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Motupipi Estuary 2008

Fine Scale Monitoring

Prepared for Tasman District Council
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Cover Photo: Motupipi Estuary

Motupipi Estuary 2008

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Prepared for
Tasman District Council

By

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All photos by Wriggle except where noted otherwise.

MOTUPIPI ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the 2008 fine scale monitoring for Motupipi Estuary, a 100ha tidal lagoon estuary on the Golden Bay coast and one of the key estuaries in Tasman District Council's long-term estuary monitoring programme. This programme uses sediment health as a primary indicator of estuary condition. The report describes the following work:

- Fine scale monitoring of sediment grain size and chemistry.
- Fine scale monitoring of sediment dwelling plants and animals.
- Establishment of sediment rate monitoring plates.

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, 2007a).

The following table summarises monitoring results for the Motupipi Estuary:

Indicator	Rating	Result
RPD Depth (Sediment oxygenation)	**Fair (East Arm)** **Very Good (West Arm)**	The Redox Potential Discontinuity (RPD) layer was moderately shallow (3cm depth) in the western arm giving it a moderate degree of sediment oxygenation. In the eastern arm it was much deeper (>10cm deep) and therefore sediments were likely to be well oxygenated. Such RPD values fit the "fair" to "very good" condition rating and indicate that the benthic invertebrate community is likely to be in a "transitional" to "normal" state. This was confirmed by macrofauna sampling at each site (see below).
Macrofauna (Infauna and epifauna)	**Unbalanced - slightly polluted**	The benthic community condition was "unbalanced", giving it a "slightly polluted" classification. These conditions resulted in a community dominated by organisms that prefer low-moderate mud and organic enrichment levels, primarily small surface and subsurface deposit-feeders and suspension feeders.
Organic Matter (TOC)	**Good**	The indicator of organic enrichment (TOC) at both sites was at low concentrations. This reflects the well-flushed nature of the estuary and a likely low-moderate load of organic matter (sourced from phytoplankton and macroalgae) depositing on the sediments.
Nutrients (Total Nitrogen and Phosphorus)	**Moderate Enrichment**	Total phosphorus (a key nutrient in the eutrophication process) was elevated to the "enriched" category at both sites. This means that the Motupipi Estuary sediments have a large store of P (derived from both recent and historical catchment inputs), that could potentially fertilize nuisance algal growth. Total nitrogen was at "low-moderate enrichment" levels at both sites.
Sediment (Grain Size, Rate of Sedimentation)	**Baseline established**	The two fine scale indicators of increased muddiness in the estuary are grain size (% mud, sand, gravel), and sedimentation rate (mm of sediment deposited/yr). In regard to grain size, both sites were dominated by sandy sediments with a significant mud component (12-46% mud). A grain size condition rating has yet to be developed for the Motupipi Estuary. Sedimentation plates have been deployed in estuary to enable long term monitoring of sedimentation rates. The rate of sedimentation has yet to be determined.
Metals (Cd, Cr, Cu, Ni, Pb, Zn)	**Good-Very Good**	Heavy metals (copper, cadmium, chomium, lead, nickel and zinc), 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, except for nickel and chromium which are known to be naturally high throughout the Nelson region.

EXECUTIVE SUMMARY (CONTINUED)

Overall, the results showed that the dominant intertidal habitat (i.e. unvegetated tidal-flat) in the Motupipi Estuary was generally in good to fair condition. However, of concern were the elevated nutrient and mud contents, and low sediment oxygenation in the western arm which creates moderately stressful conditions for biota and, as a consequence, the benthic community condition was "unbalanced", giving it a "slightly polluted" classification.

The cause of the unbalanced benthic community was likely attributable to the following:

- Excessive inputs of fine sediment causing elevated sediment mud contents,
- Excessive nutrient inputs causing elevated macrophyte and microalgal growth in the estuary, and whose decay leads to sediment deoxygenation.

The shallow nature of the RPD and muddy sediments indicate a need for caution and the potential need for better managing fine sediment discharges in the catchment. If nutrient enrichment continues (particularly in combination with an increased mud content), sediment anoxia could get worse and result in sediment nutrients becoming much more available for nuisance algal growth. Under such conditions, a return to oxygenated sediment conditions is difficult to achieve - even if catchment nutrient loads are reduced.

