3.3	Initiate Evaluation and Response Plan

Sediment Mud Content

In their natural state, most NZ estuaries would have been dominated by sandy or shelly substrates. Fine sediment is likely to cause detrimental and difficult to reverse changes in community composition (including invasive species), turbidity (from re-suspension), and amenity values. Increasing mud content can indicate where changes in land use management may be needed.

SEDIMENTATION MUD CONTENT

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<2%	Monitor at 5 year intervals after baseline established
Good	2-5%	Monitor at 5 year intervals after baseline established
Fair	5-15%	Monitor at 5 year intervals after baseline established
Poor	>15%	Monitor at 5 year intervals. Initiate ERP
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

2. Methods (Continued)

Sedimentation Rate

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

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

Redox Potential Discontinuity (sediment oxygenation)

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

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

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

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

Metals

Heavy metals provide a low-cost preliminary assessment of toxic contamination, and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for 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

2. Methods (Continued)

Total Organic Carbon

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, which contribute to the release of excessive nutrients and have adverse impacts on biota - key symptoms of eutrophication. Hyland et al. (2005) recently expanded upon the Pearson and Rosenberg (1978) model (which describes benthic community response along an organic enrichment gradient) by using it as a conceptual basis for defining lower and upper thresholds in total organic carbon (TOC) concentrations corresponding to low versus high levels of benthic species richness in samples from seven coastal regions of the world. Specifically, it was shown that risks of reduced macrobenthic species richness from organic loading and other associated stressors in sediments should, in general, be relatively low where TOC values were <1%, and relatively high where values were >3.5%.

While not a direct measure of causality (i.e. it does not imply that the observed bioeffect was caused by TOC itself), it was anticipated that these TOC thresholds may serve as a general screening-level indicator, or symptom, of ecological stress in the benthos from related factors. Such factors may include high levels of ammonia and sulphide, or low levels of dissolved oxygen associated with the decomposition of organic matter, or the presence of chemical contaminants co-varying with TOC in relation to a common controlling factor such as sediment particle size. Magni et al. (2009) confirmed similar TOC categories for Mediterranean coastal lagoons (high values >2.8% TOC) and Robertson (2013) recently confirmed similar TOC categories for a wide range of NZ estuaries (high values at 2.3%).

Based on these newly available data, the TOC Condition Rating has been modified as follows:

TOTAL ORGANIC CARBON CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<1%	Monitor at 5 year intervals after baseline established
Good	1-1.5%	Monitor at 5 year intervals after baseline established
Fair	1.5-2.5%	Monitor at 2 year intervals and manage source
Poor	>2.5%	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

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

3. RESULTS AND DISCUSSION

The results and discussion section is divided into an assessment of the key biotic indicator, macro-invertebrate condition, followed by an analysis of the primary environmental variables in relation to the key estuary problems that the fine scale monitoring is addressing: eutrophication, sedimentation and toxicity.
A summary of the 16 February 2013 monitoring results of Freshwater Estuary is presented in Table 3 (detailed results presented in Appendices 2 and 3), along with summary results of the 2009-2011 monitoring (Robertson and Stevens 2009, 2010, 2011). Sedimentation rate monitoring results are summarised in Table 4 with detailed results in Appendix 2.

Table 3. Physical, chemical and macrofauna results (means) for Freshwater Estuary 2009-2013.

Year/Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. Species
	cm	ppt	%				mg/kg								No./m²	No./core
2009 A	1-5	32	0.20	0.8	98.7	0.5	<0.01	3.00	1.37	2.40	0.60	5.83	<500	153	2158	10.7
2009 B	1-10	32	0.17	0.3	99.2	0.5	<0.01	4.00	1.63	3.13	0.78	7.57	<500	177	7564	16.8
2010 A	1-5	32	0.23	2.4	93.5	4.1	<0.01	2.57	1.23	2.37	0.59	5.57	<500	167	2158	9.1
2010 B	1-10	32	0.20	1.6	98.1	0.3	<0.01	3.50	1.47	2.90	0.73	7.23	<500	193	4647	12.4
2011 A	1-6	32	0.18	1.4	98.0	0.6	<0.01	2.93	1.33	2.57	0.63	5.70	< 510	153	3399	11.3
2011 B	1-6	32	0.18	0.9	99.0	0.1	<0.01	3.90	1.57	2.97	0.75	7.10	< 510	180	6000	15.6
2013 A	1-10	31	0.23	1.3	98.5	0.3	<0.01	2.77	1.27	2.53	0.58	5.70	<500	155	1399	7.0
2013 B	1-5	31	0.22	0.6	99.3	0.1	<0.01	3.53	1.60	3.10	0.73	7.40	<500	189	3714	8.2

MACRO-INVERTEBRATE CONDITION

Macro-invertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong link with the sediments, which, at the same time, are linked to the water column (Dauer et al. 2000). Because they integrate recent pollution history in the sediment, macro-invertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors at a community level.

The response of macro-invertebrates to stressors in Freshwater Estuary has been examined in three steps:

1. Assessment of species richness, abundance and feeding types.
2. Assessment of the response of the macro-invertebrate community to increasing mud and organic matter over the 12 years of monitoring based on identified tolerance thresholds for NZ taxa (Robertson 2013).
3. Use of multivariate techniques to explore differences in the macro-invertebrate communities at Sites A and B over the four years of monitoring since 2009.

Species Richness and Abundance

The first step showed that between 2009 and 2013 macro-invertebrate species richness and abundance showed slight variation from year to year (Table 3 and Figure 2) most likely related to climatic influences given the otherwise pristine condition of the estuary. Differences between the sites were also evident, Site B having consistently higher abundance and species richness than Site A. This is most likely attributable to the closer proximity of Site B to the main Freshwater River low tide channel (some flood scouring of Site B has previously been noted - Robertson and Stevens 2011, see also Figure 9).

Overall, the number of species (7-17 species/core) recorded from Freshwater Estuary in the baseline monitoring period (2009-2013) was similar to that recorded from the largely undisturbed intertidal sandflats in the central basin areas of other Southland estuaries, while abundance (1,400 to 7,500m^{-2}) was low to moderate (Figure 2). Both richness and abundance were generally lower than for other NZ estuary sites monitored using the NEMP (Robertson and Stevens 2011). However, the macroinvertebrate community at Freshwater Estuary differed in that it was dominated by filter feeders and surface grazers reflecting the clean, sandy, un-enriched sediments present. Such results highlight the importance of having reference estuaries with undisturbed catchments against which other estuaries can be evaluated.

