Wriggle coastalmanagement

Jacobs River Estuary

Intertidal Fine Scale Monitoring 2010/2011

Prepared for Environment Southland
July 2011

Cover Photo: Whitebait Stand - Aparima Arm, Jacobs River Estuary.

Aparima Arm - Jacobs River Estuary.

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By

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JACOBS RIVER ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the baseline 2003-2006 and the 2011 fine scale monitoring of three intertidal sites within Jacobs River Estuary, a medium-sized (720ha) tidal lagoon estuary near Riverton. It also includes results of the annual broad scale macroalgal and sediment rate monitoring in order to provide a clearer understanding of overall estuary condition. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. In summary the findings were as follows;

FINE SCALE RESULTS

- **Sedimentation.** Although sand dominates the fine scale sites, they have varying levels of mud content. Some invertebrate species intolerant of mud have been lost. There is evidence of increased muddiness at the sites since 2003.
- **Eutrophication**. In general, the sediments at the three fine scale sites showed a very shallow RPD depth (<1cm) but because of the predominance of sand and the relatively well flushed locations of these sites, levels of oxygenation were sufficient to maintain a moderately well-balanced invertebrate community and low organic carbon and nutrient concentrations (low-fair condition ratings).
- **Toxicity.** Heavy metals were well below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity) at all sites, reflecting the absence of significant sources of toxicants in the catchment.

ESTUARY CONDITION AND ISSUES

The 2011 fine scale monitoring of unvegetated, lower intertidal sandflats in Jacobs River Estuary indicates low accumulations of organic matter and nutrients, sediments and heavy metals in the sediments of the three fine scale sites. The level of sediment oxygenation, as indicated by the RPD depth, was relatively poor, but was not so degraded that the upper sediment surface was black and anoxic. The macro-invertebrate community at each of the sites was indicative of low-moderate levels of eutrophication and sedimentation.

However, the results of the broad scale monitoring (2003, 2007-2011) indicates major problems. Annual macroalgal monitoring shows that the estuary has significant eutrophication and sedimentation problems, that are not reflected in the fine scale monitoring results (see summary of ratings below).

	2003	2007	2008	2009	2010	2011
Macroalgal Rating	Good	Fair	Poor	Poor	Poor	Poor
Soft Mud Rating	Poor	Not Measured	Poor	Not Measured	Not Measured	Not Measured

This broad scale monitoring shows gross nuisance conditions have been occurring since at least 2008 and now occupy 25% of the estuary (compared with 4% in 2007 and <4% in 2003). Such information provides clear evidence that the condition of the Jacobs River Estuary has deteriorated in the last 10 years. This deterioration was clearly presented in the 2009 annual monitoring report and included management recommendations for catchment nutrient load reductions.

The presence of large "highly eutrophic" zones in the estuary, that are currently not addressed in the fine scale monitoring programme, indicate that the fine scale programme should be expanded to include at least two of these areas. Fine scale monitoring at such sites would provide additional information to help make effective management decisions and determine the effectiveness of any actions taken.

RECOMMENDED MONITORING AND MANAGEMENT

In order to assess ongoing trends in the fine scale condition of the estuary it is recommended that two more fine scale monitoring sites be included in vulnerable poorly flushed areas in the estuary. The two new sites should be monitored in February 2012 and again in February 2015 when the 5 yearly fine scale trend monitoring at three existing sites falls due. Macroalgal mapping and sedimentation rate should continue to be monitored annually until conditions improve.

To rectify eutrophication and sedimentation problems and restore high value habitat, it is recommended that inputs of fine sediment and nutrients are reduced to levels that the estuary can assimilate. However, because of the complex nature of the estuary, effective management requires the following information: 1. Develop contaminant input budgets, 2. Characterise the condition of poorly flushed areas and the water column, 3. Identify the fate of contaminants.

1. INTRODUCTION

Jacobs River Estuary

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

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

Monitoring

Broad Scale Mapping
Sediment type
Saltmarsh
Seagrass
Macroalgae
Land margin

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

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

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

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

Other Information
Previous reports, Observations, Expert opinion

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

Recommended Management
- Identify/reduce sediment sources.
- Set nutrient, sediment guidelines.
- Margin vegetation enhancement.
- Manage for sea level rise.
- Enhance saltmarsh.
- Manage weeds and pests.

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

ES began monitoring Jacobs River Estuary in February 2003, with the work being undertaken by Cawthron Institute using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002).

The Jacobs River Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (Table 1) and appropriate monitoring design. A preliminary EVA has been completed for Jacobs River Estuary and is reported on in Robertson and Stevens (2008).
2. **Broad Scale Habitat Mapping** (EMP approach). This component, which documents the key habitats within the estuary, and changes to these habitats over time, was undertaken in 2003 (Robertson et al. 2003) and 2008 (Stevens and Robertson 2008).
3. **Fine Scale Monitoring** (EMP approach). Monitoring of physical, chemical and biological indicators (Table 2) including sedimentation plate monitoring. This component, which provides detailed information on the condition of the Jacobs River Estuary, has been undertaken in 2003, 2004, 2005, 2006 (Robertson and Stevens 2006) and 2011. The February 2011 monitoring is the subject of the current report.

Jacobs River Estuary is a medium-sized "tidal lagoon" type estuary (area 720ha), discharging to the sea at Riverton. Situated at the confluence of the Pourakino and Aparima Rivers, it drains a primarily agricultural catchment.

Estuary Type/Area	Tidal Lagoon, 720ha
Catchment	1527 km^2
Dairy cows	64,611 cows
Nitrogen loading	846 t/y
Catchment geology	Gravel, sandstone/siltstone, igneous
Saltmarsh (ha)	70 ha primarily jointed wire rush
Salinity	Well mixed, sea water dominated
Mean depth (m)	1-2m
Tidal flats	Extensive intertidal flats

This shallow estuary (mean depth ~2m) is bordered by a mix of vegetation and landuses (urban and grazed pasture) and has a mixture of well flushed and poorly flushed areas. The estuary has extensive mudflats, seagrass and saltmarsh areas. The township of Riverton, its fishing wharves and a road bridge are located near the mouth. Water quality is moderately degraded and nuisance blooms of macroalgae (*Enteromorpha* and *Gracilaria*) are common within the estuary with several very eutrophic arms. As a result of intensive landuse in the catchment, faecal contamination at the shellfish and bathing site within the estuary is one of the most degraded in Southland. From 1999-2010, there has been 100% breach of the national shellfish guidelines (ES Health Report: Water 2010).

Human use of the estuary is high and is used for walking, shellfish collecting, boating, fishing, duck shooting, bird watching, bathing, and white-baiting. Habitat diversity is moderate with tidal flats and saltmarsh providing conditions suitable for native fish, birdlife and tidal flat organisms. However, as a consequence of historical drainage, extensive weed growth and the grazing of margins, the estuary is expected to be more vulnerable to such issues as eutrophication. Therefore, it has been recommended that management actions be taken to improve the situation.

1. Introduction (Continued)

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

Major Estuary Issues	
Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there.
Disease Risk	Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time. When 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. See ES Water 2010:Our Health and Our Ecosystems- State of the Environment Reports
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to estuaries through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Loss	Estuaries have many different types of habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is commonplace with the major causes cited as sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff and wastewater discharges.

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

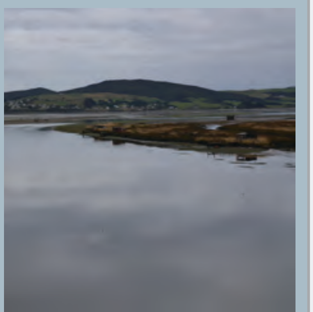
Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Sedimentation	Grain Size	Fine scale measurement of sediment type.
Eutrophication	Nuisance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

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

2. METHODS

FINE SCALE MONITORING

Quadrat for epifauna sampling.



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

For Jacobs River Estuary, three fine scale sampling sites (Figure 1, Appendix 1) were selected in unvegetated, mid-low water habitat of the dominant substrate type (avoiding areas of significant vegetation and channels). At each site, a 60m x 30m area in the lower intertidal was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and the following sampling undertaken:

Physical and chemical analyses

- Within each plot, one random core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average redox potential discontinuity (RPD) depth (i.e. depth to light grey/black anoxic layer) recorded.
- At each site, three samples (each a composite from four plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. All samples were kept in a chillybin in the field.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details in Appendix 3):
    - Grain size/Particle size distribution (% mud, sand, gravel).
    - Nutrients - total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC).
    - Trace metal contaminants (total recoverable Cd, Cr, Cu, Ni, Pb, Zn). Analyses were based on whole sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results are checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Epifauna (surface-dwelling animals)

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

Infauna (animals within sediments)

- One randomly placed sediment core was taken from each of ten plots using a 130mm diameter (area = 0.0133m^2) PVC tube.
- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled plastic bag.
- Once all replicates had been collected at a site, the plastic bags were transported to a nearby source of seawater and the contents of the core were washed through a 0.5mm nylon mesh bag. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.
- The samples were then transported to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).

2. Methods (Continued)

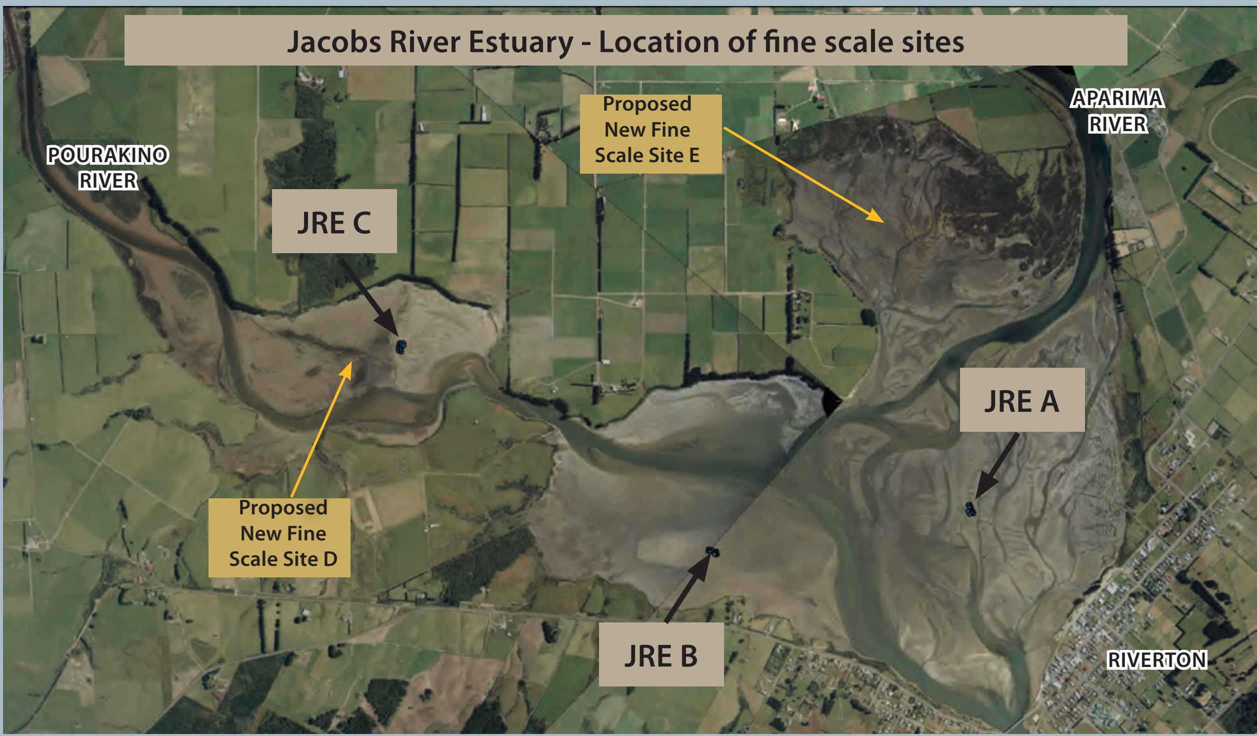


Figure 1. Location of sediment plates and fine scale monitoring sites in Jacobs River Estuary (PhotoLINZ).

Sedimentation Rate (Plate Deployment)

Sediment plates were deployed at 3 sites in Jacobs River Estuary in February 2011 (Figure 1 and Appendix 1). Determining the sedimentation rate from the present and into the future involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried, levelled, and the elevation measured, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. In the future, these depths will be measured every 1-5 years and, over the long term, will provide a measure of rate of sedimentation in representative parts of the estuary.

CONDITION RATINGS

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

Sedimentation Rate

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

SEDIMENTATION RATE CONDITION RATING

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

2. Methods (Continued)

Benthic Community Index (Mud Tolerance)

Soft sediment macrofauna can also be used to represent benthic community health in relation to the extent of mud tolerant organisms compared with those that prefer sands. Using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) a "mud tolerance" rating has been developed similar to the "organic enrichment" rating identified below.

The equation to calculate the Mud Tolerance Biotic Coefficient (MTBC) is a s follows;

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

The characteristics of the above-mentioned mud tolerance groups (SS, S, I, M and MM) are summarised in Appendix 2 and 3.

