coastalmanagement

Waikawa Estuary

Fine Scale Monitoring 2012/13

Prepared for

Environment Southland

August 2013

Cover Photo: The wharf, Waikawa Estuary.

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By

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All photos by Wriggle except where noted otherwise.

EXECUTIVE SUMMARY

This report summarises the results of the baseline 2005-2008 and 2013 fine scale monitoring of two intertidal sites within Waikawa Estuary, a 760ha tidal lagoon estuary, located on the Catlins coast. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. The fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations are summarised below.

FINE SCALE MONITORING RESULTS

- Sandy habitat dominated, with mud content relatively low at both sites. Since 2005, fine scale sites have become less muddy or stayed similar to baseline levels.
- The benthic invertebrate mud tolerance rating was "low" at Site A and "very low" at Site B - generally dominated by species with a preference for sand with small amounts of mud. This indicates both sites were in good condition, with the mud tolerance rating declining (showing improving conditions) since 2005.
- Macro-invertebrate abundance and species richness had declined considerably since the baseline period 2005-2008 particularly at Site A, and the 2013 communities were significantly different in structure from the baseline communities. The reason for this decline was not known (possibly related to climatic variations), but can be partially explained by the reduction in mud concentrations in 2013.
- Sediment oxygenation was moderate (Redox Potential Discontinuity (RPD) depth 1-2cm).
- Sediment nutrient enrichment indicators (Organic Carbon, Nitrogen and Phosphorus) were at low to very low concentrations.
- The benthic invertebrate organic enrichment rating was "very good" at Site A (dominated by organisms intolerant of enrichment) and "good" at Site B (dominated by organisms tolerant of slight enrichment) . This indicates that the estuary has a low to moderate level of enrichment (i.e. mesotrophic state). The enrichment tolerance rating showed improving sediment conditions since 2005.
- Heavy metals, used as an indicator of toxicity, were well below the ANZECC (2000) ISQG-Low trigger values.

CONDITION SUMMARY

Key To Ratings		
	High/Poor	Good
	Fair	Very Good

		Site A					Site B				
		2005	2006	2007	2008	2013	2005	2006	2007	2008	2013
Sediment (muddiness)	Percent mud content	Fair	Fair	Fair	Fair	Fair	Very Good	Very Good	Good	Good	Good
	Invertebrates (mud response)	Good	Fair	Good	Good	Good	Good	Good	Good	Good	Very Good
Eutrophication	RPD depth (sediment oxygenation)	Good	Good	Good	Good	Fair	Good	Good	Good	Good	Fair
	TOC (Total Organic Carbon)	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
	Total Phosphorus (TP)	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
	Total Nitrogen (TN)	Good	Fair	Fair	Fair	Fair	Good	Good	Good	Good	Good
	Invertebrates (enrichment response)	Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Toxicity	Metals (Cd, Cu, Cr, Pb, Zn,Ni)	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good

ESTUARY CONDITION AND ISSUES

The results from the 2013 monitoring show that the intertidal sandy habitat that dominates the two sites at Waikawa Estuary was generally in a "very good - moderate" condition and had not deteriorated since 2005. The low mud content, low nutrients and a benthic invertebrate community dominated by species with a preference for sand, indicates that this estuary is generally in a mesotrophic state.

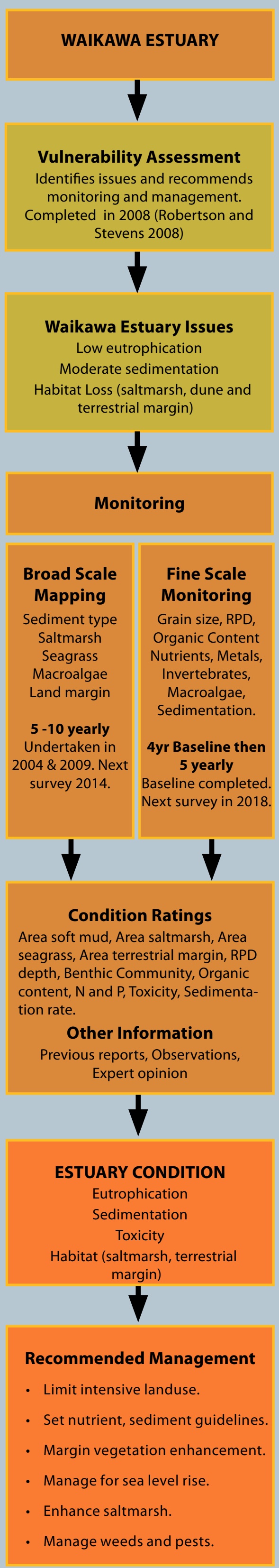
However, the wider estuary is currently impacted by excessive sedimentation, loss of saltmarsh habitat, and margin development which need to be taken into account when evaluating overall estuary condition.

RECOMMENDED MONITORING AND MANAGEMENT

It is recommended that monitoring of the two fine scale sites be undertaken every five years. The next fine scale monitoring for this site is therefore scheduled for February 2018. Five yearly broad scale habitat mapping is next scheduled for 2013/14, and annual measurements of sedimentation rate are also recommended.

Overall, the combined broad and fine scale monitoring results reinforce the need for management of fine sediment 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.

1. INTRODUCTION



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

ES began monitoring Waikawa Estuary in 2004/5 and now has 4 years of fine scale baseline monitoring data, with the work being undertaken by Wriggle Coastal Management using the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) plus recent extensions.

The Waikawa Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (Table 1) and appropriate monitoring design. This component has been completed for Waikawa Estuary and is reported on in Robertson and Stevens (2008).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component, which documents the key habitats within the estuary, and changes to these habitats over time, was undertaken in 2004 (Robertson et al. 2004) and again in 2009 (Stevens and Robertson 2009).
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 2) including sedimentation plate monitoring. This component, which provides detailed information on the condition of Waikawa Estuary, has been undertaken in 2005, 2006, 2007, 2008 (see Stevens and Asher 2005, Robertson and Asher 2006, Robertson and Stevens 2007, 2008), and 2013 - the subject of this report. The sediment plate results are reported on separately in Stevens and Robertson 2013.

Waikawa Estuary (760ha) is a moderately large, shallow, well flushed "tidal lagoon" type estuary consisting of one central basin (Figure 1). It has a 3m spring tidal range and serves as a port for several fishing boats which operate from the jetties near the main centre of Waikawa township. The estuary discharges into the adjacent Porpoise Bay.

Waikawa Estuary is regionally popular as well as being on the "southern scenic route" used by many tourists. It provides a natural focal point for locals and visitors and its human uses include; shellfish gathering, swimming, boating, fishing, walking, and aesthetics. Ecologically, it is valued for it's high biodiversity including fish and birdlife. In addition, the endemic Hector's dolphins, which are resident in the Porpoise Bay area during the months of October to March, are dependent on the Waikawa Estuary and Porpoise Bay for food.

The Waikawa River is the main tributary, and while most of the lower catchment is developed as pastoral land, much of the upper catchment remains forested. The harbour margin has been slightly modified over the years with the reclamation of saltmarsh areas and the development of a small area of rockwall. The only significant structures in the harbour are wharves, pile moorings and a slipway which services the fishing fleet.

Estuary vulnerability assessments (Robertson and Stevens 2007, 2008) rated ecological vulnerability for the majority of estuary habitats in the low or low-moderate class. However, two key issues were identified as follows: excessive sedimentation, and loss of saltmarsh habitat/margin development.

