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Waikawa Estuary 2007

Fine Scale Monitoring & Historical Sediment Coring

Prepared for

Environment Southland
October 2007

Cover Photo: Mid Waikawa Estuary near Un-named Island.

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By

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All photos by Wriggle except where noted otherwise.

WAIKAWA ESTUARY - EXECUTIVE SUMMARY

Photo: Les McGraw, Environment Southland

The present report summarises the results of the 2007 fine scale monitoring for Waikawa Estuary, one of the key estuaries in Environment Southland's long-term estuary monitoring programme. The report, including sediment chemistry and macrofauna monitoring results from 2005 and 2006, describes the following work:

- Fine scale monitoring of sediment chemistry.
- Fine scale monitoring of sediment dwelling plants and animals.
- Broad scale mapping of macroalgal beds (i.e. sea lettuce (*Ulva*), *Gracilaria, Enteromorpha*).
- Assessment of the recent historical sedimentation rate (using radio-isotopes).
- Establishment of sediment rate monitoring plates.
- Completion of an "Estuary Vulnerability Assessment".

The methods used are based on the tools included in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002), and a number of extensions to the EMP and its monitoring outputs developed by Wriggle Coastal Management (see Robertson & Stevens 2006, 2007) in order to help address issues raised under the existing monitoring programme. The improvements include:

- Upper estuary sedimentation monitoring.
- Nuisance macroalgal monitoring.
- Condition ratings for reporting.
- An "Estuary Vulnerability Matrix".

The following table summarises monitoring results for Waikawa Estuary (2005-07):

Indicator	Results
Metals (Cd, Cr, Cu, Ni, Pb, Zn)	Heavy metals, Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni) & Zinc (Zn), used as an indicator of potential toxicants, were at very low concentrations at both sites with all values well below the ANZECC (2000) ISQG-Low values.
Nutrients (Total Nitrogen - TN and Total Phosphorus - TP)	The indicators of nutrient enrichment (TN and TP) at both sites were at low concentrations for all years. The ratio of TN:TP in the intertidal sediments was close to 1:1 or in many cases less than 1:1, indicating a strong likelihood of nitrogen as the nutrient most likely to be limiting eutrophication.
Organic matter (Total Organic Carbon - TOC)	The indicator of organic enrichment (TOC) at both sites was at low concentrations for all years.
Grain Size (% mud, sand, gravel)	Sites were dominated by sandy sediments (~90% sand) with a ~10% mud content. The site closest to the sea (Site B) had the least amount of mud. Particle size changed little between 2004/5 & 2006/7, indicating that mud-sized particles are not obviously depositing in the firm sandy areas that dominate the lower estuary.
Macrofauna (infauna and epifauna)	Infauna abundance was dominated in all years by polychaetes (>50%), followed by Crustacea and molluscs. Infauna richness (the total number of species at each site) ranged from 32 to 39, (mean=14 to 20). Overall the infauna community composition and abundance was typical of most New Zealand estuaries (Robertson et al. 2002), with differences relatively small between years and likely to be within the bounds of natural variation.
Macroalgal Cover	Potentially nuisance macroalgae were present, but generally at low densities: 1-10% in the upper estuary, and <1% in the lower estuary. There were small areas of >80% cover in the mid estuary.
Sedimentation Rate	The average rate of sedimentation was estimated for three time periods as follows: 1996-2007, 10.7mm/year. 1967-1996, 3.1mm/year. 1878-1967, 1.5mm/year.

EXECUTIVE SUMMARY (CONTINUED)

CONDITION RATINGS

The condition ratings for individual indicators monitored for the Waikawa Estuary sediments in 2007 are summarised in the following table. Indicators are grouped within the three major estuary issues being monitored under this programme; toxins, eutrophication, and sedimentation. An overall issue rating for these major issues is given based on the monitoring results.

Major Estuary Issue	Indicator	Condition Rating	Overall Issue Rating
Toxins	Cadmium	Very Good	Toxins *Very Good*
	Chromium	Very Good	
	Copper	Very Good	
	Nickel	Very Good/Good	
	Lead	Very Good	
	Zinc	Very Good	
	Macrofauna	*Not yet developed*	
Eutrophication	Total Nitrogen	Very Good	Eutrophication *Very Good/Good*
	Total Phosphorus	Low-Mod Enrichment	
	Total Organic Carbon	Very Good	
	Macroalgae	Good	
	Macrofauna	*Not yet developed*	
Sedimentation	Sedimentation rate	High	Sedimentation *High*
	Grain Size	*Not yet developed*	

RECOMMENDED MONITORING

Based on existing monitoring results and improvements made to the EMP to produce better outputs for ES to manage key issues facing their estuaries, it is recommended that monitoring continue as outlined below:

Fine Scale Monitoring	Complete the final year of the scheduled four year baseline monitoring in Waikawa in January-March 2008. After this, reduce monitoring to five yearly intervals or as deemed necessary based on the condition ratings.
Broad Scale Macroalgal Mapping	Map macroalgal cover in January-March 2008 while doing the fine scale monitoring. After this, reduce monitoring to five yearly intervals or as deemed necessary based on the condition ratings.
Broad Scale Sedimentation Rate Mapping	Measure sediment plate depths in January-March 2008 while doing the fine scale monitoring. Monitor annually thereafter.
Broad Scale Habitat Mapping	In 2009, repeat the inaugural broad scale (baseline) survey established in 2005.

ISSUES

The estuary vulnerability assessment 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:

- **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. Additionally, there have been significant areas of saltmarsh drained for pastoral use in the past and this has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary.

It is recommended that options be considered to identify the likely cause of sedimentation and look at sediment management options; and options be considered to prevent the further loss of, and/or restoration of, salt marsh and margin habitat.

1. INTRODUCTION

OVERVIEW

To assess some of the major issues faced by New Zealand estuaries (Table 1), Environment Southland (ES) established a long-term monitoring programme in the 1990's based on the tools included in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002). The EMP consists of two main elements:

1. Broad scale habitat mapping (using GIS based computer software).
2. Fine scale (i.e. detailed) monitoring of dominant intertidal habitat in the mid estuary area.

Broad scale habitat mapping records the location and type of vegetation (e.g. saltmarsh, seagrass, macroalgae) and substrate (e.g. mud, sand, gravel, etc); and is used to provide information primarily on the issues of habitat and margin loss, sedimentation (through the mapping of substrate type), and eutrophication (by mapping macroalgae percent cover).

Figure 1 Mid Waikawa Estuary near Un-named Island.

Fine scale monitoring focuses primarily on the physical, chemical, and biological characteristics of estuary sediments as these tend to be the most sensitive to degradation (Church 1975). Fine scale monitoring includes various indicators of estuary condition to provide information on sedimentation, eutrophication, and toxins (i.e. sediment particle size, organic matter, nutrients, heavy metals, and sediment macrofauna).

In 2006, ES contracted Wriggle Coastal Management (Wriggle) to review the EMP monitoring undertaken by ES between 2001 and 2006, and to provide an overview "State of the Environment" assessment of the condition of Southland's estuaries (Robertson & Stevens 2006). The report expanded the reporting of EMP monitoring data by developing key condition indicators (summarised in Table 2) and proposing interim condition ratings to evaluate estuary condition. A suggested monitoring or management response was linked to each condition rating, while recommendations were made to address any identified gaps in the existing monitoring programme.

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

Issue	Impact
Sedimentation	If sediment inputs are excessive, they infill quickly with muds, reducing biodiversity and human values and uses.
Eutrophication	If nutrient inputs are excessive, they experience 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 salt marsh) are lost or damaged through drainage, reclamation, building of structures, stock grazing or vehicle access, biodiversity and estuary productivity declines.
Margin Loss	If the natural terrestrial margin around the estuary is degraded through such actions as roading, stormwater outfalls, property development and weed growth, the natural character is diminished and biodiversity reduced.

OVERVIEW (CONTINUED)

Following from this work, Wriggle developed a number of extensions to the EMP and its monitoring outputs in order to help address issues raised under the existing monitoring programme. The extensions developed include:

- Establishment of sedimentation rate measures (using plates buried in sediment).
- Estimation of historical sedimentation rates (using radio-isotope ageing of sediment cores).
- Assessment of the percentage cover of macroalgae and seagrass (reported as separate GIS layers).
- Broad scale mapping of the 200m terrestrial margin surrounding the estuary.
- Further development and refinement of condition ratings for key indicators.
- Provision of georeferenced digital photos (as a GIS layer).
- Development of an Upper Estuary Monitoring and Assessment Protocol.
- Development of an Estuary Vulnerability Matrix.

Where relevant, these extensions have been integrated into the existing ES estuary monitoring programme to assist in the interpretation of monitoring results, and to help ES determine appropriate management options.

SCOPE

Figure 2 Looking from Curio Bay towards the entrance to Waikawa Estuary.

For Waikawa Estuary, broad scale mapping was first undertaken in 2004, with a four year baseline of fine scale monitoring started in 2005 and repeated in 2006. Results of this monitoring are presented in Robertson et al. (2004), Stevens & Asher (2005), Robertson & Asher (2006), and Robertson & Stevens (2006).

As part of the ongoing monitoring of Waikawa Estuary, ES contracted Wriggle to undertake a series of monitoring studies in February and March 2007 when a variety of Southland estuaries were visited and monitored over a three week period. Within Waikawa the following work was undertaken:

- Fine scale monitoring of sediment chemistry.
- Fine scale monitoring of sediment dwelling plants and animals.
- Broad scale mapping of macroalgal beds (i.e. sea lettuce (*Ulva*), *Gracilaria, Enteromorpha*).
- Assessment of the recent historical sedimentation rate (using radio-isotopes).
- Establishment of sediment rate monitoring plates.
- Completion of an "Estuary Vulnerability Assessment".

Table 2 Summary of the broad and fine scale EMP indicators used by Environment Southland.

