coastalmanagement

Waikawa Estuary

Fine Scale Monitoring 2007/08

Prepared for Environment Southland
June 2008

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By

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Cover Photo: Waikawa Estuary arm near mouth.

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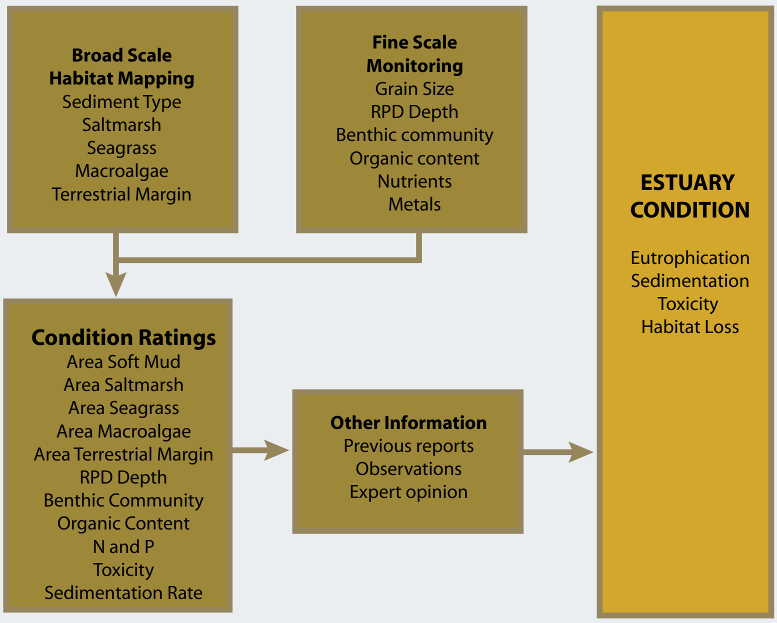
All photos by Wriggle except where noted otherwise.

WAIKAWA ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the 2008 fine scale monitoring for Waikawa Estuary, a 760ha tidal lagoon estuary on the Catlins coast, and one of the key estuaries in Environment Southland's (ES) long-term estuary monitoring programme. This programme uses sediment health as a primary indicator of estuary condition and includes two main components, broad scale mapping and detailed fine scale monitoring. The current report describes the fine scale monitoring undertaken in February 2008 (including the measurement of sedimentation rate and broad scale macroalgal mapping) and also provides a review of the previous 3 years of monitoring data. The methods used were based on the tools included in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002), and a number of recent extensions (Robertson and Stevens 2006 and 2008).

Fine scale monitoring provides detailed physical, chemical and biological information that is used to develop condition ratings for indicators of estuary condition. These indicator ratings (both broad and fine scale) are then combined with other available data and relevant expert information to assess the overall condition of the estuary in relation to the key issues of sedimentation, eutrophication, toxicity and habitat loss. Disease risk, the other major estuary issue, will be monitored and reported separately by ES (beginning 2008/09) through its shellfish monitoring programme. In most cases, both broad and fine scale information is required to assess the extent to which an estuary is manifesting a particular issue. For example, the macroalgal rating (derived from broadscale mapping of the percentage macroalgal cover), is combined with a number of fine scale ratings (organic carbon, nutrients, sediment oxygenation, grain size, and benthic community index) and other information (e.g. flushing characteristics) to help assess the extent of eutrophication in the estuary. A summary of the approach is outlined in the figure below.



Using this approach, the key findings of the fine scale monitoring in relation to the condition of Waikawa Estuary and the key estuary issues were as follows:

EXECUTIVE SUMMARY (continued)

FINE SCALE MONITORING RESULTS

The results of the 4 years of fine scale baseline monitoring of dominant intertidal habitat at 2 sites in Waikawa Estuary were as follows:

Organic Matter. Total organic carbon (TOC), the indicator of organic enrichment at both sites A and B in 2008 was at low concentrations (mean <1%) and met the "good" to "very good" condition rating. The rating was the same in the previous 3 years of monitoring but over this period there was a general trend of increasing concentrations at both sites.

Nutrients (Nitrogen and Phosphorus). Total phosphorus (TP - a key nutrient in the eutrophication process) was present in the "low to moderate enrichment" category at both sites for all 4 years of monitoring (mean 200-320mg/kg). Total nitrogen (TN - the other key nutrient in the eutrophication process) was in the low enrichment or "very good" category at both sites for all 4 years of monitoring (mean less than 500mg/kg).

Grain Size. Grain size (% mud, sand, gravel), the indicator of site muddiness, showed that both sites were dominated by sandy sediments (Site A 87-90% sand and Site B 95-97% sand). The mud fraction was also significant (5-10% mud content), particularly at Site A closest to the muddy upper half of the estuary.

Metals (Cd, Cr, Cu, Ni, Pb, Zn). Heavy metals, used as an indicator of potential toxicants, were at very low concentrations at both intertidal sites for all 4 years of baseline monitoring, with all values well below the ANZECC (2000) ISQG-Low trigger values.

RPD Depth. RPD depth, which is a key indicator of sediment oxygenation, was moderately shallow at Site B (closest to the estuary mouth and channel) and varied from 4-5cm, but was much deeper at Site A (mid estuary), where it was greater than 10cm depth. Such values, as well as the dominance of sandy sediments and the presence of numerous infauna feeding voids and burrows below the RPD, indicate a "good" to "very good" condition rating for sediment oxygenation (i.e. RPD) at both sites.

Benthic Macrofauna. Both sites had a high diversity and moderate abundance of macrofauna. However, they differed in the types of species making up the community at each site. Using multivariate statistics it was also shown that the benthic communities at each site were relatively different from each other and that there was greater community variation between replicates at Site B than at Site A. Using the recently developed AMBI benthic community index (Borja et al. 2000), the benthic community condition was found to be "unbalanced", giving it a "slightly polluted" classification, i.e. a community with elevated numbers of organisms that tolerate moderate mud and organic enrichment levels.

Sedimentation Rate. The results showed that the sites were still stabilising and it was too early to measure rates reliably.

BROAD SCALE MONITORING RESULTS

Macroalagal Cover. Compared with the previous year, the 2007/08 macroalgal cover reduced significantly, with only 2% of the estuary having a cover >5%. Macroalgae was again most widespread in the upper estuary and the condition rating placed the estuary at the lower end of the "Low" category (MC=0.3).

EXECUTIVE SUMMARY (continued)

CONDITION RATINGS

The fine scale condition ratings for the key fine scale indicators in 2005-2008 are summarised as follows.

Location and Year	RPD Depth	Benthic Community	Organic Matter	TP	TN	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Site A 2005	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site A 2006	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site A 2007	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site A 2008	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2005	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2006	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2007	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2008	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD

The broad scale condition ratings for macroalgal cover in 2007 and 2008 are summarised as follows.

Location	Year	Macroalgal Coefficient	Macroalga Cover
Waikawa Estuary	2007	0.8	LOW
Waikawa Estuary	2008	0.3	LOW

ESTUARY ISSUES

The fine scale results, as well as other information, were used to provide an understanding of the estuary condition in relation to the key estuary issues of sedimentation, eutrophication and toxicity.

ISSUE RATING EUTROPHICATION

LOW to MODERATE

- **Eutrophication.** The major indicators of organic enrichment show that the estuary had a low to moderate level of enrichment and therefore was more oligotrophic to mesotrophic (low - moderate fertility) than eutrophic (high fertility). Such conclusions were inferred from the relatively deep RPD (i.e. depth of anoxic layer), the "unbalanced" nature of the benthic invertebrate community, and the low-moderate nutrient concentrations. Taken in combination with the low presence of macroalgae in the estuary, the results indicate a low to moderately enriched estuary. Such enrichment, although not yet a problem, does indicate a need for caution, particularly in relation to factors that could increase nutrient and fine sediment concentrations in the estuary. In order to ensure nutrient loads to the estuary do not increase and cause a shift towards greater enrichment, it is recommended that nutrient load management and long term monitoring in the catchment be encouraged.

ISSUE RATING SEDIMENTATION

HIGH SEDIMENTATION

- **Sedimentation**. If sediment inputs to the estuary are excessive, the estuary infills quickly with muds, reducing biodiversity and human values and uses. In estuaries with large intertidal areas, like the Waikawa, fine muds tend to settle in three main areas; the unvegetated intertidal area in the upper to mid estuary, saltmarsh areas (primarily in the upper estuary) and small sheltered estuary arms. Broad scale mapping (Robertson et al. 2004) showed that the upper one-third to half of the estuary consists of soft and very soft muds, and the lower half consists of sands and muddy sands. Fine scale monitoring (2005-2008) showed that the mud content of Sites A and B, which are both located in the sandy, lower estuary, was less than 10%. Also, by using the results of Site A (which is situated adjacent to the boundary with the muddy upper estuary and therefore acts as an indicator of any expansion in the soft mud area within the estuary), it seems likely that the upper muddy area has possibly expanded since 2005. This is to be expected given the high sedimentation rates reported for the upper estuary over the last 10 years (10.7mm/yr) (Robertson and Stevens 2007).

EXECUTIVE SUMMARY (continued)

- Such excessive sedimentation indicates a need to reduce sediment loads to the estuary and to continue with the long term monitoring programme. In the future, the extent of sedimentation in the estuary will continue to be monitored using the combined tools of broad scale habitat maps, fine scale monitoring at key sites, and sedimentation rate monitoring using the 12 sedimentation plates that were deployed in 2007.

ISSUE RATING TOXICITY
LOW TOXICITY

- **Toxicity**. If potentially toxic contaminant inputs (e.g. heavy metals) are excessive, estuary biodiversity is threatened and shellfish and fish may be unsuitable for eating. In the sandy fine scale sites in the Waikawa Estuary the extent of contamination with toxic substances was rated "very good" reflecting the low levels of heavy metals. However, such positive results for the intertidal sandy sediments can be misleading when using the findings to assess overall toxicity within the whole estuary. Because metals entering the estuary are mostly bound to fine sediments, they tend to end up at the highest concentrations in the muddy upper one-third of the estuary (i.e. away from the two fine scale sites). To further assess this issue, the metal concentrations which were measured in 1995 in the upper estuary very soft muds (Robertson 1995) were compared with results for the lower estuary sites A and B. The results showed the 1995 upper estuary concentrations were higher than at the 2008 fine scale sandy sites but still much less than ANZECC guidelines. Overall, this information suggest that toxicity in the Waikawa Estuary be rated in the "low" category. In the future, it is recommended that ongoing monitoring includes an upper estuary site in its physical and chemical fine scale monitoring programme.

MONITORING

Waikawa Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's existing coastal monitoring programme being undertaken in a staged manner throughout the Southland region. Based on the 2005, 2006, 2007 and 2008 baseline monitoring results and condition ratings, it is recommended that monitoring continue as follows.

Fine Scale Monitoring.
Undertake monitoring at 5 yearly intervals or as deemed necessary based on the condition ratings. Include a new site for physical and chemical parameters in upper estuary. The next fine scale monitoring is scheduled for February 2012.

Sedimentation Rate Monitoring.
Monitor the depths of the existing 12 sediment plates at 5 yearly intervals. The next sediment plate monitoring should be undertaken during the broad scale mapping exercise scheduled for 2009. Following the 2009 monitoring, it is recommended that the depth of all plates be measured whenever fine scale monitoring is undertaken.

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 at the same time that sediment plates are measured in the estuary, or 5 yearly in the absence of obvious changes in the estuary.

MANAGEMENT

The fine scale monitoring reinforced the need for management of nutrients, toxins and fine sediment sources entering the estuary. It is understood that ES ishj currently working to identify catchment nutrient, toxin and sediment sources and "hotspots", and to implement BMPs (Best Management Practices) for reducing nutrient, toxin and sediment mobilisation and runoff to surface and groundwater in the catchment. The findings of this report provide support for such management.

1. INTRODUCTION

OVERVIEW

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. In 2000, Environment Southland (ES) identified a number of estuaries in it's region as immediate priorities for long term monitoring: New River Estuary, Jacobs River Estuary, Fortrose Estuary, Waikawa Estuary, Haldane Estuary, Waiau Lagoon and Freshwater Estuary.