1. Introduction (continued)

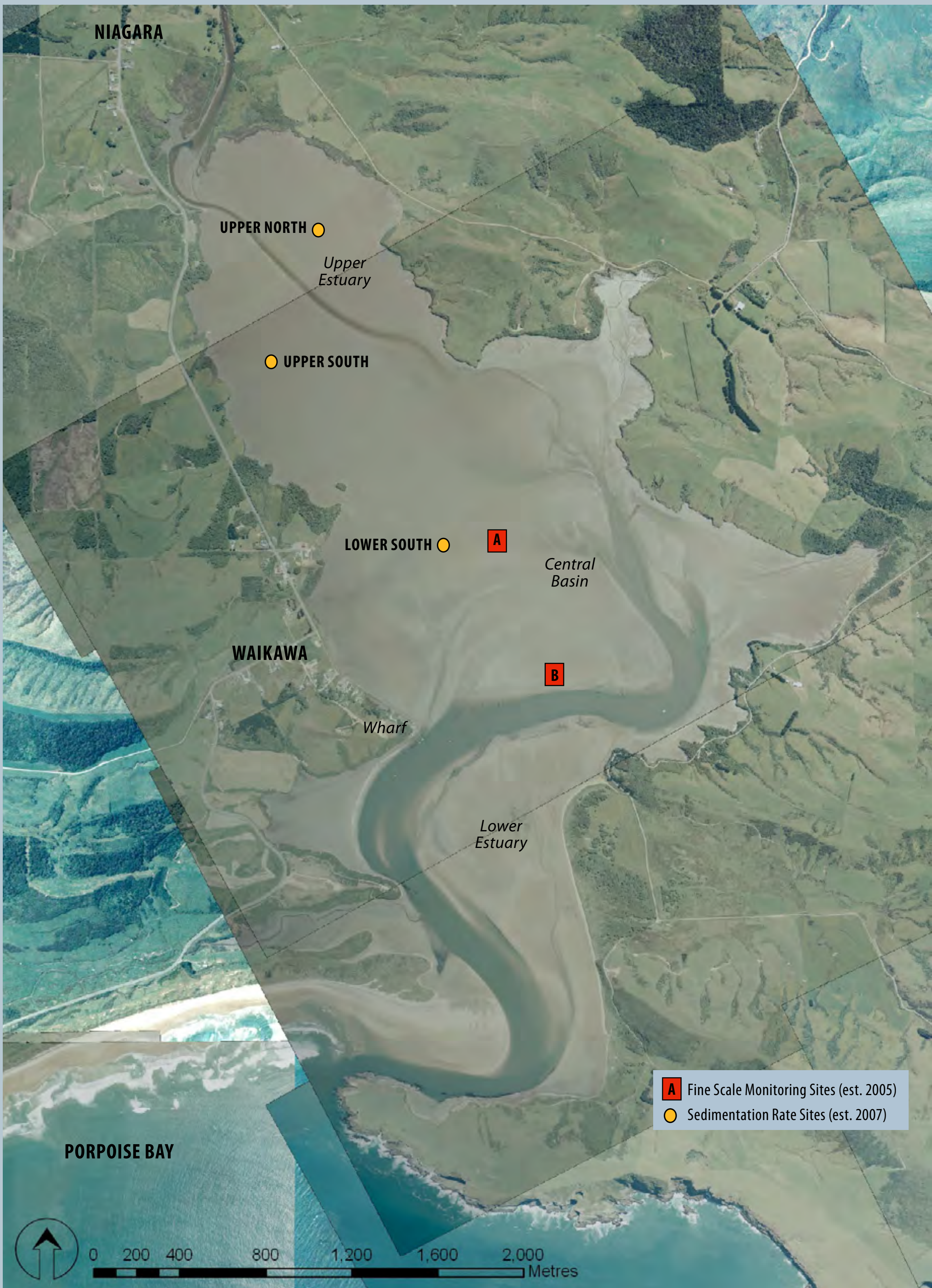


Figure 1. Waikawa Estuary - location of fine scale monitoring sites and sediment plates (photo, ES 2008).

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 *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 NEMP (Robertson et al. 2002) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water. Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary) are selected and samples collected and analysed for the following variables.

- Salinity, Oxygenation (Redox Potential Discontinuity - RPD), Grain size (% mud, sand, gravel).
- Organic Matter: Total organic carbon (TOC).
- Nutrients: Total nitrogen (TN), Total phosphorus (TP).
- Heavy metals: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni) and Zinc (Zn).
- Macro-invertebrate abundance and diversity (infauna and epifauna).

For Waikawa Estuary, two fine scale sampling sites (Figure 1) were selected in unvegetated, mid-low water intertidal flats (avoiding areas of significant vegetation and channels). At both sites, 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 (precise locations are in Appendix 2), 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 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 1):
    - Grain size/Particle size distribution (% mud, sand, gravel).
    - Nutrients - TN, TP and TOC.
    - Heavy metal contaminants (Cd, Cr, Cu, Ni, Pb, Zn). Non-normalised whole sample fractions used to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Epifauna (surface-dwelling animals).

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

Infauna (animals within sediments).

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

Condition Ratings

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

Sediment Mud Content

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

SEDIMENTATION MUD CONTENT

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

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. This rating provides an indication of the overall tolerance for mud of the macro-invertebrate community. However, it does not account for changes in species numbers directly, therefore an assessment of differences in both species numbers and abundance between each of the mud tolerance groups is required.

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 <1cm (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 Waikawa, 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 Waikawa, 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; $BC = \{(0 \times \%GI) + (1.5 \times \%GII) + (3 \times \%GIII) + (4.5 \times \%GIV) + (6 \times \%GV)\}/100$. The characteristics of the ecological groups (GI, GII, GIII, GIV and GV) are summarised in Appendix 3.

Note that this rating provides an indication of the combined tolerance for organic enrichment of the macro-invertebrate community, and also includes influences from mud and toxins. However, it does not account for changes in species numbers directly, therefore a species diversity index is also required to assess differences in both species numbers and abundance between each of the enrichment tolerance groups.

BENTHIC COMMUNITY ORGANIC ENRICHMENT RATING			
ENRICHMENT TOLERANCE	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
Exceeded	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

Barry Robertson (Wriggle) and Nick Ward (ES) collecting samples in Waikawa Estuary, Feb. 2013.

3. RESULTS AND DISCUSSION

OUTLINE

A results summary of the 2005-2008 baseline, and the first repeat fine scale monitoring of Waikawa Estuary (14 February 2013) is presented in Table 3 (detailed 2013 results 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 Waikawa 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
2005 A	3	30	0.77	11.3	84.6	4.1	0.10	10.39	3.25	5.50	2.24	14.90	610	351	6,030	13.4
2005 B	3	30	0.30	1.8	98.0	0.3	0.10	4.93	1.31	2.30	0.97	3.30	98	186	4,178	13.3
2006 A	3	30	0.39	5.3	93.3	1.5	0.10	7.10	1.93	3.67	1.47	12.33	227	304	12,308	19.2
2006 B	3	30	0.29	1.1	98.3	0.6	0.10	5.67	1.27	4.00	1.13	7.33	127	242	4,493	17.1
2007 A	3	30	0.73	10.1	88.6	1.3	0.01	7.93	3.13	5.00	1.78	15.17	500	298	8,318	19.5
2007 B	3	30	0.59	3.1	96.8	0.1	0.01	6.70	2.63	4.27	1.49	11.43	500	229	3,938	16.4
2008 A	4	31	0.89	9.2	89.8	1.0	0.02	9.07	3.50	5.80	2.03	17.33	500	313	10,650	20.2
2008 B	4	31	0.65	2.5	97.2	0.4	0.01	7.40	2.47	4.47	1.60	12.00	500	250	3,143	15.5
2013 A	2	31	0.37	6.3	92.2	1.4	0.02	6.37	2.37	3.87	1.57	12.97	500	273	2,453	9.7
2013 B	2	31	0.37	2.7	96.0	1.3	0.01	5.30	1.97	3.33	1.40	10.00	500	243	2,303	11.8