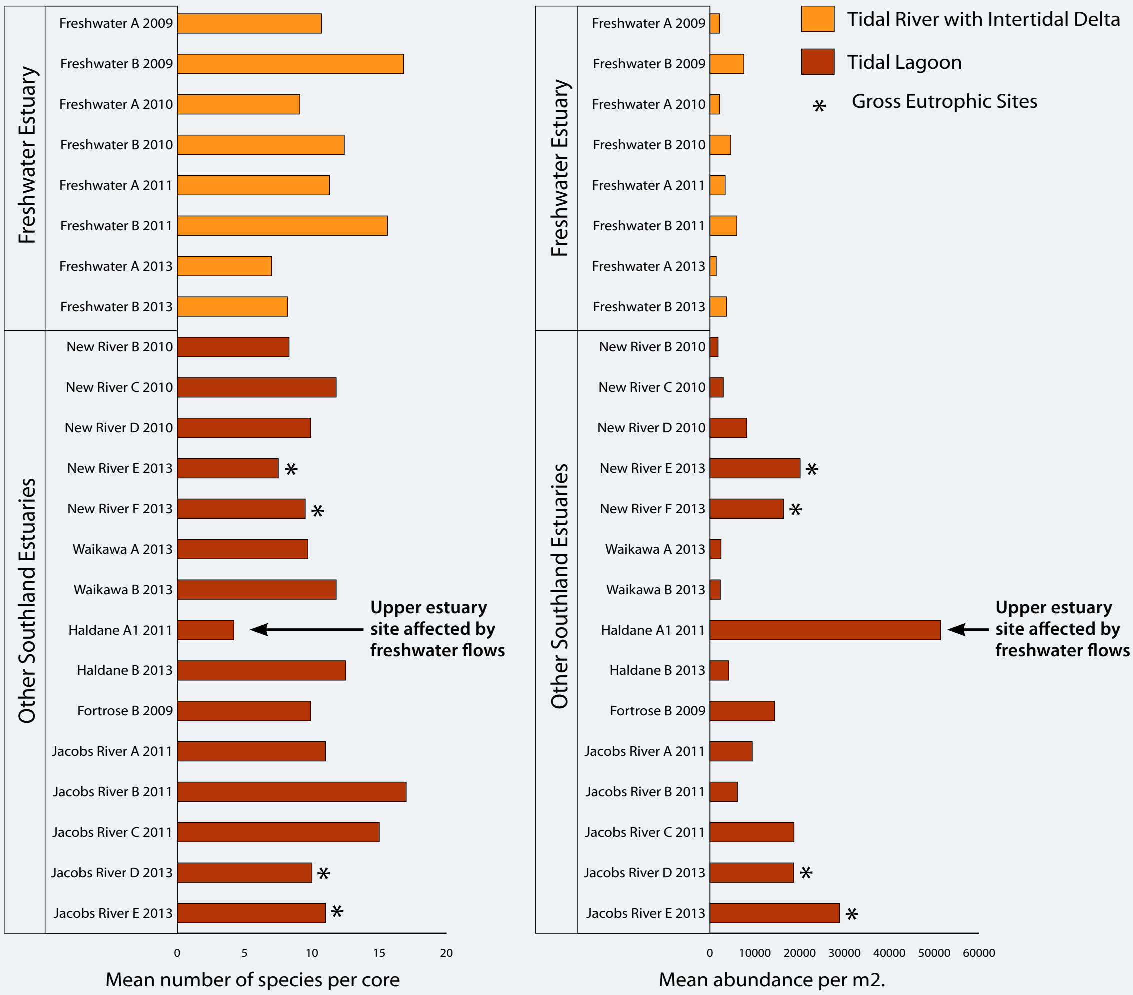


Figure 2. Mean number of species per core and mean abundance per m² in Freshwater Estuary 2009-2013, compared with other Southland estuaries.

3. Results and Discussion (Continued)

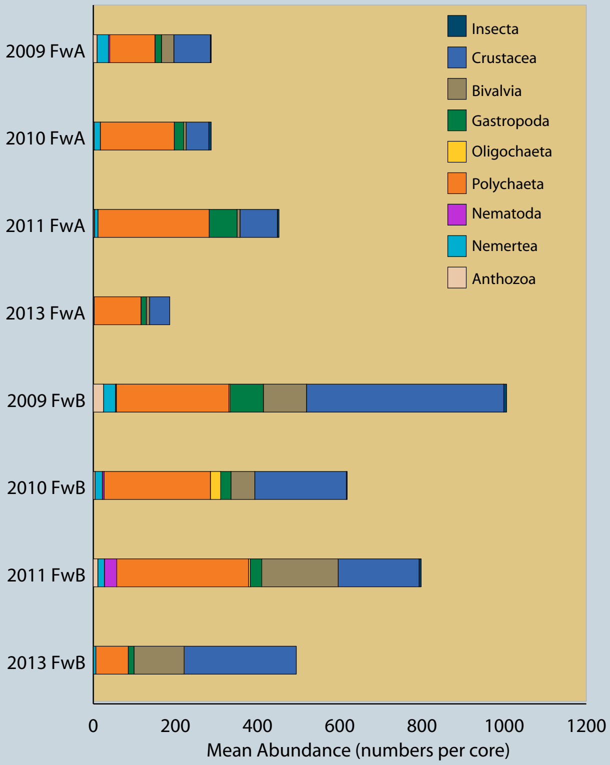


Figure 3. Mean abundance of major infauna groups, Freshwater Estuary, 2009-2013.

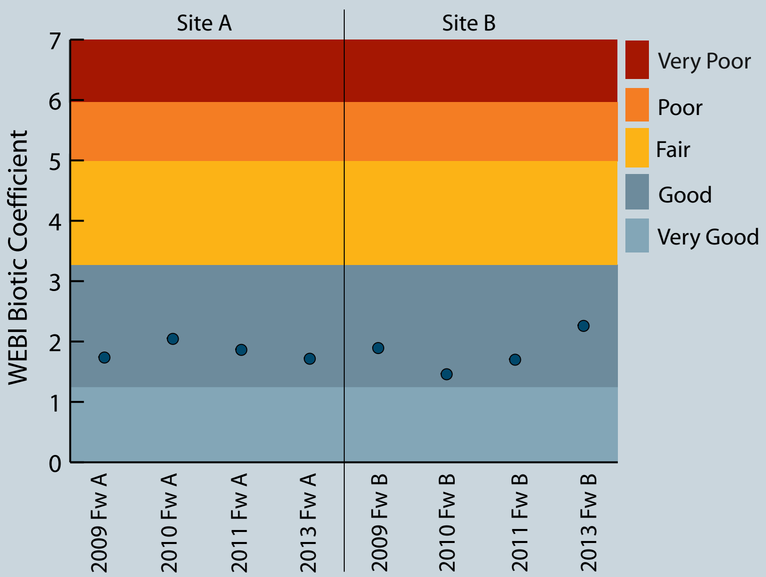


Figure 4. WEBI mud and organic enrichment macro-invertebrate rating, Freshwater Estuary, 2009-2013.