MONITORING

Based on the 2008 monitoring results and condition ratings, it is recommended that monitoring continue as outlined below:

- **Fine Scale Monitoring**. Complete the four years of the annual scheduled baseline monitoring in Motupipi Estuary to Jan-Feb 2011. After the four year baseline is completed, reduce monitoring to five yearly intervals or as deemed necessary based on the condition ratings.
- **Sedimentation Rate Monitoring**. Measure the depths of the existing 8 sediment plates in January-March 2009 while doing the fine scale monitoring. At the same time, it is recommended that four new plates should be deployed in the area of very soft and anoxic muds adjacent to the old Rototai landfill. Following the 2009 monitoring, it is recommended that the depth of all plates be measured annually thereafter.

MANAGEMENT

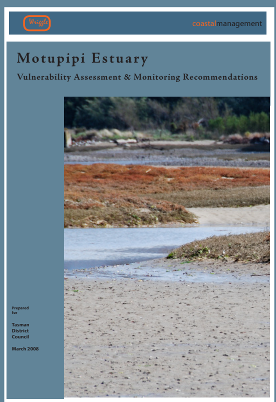
The fine scale monitoring reinforced the need for management of nutrient and fine sediment sources entering the estuary. It is recommended that options be considered for the following (as identified in the estuary vulnerability assessment - Robertson and Stevens 2008):

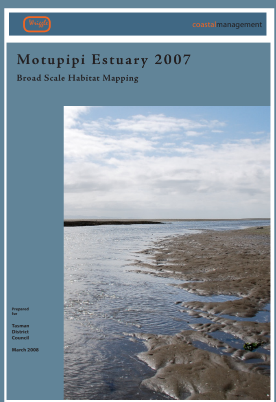
Identify and Implement Catchment BMPs
Catchment runoff was identified as one of the major stressors in Motupipi Estuary. To prevent avoidable inputs, best management practices (BMP's) should be identified and implemented to reduce the runoff of sediment and nutrients from catchment "hotspots". TDC and Landcare Research, with Foundation for Research Science and Technology Envirolink funding, are currently working with farmers in the catchment to identify catchment nutrient sources and "hotspots", and to implement BMPs for reducing nutrient mobilisation and runoff to surface and groundwater.

Set Limits on Nutrient Inputs
Because nutrient input was both high and strongly related to the eutrophication symptoms, it is recommended that catchment nutrient inputs be reduced. Currently the nitrogen input (as estuary areal load) is likely to be in the range of 60-100 $mg.m^{-2}.d^{-1}$ which is elevated when compared with the 50 $mg.m^{-2}.d^{-1}$ upper limit suggested by Heggie (2006) for ensuring no eutrophication of temperate Australian estuaries. A Total Daily Maximum Load to the estuary of about 50 kgN/day (as opposed to the current input of 60-100 kg/day) is suggested as a preliminary guideline.

1. INTRODUCTION

OVERVIEW





Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. As part of the Tasman District Council (TDC) long-term estuary monitoring programme, Wriggle Coastal Management was contracted to undertake monitoring of the Motupipi Estuary, which has been given special significance in the TDC Transitional Regional Management Plan. The approach follows the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions (Table 1) and consists of three components:

1. **Ecological Vulnerability Assessment** of the estuary to major issues and appropriate monitoring design. This component has been completed for Motupipi Estuary and is reported on in Robertson and Stevens (2008).

2. **Broad scale habitat mapping,** including historical comparisons (EMP approach). This component, which documents the key habitats within each estuary and changes to these habitats over time, has been completed for the Motupipi Estuary (Stevens and Robertson 2008).

3. **Fine scale physical, chemical and biological monitoring**, (EMP approach) including sedimentation plate deployment. This component, which provides detailed information on the condition of the Motupipi Estuary, is the subject of the current report.