BENTHIC COMMUNITY MUD TOLERANCE RATING

MUD TOLERANCE RATING	DEFINITION	MTBC	RECOMMENDED RESPONSE
Very Low	Strong sand preference dominant	0-1.2	Monitor at 5 year intervals after baseline established
Low	Sand preference dominant	1.2-3.3	Monitor 5 yearly after baseline established
Fair	Some mud preference	3.3-5.0	Monitor 5 yearly after baseline est. Initiate ERP
High	Mud preferred	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very High	Strong muds preference	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Some mud preference	>1.2	Initiate Evaluation and Response Plan

Redox Potential Discontinuity

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

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

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

RPD CONDITION RATING

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

Total Organic Carbon

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, release of excessive nutrients and adverse impacts to biota - all symptoms of eutrophication.

TOTAL ORGANIC CARBON CONDITION RATING

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

2. Methods (Continued)

Total Phosphorus

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

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

Total Nitrogen

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

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

Benthic Community Index (Organic Enrichment)

Soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). The AZTI (AZTI-Tecnalia Marine Research Division, Spain) Marine Benthic Index (AMBI) (Borja et al. 2000) has been verified in relation to a large set of environmental impact sources (Borja, 2005) and geographical areas (in N and S 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 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, in low-salinity locations and naturally enriched sediments. The equation to calculate the AMBI Biotic Coefficient (BC) is as follows; BC = {(0 x %GI) + (1.5 x %GII) + (3 x %GIII) + (4.5 x %GIV) + (6 x %GV)}/100. The characteristics of the ecological groups (GI, GII, GIII, GIV and GV) are summarised in Appendix 3.

BENTHIC COMMUNITY ORGANIC ENRICHMENT RATING			
ECOLOGICAL RATING	DEFINITION	BC	RECOMMENDED RESPONSE
Very Low	Intolerant of enriched conditions	0-1.2	Monitor at 5 year intervals after baseline established
Low	Tolerant of slight enrichment	1.2-3.3	Monitor 5 yearly after baseline established
Moderate	Tolerant of moderate enrichment	3.3-5.0	Monitor 5 yearly after baseline est. Initiate ERP
High	Tolerant of high enrichment	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very High	Azoic (devoid of invertebrate life)	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend to slight enrichment	>1.2	Initiate Evaluation and Response Plan

Metals

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

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

3. RESULTS AND DISCUSSION

OUTLINE

A summary of the 21 February 2011 fine scale monitoring results of Jacobs River Estuary is presented alongside the 2003-2006 baseline results in Table 3, with detailed results presented in Appendix 2. The results and discussion section is divided into three subsections based on the key estuary problems that the fine scale monitoring is addressing: eutrophication, sedimentation, and toxicity. Within each subsection, the results for each of the relevant fine scale indicators are presented. A summary of the condition ratings for each of the three sites is presented in the accompanying figures.

Table 3. Physical, chemical and macrofauna results (means) for Jacobs River Estuary (2003-2011).

Site		RPD	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. of Species	No. of Species
		cm	%				mg/kg								No./m²	No./core	No./Site
2003	A		0.89	1.03	98.76	0.22	0.48*	14.70	24.00	8.36	12.08	73.10	120.50	494.70	4508	8	21
	B		0.44	2.83	96.45	0.71	0.19*	11.90	6.19	4.44	5.90	17.30	147.00	203.40	3870	12	24
	C		0.67	3.95	95.25	0.80	0.11*	10.43	5.57	3.87	4.72	17.40	222.00	276.40	5453	10	20
2004	A		1.09	0.78	98.79	0.45	<1.00	10.27	23.20	2.90	11.10	83.10	149.00	463.70	7335	14	23
	B		0.56	3.89	95.07	1.05	<1.00	6.93	5.80	1.64	5.57	50.70	252.00	198.10	6780	15	28
	C		0.81	6.35	92.82	0.81	<1.10	7.16	4.91	1.61	4.87	51.60	249.00	266.50	9330	12	22
2005	A		1.02	4.88	94.69	0.46	<0.05	9.87	23.70	11.90	3.22	52.30	255.00	507.70	6105	12	21
	B		0.57	6.24	93.01	0.75	<0.05	8.21	6.61	6.40	1.85	19.20	262.00	248.40	5693	15	32
	C		0.69	8.65	90.74	0.59	<0.05	7.89	5.66	5.40	1.81	20.00	358.00	335.80	7013	13	24
2006	A		0.99	1.50	98.00	0.50	0.10	8.87	21.67	11.33	2.90	56.33	140.00	577.33	6188	13	26
	B		0.88	7.70	92.13	0.20	0.10	7.13	6.47	6.00	1.73	19.00	250.00	219.33	5828	16	26
	C		0.97	13.60	85.90	0.57	0.10	7.47	6.47	5.33	2.03	21.33	333.33	389.33	4163	10	22
2011	A	0	0.13	6.90	92.93	0.23	0.07	10.60	25.00	13.20	3.43	58.33	500.00	500.00	9421	11	24
	B	1	0.17	4.83	94.80	0.37	0.02	7.03	6.17	5.73	1.71	16.83	500.00	204.33	6098	17	30
	C	1	0.23	4.73	94.63	0.63	0.02	6.97	5.13	4.90	1.65	16.77	500.00	233.33	18715	15	23

*denotes unreliable chemical results

SEDIMENTATION

Accelerated soil erosion from developed catchments is a major issue for tidal lagoon estuaries in New Zealand as they form a sink for fine suspended sediments. NZ estuaries are particularly sensitive to increased muddiness given the facts that they are generally sand dominated, have a diverse and healthy biology, and a short history of catchment development. Increased muddiness results in reduced sediment oxygenation, production of toxic sulphides, increased nuisance macroalgal growth, and a shift towards a degraded invertebrate and plant community. Such a change reduces feeding grounds and habitat for bird and fish species. Unless the input of fine sediment is reduced to a level below the assimilative capacity of the estuary then they will rapidly infill, high value habitat will be lost and their value for fish, birdlife and humans will be greatly reduced. Sediments containing high mud content (i.e. around 30% mud with a grain size < 63μm) are now typical in NZ estuaries that drain developed catchments. In such mud-impacted estuaries, the muds generally occur in the areas that experience low energy tidal currents and waves [i.e. the intertidal margins of the upper reaches of estuaries (e.g. Waihopai Arm, New River Estuary), and in the deeper subtidal areas at the mouth of estuaries (e.g. Hutt Estuary)] (Figure 2). In contrast, the main intertidal flats of developed estuaries (e.g. New River Estuary and Porirua Harbour) are usually characterised by sandy sediments reflecting their exposure to wind-wave disturbance and are hence low in mud content (2-10% mud). In estuaries where there are no large intertidal flats, then the presence of mud along the narrow channel banks in the lower estuary can also be elevated (e.g. Hutt Estuary and Whareama Estuary, Wairarapa Coast). In estuaries with undeveloped catchments, like Freshwater Estuary, Stewart Island, the mud content is usually low (<2% mud), unless the catchment is naturally erosion-prone, the geology dominated by soft rock types and a low predominance of wetland filters.

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

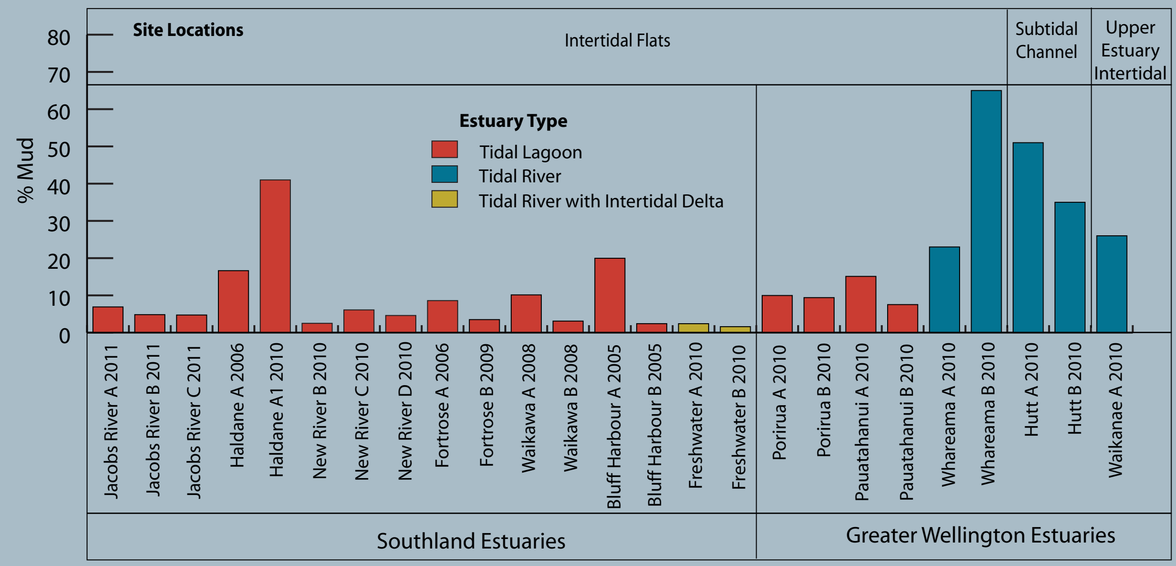


Figure 2. Percent mud content at fine scale monitoring sites, Southland and Greater Wellington estuaries.

GRAIN SIZE

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results (Figure 3) show that all three Jacobs River Estuary sites were dominated by sandy sediments (>86% sand in all years) and a low-moderate mud content (<14% mud) compared with fine scale sites in other tidal lagoon type estuaries in the Greater Wellington and Southland regions (Figure 2).

The results also show that the mud content at each site varies between years, which probably reflects the relatively mobile nature of the sediments and exposure to resuspension at each of these sites.

The source of these fine muds is almost certainly from the surrounding Pourakino and Aparima catchments rather than the sea. To address the potential for ongoing sedimentation within the estuary and to measure its magnitude, sediment plates were deployed at 3 sites in the estuary in February 2011.

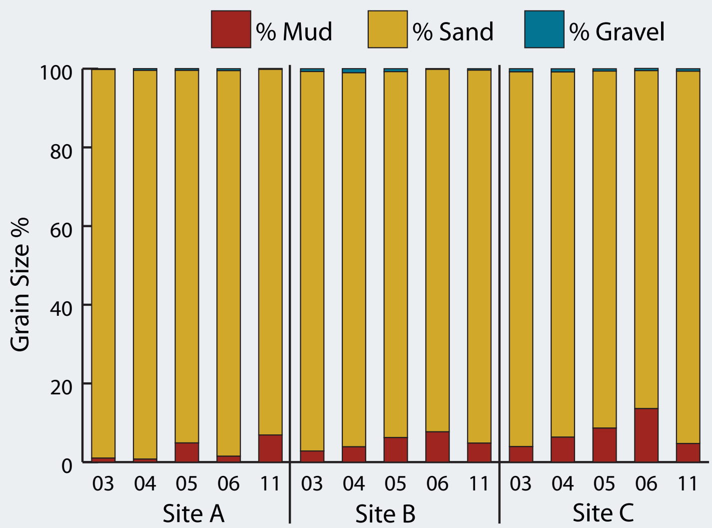


Figure 3. Grain size, Jacobs River Estuary.

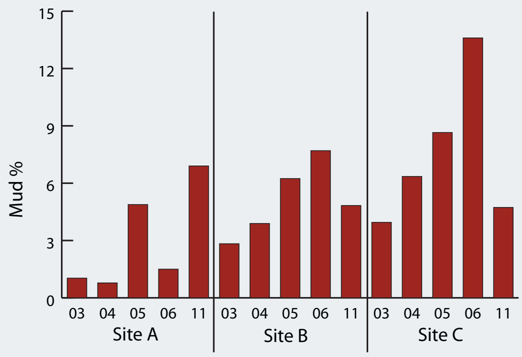


Figure 3a. Percentage mud, Jacobs River Estuary.

Macro-invertebrate Tolerance to Muds

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

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

The first step showed that the macro-invertebrate community at all three sites in Jacobs River Estuary in the baseline monitoring period (2003-2006) and in 2011 included a moderate range of species (8-17 species/core) compared with results from the intertidal mudflats in other NZ estuaries (Figure 4). Similarly, the overall community abundance at all three sites in Jacobs River Estuary in 2003-2006 and in 2011 was low to moderate at 4,000 - 19,000m^{-2} (Figure 5) compared with other NZ estuaries.

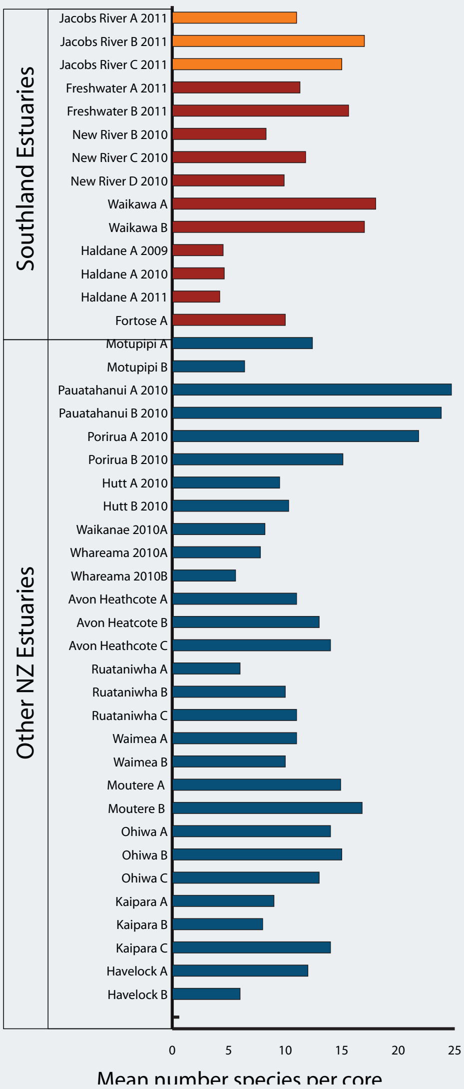


Figure 4. Mean number of infauna species, Jacobs River Estuary compared with other NZ estuaries.

