Wriggle

coastalmanagement

Haldane Estuary

Fine Scale Monitoring 2010/11

Prepared
for
Environment Southland
June 2011

Cover Photo: Haldane Estuary

Northern Haldane Estuary looking to the southwest

Haldane Estuary

Fine Scale Monitoring 2010/11

Prepared for
Environment Southland

By

Barry Robertson and Leigh Stevens

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

Contents

List of Figures

List of Tables

All photos by Wriggle except where noted otherwise.

HALDANE ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of four years (2006, 2009, 2010 and 2011) of fine scale monitoring of one intertidal site within Haldane Estuary, a 206ha, tidal lagoon estuary with a small freshwater influence, on the Eastern Southland coast. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. The following table summarises fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

FINE SCALE MONITORING RESULTS

- Sediment plates indicate a "very low to moderate" rate of sedimentation after two years.
- Mud content increased by 25% since 2009 and benthic invertebrates indicated disturbed conditions.
- The benthic invertebrate mud tolerance rating was "high" - dominated by mud tolerant species only.
- Sediment Oxygenation: RPD was 3cm deep indicating moderate oxygenation.
- The benthic invertebrate organic enrichment rating was "good" - dominated by organisms tolerant to slight enrichment.
- The indicator of organic enrichment (Total Organic Carbon) was at low concentrations in all years.
- Nutrient enrichment indicators (TN and TP) were at low-moderate concentrations in all years.
- Heavy metals were well below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity).
- Macroalgal cover was low.

CONDITION RATINGS

	Site A 2006	Site A1 2009	Site A1 2010	Site A1 2011
Sedimentation Rate	NA	NA	Low	Very Low-Moderate
Invertebrates (mud tolerance)	High	High	High	High
RPD Profile (sediment oxygenation)	Good	Good	Fair	Fair
TOC (Total Organic Carbon)	Very Good	Very Good	Very Good	Very Good
Total Phosphorus (TP)	Good	Good	Good	Good
Total Nitrogen (TN)	Very Good	Very Good	Very Good	Very Good
Metals (Cd, Cu, Cr, Pb, Zn)	Very Good	Very Good	Very Good	Very Good
Metals (Ni)	Good	Good	Good	Good
Invertebrates (organic enrichment)	Good	Good	Good	Good

ESTUARY CONDITION and ISSUES

Overall, the four years of baseline monitoring shows that the dominant upper estuary intertidal habitat (i.e. unvegetated tidal-flat) in Haldane Estuary was generally in a fair to moderate condition. The presence of elevated mud contents, low RPD and a benthic invertebrate community dominated by high numbers of a few mud tolerant species, suggests that the upper half of the main estuary basin is currently experiencing sedimentation problems - particularly related to excessive muddiness. It is expected that the lower estuary is in a better condition and hence is recommended as a site for future monitoring.

RECOMMENDED MONITORING AND MANAGEMENT

Following completion of 4 years of baseline monitoring, fine scale monitoring (including sedimentation rate) should now be undertaken at 5 yearly intervals with the next survey scheduled to take place in February 2016. An additional site is also recommended for the lower estuary. In order to address suspected patchiness in the upper estuary in relation to sedimentation, it is recommended that additional sediment plates be deployed and sedimentation rate monitored annually.

The fine scale monitoring results reinforce the need for management of fine sediment and nutrient sources entering the estuary. It is recommended that sources of elevated loads in the catchment be identified and management undertaken to minimise their adverse effects on estuary uses and values. Because the estuary has been historically cut-off from its high value saltmarsh habitat through causeway development, it is recommended that plans be developed to improve this connection.

1. INTRODUCTION

HALDANE ESTUARY

Vulnerability Assessment
Identifies issues and recommends monitoring and management. Completed in 2008 (Robertson and Stevens 2008)

Haldane Estuary Issues
Low eutrophication
Moderate sedimentation
Habitat Loss (saltmarsh, dune and terrestrial margin)

Monitoring

Broad Scale Mapping
Sediment type
Saltmarsh
Seagrass
Macroalgae
Land margin

5 -10 yearly
First undertaken in 2005.
Macroalgae not yet undertaken.

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

4yr Baseline then 5 yearly
Baseline now completed.
Next survey 2016.

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
Eutrophication
Sedimentation
Toxicity
Habitat (saltmarsh, terrestrial margin)

Recommended Management
- Limit intensive landuse.
- 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, Waiau Lagoon, and Lake Brunton.

ES began monitoring Haldane Estuary in February 2006, with the work being undertaken by Wriggle Coastal Management using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions.

The Haldane Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** of the estuary to major issues (Table 1) and appropriate monitoring design. This component has been completed for Haldane 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 2005 (Stevens and Asher 2005).
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 Haldane Estuary, has been undertaken in 2006, 2009 and 2010. The February 2011 monitoring is the subject of the current report.

Haldane Estuary is a medium-sized "tidal lagoon" type estuary (area 206ha), that discharges to the beach at the western end of Haldane Bay. Situated at the confluence of the Waikopikopiko and the Waionepu Streams, it drains a primarily native bush catchment. The estuary is relatively shallow (mean depth approximately 1-2m) and bordered primarily by grazed pasture. The estuary has extensive tidal flats (>80% of estuary exposed at low tide), but much of its saltmarsh habitat (>30ha) was cutoff from the estuary when a road was established within it.

As a consequence of the much lower saltmarsh area, the estuary is expected to be more vulnerable to such issues as eutrophication and sedimentation (given that saltmarsh acts to reduce nutrient and sediment impacts), despite the fact that the estuary is well flushed (i.e. low residence time), and tidally-dominated.

A recent vulnerability assessment (Robertson and Stevens 2008) identified habitat loss (i.e. saltmarsh and terrestrial margin development) as the most significant issue in the estuary. It also indicated that sea level rise is likely to expand the estuary and improve habitat diversity, if estuary margins are allowed to naturally migrate inland.

Upper estuary sand and mud flats.

1. Introduction (Continued)

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

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

Table 2. Summary of the broad (unshaded - not in this report) and fine scale (shaded - in this report) EMP indicators.

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

2. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the EMP (Robertson et al. 2002) and provides detailed information on the condition of the estuary. Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary) are selected and samples collected and analysed for physical, chemical and biological variables. In 2006, one fine scale sampling site (Site A, Figure 1), was selected in unvegetated mid-low water mudflats, which is the dominant intertidal habitat in Haldane Estuary. A 60m x 30m area in the lower intertidal was marked out and divided into 12 equal sized plots. In 2009, the site was shifted slightly to get further away from the freshwater influence of the main input stream (renamed Site A1). In 2010, sampling Site A1 was again selected for monitoring. At the site, 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 recorded.
- At the site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. 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 (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).

Sedimentation Plate Deployment. Determining the future sedimentation rate involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried and levelled, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. One site (with four plates) was established in Haldane Estuary on 16 February 2009 (Figure 1). The site was located at Site A1 in muddy sand habitat in an area of the estuary where sedimentation rates are likely to be elevated. Four plates (20cm wide square concrete blocks) were buried at 5m, 10m, 20m, and 25m from the south eastern corner peg of Site A1. The GPS positions of each plate were logged, and the depth from the mud surface to the top of the sediment plate recorded (Appendix 2). These depths will be measured every 1-5 years and, over the long term, will provide a measure of rate of sedimentation in the estuary.

Figure 1. Haldane Estuary - location of fine scale monitoring sites and sediment plates (photo, ES 2004)

2. Methods (Continued)

CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented below) have been proposed for Haldane 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 ERP
Very High	>10mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

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 described on the following page. The equation to calculate the Mud Tolerance Biotic Coefficient (MTBC) is as follows;

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

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

BENTHIC COMMUNITY MUD TOLERANCE RATING

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

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 ERP
Poor	<1cm depth below sediment surface	Monitor at 2 year intervals. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Total Phosphorus

In shallow estuaries like Haldane, 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 Haldane, 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

2. Methods (Continued)

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, and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for other major contaminant classes: pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

METALS CONDITION RATING

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

Haldane Estuary

3. RESULTS AND DISCUSSION

OUTLINE

A summary of the results of the 2006, 2009, 2010 and 2011 fine scale monitoring of Haldane Estuary is presented in Table 3 (detailed results for 2011 in Appendices 2 and 3). The results and discussion section is divided into three subsections based on the key estuary problems that the fine scale monitoring is addressing: eutrophication, sedimentation, and toxicity. Within each subsection, the results for each of the relevant fine scale indicators are presented. A summary of the condition ratings for each of the two sites is presented in the accompanying figures.