Motupipi Estuary is a small to medium-sized (100 ha), shallow (1m mean depth), well flushed estuary consisting of two arms, the eastern arm (60 ha) and the western arm (38 ha). The western arm receives the main river input from the Motupipi River, and consequently is the most affected by freshwater influences. Catchment runoff of nutrients, sediment and pathogens is elevated (Robertson and Stevens 2008). The estuary is highly valued and has a variety of habitat types including saltmarsh vegetation, seagrass beds, mud and sand intertidal flats, shellfish beds, water column, subtidal sand/mud and kelp beds. There are indications of moderate macroalgal and phytoplankton blooms.

The current report documents the following:

- The results of the fine scale monitoring of Motupipi Estuary intertidal sites undertaken in January 2008.

- The establishment of sediment plates in Motupipi Estuary.

- Condition ratings for Motupipi Estuary based on the 2008 fine scale results. A suggested monitoring or management response is linked to each condition rating.

This report is the first of a series of four, which will characterise the baseline fine scale conditions in the estuary over a 4 year period. The results will 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).

1. Introduction (continued)

Table 1. Extensions to the EMP (developed by Wriggle Coastal Management)

Extensions to Estuary Monitoring Protocol
Development of an Estuary Vulnerability Matrix.
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.
Establishment of condition ratings for key indicators.
Provision of georeferenced digital photos (as a GIS layer).
Development of an Upper Estuary Monitoring and Assessment Protocol.

Table 2. 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	Eutrophication is an increase in the rate of supply of organic matter to an ecosystem. 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 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 discontinuity profile (RPD) in sediment estimates likely presence of deoxygenated, reducing conditions.
Toxins	Contamination in Bottom Sediments	Chemical analysis of indicator metals (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)

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 Summary.
Section 5 Monitoring recommendations.
Section 6 Management recommendations.
Section 7 References.

Appendix 1: Details of analytical methods.
Appendix 2: Detailed fine scale monitoring results - Motupipi Estuary 2008.