In 2013 at Site A, the macro-invertebrate community was dominated by polychaetes and crustaceans with moderate numbers of gastropods present (Figure 3). At Site B, the dominant groups in the community were crustaceans, bivalves and polychaetes with a small number of gastropods present. There was a 28% reduction in the number of polychaetes at this site compared with previous years, however, this is likely to be the result of natural fluctuations. The elevated numbers of bivalves at Site B was likely related to the higher tidal currents at this site favouring filter feeders.

WEBI Mud and Organic Enrichment Index

The benthic invertebrate mud and organic enrichment tolerance rating (using the recently revised approach for NZ estuaries - see section on condition ratings) for Freshwater Estuary (Sites A and B) from 2009 to 2013 ranged from 1.5 to 2.3 (Figure 4) and were all in the "good" category. The ratings reflect the moderately productive but unmodified condition of the estuary, with a dominance of species that prefer low levels of mud or organic enrichment. This supports the premise that the macro-invertebrate communities at these sites were in a healthy state and that there was little degradation of the community being caused by mud and organic matter. Over time, the undisturbed reference sites at Freshwater Estuary will enable a better understanding of the key drivers of community change in NZ estuary systems, and the thresholds at which significant shifts occur.

Multivariate Analysis

Multivariate techniques were also used to explore the difference between the macro-invertebrate communities at the two Freshwater Estuary sampling sites. Figure 5 (NMDS Plot) shows sites A and B, while very similar, are distinct, while there has a small change in the community at both sites is evident in 2013 compared to the 2009-2011 period.

Overall, the results of the macro-invertebrate analysis indicate that the communities at the two sites in Freshwater Estuary were in good condition and typical of those expected for estuaries with very low mud content and low nutrient enrichment.

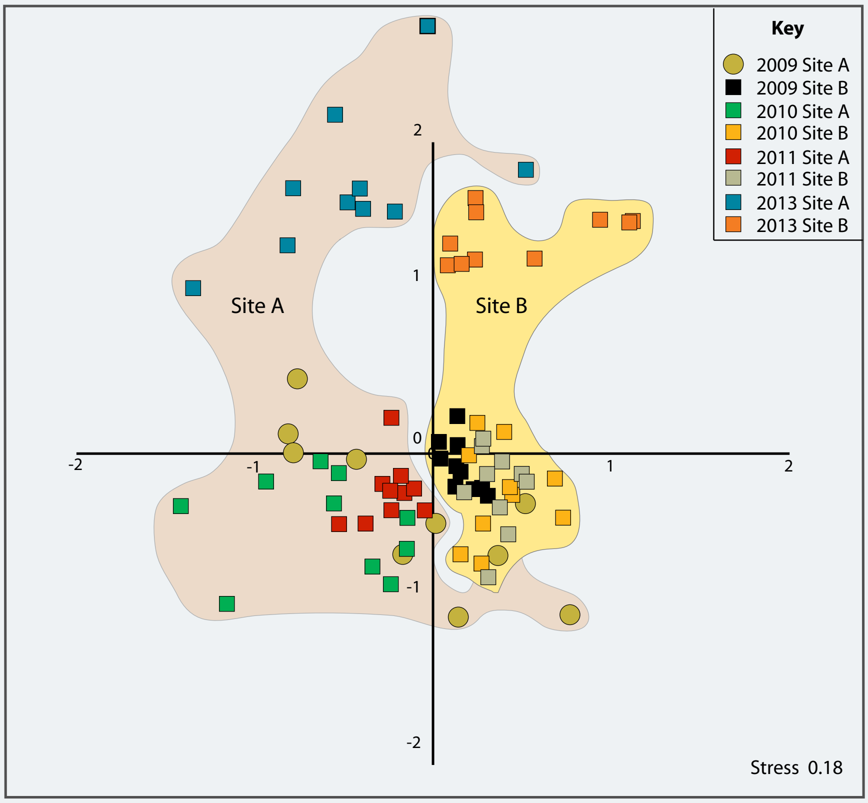


Figure 5. NMDS plot showing the relationship among samples in terms of similarity in macro-invertebrate community composition at Sites A and B for the four years of sampling. The plot shows each of the 10 replicate samples for each year and is based on Bray Curtis dissimilarity and square root transformed data.

The approach involves multivariate data analysis methods, in this case nonmetric multidimensional scaling (NMDS) using PRIMER vers. 6.1.10. The analysis basically plots the site 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)

PRIMARY ENVIRONMENTAL VARIABLES

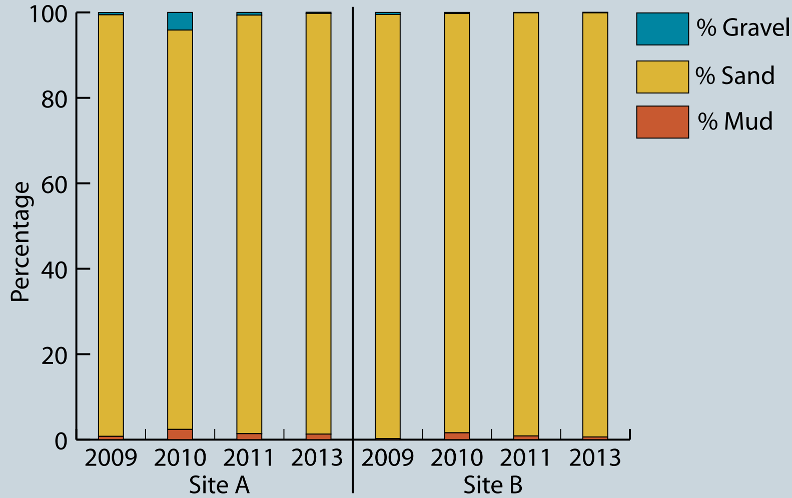


Figure 6. Grain size (means), 2009-2013, Freshwater Estuary.

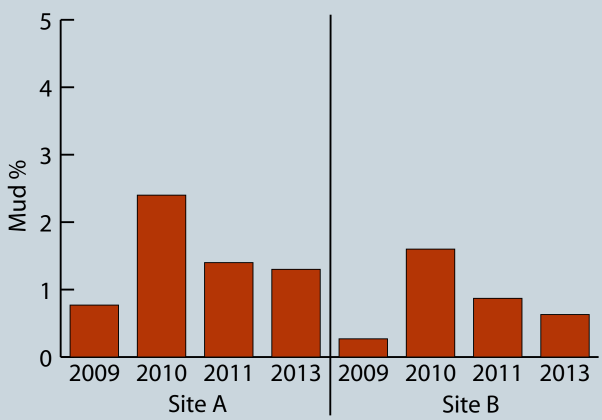


Figure 7. Percentage mud (means), 2009-2013, Freshwater Estuary.

The next step is to explore the primary environmental variables that are most likely to be driving the macrobenthic response in relation to the key issues of sedimentation, eutrophication, and toxicity.