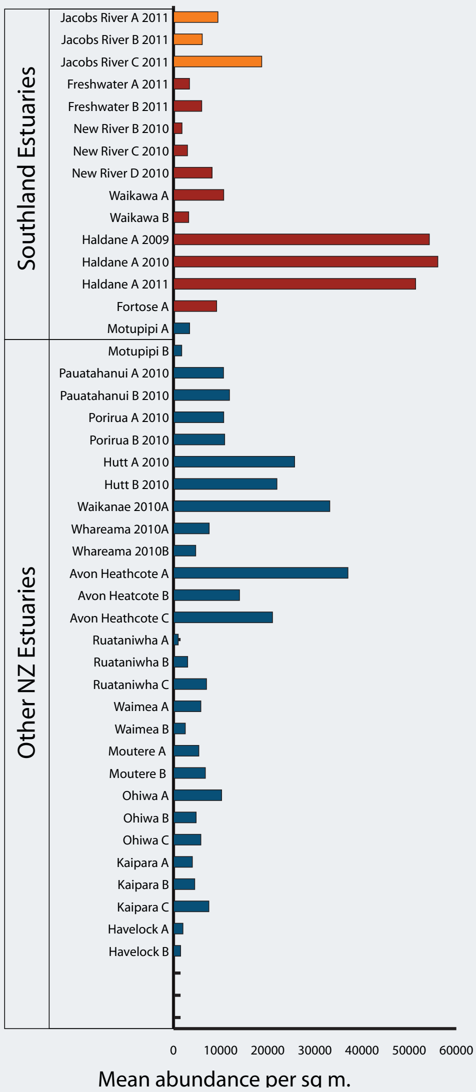


Figure 5. Mean total abundance of macrofauna, Jacobs River Estuary compared with other NZ estuaries.

3. Results and Discussion (Continued)

In the second step, the results of the multivariate analysis (NMDS Plot, Figure 6) show that there was a difference in the benthic invertebrate communities between each of the sites for all the five years of monitoring. In addition, the plot shows that there were year to year differences at each site, with the most pronounced difference being at Site C (Pourakino Arm) in 2011. Figure 6 shows that for this site, the 2011 results were well separated and therefore significantly different from the 2003-2006 results. The reason for such a difference is uncertain, and is unlikely to be a result of the decline in mud content given that 2003 and 2011 had similar mud contents yet very dissimilar invertebrate communities. The following section examines this conclusion in more detail.

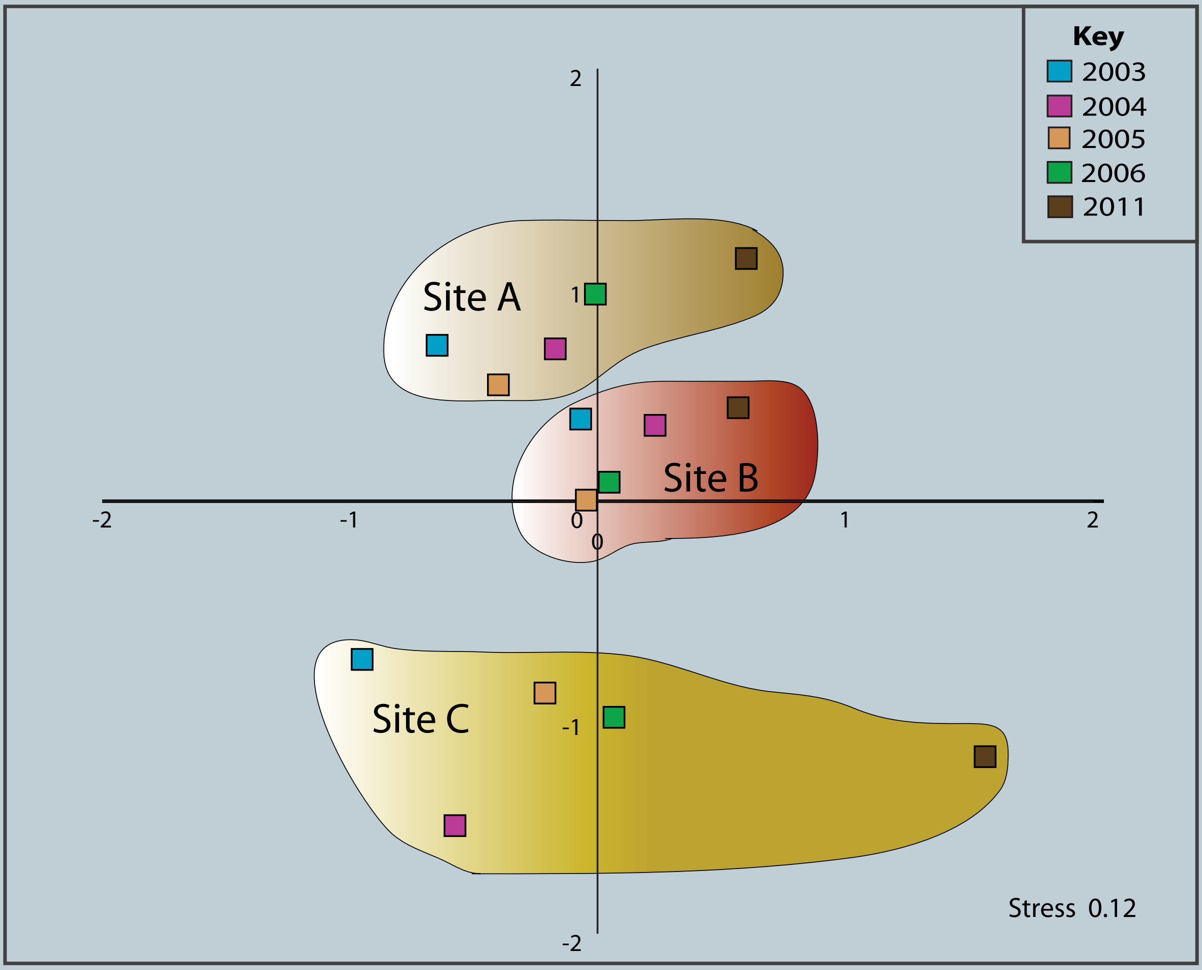


Figure 6. NMDS plot showing the relationship among mean samples in terms of similarity in macro-invertebrate community composition for Jacobs River Estuary Sites A, B and C, for 2003, 2004, 2005, 2006 and 2011. The plot shows the mean of each of the 10 replicate samples for each site and is based on Bray Curtis dissimilarity and fouth root transformed data.

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

3. Results and Discussion (Continued)

In the third step, the species present at each site were divided into 6 groups based on their tolerance to mud and the results used to calculate a mud tolerance rating for each year and site (Figure 7). The results show that Sites B (Middle) and A (Riverton) were in the "low" or "very low" category for each of the 5 years of monitoring which indicates that the communities at these sites were dominated by species that prefer sand or a little mud rather than those with a mud or strong mud preference (Figure 8). However, at the more upstream Site C (Pourakino Arm), the rating was consistently in the "fair" category for each of the 5 years of monitoring which indicates a community dominated by species that prefer mud at this site.

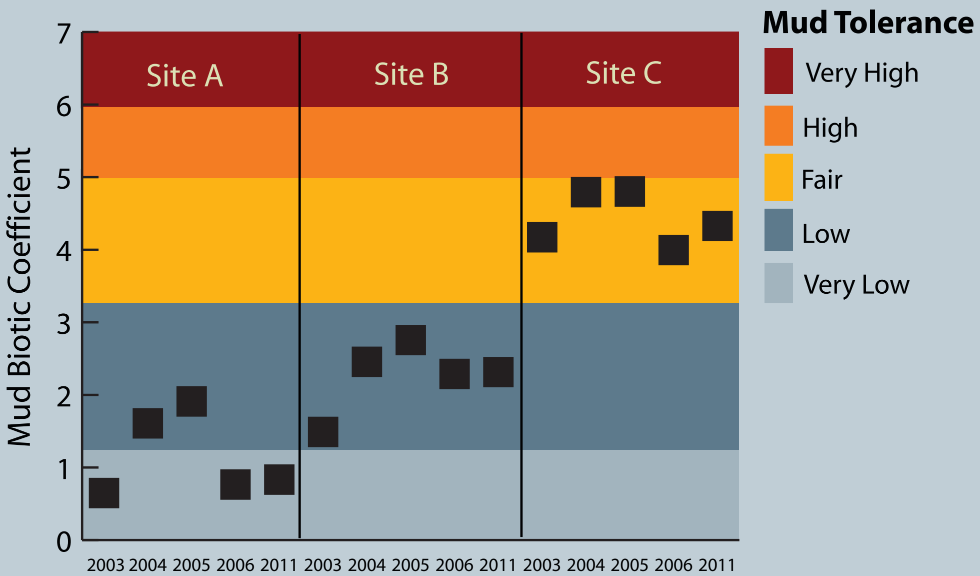


Figure 7. Mud tolerance macroinvertebrate rating at 3 sites in Jacobs River Estuary 2003-2011.

These results are explored in more detail in Figure 8. This plot shows that, for each of the five years of monitoring, the benthic invertebrate community was dominated by a variety of polychaete, gastropod, nemertean, crustacean and bivalve species with varying tolerances to mud. The important findings were as follows:

- **Low Numbers of Strong Sand Preference Species.** Only two strong sand preference (i.e. highly mud intolerant) species were present, but only at two of the sites. These included the pipi (*Paphies australis*) and the small surface deposit-feeding spionid polychaete *Aonides oxycephala* that lives throughout the sediment to a depth of 10cm. Although *Aonides* is free-living, it is not very mobile and prefers to live in fine sands. *Aonides* was relatively common at Sites A and B between 2003 and 2011 but at Site C, it was absent between 2003 and 2006 but present in 2011. On the other hand, pipi were relatively common for all 5 years of monitoring only at Site A. Low numbers were also present at Site C.

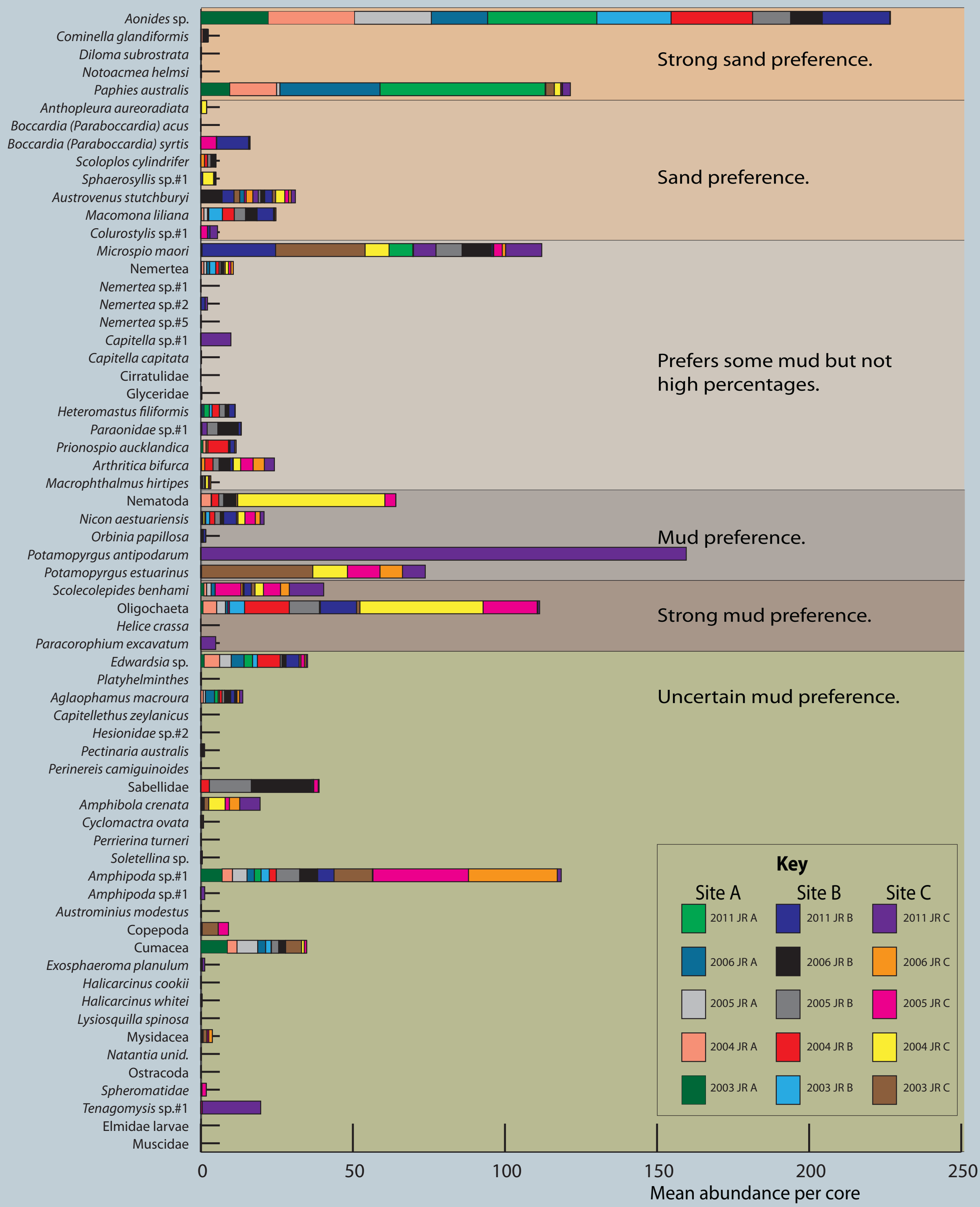


Figure 8. Jacobs River Estuary 2003-2011 - mud sensitivity of macro-invertebrates at three sites (see Appendix 3 for sensitivity details).