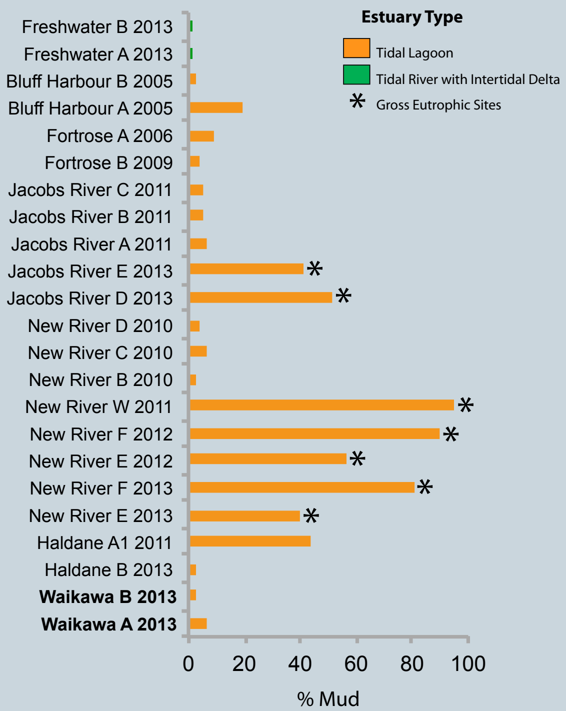


Figure 2. Percentage of mud at fine scale sites in Southland estuaries.

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 <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)]. 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. Waikawa Estuary has a primarily moderate-hard rock type (sandstone/siltstone conglomerate) catchment, dominated by grassland and bush. As a consequence, it is expected to provide only low-moderate loads of sediment, nutrients, pathogens and potentially toxic contaminants to the estuary. Nevertheless, some activities in the catchment have the potential to increase loads to excessive levels, e.g. drainage works, forest clearance, and intensification of agricultural landuse. If inputs are high enough, then adverse effects would be expected.

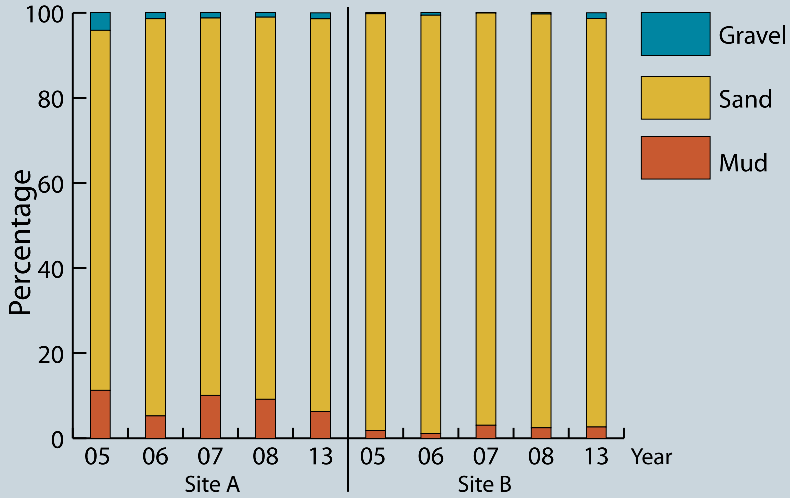


Figure 3. Grain size, 2005-2008 and 2013, Waikawa Estuary.

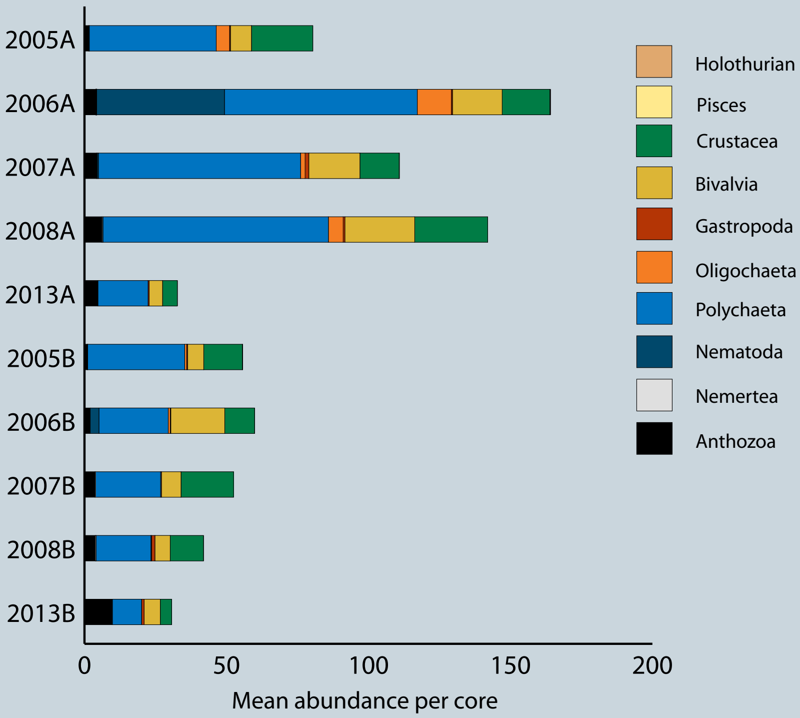


Figure 4. Mean abundance of major infauna groups, Waikawa Estuary, 2005-2008 and 2013.

In order to assess sedimentation in Waikawa Estuary, a number of indicators have been used: grain size, presence of mud tolerant invertebrates, and sedimentation rate (sediment plate results are reported on separately in Stevens and Robertson 2013).

Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results (Figure 3) showed that both sites were dominated by sandy sediments with Site A being the muddiest (6.3%) and Site B, which was closest to the influence of the ocean, less muddy (2.7%). In comparison to fine scale sites in most other Southland estuaries (Figure 2), these results indicate that the mud content at both sites was low. The results also showed that there was only slight variation in the mud content over the 2005-2013 period at Site B, but at Site A it declined overall by 44% (from 11.3 to 6.3%). This decline at Site A is supported by sedimentation rate monitoring at this site (Stevens and Robertson 2012) which showed that a front of soft muddy sediments adjacent to this site has been retreating back up the estuary since sediment rate monitoring began in 2007.

Macro-invertebrate Community

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

1. Comparing the mean abundance and species richness, and additionally, the mean abundance of the major invertebrate groups, at each of the Waikawa sites (Table 3 and Figures 4 and 5).
2. Using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) to assess the mud tolerance of the Waikawa Estuary macro-invertebrate community (Figure 6).
3. Using multivariate techniques to explore differences between the macro-invertebrate communities over time and at different sites (Figure 7).

3. Results and Discussion (continued)

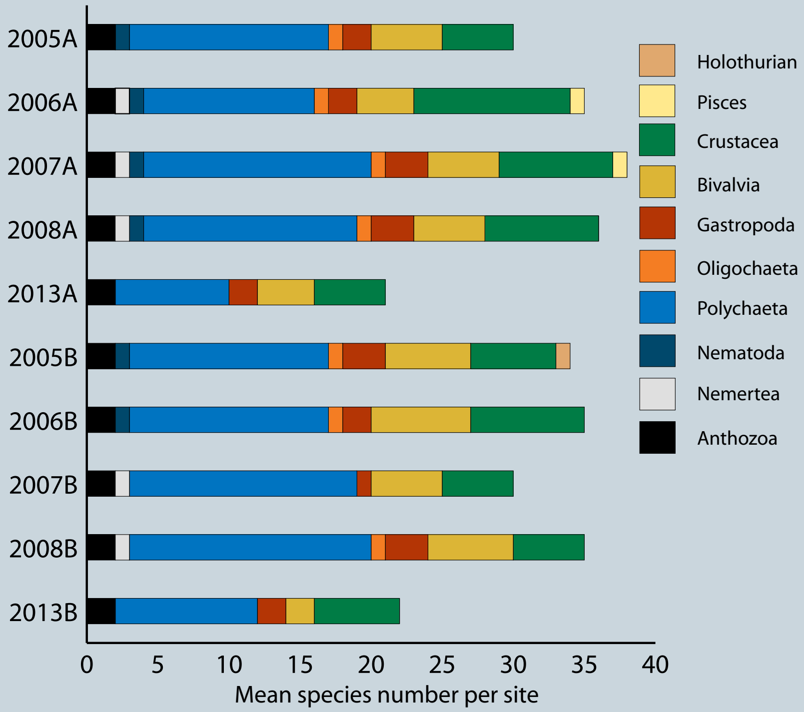


Figure 5. Mean species number per site of major infauna groups, Waikawa Estuary, 2005-2008 and 2013.