Table 3. Physical, chemical and macrofauna results (means) for Haldane Estuary.

Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. Species
	cm	ppt	%				mg/kg								No./m^2	No./core
A 2006	3	NA	0.85	16.6	83.3	0.1	0.100	10.1	4.1	7.0	2.2	23.9	313	393	32,595	4.7
A1 2009	3	30	0.27	29.7	70.3	0.1	0.027	9.9	5.5	7.5	2.6	27.7	590	356	54,270	4.5
A1 2010	3	30	0.43	41.4	58.6	0.1	0.016	9.8	5.0	6.8	2.6	27	583	370	56,070	4.6
A1 2011	3	30	0.47	43.4	56.6	0.1	0.02	10.1	5.63	7.23	2.8	29.3	563	370	51,362	4.2

SEDIMENTATION

Soil erosion is a major issue in New Zealand and the resulting suspended sediment impacts are of particular concern in estuaries because they act as a sink for fine sediments or muds. Sediments containing high mud content (i.e. around 30% with a grain size < 63 µm) are now typical in NZ estuaries that drain developed catchments. In such mud-impacted estuaries, the muds generally occur in the areas that experience low energy tidal currents and waves [i.e. the intertidal margins of the upper reaches of estuaries (e.g. Waihopai Arm, New River Estuary), and in the deeper subtidal areas at the mouth of estuaries (e.g. Hutt Estuary)] (Figure 2). In contrast, the main intertidal flats of developed estuaries (e.g. New River Estuary) 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 the mud content is extremely low (e.g. Freshwater Estuary, Stewart Island where the mud content is <1%), unless the catchment is naturally erosion-prone, with a low predominance of wetland filters. The Haldane Estuary catchment has a very low long-term mean erosion rate of 21 tSS.km^{-2}.yr^{-1} (Clues Model Default loads) and, although a significant area is developed, it still has 63% as undeveloped native forest. As a consequence, ongoing sedimentation should not be a major issue in this estuary unless excessive sediment loadings are still occurring from certain developed sections of the catchment (e.g. drain clearance, forest harvesting/clearance, and cultivation).

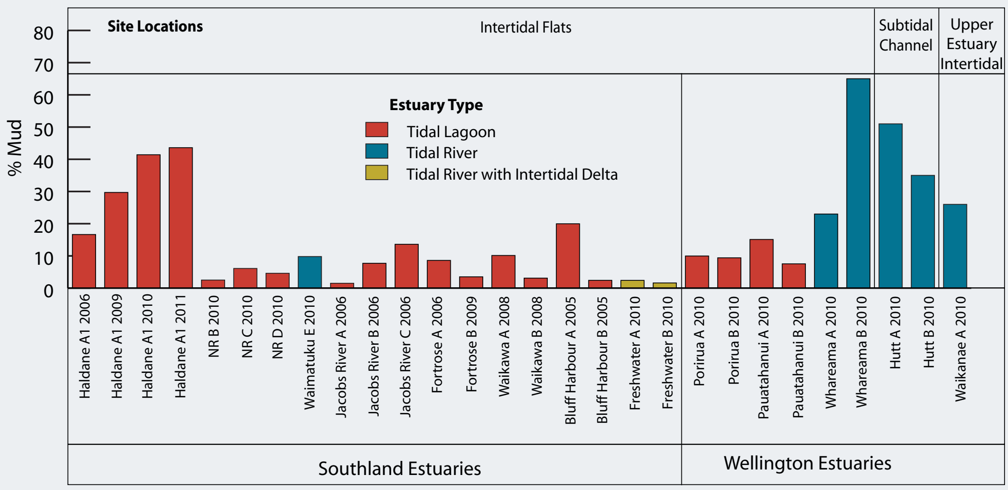

Figure 2. Percentage of mud at fine scale sites in NZ estuaries.

3. Results and Discussion (Continued)

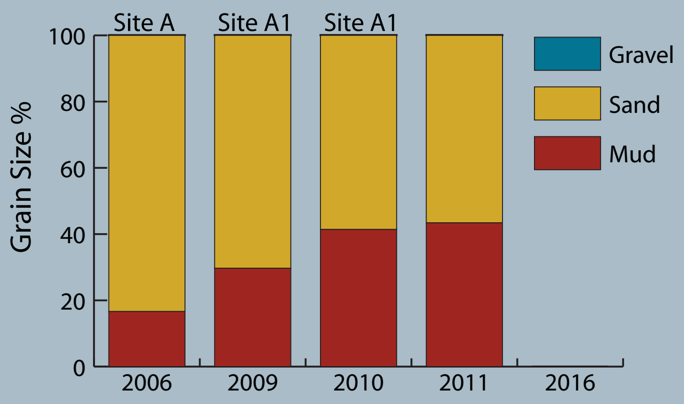

Figure 3. Grain size, Haldane Estuary.

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

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 mud content at the site increased massively from 29% mud in 2009 to 41% mud in 2010. There was a slight increase to 43.4% in 2011. Such a mud content is high compared with the dominant habitat at fine scale sites in other Southland estuaries (Figure 3). The source of these muds was almost certainly from the surrounding catchment.

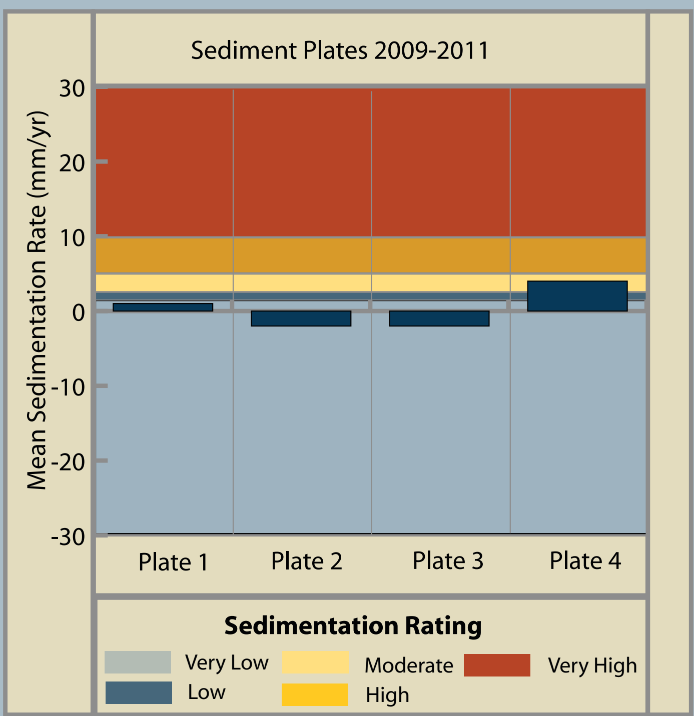

Figure 4. Haldane Estuary sedimentation rate.

2009 - 2011 SEDIMENTATION RATE RATING	Very Low - Moderate

Rate of Sedimentation

Four sedimentation plates were deployed in the estuary in February 2009 (Figure 1) to enable long term monitoring of sedimentation rates. Monitoring of the overlying sediment depth above each plate after two years of burial indicated a mean sedimentation rate of 0.3mm/yr (range -23.0 to 4.0 mm/yr).

Such findings indicate that the sedimentation rates at the intertidal flat at Site A1 in the upper part of the main body of the Haldane Estuary are currently stable and have returned to the 2009 levels, following the much higher levels recorded in 2010 when flooding occurred in the catchment. Deployment of additional plates in the upper estuary is recommended as a means of assessing whether current results are representative of other parts of the upper estuary.