In 2002, ES chose to begin the estuary monitoring programme in a staged manner, with the New River, Jacobs River and Fortrose as the first estuaries. Monitoring of Waikawa Estuary began in 2004/05 and now has 4 years of fine scale baseline monitoring data. Wriggle Coastal Management and ES currently undertake the work using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions (Table 1).

The Waikawa Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment.** Assessment of the vulnerability of the estuary to major issues and appropriate monitoring design. This component has been undertaken for Waikawa Estuary and is reported in Robertson and Stevens (2007).
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 2004/5, and is reported separately in Robertson et al. (2004).
3. **Fine Scale Monitoring.** Monitoring of physical, chemical and biological variables including sedimentation plate monitoring (EMP approach). This component, which provides detailed information on estuary condition, is the subject of the current report. The first 3 years of monitoring are reported in Stevens and Asher (2005), Robertson and Asher (2006) and Robertson and Stevens (2007).

Waikawa Estuary (760ha) is a large, shallow, well flushed "tidal lagoon" type estuary consisting of one central basin. 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 the local people that live near or visit its shores 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 through reclamation of saltmarsh areas and introduction of a small area of rockwall. The only structures in the harbour are wharves, pile moorings and a slipway which services the fishing fleet.

The estuary vulnerability assessment (Robertson and Stevens 2007) found ecological vulnerability for the majority of estuary habitats was rated in the low or low-moderate class for Waikawa Estuary. However, two key issues were identified as follows:

1. Introduction (continued)

OVERVIEW

- **Excessive sedimentation:** Approximately half of the estuary surface is covered by soft muds and recent sedimentation rates are high. The likely ecological response is one of lowered biodiversity and lowered aesthetic and human use values in the upper estuary.

- **Loss of salt marsh habitat and margin development:** Historical clearance of bush around the terrestrial fringe of the estuary means it is now dominated by grazed pasture, greatly reducing the buffering function provided previously by the bush-covered margin. This buffer protects against introduced weeds and grasses, naturally filters sediments and nutrients and provides valuable ecological habitat. Additionally, there have been significant areas of saltmarsh drained for pastoral use in the past and this has most likely contributed to reduced biodiversity and increased sedimentation in the estuary.

The combination of these factors, plus the documented long term, low-moderate risks to Waikawa Estuary from a number of sources (i.e. catchment landuse practices, invasive weeds and pests, margin development) (Robertson and Stevens 2007), provide the need for a long term monitoring programme. The information gathered in the programme will help guide management actions, allow effectiveness to be monitored, and identify any need for revised actions.

The current report documents the following;

- The results of the fine scale monitoring undertaken in February 2008 of 2 intertidal sites in Waikawa Estuary.
- The monitoring of sedimentation rate in Waikawa Estuary.
- Broad scale mapping of macroalgal cover.
- Condition ratings for the Waikawa Estuary based on the 2005-2008 fine scale results. A suggested monitoring or management response is linked to each condition rating.

This report is the fourth of a series of four, which characterises the baseline fine scale conditions in the estuary from 2005 to 2008. The results help determine the extent to which the estuary is affected by major estuary issues (Table 2), both in the short and long term. The survey focuses on providing detailed information on indicators of chemical and biological condition (Table 3) of the dominant habitat type in the estuary (i.e. unvegetated intertidal mudflats at low-mid water).

STRUCTURE

The report is structured in the following general sections:

Section 1 Introduction to the scope and structure of the study.
Section 2 Methods for the fine scale assessment, sedimentation rate, and the estuary condition ratings.
Section 3 Results and discussion.
Section 4 Conclusions.
Section 5 Monitoring recommendations.
Section 6 Management recommendations.
Section 7 Acknowledgements.
Section 8 References.
Appendix 1: Details of analytical methods.
Appendix 2: Detailed fine scale monitoring results - Waikawa Estuary 2008.
Appendix 3: Characteristics of the benthic invertebrate community.

1. Introduction (continued)

Table 1. Coastal Monitoring Tools (Wriggle Coastal Management).

Resource	Tools for Monitoring and Management
Estuaries	Estuary vulnerability matrix. Broad scale estuary and 200m terrestrial margin habitat mapping. Fine scale estuary monitoring. Sedimentation rate measures (using plates buried in sediment). Historical sedimentation rates (using radio-isotope ageing of sediment cores). Macroalgae and seagrass mapping (reported as separate GIS layers). Condition ratings for key indicators. Georeferenced digital photos (as a GIS layer). Upper estuary monitoring and assessment.
Beaches, Dunes	Beach and dune vulnerability matrix. Broad scale beach, dune and terrestrial margin mapping. Fine scale beach monitoring.
Rocky Shores	Rocky shore vulnerability matrix. Broad scale rocky shore and terrestrial margin mapping. Fine scale rocky shore monitoring.

Table 2. Summary of the major issues affecting most NZ estuaries.

Issue	Impact
Sedimentation	If sediment inputs are excessive, an estuary infills quickly with muds, reducing biodiversity and human values and uses.
Eutrophication	Eutrophication is an increase in the rate of supply of organic matter to an ecosystem. If nutrient inputs are excessive, the ecosystem experiences macroalgal and/or phytoplankton blooms, anoxic sediments, lowered biodiversity and nuisance effects for local residents.
Disease Risk	If pathogen inputs are excessive, the disease risk from bathing, wading or eating shellfish increases to unacceptable levels.
Toxins	If potentially toxic contaminant inputs (e.g. heavy metals, pesticides) are excessive, estuary biodiversity is threatened and shellfish and fish may be unsuitable for eating.
Habitat Loss	If habitats (such as saltmarsh) are lost or damaged through drainage, reclamation, building of structures, stock grazing or vehicle access, biodiversity and estuary productivity declines.
	If the natural terrestrial margin around the estuary is modified by forest clearance or degraded through such actions as roading, stormwater outfalls, property development and weed growth, the natural character is diminished and biodiversity reduced.

Table 3. Summary of the broad and fine scale EMP indicators.

Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Eutrophication	Nuisance Macroalgal Cover	Broad scale mapping - estimates the change in the area of nuisance macroalgal growth (e.g. sea lettuce (*Ulva*), *Gracilaria* and *Enteromorpha*) over time.
Eutrophication	Organic and Nutrient Enrichment	Chemical analysis of total nitrogen, total phosphorus, and total organic carbon (calculated from ash free dry weight) 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.

1. Introduction (continued)

Figure 1. Location of sedimentation and fine scale monitoring sites, Waikawa Estuary (Photo ES).

2. METHODS

FINE SCALE MONITORING

Quadrat for epifauna sampling.

Fine scale monitoring is based on the methods described in the EMP (Robertson et al. 2002) and provides detailed information on 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 2 per estuary) are selected and samples collected and analysed for the following variables:

- Salinity, Depth to black sulphide layer (Redox Potential Discontinuity - RPD), Grain size (% mud, sand, gravel).
- Organic Matter: Ash free dry weight (AFDW) (converted and reported as total organic content - TOC).
- Nutrients: Total nitrogen (TN), Total phosphorus (TP).
- Metals: Total recoverable Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni) and Zinc (Zn).
- Macroinvertebrate abundance and diversity (infauna and epifauna)

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

Physical and chemical analyses:

- Within each plot, one random core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average RPD depth recorded.
- Three samples from each site (each a composite from four plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to the infauna cores. All samples were kept in a chillybin in the field. Chilled samples were sent to R.J. Hill Laboratories for analysis (details Appendix 1) for:
  - Grain size/Particle size distribution (% mud, sand, gravel).
  - Nutrients (TN and TP).
  - AFDW (as a measure of total organic content).
  - 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 produced by Australian and New Zealand Environment and Conservation Council (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- In addition, salinity of the overlying water was measured at low tide at each site in order to provide a better definition of habitat type.

Infauna (animals within sediments):

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

2. Methods (continued)

FINE SCALE MONITORING (CONTINUED)

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.

BROAD SCALE MACROALGAE MAPPING

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: seagrass, macroalgae, rushland, etc). It follows the EMP approach originally described for use in NZ estuaries by Robertson et al. (2002) with a combination of aerial photography (1:10,000), detailed ground-truthing, and GIS-based digital mapping used to record the primary habitat features present. Very simply, the method for the macroalgal component involves three key steps:

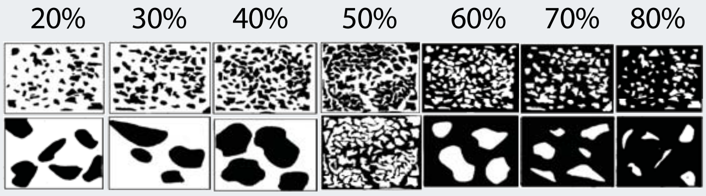
- Obtaining laminated aerial photos for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing).
- Digitising the field data into GIS layers (ArcMap 9.2).

For the 2008 study, rectified 0.5m/pixel resolution colour aerial photos flown in 2005 were used as a base layer. Two scientists ground-truthed the spatial extent of dominant habitat and substrate types by walking the extent of the estuary recording features directly on the 1:5,000 laminated aerial photos in February 2008. The % cover of intertidal macroalgae within the estuary was visually classified into seven categories using a visual rating scale (see examples below and left) to describe macroalgae density and distribution within the estuary.

>1 %
1-5%
5-10 %
10-20 %
20-50 %
50-80 %
80-100 %

Categories of percentage cover used to classify macroalgae and seagrass.

Visual rating scale for percentage cover estimates



SEDIMENT PLATE MONITORING

Determining the sedimentation rate from now into the future involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried, levelled, and the elevation measured, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate (>3) are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance.

Three sites (Upper Sth, Upper Nth and Lower Sth) were established in Waikawa Estuary on 2-4 March 2007 (Figure 1). The Upper sites, one on each side of the main channel, were in deep soft muds in the upper third of the estuary where sedimentation rates are likely to be greatest. The Lower site was located just inside the boundary between soft mud and firm muddy sand, on the firm muddy sand side. This site was chosen to indicate any expansion or contraction of the soft mud front. At each site, four plates (20cm square concrete blocks) were buried (Figure 1) approximately 30m apart in a square configuration deep in the sediments where stable substrate is located. The position of each plate was marked with wooden stakes driven into the sediment, their GPS positions logged, and the depth from the undisturbed mud surface to the top of the sediment plate and the top of the wooden stakes was recorded. In the future, these distances will be measured annually and, over the long term, will provide a measure of rates of sedimentation in the estuary.

2. Methods (continued)

CONDITION RATINGS

RATING
Very Good
Good
Fair
Poor
Early Warning Trigger

At present, there are no formal criteria for rating the overall condition of NZ estuaries, and development of scientifically robust and nationally applicable condition ratings requires a significant investment in research and is unlikely to produce immediate answers. Therefore, to help ES interpret their monitoring data, a series of interim broad and fine scale estuary "condition ratings" (presented below) have been proposed for Waikawa Estuary (based on the ratings developed for New Zealand estuaries - Robertson & Stevens 2006, 2007, 2008). The condition ratings are designed to be used in combination with each other (usually involving expert input) when evaluating overall estuary condition and deciding on appropriate management responses. The ratings are based on a review of monitoring data, use of existing guideline criteria, and expert opinion. They indicate whether monitoring results reflect good or degraded conditions, and also include an "early warning trigger" so that ES is alerted where rapid or unexpected change occurs. For each of the condition ratings, a recommended monitoring frequency is proposed and a recommended management response is suggested. In most cases the management recommendation is simply that ES develop an Evaluation and Response Plan (ERP) to further evaluate an issue and consider what response actions may be appropriate. It is expected that the proposed ratings will continue to be revised and updated as better information becomes available, and new ratings developed for other indicators.