Level	#	Indicator	Method
Broad Habitat	1	Saltmarsh Habitat Index	Broad scale mapping - estimates the change in saltmarsh habitat over time.
Broad Habitat	2	Seagrass Habitat Index	Broad scale mapping - estimates the change in seagrass habitat over time.
Nutrient Enrichment	3	Nuisance Macroalgal Cover Index	Broad scale mapping - estimates the change in the area of nuisance macroalgal growth (e.g. sea lettuce (*Ulva*), *Gracilaria* and *Enteromorpha*) over time.
Sedimentation	4	Soft Mud Sediment Index	Broad scale mapping - estimates change in the amount of soft mud habitat over time.
Organic & Nutrient Enrichment	5	Organic and Nutrient Enrichment Indicator	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.
Contamination	6	Contamination in Bottom Sediments Indicator	Chemical analysis of indicator metals (cadmium, chromium, copper, nickel, lead and zinc) in replicate samples from the upper 2cm of sediment.
Biodiversity	7	Condition of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna) - 0.0133m^2 replicate cores. Type and number of animals living on the sediment surface (epifauna) - 0.25m^2 replicate quadrats.

1. INTRODUCTION (CONTINUED)

REPORT STRUCTURE

This report presents the results of the 2007 monitoring of Waikawa Estuary. It represents the first "stand alone" report of fine scale results for Waikawa Estuary, and incorporates several extensions to the monitoring previously undertaken. The major extensions are:

Inclusion of upper estuary sedimentation monitoring: Sedimentation has been identified as a major issue and has been addressed in two ways. Firstly through the radio-isotope analysis of a sediment core to age the sediment and determine historical sedimentation rates in the estuary. Secondly, through the establishment of sediment plates so that rates of sediment accumulation from the present and into the future can be measured. Both methods are described in Section 2.

Inclusion of nuisance macroalgal monitoring: Eutrophication, commonly observed through the presence of nuisance macroalgae, has been identified as a potential problem. Methods for assessing and reporting macroalgal percent cover have been improved and are described in Section 2.
The spatial location, size, and type of broad scale macroalgae features in the estuary are provided as ArcMap 9.2 Geographic Information System (GIS) shapefiles on a separate CD. As the GIS structure allows data to be easily managed, and contains a much greater level of detail than can be concisely presented in a summary report, the GIS should be used as the primary resource for assessing broad scale data. Results are summarised in the current report in Section 4.

Inclusion of condition ratings for reporting: Interim condition ratings (see Robertson & Stevens 2006, 2007) developed specifically for the EMP indicators used by ES for Southland's estuaries (Table 2), have been further developed and proposed to evaluate the monitoring results. These are described in Section 3.

Inclusion of an "Estuary Vulnerability Matrix": The matrix brings together existing knowledge of an estuary so that the major susceptibilities and risks can be identified and, from this, any specific environmental information requirements needed for management determined. The matrix is described in Section 5.

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 broad scale mapping of macroalgal cover.
Section 3 Interim condition ratings for Southland estuaries.
Section 4 Results and discussion.
Section 5 Estuary Vulnerability Assessment.
Section 6 Summary.
Section 7 Recommendations.
Section 8 References.

Appendix 1: Details of analytical methods.
Appendix 2: Lead dating of sediment.
Appendix 3: Detailed fine scale monitoring results - Waikawa Estuary 2007.

SAMPLING LOCATIONS WITHIN WAIKAWA ESTUARY

Figure 3 Location of sedimentation and fine scale monitoring sites in Waikawa Estuary (photo Les McGraw, Environment Southland).

2. METHODS

FINE SCALE MONITORING

Figure 4 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 of an estuary, representative sampling sites (usually two per estuary) are selected and samples collected and analysed for the following variables:

- 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).
- Heavy metals: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni) and Zinc (Zn).
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Sediment oxygenation (Redox Potential Discontinuity - RPD).

Extensive monitoring and analysis of results from other New Zealand estuaries (and particularly from Southland) has enabled improvements to be made to the EMP. For estuaries that have condition ratings in the very good-good and low-moderate range (i.e. Waikawa Estuary), reducing sample replication for chemistry from ten individual samples to three composite samples provides an appropriate balance between management needs and cost in estuaries with low contaminant loads.

In addition, salinity measurements of the overlying water have been included at each site during low tide periods in order to provide a better definition of habitat type. This is to assist in using condition ratings, and to better understand and interpret differences between estuaries.

Ways to measure historical sedimentation rates and establish sedimentation rate monitoring plates have also been included, and methods for assessing the percentage cover of macroalgae and seagrass developed.

Details on these and the field sampling and analysis methods used are presented in the remainder of this section, with details on analytical methods provided in Appendix 1.

Nutrients and Contaminants in Waikawa Estuary

Based on the presence of low concentrations of nutrients and contaminants in the estuary and the absence of intensive farming, horticulture, or urban and industrial development in the Waikawa Catchment, it is therefore recommended that replication within sites be minimised (i.e. 3 per site)

Figure 5 Core sample from Waikawa Estuary.

FINE SCALE MONITORING (CONTINUED)

Figure 6 Sampling RPD layer.

Figure 7 Counting epifauna.

Two fine scale sampling sites (Figure 3) 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. During each period of sampling ten plots are selected, a random position defined within each, and the following sampling undertaken:

Physical and chemical analyses:

- 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 or stored as appropriate.
- The chilled samples were sent to an analytical laboratory (R.J. Hill Laboratories), where they were analysed for the following characteristics:
  - 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 ANZECC guidelines.
- Samples were tracked using standard Chain of Custody forms and results are checked and transferred electronically to avoid transcription errors.
- Photographs to record the general site appearance.

Sediment core profiles and depth of Redox Potential Discontinuity (RPD)

- One random 60mm diameter 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.

Epifauna (surface-dwelling animals):

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

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 with 1% glyoxol fixative.
- The samples were then transported to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants).

2. METHODS (CONTINUED)

BROAD SCALE MAPPING OF MACROALGAE

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). The approach, originally described for use in NZ estuaries by Robertson et al. (2002), uses a combination of aerial photography, together with detailed ground-truthing and GIS-based digital mapping, to record the primary habitat features present. Very simply, the method involves three key steps:

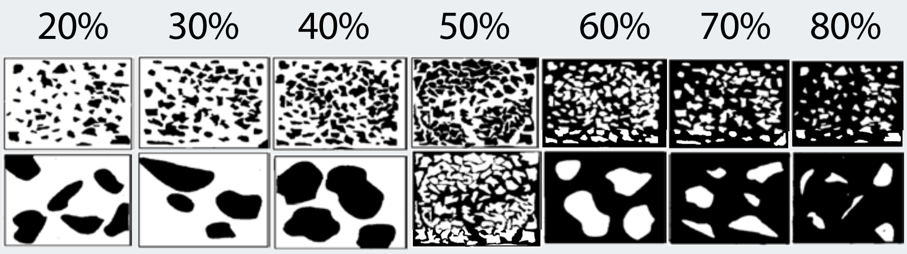
1. Obtaining laminated aerial photos for recording dominant habitat features.
2. Carrying out field identification and mapping (i.e. ground-truthing).
3. Digitising the field data into ArcMap 9.2 GIS layers.

For the 2007 study, macroalgae within the estuary was classified based on six bands of percentage cover and recorded on existing aerial photos:

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

Estimates of percentage cover were made by experienced scientists using a visual rating scale as presented below, with field examples shown in Figure 8.

Visual rating scale for percentage cover estimates



This enabled a map to be generated showing where different densities of macroalgae were concentrated within the estuary (recorded in separate GIS layers using a Wacom Intuos3 electronic drawing tablet within ArcMap 9.2).

A.

B.

Figure 8 Examples of macroalgae percentage cover: A. 20-50% *Gracilaria* and B. >80% *Enteromorpha* (photos from New River Estuary).

2. METHODS (CONTINUED)

HISTORICAL SEDIMENTATION RATE

Figure 9 Collecting sediment core and cutting for analysis.

To age sediment using radio-isotopes and calculate recent sediment deposition to ~100 years before present, a historical sediment core was taken from soft intertidal muds in Waikawa Estuary on 4 March 2007 (Figure 3, Upper South). The core was collected by slowly inserting a 1m long, 10cm diameter PVC pipe into the estuary muds (Figure 9), measuring core compression, then removing the pipe (and intact core) from the estuary bed and transporting it upright on a sled to the estuary margin for processing. From here, the PVC pipe was laid horizontally, split in half, the core photographed, and then cut into 2cm slices. Each slice was described, bagged and labelled. Samples from representative depths were selected based on the visual character of the core (e.g. changes grain size/texture/colour/biota) for analysis at the National Radiation Laboratory, Christchurch for the following:

Beryllium (^{7}Be): a natural isotope (very short half-life) used to indicate the depth of surface mixing (i.e. it will not be present in older sediments).
Caesium (^{137}Cs): an isotope with a half life of 30 years that was introduced by atmospheric nuclear weapons tests beginning in 1953 (i.e. will only be present in sediments post 1953).
Lead (^{210}Pb): a natural isotope (half life of 22 years); useful in dating sediments younger than 100-150 years. The difference between the ^{210}Pb concentration in the core sample below the surface and the concentration at the surface is used to age the sediment.
Radium (^{226}Ra & ^{228}Ra): the two most common isotopes of radium. ^{226}Ra has a long half-life (1,600 years) compared to that of ^{228}Ra (5.75 years). ^{226}Ra decays by emitting the nucleus of a helium atom (alpha particle), whereas ^{228}Ra emits an electron (beta particle).

At the National Radiation Laboratory, 15g samples of dried sediment were ground, homogenised, embedded in epoxy resin, and then left for 30 days to allow equilibration between ^{226}Ra, ^{214}Bi (Bismuth - a radon decay product), and ^{214}Pb. Samples were then placed on a Hyper Pure Germanium gamma detector, counted for 23 hours, and then counts were analysed with GENIE-2000 software. This allowed total ^{7}Be, ^{137}Cs, ^{210}Pb, ^{226}Ra, and ^{228}Ra to be calculated with a 95% confidence interval. Appendix 2 details methods used to calculate the historic sedimentation rates using the isotope results.

FUTURE SEDIMENTATION RATE

Figure 10 Digging hole to place sediment plate.

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 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 3). 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 10) 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.

3. ESTUARY CONDITION RATINGS

OVERVIEW

RATING
Very Good
Good
Fair
Poor
Early Warning Trigger

At present, there are no formal criteria for rating the overall condition of estuaries in NZ, 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 have been proposed for Southland's estuaries (Robertson & Stevens 2006, 2007, this report). The interim condition ratings (presented below) are based on a review of monitoring data, use of existing guideline criteria (e.g. ANZECC (2000) sediment guidelines), and expert opinion. They indicate whether monitoring results reflect poor, fair, good, or very good 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 a plan to further evaluate an issue and consider what response actions may be appropriate.