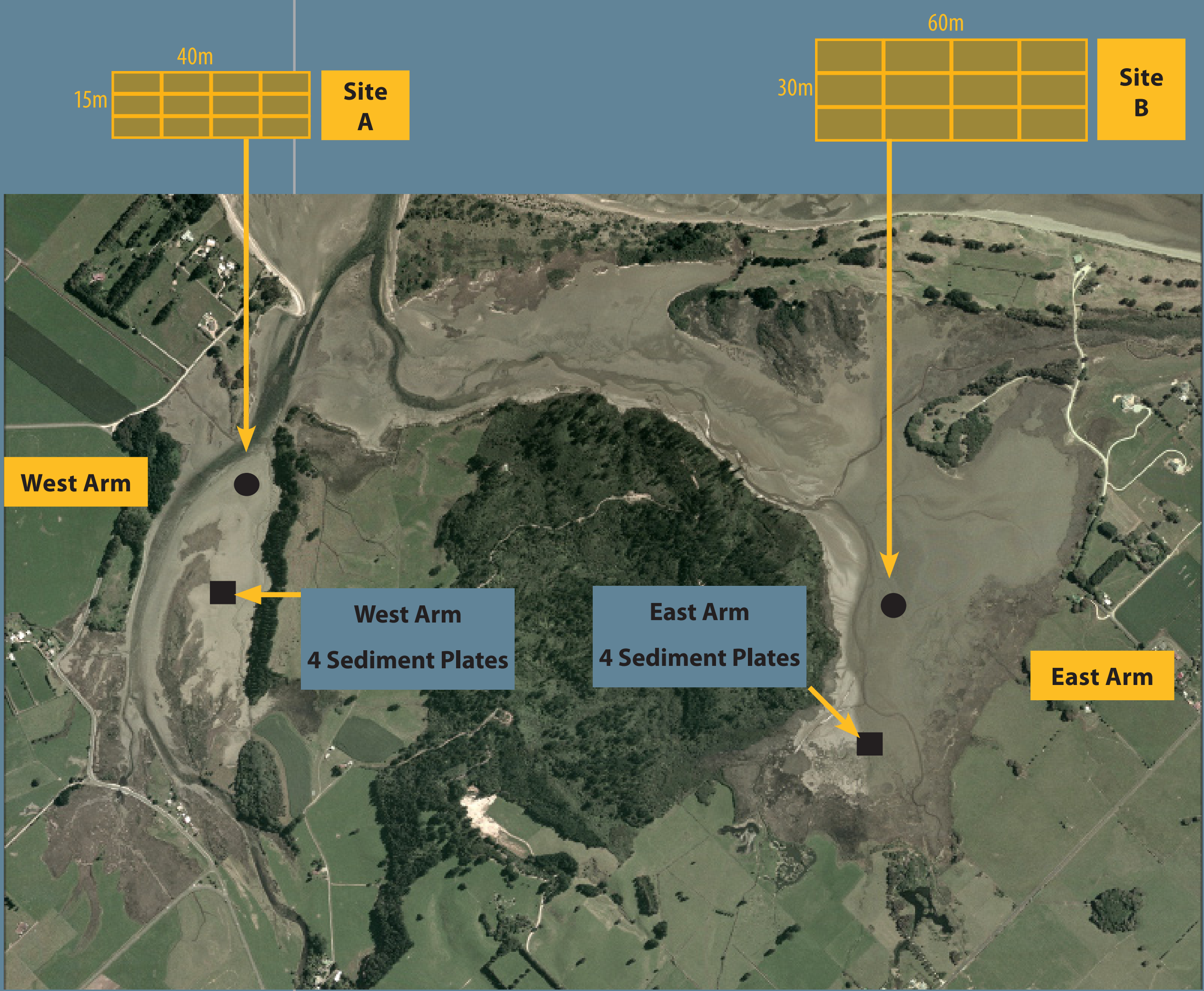


Figure 1. Location of sedimentation and fine scale monitoring sites in Motupipi Estuary.

2. METHODS

FINE SCALE MONITORING

Quadrat for epifauna sampling.

Sampling RPD layer.

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, Oxygenation (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).
- Heavy metals: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni) and Zinc (Zn).
- Macroinvertebrate abundance and diversity (infauna and epifauna)

For the Motupipi Estuary, two fine scale sampling sites (Figure 3) were selected in unvegetated, mid-low water mudflats (avoiding areas of significant vegetation and channels). At Site A, a 40m x 15m area in the lower intertidal was marked out and divided into 12 equal sized plots. At Site B, the area was 60m x 30m. 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.
- At each site, three samples (each a composite from 4 plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to the cores.
- All samples were kept in a chillybin in the field or stored as appropriate.
- Chilled samples were sent to R.J. Hill Laboratories for analysis (details in Appendix 1):
  - 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 or composited to allow direct comparison with ANZECC guidelines.
  - Synthetic organic contaminants (polychlorinated biphenyls and pesticides)
- Samples were tracked using standard Chain of Custody forms and results are checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- 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.

Epifauna (surface-dwelling animals):

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

2. Methods (Continued)

FINE SCALE MONITORING (CONTINUED)

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).

Sedimentation Plate Deployment:

Determining the sedimentation rate from now and into the future involves a simple method of measuring how much sediment builds up over a buried plate (concrete paver) 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.

Establishing sediment rate sites.

Two sites (East Arm and West Arm) were established in Motupipi Estuary on 25-27 September 2007 (Figure 3). The sites were located in mud/sand habitat in areas of each estuary arm where sedimentation rates are likely to be elevated. At each site, four plates (20cm square concrete block pavers) were buried (to approximately 200mm depth or where stable substrate is located) (Figure 10), approximately 30m apart in a square configuration. 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 depths will be measured annually and, over the long term, will provide a measure of the rate of sedimentation in the estuary.

CONDITION RATINGS

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 TDC interpret their monitoring data, a series of interim broad and fine scale estuary “condition ratings” (presented below) have been proposed for the Motupipi Estuary (based on the ratings developed for Southland’s estuaries - Robertson & Stevens 2006, 2007a).

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.

RATING
Very Good
Good
Fair
Poor
Early Warning Trigger

The ratings 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 good or degraded conditions, and also include an “early warning trigger” so that TDC 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.

2. Methods (Continued)

OVERVIEW

In most cases the management recommendation is simply that TDC 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 will be developed for other indicators. Note that only fine scale ratings are presented in this section. Examples of broad scale ratings are included in Stevens and Robertson 2008.