Redox Potential Discontinuity

The RPD is the grey layer between the oxygenated yellow-brown sediments near the surface and the deeper anoxic black sediments. The RPD marks the transition between oxygenated and reduced conditions and 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. In addition, nutrient availability in estuaries is generally much greater where sediments are anoxic, with consequent exacerbation of the eutrophication process. The majority of the other eutrophication indicators (e.g. macroalgal blooms, soft muds, sediment organic C, TP, and TN) are less critical, in that they can be elevated, but not necessarily causing sediment anoxia and adverse impacts on 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 yr intervals after baseline established
Good	3-10cm depth	Monitor at 5 yr intervals after baseline established
Fair	1-3cm depth	Post baseline, monitor at 2 yr intervals. Initiate ERP
Poor	<1cm depth	Post baseline, monitor at 2 yr intervals. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan (ERP)

Metals

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

METALS CONDITION RATING

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

2. Methods (continued)

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
Low-Mod Enrichment	200-500mg/kg	Monitor at 5 year intervals after baseline established
Enriched	500-1000mg/kg	Post baseline, monitor at 2 yr intervals. Initiate ERP
Very Enriched	>1000mg/kg	Post baseline, monitor at 2 yr intervals. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan (ERP)

Total Organic Carbon

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, release of excessive nutrients, and adverse impacts to biota - all symptoms of eutrophication. As organic input to the sediment increases the number of suspension-feeders (e.g. bivalves and certain polychaetes) declines and the number of deposit-feeders (e.g. opportunistic polychaetes) increases (Pearson and Rosenburg, 1978).

TOTAL ORGANIC CARBON CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<1%	Monitor at 5 year intervals after baseline established
Low-Mod Enrichment	1-2%	Monitor at 5 year intervals after baseline established
Enriched	2-5%	Post baseline, monitor at 2 yr intervals, manage source
Very Enriched	>5%	Post baseline, monitor at 2 yr intervals, manage source
Early Warning Trigger	>1.3 x Mean of highest baseline yr	Initiate Evaluation and Response Plan (ERP)

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
Low-Mod Enrichment	500-2000mg/kg	Monitor at 5 year intervals after baseline established
Enriched	2000-4000mg/kg	Post baseline, monitor at 2 yr intervals. Initiate ERP
Very Enriched	>4000mg/kg	Post baseline, monitor at 2 yr intervals. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan (ERP)

Sedimentation Rate

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

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

2. Methods (continued)

Macroalgae Index

Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota.

A continuous index (the macroalgae coefficient - MC) has been developed to rate macroalgal condition based on the percentage cover of macroalgae in defined categories using the following equation:

MC=((0 x %macroalgal cover <1%)+(0.5 x %cover 1-5%)+(1 x %cover 5-10%)+(3 x %cover 10-20%)+(4.5 x %cover 20-50%)+(6 x %cover 50-80%)+(7.5 x %cover >80%))/100.

This interim index will continue to be refined as it is applied to estuary data from throughout NZ.

MACROALGAE CONDITION RATING		
RATING	MACROALGAE COEFFICIENT (MC)	RESPONSE
Very low	0.0 - 0.2	Monitor at 5 year intervals after baseline established
Low	0.2 - 0.8	Monitor 5 yearly after baseline established
Low Low-Moderate	0.8 - 1.5	Monitor 5 yearly after baseline established
Low-Moderate	1.5 - 2.2	Post baseline, monitor yearly. Initiate ERP
Moderate	2.2 - 4.5	Post baseline, monitor yearly. Initiate ERP
High	4.5 - 7.0	Post baseline, monitor yearly. Initiate ERP
Very High	>7.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend of increasing MC or nuisance conditions	Initiate Evaluation and Response Plan (ERP)

Macrofauna Biotic Index

Soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). The AZTI (AZTI-Tecnalia Marine Research Division, Spain) Marine Benthic Index (AMBI) (Borja et al. 2000) has been verified successfully in relation to a large set of environmental impact sources (Borja, 2005) and geographical areas (in both northern and southern hemispheres) and so is used here. However, although the AMBI is particularly useful in detecting temporal and spatial impact gradients care must be taken in its interpretation in some situations. In particular, its robustness can be reduced when only a very low number of taxa (1–3) and/or individuals (<3 per replicate) are found in a sample. The same can occur when studying low-salinity locations (e.g. the inner parts of estuaries), some naturally-stressed locations (e.g. naturally organic matter enriched bottoms; *Zostera* beds producing dead leaves; etc.), or some particular impacts (e.g. sand extraction, for some locations under dredged sediment dumping, or some physical impacts, such as fish trawling).

The equation to calculate the AMBI Biotic Coefficient (BC) is a s follows;

BC = {(0 x %GI) + (1.5 x %GII) + (3 x %GIII) + (4.5 x %GIV) + (6 x %GV)}/100.

The characteristics of the above-mentioned ecological groups (GI, GII, GIII, GIV and GV) are summarized in Appendix 3.

BENTHIC COMMUNITY CONDITION RATING			
RATING	DEFINITION	BC	RECOMMENDED RESPONSE
Normal	Unpolluted	0-0.2	Monitor at 5 year intervals after baseline established
Impoverished (low abundance)	Unpolluted	0.2-1.2	Monitor at 5 year intervals after baseline established
Unbalanced assemblage	Slightly polluted	1.2-3.3	Monitor 5 yearly after baseline established
Transitional to polluted	Moderately polluted	3.3-4.3	Monitor 5 yearly after baseline est. Initiate ERP
Polluted	Moderately polluted	4.3-5.0	Post baseline, monitor yearly. Initiate ERP
Heavily polluted	Heavily polluted	5.0-5.5	Post baseline, monitor yearly. Initiate ERP
Very Heavily polluted	Heavily polluted	5.5-6.0	Post baseline, monitor yearly. Initiate ERP
Extremely polluted	Azoic (devoid of life)	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend to slightly polluted	>1.2	Initiate Evaluation and Response Plan

3. RESULTS AND DISCUSSION

The 2008 fine scale indicator results (grain size, sedimentation rate, organic carbon, phosphorus, nitrogen, metals, redox potential discontinuity (RPD), and benthic infauna and epifauna) for the dominant intertidal habitat in Waikawa Estuary are presented in the following section, and summarised in Tables 4 and 5. The 2008 broad scale macroalgal mapping results are also presented in this section along with the results of the 2005-2007 fine scale monitoring. Detailed results of the 2008 monitoring are presented in Appendix 1.

GRAIN SIZE

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results show that both sites were dominated by sandy sediments (Site A, 85-90% sand and Site B, 95-97% sand). The mud fraction was also significant (5-10% mud content), particularly at Site A. Sites A and B are both located in the sandy, lower estuary, with Site A situated adjacent to the boundary with the muddy upper estuary to act as an indicator of any expansion in the soft mud area within the estuary.

Figure 2. Grain size, Waikawa Estuary Sites A and B, 2005-2008.

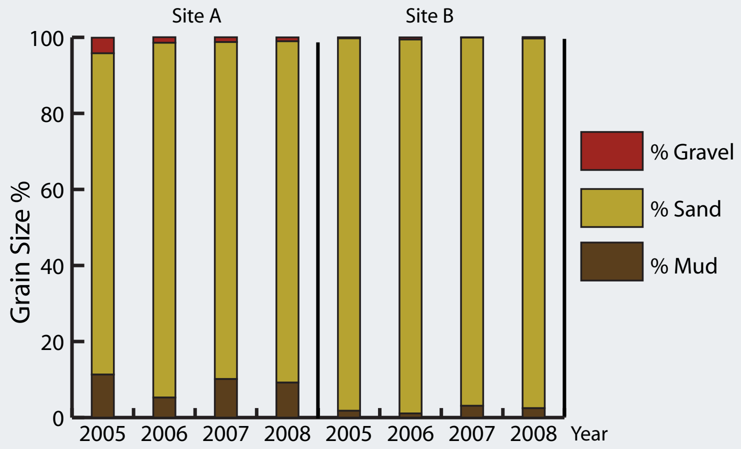


Table 4. Physical and chemical results (means) for Waikawa Estuary, 10 February 2008.

Estuary	Site	Reps.	RPD	Salinity	AFDW	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
			cm	ppt	%					mg/kg							
Waikawa	A	3	>10	31	1.70	0.89	9.20	89.77	1.03	0.02	9.07	3.50	5.80	2.03	17.3	<500	313
	B	3	4	31	1.23	0.65	2.47	97.23	0.37	0.01	7.40	2.47	4.47	1.60	12.0	<500	250

Table 5. Macrofauna results (means) for Waikawa Estuary, 10 February 2008.

Estuary	Site	Reps.	Infauna		Epifauna	
			Mean Abundance/m^2	Mean No. Species/core	Mean Abundance/quadrat	Mean No. Species/quadrat
Waikawa	A	10	10,650	20.2	5.7	2.0
	B	10	3,218	16.2	13.0	2.0

RATE OF SEDIMENTATION

Sedimentation plates were deployed in the estuary in January 2007 to enable long term monitoring of sedimentation rates. The locations of the 12 sedimentation plates buried in soft muddy sediments in Waikawa Estuary are shown in Figure 1.

The average changes in the distance (mm) from the sediment surface to the buried plates for the 1 year period between February 2007 and February 2008 are shown in Table 6. The results show that on average, the depth of sediment covering each plate has declined by approximately 10mm (a range of 17mm decline to a 3mm gain) in the first year since the plates were deployed. Such findings are expected, given that monitoring is in the early stages when the disturbed sediment surface is still settling and the baseline levels are being established.

Over the next 5 years this natural year to year variability will be used to characterise baseline conditions. Following establishment of this baseline, ongoing monitoring results will be used to determine the sedimentation rate in the estuary, with a sediment condition rating used to assess any changes.

Table 6. Mean change in sediment plate depth (full data in Appendix 2).

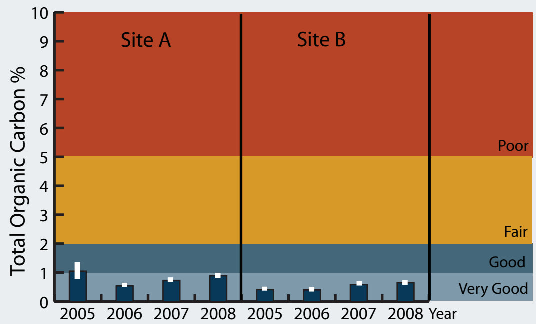
Site	No. of Plates	Mean Change in sediment depth to plate between 3/2/07 and 10/2/08
Upper South Arm	4	-11.25mm
Upper North Arm	4	-9.25mm
Lower South Arm (located at sand/mud transition mid estuary)	4	-6mm

ORGANIC MATTER (TOC)

Figure 3 shows that the indicator of organic enrichment (TOC) at both Sites A and B was at low concentrations (mean <1.1%) and met the “good” to “very good” condition rating.

Over the 4 year monitoring period there was a general trend of increasing concentrations at both sites. The low TOC levels reflect the generally well-flushed nature of much of the estuary area and a likely low to moderate load of organic matter depositing on the sediments.

Figure 3. Total organic carbon (mean and range), Waikawa Estuary Sites A & B, 2005-2008.

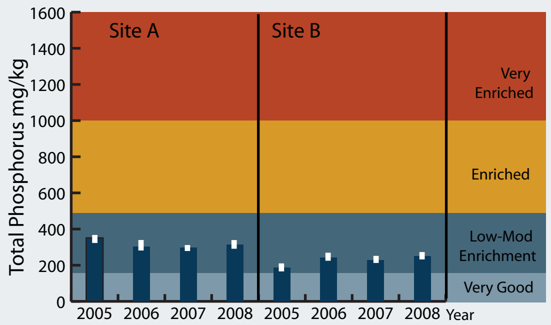


3. Results and Discussion (continued)

TOTAL PHOSPHORUS

Total phosphorus (a key nutrient in the eutrophication process) was present in the "low to moderate enrichment" category (Figure 4) at both sites for all 4 years of monitoring (mean 200-350mg/kg). Although there was some variation between years, the difference was relatively small and there was no discernible trend of increasing or declining concentrations. In terms of the adequacy of the sampling design, in particular sampling replication at each site, the data showed that the variation between the 10 replicates in 2005 at each site was relatively low (generally within 10% of the mean). Given the low-moderate TP concentrations, and the absence of any trend of increasing concentrations, it is recommended that the next monitoring be undertaken in 5 years time (i.e. February 2013) using 3 replicates at each site.