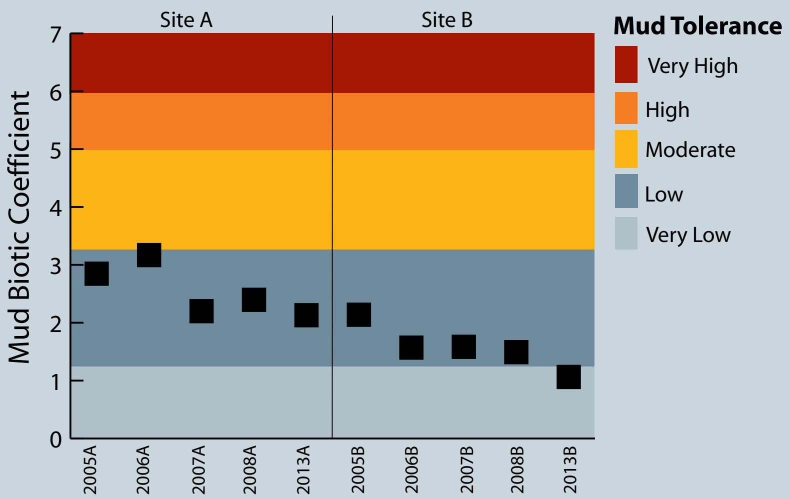


Figure 6. Mud tolerance macro-invertebrate rating, Waikawa Estuary, 2005-2008 and 2013.

In the first step, the 2013 results indicate that the macro-invertebrate abundance and species richness had declined considerably since the baseline period 2005-2008 (Figures 4 and 5). Abundance declined by 74% at Site A, and 37% at Site B, compared with the mean abundance during the baseline years. Species richness showed a decline of 44% at Site A and 14% at Site B, compared with the baseline years.

Figures 4 and 5 also show that these declines were primarily attributable to reductions in both abundance and species numbers over all the major infauna groups. Another interesting occurrence was a particularly large increase in the number of juvenile nematodes in 2006 at Site A which was likely to have been the result of natural population fluctuations (Li and Vincx, 1993).

In the second step, the potential cause for this decline was explored using the macro-invertebrate mud tolerance rating. Figure 6 shows that the rating in 2013 had declined at both sites, but was most pronounced at Site B. However, it was also apparent that there was an overall trend at both sites towards declining populations of mud tolerant organisms (i.e. more sand tolerant organisms) over the five years of monitoring. These findings suggest that decreasing mud content may be partly responsible for the recent reductions in species richness and abundance. Other factors are likely to be related to natural causes, particularly those associated with climatic influences. This plot also shows that the communities at both sites were dominated by sand preferring, and moderately mud tolerant species, rather than the more strongly mud tolerant organisms.

In the third step, the results of the multivariate analysis (NMDS Plot, Figure 7) clearly portray the difference in benthic invertebrate communities present between the years with a pronounced difference in 2013. As expected, there was also a clear distinction in communities present between the two sites, with Site A located in the muddier, less disturbed upper estuary and Site B at the sandier lower estuary (more influence from the sea). The results indicate slight differences in mud content between the years but not sufficient to explain the community shifts in 2013.

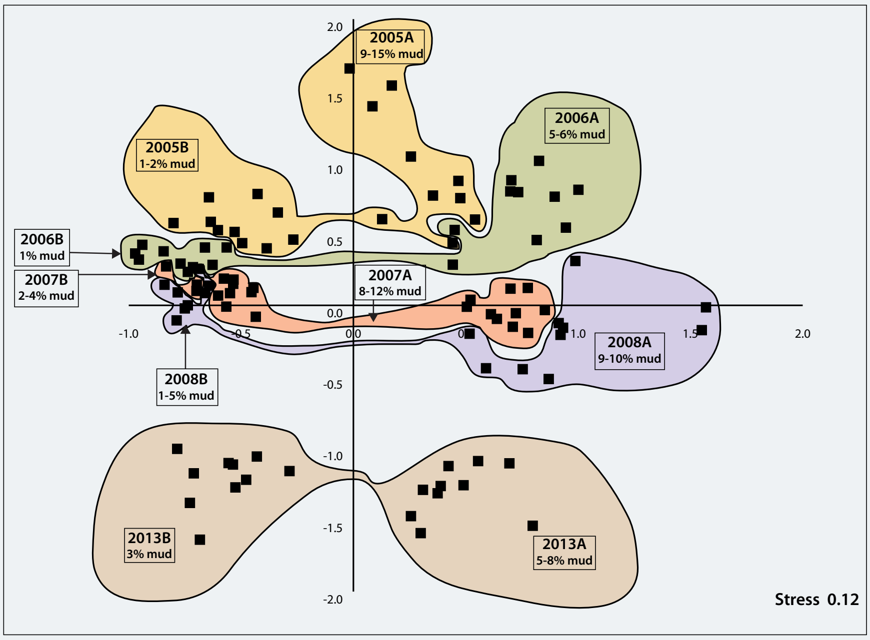


Figure 7. NMDS plot showing the relationship among samples in terms of similarity in macro-invertebrate community composition at Sites A and B for the five years of sampling. The plot shows each of the 10 replicate samples for each year and is based on Bray Curtis dissimilarity and square root transformed 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.

At a more detailed level, the invertebrate abundance data (Table 4) shows that in 2013 at Site A, the most abundant species present was the polychaete, *Macroclymenella stewartensis*. This bamboo worm prefers sandy sediments and is common at low water in estuaries. At Site B, the most abundant organism was the anenome, *Anthopleura aureoradiata* which has a strong sand preference.

Other '"sand preference" organisms present at both sites included:

- The cockle, *Austrovenus stutchburyi* - a suspension feeding bivalve.
- *Boccardia (Paraboccardia) syrtis*, a small surface deposit-feeding spionid polychaete worm.

Low numbers of *Prionospio aucklandica*, a surface deposit-feeding spionid worm were found at both Sites A and B. At Site A, the Phoxocephalid and Tanaid crustaceans and the bivalves, *Macomona liliana* and *Nucula* sp., were present in small numbers. All of these organisms prefer sandy sediments with some mud present.

Overall, it is clear that the fine scale sampling in 2013 showed a macro-invertebrate community that was adapted to a more sand-dominated habitat.

3. Results and Discussion (continued)

Table 4. Macrofauna mean abundance per core 2013, Waikawa Estuary, and mud (MUD) and organic enrichment (AMBI) tolerance groups (NA=tolerance not yet ascribed).