3. Results and Discussion (Continued)

- **Low Numbers of Sand Preference Organisms.** Eight "sand preference" species were also found at all the sites in 2003-2011, but were generally only present in low numbers. The most abundant species were cockles (*Austrovenus stutchburyi*) and the adult wedge shell *Macomona liliana*. Both are particularly important species in that they are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). Cockles are suspension-feeders who prefer sand environments with an optimum range of 5-10% mud but can be also be found sub-optimally in 0-60% mud. *Macomona* is a deposit feeding wedge shell that lives at depths of 5–10cm in the sediment and uses a long inhalant siphon to feed on surface deposits and/or particles in the water column. It is rarely found beneath the RPD layer and is adversely affected at elevated suspended sediment concentrations (optimum range of 0-5% mud but can be also be found sub-optimally in 0-40% mud). Currently, the mud concentrations at the Jacobs River Estuary sites of generally <10%, are expected to provide favourable habitat for these species.
- **High Numbers of Two Species That Prefer Some Mud But Not High Percentages.** In particular, there were elevated numbers of *Microspio maori*, a small, common, intertidal spionid which prefers 0-20% mud and can handle moderately enriched situations and the small, sedentary deposit feeding bivalve, *Arthritica bifurca* which prefers 20-40% mud is also found at lower mud contents. It lives in the sediment at a depth below 2cm.
- **High Numbers of a Mud-Loving Snail.** Organisms that prefer "moderate or high mud contents" were also found at the sites but their numbers were low, except for the small native estuarine snails *Potamopyrgus estuarinus* and *P. antipodarum* which were common at Site C (Pourakino Arm). They feed on decomposing animal and plant matter, bacteria and algae, and are intolerant of anoxic surface muds but are tolerant of muds. Their absence from the more downstream sites A and B was likely related to their requirement for brackish water for their survival. The presence of high numbers of snails at Site C was also likely to be part of the explanation for the "fair" mud tolerance rating for this site (Figure 7).
- **Moderate Numbers of Strong Mud Preference Species.** Also present at all the sites were the surface deposit feeding spionid polychaete *Scolecolepides benhami* and segmented oligochaete worms. The spionid is very tolerant of mud, fluctuating salinities, organic enrichment and toxicants (e.g. heavy metals). It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark.

EUTROPHICATION

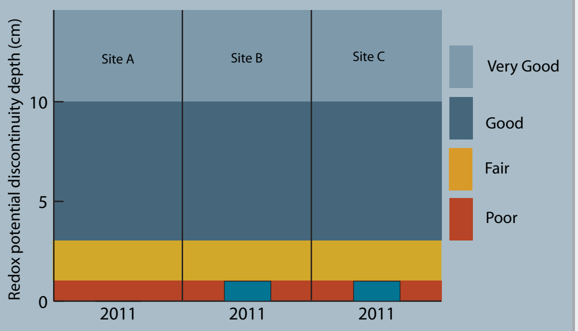


Figure 9. RPD depth (mean and range) Jacobs River Estuary.

2011 RPD RATING	Poor - Fair

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

Redox Potential Discontinuity (RPD)

Figures 9 and 10 shows the sediment profile and RPD depths for Jacobs River Estuary and the likely benthic community that is supported at each site based on the measured RPD depth (adapted from Pearson and Rosenberg 1978). The results showed that the 2011 RPD depths at Jacobs River Estuary fine scale sites were at a shallow depth (0-1cm) and therefore the sediments are likely to be poorly oxygenated. Such shallow RPD values fit the “poor - fair” condition rating and indicate that the benthic invertebrate community was likely to be in a transitional state or skewed towards species that are tolerant of moderate enrichment.

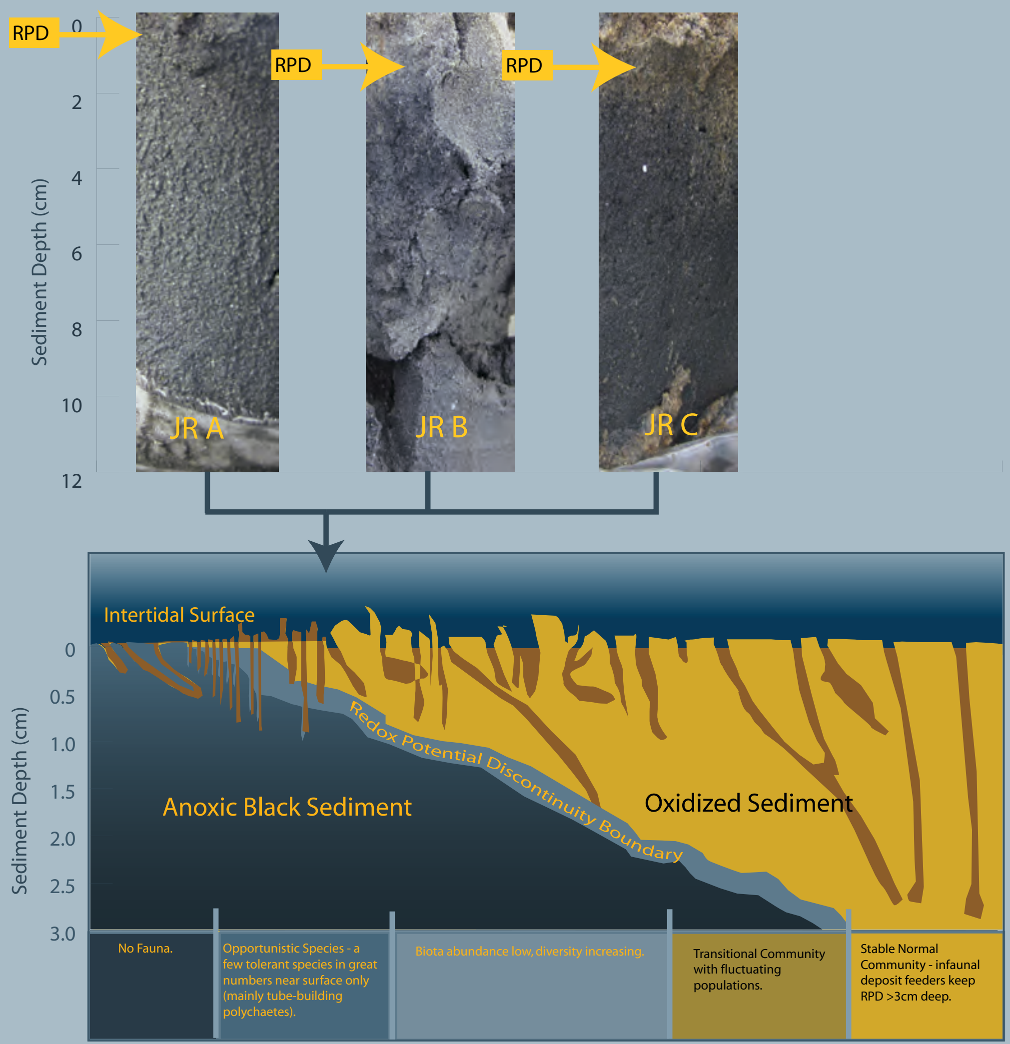


Figure 10. Sediment profiles, depths of RPD and predicted benthic community type, Jacobs River Estuary, 21 February 2011. Arrow below core relates to the type of community likely to be found in the core.

3. Results and Discussion (Continued)

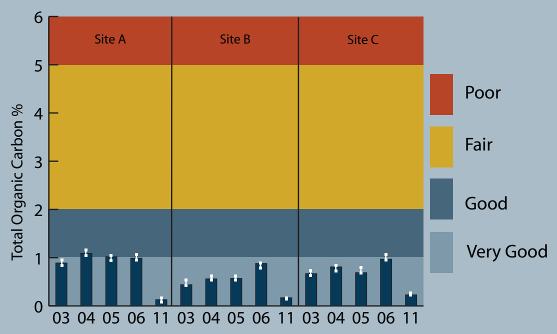


Figure 11. Total organic carbon (mean and range) at 3 intertidal sites, 2003-2011.

2011 TOC RATING	Very Good

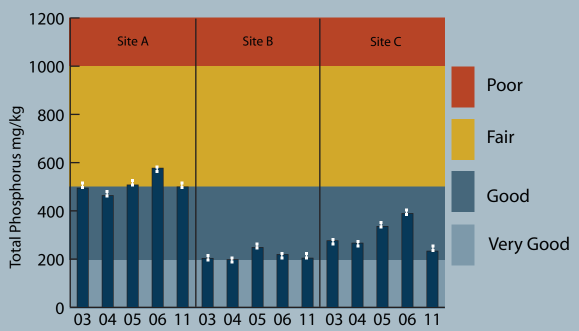


Figure 12. Total phosphorus (mean and range) at 3 intertidal sites, 2003-2011.

2011 TP RATING	Good - Fair

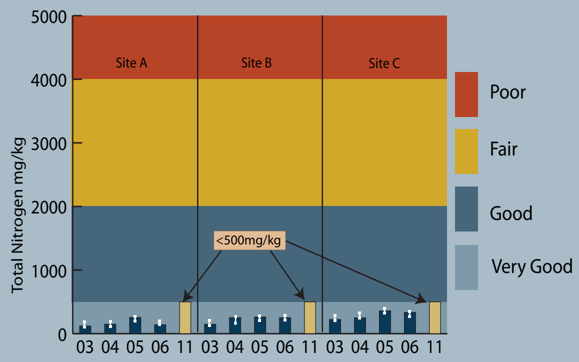


Figure 13. Total nitrogen (mean and range) at 3 intertidal sites, 2003-2011.

2011 TN RATING	Very Good

ORGANIC MATTER (TOC)

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

The indicator of organic enrichment (TOC) at all three sites in 2011 (Figure 11) was at very low concentrations (0.13 - 0.23%) and met the "very good" condition rating. These conditions were lower than those measured during the four year baseline monitoring period 2003-2006, particularly at Site A. Such lower TOC concentrations were likely to be the result of over-estimation in 2003-2006 because ash free dry weight and a standard conversion factor were used to estimate TOC, whereas in 2011, TOC has been measured directly.

TOTAL PHOSPHORUS

Total phosphorus (a key nutrient in the eutrophication process) was present in the "low to moderate enrichment" category (Figure 12) at all three sites in 2011 and met the "good - fair" condition rating. These 2011 results were similar to those measured during the four year baseline monitoring period 2003-2006.

TOTAL NITROGEN

Total nitrogen (the other key nutrient in the eutrophication process) was in the "low enrichment" category (Figure 13) at all 3 sites in 2011 and met the "very good" condition rating. These 2011 results were similar to those measured during the four year baseline monitoring period 2003-2006.

Such conditions indicate a low extent of accumulation of organic matter and nutrients in the sediments of the area of the estuary represented by the three fine scale sites. However, because the estuary has deteriorated since early 2000, these three sites only represent approximately 30-40 % of the estuary and are relatively well-flushed (i.e. they are unlikely to accumulate nuisance levels of macroalage and sediment). In the remainder of the estuary, high cover of nuisance macroalgal growth was common in 2011 (Stevens and Robertson 2011) (Figure 14) and therefore, although not yet measured, much more elevated TOC, TN and TP concentrations are expected. For example, in similar eutrophic areas in the New River Estuary in 2011, concentrations of TOC, TP and TN were 4%, 1,200mg/kg and 5,900mg/kg respectively (Robertson and Stevens 2011).