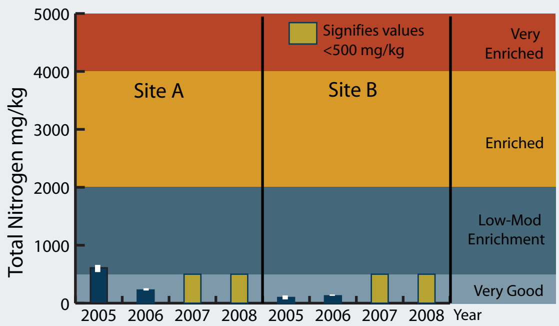
Figure 4. Total phosphorus (mean and range), Waikawa Estuary Sites A & B, 2005-2008.



TOTAL NITROGEN

Total nitrogen (the other key nutrient in the eutrophication process) was in the low enrichment or "very good" category (Figure 5) at both sites for all 4 years of monitoring (mean less than 500mg/kg), except for Site A in 2005 when it was in the "low-moderate" enrichment category. Because of our change in analytical methods, the measured values were less than the 500mg/kg detection limit for total nitrogen in 2007 and 2008. The actual difference between replicate samples could not be determined. However, because all values were less than the detection limit it is inferred that 3 replicates are sufficient to indicate low nitrogen enrichment. Likewise, the variation between years is difficult to establish for the same reason. As a consequence, a trend of increasing concentrations will only become obvious if TN exceeds the detection limit. Given the low-moderate TN concentrations, and the absence of any trend of increasing concentrations, it is recommended that the next monitoring be undertaken in 5 years time (i.e. February 2013) using 3 replicates at each site.

Figure 5. Total nitrogen (mean and range), Waikawa Estuary Sites A & B, 2005-2008.



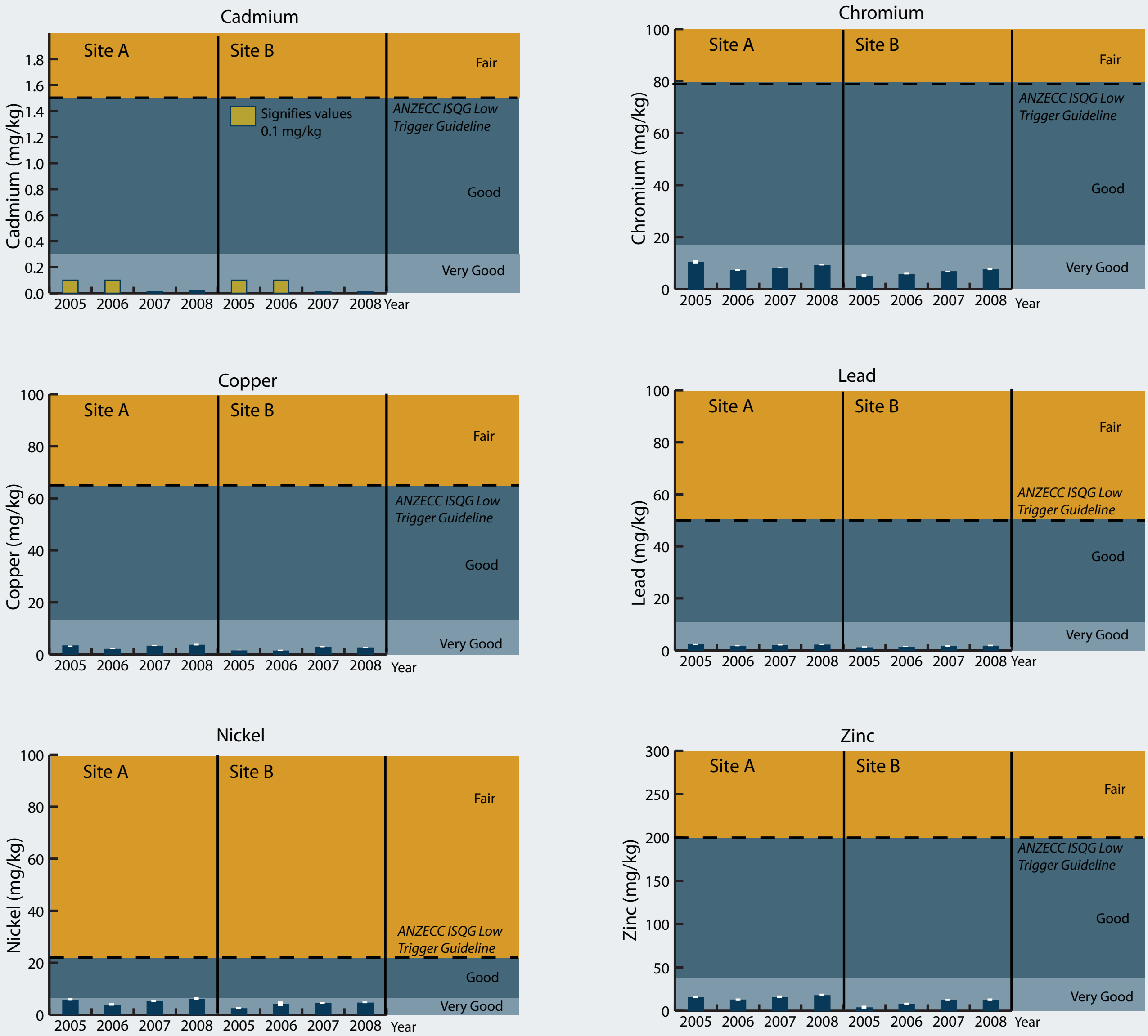
3. Results and Discussion (continued)

METALS

Heavy metals (total recoverable Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations at both intertidal sites for all 4 years of monitoring, with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 6). Metals met the "very good" condition rating for cadmium, chromium, copper, lead, nickel and zinc at all sites. Such low concentrations reflects the absence of significant sources of heavy metals or other contaminants in the catchment (i.e. urban development).

Although there was some variation between years, and a discernible trend of increasing concentrations over time for most metals, the fact that the concentrations for all years were in the very low category signifies a solid baseline against which any future changes can be assessed. In terms of the adequacy of the sampling design, in particular sampling replication at each site, the data showed that the variation between the 3 replicates at each site was relatively low (generally within 10% of the mean). Given the low metal concentrations, and the absence of any rapid trend of increasing concentrations, it is recommended that the next monitoring be undertaken in 5 years time (i.e. February 2013) using 3 replicates at each site.

Figure 6. Metals (mean and range) Waikawa Estuary Sites A & B, 2005-2008.

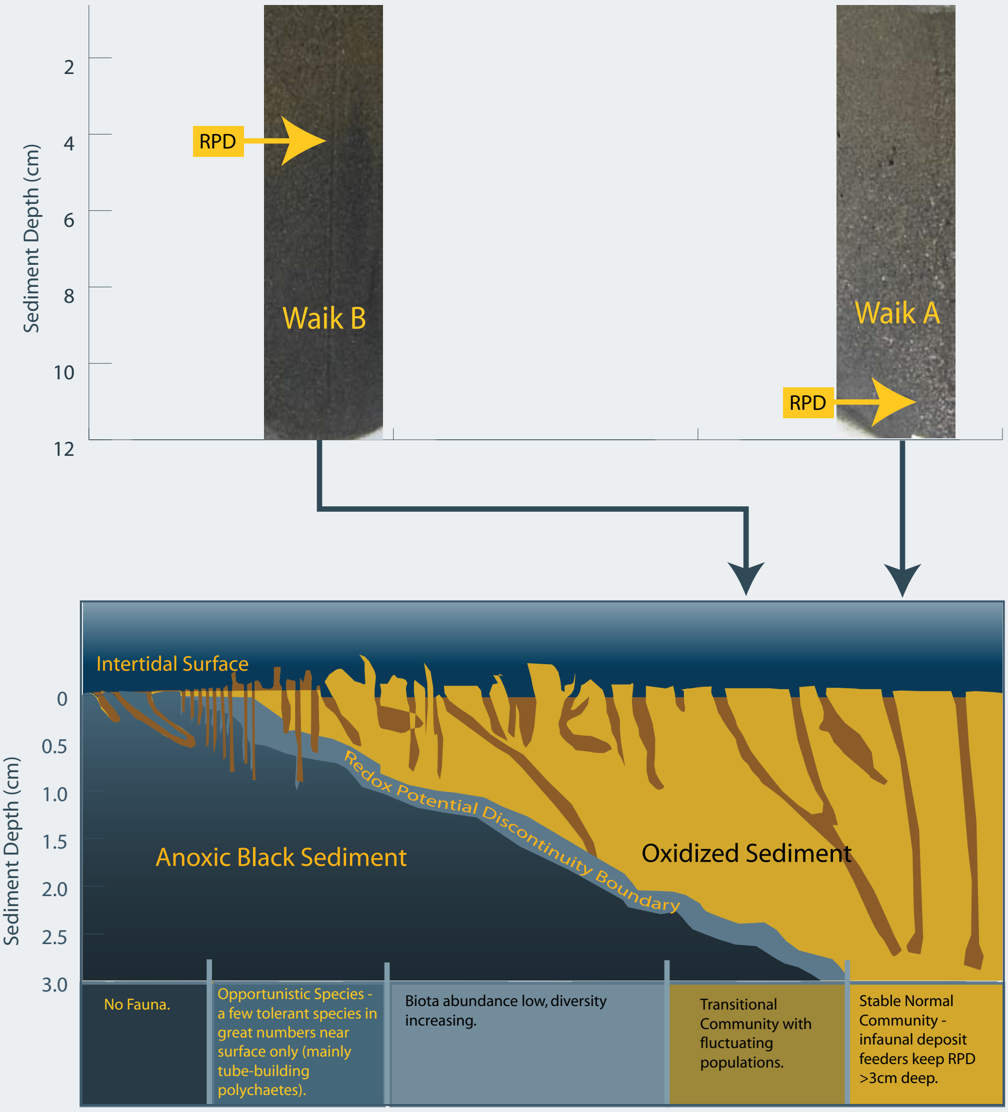


REDOX POTENTIAL DISCONTINUITY DEPTH

RPD depth, which is a key indicator of sediment oxygenation, was moderately shallow at Site B (closest to the estuary mouth) and varied from 4-5cm, but was much deeper at Site A (closest to the muddy upper end of the estuary), where it was greater than 10cm depth. Such values, as well as the dominance of sandy sediments and the presence of numerous infauna feeding voids and burrows below the RPD, indicate a "good" to "very good" condition rating for sediment oxygenation (i.e. RPD) at both sites.

Figure 7 shows the sediment profiles and RPD depths for each of the two Waikawa Estuary sampling sites (also Table 4). The figure also indicates the likely benthic community (adapted from Pearson and Rosenberg 1978) that is supported at each site based on the measured RPD depth. For the Waikawa Estuary the 2008 results indicated that the benthic invertebrate community was likely to be either in an unstable "transitional" state or a stable "normal" state. Variability in the measurements of the RPD depth previously mean that only the 2008 results are presented.

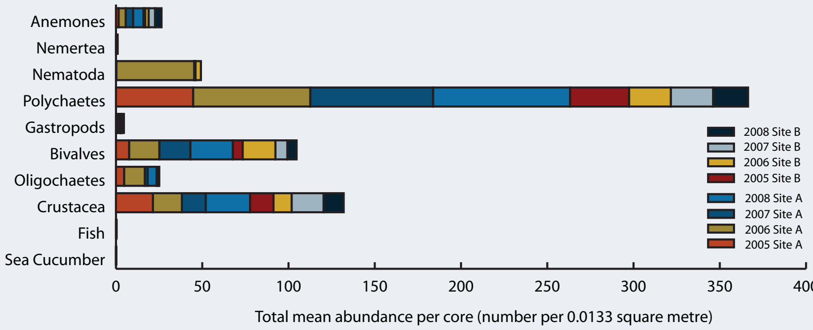
Figure 7. Sediment profiles and RPD depths, Waikawa Estuary Sites A and B, 2008.