Macro-invertebrate Tolerance to Muds

Sediment mud content is a major determinand of the structure of the benthic invertebrate community. This section examines this relationship in the Haldane 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 5 and 6).
2. Using multivariate techniques to explore whether the macro-invertebrate communities at Site A differs between each of the three years of monitoring (Figure 7).
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 Haldane Estuary macro-invertebrate community of monitoring from 2009-2011 (Figures 8 and 9).

The first step showed that the macro-invertebrate community in the Haldane Estuary was very different from communities present on the sand-dominated, intertidal flats of the main body of other NZ estuaries in that it had a very high mean abundance of individuals (51,360.m^{-2}) and a very low number of species (mean 4-5 per core) (Figures 5 and 6). Such community statistics are however typical of the disturbed areas of upper estuaries draining partially developed catchments.

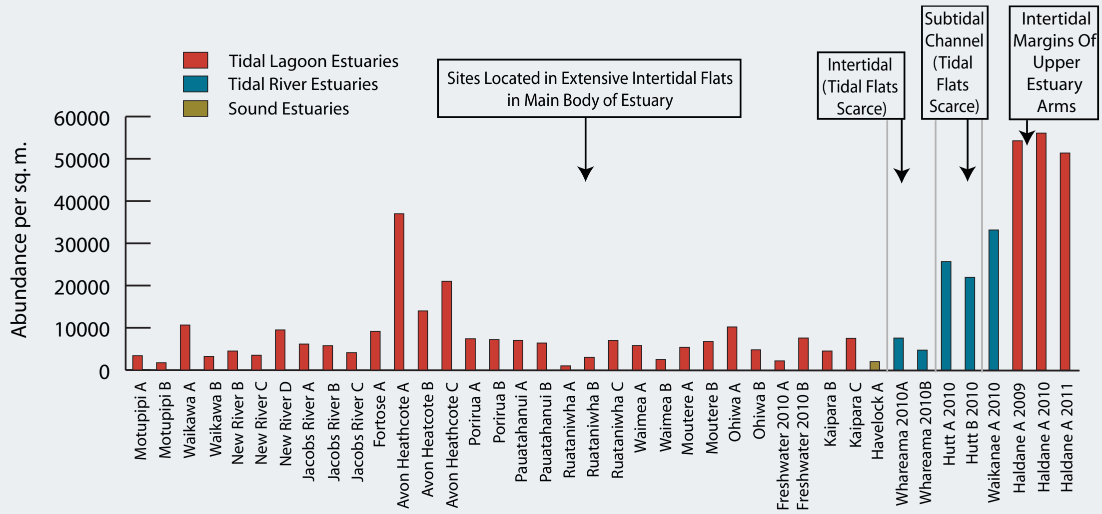

Figure 5. Mean total abundance of macrofauna, Haldane Estuary compared with other NZ estuaries.

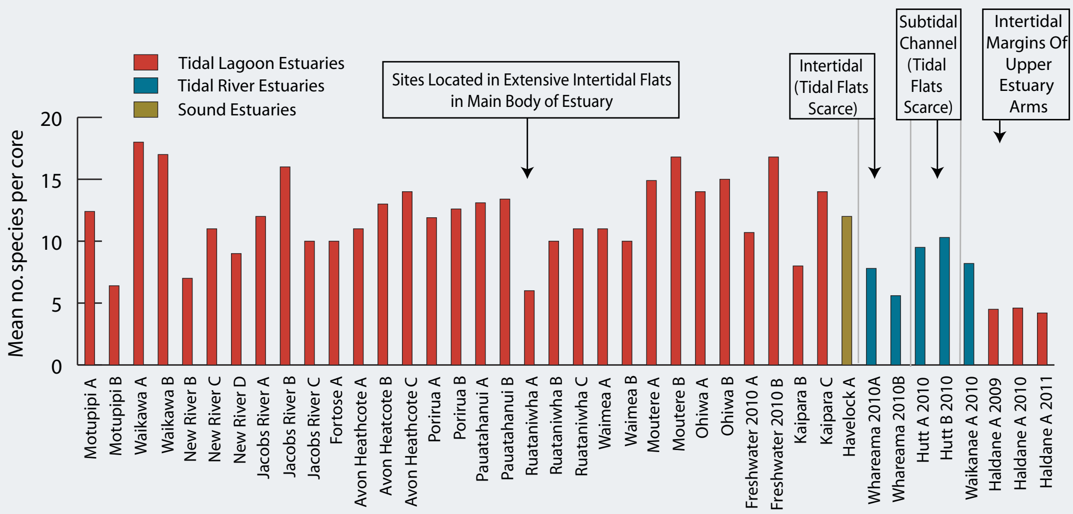

Figure 6. Mean number of infauna species, Haldane Estuary compared with other NZ estuaries (Source Robertson et al. 2002, Robertson and Stevens 2006).

3. Results and Discussion (Continued)

In the second step, the results of the multivariate analysis (NMDS Plot, Figure 7) show that there was a difference in benthic invertebrate community structure at the sites over the four years of monitoring.

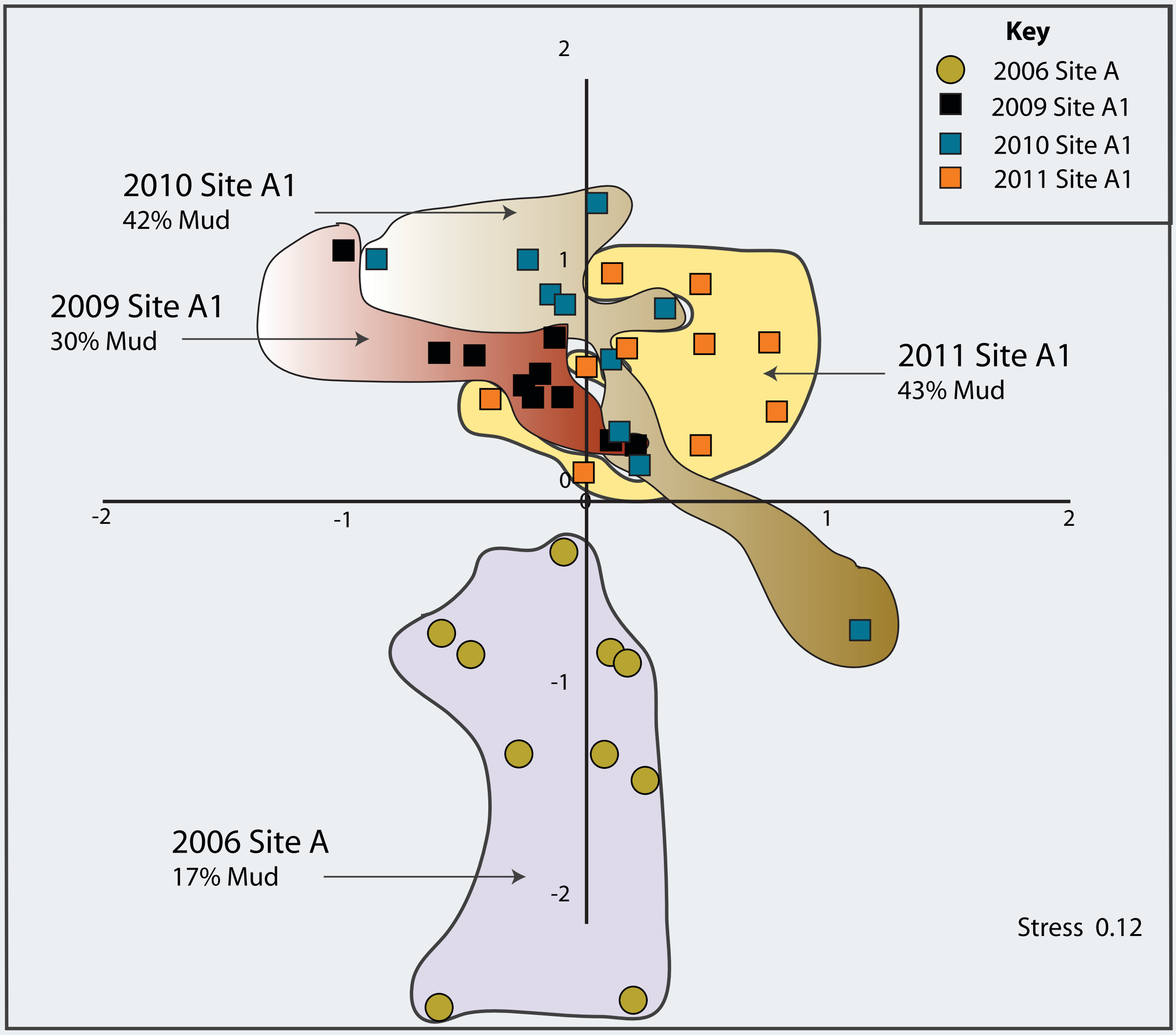

Figure 7. NMDS plot for Haldane Estuary.
Shows the relationship among samples in terms of similarity in macro-invertebrate community composition at sites A1 and A for the four years of sampling. The plot shows each of the 10 replicate samples for each year and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves multivariate data analysis methods, in this case nonmetric multidimensional scaling (NMDS) using PRIMER vers. 6.1.10. The analysis basically plots the site and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities i.e. how low the calculated stress value is. Stress values greater than 0.3 indicate that the configuration is no better than arbitrary and we should not try and interpret configurations unless stress values are less than 0.2.