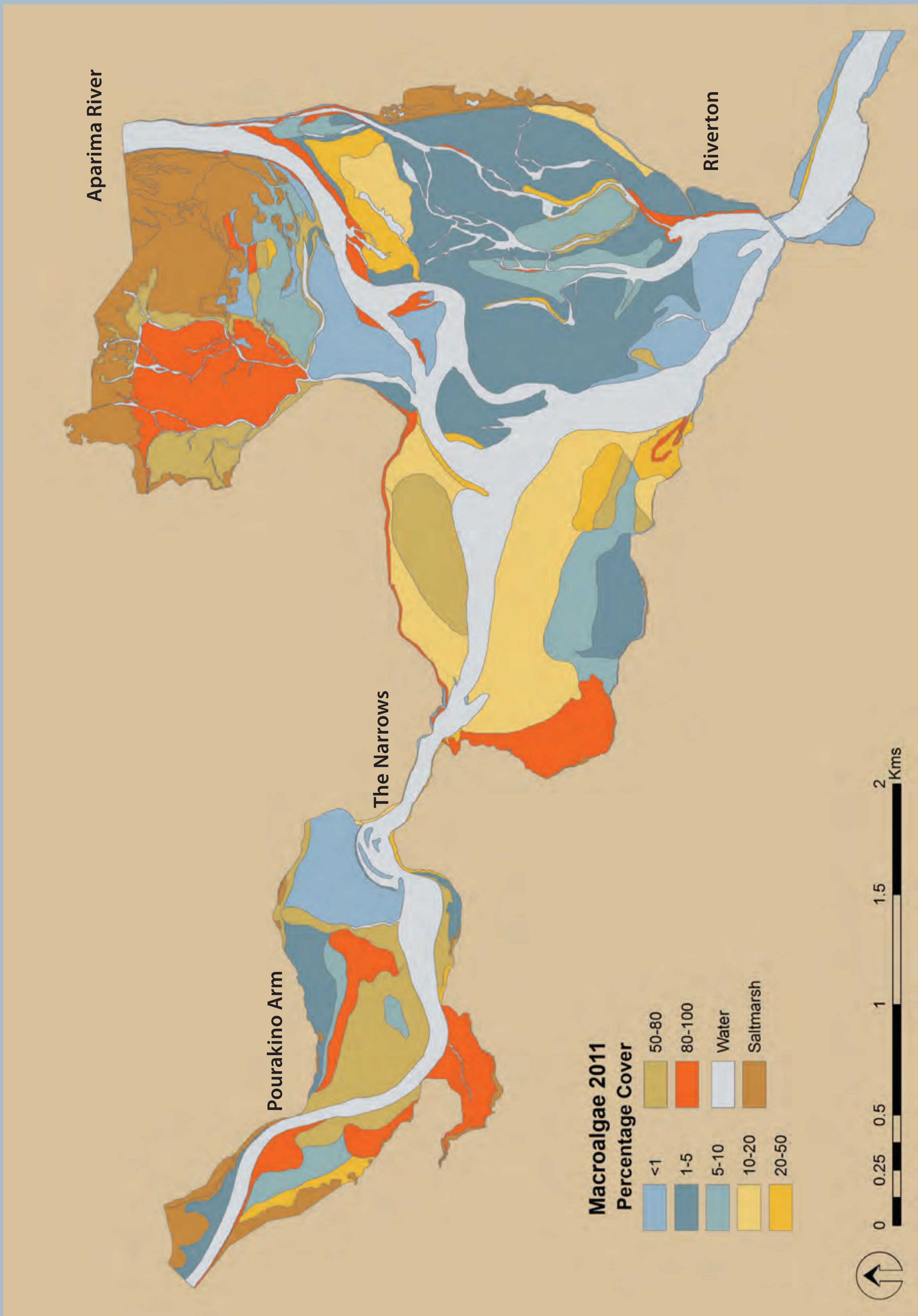


Figure 14. Jacobs River Estuary 2011 macroalgae percent cover (Stevens and Robertson 2011).

Macro-invertebrate Organic Enrichment Index

The benthic invertebrate organic enrichment rating for Jacobs River Estuary was in the "low to fair" category, indicating slight to moderate organic enrichment for 2003-2006 and 2011 (Figure 15). Such a rating likely reflects the moderate sediment nutrient concentrations, and the exposed nature of these sites situated in well flushed central parts of the estuary. As in previous years, the 2011 conditions resulted in a community dominated by a broad range of species sensitivities (Figure 16) including:

- Low-moderate abundances and numbers of species that are very sensitive to organic enrichment (e.g. the small, sedentary deposit feeding bivalve, *Arthritica bifurca*, cockles *Austrovenus stutchburyi*, the wedge shell *Macomona liliana*, and the polychaete *Boccardia* sp.).
- Low-moderate abundances and numbers of species that are indifferent to organic enrichment (slightly unbalanced) for example, pipis (*Paphies australis*), the burrowing anemone *Edwardsia* sp., mysid shrimps, and various polychaetes.
- Moderate numbers of species and elevated abundances of species that are tolerant to excess organic enrichment (unbalanced situation) for example, the spionid polychaetes *Microspio maori* and *Aonides oxycephala*, and at Site C (Pourakino Arm) the small native estuarine snails *Potamopyrgus estuarinus* and *P. antipodarum*.
- Low abundances and diversity of species that are very tolerant to organic enrichment (slight to pronounced unbalanced situations), for example the polychaete *Heteromastus filiformis*.
- Low abundances of one particular species (the polychaete *Capitella* sp.) that is a 1st order opportunistic species and therefore highly tolerant of organic enrichment (pronounced unbalanced situations).

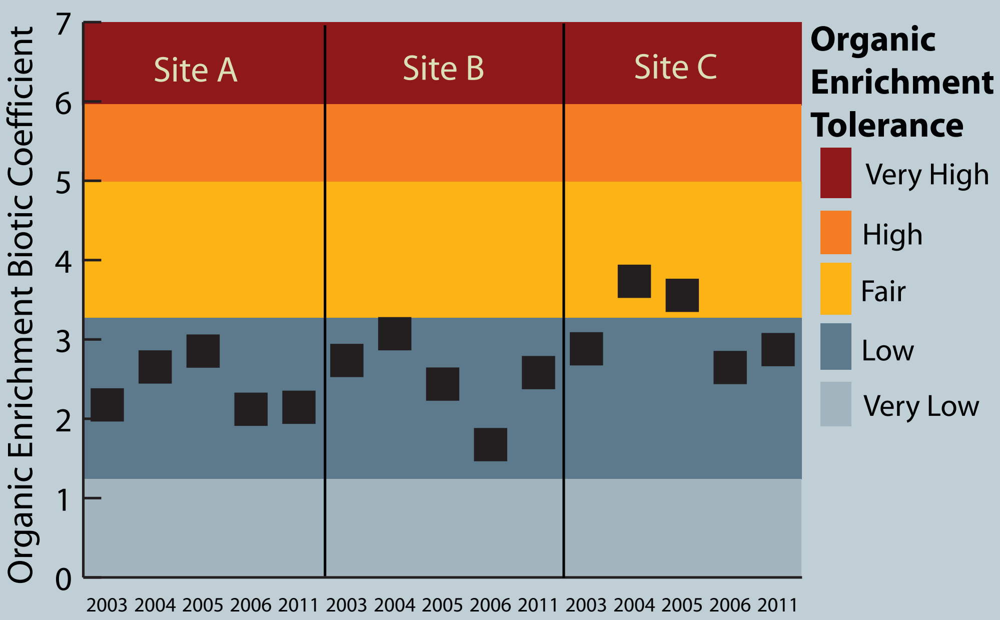


Figure 15. Benthic invertebrate organic enrichment rating at 3 sites in Jacobs River Estuary 2003-2011.

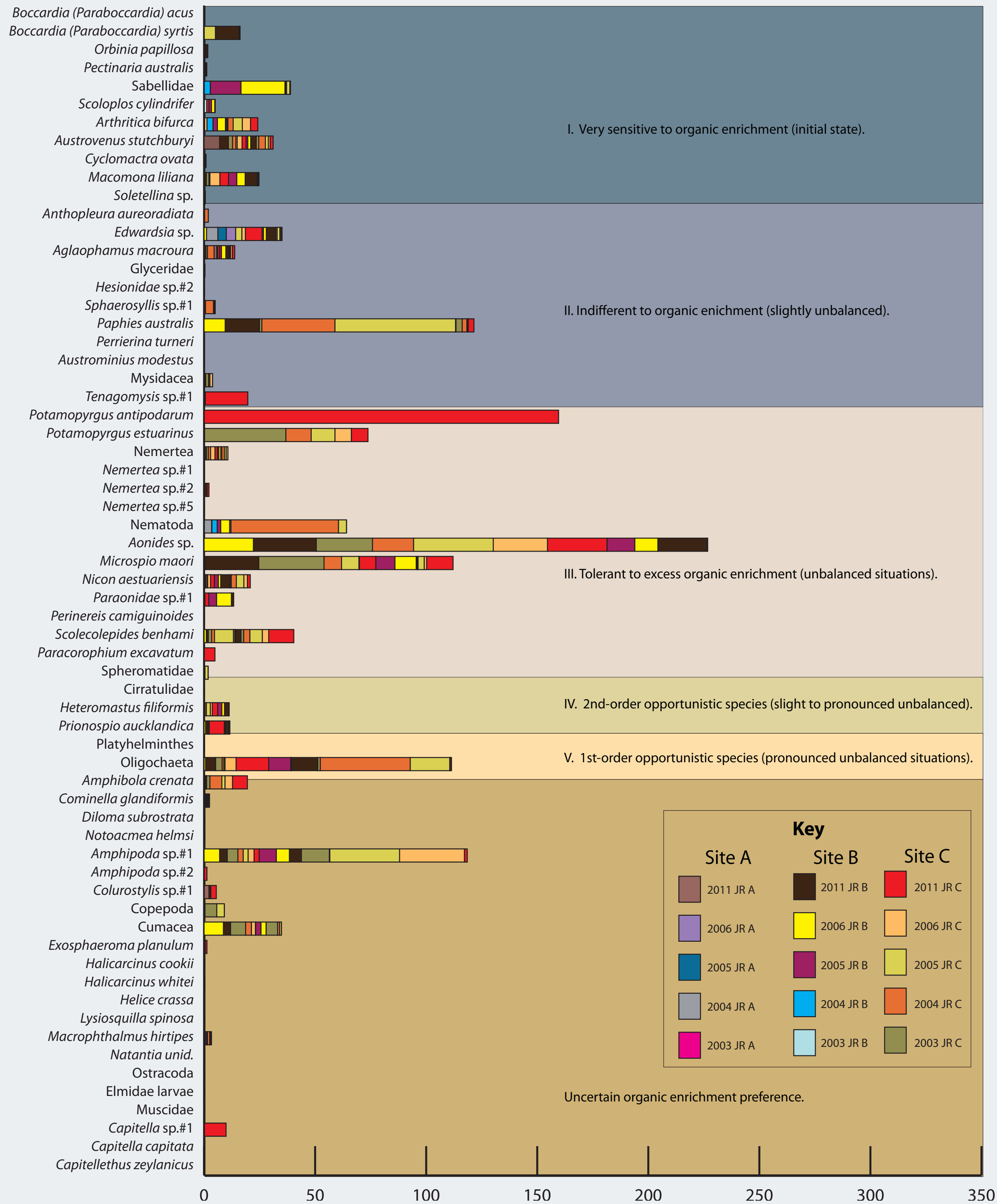


Figure 16. Organic enrichment sensitivity of macroinvertebrates, Jacobs River Estuary 2003-2011 (see Appendix 3 for sensitivity details).

3. Results and Discussion (Continued)

TOXICITY

METALS

Heavy metals (Cd, Cr, Cu, Pb, Ni, Zn), used as an indicator of potential toxicants, were at low to very low concentrations in all years including the recent monitoring undertaken in 2011, with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 17). In 2011, metals met the "very good" condition rating for cadmium, chromium and lead and the "good - very good" condition rating for copper, nickel and zinc. These results were similar to the 4 baseline years (2003 - 2006) at all sites. The only outstanding feature was that compared with the other 2 sites, Site A (near Riverton) showed elevated levels of copper, nickel and zinc but these metals still met the "good" category. Copper levels at Site A in all 5 years were 3-4 times greater than those at other long term monitoring sites in Southland estuaries, including Sites B and C at Jacobs River Estuary. In the Longwood range elevated levels of Ni, Cu and zinc have been reported and attributed to the natural geology of the area (Williams 1967), therefore the possible source of these metals may be from natural leaching from the catchment or from a localised source such as an old refuse site.

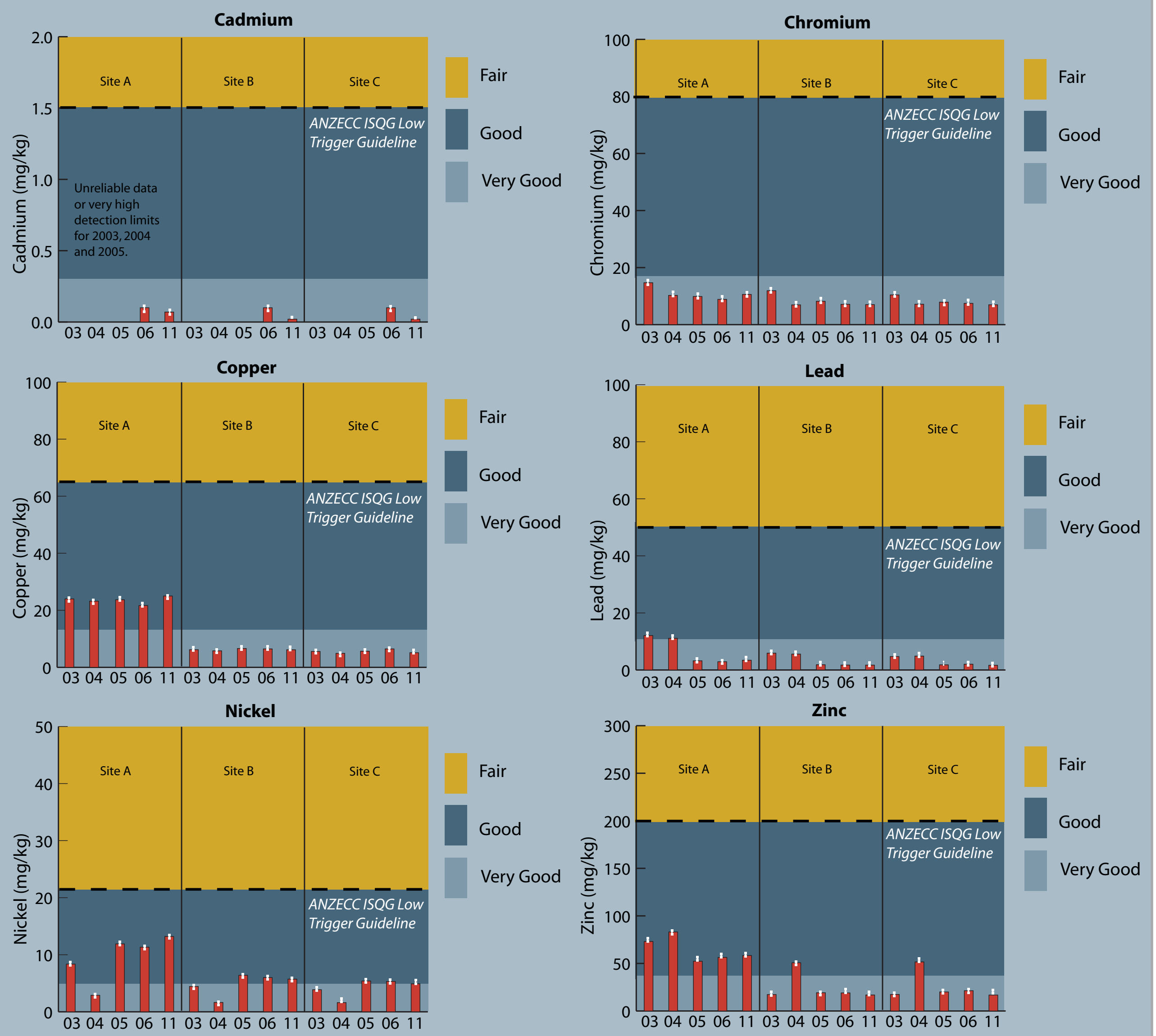


Figure 17. Total recoverable metals (mean and range) at 3 intertidal sites, Jacobs River Estuary.