The primary variables are related to sediment ***muddiness*** - in particular sediment grain size (often the primary controlling factor) and sedimentation rate; and ***eutrophication***, commonly assessed by sediment RPD depth (a measure of both available oxygen and the presence of eutrophication related toxicants such as ammonia and sulphide), organic matter (measured as TOC), and nutrients (Dauer et al. 2000, Magni et al. 2009). The influence of non-eutrophication related ***toxicity*** is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs assessed where inputs are likely, or metal concentrations are found to be elevated.

SEDIMENT INDICATORS

Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments, unless in naturally erosion-prone catchments with few wetland filters, generally have a very low mud content (e.g. ~1% mud at Freshwater Estuary, Stewart Island). In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >30% mud). Fine sediment is not spread evenly throughout an estuary, with mud commonly accumulating where salinity driven flocculation occurs, or in areas experiencing low energy tidal currents and waves i.e. upper estuary intertidal margins and deeper subtidal basins. Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud) due to resuspension and export of fine sediments.

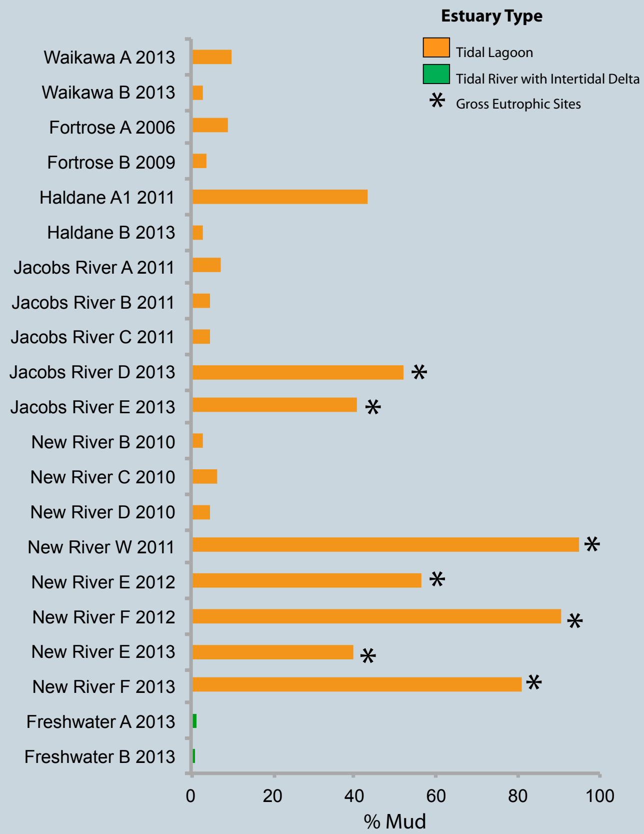


Figure 8. Percentage of mud at fine scale sites in Southland estuaries.

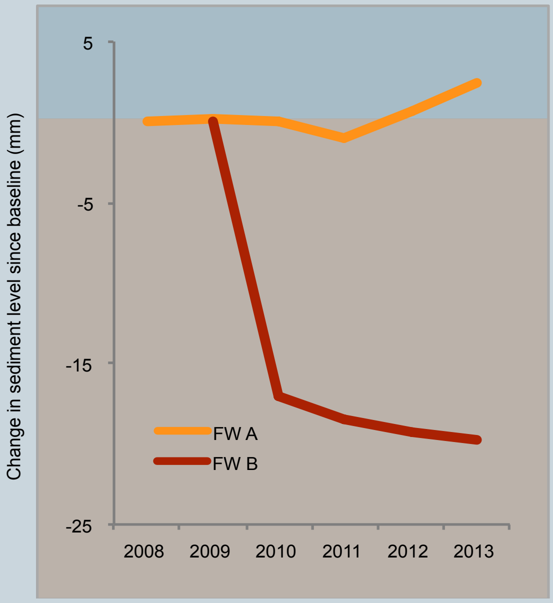


Figure 9. Change in sediment levels over buried plates at Freshwater Estuary 2008-2013.

The grain size results (Figure 6) show that both sites were dominated by sandy sediments in all four years of baseline monitoring. In 2013, the sediment mud content was very low (1.3% mud at Site A and 0.6% at Site B), a condition rating of "very good". The results also showed that there was only slight variation in the mud content over the 2009-2013 period at both sites (Figure 7).

Given the catchment is undeveloped, contains extensive, filtering, wetland areas, and is protected within a National Park, low sediment yields are expected which is reflected in the low mud content in the estuary sediments. The mud content at Freshwater Estuary was very low in comparison to fine scale sites in other Southland estuaries (Figure 8), .

Sedimentation Rate

Monitoring of changes in the depth of sediment overlying buried plates indicated a mean sedimentation rate of 0.5 mm/yr at Site A and -4.9mm/yr at Site B (Figure 9, Table 4), a condition rating of "very low".

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

The variability evident in the sedimentation rate measures at the Freshwater sites, particularly at Site B, is attributed to localised flood and wind disturbances in this dynamic estuary. Because the period of measurement is still very short (4-5 years), such changes are expected to average out over time and need to be considered in conjunction with the sediment grain size results when assessing the significance of changes.

Table 4. Sedimentation rate monitoring results, Freshwater Estuary, 2008-2013.

SITE	Overall Rate (mm/yr)	SEDIMENTATION RATE CONDITION RATING
Site A (2008-2013)	0.5	VERY LOW
Site B (2009-2013)	-4.9	VERY LOW

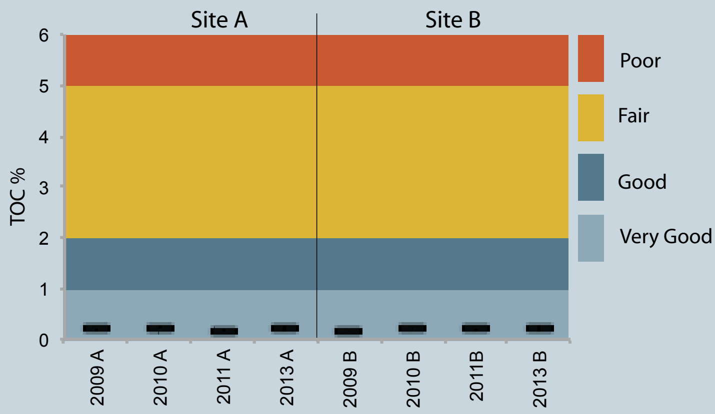


Figure 10. Total organic carbon (mean and range), Freshwater Estuary.