3. Results and Discussion (Continued)

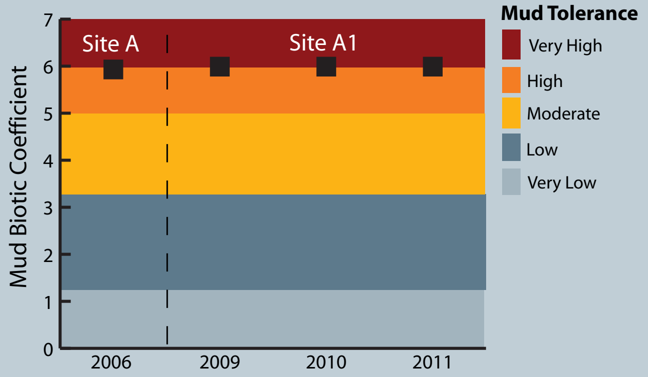

Figure 8. Mud tolerance macroinvertebrate rating.

In the third step, the results show that the Haldane Estuary macro-invertebrate mud tolerance rating was in the "high" category which indicates that the community was dominated by species that prefer mud rather than those that prefer sand (Figure 8).

These results are explored in more detail in Figure 9. This plot shows that, for each of the four years of monitoring, the benthic invertebrate community was dominated by two species, both of which were very tolerant of mud, low salinity and moderate organic enrichment.

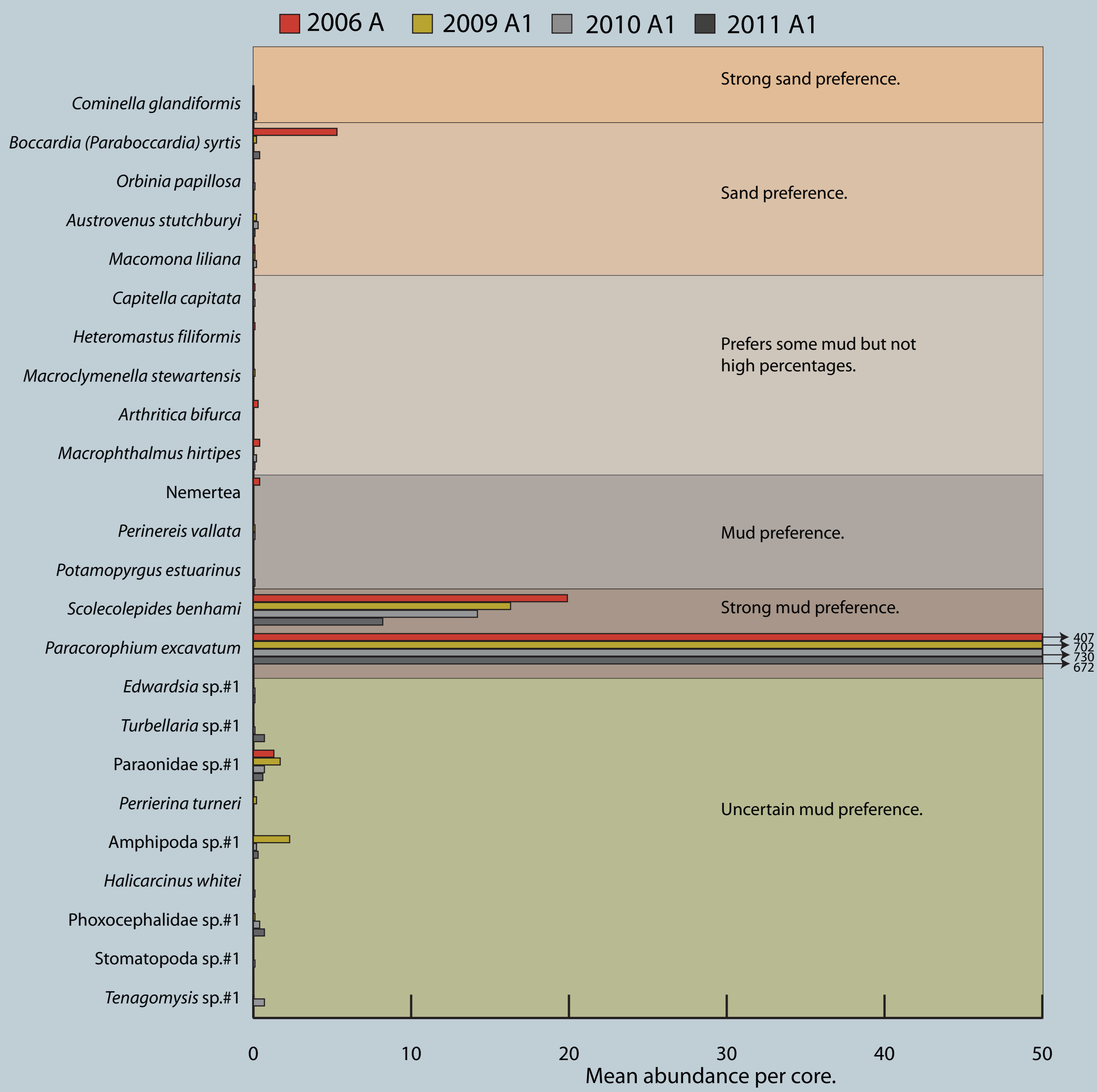

Figure 9. Haldane Estuary - benthic invertebrate mud sensitivity (see Appendix 3 for sensitivity details).

Paracorophium sp.

Scolecolepides benhami

Cockle - *Austrovenus stutchburyi*

These mud-tolerant species included:

- The tube-dwelling amphipod *Paracorophium excavatum*, which is the dominant coriphiod amphipod in the South Island. *Paracorophium* is well-known as a major primary coloniser (and hence indicator) of disturbed estuarine intertidal flats (Ford et al. 1999). Examples of common disturbances are, macroalgal mats settling on the tidal flats as a result of coastal eutrophication and mud deposition after mobilisation of fine sediments from exposed soil surfaces in the catchment. In these situations, *Paracorophium* can become very abundant and, through its burrowing activities, increases oxygen exchange which in turn mitigates the effect of the disturbance. Given the large increase in mud content at Site A1 over the last two years (from 30% mud to 43% mud), it is likely that the high numbers of *Paracorophium* was a response to disturbance caused by increased muddiness.
- The other abundant species was the surface deposit feeding spionid polychaete *Scolecolepides benhami*. This spionid is very tolerant of mud, fluctuating salinities, organic enrichment and toxicants (e.g. heavy metals). It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. The results of the 2011 sampling shows the numbers of *Scolecolepides* to be down by 50% compared with 2009.

Very low numbers of "sand preference" organisms were also found at the site in 2009 and 2010. In the 2011 sampling, only one adult cockle (*Austrovenus stutchburyi*) was found and the adult wedge shell *Macomona liliana* was absent. Both these species are particularly important 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).

The native orbiniid polychaete, *Orbinia papillosa,* which is a long, slender, unselective deposit feeder was also found at the site in very low numbers in 2009 and 2010 but was absent in 2011. It prefers sand environments with an optimum range of 5-10% mud but can be also be found sub-optimally in 0-40% mud.