Taxa		2013 Waikawa A	2013 Waikawa B	MUD Group	AMBI Group
ANTHOZOA	*Anthopleura aureoradiata*	4.3	9.6	1	II
	Edwardsia sp.#1	0.4	0.2	2	II
POLYCHAETA	*Aglaophamus* sp.#1	0.4	1.5	2	II
	Aonides sp.#1	0.0	1.5	1	III
	Boccardia (Paraboccardia) syrtis	1.8	1.8	2	III
	Glycera lamelliformis	0.2	0.0	3	II
	Glyceridae (unidentified juveniles)	0.0	0.3	3	II
	Heteromastus filiformis	0.8	0.0	3	IV
	Macroclymenella stewartensis	13.3	2.9	3	I
	Magelona sp.#1	0.2	0.0	NA	I
	Nereidae (unidentified juveniles)	0.1	0.0	4	III
	Orbinia papillosa	0.0	0.1	2	I
	Prionospio aucklandica	0.8	1.2	3	IV
	Spionidae sp.#1	0.0	0.1	NA	III
	Syllidae sp.#2	0.0	0.4	2	II
	Travisia olens	0.0	0.5	1	I
GASTROPODA	*Cominella glandiformis*	0.1	0.6	1	NA
	Diloma subrostrata	0.3	0.3	1	NA
	Notoacmaea helmsi	0.0	2.0	1	NA
BIVALVIA	*Austrovenus stutchburyi*	1.6	5.5	2	III
	Macomona liliana	0.9	0.0	2	II
	Nucula sp.#1	2.1	0.0	2	I
	Soletellina sp.#1	0.1	0.2	1	II
CRUSTACEA	Amphipoda sp.#1	0.4	2.0	NA	NA
	Amphipoda sp.#2	0.1	0.0	NA	NA
	Austrominius modestus	0.0	0.8	NA	NA
	Colurostylis lemurum	0.0	0.2	2	II
	Halicarcinus whitei	0.2	0.0	NA	III
	Isocladus sp.#1	0.0	0.7	NA	NA
	Macrophthalmus hirtipes	0.0	0.2	3	III
	Phoxocephalidae sp.#1	2.8	0.1	NA	I
	Tanaidacea sp.#1	1.6	0.0	3	II

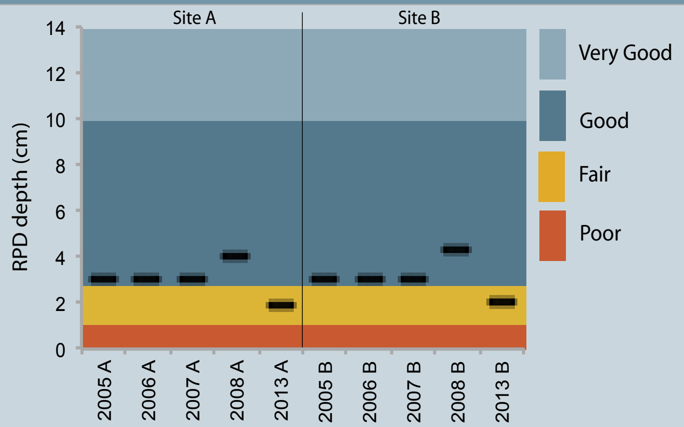


Figure 8. Redox Potential Discontinuity depth, Waikawa Estuary.

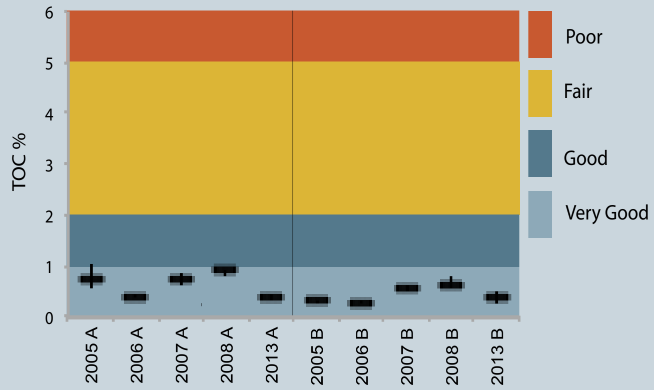


Figure 9. Total organic carbon (mean and range), Waikawa Estuary.

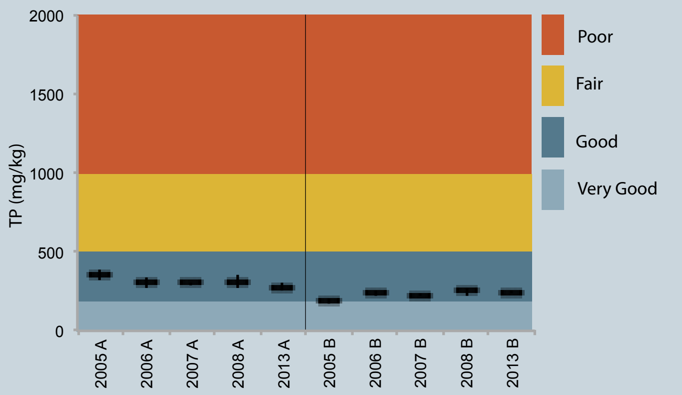


Figure 10. Total phosphorus (mean and range), Waikawa Estuary.

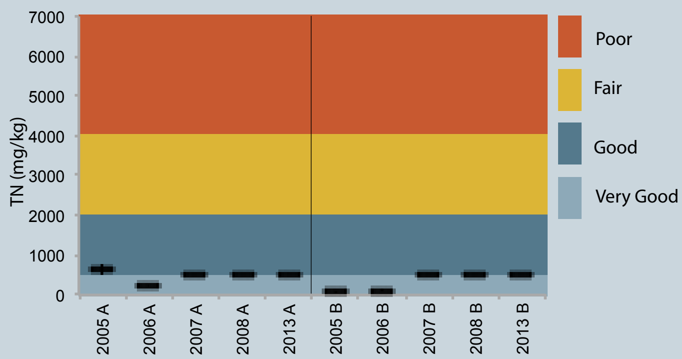


Figure 11. Total nitrogen (mean and range), Waikawa Estuary.

EUTROPHICATION

The primary fine scale indicators of eutrophication are grain size, RPD depth, 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.

Grain Size

This indicator has been discussed in the sediment section and is not repeated here. However, in relation to eutrophication, the low mud content at both sites in 2013 (Figure 3) indicates sediment porosity is sufficient to maintain good upper sediment oxygenation.

Redox Potential Discontinuity (RPD)

Figure 8 shows the RPD depths for the two Waikawa sampling sites (also Table 3). The 2013 results indicate moderate RPD depths (Site A 2cm and Site B 1cm), a slight deterioration from measures in previous years (3-5cm). Such moderate RPD values with a high sand content, fit the "fair" condition rating and indicate that the benthic invertebrate community was likely to be in a "transitional" state.

Total Organic Carbon and Nutrients

The concentrations of sediment nutrients (total nitrogen - TN and phosphorus - TP) and organic matter (total organic carbon - TOC) also provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow RPD, excessive algal growth, low biotic index), then TN, TP and TOC concentrations provide a good indication of loadings exceeding the assimilative capacity of the estuary. However, a low TOC, TN or TP concentration does not necessarily indicate an absence of eutrophication symptoms. It may be that the estuary, or part of an estuary, has reached a eutrophic condition and exhausted the nutrient supply. Obviously, the latter case is likely to better respond to input load reduction than the former.

In relation to Sites A and B at Waikawa Estuary in 2013, the results showed concentrations of TOC, TP and TN were low, and generally very similar to the results from the 2005-2008 baseline monitoring (Figures 9 -11).

Macro-invertebrate Organic Enrichment Index

The benthic organic enrichment rating, based on the tolerances to enrichment presented in Table 4, showed that at Site A in 2013, the benthic invertebrate community condition was in the upper range of the "very low" category, indicating only slight organic enrichment (Figure 12). This rating showed an improvement from the "low" category in 2005-2008 and is partly a reflection of the decrease in mud content at this site.

In contrast, the sandier, sea-influenced lower estuary Site B showed little difference from the baseline 2005-2008 years and was rated in the "low" category, indicating slight to moderate organic enrichment.

The ratings also indicate that the macroinvertebrate community was dominated by organisms that are intolerant of enrichment rather than highly tolerant species e.g. *Macroclymenella stewartensis*.