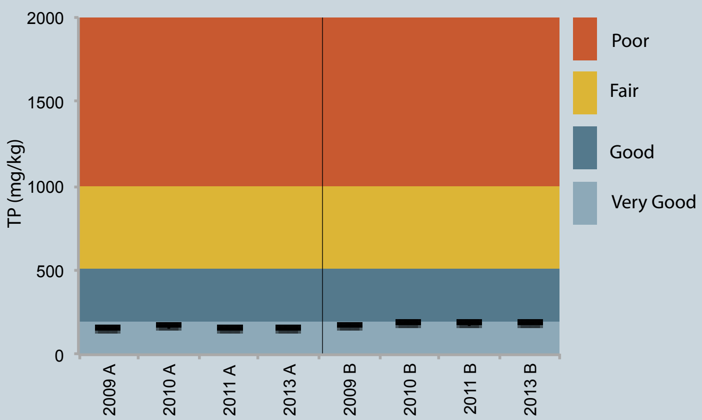


Figure 11. Total phosphorus (mean and range), Freshwater Estuary.

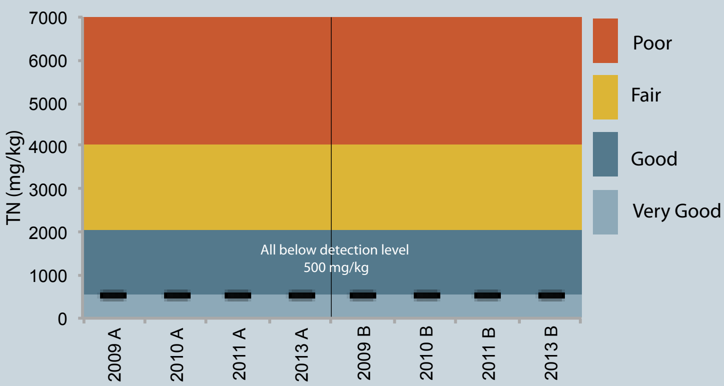


Figure 12. Total nitrogen (mean and range), Freshwater Estuary.

EUTROPHICATION INDICATORS

The primary variables indicating eutrophication impacts are grain size, RPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal cover.

Grain Size

This indicator has been discussed in the sediment section and is not repeated here. However, in relation to eutrophication, the very low mud content indicates upper sediment oxygenation is likely to be good, and sediment bound nutrients and metals, that are most strongly associated with fine sediments, are likely to be low.

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the degree of sediment oxygenation. The 2013 results, like in previous years, fit the "good" condition rating with oxygenated sediments extending from 1cm to 5-10cm (Table 3, Appendix 2, Figure 13). Although sediments commonly had patches of darker sediments near the surface, indicating lower oxygen and the presence of sulphides, this reflects the location of the sites within seagrass beds (the dominant habitat within the estuary) and does not indicate degraded conditions. Because seagrasses require oxygen to grow, they have adapted efficient strategies to transport oxygen to, and release oxygen from their roots, which both provides a source of oxygen to the surrounding sediment and shields plants against harmful toxins such as sulphides (Larkum et al. 1989).

As a consequence, sediments remain oxygenated while organic matter is naturally broken down and processed by the macro-invertebrate community present, evident in the extensive infauna feeding voids and burrows below the darker surface RPD layers.

Total Organic Carbon and Nutrients

The concentrations of sediment nutrients (total nitrogen - TN and phosphorus - TP) and organic matter (total organic carbon - TOC) provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow RPD, excessive algal growth, high WEBI biotic coefficient), then TN, TP and TOC concentrations provide a good indication of loadings exceeding the assimilative capacity of the estuary.

3. Results and Discussion (Continued)

Figure 13. Variable sediment RPD evident within seagrass at Site B, Feb. 2013.

The 2009-2013 results showed TOC, TP and TN concentrations at both sites were very low (Figures 10-12), fitting condition ratings of "very good". Although low TOC, TN, or TP concentrations do not directly indicate an absence of eutrophication symptoms (e.g. excessive algal growths may have exhausted the available nutrient supply when eutrophic conditions exist), in a situation like Freshwater when there are no significant anthropogenic inputs of nutrients present, it provides a very strong indication that the estuary is not suffering from excessive enrichment.

The results 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. For example, much of the upper intertidal seagrass flats on the southern side of the estuary were covered by the seaweed Neptune's necklace (*Hormosira banksii*) when sampled in February 2013 (see photo below). Although much of this marine sourced seaweed is likely to have refloated and been washed from the estuary, it is nevertheless likely to be an occasional, but important, source of nutrients and organic matter.

Neptune's necklace deposited on intertidal seagrass flats, Feb. 2013.

Macroalgal Cover

Although the fine scale sites themselves had little macroalgal growth in 2013 and the estuary is in a low-moderate (good) trophic state, Freshwater Estuary supports a relatively high cover of non-nuisance macroalgae (Stevens and Robertson 2008, 2013). This is dominated by *Gracilaria* and *Ulva* growing on hard substrate (shell or rock) on the intertidal flats (photo below left), with epiphytic growths of macroalgae also evident on the leaves of seagrass within the immediate vicinity of Freshwater River (photo below right).

In a national context it is of particular interest that the estuary remains pristine (i.e. low sediment organic matter, RPD, and nutrients) despite the presence of an extensive macroalgal cover. Identifying the source of nutrients supporting such growth, and the processes that maintain Freshwater Estuary in such good condition, would provide valuable information for NZ estuary management in the future.

Growths of non-nuisance macroalgae present on the lower intertidal sandflats in Freshwater Estuary.

Epiphytic macroalgal growths on seagrass near Freshwater River.

TOXICITY

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were all at very low concentrations in 2013 with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 14). As in previous years, all metals met the "very good" condition rating, with concentrations well below criteria that cause stress to macrobenthos indicating that there is no widespread metal toxicity in Freshwater Estuary.

In addition, well oxygenated, low sulphide sediment conditions indicate toxicity effects related to elevated levels of sediment ammonia or sulphide are highly unlikely to exist.