Clearly these three latter species were outside of their optimum mud content range at Site A1 in Haldane Estuary in previous years and in the case of *Macomona* and *Orbinia*, at the upper limit of their distribution ranges. As predicted in 2010, further mud content increases at Site A1 in 2011, indicate such organisms are likely to be in the process of disappearing from the site.

Overall, the sedimentation results indicate that the upper half of the main estuary basin in Haldane Estuary is adversely affected by the elevated (and rapidly increasing) sediment mud content. It is therefore urgently recommended that studies be undertaken to identify the source of these sediment loads and management actions taken to reduce their impacts on the estuary. In addition, because such inputs may be affecting the sandy lower half of the estuary, it is recommended that an extra fine scale sampling site be introduced to that area.

The results also indicate that the surface sediments are eroding from at least part of the upper estuary area, but it is uncertain whether this erosion is representative of all areas in the upper estuary. Additional sediment plate deployment and monitoring is recommended to assess this situation.

EUTROPHICATION

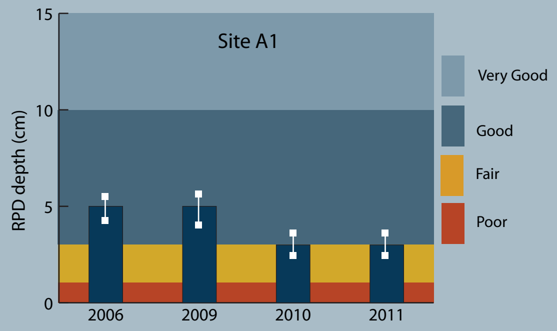

Figure 10. RPD depth (mean and range) Haldane Estuary.

2011 RPD RATING
Good - 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 (Stevens and Asher 2005).

Redox Potential Discontinuity (RPD)

Figures 10 and 11 show the sediment profiles and RPD depths for the Haldane sampling site (also Table 3) and indicates the likely benthic community that is supported at the site based on the measured RPD depth (adapted from Pearson and Rosenberg 1978). The results from 2010 and 2011 showed that the RPD depth in Haldane Estuary was moderately shallow (3cm) and therefore likely to be moderately oxygenated. Such moderate RPD values fit the "good-fair" condition rating and indicate that the benthic invertebrate community was likely to be in a "normal to transitional" state. Compared with 2006 and 2009, the results showed a decline in RPD depth indicating a shift towards more poorly oxygenated sediments, which is likely a response to the increased sediment muddiness.

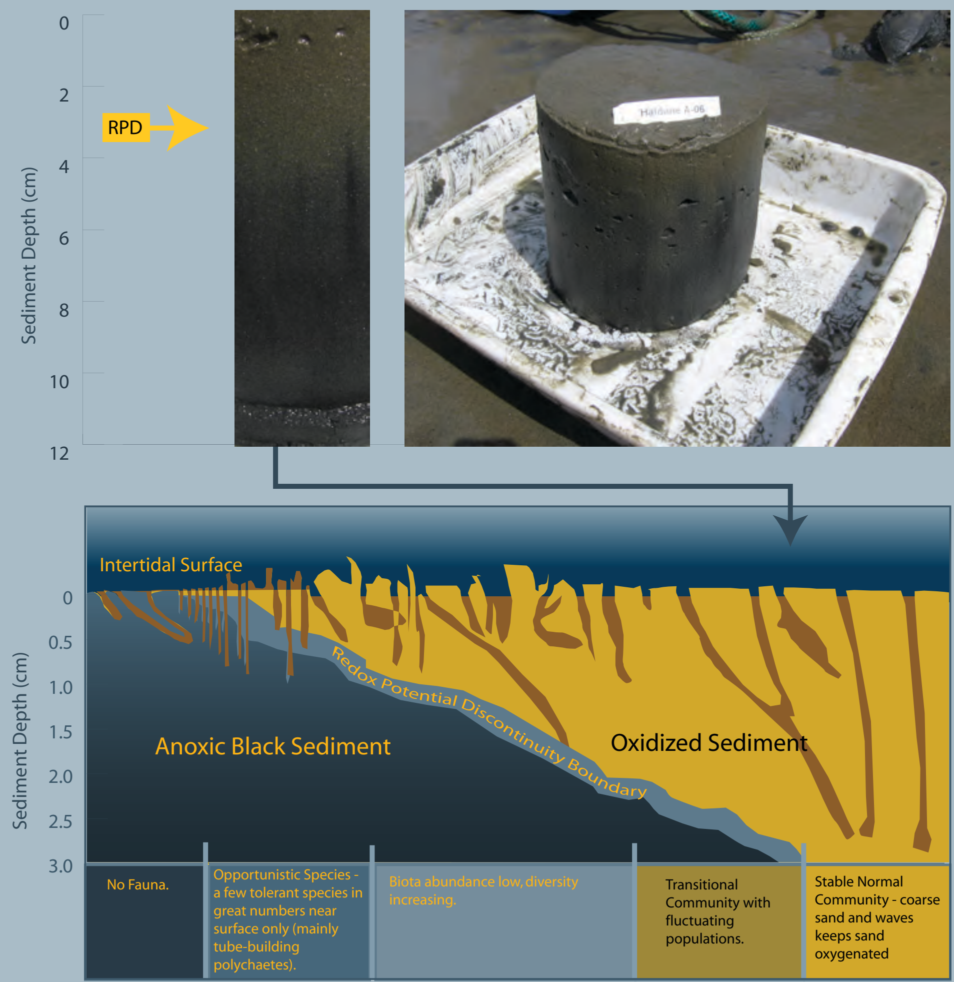

Figure 11. Sediment profiles, depths of RPD and predicted benthic community type, Haldane Estuary, 11 Feb 2011. Arrow below core relates to the type of community likely to be found in the core.

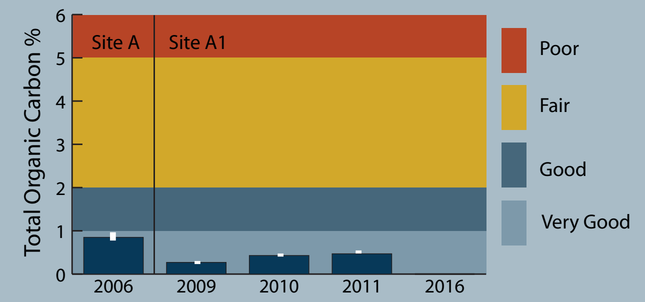

Figure 12. Total organic carbon, (mean and range) Haldane Estuary.

2011 TOC RATING	Very Good

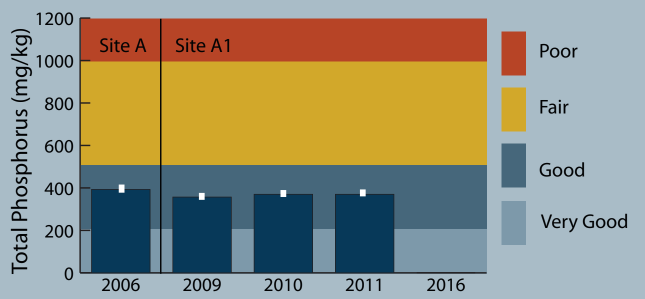

Figure 13. Total phosphorus, (mean and range) Haldane Estuary.

2011 TP RATING	Good

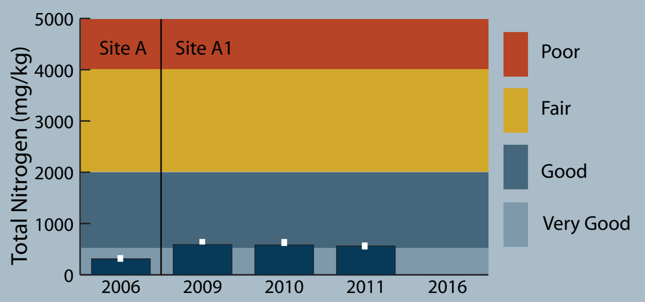

Figure 14. Total nitrogen, (mean and range) Haldane Estuary.