At this stage, the interim condition ratings reflect the best guidance able to be provided based on the available information and budget. 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 e.g. macroinvertebrate (infauna and epifauna) density and abundance, grain size. The interim condition ratings for Waikawa Estuary, based on Robertson & Stevens (2006, 2007) are presented below along with a brief rationale for their use.

Metals

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

METALS CONDITION RATING

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

Total Nitrogen

In shallow estuaries like those in Southland, 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	Monitor at 2 year intervals and manage source
Very Enriched	>4000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

3. ESTUARY CONDITION RATINGS (CONTINUED)

Total Phosphorus

In shallow estuaries like those in Southland, 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	Monitor at 2 year intervals and manage source
Very Enriched	>1000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Total Organic Carbon

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

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

Macroalgae Percent Cover

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.

MACROALGAE CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	%cover <1%. No nuisance conditions	Monitor at 5 year intervals after baseline established
Good	%cover 1-10%. No nuisance conditions	Monitor at 5 year intervals after baseline established
Fair	%cover 10-50%. Isolated nuisance conditions	Monitor yearly. Initiate Evaluation & Response Plan
Poor	%cover >50%. Widespread nuisance conditions	Monitor yearly. Initiate Evaluation & Response Plan
Early Warning Trigger	Trend of % cover increasing	Initiate Evaluation and Response Plan

Sedimentation Rate

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

SEDIMENTATION RATE CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Low	<1mm/yr (typical pre-European rate)	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	Monitor yearly. Initiate Evaluation & Response Plan
Very High	>20mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

4. RESULTS AND DISCUSSION

RESULTS SUMMARY	This section presents the results of the fine scale sampling and analysis, and the assessment of macroalgal cover and sedimentation rates. Physical and chemical results are shown in Table 3, with all results (including the fine scale sampling results from 2005 and 2006) presented graphically in Figures 11 to 22. Interim condition ratings have been included in the figures where available to provide a context for the results. Infauna have been summarised into the three most dominant groups present: polychaetes, molluscs (snails and bivalves) and Crustacea, with a full listing of all infauna and epifauna presented in Appendix 3. Results for each of the indicators used to monitor estuary condition are summarised below and evaluated based on the estuary condition ratings described in Section 3.
Metals (Cd, Cr, Cu, Ni, Pb, Zn)	Heavy metals, used as an indicator of potential toxicants, were at very low concentrations at both sites with all values well below the ANZECC (2000) ISQG-Low trigger values. **Metals met the "very good" condition rating** (Figures 11-16).
Nutrients (Total Nitrogen and Phosphorus)	The indicators of nutrient enrichment (TN and TP) at both sites were at low concentrations for all years. The ratio of TN:TP in the intertidal sediments was close to 1:1 or in many cases less than 1:1, indicating a strong likelihood of nitrogen as the nutrient most likely to be limiting eutrophication in the Waikawa Estuary. **TN met the "very good" condition rating** (Figure 17). **TP met the "good" condition rating** (Figure 18).
Organic matter (Total Organic Carbon)	The indicator of organic enrichment (TOC) at both sites was at low concentrations for all years. **TOC met the "very good" condition rating** (Figure 19).
Grain Size (% mud, sand, gravel)	Both sites were dominated by sandy sediments (~90% sand) with a ~10% mud content (Figure 20). The site closest to the sea, Site B, had the least amount of mud. Particle size changed little between 2004/5 and 2006/7, indicating that mud-sized particles are not obviously depositing in the firm sandy areas that dominate the lower two-thirds of the estuary. A grain size **condition rating has yet to be developed** for Southland's estuaries.
Macrofauna (infauna and epifauna)	Infauna abundance was dominated in all years by polychaetes (>50%), followed by Crustacea and molluscs (Figure 21). Infauna richness (the total number of species at each site) ranged from 32 to 39, (mean=14 to 20) (Figure 22). Overall the infauna community composition and abundance was typical of most New Zealand estuaries (Robertson et al. 2002) with differences in abundance and diversity relatively small between years, and likely to be within the bounds of natural variation. A macrofauna **condition rating has yet to be developed** for Southland's estuaries.
Macroalgal Cover	Potentially nuisance macroalgae were present, but generally at low densities: 1-10% in the upper estuary, and <1% in the lower estuary. There were small areas of >80% cover in the mid estuary (Figure 23). **Macroalgae met the "good" condition rating**.
Sedimentation Rate	The average rate of sedimentation was estimated for three time periods (see Figure 24, Table 5) as follows: 1996-2007, 10.7mm/year. This is in the **"high" condition rating**. 1967-1996, 3.1mm/year. This is in the **"low" condition rating**. 1878-1967, 1.5mm/year. This is in the **"low" condition rating**. Sedimentation plates have been deployed in the estuary to enable long term monitoring of sedimentation rates.

Table 3 Physical and chemical results for Waikawa Estuary, March 2007.

Estuary	Site	Rep.	RPD	Salinity	AFDW	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
			cm	ppt@15^{0}C	%				mg/kg							
Waikawa	A	01	>20	20.8	1.30	10.2	89.0	0.9	0.01	7.4	2.9	4.6	1.67	14.3	<500	287
Waikawa	A	02	>20	20.8	1.68	11.9	86.7	1.4	0.02	8.6	3.5	5.7	1.94	16.2	<500	309
Waikawa	A	03	>20	20.8	1.20	8.3	90.2	1.5	0.01	7.8	3.0	4.7	1.73	15.0	<500	297
Waikawa	B	01	>20	20.8	1.16	3.5	96.5	<.01	0.02	7.0	2.7	4.4	1.53	11.8	<500	236
Waikawa	B	02	>20	20.8	0.99	3.5	96.5	0.1	0.01	7.3	2.7	4.5	1.61	12.0	<500	237
Waikawa	B	03	>20	20.8	1.21	2.3	97.5	0.2	0.01	5.8	2.5	3.9	1.33	10.5	<500	215

CADMIUM

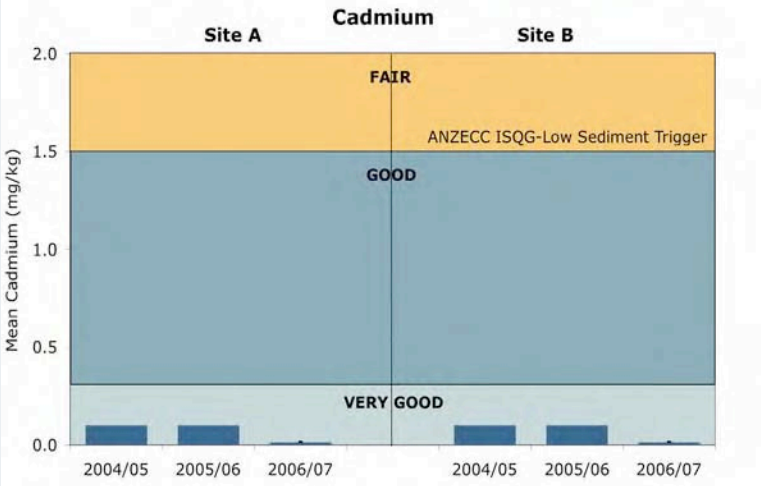


Figure 11 Mean and range of sediment cadmium concentrations.

CHROMIUM

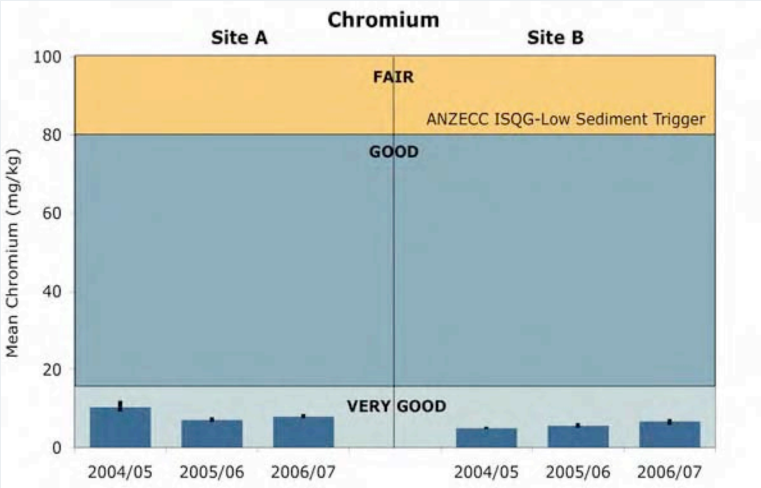


Figure 12 Mean and range of sediment chromium concentrations.

COPPER

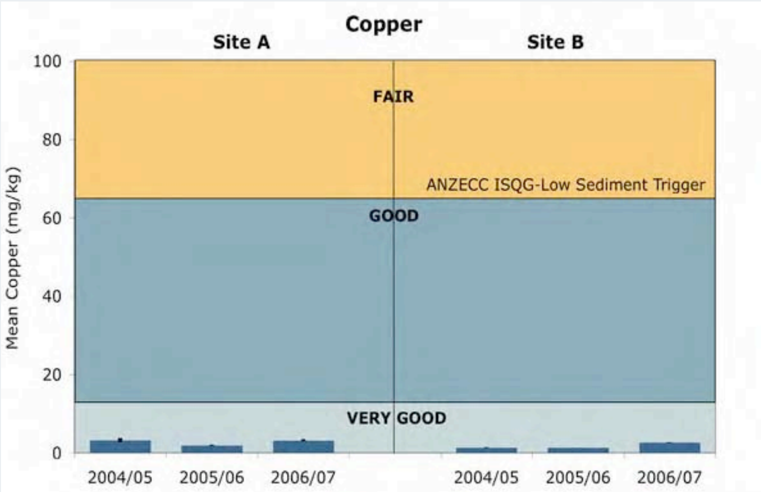


Figure 13 Mean and range of sediment copper concentrations.