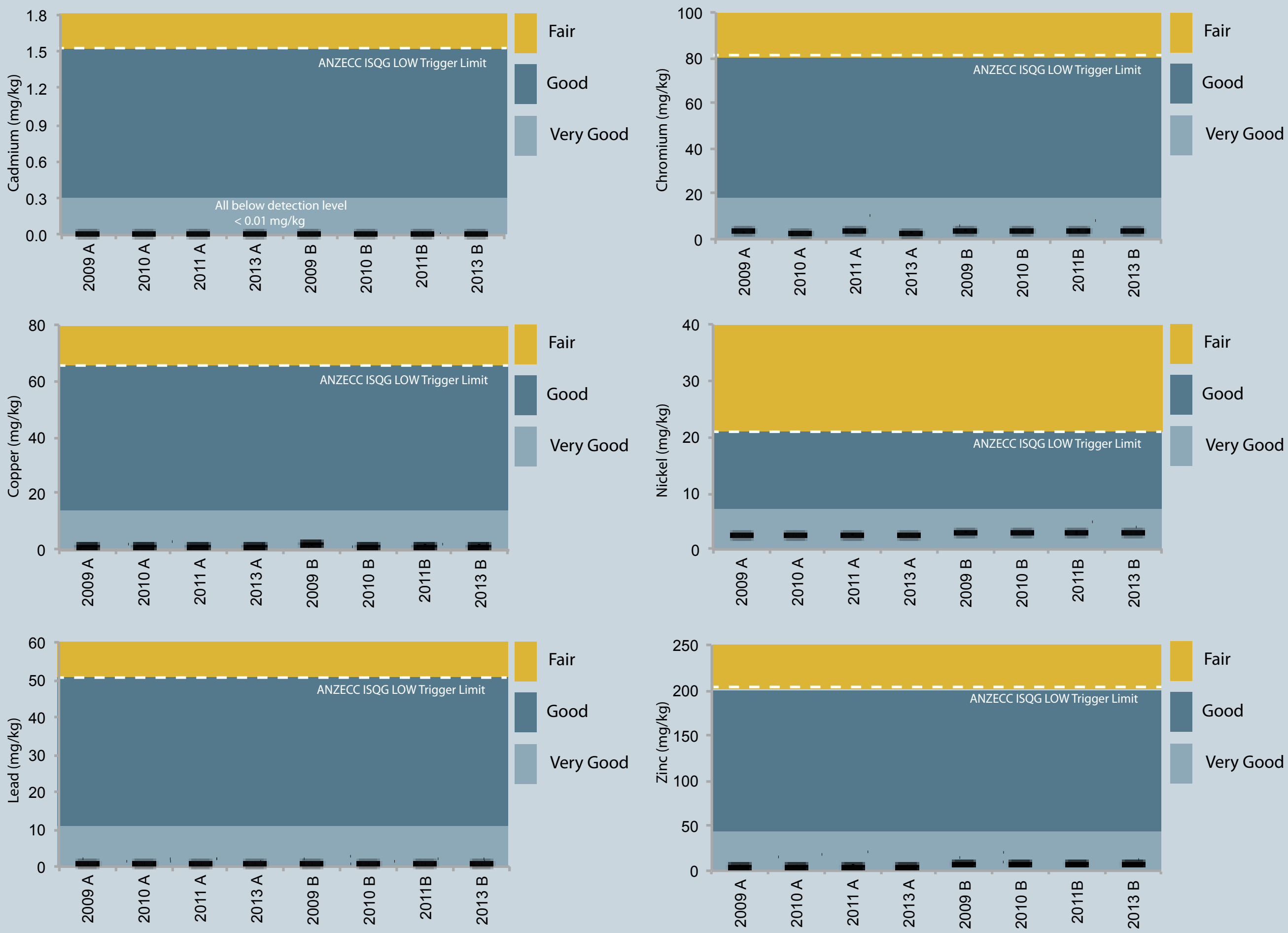
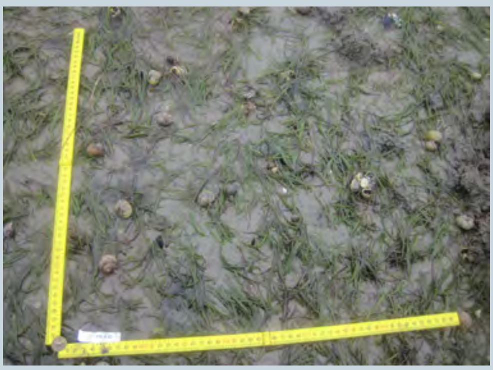


Figure 14. Sediment metal concentrations (mean and range), 2009-2013, Freshwater Estuary.



4. CONCLUSIONS

Results of the four years of baseline monitoring at two sites in Freshwater Estuary showed the estuary was in very good condition. The key findings were as follows:

- Sites, representative of the wider estuary, were dominated by sandy sediments with very low mud content.
- RPD depth (1-10cm), while variable due to seagrass presence, indicated well-oxygenated sediments.
- Concentrations of sediment organic carbon (TOC), and nutrients (TP and TN) were very low.
- The benthic invertebrate community was characterised by species that prefer sediments with low mud content and low organic enrichment (WEBI rating "good").
- Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations (i.e. low metal toxicity).

These results, in combination with the 2013 broad scale habitat mapping results (Stevens and Robertson 2013), i.e. very high seagrass cover, low incidence of muddy sediments, absence of widespread nuisance macroalgal impacts, confirm the pristine state of this moderately productive reference estuary. The estuary's good condition, relatively unchanged since at least 2009, is attributed to the very low inputs of fine sediments, nutrients and toxicants from the estuary's undeveloped native forest catchment.

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 2013 monitoring results and condition ratings, and trends following completion of the 4 year baseline (2009-2013), it is recommended that monitoring continue as outlined below:

- Repeat fine scale monitoring at 5 yearly intervals (next scheduled for February 2018).
- Continue the existing programme of sedimentation rate measurements five yearly, or annually if the estuary is being monitored for other reasons.
- Undertake broad scale habitat mapping (including macroalgal cover) five yearly (next scheduled for 2018).

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.

However, because the estuary is moderately productive (evident in the extensive macroalgal cover), yet continues to remain in good condition (i.e. low sediment organic matter, RPD, and nutrients), identifying the processes that maintain Freshwater Estuary in such good condition would provide valuable information for New Zealand estuary management in the future.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

ANZECC, 2000. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

Borja, A., Franco, J., Perez, V. 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar. Poll. Bull. 40, 1100–1114.

Dauer, D.M., Ranasinghe, J.A., Weisberg, S.B. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. Estuaries Vol. 23, No. 1, 80-96.

Hyland J., Balthis L., Karakassis I. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Marine Ecology Progress Series, 295, 91–103.

Jørgensen, N. and Revsbech, N.P. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. Limnology and Oceanography 30:111-122.

Larkum, A.W.D., Roberts G., Kuo, J., Strother, S. 1989. Gaseous movements in seagrasses, p. 686–722. In A.W.D. Larkum, A.J. McComb, and S.A. Shepherd [eds.], Biology of seagrasses. Elsevier.

Lohrer, A.M. Thrush, S.F. and Gibbs, M.M. 2004. Bioturbators enhance ecosystem function through complex biogeochemical interactions. Nature 431:1092–95.

Magni P., Tagliapietra D., Lardicci C. 2009. Animal-sediment relationships: evaluating the "Pearson-Rosenberg paradigm" in Mediterranean coastal lagoons. Marine Pollution Bulletin, 58, 478–86.

Norkko, A., Talman, S., Ellis, J., Nicholls, P. and Thrush, S. 2001. Macrofaunal sensitivity to fine sediments in the Whitford embayment. NIWA client report ARC01266/2, prepared for Auckland Regional Council, June 2001.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review 16, 229–311.

Robertson, B.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., ThompsonS.J., Tuckey, B.J. 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

Robertson, B.M. and Stevens, L. 2006. Southland Estuaries State of Environment Report 2001-2006. Prepared for Environment Southland.