2011 TN RATING	Very Good

The combined 2011 results for Haldane (i.e. low-moderate concentrations of N, P and TOC, the moderate sediment oxygenation or RPD, and low observed presence of nuisance macroalgae) indicate a low-moderate presence of eutrophication symptoms in the Haldane Estuary in 2011.

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) decline and deposit-feeders (e.g. opportunistic polychaetes) increase as organic input to the sediment increases (Pearson and Rosenburg 1978).

The indicator of organic enrichment (TOC) was at very low concentrations (mean 0.47% for 2011) and for all four years of monitoring met the "very good" condition rating (Figure 12). Lower TOC concentrations were measured in 2009, 2010 and 2011 compared with 2006, which is likely to be the result of a method change. Ash free dry weight and a standard conversion factor were previously used to estimate TOC, which in 2009, 2010 and 2011 was measured directly.

The low TOC levels reflect the generally well-flushed nature of much of the estuary area and a likely moderate load of organic matter, sourced primarily from the catchment and benthic microalgae on the sediments.

TOTAL PHOSPHORUS (TP)

Total phosphorus, a key nutrient in the eutrophication process, was present at low-moderate concentrations for all four years (mean 370mg/kg for 2010 and 2011), and met the "good" condition rating (Figure 13). This means that the Haldane Estuary sediments have a moderate store of P in the sediments (sourced from both recent and historical catchment inputs).

TOTAL NITROGEN (TN)

Total nitrogen (the other key nutrient in the eutrophication process) was present at low concentrations for all four years (mean 563mg/kg for 2011) and met the "good" condition rating (Figure 14). This means that the Haldane sediments have a low store of N in the sediments (sourced from both recent and historical catchment inputs).

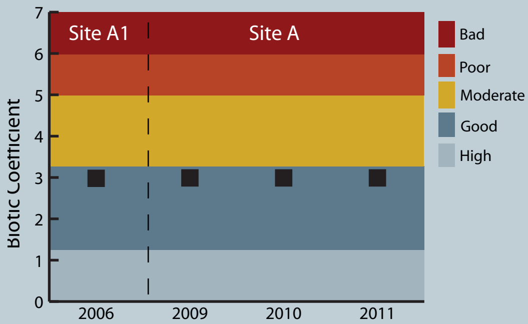

Figure 15. Benthic invertebrate organic enrichment rating, Haldane Estuary.

Macro-invertebrate Organic Enrichment Index

The benthic invertebrate community condition (a key indicator of response to both man-made and natural stressors) in the Haldane Estuary was in the upper range of the "good" category, indicating slight to moderate organic enrichment, for 2006, 2009, 2010 and 2011 (Figure 15). Such a rating likely reflects the moderate sediment nutrient concentrations in this estuary, and low catchment nutrient loads. As in previous years, the 2011 conditions resulted in a community dominated by species tolerant of moderate organic enrichment levels (Figure 16). The community was comprised primarily of small surface and subsurface deposit-feeders (Appendix 3).

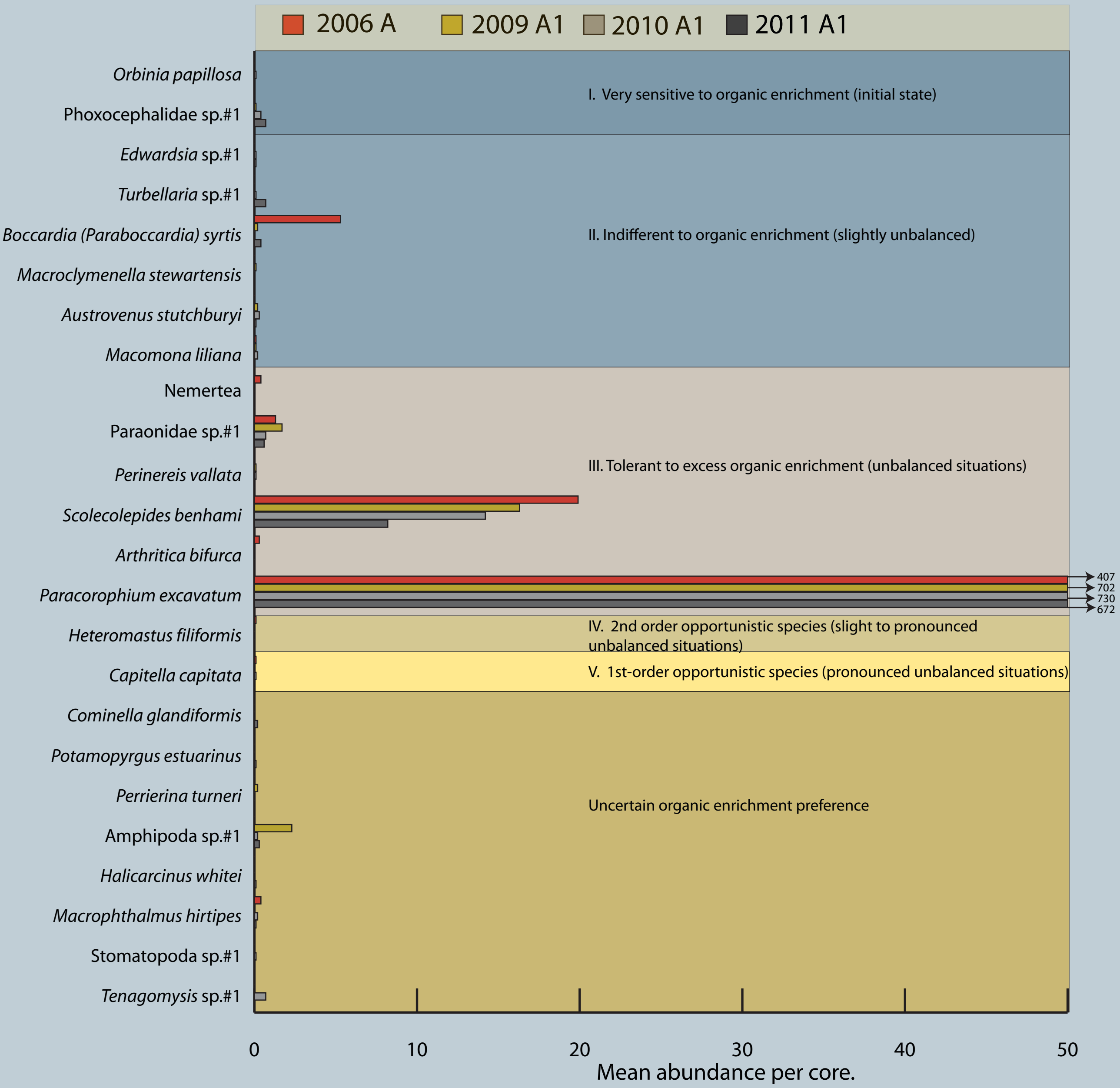

Figure 16. Haldane Estuary - organic enrichment sensitivity of macroinvertebrates at Sites A and A1 (see Appendix 3 for sensitivity details).

3. Results and Discussion (Continued)

In terms of eutrophication, the results suggest that the estuary has a low to moderate level of enrichment. Currently the nitrogen input (as estuary areal load) is estimated to be 30 mg.m^{-2}.d^{-1} (based on NIWA's Clues model outputs), which is in the range that is not expected to cause nuisance macroalgal conditions in tidal lagoon estuaries (Figure 12). Also it is low compared with the 50 mg.m^{-2}.d^{-1} upper limit suggested by Heggie (2006) for ensuring no eutrophication of temperate tidal lagoon estuaries.

TOXICITY

METALS

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at low to very low concentrations in 2006, 2009, 2010 and 2011 with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 13). Metals met the "very good" condition rating for cadmium, chromium, copper, lead, and zinc at all sites, and the "good" condition rating for nickel. These results indicate that there is no widespread toxicity in Haldane Estuary.