NICKEL

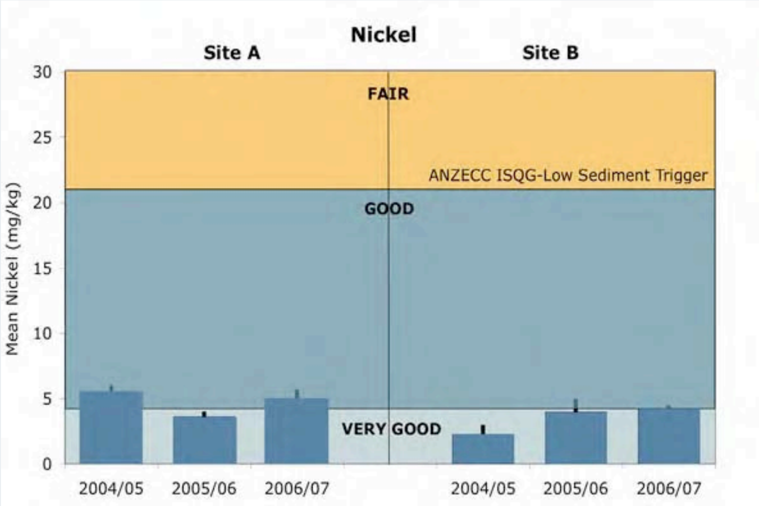


Figure 14 Mean and range of sediment nickel concentrations.

LEAD

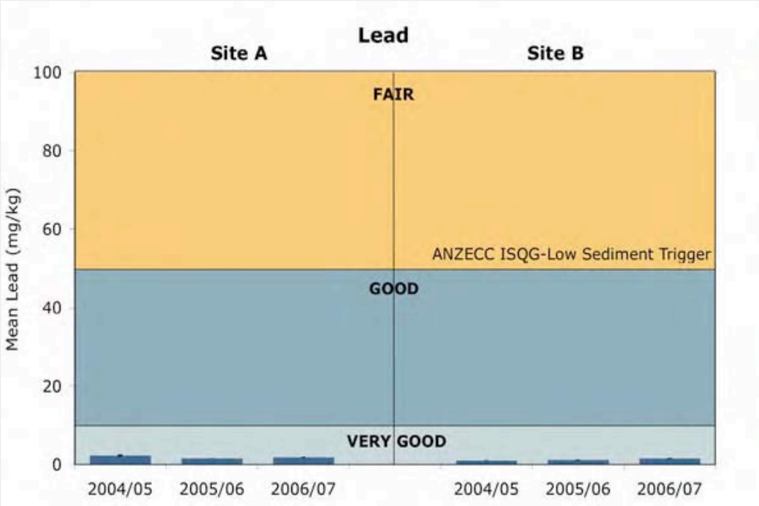


Figure 15 Mean and range of sediment lead concentrations.

ZINC

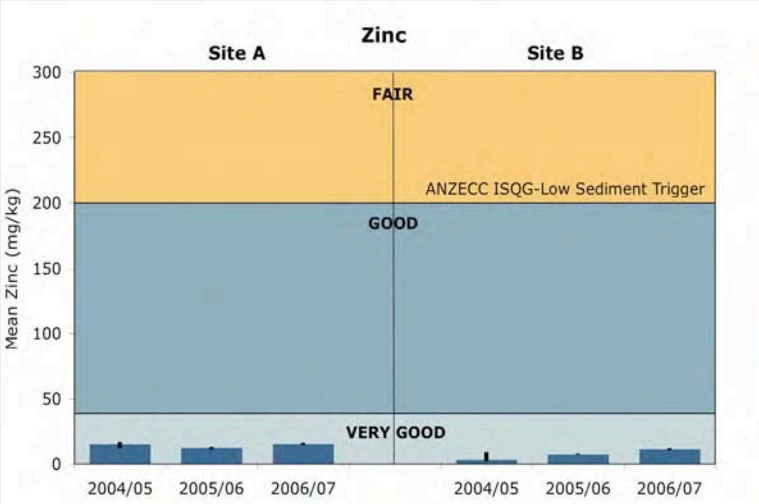


Figure 16 Mean and range of sediment zinc concentrations.

TOTAL NITROGEN

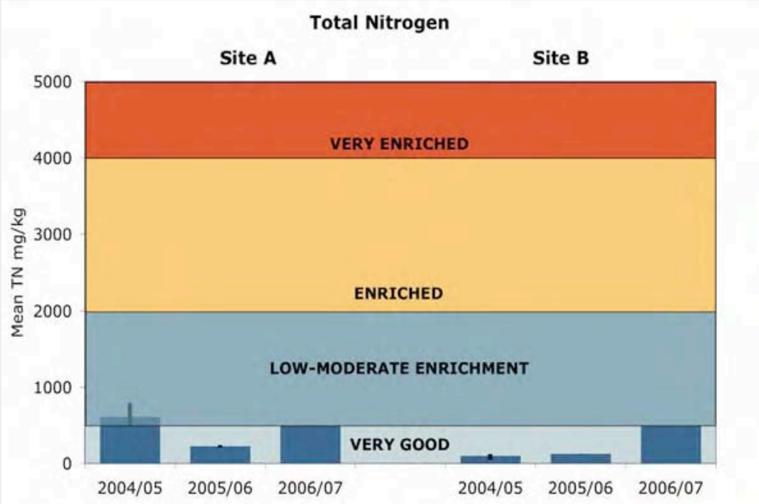


Figure 17 Mean and range of sediment total nitrogen concentrations.

TOTAL PHOSPHORUS

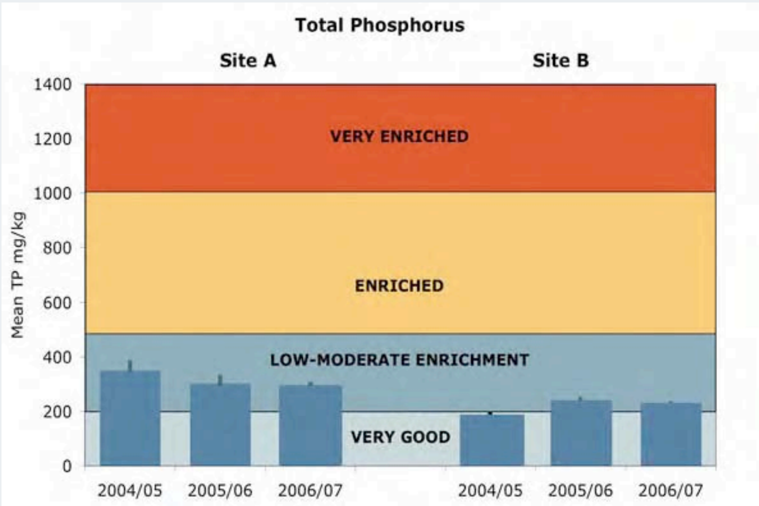


Figure 18 Mean and range of sediment total phosphorus concentrations.

TOTAL ORGANIC CARBON

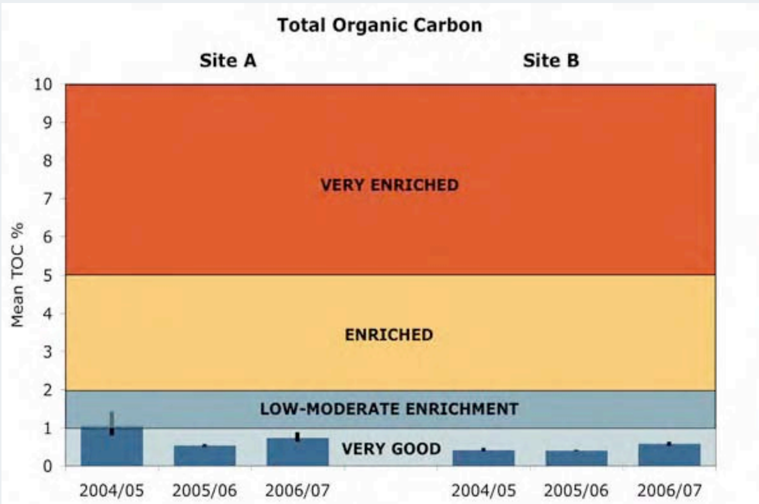


Figure 19 Mean and range of sediment total organic carbon concentrations.

GRAIN SIZE

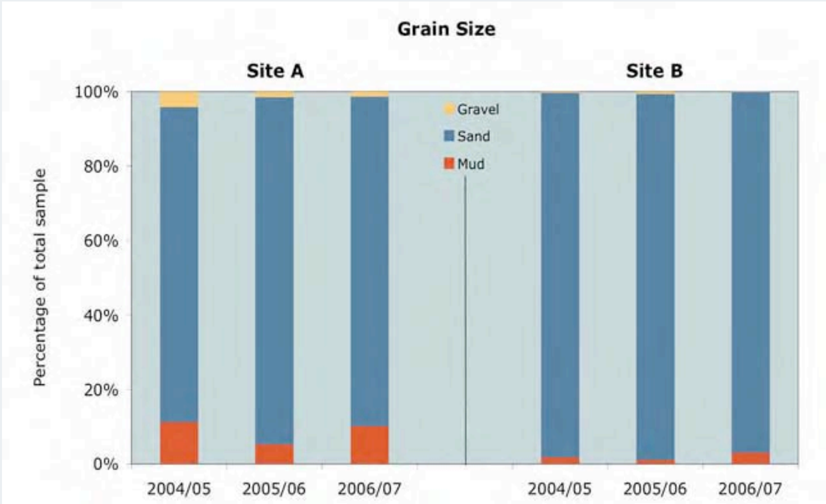


Figure 20 Mean sediment grain size.

INFAUNA (ABUNDANCE)

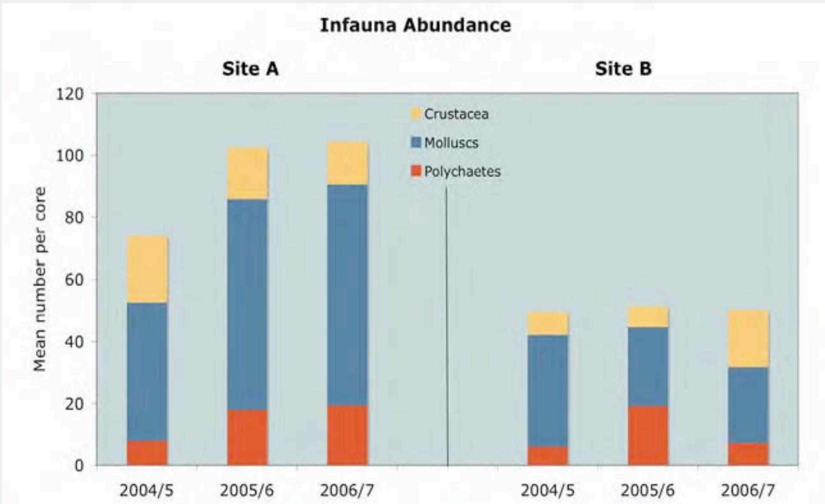


Figure 21 Mean abundance of major groups of infauna in 10 cores.