4. CONCLUSIONS

This report documents the results of the 2011 fine scale monitoring of Jacobs River Estuary and draws comparisons with the 2003-2006 baseline survey. In summary the findings (including a summary of condition ratings) were as follows;

- **Sedimentation.** Sand dominated the three fine scale sites, and mud contents ranged from 0.8-13% mud. The lowest mud contents at each site were recorded in 2003 and since then have varied between years and sites which was likely related to flood events in the catchment. The more sheltered Pourakino Arm (Site C) had the highest mean mud content over the 2003-2011 period, which partly explains the dominance by mud tolerant invertebrates ("fair" rating) at this site. The other reason was the higher degree of exposure of Site C to brackish conditions. The other two sites were in the "low" or "very low" categories (i.e. dominated by species that prefer sand or a little mud rather than those with a mud or strong mud preference).
- **Eutrophication.** In general, the sediments at the three fine scale sites showed a very shallow RPD depth (<1cm) but because of the predominance of sand and the relatively well flushed locations of these sites, levels of oxygenation were sufficient to maintain a moderately well-balanced invertebrate community and low organic carbon and nutrient concentrations (low-fair condition ratings).
- **Toxicity.** Heavy metals were well below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity) at all sites, reflecting the absence of significant sources of toxicants in the catchment.

CONDITION RATINGS	Site A					Site B					Site C				
	2003	2004	2005	2006	2011	2003	2004	2005	2006	2011	2003	2004	2005	2006	2011
% Mud	1.0	0.8	4.9	1.5	6.9	2.8	3.9	6.2	7.7	4.8	4.0	6.4	8.7	13.6	4.7
Sediment Oxygenation RPD	Fair	Fair	Fair	Fair	High/Poor	Fair	Fair	Fair	Fair	High/Poor	Fair	Fair	Fair	Fair	High/Poor
Invertebrates Mud Tolerance	Very good	Good	Good	Very good	Very good	Good	Good	Good	Good	Good	Fair	Fair	Fair	Fair	Fair
TOC (Total Organic Carbon)	Very good	Good-Very Good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good
Total Phosphorus	Fair	Good	Fair	Fair	Fair	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Total Nitrogen	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good
Invertebrates Org. Enrichment	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Fair	Fair	Good	Good
Metals (Cd, Cu, Cr, Ni, Pb, Zn)	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good
Sedimentation Rate	Plates deployed in 2011 - sedimentation rate not yet measured.														

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

Such findings however, must be considered in relation to the estuary as a whole, in particular, the results from the broad scale habitat mapping (Robertson et al. 2003, Stevens and Robertson 2008) and annual macroalgal (Stevens and Robertson 2008, 2009, 2010 and 2011) and sedimentation rate monitoring. These broad scale studies indicate that the estuary has eutrophication and sedimentation problems which have been identified as early as 2008.

The two key indicators used in these studies to identify such conditions were the presence of high macroalgal cover and soft muddy sediments. If both are present in an area, then conditions for animal life in the sediments is generally very poor. This is confirmed by a recent survey of highly eutrophic, muddy areas in the Waihopai Arm of the New River Estuary (Robertson and Stevens 2011).

Broad scale macroalgal and sediment type monitoring of Jacobs Estuary since 2003 indicated the following:

4. Conclusions (Continued)

- High macroalgal cover (>50% cover) covered approximately 30% of the whole estuary in 2011 (compared with <5% in 2003, 5% in 2007, 34% in 2008, 32% in 2009 and 33% in 2010 - note the 2003 estimate was based on both personal observation and limited broad scale mapping).
- Soft muddy sediments covered approximately 33% of the whole estuary in both 2003 and 2008 (next sediment mapping planned for 2013).
- The area covered by both high macroalgal cover and soft muddy sediments in 2011 was estimated to be 25% of the whole estuary (with the majority in the Pourakino Arm, and the western and northern arms of the main basin). In 2007, the estimate was 4% of the estuary.

Given that gross nuisance conditions, now occupy 25% of the estuary (compared with 4% in 2007 and <4% in 2003), there is clear evidence that the condition of the Jacobs River Estuary has deteriorated in the last 10 years. To date, this deterioration has been clearly presented in the results of the macroalgal mapping and broad scale habitat mapping since 2003 (see table below).

	2003	2007	2008	2009	2010	2011
Macroalgal Rating	Good	Fair	Poor	Poor	Poor	Poor
Soft Mud Rating	Poor	Not Measured	Poor	Not Measured	Not Measured	Not Measured

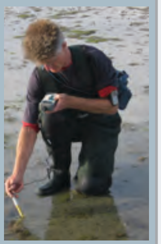
Such findings triggered recommendations for an immediate reduction in nutrient and sediment loads from the catchment (Stevens and Robertson 2009, 2010) as follows:

> *The large increase in macroalgal cover from 2007 (see Stevens and Robertson 2007, 2008), combined with the presence of nuisance conditions, means macroalgae should continue to be monitored annually. In addition, the following management is recommended:*
>
> ***Set Limits on Nutrient Inputs**. Because nutrient inputs to Jacobs River Estuary are high and strongly related to the eutrophication symptoms (Robertson and Stevens 2008), it is recommended that catchment nutrient inputs be reduced. A Total Daily Maximum Load to the Jacobs River Estuary of about 0.7 tonnes N/day (as opposed to the current input of 1.6 tonnes/day) is suggested as a preliminary guideline to achieve a more moderately enriched estuary.*

Unfortunately, these management recommendations have not yet been undertaken and therefore the estuary degradation has continued. As a consequence, further recommendations for management are put forward in Section 5.

Also, the presence of large "highly eutrophic" zones in the estuary, that are currently not addressed in the fine scale monitoring programme, indicate that it is time that the fine scale programme was expanded to include at least two of these areas. Fine scale monitoring at such sites would provide additional information (nutrients, organic carbon, RPD, macroinvertebrates, grain size and heavy metals) to help in making more effective management decisions.

5. FUTURE MONITORING



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

Fine Scale Monitoring.

Expand the number of fine scale monitoring sites to include two more sites that are representative of more vulnerable poorly flushed areas in the estuary. Monitor the two new sites in February 2012 and again in February 2015 when the 5 yearly fine scale trend monitoring at the three existing sites falls due.

Macroalgal Monitoring.

Continue with the programme of annual broad scale mapping of macroalgae. Next monitoring February 2012.

Broad Scale Habitat Mapping.

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

Sedimentation Rate Monitoring.

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

6. MANAGEMENT

Eutrophication and sedimentation have been identified as a major issue in Jacobs River Estuary as has been the case for several other Southland estuaries (e.g. New River, Waimatuku and Waituna Lagoon). To address these issues, it is recommended that appropriate catchment nutrient and sediment guideline criteria be developed for each estuary type in Southland and that these guideline criteria are then used to assess the extent to which catchment loads meet these guidelines. Estuaries where guidelines are exceeded are prioritised for more extensive investigations, monitoring and management. The key steps in such an approach are as follows:

- Assign catchment nutrient and sediment load guideline criteria to each Southland estuary (using criteria appropriate to each type of estuary). Guideline criteria should be based on available catchment load/estuary response information from other relevant estuaries.
- Estimate catchment nutrient and suspended sediment loads to each estuary using available catchment models and stream monitoring data.
- Determine the extent to which each estuary meets guideline catchment load criteria.
- Rank estuaries according to exceedance of recommended guideline criteria.
- Assess the potential for requiring more detailed assessments of priority estuaries (e.g. estuary response modelling, stream and tributary monitoring, catchment load modelling).
- Develop plans for the effective management and restoration of priority estuaries.

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

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with organizing and field assistance from Greg Larkin (Coastal Scientist, Environment Southland). Thanks to Maz Robertson (Wriggle) for editing.

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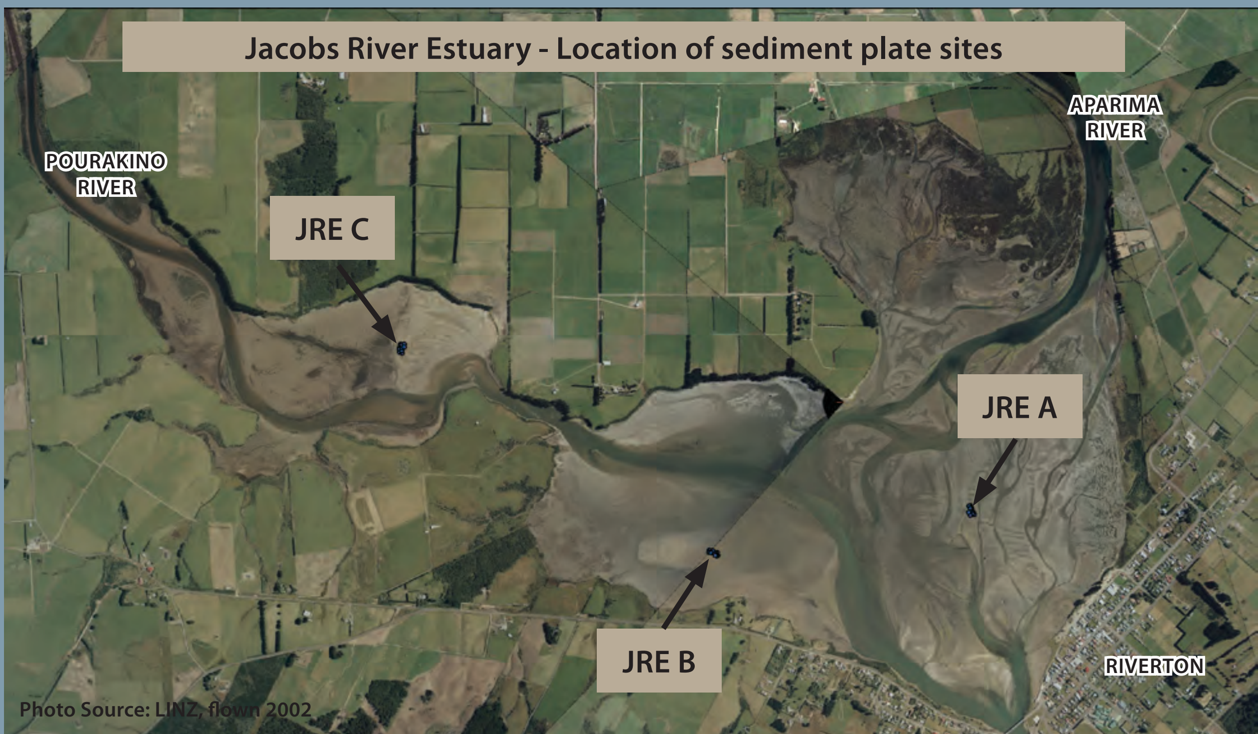
APPENDIX 1. SEDIMENT PLATE LOCATIONS

Site	Plate	NZGD2000 NZTM East	NZGD2000 NZTM North	NZMG 260 East	NZMG 260 North	2011 height/ depth (mm)*
JRE A	Peg 1	1216362	4855928	2126170	5417975	150
	Peg 2	1216360	4855924	2126169	5417970	150
	Peg 3	1216359	4855919	2126167	5417966	150
	Plate 1	1216361	4855927	2126170	5417973	202
	Plate 2	1216361	4855925	2126169	5417971	256
	Plate 3	1216360	4855923	2126168	5417969	231
	Plate 4	1216359	4855920	2126168	5417966	232
JRE B	Peg 1	1214906	4855311	2124715	5417361	190
	Peg 2	1214910	4855308	2124719	5417358	190
	Peg 3	1214914	4855304	2124723	5417355	190
	Plate 1	1214908	4855309	2124717	5417360	202
	Plate 2	1214909	4855308	2124718	5417359	199
	Plate 3	1214912	4855306	2124721	5417357	196
	Plate 4	1214913	4855305	2124722	5417356	194
JRE C	Peg 1	1212947	4856458	2122761	5418511	150
	Peg 2	1212942	4856458	2122757	5418512	150
	Peg 3	1212936	4856458	2122751	5418512	150
	Plate 1	1212945	4856458	2122759	5418511	105
	Plate 2	1212943	4856458	2122757	5418511	90
	Plate 3	1212941	4856458	2122756	5418512	107
	Plate 4	1212939	4856458	2122754	5418512	120

Baseline against which future change to be measured.