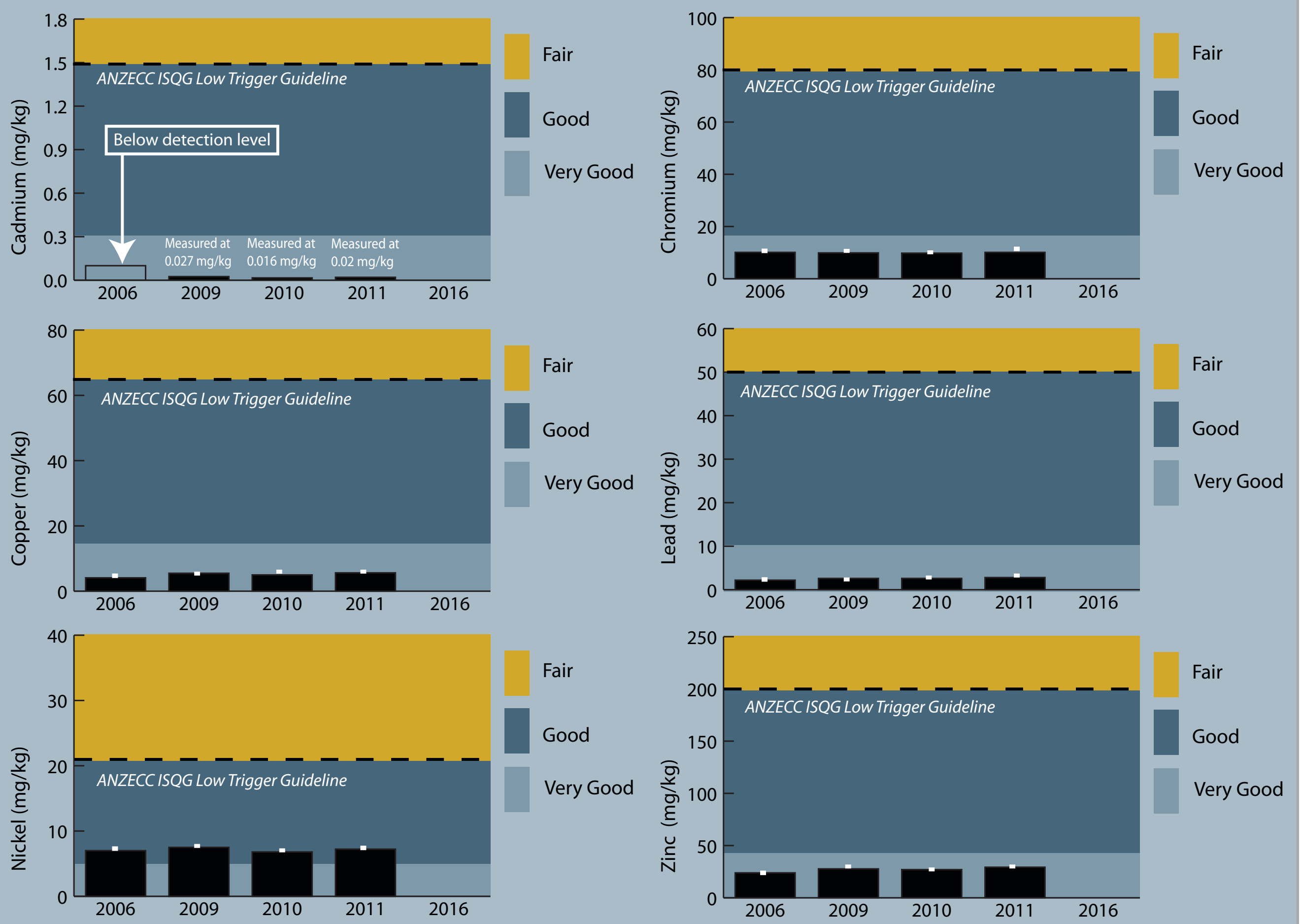

Figure 17. Sediment metal concentrations (mean and range, Site A 2006, Site A1 2009, 2010, 2011), Haldane Estuary.

4. SUMMARY AND CONCLUSIONS

The fourth year of fine scale monitoring results for estuary condition showed that Haldane Estuary was generally in good condition. Conditions were similar to those measured in 2006, 2009 and 2010 with the key findings as follows:

- The sediments were dominated by sands but mud concentrations were high and had increased by 25% since 2009. However, the 2011 results indicate that the sedimentation rates in the upper part of the main body of the Haldane Estuary are currently stable and have returned to the 2009 levels prior to flood impact. As it is uncertain whether this is representative of all areas in the upper estuary, additional sediment plate deployment and fine scale monitoring sites are recommended to assess this situation.
- Sediment levels of organic carbon, nitrogen and phosphorus were low-moderate. However, compared with previous years, the results showed a decline in RPD depth indicating a shift towards more poorly oxygenated sediments, which was likely to be a response to the increased sediment muddiness.
- The benthic invertebrate community was dominated by mud-tolerant organisms and the macro-invertebrate mud tolerance rating was in the "high" category. The types of species present indicated that the site was "disturbed".
- The benthic invertebrate organic enrichment index was in the upper range of the "good" category, indicating that the benthic invertebrate community was dominated by species that tolerate slight to moderate organic enrichment.
- Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at low to very low concentrations.
- In terms of eutrophication, the results suggest that the estuary has a low to moderate level of enrichment.

5. MONITORING

Haldane Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's coastal monitoring programme being undertaken in a staged manner throughout the Southland region. Based on the 2006, 2009, 2010 and 2011 monitoring results and condition ratings, it is recommended that monitoring continue as outlined below:

Fine Scale Monitoring
As the four years of baseline monitoring have now been completed it is recommended that ES now undertake monitoring at five yearly intervals or as deemed necessary based on the condition ratings. The next fine scale monitoring is scheduled for February 2016. It is also recommended that an additional monitoring site be included in the programme in the lower estuary.

Sedimentation Rate Monitoring.
Because sedimentation is a priority issue in the estuary, and mud contents have increased by 25% since 2009, 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.

Macroalgal Mapping.
Macroalgal cover was not observed to be causing conditions unsuitable for estuarine animals (e.g. low levels of sediment dissolved oxygen from rotting algae) nor were nuisance effects from smells evident. Consequently it is recommended that macroalgae be monitored five yearly in the absence of obvious changes in the estuary.

6. MANAGEMENT

The fine scale monitoring results, in particular increased sediment muddiness from a catchment predicted to have relatively low natural inputs, reinforced the need for targeted investigation of fine sediment sources entering the estuary. Consequently, it is recommended that sources of elevated loads in the catchment be identified and management undertaken to minimise their adverse effects on estuary uses and values. Further, because the estuary has been historically cut-off from its high value saltmarsh habitat through causeway development, it is recommended that plans be developed to improve this connection.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with organizing and field assistance from Greg Larkin (Coastal Scientist, Environment Southland).

8. REFERENCES

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

Borja A. and Muxika, H. 2005. Guidelines for the use of AMBI (AZTI's Marine Biotic Index) in the assessment of the benthic ecological quality. Marine Pollution Bulletin 50: 787-789.

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

Ford, R.B., Thrush, S.F. & Probert, P.K. 1999. Macrobenthic colonisation of disturbances on an intertidal sandflat: the influence of season and buried algae Marine Ecology Progress Series 191: 163-174.

Gibbs, M., and Hewitt, J. 2004. Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC. Technical Paper 264. NIWA Client Report: HAM2004-060.

Heggie, D. 2006. Clean or green –Nitrogen in temperate estuaries. Aus Geo News. Issue 81.

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

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

Lohrer AM, Thrush SF, Gibbs MM. 2004. Bioturbators enhance ecosystem function through complex biogeochemical interactions. Nature 431:1092–95.

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

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

Robertson B.M., Asher, R. 2006. Environment Southland Estuary Monitoring 2006. Prepared for Environment Southland.

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

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

Robertson, B.M. and Stevens, L. 2009. Haldane Estuary. Fine Scale Monitoring 2009/10. Report prepared for Environment Southland. 17p.

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

Stevens, L., and Asher, R. 2005. Broad scale intertidal habitat mapping of Haldane Estuary. Prepared for Environment Southland.

Thrush S.F., 1988. The comparison of macrobenthic recolonization patterns near and away from crab burrows on a sublittoral sandflat. J. Mar. Res. 46:669-681.

Thrush S.F., Hewitt J.E., Norkko A., Nicholls P.E., Funnell G.A., Ellis .J.I., 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progress Series 263:101-112.