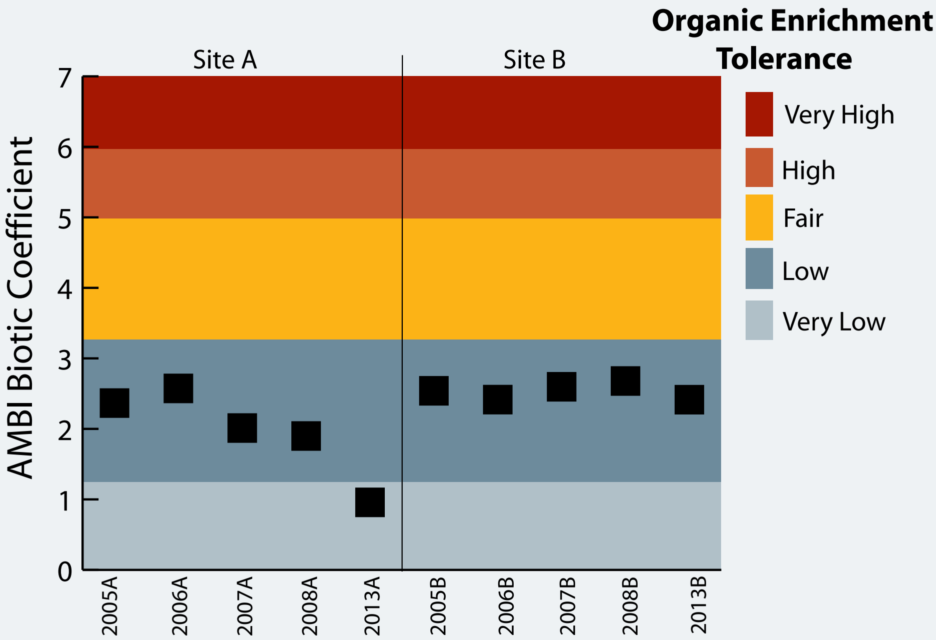


Figure 12. Benthic invertebrate organic enrichment rating, Waikawa Estuary.

3. Results and Discussion (continued)

TOXICITY

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at low to very low concentrations in 2013 at Sites A and B with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 12). All metals met the "very good" condition rating, with values generally similar to or lower than those from the baseline monitoring in previous years. These results indicate that there is no wide-spread metal toxicity in Waikawa Estuary.

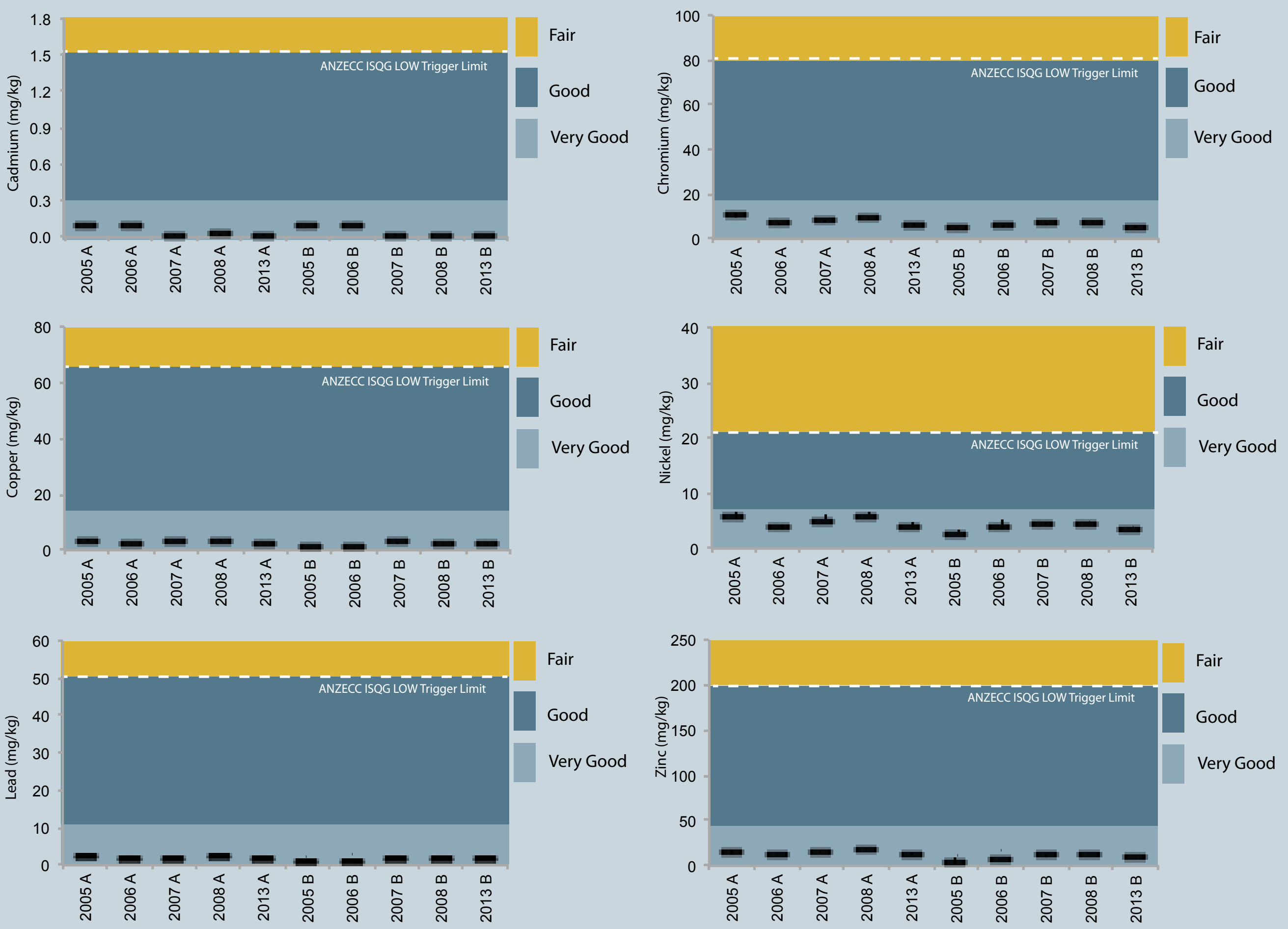


Figure 13. Sediment metal concentrations (mean and range), 2005-2008 and 2013, Waikawa Estuary.

4. SUMMARY AND CONCLUSIONS

In 2013, monitoring at two sites in Waikawa Estuary showed that the estuary was generally in good condition.

The key findings were as follows:

- Sandy habitat dominated with sediment mud content relatively low at both sites. Results show the intertidal fine scale sites have become less muddy or stayed at similar levels to the baseline period. Site A (the site furthest from the estuary mouth) in particular was showing a favourable trend towards decreasing mud, consistent with observations that areas of intertidal flats in the central basin, previously covered in soft mud, have become noticeably sandier over the past 5 years.
- As expected in sand dominated sediments, the benthic invertebrate community was characterised by species that prefer sediments with low mud content and low organic enrichment. The mud tolerance rating showed that both sites were in good condition, with the mud tolerance rating declining (showing improving conditions) since 2005.
- However, the 2013 results also showed that macro-invertebrate abundance and species richness declined considerably since the baseline period 2005-2008, and that the 2013 communities were significantly different in structure from the baseline communities. The reason for this decline was not known (possibly related to climatic variations), but can be partially explained by the reduction in mud concentrations recorded in 2013.
- Sediment oxygenation was moderate (RPD 1-2cm) and concentrations of organic carbon (TOC), and nutrients (TP and TN) were low to very low.
- The enrichment tolerance rating showed that both sites were in good condition, with condition improving since 2005, and that overall the estuary has a low to moderate level of enrichment (i.e. mesotrophic state).
- Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations (i.e. low metal toxicity).

5. MONITORING

Waikawa Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's coastal monitoring programme being undertaken in a staged manner throughout the Southland region. Based on the 2013 monitoring results and condition ratings, and trends following completion of the 4 year baseline (2005-2008) , it is recommended that monitoring continue as outlined below:

- Repeat fine scale monitoring at 5 yearly intervals (next scheduled for February 2018).
- Continue existing programme of annual measurements of sedimentation rate.
- Undertake broad scale habitat mapping (including macroalgal cover) five yearly (next scheduled for 2013/14).