APPENDIX 1. DETAILS ON ANALYTICAL METHODS

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

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

APPENDIX 2. 2011 DETAILED RESULTS

Physical and chemical results for Jacobs River Estuary, 20 February 2011.

Site	Rep.*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt@15°C	%				mg/kg							
JRA	1-4	0	31	0.16	4.7	95.3	0.1	0.076	10.9	25	13.5	3.5	59	500	480
JRA	5-8	0	31	0.11	8.4	91.1	0.5	0.073	10.5	25	13.1	3.4	57	500	520
JRA	9-10	0	31	0.12	7.6	92.4	0.1	0.071	10.4	25	13	3.4	59	500	500
JRB	1-4	1	30	0.16	5.6	94.4	0.1	0.022	6.8	6.1	5.8	1.66	16.5	500	196
JRB	5-8	1	30	0.17	0.8	98.2	0.9	0.02	6.3	4.8	5.1	1.59	14	500	177
JRB	9-10	1	30	0.19	8.1	91.8	0.1	0.029	8	7.6	6.3	1.88	20	500	240
JRC	1-4	1	31	0.23	5.7	94	0.3	0.017	7.3	5.9	5.1	1.91	17.8	500	240
JRC	5-8	1	31	0.21	5.7	93.1	1.2	0.015	6.4	4.6	4.5	1.49	15.3	500	210
JRC	9-10	1	31	0.24	2.8	96.8	0.4	0.016	7.2	4.9	5.1	1.55	17.2	500	250

* composite samples

Station Locations

JRE A	JRE A-01	JRE A-02	JRE A-03	JRE A-04	JRE A-05	JRE A-06	JRE A-07	JRE A-08	JRE A-09	JRE A-10
NZTM260 East	1215965	1215958	1215951	1215946	1215940	1215946	1215949	1215955	1215946	1215938
NZTM260 North	4855588	4855602	4855617	4855631	4855630	4855617	4855600	4855590	4855584	4855597

JRE B	JRE B-01	JRE B-02	JRE B-03	JRE B-04	JRE B-05	JRE B-06	JRE B-07	JRE B-08	JRE B-09	JRE B-10
NZTM260 East	1214652	1214642	1214628	1214612	1214610	1214620	1214637	1214653	1214650	1214641
NZTM260 North	4855391	4855391	4855402	4855403	4855394	4855392	4855385	4855377	4855374	4855376

JRE C	JRE C-01	JRE C-02	JRE C-03	JRE C-04	JRE C-05	JRE C-06	JRE C-07	JRE C-08	JRE C-09	JRE C-10
NZTM260 East	1213032	1213028	1213027	1213028	1213040	1213039	1213041	1213039	1213051	1213050
NZTM260 North	4856457	4856441	4856431	4856415	4856412	4856425	4856438	4856455	4856457	4856442

Epifauna (numbers per 0.25m² quadrat) - 20-21 February 2011

JRE A

Scientific name	Common name	JRE A-01	JRE A-02	JRE A-03	JRE A-04	JRE A-05	JRE A-06	JRE A-07	JRE A-08	JRE A-09	JRE A-10
Amphibola crenata	Estuarine mud snail						1				

JRE B

Scientific name	Common name	JRE B-01	JRE B-02	JRE B-03	JRE B-04	JRE B-05	JRE B-06	JRE B-07	JRE B-08	JRE B-09	JRE B-10
Amphibola crenata	Estuarine mud snail	3	1	1		2	1	3	4	6	
Austrovenus stutchburyi	Cockle	1									

JRE C

Scientific name	Common name	JRE C-01	JRE C-02	JRE C-03	JRE C-04	JRE C-05	JRE C-06	JRE C-07	JRE C-08	JRE C-09	JRE C-10
Amphibola crenata	Estuarine mud snail	2	14	11	10		3	4	5		14
Potamopyrgus estuarinus	Estuarine snail			1		1				7	

Algae (Percent cover) - 20-21 February 2011

Station:	JRE A-01	JRE A-02	JRE A-03	JRE A-04	JRE A-05	JRE A-06	JRE A-07	JRE A-08	JRE A-09	JRE A-10
Ulva intestinalis	1	5	1	5	1	5	5	1	1	5

Station:	JRE B-01	JRE B-02	JRE B-03	JRE B-04	JRE B-05	JRE B-06	JRE B-07	JRE B-08	JRE B-09	JRE B-10
Gracilaria chilensis				1	5	1		1		
Ulva intestinalis	1		5	1	5	5	1	1	1	1
Ulva lactuca			1							

Scientific name	JRE C-01	JRE C-02	JRE C-03	JRE C-04	JRE C-05	JRE C-06	JRE C-07	JRE C-08	JRE C-09	JRE C-10
Gracilaria chilensis	1					1				

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

See following page.

APPENDIX 2. 2011 DETAILED RESULTS (CONTINUED)

Taxa	AMBI	AMBI	MUD	JR A-01	JR A-02	JR A-03	JR A-04	JR A-05	JR A-06	JR A-07	JR A-08	JR A-09	JR A-10	JR B-01	JR B-02	JR B-03	JR B-04	JR B-05	JR B-06	JR B-07	JR B-08	JR B-09	JR B-10	JR C-01	JR C-02	JR C-03	JR C-04	JR C-05	JR C-06	JR C-07	JR C-08	JR C-09	JR C-10
Anthozoa	*Edwardsia* sp.#1	II	NA	6	2	4	3	2		5	2	2	2	9	2	3	3	3	6	3	3	8	3				1		1	1		2	
Nemertea	Nemertea sp.#1	III	3							1																							
	Nemertea sp.#2	III	3									1		1	1	2	1	2	2	1	1	1	1	1	1	1	1					3	1
	Nemertea sp.#5	III	3																							1					1		
Polychaeta	*Aglaophamus macroura*	II	NA	1	1		3			4	1	1	1	1	1	2		2	1	1	2	2	1		1	2		2	2	2			2
	Aonides sp.#1	III	1	21	38	37	71	41	16	10	50	25	50	25	23	28	27	30	31	22	12	10	14										
	Boccardia (Paraboccardia) acus	I	2											1																			
	Boccardia (Paraboccardia) syrtis	I	2	13	4	7	3	9		4	9	2		10	27	5	7	11	10	6	20	5	4				1	1					
	Capitella sp.#1	V	3															1						7		9	2		1	22	15	3	39
	Hesionidae sp.#2	II	NA	2																													
	Heteromastus filiformis	IV	3	2	2			1	4		6	2	1	5	1	3		2	1	1		4	3										
	Microspio maori	II	3	13	15	2	16	3		2	4	14	9							2	1	2		20	7	6	2	2	14	48	13	2	5
	Nicon aestuariensis	III	4		2					1				2	4	2	2	5	6	5	5	6	5	1	4	2	1		2		2		1
	Orbinia papillosa	I	4				1		1				1	1	1	2	1			1	1		1										
	Paraonidae sp.#1	III	3												1		1			2		1	4										
	Pectinaria australis	I	NA													1							2										
	Prionospio aucklandica	IV	3											3	1	1	1	2	1	1	3		2										
	Sabellidae sp.#1	I	NA													2						2					1						
	Scolecolepides benhami	III	5	5	29	4	2	1	1	38	3	2			1	5	2	1	1	2	1	8	3	16	21	11	10	4	5	13	19	7	7
	Scoloplos (Scoloplos) cylindrifer	I	2													1		1															
	Sphaerosyllis hirsuta	II	2													1			1														
Oligochaeta	*Oligochaeta*	I							3	1		13	3	8	7	30	26	18	4	7	3	1			4		1						
Gastropoda	*Amphibola crenata*	NA	NA									1						1						4	12	6	7	6	11	1	9	8	3
	Cominella glandiformis	NA	1					1			1							1	1			1											
	Notoacmaea helmsi	NA	1					1									1																
	Potamopyrgus antipodarum	III	4																					197	246	301	121	181	67	161	254	53	15
	Potamopyrgus estuarinus	III	4																					5	12	11	4	7	4	5	11	14	2
Bivalvia	Arthritica sp.#1	I	3											1	1	4			1				2	1	9	3	2	2	2	1	4	4	5
	Austrovenus stutchburyi	I	2	1		1			1	1	1		1	3	3		2	2	2	3	6	2	2	2	1	2	1	3	2	1	1	1	
	Macomona liliana	I	2								1	1		7	5	4	4	5	5	6	5	7	6										
	Paphies australis	II	1	80	47	95	65	67	35	63	20	46	25										1			1	6	6	1			2	10
Crustacea	Amphipoda sp.#1	NA	NA	3	1		5	1	3	3		5	1	18	2	2	8	2	1	9	5		7	2	2	4				2	3		
	Amphipoda sp.#2	NA	NA																					2						10	1		
	Colurostylis sp.#1	NA	2			1	2	1	1	12	3	2					3		2	2			1		1	1		8	6	2		1	6
	Exosphaeroma planulum	NA	NA					1		1						1									3			1		3			1
	Halicarcinus whitei	NA	NA									1		1	1			1															
	Paracorophium excavatum	III	5																					13	5	5		4	3	2	1	3	13
	Tenagomysis sp.#1	II	NA								1	3	1													1		10	124	29	9	3	16
Total species in sample				**12**	**10**	**8**	**10**	**12**	**8**	**13**	**14**	**16**	**10**	**16**	**17**	**19**	**15**	**18**	**17**	**17**	**14**	**15**	**19**	**14**	**14**	**17**	**15**	**14**	**16**	**16**	**14**	**14**	**15**
Total specimens in sample				**148**	**141**	**151**	**171**	**129**	**62**	**145**	**105**	**109**	**92**	**101**	**78**	**77**	**70**	**102**	**98**	**85**	**69**	**66**	**65**	**272**	**325**	**367**	**164**	**237**	**246**	**303**	**343**	**106**	**126**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group	Species	Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Hirudinea	Hirudinea sp.1	NA	NA	Unidentified leech. Leeches are most common in warm, protected shallows where there is little disturbance from currents. Free-living leeches avoid light and generally hide and are active or inactive under stones or other inanimate objects, among aquatic plants, or in detritus. Some species are most active at night. Silted substrates are unsuitable for leeches because they cannot attach. Some species can tolerate mild pollution.
Anthozoa	*Anthopleura aureoradiata*	II	SS Optimum range 5-10% mud,* distribution range 0-15%*	Mud flat anemone, attaches to cockle shells and help reduce the rate at which cockles accumulate parasites. Grows up to 10mm, intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al., 2001). Very tolerant to a range of Polycyclic Aromatic Hydrocarbons (PAH's). *Anthopleura* are also tolerant to UV light, because they have mycosporine-like amino acids in their tissue which act like a biological sunscreen. It has green plant cells in its tissues that convert solar energy to food. Its column is rough with warts.
Anthozoa	*Edwardsia* sp.#1	II	NA	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
Nemertea	Nemertea sp.	III	I Optimum range 55-60% mud,* distribution range 0-95%*	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp	III	M Mud tolerant.	Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5mm mesh sieve. Generally reside in the upper 2.5cm of sediment. Intolerant of anoxic conditions.
Polychaetes	*Abarenicola affinis*	III	NA	An endemic species that belongs to Family Arenicolidae. Lower shore, burrowing in medium to fine, sheltered sands and discharging a pile of sandy coils on the surface. *Abarenicola affinis* thrives in organically enriched sediments. The once well-known *Abarenicola affinis* population of Wellington's Petone Beach has dwindled greatly in number since the closure of an abattoir outfall, and now Otago Harbour may have New Zealand's biggest population of lugworms.
Polychaetes	*Aglaophamous macroura.*	II	NA	A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate. Feeding type is carnivorous. Significant avoidance behaviour by other species. Feeds on *Heteromastus filiformis, Orbinia papillosa* and *Scoloplos cylindrifer* etc.
Polychaetes	*Aonides oxycephala*	III	SS Optimum range 0-5% mud*, distribution range 0-80%**.	A small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. Although Aonides is free-living, it is not very mobile and prefers to live in fine sands. Aonides is very sensitive to changes in the silt/clay content of the sediment. **But is generally tolerant of organically enriched situations.** In general, polychaetes are important prey items for fish and birds.
Polychaetes	*Boccardia (Paraboccardia) syrtis and acus*	I	S Optimum range 10-15% mud,* distribution range 0-50%*	Small surface suspension-feeding spionids (also capable of detrital feeding). Prefers sand with low-mod mud content but found in a wide range of sand/mud. **Prefers 10-15% mud but can live in 0-50% mud.** It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions. When in dense beds, the community tends to encourage build-up of muds.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaetes	*Capitella capitata*	V	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *Heteromastus f.*	A blood red capitellid polychaete which is **very pollution tolerant.** Common in suphide rich anoxic sediments.
	Glyceridae	II	I Optimum range 10-15% mud,* distribution range 0-95%*	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15cm. They are distinguished by having 4 jaws on a long eversible pharynx. **Intolerant of anoxic conditions. Prefer 10-15% mud but found in wide range. Intolerant of low salinity.**
	Heteromastus filiformis	IV	I Optimum range 10-15% mud,* distribution range 0-95%*	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate to high organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	Microspio maori	III	S Expect optimum range in 0-20% mud.	A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in low numbers in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary very abundant (5% mud, moderate organic enrichment). Prey items for fish and birds.
	Nereidae	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of high sulphide concentrations.
	Nicon aestuariensis	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. **Prefers to live in moderate mud content sediments.**
	Orbinia papillosa	1	S Optimum range 5-10% mud,* distribution range 0-50%*	Family Orbiniidae. Live in sandy or fine sand sediments. Do not have a burrow. A large non selective deposit feeder. Endemic orbiniid. Without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant. Prefers 5-10% mud but found from 0-50% mud. Sensitive to changes in sedimentation rate. Low numbers in Bluff Harbour (2-20% mud), New River Estuary (1-6% mud).
	Owenia petersenae	II	NA	Oweniidae. Members of the Oweniidae have characteristic tubes which are considerable longer than the animal and are composed of shell fragments and sand grains which are stacked on top of each other. Oweniids often remain intact within their tubes and must be carefully removed for proper examination. *O. fusiformis* is currently thought to include a variety of species. Normally a suspension feeder, but is capable of detrital feeding. Is a cosmopolitan species frequently abundant on sandflats. **Are classified as intermediate type species along organic enrichment gradients (Pearson and Rosenberg 1978).**