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

APPENDIX 1. DETAILS ON ANALYTICAL METHODS

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

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

APPENDIX 2. 2011 DETAILED RESULTS

Station Locations

Haldane Site A1 2011	1	2	3	4	5	6	7	8	9	10
NZMGEAST	2206010	2206009	2206015	2206020	2206024	2206015	2206010	2206005	2205996	2205987
NZMGNORTH	5388778	5388778	5388763	5388749	5388735	5388732	5388747	5388757	5388778	5388774

Physical and Chemical Results for Haldane Estuary (Site A1), 11 February 2011.

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg							
Haldane A1	1-4	3	30	0.48	53.1	46.9	< 0.1	0.022	10.5	5.9	7.5	2.9	31	510	380
Haldane A1	5-8	3	30	0.52	39.5	60.5	< 0.1	0.02	10	5.7	7.2	2.8	29	590	360
Haldane A1	9-10	3	30	0.42	37.5	62.4	< 0.1	0.019	9.9	5.3	7	2.6	28	590	370

* composite samples

Haldane Estuary Sediment Plate Baseline (depths in mm).

Site	No	NZMG East	NZMG North	Plate depth 16/2/09	Plate depth 18/2/10	Plate depth 16/2/11	Mean Sed. Rate (mm/yr)
Haldane A1	1	2206006	5388783	235	225	237	1.0
	2	2205997	5388784	223	215	219	-2.0
	3	2205991	5388782	218	195	214	-2.0
	4	2205986	5388781	274	266	282	4.0

APPENDIX 2. 2011 DETAILED RESULTS (CONTINUED)

Epifauna (numbers per 0.25m² quadrat)

Haldane Estuary Site A1 11 February 2011										
Station	Hal A1-01	Hal A1-02	Hal A1-03	Hal A1-04	Hal A1-05	Hal A1-06	Hal A1-07	Hal A1-08	Hal A1-09	Hal A1-10
Amphibola crenata						2				
No. species/quadrat						**1**				
No. individuals/quadrat						**2**				

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

Haldane Estuary Site A1 11 February 2011												
Group	**Species**	AMBI	Hal A1-01	Hal A1-02	Hal A1-03	Hal A1-04	Hal A1-05	Hal A1-06	Hal A1-07	Hal A1-08	Hal A1-09	Hal A1-10
ANTHOZOA	*Edwardsia* sp.#1	II										1
TURBELLARIA	*Turbellaria* sp.#1	II		2					1			4
POLYCHAETA	*Boccardia (Paraboccardia) syrtis*	II					1		3			
	Capitella sp.#1	V										
	Macroclymenella stewartensis	II										
	Orbinia papillosa	IV										
	Paraonidae sp.#1	III					5					1
	Perinereis vallata	III										
	Scolecolepides benhami	III	14	6	5	2	14	10	12	7	7	5
GASTROPODA	*Cominella glandiformis*	NA						1			1	
	Potamopyrgus estuarinus	NA						1				
BIVALVIA	*Austrovenus stutchburyi*	II									1	
	Macomona liliana	II										
	Perrierina turneri	NA										
CRUSTACEA	Amphipoda sp.#1	NA					1				1	1
	Halicarcinus whitei	NA								1		
	Macrophthalmus hirtipes	NA		1								
	Paracorophium excavatum	III	753	712	724	573	698	773	655	577	635	615
	Phoxocephalidae sp.#1	I		2		2	1	1			1	
	Stomatopoda sp.#1	NA										
	Tenagomysis sp.#1	NA										
Total species in sample			**2**	**5**	**2**	**3**	**6**	**5**	**4**	**3**	**6**	**6**
Total specimens in sample			**767**	**723**	**729**	**577**	**720**	**786**	**671**	**585**	**646**	**627**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Anthozoa	*Edwardsia* sp.#1	III	Uncertain	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.
Turbellaria	Turbellaria	III	S Prefer sand habitats	Free-living flatworms that prefer sandy habitats rather than mud. They are predators
Nematoda	Nemertea	III	I Optimum range 55-60% mud,* distribution range 0-95%*	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Polychaeta	*Boccardia (Paraboccardia) syrtis*	I	S Optimum range 10-15% mud,* distribution range 0-50%*	A small surface deposit-feeding spionid. Prefers low-mod mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
	Capitellidae	V or IV	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *Heteromastus filiformis*	Subsurface deposit feeder, occurs down to about 10 cm sediment depth. Common indicator of organic enrichment. Bio-turbator. Prey for fish and birds.
	Macroclymenella stewartensis	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation	Bamboo worms. A sub-surface, deposit-feeder that is usually found in tubes of fine sand or mud. This species is found throughout the sediment to depths of 15cm and potentially has a key role in the re-working and turn-over of sediment. This worm may modify the sediment conditions, making it more suitable for other species (Thrush et al. 1988). Common at low water in estuaries. Prefers sand. Intolerant of anoxic conditions.
	Orbinia papillosa	I	S Optimum range 5-10% mud,* distribution range 0-40%*	Endemic orbiniid. Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.
	Paraonidae	III	Uncertain *Aricidea* sp. is an I Optimum range 35-40% mud,* distribution range 0-70%*	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15cm and appear to be sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content.
	Perinereis vallata	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers sandy sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Polychaeta	*Scolecolepides benhami*	III	MM Optimum range 25-30% mud,* distribution range 0-100%*	A Spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. **Strong Mud Preference.** Prey items for fish and birds. Rare in Freshwater Estuary (<1% mud) and Porirua Estuary (5-10% mud). Common in Whareama (35-65% mud), Fortrose Estuary (5% mud), Waikanae Estuary 15-40% mud. Moderate numbers in Jacobs River Estuary (5-10% muds) and New River Estuary (5% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai arm, New River Estuary.
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	*Potamopyrgus estuarinus*	II	M Tolerant of muds	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
Bivalvia	*Arthritica* sp.1	III	I Optimum range 55-60% mud*, or 20-40%***, distribution range 5-70%**	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
Bivalvia	*Austrovenus stutchburyi*	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. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects. Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community who are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group *****	Tolerance to Mud****	Details
Bivalva	*Mocomona liliana*	I	S Prefers sand with some mud (optimum range 0-5% 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. Thrush et al. (2006) shows that this large deposit feeding bivalve is important in that it enhances nutrient and oxygen fluxes and its presence influences the types of other macroinvertebrate species present. These bivalves draw organic material and microphytes from the sediment surface with their inhalant siphon and defecate directly into the sediment around their shell, enhancing the concentration of organic matter at 5–10 cm below the sediment surface. Sand Preference: **Prefers 0-5% mud (range 0-40% mud).**
Bivalva	*Perrierina turneri*	NA	Uncertain	A small bivalve - relatively uncommon.
Crustacea	Amphipoda	NA	Uncertain	An intertidal soft shore nereid (common and very active, omnivo-rous worms). Prefers sandy sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
Crustacea	*Halicarcinus whitei*	NA	NA	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
Crustacea	*Macrophthalmus hirtipes*	NA	I Optimum range 45-50% mud,* distribution range 0-95%*	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
Crustacea	*Paracorophium* sp.	III	MM Optimum Range 95-100% mud (found in 40-100% mud)*	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud prefer-ence. Optimum Range 95-100% mud (found in 40-100% mud) in upper Nth. Is. estuaries. In Sth. Is. and lower Nth. Is. common in Waikanae Estuary (15-40% mud), Haldane Estuary (25-35% mud) and in Fortrose Estuary (4% mud). Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites like Whareama A and B (30-70% mud) we get very few.
	Phoxocephalidae sp.	I	Uncertain	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Stomatopoda sp.	NA	Uncertain	Mantis shrimp or stomatopods are marine crustaceans. They are neither shrimp nor mantids, but receive their name purely from the physical resemblance to both the terrestrial praying mantis and the shrimp. Considered to have the most complex eyes in the animal kingdom.
	Tenagomysis sp	NA	Uncertain	*Tenagomysis* is a genus of mysid shrimps in the family Mysidae. At least nine of the fifteen species known are from New Zealand

APPENDIX 3. INFAUNA CHARACTERISTICS

* 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.