Robertson, B.M. and Stevens, L.M. 2008. Southland Coast - Te Waewae Bay to the Catlins, habitat mapping, risk assessment and monitoring recommendations. Report prepared for Environment Southland. 165p.

Robertson, B.M. and Stevens, L.M. 2009. Freshwater Estuary Fine Scale Monitoring 2008/09. Report prepared by Wriggle Coastal Management for Environment Southland. 24p.

Robertson, B.M. and Stevens, L.M. 2010. Freshwater Estuary Fine Scale Monitoring 2009/10. Report prepared by Wriggle Coastal Management for Environment Southland. 32p.

Robertson, B.M. and Stevens, L.M. 2011. Freshwater Estuary Fine Scale Monitoring 2010/11. Report prepared by Wriggle Coastal Management for Environment Southland. 33p.

Robertson, B.P. 2013 (In press). Determining the sensitivity of macro-invertebrates to fine sediments in representative New Zealand estuaries. Honours thesis, University of Victoria, Wellington.

Stevens, L.M. and Robertson, B.M. 2008. Freshwater Estuary. Broad Scale Habitat Mapping 2007/08. Report prepared by Wriggle Coastal Management for Environment Southland. 24p.

Stevens, L.M. and Robertson, B.M. 2013 (In Press). Freshwater Estuary. Broad Scale Habitat Mapping 2012/13. Report being prepared by Wriggle Coastal Management for Environment Southland.

Thrush, S.F., Hewitt, J.E., Gibb, M., Lundquist, C., Norkko, A. 2006. Functional role of large organisms in intertidal communities: Community effects and ecosystem function. Ecosystems 9: 1029-1040.

APPENDIX 1. ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMEC	Coastal Marine Ecology Consultants (Gary Stephenson). *	N/A
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g/100g dry wgt
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.

Station Locations

Freshwater A 2013	1	2	3	4	5	6	7	8	9	10
NZMG EAST	1217519	1217502	1217488	1217476	1217469	1217515	1217513	1217491	1217476	1217471
NZMG NORTH	4793036	4793041	4793049	4793053	4793043	4793025	4793012	4793023	4793027	4793031
Freshwater B 2013	1	2	3	4	5	6	7	8	9	10
NZMG EAST	1213305	1213376	1213394	1213403	1213409	1213399	1213387	1213371	1213382	1213398
NZMG NORTH	4793247	4793233	4793222	4793217	4793220	4793229	4793239	4793251	4793260	4793249

APPENDIX 2. 2013 DETAILED RESULTS

Physical and Chemical Results for Freshwater Estuary (Sites A and B), 16 February 2013

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg							
Freshwater A	1-4	1-10v	32	0.21	1.3	98.4	0.3	< 0.01	2.5	1.3	2.5	0.57	5.5	<500	152
Freshwater A	5-8	1-10v	32	0.29	1.3	98.5	0.2	< 0.01	3	1.2	2.6	0.56	5.8	<500	153
Freshwater A	9-10	1-10v	32	0.18	1.3	98.5	0.3	< 0.01	2.8	1.3	2.5	0.6	5.8	<500	161
Freshwater B	1-4	1-5v	32	0.23	0.6	99.3	< 0.1	< 0.01	3.7	1.7	3.1	0.78	7.6	<500	188
Freshwater B	5-8	1-5v	32	0.17	0.7	99.1	0.2	0.01	3.6	1.5	3.1	0.74	7.3	<500	189
Freshwater B	9-10	1-5v	32	0.27	0.6	99.4	< 0.1	< 0.01	3.3	1.6	3.1	0.68	7.3	<500	190

* composite samples
v = variable

Percentage Cover of Macrophytes for Freshwater Estuary (Sites A and B), 16 February 2013.

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	80-100	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 (seagrass) % cover	50-80	20-50	50-80	10-20	80-100	80-100	10-20	80-100	20-50	10-20

Epifauna (numbers per 0.25m² quadrat) 16 February 2013

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	3	12	9	7	12	5	13	12	9	3
Austrominius modestus Estuarine barnacle	23	60	75	10	15	30	70	50	15	35
Diloma subrostrata Mudflat topshell	1		1			2				
Mytilus galloprovincalis Blue mussel	1	1	1			1	2	3	1	3
Paphies australis Pipi										
No. species/quadrat	4	3	4	2	2	4	3	3	3	3
No. individuals/quadrat	28	73	86	17	27	38	85	65	25	41

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		3			1					2
Austrominius modestus Estuarine barnacle		20		20		50				
Austrovenus stutchburyi Cockle		1			1	2			1	
Cellana strigilus redmiculum					1					
Diloma subrostrata Mudflat topshell				1	4		5			
Mytilus galloprovincalis Blue mussel						17				
Notoacmea helmsi					1					
Paphies australis Pipi										
Xenostrobus pulex Black mussel										
No. species/quadrat	0	3	0	2	5	3	1	0	1	1
No. individuals/quadrat	0	24	0	21	8	69	5	0	1	2

Sedimentation rate monitoring results, Freshwater Estuary, February 2008 - February 2013.

	Sediment Depth (mm)					Change (mm)				Site Mean (mm/yr)				Overall Rate (mm/yr)	SEDIMENTATION RATE CONDITION RATING
SITE	10 Apr 2008	27 Feb 2009	14 Feb 2010	12 Feb 2011	16 Feb 2013	2008-2009	2009-2010	2010-2011	2011-2013	2008-2009	2009-2010	2010-2011	2011-2013	2008-2013	
Site A (west)	235	240	236	235	233	5	-4	-1	-2	0.3	-0.3	-1.0	3.5	0.5	VERY LOW
	250	244	245	247	250	-6	1	2	3						
	286	281	284	285	285	-5	3	1	0						
	278	285	284	278	291	7	-1	-6	13						
Site B (east)	-	125	115	118	134	-	-10	3	16	-	-17.0	-1.5	-1.3	-4.9	VERY LOW
	-	127	119	116	105	-	-8	-3	-11						
	-	144	116	110	106	-	-28	-6	-4						
	-	162	140	140	134	-	-22	0	-6						

Appendix 2. 2013 Detailed Results (continued)