BENTHIC INVERTEBRATE COMMUNITY

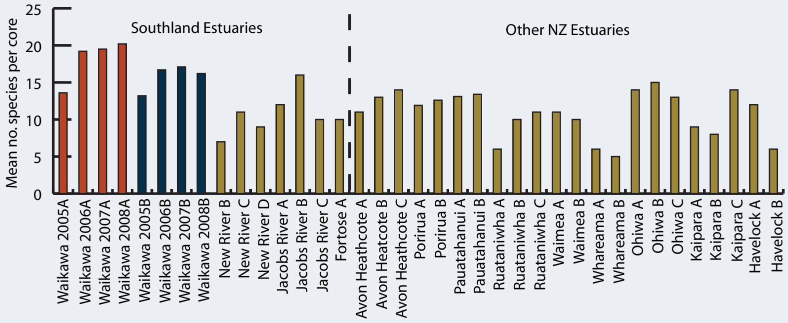
The benthic invertebrate community is another important indicator as it provides an integrated measure of the biological community and therefore reflects the combination of all environmental conditions. Like other NZ estuaries, the intertidal benthic community at both sites and in all 4 years of monitoring was dominated in terms of abundance by polychaetes, followed by crustaceans and bivalves (Figure 8).

Figure 8. Mean total abundance of macrofauna groups, Waikawa Estuary, 2005-2008.



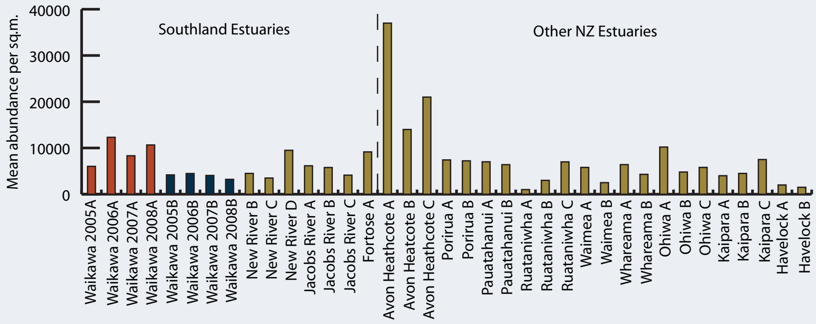
The community at both sites also included a wide range of species (mean 14-20 species per core). Compared with the intertidal mudflats in other NZ estuaries that drain developed catchments, the community diversity was relatively high (Figure 9).

Figure 9. Mean number of macrofauna species, Waikawa Estuary compared with other NZ estuaries (source: Robertson et al. 2002, Robertson and Stevens 2006).



In terms of overall community abundance, Waikawa Estuary was moderate at 5,000-12,000m^2 (Figure 10) compared with other NZ estuaries with developed catchments. Like diversity (Figure 9), abundance was lowest at Site B (i.e. the site with the lowest RPD).

Figure 10. Mean total abundance of macrofauna, Waikawa Estuary compared with other NZ estuaries (source: Robertson et al. 2002, Robertson and Stevens 2006).



In terms of the community composition, differences were present between Sites A and Site B. This is particularly apparent in Table 7 which shows the 10 most abundant species present at each site for each of the 4 years of record. In addition to the very different communities at Sites A and B, there is also some minor variation between years at each site.

Table 7. Mean abundance (per 0.133m²) of the 10 most abundant macrofauna species, Waikawa Estuary 2005-2008.

Waikawa Estuary , Site A											
2005 (Site A shifted after 2005)		AMBI	2006		AMBI	2007		AMBI	2008		AMBI
Paraonidae	164	III	NEMATODA	451	III	Sphaerosyllis sp.	239	II	Macroclymenella stewartensis	281	NA
Amphipoda	163	NA	Sphaerosyllis sp.	196	II	Paraonidae	185	III	Sphaerosyllis sp.	194	II
Macroclymenella stewartensis	162	NA	Paraonidae	186	III	Macroclymenella stewartensis	148	NA	Paraonidae	149	III
Boccardia sp.	57	I	Macroclymenella stewartensis	134	NA	Nucula gallinacea	77	III	Nucula gallinacea	111	III
OLIGOCHAETA	47	NA	OLIGOCHAETA	120	NA	Austrovenus stutchburyi	62	NA	Amphipoda	93	NA
Austrovenus stutchburyi	42	NA	Nucula cf gallinacea	75	III	Boccardia sp.	54	I	Tanaid sp.	86	II
Cumacea	39	NA	Austrovenus stutchburyi	73	NA	Amphipoda	54	NA	Austrovenus stutchburyi	84	NA
Heteromastus filiformis	35	IV	Amphipoda c	65	NA	Cumacea	38	NA	Boccardia sp.	59	I
Prionospio sp.	15	III	Boccardia sp.	53	I	Anthopleura aureoradiata	35	II	OLIGOCHAETA	52	NA
Waikawa Estuary , Site B											
2005		AMBI	2006		AMBI	2007		AMBI	2008		AMBI
Paraonidae	151	III	Perrierina turneri	128	NA	Cumacea	97	NA	Austrominius modestus	74	NA
Cumacea	69	NA	Aonides sp.	82	III	Austrominius modestus	72	NA	Austrovenus stutchburyi	41	NA
Austrominius modestus	62	NA	Cumacea	44	NA	Cirratulidae	57	iV	Aonides sp.	35	III
Aonides sp.	49	III	Austrominius modestus	42	NA	Austrovenus stutchburyi	48	NA	Boccardia sp.	32	I
Boccardia sp.	36	I	Aglaophamus macroura	40	II	Aonides sp.	44	III	Anthopleura aureoradiata	28	II
Scolelepis sp.	29	III	Austrovenus stutchburyi	40	NA	Boccardia sp.	34	I	Heteromastus filiformis	27	IV
Syllidae	26	II	Boccardia sp.	37	I	Anthopleura aureoradiata	28	II	Cumacea	15	NA
Austrovenus stutchburyi	24	NA	NEMATODA	31	III	Macroclymenella stewartensis	20	NA	Amphipoda	15	NA
Paphies australis	21	NA	Heteromastus filiformis	27	IV	Travisia olens	16	I	Macroclymenella stewartensis	14	NA

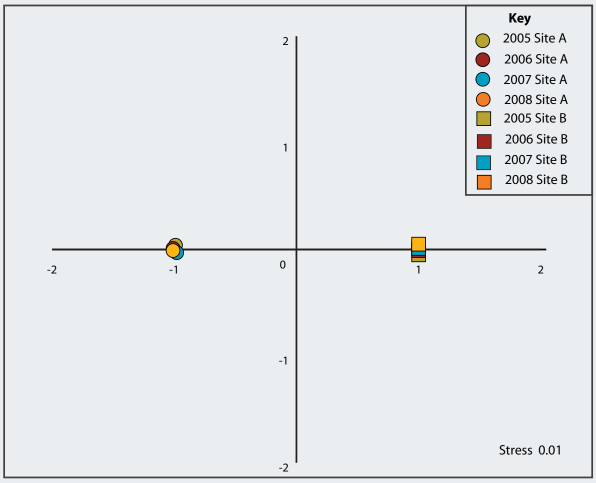
The variation in the community composition between sites and between years was further explored using multivariate data analysis methods, in this case non-metric multidimensional scaling (NMDS) using PRIMER vers. 6.1.10. The analysis basically plots the site, year and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. For example, if all Site A points for each year are clustered in one area of the matrix and Site B points for each year are clustered in another area but spread further apart, then Site A communities are similar to each other and are very different from Site B communities, while Site B communities are both different from Site A, but also different from each other. 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.

The NMDS ordination plots for Waikawa Estuary are presented in Figure 11. The plot on the left shows the coordinate points for each of the 10 replicate samples taken at Sites A and B for the 4 years of monitoring 2005-2008. The stress value of 0.18 indicates that the configuration can be reliably interpreted, but only just. The plot on the right, differs from the left plot in that the 10 replicates have been averaged. The result is a very low stress level of 0.01 and therefore can be very reliably interpreted. Overall, the results from the two plots indicate the following:

- The community composition at Site A was distinct from that at Site B (i.e. the Site A points were well separated from the Site B points in both plots).
- On average, the community composition at both Site A and Site B did not vary much between each of the 4 years of baseline monitoring (i.e. coordinate points are clustered together at each site in the plot on the right).
- Community composition tended to be much more variable at Site B than at Site A (i.e. the left hand plot shows that Site A replicates for each year tended to be well clustered, whereas the Site B points for each year were more spread out).

Such findings provide a relatively robust baseline measure of community composition from which future monitoring data can be compared and any long term changes identified.

Figure 11. NMDS plots showing the relationship among samples in terms of similarity in community composition for Sites A and B, for each of the 4 sampling occasions (February 2005, 2006, 2007 and 2008). The left hand plot shows each of the 10 replicate samples for the 4 years of monitoring and is based on Bray Curtis dissimilarity and fourth root transformed data. The right hand plot shows the yearly averages of each of the 10 replicate samples and is based on Bray Curtis dissimilarity and square root transformed data.

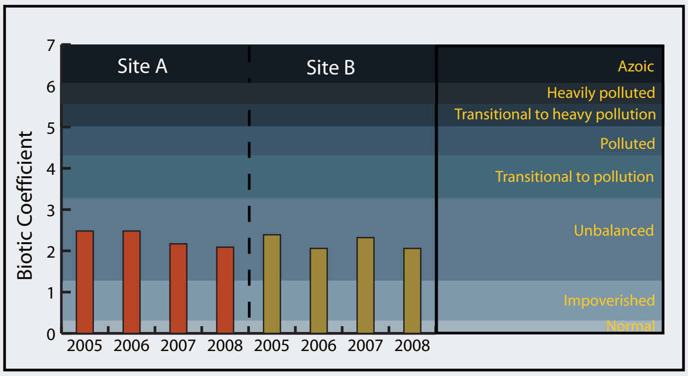


BENTHIC COMMUNITY INDEX

The variation in community composition was also explored using a new benthic community index, the AZTI's Marine Biotic Index (AMBI) which was developed by Borja et al. (2000) after identifying a need for new tools to assess the environmental status of coastal and estuarine systems. Results from around the world show that in many cases, the AMBI provides a very good indication of environmental conditions and therefore has become a promising tool for assessing estuary condition by placing individual species into groups able to tolerate different levels of environmental degradation. Based on the groupings of species present it is then possible to classify the overall quality of the environmental conditions present, ranging from normal, through to polluted (Figure 12). Within NZ, use of the index to date has been limited but initial evaluations on estuaries in the Tasman and Wellington regions have been promising (Robertson and Stevens 2008, 2008a and b) and based on these results we have applied it to Waikawa.

Use of the AMBI in Waikawa Estuary to represent benthic community health and provide an estuary condition classification (for dominant intertidal areas) returned promising results. The results (detailed in Appendix 2 and 3) showed that the benthic invertebrate community at both sites in the Waikawa Estuary were "unbalanced", indicating a "slightly polluted" classification (Figure 12).

Figure 12. Benthic community condition rating for 2 sites Waikawa Estuary 2005-2008.

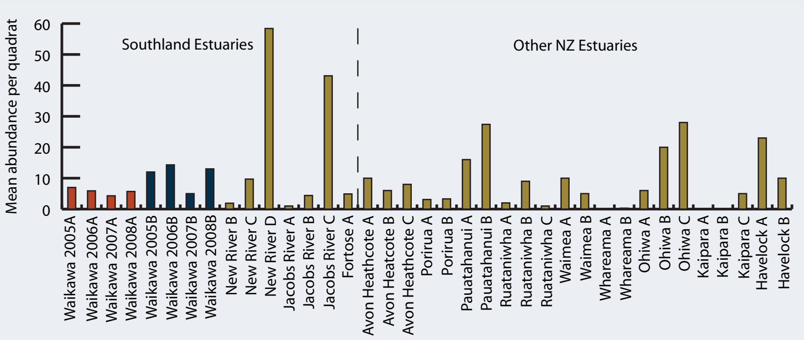


The unbalanced classification of the community reflects an increasing abundance of species that tolerate moderate organic enrichment (i.e. surface deposit feeding species such as tube-building spionid polychaetes), but not to the extent of having large numbers of species that tolerate high levels of enrichment (mainly small-sized, sub-surface deposit feeding polychaetes such as *Heteromastus*). Such a benthic community rating is consistent with the developed catchment, elevated sedimentation rates and the relatively low eutrophication risk rating of the estuary (Robertson and Stevens 2007).