INFAUNA (RICHNESS)

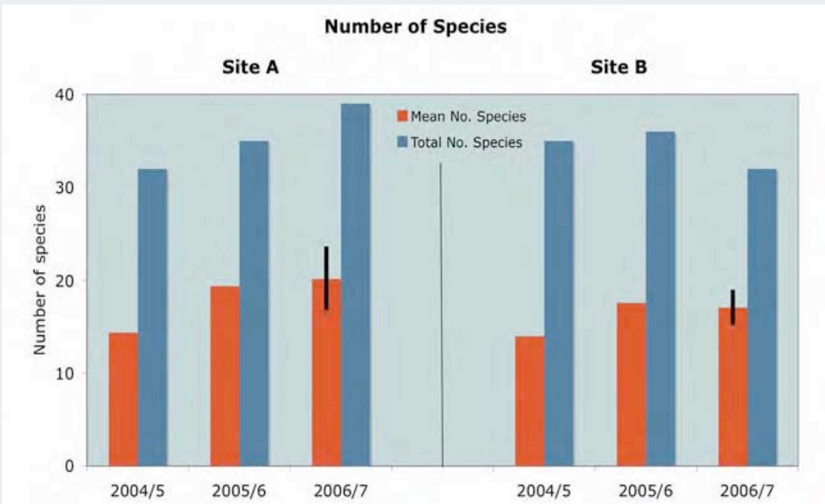


Figure 22 Mean number of species (and standard deviation) and total number of species in 10 cores.

MACROALGAL COVER

The distribution of potentially nuisance macroalgae present in the estuary is shown in Figure 23. Although present in the estuary, algae were generally at low densities (1-10% cover in the upper estuary and <1% cover in the lower estuary), except for small areas of greater than 80% cover in the mid estuary.

In terms of species, the low density areas were dominated by the red algae *Gracilaria* sp. and the high density areas by sea lettuce, *Ulva* sp. It was noted that the estuary subtidal channels had much higher concentrations of *Gracilaria* and *Enteromorpha* than intertidal areas.

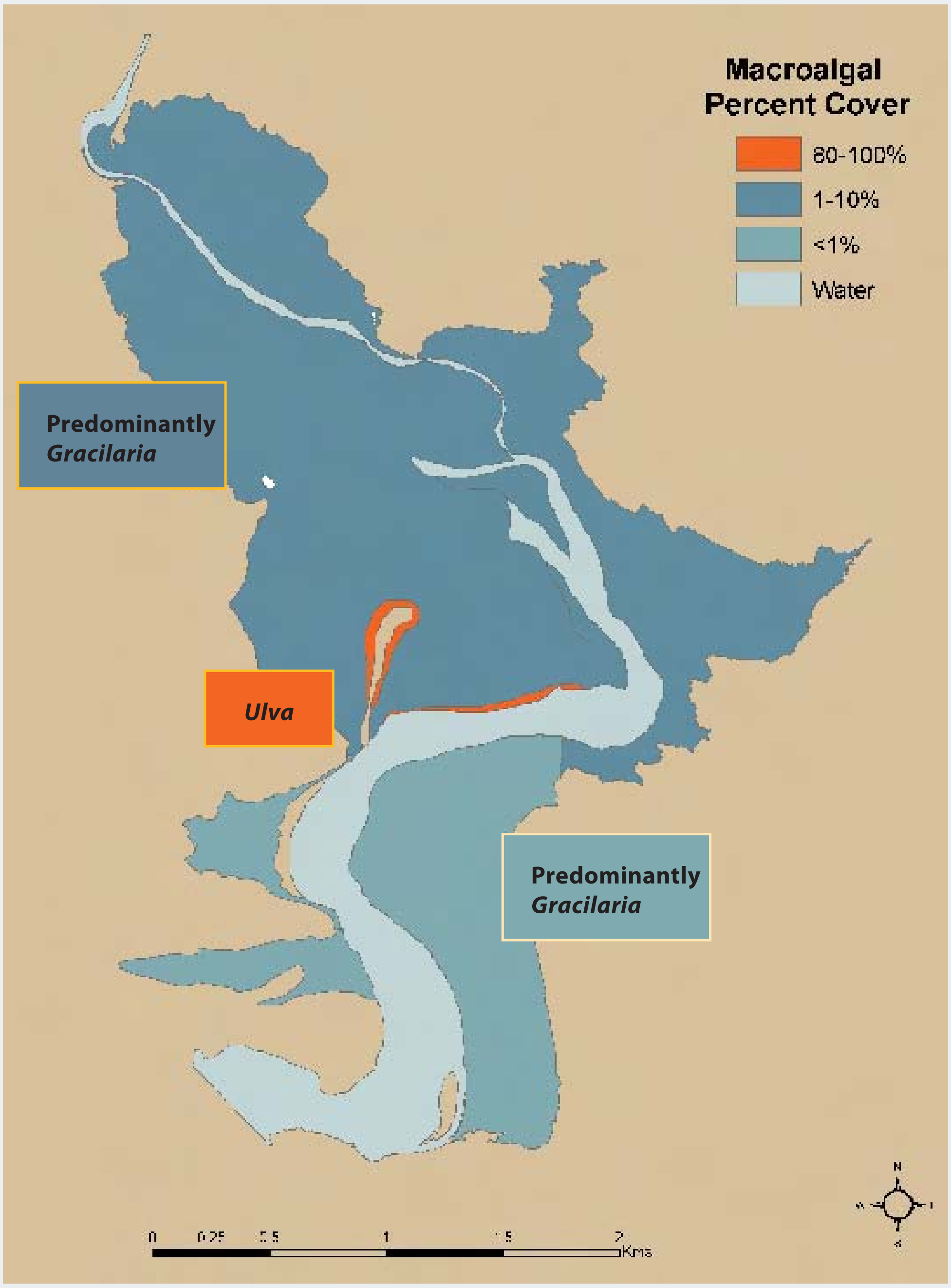
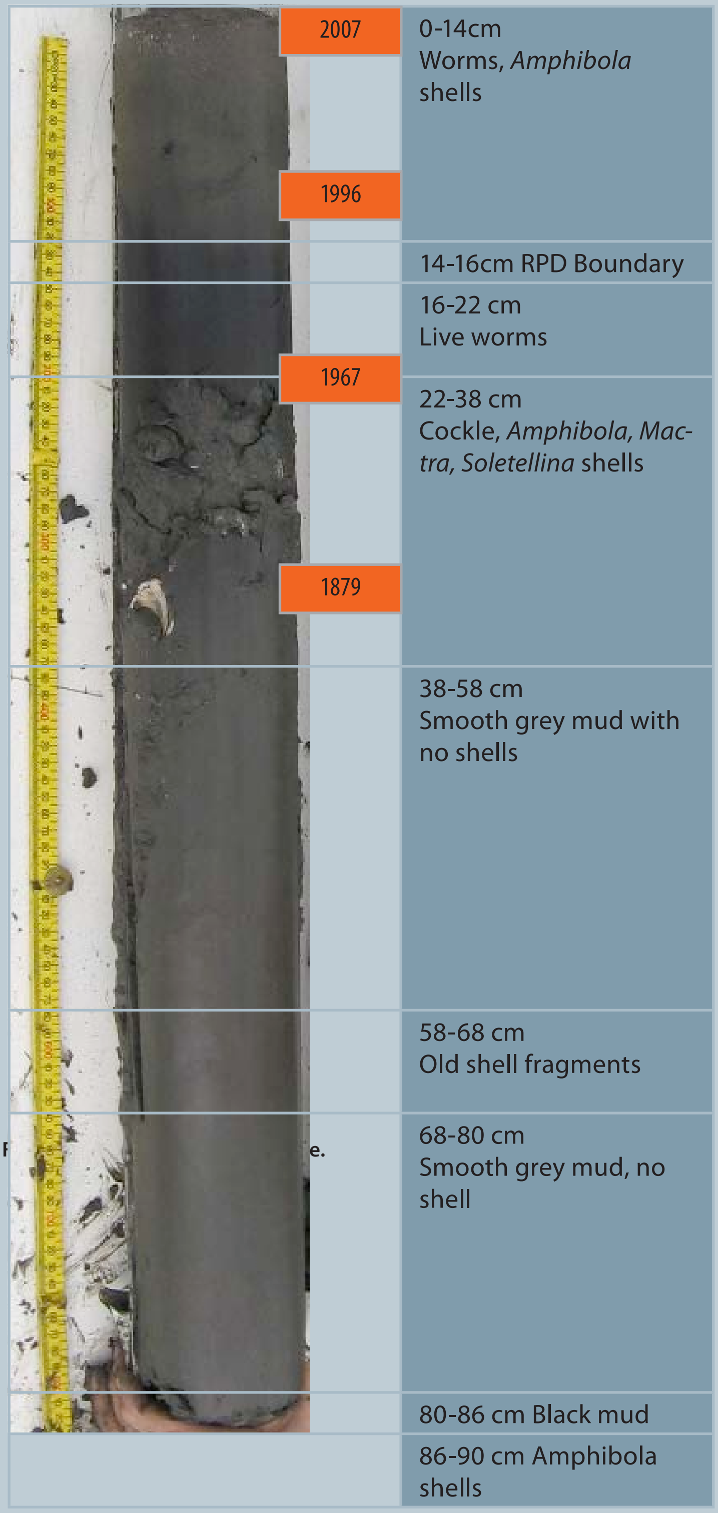


Figure 23 Percentage cover of macroalgae in Waikawa Estuary, March 2007.

HISTORICAL SEDIMENT CORE ANALYSIS



The Waikawa Estuary core was collected from offshore, intertidal sediments located at the western end of the estuary in very soft muds (Upper Sth site, Figure 3) on 4 March 2007.