Infauna (numbers per 0.01327m² core) **(Note NA = Not Assigned)**

Freshwater Estuary Site A 16 February 2013

Group	Species	WEBI GROUP	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	2										
NEMERTEA	Nemertea sp.#1	3								1		1
	Nemertea sp.#2	3										
POLYCHAETA	*Aonides* sp.#1	1			1	5	6	3	19	13	10	
	Neanthes sp.#1	3	1	3	1		2	1	5	1	4	1
	Orbinia papillosa	1					2	1		1	1	
	Pectinaria australis	3		1						1		
	Prionospio aucklandica	2	2				5	5	8	7	3	
	Scoloplos cylindrifer	1					1					
GASTROPODA	*Amphibola crenata*	3					1	1	2		1	
	Cominella glandiformis	3	1									
	Diloma subrostrata	2					1				1	
	Notoacmaea helmsi	2					1		2	2		
BIVALVIA	*Arthritica* sp.#1	4		1				1				
	Austrovenus stutchburyi	2										
	Cyclomactra ovata	2										
	Mytilus galloprovincialis	NA	2									
	Paphies australis	2		2			1					1
	Perrierina turneri	1										
CRUSTACEA	*Amphipoda* sp.#1	4										6
	Amphipoda sp.#2	4						2		1		
	Amphipoda sp.#4	2	1	3	1		3	11		4	3	
	Austrominius modestus	2										
	Corophium sp.#1	NA										1
	Halicarcinus varius	3	1		1			1				
	Halicarcinus whitei	3	1		1	2	1					
	Macrophthalmus hirtipes	5		1			1			1		
	Paravireia pistus	NA										
	Phoxocephalidae sp.#1	2			1						1	
Total individuals in sample			**9**	**11**	**6**	**7**	**25**	**26**	**36**	**32**	**24**	**10**
Total species in sample			**7**	**6**	**6**	**2**	**12**	**9**	**5**	**10**	**8**	**5**

Appendix 2. 2013 Detailed Results (continued)

Infauna (numbers per 0.01327m² core) **(Note NA = Not Assigned)**

Freshwater Estuary Site B 16 February 2013												
Group	**Species**	WEBI GROUP	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	2										
NEMERTEA	Nemertea sp.#1	3										1
	Nemertea sp.#2	3		1		1	1		1			
POLYCHAETA	*Aonides* sp.#1	1		1								
	Neanthes sp.#1	3		5	5	16	7	4	7			3
	Orbinia papillosa	1						4				
	Pectinaria australis	3										
	Prionospio aucklandica	2										
	Scoloplos cylindrifer	1		9	8	5		1	2			
GASTROPODA	*Amphibola crenata*	3						3				
	Cominella glandiformis	3										
	Diloma subrostrata	2					2					
	Notoacmaea helmsi	2		1		1	3	4				
BIVALVIA	*Arthritica* sp.#1	4					1	1				1
	Austrovenus stutchburyi	2								1		2
	Cyclomactra ovata	2	2	4		2	2	2	1	1	1	
	Mytilus galloprovincialis	NA							1			
	Paphies australis	2		1				4				
	Perrierina turneri	1	21	6	9	5	6	2	5	16	22	6
CRUSTACEA	*Amphipoda* sp.#1	4	6	22	26	15	21	1	10	1	43	8
	Amphipoda sp.#2	4		12	3	2		4	2			
	Amphipoda sp.#4	2										
	Austrominius modestus	2	3	29	4	11	9	5	1			15
	Corophium sp.#1	NA						12				
	Halicarcinus varius	3										
	Halicarcinus whitei	3										
	Macrophthalmus hirtipes	5		1			1			1	1	
	Paravireia pistus	NA										
	Phoxocephalidae sp.#1	2	1									
Total individuals in sample			**33**	**92**	**55**	**58**	**55**	**47**	**30**	**20**	**68**	**36**
Total species in sample			**5**	**12**	**6**	**9**	**11**	**13**	**9**	**5**	**5**	**7**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		WEBI Group *	Details
Anthozoa	*Edwardsia* sp.#1	2	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	3	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp.	1	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.	1	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 syrtis	2	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 in unenriched conditions.
	Capitellidae	4	Subsurface deposit feeder, occurs down to about 10cm sediment depth. Common indicator of organic enrichment. Bio-turbator. Prey for fish and birds.
	Dorvilleidae sp.	2	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	3	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.
	Hesionidae sp.#1	1	Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The New Zealand species are little known.
	Heteromastus filiformis	3	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.
	Neanthes sp #1	3	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. Sensitive to large increases in sedimentation.
	Nicon aestuariensis	3	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	1	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.

Appendix 3. Infauna Characteristics (Continued)

Group	Species	WEBI Group *	Details
Polychaeta	Paraonidae	3	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*	3	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	Phyllodocidae	2	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*	2	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).
Polychaeta	*Scolecolepides benhami*	4	A surface deposit feeding spionid. It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. 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.
Polychaeta	*Scoloplos cylindrifer*	1	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.
Polychaeta	Syllidae	3	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	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Gastropoda	*Amphibola crenata*	3	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.

Appendix 3. Infauna Characteristics (Continued)

Group and Species		WEBI Group *	Details
Gastropoda	*Cominella glandi-formis*	3	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.
	Diloma subrostrata	2	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.
	Notoacmaea helmsi	2	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Has a strong sand preference.
	Potamopyrgus estuarinus	3	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	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
	Austrovenus stutchburyi	2	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 macro-invertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).
	Cyclomactra ovata	2	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water.
	Macomona liliana	2	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.
	Mytilus gallopro-vincialis	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	Species	WEBI Group *	Details
Bivalvia	*Paphies australis*	2	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. Common at mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud.
Bivalvia	*Perrierina turneri*	1	A small bivalve - relatively uncommon.
Crustacea	*Amphipoda* sp. 1	4	An unidentified amphipod.
Crustacea	*Amphipoda* sp. 2	4	An unidentified amphipod.
Crustacea	*Amphipoda* sp. 3	2	An unidentified amphipod.
Crustacea	*Austrominius modestus*	2	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.
Crustacea	*Colurostylis* sp.#1	1	A cumacean that prefers sandy environments. 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.
Crustacea	*Corophium* sp.	NA	A species of amphipod in the Family Corophiidae.
Crustacea	*Halicarcinus varius*	3	Pillbox crabs are usually found on the sand and mudflats but may also be encountered under stones on the rocky shore. *Halicarcinus varius* (10mm) has a pear-shaped carapace, its upper half covered in small hairs. Males have hairy nippers. Its colour varies from white/green to yellow, found in sheltered areas on brown seaweeds or under stones.
Crustacea	*Halicarcinus whitei*	3	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
Crustacea	*Helice crassa*	5	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
Crustacea	*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.
Crustacea	Isopoda Valvifera	NA	A species of isopod in the Suborder Valvifera.
Crustacea	*Macrophthalmus hirtipes*	5	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
Crustacea	*Paracorophium excavatum*	4	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 and has a very strong mud preference. Often present in estuaries with regular low salinity conditions. Very few present in muddy, high salinity sites like Whareama Estuary.

Appendix 3. Infauna Characteristics (Continued)

Group	Species	WEBI Group *	Details
Crustacea	*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).
Crustacea	Phoxocephalidae	2	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
Crustacea	Tanaidacea sp.	1	Small, mostly marine-dwelling crustaceans that are diverse and abundant in some marine environments.
Crustacea	*Waitangi* sp.	2	An amphipod of the Phoxocephalidae Family with a strong sand preference.
Insecta	Chironomidae larvae	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.

* Wriggle Estuary Biotic Index (WEBI).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.