EPIFAUNA

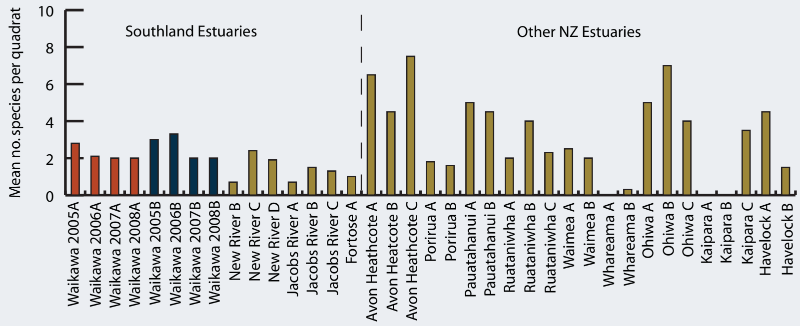
Surface dwelling organisms (epifauna) were also recorded using quadrats rather than the much smaller cores used to sample the whole benthic community (i.e. infauna and epifauna). These results, although not used in the benthic community index, show that surface dwelling organisms were more abundant at Site B compared with Site A, but in terms of species diversity, they were similar (Figures 13 and 14). See Appendix 2.

Figure 13. Mean abundance of epifauna per quadrat(0.25m²) Waikawa Estuary compared with other NZ estuaries (source: Robertson et al. 2002, Robertson and Stevens 2006).



In addition, the results show that, compared with other NZ estuaries with developed catchments, epifauna abundance and diversity at both sites and for all 4 years of monitoring, was moderate.

Figure 14. Mean number of epifauna species per quadrat, Waikawa Estuary compared to other NZ estuaries (source: Robertson et al. 2002, Robertson and Stevens 2006).



In terms of species, the epifauna at both sites and for all years was dominated by shellfish; primarily the mudflat topshell (*Diloma subrostrata*), but also included the cockle (*Austrovenus stutchburyi*), the estuarine limpet (*Notoacmea helmsi*), the mudflat whelk (*Cominella glandiformis*), the estuarine barnacle (*Elminius modestus*) and the mudflat anemone (*Anthopleura aureoradiata*).

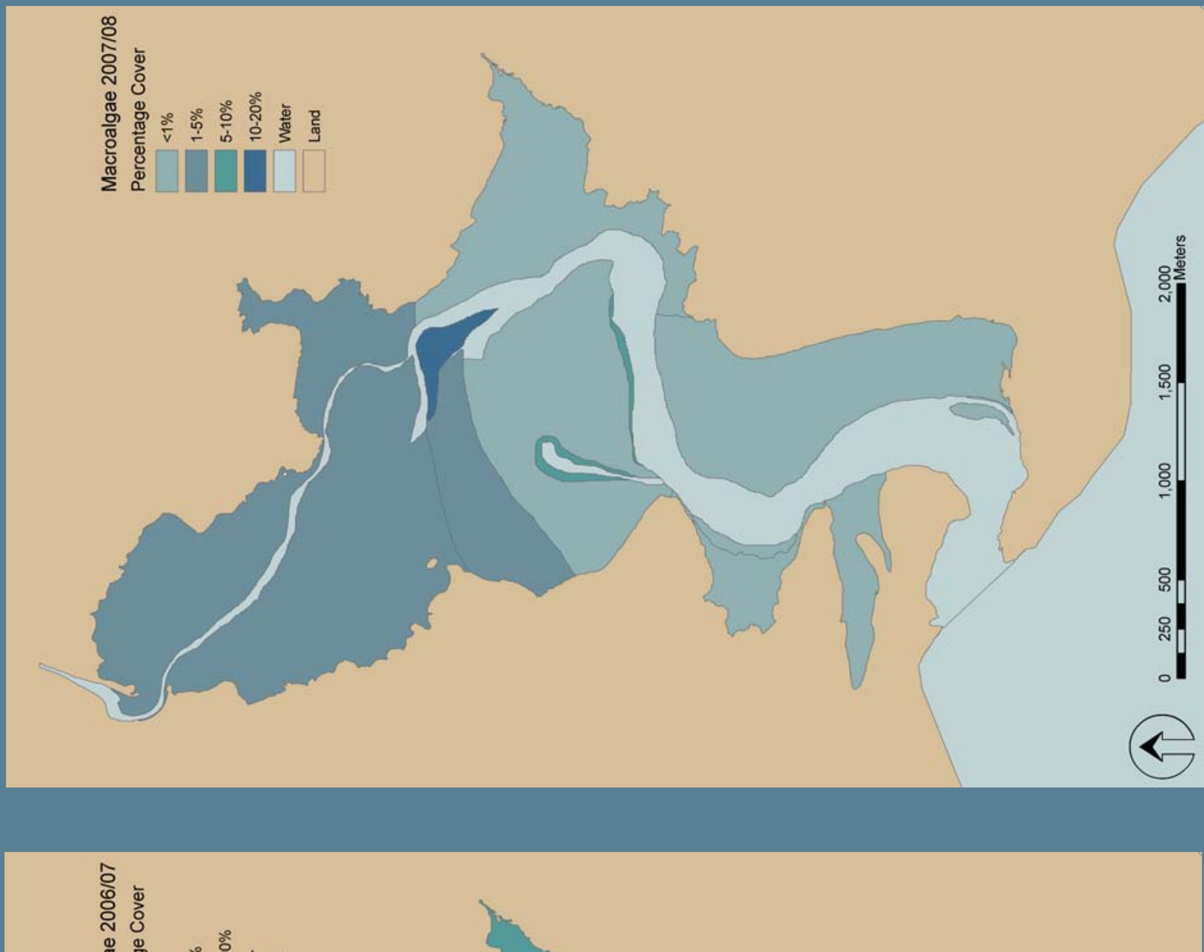
MACROALGAE

The extent of macroalgal cover in Waikawa Estuary is measured annually and the results used to help assess the extent of estuary eutrophication. Estuary eutrophication can result in regular macroalgal blooms. These can deprive seagrass areas of light causing their eventual decline, while decaying macroalgae can accumulate on shorelines causing depletion of sediment dissolved oxygen and nuisance odours. Table 8 and Figure 15 summarise the results of macroalgal mapping within Waikawa Estuary in February 2007 and February 2008.

Table 8. Summary of intertidal macroalgal cover results, February 2007 and 2008.

2007				2008			
%Cover	Ha	%	Dominant species	% Cover	Ha	%	Dominant species
<1%	126.5	24.3	-	<1%	273	52.5	-
1-5%	0	0.0	*Gracilaria, Ulva*	1-5%	235.6	45.3	*Gracilaria, Ulva*
5-10%	388.2	74.7	*Gracilaria, Ulva*	5-10%	5.1	1.0	*Ulva*
10-20%	0	0.0	*Gracilaria, Ulva*	10-20%	6.3	1.2	*Gracilaria*
20-50%	0	0.0	-	20-50%	0	0.0	-
50-80%	0	0.0	-	50-80%	0	0.0	-
>80%	5.1	1.0	*Ulva*	>80%	0	0.0	-
Cover>5%	**393**	**76**		**Cover>5%**	**11**	**2**	
TOTAL	**520**	**100**		**TOTAL**	**520**	**100**	

Figure 15. Map of Macroalgal Cover - Waikawa Estuary, February 2007 and 2008.



The results show that in February 2007 a >5% cover of macroalgae was present across 76% of the estuary, located mainly in the upper reaches (Figure 15) (Robertson and Stevens 2007). Nearly all of the macroalgae was a 5-10% cover of *Gracilaria* containing smaller amounts of sea lettuce - *Ulva*, with a small area (5ha, 1%) in the middle of the estuary having an 80-100% cover of *Ulva*. The condition rating (the Macroalgae Coefficient - MC) placed the estuary at the upper end of the "Low" category (MC=0.8).

In February 2008 the macroalgal cover reduced significantly with only 2% of the estuary having a cover >5%. Macroalgae was again most widespread in the upper reaches, with a 1-5% cover of *Gracilaria* containing smaller amounts of *Ulva* (45% of the total estuary). A small area (6ha) of 10-20% *Gracilaria* cover was located centrally in the estuary between low tide channels, while the small area in the middle of the estuary that had an 80-100% cover of *Ulva* in 2007 had reduced to a 5-10% cover (Figure 15). The condition rating placed the estuary at the lower end of "Low" category (MC=0.3).

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 at the same time that sediment plates are measured or 5 yearly in the absence of obvious changes in the estuary.

CONDITION RATINGS

The fine scale condition ratings for the key fine scale indicators in 2005-2008 are summarised as follows:

Fine Scale Indicators											
Location and Year	RPD Depth	Benthic Community	Organic Matter	TP	TN	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Site A 2005	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site A 2006	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site A 2007	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site A 2008	VERY GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2005	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2006	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2007	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD
Site B 2008	GOOD	UNBALANCED	VERY GOOD	LOW-MOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD

The broad scale condition ratings for macroalgal cover in February 2007 and February 2008 are summarised as follows:

Broad Scale Indicators			
Location	Year	Macroalgal Coefficient	Macroalgal Cover
Waikawa Estuary	2007	0.8	LOW
Waikawa Estuary	2008	0.3	LOW

4. CONCLUSIONS

In conclusion, the first 4 years of fine scale monitoring results for a range of physical, chemical and biological indicators of estuary condition show that the dominant intertidal habitat in the Waikawa Estuary (unvegetated muddy sand) was generally in good condition.

In order to provide a more comprehensive assessment of overall estuary condition, these results, in combination with other relevant information, are used in the following subsections to provide an understanding of the estuary condition in relation to the key issues of sedimentation, eutrophication and toxicity.

ISSUE RATING EUTROPHICATION
LOW to MODERATE

EUTROPHICATION

Eutrophication is the process where water bodies receive excess nutrients that stimulate excessive plant growth. In estuaries like Waikawa, macroalgal (e.g. sea lettuce) and benthic microalgal blooms are the main threat which can lead to sediment anoxia, elevated organic matter and nutrients, increasing muddiness, lowered clarity and benthic community changes.

In terms of the eutrophication indicators for the intertidal area, the results were in the low to low-moderate category for nutrients (TN and TP) and organic content, and the sediments were very well to moderately oxygenated, as inferred from the relatively deep RPD layer at all sites. Although the sediment biota results indicated a very diverse and abundant community, the presence of elevated numbers of moderately pollution tolerant organisms meant that its condition was "unbalanced", giving it a "slightly polluted" classification. Taken in combination with the low presence of macroalgae in the estuary (Stevens and Robertson 2007, 2008), the results indicate a low to moderately enriched estuary. Such enrichment, in particular the unbalanced nature of the biotic community and the increasing RPD at Site B, while not yet a problem, indicates a need for caution, particularly in relation to factors that could increase nutrient and fine sediment concentrations in the estuary. In order to ensure nutrient loads to the estuary do not increase and cause a shift towards greater enrichment, it is recommended that nutrient load management and long term monitoring in the catchment is encouraged.