The sediment core was compressed by 12.6% (13.0cm) during collection (total corer depth 103cm, compressed core depth 90cm). While it is possible that some sediment bypass occurred, it was assumed that all core shortening was a result of sediment compaction spread equally over the entire core. Depths shown in Figure 24 and used in the text are compressed depths. Both compressed and uncompressed core depths, along with the results of the radio-isotope analysis by the National Radiation Laboratory are presented in Table 4.

The entire core (Figure 24) was soft mud, the top 15cm well oxygenated, with live worms present down to 22cm. Mud snail (*Amphibola*) shells were present near the surface, with a mixture of cockle, mud snail, *Mactra,* and *Soletellina* shells present between 22 and 38cm. Below this depth the core was predominantly smooth grey mud, largely free of shells other then a few fragments between 58 and 68cm. At the lower end of the core, black mud appeared at 80-86cm and mud snail shells were present from 86cm to the bottom of the core (90cm).

The estimated age of the sediments, derived from radio-isotope analysis, is shown on Figure 26 and described below. ^{7}Be, because it has a short half life (53.3 days) and originates from the atmosphere, is used to determine the depth of sediment recently exposed to the atmosphere (i.e. the upper mixed sediment layer exposed with the past few months). The presence of ^{7}Be in the upper 6-8cm of the Waikawa core and its absence below 8cm (Table 4) indicates a 6-8cm deep well-mixed layer at this site. This is consistent with field observations of both physical and biological mixing in the upper core. Below this depth, there was a relatively uniform decrease in isotope values providing data suitable for ageing the core to an uncompressed depth of 16-18cm for ^{137}Cs, and to 28-30cm for ^{210}Pb.

HISTORICAL SEDIMENT CORE ANALYSIS (CONTINUED)

^{137}Cs activity introduced following atmospheric nuclear weapons tests beginning in 1953 provides a marker for recent sediment deposition. Peak atmospheric fall-out of ^{137}Cs in New Zealand occurred in 1964, with elevated levels occurring from 1959-1964 (Cambray et al. 1979; Loughran et al. 1988). Based on this, the maximum depth of ^{137}Cs activity has been ascribed to 1960 and used to estimate a gross sedimentation rate over the past 47 years (1960-2007) of 4.3mm/year. As ^{137}Cs activity could also have been present in sediments from 16-28cm that were not analysed, an upper range is 7.2mm/year.

Table 4 Results of the radio-isotope analysis of the historical sediment core.

Compressed Depth (cm)	Uncom-pressed Depth (cm)	Total ^{210}Pb	^{226}Ra (=Supported ^{210}Pb)	Unsupported ^{210}Pb	^{137}Cs	^{7}Be
0-2	2.3	57.2	19.8	37.4	0.7	19.3
2-4	4.5	61.9	17.6	44.3	0.86	9.8
6-8	6.8	59	17.8	41.2	0.47	4.3
8-10	11.3	49.1	17.4	31.7	0.83	<0.64
16-18	20.3	31.3	18.6	12.7	0.48	<0.64
28-30	33.8	20.8	20	0.8	<0.53	<0.69
40-42	47.3	19.7	20.8	-1.1	<0.52	<0.68
60-62	69.8	22.8	23.2	-0.4	<0.50	<0.69
78-80	90.1	20.6	23.2	-2.6	<0.50	<0.72

^{210}Pb is used to determine sedimentation rates over the last 100-150 years and enables estimates to be made of different deposition rates within this period. Calculation details are provided in Appendix 2 and results are presented in Table 5. The results show that there has been approximately 135mm of sediment deposited since~1878 (129 years), an overall average of 2.6mm/year. Within this period, the sediment deposition rate prior to ~1967 was relatively low (1.5mm/year), increasing to an average of 5.1mm/year (range 3.1-10.7mm/year) since 1967, with the highest deposition present over the past 11 years.

The data also show that prior to 1878, the upper Waikawa Estuary was still covered with at least 0.5m of smooth grey mud. The general absence of shell fragments in this layer is a bit of a mystery and possibly points to a period of very rapid sedimentation (perhaps a result of land clearance in the mid 1800's).

Table 5 Sedimentation rates using unsupported Pb profiles.

Compressed Depth (cm)	Uncom-pressed Depth (mm)	Unsupported ^{210}Pb	Years Before Present (date)	Period (years)	Period Length (years)	Sediment Depth Deposited in Period (mm)	Sedimentation Rate in Period (mm/year)
8-10	113	31.7	11 (1996)	1996-2007	11	112.6	10.7
16-18	203	12.7	40 (1967)	1967-1996	29	90.08	3.1
28-30	338	0.8	129 (1878)	1878-1967	89	135.12	1.5

SEDIMENTATION PLATE DEPLOYMENT


Figure 25 Sledding materials to sites - New River Estuary


Figure 26 Measuring sediment height - New River Estuary

The locations of the 12 sedimentation plates buried in soft muddy sediments in Waikawa Estuary are shown in Figure 3, while the distance (mm) from the sediment surface to the buried plate, and the height of the two marker stakes either side of each plate above the sediment surface is shown in Table 6. Following establishment of this baseline, ongoing monitoring results can be used to determine the sedimentation rate in the estuary, with a sediment condition rating developed and used to assess any changes.

Table 6 Location and depth of plates below surface, and height of two marker pegs above surface.

Site	No.	DATE	NZMG EAST	NZMG NORTH	Height of Nth Stake (mm)	Height of Sth Stake (mm)	Plate Depth (mm)
Upper Sth	1	2/3/07	2213599	5392276	190	190	212
Upper Sth	2	2/3/07	2213604	5392304	190	190	223
Upper Sth	3	2/3/07	2213643	5392302	190	190	215
Upper Sth	4	2/3/07	2213632	5392270	190	190	230
Upper Nth	5	2/3/07	2213876	5392947	190	190	253
Upper Nth	6	2/3/07	2213872	5392914	190	190	210
Upper Nth	7	2/3/07	2213841	5392915	190	190	270
Upper Nth	8	2/3/07	2213839	5392947	185	190	257
Lower Sth	9	4/3/07	2214340	5391474	185	190	258
Lower Sth	10	4/3/07	2214367	5391470	190	190	225
Lower Sth	11	4/3/07	2214366	5391440	190	190	250
Lower Sth	12	4/3/07	2214339	5391440	190	190	255

5. ESTUARY VULNERABILITY ASSESSMENT

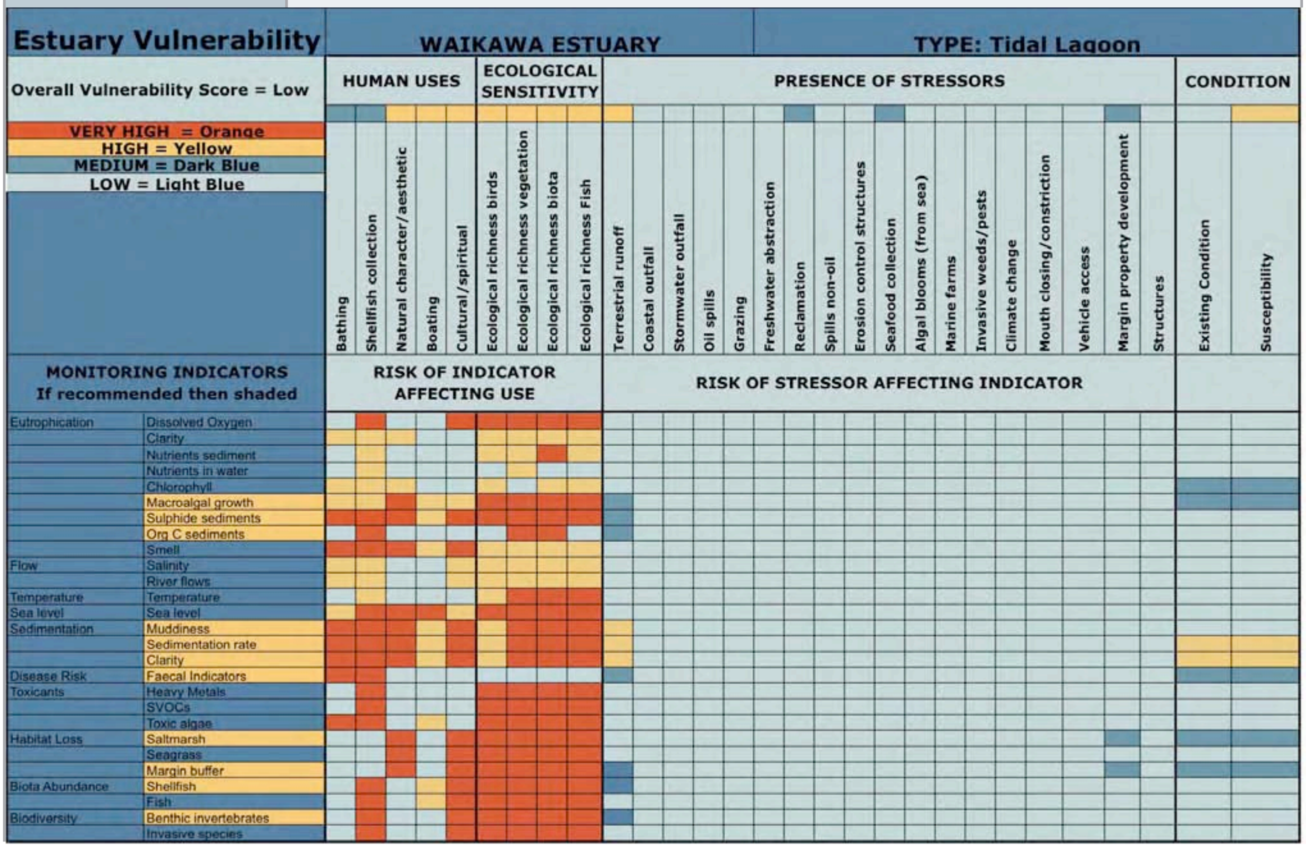
In addition to the fine scale monitoring described in the previous sections, an "Estuary Vulnerability Matrix" has also been undertaken for Waikawa. The matrix, based on that described in UNESCO (2000), is essentially a framework that has been used to bring together existing knowledge on the estuary so that the major susceptibilities and risks can be identified, and from this any specific environmental information requirements needed for management determined.