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaetes	Paraonidae sp.#1	III	NA	Slender burrowing worms, selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands to a depth of 15cm. Sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content. **Aricidea prefer 35-40% mud (range 0-70% mud).**
	Pectinaria australis	I	NA	Subsurface deposit-feeding/herbivore. Lives in a cemented sand grain cone-shaped tube. Feeds head down with tube tip near surface. Prefers fine sands to muddy sands. Mid tide to coastal shallows. Belongs to Family Pectinariidae. Often present in NZ estuaries. **Density may increase around sources of organic pollution and eelgrass beds. Intolerant of anoxic conditions.**
	Phyllodocidae	II	NA	The phyllodocids are a colourful family of long, slender, and very active carnivorous worms characteristically possessing enlarged dorsal and ventral cirri which are often flattened and leaf-like (paddleworms). They are common intertidally and in shallow waters.
	Polydora sp	I	S Optimum range 10-15% mud,* distribution range 0-50%*	A Spionid. Polydora-group have many NZ species. Difficult to identify unless complete and in good condition. The Polydora group of species specialise in boring into shells. *Boccardia acus* bores into the upper exposed shell of the cockle *Austrovenus stutchburyi*. Several other Polydora group species live free in tubes in the sand. The tubes of the most widely-occurring species, *Boccardia syrtis*, form a visible fine turf on sandstone reefs and on some sand flats.
	Polynoidae	II	NA	The polynoid scale worms are dorsoventrally flattened predators. Lower intertidal and subtidal to deep sea throughout New Zealand. Conspicuous but never abundant.
	Prionospio aucklandica originally *Aquilaspio aucklandica.*	IV	I Optimum range 65-70% mud* or 20- 50%**, distribution range 0-95%*. Sensitive to changes in sediment mud content.	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was originally *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A suspension feeding spionid (also capable of detrital feeding) that **prefers living in muddy sands (65-70% mud) but doesn't like higher levels.** But animals found in 0-95% mud. **Commonly an indicator of increase in mud content. Tolerant of organically enriched conditions.** Common in Freshwater estuary (<1% mud). Present in Waikawa (10% mud), Jacobs River Estuary (5-10% muds).
	Sabellidae sp.#1	I	NA	Sabellids are not usually present in intertidal sands, though some minute forms do occur low on the shore. They are referred to as fan or feather-duster worms and are so-called from the appearance of the feeding appendages, which comprise a crown of two semicircular fans of stiff filaments projected from their tube.
	Scolecolepides benhami	III	MM Optimum range 25-30% mud,* distribution range 0-100%*	A Spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. **Strong Mud Preference but prefers moderate mud content (25-30% mud).** But also found in 0-100% mud environments. Rare in Freshwater Estuary (<1% mud) and Porirua Estuary (5-10% mud). Common in Whareama (35-65% mud), Fortrose Estuary (5% mud), Waikanae Estuary 15-40% mud. Moderate numbers in Jacobs River Estuary (5-10% muds) and New River Estuary (5% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Rrm, New River Estuary.
	Scolelepis (Microspio) sp	III	NA	A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary (5% mud),

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaetes	*Scoloplos cylindrifer*	I	S Optimum range 0-5% mud,* distribution range 0-60%*	Originally, *Haploscoloplos cylindrifer.* Belongs to Family Orbiniidae which are thread-like burrowers without head appendages. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. **Prefers 0-5% mud (range 0-60% mud).** **Pollution and mud intolerant**.
Polychaetes	Syllidae	II	S Optimum range 25-30% mud,* distribution range 0-40%*	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers mud/sand sediments (25-30% mud).
Gastropoda	*Amphibola crenata*	NA	NA	A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria.
Gastropoda	*Cominella glandiformis*	NA	SS Optimum range 5-10% mud*, distribution range 0-10%**.	Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds. **Strong Sand Preference. Optimum mud range 5-10% mud.**
Gastropoda	*Diloma subrostrata*	NA	SS Optimum range 5-10% mud*, distribution range 0-15%**.	The mudflat top shell, lives on mudflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ. Feeds on the film of microscopic algae on top of the sand. **Strong Sand Preference . Optimum mud range 5-10% mud.**
Gastropoda	*Notoacmaea helmsi*	I	SS Optimum range 0-5% mud*, distribution range 0-10%**.	Endemic to NZ. Small grazing limpet attached to stones and shells in intertidal zone. **Intolerant of anoxic surface muds and sensitive to pollution.** **Strong sand preference 0-5% mud (range 0-10% mud).** Present in Porirua Harbour 4-5% mud, Freshwater estuary <1% mud. A few in Fortrose (5% mud).
Gastropoda	*Potamopyrgus estuarinus*	NA	M Tolerant of muds.	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feed on decomposing animal and plant matter, bacteria, and algae. **Intolerant of anoxic surface muds. Tolerant of muds.**
Bivalves	*Arthritica bifurca*	III	I Optimum range 55-60% mud*, or 20-40%***, distribution range 5-70%**.	A small sedentary deposit feeding bivalve, preferring a moderate mud content. Lives greater than 2cm deep in the muds. **Prefers 55-60% mud (range 5-70% mud).**
Bivalves	*Austrovenus stutchburyi*	II	S Prefers sand with some mud (optimum range 5-10% mud* or 0-10% mud**, distribution range 0-85% mud**).	Family Veneridae. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. **Can live in both mud and sand but is sensitive to increasing mud - prefers low mud content (5-10% but can be found in 0-60% mud). Rarely found below the RPD layer.** Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns.
Bivalves	*Hunkydora australica novozelandica*	NA	NA	Belongs to the Family Myochamidae, large marine bivalves of the Pholadomyoida order. The valves are unequal, the left valve flat, and the right convex, and overlapping the left. DOC threat classification 7 - range restricted.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group	Species	Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Bivalves	*Macomona liliana*	II	S Prefers sand with some mud (optimum range0-5% mud* distribution range 0-40% mud**).	A deposit feeding wedge shell. This species lives at depths of 5–10cm in the sediment and uses a long inhalant siphon to feed on surface deposits and/or particles in the water column. Rarely found beneath the RPD layer. Adversely affected at elevated suspended sediment concentrations. Sand Preference: **Prefers 0-5% mud (range 0-60% mud).**
Bivalves	*Mactra Ovata (Cyclomactra ovata)*	I	NA	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water. Mud Tolerance; prefers 0-10% mud (range 0-80%).
Bivalves	*Nucula hartvigiana*	I	S Optimum range 0-5% mud,* distribution range 0-60%*	Small deposit feeder. Nut clam of the family Nuculidae (<5mm), is endemic to New Zealand. Often abundant in top few cm. It is found intertidally and in shallow water, especially in *Zostera* sea grass flats. It is often found together with the New Zealand cockle, *Austrovenus stutchburyi*, but is not as abundant. Like *Arthritica* this species feeds on organic particles within the sediment. Has a plug-like foot, which it uses for motion in mud deposits. **Intolerant of organic enrichment.** Prefers 0-5% mud (range 0-60%). High abundance in Porirua Harbour near sea (Railway and Boatshed sites). None in Freshwater estuary.
Bivalves	*Paphies australis*	II	SS (adults) S or M (Juveniles) Strong sand preference (adults optimum range 0-5% mud*, distribution range 0-5% mud**). Juveniles often found in muddier sediments.	The pipi is endemic to New Zealand. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7m. **Optimum mud range 0-5% mud and very restricted to this range.** Common at mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud.
Bivalves	*Solletellina*	I	NA	*Soletellina* is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells.
Oligichaeta	Oligochaete sp.	I ?	MM Optimum range 95-100% mud*, distribution range 0-100%**.	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Crustacea	*Amphipoda* sp.1	NA	NA	An unidentified amphipod.
Crustacea	*Austrominius modestus*	II	NA	Small acorn barnacle (also named *Elminius modestus)*. Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones.

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Organic Enrichment Tolerance- AMBI Group *****	Mud Tolerance ****	Details
Crustacea	*Callianassa filholi*	NA	NA	Ghost shrimp, Decapoda, endemic to NZ. Makes long, semi-permanent burrows between low water of neap and spring. Up to 5cm long it is pale milk white with coral pink. Can't walk on a firm surface. A male and a female normally occupy a burrow. When feeding the shrimp moves close to one of the entrances.
	Copepoda	NA	NA	Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat and they constitute the biggest source of protein in the oceans. Usually having six pairs of limbs on the thorax. The benthic group of copepods (Harpactacoida) have worm-shaped bodies.
	Cumacea	NA	NA	Cumacea is an order of small marine crustaceans, occasionally called hooded shrimps. Some species can survive in water with a lower salinity rate, like in brackish water (e.g. estuaries). Most species live only one year or less, and reproduce twice in their lifetime. Cumaceans feed mainly on microorganisms and organic material from the sediment. Species that live in the mud filter their food, while species that live in sand browse individual grains of sand.
	Decapoda (larvae)	NA	NA	Unidentified crab larvae.
	Exosphaeroma sp.	NA	NA	Small seaweed dwelling isopod.
	Flabellifera	NA	NA	Flabellifera is the second largest isopod suborder.
	Macrophthalmus hirtipes	NA	I Optimum range 45-50% mud, distribution range 0-95%*.	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
	Mysidacea sp.1	II	NA	Mysidacea is a group of small, shrimp-like creatures. They are sometimes referred to as opossum shrimps. Wherever mysids occur, whether in salt or fresh water, they are often very abundant and form an important part of the normal diet of many fishes
Osteichthyes	*Peltorhamhus novaezelandiae*	NA	NA	Juvenile common sole. The young of many adult flatfish species are strongly dependent on estuarine areas. In New River estuary many juvenile flatfish inhabit the small channels at low tide and are preyed on by other fish. Flatfish depend on benthic invertebrates as a food source with diet consisting of mainly small crabs, worms and crustaceans. Flatfish are fast growing and are a relatively dependable fishery from year to year.
Pycnogonidae	Pycnogonid sp.	I	NA	Sea spiders either walk along the bottom with their stilt-like legs or swim just above it using an umbrella pulsing motion.[1] Most are carnivorous and feed on cnidarians, sponges, polychaetes and bryozoans. Sea spiders are generally predators or scavengers. They will often insert their proboscis, a long appendage used for digestion and sucking food into its gut, into a sea anemone and suck out nourishment. The sea anemone, large in comparison to its predator, almost always survives this ordeal. Studies have shown that adult taste preferences depend on what the animals were fed as young

APPENDIX 3. INFAUNA CHARACTERISTICS

NA=Not Allocated

* Preferred and distribution ranges based on findings from the Whitford Embayment in the Auckland Region (Norkko et al. 2001).
** Preferred and distribution ranges based on findings from 19 North Island estuaries (Gibbs and Hewitt 2004).
*** Preferred and distribution ranges based on findings from Thrush et al. (2003)

**** Tolerance to Mud Codes are as follows (from Gibbs and Hewitt, 2004, Norkko et al. 2001) :

1 = SS, strong sand preference.
2 = S, sand preference.
3 = I, prefers some mud but not high percentages.
4 = M, mud preference.
5 = MM, strong mud preference.

***** AMBI Sensitivity to Organic Enrichment Groupings (from Borja et al. 2000)

Group I. Species very sensitive to organic enrichment and present under unpolluted conditions (initial state). They include the specialist carnivores and some deposit-feeding tubicolous polychaetes.
Group II. Species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.
Group III. Species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations). They are surface deposit-feeding species, as tubicolous spionids.
Group IV. Second-order opportunistic species (slight to pronounced unbalanced situations). Mainly small sized polychaetes: subsurface deposit-feeders, such as cirratulids.
Group V. First-order opportunistic species (pronounced unbalanced situations). These are deposit-feeders, which proliferate in reduced sediments.
The distribution of these ecological groups, according to their sensitivity to pollution stress, provides a Biotic Index with 5 levels, from 0 to 6.