ISSUE RATING SEDIMENTATION
HIGH SEDIMENTATION

SEDIMENTATION

If sediment inputs to an estuary are excessive, the estuary infills quickly with muds, reducing biodiversity and human values and uses. In estuaries with large intertidal areas, like the Waikawa, fine muds tend to settle in three main areas; the unvegetated intertidal area in the upper to mid estuary, saltmarsh areas (primarily in the upper estuary) and small sheltered estuary arms. Broad scale mapping (Robertson et al. 2004) showed that the upper one-third to half of the estuary consists of soft and very soft muds, and the lower half consists of sands and muddy sands. Fine scale monitoring (2005-2008) showed that the mud content of Sites A and B, which are both located in the sandy, lower estuary, was less than 10%. Also, by using the results of the transitional sediment plate at Site A (which is situated adjacent to the boundary with the muddy upper estuary and therefore acts as an indicator of any expansion in the soft mud area within the estuary), it is likely that the upper muddy area has expanded since 2005. This is to be expected given the high sedimentation rates reported for the upper estuary over the last 10 years (10.7mm/yr) (Robertson and Stevens 2007). Such excessive sedimentation indicates a need to reduce sediment loads to the estuary and to continue with the long term monitoring programme. In the future, the extent of sedimentation in the estuary will continue to be monitored using the combined tools of broad scale habitat maps, fine scale monitoring at key sites and sedimentation rate monitoring using the 12 sedimentation plates that were deployed in 2007.

4. Conclusions (continued)

ISSUE RATING TOXICITY

LOW TOXICITY

TOXICITY

The extent of contamination with toxic substances was rated “very good” reflecting the low levels of heavy metals (total recoverable Cd, Cr, Cu, Ni, Pb, Zn) in the intertidal sediments at the fine scale sites compared with ANZECC (2000) sediment guideline criteria.

However, such positive results for the intertidal sandy sediments can be misleading when using the findings to assess overall toxicity within the whole estuary. Because metals entering the estuary are mostly bound to fine sediments, they tend to end up at the highest concentrations in the muddy upper one-third of the estuary (i.e. away from the two fine scale sites).

To further assess this issue, metal concentrations measured in 1995 in very soft muds in the upper estuary in 1995 (Robertson 1995), were compared with the ANZECC (2000) ISQG Low guideline criteria and the mean 2008 concentrations at sites A and B (Table 9). The results show that the 1995 upper estuary concentrations were higher than at the 2008 fine scale sandy sites but still well below the ANZECC guidelines. The higher concentrations in the upper estuary almost certainly reflects the higher mud content of these sediments.

Table 9. Intertidal metal concentrations (mg/kg) - 1995, 2008 and ANZECC (2000) sediment guideline criteria.

	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
ANZECC (2000) ISQG Low	1.500	80	65	50	21	200
Waikawa 2008 Site A	0.02	9.07	3.50	2.03	5.80	17.3
Waikawa 2008 Site B	0.01	7.40	2.47	1.60	4.47	12.0
Waikawa Upper Estuary 1995 (Robertson, 1995)	0.07	21.0	16.0	10.0	14.0	58.0

Such findings confirm that intertidal sampling provides a reliable indication of broad-scale sediment toxicity within the harbour, but because it currently addresses only the sand dominated lower and middle areas of the estuary it does not represent the worst case inputs. To remedy this situation, it is recommended that a site for metals in the upper estuary also be monitored 5 yearly as part of the ongoing long term monitoring programme.

Mud snails grazing on intertidal mudflats, Upper Waikawa Estuary.

5. MONITORING

Waikawa Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's existing coastal monitoring programme being undertaken in a staged manner throughout the Southland region. Based on the 2005, 2006, 2007 and 2008 baseline monitoring results and condition ratings, it is recommended that monitoring continue as follows.

Fine Scale Monitoring
Undertake monitoring at 5 yearly intervals or as deemed necessary based on the condition ratings. Include a new site for physical and chemical parameters in the upper estuary. The next fine scale monitoring is scheduled for February 2012.

Sedimentation Rate Monitoring
Monitor the depths of the existing 12 sediment plates at 5 yearly intervals. The next sediment plate monitoring should be undertaken during the broad scale mapping exercise scheduled for 2009. Following the 2009 monitoring, it is recommended that the depth of all plates be measured whenever fine scale monitoring is undertaken.

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 at the same time that sediment plates are measured, or 5 yearly in the absence of obvious changes in the estuary.

6. MANAGEMENT

The fine scale monitoring reinforces the need for management of nutrient, toxins and fine sediment sources entering the estuary.

It is understood that ES are currently working to identify catchment nutrient, toxin and sediment sources and "hotspots", and to implement BMPs (Best Management Practices) for reducing nutrient, toxin and sediment mobilisation and runoff to surface and groundwater.

The findings of this report provide support for such management.

7. ACKNOWLEDGEMENTS

This work has been funded by Environment Southland and has been undertaken with help from various people: local residents who provided access to the estuary, Maz Robertson for editing, and lastly the staff of Environment Southland who made it all happen. In particular, the support and feedback of Chris Arbuckle and Greg Larkin was much appreciated.

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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	Air dry (35 degC, sieved to pass 2mm and 63um sieves, gravimetric - (% sand, gravel, silt)	N/A
AFDW (% organic matter)	R.J Hill	Ignition in muffle furnace 550degC, 1 hr, gravimetric. APHA 2540 G 20th ed 1998.	0.04 g/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).	0.05 g/100g dry wgt

* Coastal Marine Ecology Consultants (established in 1990) specialise 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 hold 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. 2008 DETAILED RESULTS

Physical and chemical results Waikawa Estuary, 10 February 2008.

	Site	Rep.	RPD	Salinity	AFDW	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
			cm	ppt@15^{0}C	%				mg/kg							
Waikawa Estuary	Site	Repl.	RPD	Salinity	AFDW	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
	A	1	>10	31	1.5	9.1	90.2	0.7	0.027	9.0	3.4	5.6	2.0	17	<500	280
	A	2	>10	31	1.8	9.0	89.6	1.4	0.015	8.9	3.6	6.0	2.0	17	<500	360
	A	3	>10	31	1.8	9.5	89.5	1.0	0.018	9.3	3.5	5.8	2.1	18	<500	300
	B	1	5	31	1.1	4.6	95.3	0.1	0.015	6.9	2.6	4.5	1.6	12	<500	250
	B	2	4	31	1.5	1.5	97.7	0.9	0.011	7.6	2.4	4.4	1.6	12	<500	230
	B	3	4	31	1.1	1.3	98.7	0.1	0.014	7.7	2.4	4.5	1.6	12	<500	270

Station Locations

Waikawa A	WkA-01	WkA-02	WkA-03	WkA-04	WkA-05	WkA-06	WkA-07	WkA-08	WkA-09	WkA-10
NZMG260 East	2214541	2214557	2214573	2214590	2214592	2214573	2214555	2214547	2214546	2214558
NZMG260 North	5391446	5391445	5391449	5391446	5391459	5391458	5391460	5391461	5391473	5391469

Waikawa B	WkB-01	WkB-02	WkB-03	WkB-04	WkB-05	WkB-06	WkB-07	WkB-08	WkB-09	WkB-10
NZMG260 East	2214934	2214946	2214960	2214979	2214975	2214955	2214943	2214931	2214930	2214946
NZMG260 North	5390789	5390792	5390798	5390804	5390813	5390808	5390804	5390796	5390812	5390815

APPENDIX 2. 2008 DETAILED RESULTS (CONTINUED)

Epifauna (numbers per 0.25m² quadrat)

Waikawa A

Scientific name Common name	WkA-01	WkA-02	WkA-03	WkA-04	WkA-05	WkA-06	WkA-07	WkA-08	WkA-09	WkA-10
Anthopleura aureoradiata Mudflat anemone					1					
Austrovenus stutchburyi Cockle		1	1				1	1		1
Cominella glandiformis Mudflat whelk	1		1			2		4		
Diloma subrostrata Mudflat topshell	3	5	2	3	6	6	5	5	3	5
No. species/quadrat	2	2	3	1	2	2	2	3	1	2
No. individuals/quadrat	4	6	4	3	7	8	6	10	3	6

Waikawa B

Scientific name Common name	WkB-01	WkB-02	WkB-03	WkB-04	WkB-05	WkB-06	WkB-07	WkB-08	WkB-09	WkB-10
Austrovenus stutchburyi Cockle		1					1		1	
Cominella glandiformis Mudflat whelk									15	
Diloma subrostrata Mudflat topshell	22	10	10	9	13	11	9	1	2	10
Notoacmea helmsi Estuarine limpet					9	2			2	2
No. species/quadrat	1	2	1	1	2	2	2	1	4	2
No. individuals/quadrat	22	11	10	9	22	13	10	1	20	12

Sediment Plate Depths (2007 and 2008)

Site	No	Plate Depth (mm) 3/2/07	Plate Depth (mm) 2/10/08	Change (mm)	Mean change (mm)
Upper South Arm	1	212	203	-9	-11.25
Upper South Arm	2	223	206	-17	
Upper South Arm	3	215	210	-5	
Upper South Arm	4	230	216	-14	
Upper North Arm	5	253	237	-16	-9.25
Upper North Arm	6	210	207	-3	
Upper North Arm	7	270	259	-11	
Upper North Arm	8	257	250	-7	
Lower South Arm	9	255	250	-5	-6
Lower South Arm	10	248	238	-10	
Lower South Arm	11	225	213	-12	
Lower South Arm	12	250	253	3	

APPENDIX 2. 2008 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES	Wai A-01	Wai A-02	Wai A-03	Wai A-04	Wai A-05	Wai A-06	Wai A-07	Wai A-08	Wai A-09	Wai A-10
ANTHOZOA	*Anthopleura aureoradiata*	2	5	13	6	3	2	3	1	1	6
	Edwardsia sp.#1	2			1	3	3	2	5	2	
NEMERTEA	Nemertea *sp.#1*										
	Nemertea sp.#2							2			
NEMATODA	Nematoda				2	1					
POLYCHAETA	*Aglaophamus* sp.#1			2	1		2				
	Aonides sp.#1										
	Boccardia (Paraboccardia) acus		3	5	3	2	5	1	1		2
	Boccardia (Paraboccardia) syrtis	5	1	6	3	3	5	4	6	3	1
	Capitella capitata										
	Cirratulidae sp.#1										
	Glycera lamellipodia									1	
	Goniadidae *sp.#1*							1			
	Hemipodus simplex	1		2			1	1	2	1	
	Hesionidae sp.#1			1		1					
	Hesionidae sp.#2										
	Heteromastus filiformis	5	5	4	3	6	5	2	8	3	3
	Macroclymenella stewartensis	27	30	39	30	42	34	13	30	20	16
	Magelona sp.#1					1					
	Nicon aestuariensis										
	Orbinia papillosa			1							
	Owenia fusiformis	1									
	Paraonidae sp.#1	13	35	5	17	22	11	6	22	8	9
	Paraonidae sp.#2				1						
	Perinereis vallata										
	Phyllodocidae sp.#1										
	Platynereis australis							1			
	Polynoidae sp.#1							1			
	Prionospio aucklandica	2	6	14	2	5	4	3	6	3	
	Scolecolepides benhami										
	Sphaerosyllis sp.#1	20	22	43	21	18	15	12	19	7	17
	Spionidae sp.#1										
	Syllidae sp.#1										
	Travisia olens										
OLIGOCHAETA	Oligochaeta sp.#1	6	15	3	11		2	3	11	1	
GASTROPODA	*Cominella glandiformis*			1							
	Diloma subrostrata						1	1		1	
	Notoacmaea helmsi				1		1				
BIVALVIA	*Arthritica sp.#1*	4	6	6	5	4	1	1	1	1	2
	Austrovenus stutchburyi	7	12	15	6	9	12	8	7	5	3
	Macomona liliana	3	1	2	2	3	2	1	2	1	1
	Nucula sp.#1	4	5	22	9	27	10	11	12	5	6
	Paphies australis										
	Perrierina turneri										
	Soletellina sp.#1				2						
CRUSTACEA	Amphipoda sp.#1	5	4	14	16	6	16	8	12	2	10
	Amphipoda sp.#2			1		1	2				
	Austrominius modestus										
	Colurostylis lemurum	1	1	3	6	3			5	2	3
	Copepoda sp.#1										
	Halicarcinus whitei			1							
	Isocladus sp.#1	1		1	2			2			1
	Macrophthalmus hirtipes		1	1	1	1					
	Mysidacea sp.#1										
	Phoxocephalidae sp.#1	5	11	4	2	7	1	2	3	1	2
	Pontophilus australis										
	Tanaidacea sp.#1	2	13	5	19	10	16	11	5	3	2
OSTEICHTHYES	*Peltorhamphus* sp.#1										
Total species in sample		20	18	26	25	22	22	24	19	20	16
Total individuals in sample		**116**	**176**	**214**	**172**	**178**	**151**	**100**	**158**	**71**	**84**