6. MANAGEMENT

The 2013 fine scale monitoring results emphasise the cleaner, sandy nature of the lower half of the estuary. However, because previous monitoring has shown the upper estuary to be much muddier, it is recommended that sources of elevated sediment loads in the catchment be identified, and management undertaken, to minimise their adverse effects on estuary uses and values.

7. ACKNOWLEDGEMENTS

This work has been undertaken with the support and assistance of Nick Ward (Coastal Scientist, Environment Southland).

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson). *	N/A
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g/100g dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt

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

APPENDIX 2. 2013 DETAILED RESULTS

Station Locations

Waikawa Site A 2013	1	2	3	4	5	6	7	8	9	10
NZMG EAST	1304890	1304904	1304918	1304932	1304932	1304921	1304905	1304889	1304889	1304901
NZMG NORTH	4829572	4829573	4829575	4829575	482983	4829581	4829583	4829586	4829593	4829592
Waikawa Site B 2013	1	2	3	4	5	6	7	8	9	10
NZMG EAST	1305279	1305294	1305309	1305326	1305321	1305308	1305292	1305276	1305274	1305285
NZMG NORTH	4828912	4828920	4828922	4828930	4828941	4828933	4828928	4828926	4828934	4828940

Physical and Chemical Results for Waikawa Estuary (Sites A and B), 14 February 2013

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg							
Waikawa A	1-4	1.5	31	0.35	5.7	93.5	0.7	0.01	6.2	2.3	3.8	1.55	12.9	<500	260
Waikawa A	5-8	2.0	31	0.32	5.4	93.1	1.5	0.02	6.1	2.2	3.6	1.49	12.1	<500	260
Waikawa A	9-10	2.0	31	0.44	7.9	90.1	2	0.02	6.8	2.6	4.2	1.67	13.9	<500	300
Waikawa B	1-4	2.0	31	0.36	2.9	97.0	0.1	0.01	4.9	1.9	3.2	1.34	9.9	<500	240
Waikawa B	5-8	2.0	31	0.24	2.5	96.3	1.2	0.01	5.7	2.1	3.6	1.48	10.5	<500	250
Waikawa B	9-10	2.0	31	0.51	2.6	94.7	2.6	0.02	5.3	1.9	3.2	1.39	9.6	<500	240

* composite samples

Epifauna (numbers per 0.25m² quadrat)

Waikawa Estuary Site A 14 February 2013

Station	WkA-01	WkA-02	WkA-03	WkA-04	WkA-05	WkA-06	WkA-07	WkA-08	WkA-09	WkA-10
Notoacmea helmsi					1					
Cominella glandiformis	2	1		1	1	2	2			
Diloma subrostrata	2	1		1	3	1	1	3	1	
No. species/quadrat	**2**	**2**	**0**	**2**	**3**	**2**	**2**	**1**	**1**	**0**
No. individuals/quadrat	**4**	**2**	**0**	**2**	**5**	**3**	**3**	**3**	**1**	**0**

Waikawa Estuary Site B 14 February 2013

Station	WkA-01	WkA-02	WkA-03	WkA-04	WkA-05	WkA-06	WkA-07	WkA-08	WkA-09	WkA-10
Austrominius modestus		1		6	3	5		8		
Cominella glandiformis	3	2	1		2	9	3	1	1	
Diloma subrostrata	10	25	3	8	8		6	5	9	6
Notoacmea helmsi	1									
No. species/quadrat	**3**	**3**	**2**	**2**	**3**	**2**	**2**	**3**	**2**	**1**
No. individuals/quadrat	**14**	**28**	**4**	**14**	**13**	**14**	**9**	**14**	**10**	**6**

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

Waikawa Estuary Site A 14 February 2013

Group	Species	AMBI GROUP	MUD GROUP	Waik A-01	Waik A-02	Waik A-03	Waik A-04	Waik A-05	Waik A-06	Waik A-07	Waik A-08	Waik A-09	Waik A-10
ANTHOZOA	*Anthopleura aureoradiata*	II	1	6	6	5		2	4	8	5	4	3
	Edwardsia sp.#1	II	2	1	1	1				1			
POLYCHAETA	*Aglaophamus* sp.#1	II	2				2					1	1
	Aonides sp.#1	III	1										
	Boccardia (Paraboccardia) syrtis	III	2			4		4	6		1	3	
	Glycera lamelliformis	II	3		2								
	Glyceridae (unidentified juveniles)	II	3										
	Heteromastus filiformis	IV	3	1		2		3				2	
	Macroclymenella stewartensis	I	3	7	8	18	7	23	14	17	15	18	6
	Magelona sp.#1	I	NA				1		1	1			
	Nereidae (unidentified juveniles)	III	4				1						
	Orbinia papillosa	I	2										
	Prionospio aucklandica	IV	3	2					1	1	2	2	
	Spionidae sp.#1	III	NA										
	Syllidae sp.#2	II	2										
	Travisia olens	I	1										
GASTROPODA	*Cominella glandiformis*	NA	1								1		
	Diloma subrostrata	NA	1			2							1
	Notoacmaea helmsi	NA	1										
BIVALVIA	*Austrovenus stutchburyi*	III	2	1	2		1	1	1	2	2	5	1
	Macomona liliana	II	2		2	2	1			1	1		2
	Nucula sp.#1	I	2		2		2	2	8	1	4		2
	Soletellina sp.#1	II	1								1		
CRUSTACEA	*Amphipoda* sp.#1	NA	NA	1					1	1			1
	Amphipoda sp.#2	NA	NA			1							
	Austrominius modestus	NA	NA										
	Colurostylis lemurum	II	2										
	Halicarcinus whitei	III	NA		1			1				1	
	Isocladus sp.#1	NA	NA										
	Macrophthalmus hirtipes	III	3										
	Phoxocephalidae sp.#1	I	NA	2	1	2	2	3	3	3	1	9	2
	Tanaidacea sp.#1	II	3	1	1	1			4	2	1	3	3
Total individuals in sample				**22**	**26**	**38**	**17**	**39**	**43**	**38**	**34**	**48**	**22**
Total species in sample				**9**	**10**	**10**	**8**	**8**	**10**	**11**	**11**	**10**	**10**

Appendix 2. 2013 Detailed Results (continued)