This matrix consists of a series of steps to identify:

- Estuary uses and values.
- Ecological sensitivities.
- The stressors (likely causes of estuary issues e.g. sediment runoff, stormwater, invasive pests).
- The risks of each stressor affecting some aspect of the estuaries overall condition (e.g. muddiness, algal blooms, disease risk).
- The existing condition and future susceptibility of the estuary.
- What indicators should be monitored.

This provides a robust way of ensuring that current monitoring effort is targeted effectively, and to ensure that the key issues likely to impact on an estuary are identified so that they can be managed appropriately. It is expected that this vulnerability assessment need only be repeated if the presence of stressors alters significantly. The matrix is presented below and findings described on the following page.

Example of the Estuary Vulnerability Matrix for Waikawa Estuary



5. ESTUARY VULNERABILITY ASSESSMENT (CONTINUED)

In overview, the vulnerability assessment for the Waikawa Estuary indicates that physically it:

- Is shallow and well-flushed (residence time less than three days).
- Has extensive areas of tidal flats which are primarily sandy in the lower estuary and muddy in the upper estuary.
- Has a relatively simple shape, lacking large sheltered tidal arms where muddy sediments tend to settle and accumulate.

In terms of uses and values, it:

- Has strong spiritual and cultural affinities.
- Is well-used for fishing, boating, swimming and walking.
- Provides a natural focal point for the people who live nearby or visit its shores.

The estuary has been modified over the years, particularly the margins where saltmarsh areas have been reclaimed. There is also a small area near the wharf where the inlet is lined with rockwalls.

The available information for the estuary indicates that it has a naturally low susceptibility to sedimentation and nutrient enrichment effects based on dilution and flushing rates (i.e. in terms of its physical characteristics, it is not prone to sedimentation and enrichment effects). In addition, Waikawa Estuary has a primarily moderate-hard rock type (sandstone/siltstone conglomerate) catchment, dominated by grassland and bush. As a consequence, it is expected to provide only low-moderate loads of sediment, nutrients, pathogens and potentially toxic contaminants to the estuary.

Nevertheless, some activities in the catchment have the potential to increase loads to excessive levels, e.g. drainage works, forest clearance and intensification of agricultural landuse. If inputs are high enough, then adverse effects would be expected.

This situation of low susceptibility and low-moderate inputs of nuisance materials, has resulted in an estuary with condition ratings that also fall into the low or moderate range (except for recent sedimentation rates) as follows:

WAIKAWA ESTUARY	Sedimentation	Eutrophication	Disease Risk	Contaminants	Habitat Loss	Invaders	Shellfish Issues
Existing Condition Rating	Moderate	Low	Low	Low	Moderate	Low	Low
Susceptibility Rating	Moderate	Low	Low	Low	Moderate	Low	Low

Based on this, monitoring and management effort should focus primarily on sedimentation and habitat loss issues, both of which are being addressed by the current monitoring programme.

6. SUMMARY

The condition ratings for individual indicators monitored for the Waikawa Estuary sediments in 2007 are summarised in Table 7 and below. Indicators are grouped within the three major estuary issues being monitored under this programme; toxins, eutrophication, and sedimentation. An overall issue rating for these major issues is given based on the monitoring results.

Table 7 Summary of monitoring indicators and condition ratings for Waikawa Estuary, March 2007.

Major Estuary Issue	Indicator	Condition Rating	Overall Issue Rating
Toxins	Cadmium	Very Good	Very Good
	Chromium	Very Good	
	Copper	Very Good	
	Nickel	Very Good/Good	
	Lead	Very Good	
	Zinc	Very Good	
	Macrofauna	*Not yet developed*	
Eutrophication	Total Nitrogen	Very Good	Very Good/Good
	Total Phosphorus	Low-Mod Enrichment	
	Total Organic Carbon	Very Good	
	Macroalgae	Good	
	Macrofauna	*Not yet developed*	
Sedimentation	Sedimentation rate	High	High
	Grain Size	*Not yet developed*	

Toxins:
The extent of contamination with toxic substances was rated "very good" reflecting the low levels of heavy metals in the intertidal sediments.

Eutrophication:
The extent of enrichment with organic matter and nutrients, and therefore the potential for eutrophication, was "very good/good" as indicated by the low or low-moderate levels of TOC, TP and TN in intertidal sediments, and the generally sparse cover (mostly in the 1-10% range) of macroalgal species. The TN:TP ratio in the intertidal sediments indicated nitrogen as the nutrient most likely to be limiting eutrophication in the Waikawa Estuary.

Sedimentation:
The historical sediment core analysis indicated that recent sedimentation rates are in the high rating category for NZ estuaries, while lower rates were evident further back in time (low for both 1878-1967 and 1967-1996).

7. RECOMMENDATIONS

Waikawa Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's existing estuary monitoring programme being undertaken in a staged manner throughout Southland. Based on existing monitoring results and improvements made to the EMP to produce better outputs for ES to manage key issues facing their estuaries, it is recommended that monitoring continue as outlined below.

Fine Scale Monitoring	Complete the final year of the scheduled four year baseline monitoring in Waikawa in January-March 2008. After this, reduce monitoring to five yearly intervals or as deemed necessary based on the condition ratings.
Broad Scale Macroalgal Mapping	Map macroalgal cover in January-March 2008 while doing the fine scale monitoring. After this, reduce monitoring to five yearly intervals or as deemed necessary based on the condition ratings.
Broad Scale Sedimentation Rate Mapping	Measure sediment plate depths in January-March 2008 while doing the fine scale monitoring. Monitor annually thereafter.
Broad Scale Habitat Mapping	In 2009, repeat first broad scale survey since baseline established in 2005.

In addition to the above, the results of the historical sediment core analysis indicate that recent sedimentation rates are in the high category for NZ estuaries. Consequently it is recommended that further investigation be undertaken to explore the likely cause (e.g. was it a huge input during a large flood?) and to look at sediment management options for the estuary.

The estuary vulnerability assessment undertaken to identify any major ecological issues in the Waikawa Estuary found ecological vulnerability for the majority of estuary habitats was rated in the low or low-moderate class. However, two key issues were identified as follows:

- **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. Additionally, there have been significant areas of saltmarsh drained for pastoral use in the past and this has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary.

It is recommended that options to prevent further loss of such habitat, or restoration of habitat (e.g. planting initiatives through landcare programmes) be considered.

Acknowledgements

This survey and report has been undertaken with help from various people, local farmers who provided access to the estuary, and staff of Environment Southland. In particular, the support and feedback of Chris Arbuckle, Jane Kitson, and Greg Larkin, as well as Kirsten Meijer and Les McGraw, was much appreciated and significantly improved this report.

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

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

APPENDIX 2. LEAD DATING OF HISTORICAL CORES

Lead Dating (detailed methods in Appleby and Oldfield 1992)

^{210}Pb is used to determine sedimentation rates over the last 100-150 years (from present until the start of the Industrial time) as the ^{210}Pb radionuclide has a relatively short half life of about 22 years. The "total ^{210}Pb" content of estuary sediments is derived from two sources;

- from within the sediments, and
- from the atmosphere.

Both sources begin within the earth's crust where the decay of ^{226}Ra (half-life 1622 years) occurs. Within the estuary sediments this decays to ^{222}Rn (half-life 3.83 days), which then decays to ^{210}Pb (called the "supported ^{210}Pb" content). Within the atmosphere, the decay products are the same and the resulting ^{210}Pb quickly precipitates out of the atmosphere and is deposited at the estuary surface (called the "unsupported ^{210}Pb" content). The total ^{210}Pb content is the sum of the two and is what is measured when the sediments are analysed. However, to "date" the sediments, the concentration profile of the ^{210}Pb from the atmosphere (i.e. the unsupported lead) is used. Assuming a constant supply rate from the atmosphere (and constant initial concentration), and the rate of decay of ^{210}Pb, it is relatively straightforward to then date a sediment layer based on the difference in concentration of unsupported ^{210}Pb between the surface and the chosen layer.

If a rate of sedimentation is constant, the decay process results in an exponential decrease in ^{210}Pb activity with depth that can be used to estimate sedimentation rates and therefore sediment age back about 100–150 years. The activity of ^{210}Pb samples where the curve becomes asymptotic with respect to ^{210}Pb activity is assumed to be the supported ^{210}Pb level; that is, the amount of ^{210}Pb produced from the decay of ^{222}Rn within the sediment column and not deposited from the atmosphere. Alternatively, one can use the ^{226}Ra activity to equal the supported ^{210}Pb activity as, in the absence of atmospheric ^{210}Pb fallout, ^{210}Pb will be in radioactive equilibrium with ^{226}Ra in the sediment. These supported ^{210}Pb values are subtracted from the total ^{210}Pb values obtained in the analysis, resulting in an unsupported ^{210}Pb profile (from atmospheric deposition).

The age in years since the sediment layer at depth x was deposited (t) can then be calculated by using the relationship:

$$\mathbf{t = 1/k.logN(C_o/C_x)}$$

where:
C_o = the unsupported activity of ^{210}Pb in the modern surface sediments,
C_x = the unsupported activity of ^{210}Pb at (uncompressed) depth x, and
k = the ^{210}Pb decay constant (0.03114 yr^{-1}).