APPENDIX 2. 2008 DETAILED RESULTS (CONTINUED)

GROUP	SPECIES	Wai B-01	Wai B-02	Wai B-03	Wai B-04	Wai B-05	Wai B-06	Wai B-07	Wai B-08	Wai B-09	Wai B-10
ANTHOZOA	*Anthopleura aureoradiata*		3	1	1	6		13	4		
	Edwardsia sp.#1		1		3		3	1	2		
NEMERTEA	Nemertea *sp.#1*										
	Nemertea sp.#2		1					1	1		
NEMATODA	Nematoda										
POLYCHAETA	*Aglaophamus sp.#1*	1	2	2	1	1	1	1	2		
	Aonides sp.#1	2	5	2	2	2	3	5	6	3	5
	Boccardia (Paraboccardia) acus										
	Boccardia (Paraboccardia) syrtis	3	1	1	7	3	5	4	3	2	3
	Capitella capitata	1									
	Cirratulidae sp.#1			5		2			2	2	2
	Glycera lamellipodia										
	Goniadidae *sp.#1*										
	Hemipodus simplex	1	1		2	3	2			1	
	Hesionidae sp.#1										
	Hesionidae sp.#2			1		1				1	2
	Heteromastus filiformis	4	8	2	1		1	4	3	2	2
	Macroclymenella stewartensis	3	3	1	1	2		2		1	1
	Magelona sp.#1									1	
	Nicon aestuariensis										
	Orbinia papillosa	2	1	2				3	3		2
	Owenia fusiformis										
	Paraonidae sp.#1	1		1							1
	Paraonidae sp.#2										
	Perinereis vallata										
	Phyllodocidae sp.#1										
	Platynereis australis										
	Polynoidae sp.#1										
	Prionospio aucklandica		2		1		1	2			3
	Scolecolepides benhami	2	1	1			2	1			
	Sphaerosyllis sp.#1		1								1
	Spionidae sp.#1			1	2						1
	Syllidae sp.#1	1	1	1		2			1		
	Travisia olens	1	1	3			1	2	1	1	
OLIGOCHAETA	Oligochaeta sp.#1		1								1
GASTROPODA	*Cominella glandiformis*									1	
	Diloma subrostrata				1		1	1			
	Notoacmaea helmsi		1			1		6			
BIVALVIA	*Arthritica* sp.#1										
	Austrovenus stutchburyi	2	12	3	4	3		5	11		1
	Macomona liliana							2			
	Nucula sp.#1										1
	Paphies australis							2	1		2
	Perrierina turneri					1					
	Soletellina sp.#1	1		2			1				
CRUSTACEA	Amphipoda sp.#1	1		1	2	2	2	1	4	2	
	Amphipoda sp.#2										
	Austrominius modestus		17		7			26	24		
	Colurostylis lemurum	2	1	5		2	1		2	1	1
	Copepoda sp.#1									1	
	Halicarcinus whitei										
	Isocladus sp.#1		3	1				8			
	Macrophthalmus hirtipes										
	Mysidacea sp.#1										
	Phoxocephalidae sp.#1										
	Pontophilus australis										
	Tanaidacea sp.#1										
OSTEICHTHYES	*Peltorhamphus* sp.#1										
Total species in sample		16	21	19	14	14	13	20	16	13	16
Total individuals in sample		**28**	**67**	**36**	**35**	**31**	**24**	**90**	**70**	**19**	**29**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		AMBI Group	Details (primary source NIWA website (Guide to New Zealand Shore Polychaetes).
Anthozoa	*Anthopleura aureo-radiata*	II	The mud flat anemone which uses the shell of buried cockles as the hard substrate for attachment. The cockles are also host to a detrimental larval trematode *Curtuteria australis* that invades the bivalves through the filtration current, and the anemones significantly depress the rate by which cockles accumulate parasites in the field. This species can grow up to 10mm in diameter and is intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al., 2001). Laboratory tests have shown that *Anthopleura* are very tolerant to a range of Polycyclic Aromatic Hydrocarbons (PAH's). *Anthopleura* are also tolerant to UV light, because they have mycosporine-like amino acids in their tissue which act like a biological sunscreen.
	Edwardsia spp.	II	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
Nemertea	Nemertea	III	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp	III	Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5mm mesh sieve. Generally reside in the upper 2.5cm of sediment. Intolerant of anoxic conditions.
	Aglaophamous spp.	II	An intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate (Beesley et al. 2000). Feeding type is carnivorous.
Polychaeta	*Aonides spp.*	III	A small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. Although *Aonides* is free-living, it is not very mobile and prefers to live in fine sands. *Aonides* is very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds.
	Boccardia (Paraboccardia) syrtis and acus	I	Small surface deposit-feeding spionids. Prefers low-mod mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions. When in dense beds, the community tends to encourage build-up of muds.
	Capitella capitata	V	A blood red capitellid polychaete which is very pollution tolerant. Common in sulphide rich anoxic sediments.
	Cirratulidae	IV	Subsurface deposit feeder that prefers muddy sands. Small sized, tolerant of slight to unbalanced situations.
	Glycera lamellipodia	II	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions. Often present in muddy conditions. Intolerant of low salinity.
	Goniada sp.#1	II	Slender burrowing predators (of other smaller polychaetes) with proboscis tip with two ornamented fangs. The goniadids are often smaller, more slender worms than the glycerids. The small goniadid *Glycinde dorsalis* occurs low on the shore in fine sand in estuaries.
	Hemipodus simplex	II	A glycerid, or bloodworm, found in clean sand sites in estuaries and on clean sandy beaches. The glycerids are cylindrical, very muscular and active large predators and detritivores living in sands and sandy muds.
	Hesionidae sp	II	Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The New Zealand species are little known.
	Heteromastus filiformis	IV	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Despite being a capitellid, *Heteromastus* is not opportunistic and doesn't show a preference for areas of high organic enrichment as other members of this polychaete group do.
	Macroclymenella stewartensis	NA	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 turnover 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. Intolerant of anoxic conditions.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		AMBI Group	Details
Polychaeta	*Magelona sp.#1*	I	Small thin spionid worms which selectively deposit-feed on the surface using a pair of long, raggedly-papillose palps. 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.
Polychaeta	*Nicon aestuariensis*	III	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate to high mud content sediments.
Polychaeta	*Orbinia papillosa*	I	Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.
Polychaeta	Paraonidae sp.	III	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15cm and appear to be sensitive to changes in the mud content of the sediment. Some species of *Aricidea* are associated with sediments with high organic content.
Polychaeta	*Perinereis vallata*	III	An intertidal soft shore nereid (which are common and very active, omnivorous worms). Prefers sandy sediments.
Polychaeta	Phyllodocidae	II	The phyllodocids are a colourful family of long, slender, and very active carnivorous worms characteristically possessing enlarged dorsal and ventral cirri which are often flattened and leaf-like. They are common intertidally and in shallow waters.
Polychaeta	*Platynereis australis*	III	An intertidal soft shore nereid (which are common and very active, omnivorous worms). Prefers sandy sediments.
Polychaeta	Polynoidae	NA	Commonly known as scale-worms, they are active carnivores.
Polychaeta	*Prionospio aucklandica*	III	Renamed to *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001).
Polychaeta	*Scolecolepides benhami*	III	A surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. Prefers low-moderate mud content (<50% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions.
Polychaeta	*Sphaerosyllis sp.#1*	II	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers sandy sediments.
Polychaeta	Spionidae sp.#1	NA	An unknown spionid polychaete. Feed at the sediment-water interface - as either deposit or suspension feeders.
Polychaeta	Syllidae	II	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers sandy sediments.
Polychaeta	*Travisia olens*	I	Belongs to Family Scalibregmatidae. Intolerant of anoxic conditions and mud.
Oligochaeta	Oligochaete sp.#1	NA	Segmented worms - deposit feeders. Classified as very pollution tolerant by AMBI (Borja et al. 2000) but a review of literature suggests that there are some less tolerant species.
Gastropoda	*Cominella glandiformis*	NA	Endemic to New Zealand. A carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30m away, even when the tide is out. Intolerant of anoxic surface muds.
Gastropoda	*Diloma subrostrata*	NA	The mudflat top shell, lives on mudflats, but prefers a more solid substrate such as shells, stones etc. Endemic to New Zealand and feeds on the film of microscopic algae on top of the mud.
Gastropoda	*Notoacmaea helmsi*	NA	Endemic to New Zealand. Small limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		AMBI Group	Details
Bivalvia	*Arthritica sp.#1*	III	A small sedentary deposit feeding bivalve, preferring a moderate mud content. Lives greater than 2cm deep in the muds.
	Austrovenus stutch-buryi	NA	The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Can live in both mud and sand but is sensitive to increasing mud - prefers low mud content. Rarely found below the RPD layer.
	Mocomona liliana	NA	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.
	Nucula hartvigiana	III	The nut clam (family Nuculidae and endemic) is found intertidally and in shallow water, especially in *Zostera* sea grass flats. It is often found together with the New Zealand cockle, but is not as abundant showing a preference for mud. Like *Arthritica* this species feeds on organic particles within the sediment.
	Paphies australis	NA	Pipi (endemic) are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7m.
	Perrierina turneri	NA	A small bivalve mollusc. Not common.
	Solletellina sp.#1	NA	*Soletellina* is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells.
Crustacea	Amphipoda *sp.*	NA	Unidentified amphipods.
	Austrominius mod-estus	NA	Small acorn barnacle. Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones.
	Colurostylis lemurum	NA	A cumacean that is common in intertidal sand flats.
	Copepoda sp.#1	NA	Very small crustaceans usually having six pairs of limbs on the thorax. The benthic group of copepods (Harpac-tacoida) have worm-shaped bodies.
	Halicarcinus whitei	NA	Pillbox crabs are usually found on the sand and mudflats but may also be encountered under stones on the rocky shore. *H. whitei* lives in intertidal and subtidal sheltered sandy environments.
	Isocladus ssp.#1	NA	An isopod.
	Macrophthalmus hirtipes	NA	The stalk-eyed mud crab is endemic to New Zealand 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 brack-ish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
	Mysidacea sp.#1	II	*Mysidacea* is a group of small, shrimp-like creatures (opossum shrimps). Wherever mysids occur, whether in salt or fresh water, they are often very abundant and form an important part of the normal diet of many fishes.
	Phoxocephalidae sp.	I	A family of amphipods.
	Pontophilus australis	I	A relatively common amphipod or shrimp.
	Tanaidacea sp.#1	II	Small, mostly marine-dwelling crustaceans that are diverse and abundant in some marine environments.
Fish	*Peltorhamphus* sp.#1	NA	*Peltorhamphus tenuis* is a righteye flounder of the family Pleuronectidae, found only around New Zealand in shallow enclosed waters such as estuaries.

NA=Not Allocated

AMBI Sensitivity to Stress 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-signicant variations with time (from initial state, to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.

Group III. Species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations). They are surface deposit-feeding species, as tubicolous spionids.

Group IV. Second-order opportunistic species (slight to pronounced unbalanced situations). Mainly small sized polychaetes: subsurface deposit-feeders, such as cirratulids.

Group V. First-order opportunistic species (pronounced unbalanced situations). These are deposit-feeders, which proliferate in anoxic sediments.

The distribution of these ecological groups, according to their sensitivity to pollution stress, provides a Biotic Index with eight levels, from 0 to 7.