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

Waikawa Estuary Site B 14 February 2013													
Group	**Species**	AMBI GROUP	MUD GROUP	Waik B-01	Waik B-02	Waik B-03	Waik B-04	Waik B-05	Waik B-06	Waik B-07	Waik B-08	Waik B-09	Waik B-10
ANTHOZOA	*Anthopleura aureoradiata*	II	1	13	6	5	4	10	6	17	15	14	6
	Edwardsia sp.#1	II	2						2				
POLYCHAETA	*Aglaophamus* sp.#1	II	2	2	1	1	2	3	1	1	2		2
	Aonides sp.#1	III	1	2		1		1	2	3	3	2	1
	Boccardia (Paraboccardia) syrtis	III	2		8	2			4	1		3	
	Glycera lamelliformis	II	3										
	Glyceridae (unidentified juveniles)	II	3						3				
	Heteromastus filiformis	IV	3										
	Macroclymenella stewartensis	I	3	6	4	2	1	4	6	2	2	2	
	Magelona sp.#1	I	NA										
	Nereidae (unidentified juveniles)	III	4										
	Orbinia papillosa	I	2		1								
	Prionospio aucklandica	IV	3	2	6	1				1		1	1
	Spionidae sp.#1	III	NA										1
	Syllidae sp.#2	II	2		1			1	2				
	Travisia olens	I	1		1			2	2				
GASTROPODA	*Cominella glandiformis*	NA	1	1					2	1	1	1	
	Diloma subrostrata	NA	1	1								2	
	Notoacmaea helmsi	NA	1	5					2		7	4	2
BIVALVIA	*Austrovenus stutchburyi*	III	2	1	2	11	2	5	2	10	3	17	2
	Macomona liliana	II	2										
	Nucula sp.#1	I	2										
	Soletellina sp.#1	II	1					1	1				
CRUSTACEA	*Amphipoda* sp.#1	NA	NA	3	3		2		1	1	2	7	1
	Amphipoda sp.#2	NA	NA										
	Austrominius modestus	NA	NA	4							3		1
	Colurostylis lemurum	II	2						1	1			
	Halicarcinus whitei	III	NA										
	Isocladus sp.#1	NA	NA	1	4						1	1	
	Macrophthalmus hirtipes	III	3						1	1			
	Phoxocephalidae sp.#1	I	NA	1									
	Tanaidacea sp.#1	II	3										
Total individuals in sample				**42**	**37**	**23**	**11**	**27**	**38**	**39**	**39**	**54**	**17**
Total species in sample				**13**	**11**	**7**	**5**	**8**	**16**	**11**	**10**	**11**	**9**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment *****	Tolerance to Mud****	Details
Anthozoa	*Anthopleura aureoradiata*	II	SS Optimum range 5-10% mud*, distribution range 0-10%**	Mud flat anemone, attaches to cockle shells and helps to reduce the rate at which cockles accumulate parasites. It can also grow in small vertical shafts of its own an inch or more deep, fastened to small stones. Grows up to 10mm, intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al., 2001). It has green plant cells in its tissues that convert solar energy to food.
Anthozoa	*Edwardsia* sp.#1	II	S Prefer sand habitats	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.
Polychaeta	*Aglaophamus* sp.#1	II	S Prefer sand habitats	A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than a muddier substrate. Feeding type is carnivorous. Significant avoidance behaviour by other species.
Polychaeta	*Aonides* sp.	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 10 cm. Although it 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.
Polychaeta	*Boccardia (Paraboccardia) syrtis*	III modified from AMBI	S Optimum range 10-15% mud,* distribution range 0-50%*	A small surface deposit-feeding spionid. Prefers low-mod mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
Polychaeta	*Glycera lamellipodia*	II	I Optimum range 55-60% 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 15 cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions. Often present in muddy conditions. Intolerant of low salinity. Found in sands and sandy muds.
Polychaeta	*Heteromastus filiformis*	IV	I Optimum range 10-15%* or 20-40% 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.
Polychaeta	*Macroclymenella stewartensis*	I	I 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. Found throughout the sediment to depths of 15cm and has a key role in the reworking and turn-over of sediment. This worm may modify the sediment conditions, making it more suitable for other species (Thrush 1988). Common at low water in estuaries. Prefers sand. Intolerant of anoxic conditions.

Appendix 3. Infauna Characteristics

Group and Species		Tolerance to Organic Enrichment *****	Tolerance to Mud****	Details
Polychaeta	*Magelona sp.*	I	NA	Small thin spionid worms which selectively deposit-feed on the surface. Responds negatively to an increase in silt/clay. Highly intolerant of reducing conditions. Found throughout New Zealand. Mid-intertidal and subtidal to continental slope. Magelonids build wandering burrows in medium to fine sands. The worms are visible to the naked eye as pinkish threads when sediment clumps are broken apart by hand. Found at Waimea, Waikawa and Ohiwa estuaries. Mud Tolerance; Optimum range 10-15% mud,* distribution range 0-95%*.
	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. Rarely dominant in numbers compared to other polychaetes, but 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.
	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.
	Prionospio auck-landica	IV	I Optimum range 65-70% mud,* distribution range 0-95%*	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was renamed to *Aquilaspio auck-landica*. Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001).
	Spionidae sp.#1	III	NA	A spionid. Small burrowers or surface tube-dwellers or crevice- and algal turf-dwellers, or shell-borers with one pair of deciduous feeding palps, and multiple pairs of segmental gills. Spionids occur across the shore from the upper intertidal, and also subtidally to the deep sea. Spionids are very common polychaetes in all sandy substrata, and rather infrequent on rocky shores.
	Syllidae sp. #1	II	S Optimum range 25-30% mud,* distribution range 0-40%*	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers sandy sediments.
	Travisia olens	I	SS Optimum range 0-5% mud*, distribution range 0-5%**	Relatively uncommon but found throughout New Zealand in the intertidal and subtidally to deep sea. The former opheliid, the large fat, bad smelling, grey-white coloured *Travisia olens* is found on open to semi-protected sand beaches.
Gastropoda	*Cominella glandi-formis*	NA	SS Optimum range 5-10% mud*, distribution range 5-10%**	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.

Appendix 3. Infauna Characteristics

Group	Species	Tolerance to Organic Enrichment *****	Tolerance to Mud****	Details
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.
Gastropoda	*Notoacmaea helmsi*	NA	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. Present in Porirua Harbour 4-5% mud, Freshwater Estuary <1% mud. A few in Fortrose (5% mud).
Bivalvia	Austrovenus stutch-buryi	III modified from AMBI	S Prefers sand with some mud (optimum range 0-5% mud* distribution range 0-40% mud**).	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. 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.
Bivalvia	*Mocomona liliana*	II modified from AMBI	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 macro-invertebrate 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.
Bivalvia	*Nucula* sp. #1	I	S Prefers sand with some mud (optimum range 0-5% mud* distribution range 0-60% mud**).	Nucula is a saltwater nut clam, a marine bivalve mollusc in the family Nuculidae. Small deposit feeder which is endemic to New Zealand. 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. It has a plug-like foot, which it uses for motion in mud deposits. Intolerant of organic enrichment.
Bivalvia	*Soletellina nitida*	II	SS Optimum range 5-10% mud*, distribution range 0-10%**	Soletellina is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells. Intolerant of eutrophic or muddy conditions.
Crustacea	Amphipoda sp. #1	NA	Uncertain	An unidentified amphipod species.
Crustacea	Amphipoda sp. #2	NA	NA	An unidentified amphipod species.

Appendix 3. Infauna Characteristics

Group and Species		Tolerance to Organic Enrichment *****	Tolerance to Mud****	Details
Crustacea	*Austrominius modestus*	NA	NA	Small acorn barnacle (also named Elminius modestus). Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones. A filter feeder that prefers a sandy substrate******.
	Colurostylis lemurum	II	S Prefers sand with some mud (optimum range 0-5% mud* distribution range 0-60% mud**).	A cumacean that prefers sandy environments. Cumacea is an order of small marine crustaceans, occasionally called hooded shrimp. Their unique appearance and uniform body plan makes them easy to distinguish from other crustaceans.
	Halicarcinus whitei	NA	NA	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Isocladus sp. #1	NA	NA	Belongs to the Sphaeromatidae which is a family of isopods found in the upper intertidal of moderately sheltered and sheltered beaches and estuaries.
	Macrophthalmus hirtipes	NA	I Optimum range 45-50% mud,* distribution range 0-95%*	The stalk-eyed mud crab is endemic to NZ and prefers water-logged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
	Phoxocephalidae sp.	I	Uncertain	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Tanaidacea sp. #1	II	I Optimum range 10-15% mud,* distribution range 0-100%*	Tanaids (order Tanaidacea) make up a minor crustacean group within the class Malacostraca. There are about 940 species in this order. Tanaids are small, shrimp-like creatures ranging from 0.5 to 120 millimetres (0.020 to 4.7 in) in adult size, with most species being from 2 to 5 millimetres. Most are marine, but some are also found in freshwater coastal habitat or estuaries. The majority of species are bottom-dwellers in shallow water environments.

* 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.

***** Organic Enrichment Groupings (from either Borja et al. 2000 or Modified Sensitivity Grouping based on a review of local species data for 20 plus NZ estuaries (150 plus sites) using species abundance versus TN, TP, TOC, % mud, RPD as eutrophication indicators. All sites had low concentrations of toxicants).

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.