APPENDIX 3. 2007 DETAILED RESULTS

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	2214588	2214575	2214562	2214548	2214545	2214554	2214567	2214585	2214589	2214579
NZMG260 North	5391469	5391467	5391469	5391472	5391461	5391460	5391458	5391458	5391449	5391448

Waikawa B	WkB-01	WkB-02	WkB-03	WkB-04	WkB-05	WkB-06	WkB-07	WkB-08	WkB-09	WkB-10
NZMG260 East	2214930	2214941	2214961	2214977	2214971	2214956	2214941	2214925	2214926	2214935
NZMG260 North	5390793	5390795	5390800	5390805	5390811	5390808	5390801	5390804	5390811	5390818

Physical and Chemical Results

Estuary	Site	Repl.	RPD	Salinity	AFDW	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
			cm	ppt@15⁰C	%				mg/kg							
Waikawa	A	01	>20	20.8	1.3	10.2	89	0.9	0.01	7.4	2.9	4.6	1.67	14.3	500	287
Waikawa	A	02	>20	20.8	1.68	11.9	86.7	1.4	0.02	8.6	3.5	5.7	1.94	16.2	500	309
Waikawa	A	03	>20	20.8	1.2	8.3	90.2	1.5	0.01	7.8	3	4.7	1.73	15	500	297
Waikawa	B	01	>20	20.8	1.16	3.5	96.5	0.01	0.02	7	2.7	4.4	1.53	11.8	500	236
Waikawa	B	02	>20	20.8	0.99	3.5	96.5	0.1	0.01	7.3	2.7	4.5	1.61	12	500	237
Waikawa	B	03	>20	20.8	1.21	2.3	97.5	0.2	0.01	5.8	2.5	3.9	1.33	10.5	500	215

Epifauna (numbers per 0.25m² quadrat) and Macroalgae (percent cover 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
Cominella glandiformis Mudflat whelk	2	0	1	0	1	0	0	1	0	0
Diloma subrostrata Mudflat topshell	9	4	4	2	0	3	3	2	0	2
Notoacmea helmsi Estuarine limpet	1	0	0	0	0	0	0	0	0	0
Austrovenus stutchburyi Cockle	2	1	0	3	0	0	0	0	0	0
Anthopleura aureoradiata Mudflat anemone	0	0	0	0	0	0	0	0	2	0
Gracilaria (% cover)	5	5	5	5	5	1	1	0	1	1

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
Cominella glandiformis Mudflat whelk	1	0	0	0	0	0	0	0	0	0
Diloma subrostrata Mudflat topshell	8	11	3	5	2	2	5	3	5	1
Notoacmea helmsi Estuarine limpet	1	0	0	0	0	0	0	0	0	0
Austrovenus stutchburyi Cockle	0	0	0	0	0	0	0	1	0	0
Elminius modestus Estuarine barnacle	0	0	0	1	0	0	0	1	0	0
Ulva Sea lettuce (% cover)	0	0	0	0	0	0	1	0	0	0

APPENDIX 3. 2007 DETAILED RESULTS (CONTINUED)

Group	Species	WK A-01	WK A-02	WK A-03	WK A-04	WK A-05	WK A-06	WK A-07	WK A-08	WK A-09	WK A-10
ANTHOZOA	Anthopleura aureoradiata	3	3	6	3	0	4	6	2	3	5
	Edwardsia sp.#1	0	1	1	0	1	0	2	0	0	3
NEMERTEA	Nemertea sp.#1	0	0	1	0	0	0	0	1	0	0
	Nemertea sp.#2	0	0	0	0	0	0	0	0	0	0
NEMATODA	Nematoda	0	0	0	1	0	0	0	3	0	0
POLYCHAETA	Aglaophamus sp.#1	0	1	1	1	0	0	1	1	1	1
	Aonides sp.#1	0	0	0	0	0	0	0	0	0	1
	Boccardia (Paraboccardia) acus	4	1	1	1	1	3	0	0	1	0
	Boccardia (Paraboccardia) syrtis	4	6	5	4	4	4	7	5	1	2
	Capitella capitata	2	0	0	0	0	0	0	0	0	0
	Cirratulidae sp.#1	0	0	0	0	0	0	0	0	0	0
	Glycera lamellipodia	0	0	0	0	0	0	1	0	0	0
	Goniadidae sp.#1	0	1	1	0	0	0	0	2	0	0
	Hemipodus simplex	2	0	1	1	0	0	0	0	0	0
	Heteromastus filiformis	1	4	3	0	0	6	4	2	4	1
	Macroclymenella stewartensis	26	13	11	13	14	24	13	8	16	10
	Nicon aestuariensis	0	0	0	0	0	1	0	0	0	0
	Orbinia papillosa	0	0	0	0	0	0	0	0	0	0
	Paraonidae sp.#1	18	10	17	27	23	26	14	17	24	9
	Paraonidae sp.#2	0	0	0	0	0	0	0	0	0	0
	Perinereis vallata	0	0	0	2	0	0	0	0	0	0
	Phyllodocidae sp.#1	1	0	1	0	0	0	0	0	0	0
	Prionospio aucklandica	4	4	1	3	2	2	9	2	4	4
	Scolecolepides benhami	1	1	0	0	0	0	0	0	0	0
	Sphaerosyllis sp.#1	15	22	20	13	37	31	33	26	33	9
	Syllidae sp.#1	0	0	0	0	0	0	0	0	0	0
	Travisia olens	0	0	0	0	0	0	0	0	0	0
OLIGOCHAETA	Oligochaeta sp.#1	4	2	1	0	5	2	2	0	0	0
GASTROPODA	Cominella glandiformis	0	0	2	0	0	0	2	0	0	0
	Diloma subrostrata	0	0	0	0	0	1	1	1	1	0
	Notoacmaea helmsi	1	0	1	0	0	1	2	0	0	0
BIVALVIA	Arthritica sp.#1	1	1	3	2	2	4	4	1	2	0
	Austrovenus stutchburyi	7	3	9	3	3	12	7	6	7	5
	Macomona liliana	3	3	1	2	3	0	3	2	2	1
	Nucula sp.#1	3	6	3	9	6	12	11	8	12	7
	Paphies australis	0	0	0	0	0	0	0	0	1	0
	Soletellina sp.#1	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Amphipoda sp.#1	5	3	5	12	2	11	1	10	5	0
	Austrominius modestus	0	0	0	0	0	0	0	0	0	0
	Colurostylis lemurum	7	3	3	4	1	10	2	3	5	0
	Halicarcinus whitei	0	1	0	1	0	0	0	0	0	0
	Isocladus sp.#1	2	0	1	0	0	1	2	1	0	1
	Mysidacea sp.#1	0	2	0	0	0	0	1	0	0	0
	Phoxocephalidae sp.#1	1	0	0	0	0	2	0	0	0	0
	Pontophilus australis	0	0	0	0	0	0	0	0	0	1
	Tanaidacea sp.#1	1	3	1	5	1	7	4	3	1	3
OSTEICHTHYES	Peltorhamphus sp.#1	0	0	1	0	0	0	0	0	0	0
Total species in sample		47	47	47	47	47	47	47	47	47	47
Total individuals in sample		116	94	101	107	105	164	132	104	123	63

APPENDIX 3. 2007 RESULTS (CONTINUED)

Group	Species	WK B-01	WK B-02	WK B-03	WK B-04	WK B-05	WK B-06	WK B-07	WK B-08	WK B-09	WK B-10
ANTHOZOA	Anthopleura aureoradiata	8	1	1	2	1	5	3	1	3	3
	Edwardsia sp.#1	0	0	0	1	2	1	2	1	2	0
NEMERTEA	Nemertea sp.#1	0	0	0	0	0	0	0	0	0	0
	Nemertea sp.#2	0	0	0	1	0	0	0	0	1	0
NEMATODA	Nematoda	0	0	0	0	0	0	0	0	0	0
POLYCHAETA	Aglaophamus sp.#1	1	0	1	0	1	0	1	0	0	1
	Aonides sp.#1	8	8	5	3	1	6	3	3	2	5
	Boccardia (Paraboccardia) acus	0	0	0	0	0	0	0	0	0	0
	Boccardia (Paraboccardia) syrtis	1	1	0	5	2	1	4	10	1	9
	Capitella capitata	0	0	0	0	0	0	0	0	0	0
	Cirratulidae sp.#1	11	7	2	8	0	8	9	6	2	4
	Glycera lamellipodia	1	0	0	0	0	0	0	0	0	0
	Goniadidae sp.#1	0	0	0	0	0	0	0	0	0	0
	Hemipodus simplex	0	2	0	1	0	1	2	1	2	1
	Heteromastus filiformis	2	4	0	1	0	0	1	2	2	1
	Macroclymenella stewartensis	1	1	3	3	2	2	2	1	3	2
	Nicon aestuariensis	0	0	0	0	0	1	0	0	0	0
	Orbinia papillosa	0	2	1	1	1	1	2	1	2	1
	Paraonidae sp.#1	1	0	2	0	0	0	0	3	0	1
	Paraonidae sp.#2	0	0	0	0	0	0	1	0	0	0
	Perinereis vallata	0	0	0	0	0	0	0	0	0	0
	Phyllodocidae sp.#1	0	0	0	0	0	0	0	0	0	1
	Prionospio aucklandica	1	0	1	1	0	0	0	1	2	2
	Scolecolepides benhami	0	0	0	0	1	0	0	2	0	0
	Sphaerosyllis sp.#1	0	0	0	1	0	0	0	2	0	0
	Syllidae sp.#1	3	0	0	1	1	1	2	0	1	0
	Travisia olens	0	3	1	0	4	3	3	1	0	1
OLIGOCHAETA	Oligochaeta sp.#1	0	0	0	0	0	0	0	0	0	0
GASTROPODA	Cominella glandiformis	0	0	0	0	0	0	0	0	0	0
	Diloma subrostrata	0	0	0	0	0	0	0	0	0	0
	Notoacmaea helmsi	0	0	0	0	0	1	0	0	2	0
BIVALVIA	Arthritica sp.#1	0	0	0	0	0	0	0	1	0	0
	Austrovenus stutchburyi	8	5	6	3	3	7	8	2	3	3
	Macomona liliana	1	2	0	0	1	2	1	0	0	0
	Nucula sp.#1	0	0	0	0	0	0	0	0	0	0
	Paphies australis	3	2	0	0	1	0	0	0	0	0
	Soletellina sp.#1	1	1	1	0	0	1	0	0	0	3
CRUSTACEA	Amphipoda sp.#1	0	1	0	0	2	1	4	1	2	2
	Austrominius modestus	13	2	15	8	1	10	1	10	10	2
	Colurostylis lemurum	19	6	13	10	4	10	14	5	8	8
	Halicarcinus whitei	0	0	0	0	0	0	0	0	0	0
	Isocladus sp.#1	0	1	0	0	0	0	0	0	0	1
	Mysidacea sp.#1	0	0	0	0	0	0	0	0	0	0
	Phoxocephalidae sp.#1	0	0	0	0	0	0	0	1	0	0
	Pontophilus australis	0	0	0	0	0	0	0	0	0	0
	Tanaidacea sp.#1	0	0	0	0	0	0	0	0	0	0
OSTEICHTHYES	Peltorhamphus sp.#1	0	0	0	0	0	0	0	0	0	0
Total species in sample		47	47	47	47	47	47	47	47	47	47
Total individuals in sample		83	49	52	50	28	62	63	55	48	51