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.

RPD CONDITION RATING

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

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 Motupipi, 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

2. Methods (Continued)

Total Phosphorus

In shallow estuaries like Motupipi 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

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

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 Marine Benthic Index (AMBI) (Borja et al. 2000) has been verified successfully in relation to a very large set of environmental impact sources (Borja, 2005) and geographical areas (including both northern and southern hemisphere environments).

BENTHIC COMMUNITY CONDITION RATING			
RATING	DEFINITION	INDEX	RECOMMENDED RESPONSE
Normal	Unpolluted	0	Monitor at 5 year intervals after baseline established
Impoverished	Unpolluted	1	Monitor at 5 year intervals after baseline established
Unbalanced	Slightly polluted	2	Monitor 5 yearly. Initiate Evaluation & Response Plan
Transitional to polluted	Moderately polluted	3	Monitor 5 yearly. Initiate Evaluation & Response Plan
Polluted	Moderately polluted	4	Monitor yearly. Initiate Evaluation & Response Plan
Heavily polluted	Transitional to heavily polluted	5	Monitor yearly. Initiate Evaluation & Response Plan
Heavily polluted	Heavily polluted	6	Monitor yearly. Initiate Evaluation & Response Plan
Extremely polluted	Azoic (devoid of life)	7	Monitor yearly. Initiate Evaluation & Response Plan
Early Warning Trigger	Trend to slightly polluted		Initiate Evaluation and Response Plan

3. RESULTS AND DISCUSSION

OUTLINE

A summary of the results of the fine scale monitoring of Motupipi Estuary are presented in Tables 4 and 5 and Figures 2 to 15. Detailed results are presented in Appendix 1. In order to facilitate understanding, this results and discussion section is divided into 3 subsections based on the key estuary issues or problems that the fine scale monitoring is addressing:

- Eutrophication,
- Sedimentation, and
- Toxicity.

Within each subsection, the results for each of the relevant fine scale indicators are presented (e.g. total nitrogen is presented under the issue of eutrophication). A summary of the condition ratings for each of the two sites is presented in the accompanying figures.

Table 4. Physical and chemical results (means) for Motupipi Estuary, January 2008.

Estuary	Site	Reps.	RPD	Salinity	AFDW	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
			cm	ppt	%					mg/kg							
Motupipi	A	3	3	27	2.27	1.19	20.87	78.40	0.77	0.04	43.67	9.63	6.27	28.33	44.00	730	573
	B	3	>10	30	2.23	1.18	39.00	60.97	0.10	0.01	26.33	5.70	3.90	16.33	27.33	757	557

Table 5. Macrofauna results (means) for Motupipi Estuary, January 2008.

Estuary	Site	Reps.	Mean Total Abundance/m^2	Mean Number of Species/Core
Motupipi	A	10	3510	12.4
	B	10	1792	6.4

EUTROPHICATION

Eutrophication is the process where water bodies receive excess nutrients that stimulate excessive plant growth. In estuaries like the Motupipi Estuary, macroalgal (e.g. sea lettuce) and 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. The primary fine scale indicators are therefore grain size, RPD boundary, sediment organic matter, nitrogen and phosphorus concentrations and the community structure of certain sediment-dwelling animals. The broad scale indicators (reported in Robertson and Stevens 2007b) are the percentages of the estuary covered by macroalgae and soft muds.

2008 RPD RATING
Site A - Fair
Site B - Very Good

The Redox Potential Discontinuity (RPD)

The depth of the RPD layer is a critical estuary condition indicator in that it provides a measure of whether nutrient enrichment in the estuary exceeds the trigger leading to nuisance anoxic conditions in the surface sediments. The majority of the other indicators (e.g. macroalgal blooms, soft muds, sediment organic carbon, TP, and TN) are less critical, in that they can be elevated, but not necessarily causing sediment anoxia and adverse impacts to aquatic life. Knowing if the surface sediments are moving towards anoxia (i.e. RPD close to the surface) is important for 2 main reasons:

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

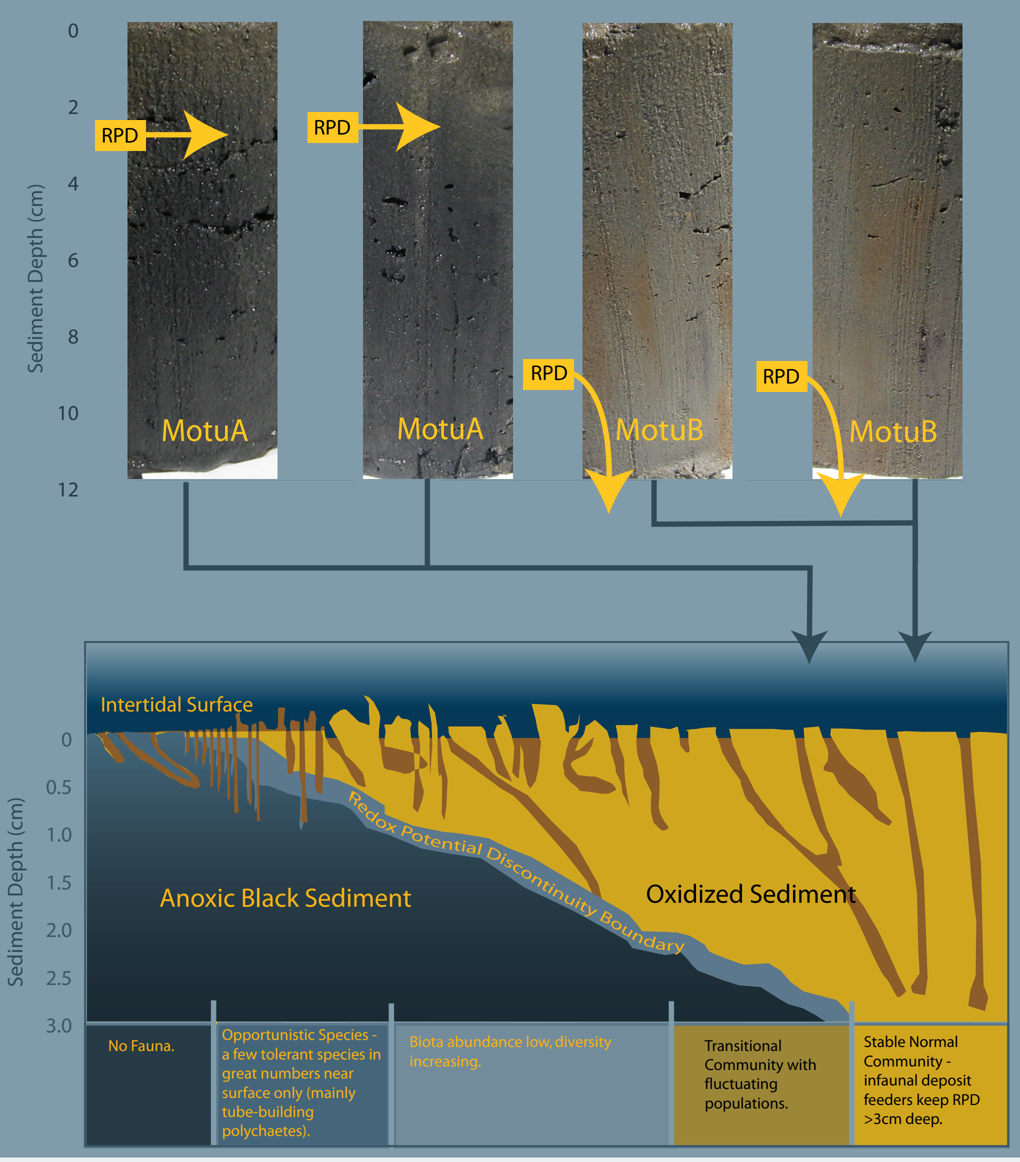
3. Results and Discussion (Continued)

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.

Figure 2 shows the sediment profiles and RPD depths for each of the two Motupipi sampling sites (also Table 4) and indicates the likely benthic community that is supported at each site based on the measured RPD depth (adapted from Pearson and Rosenberg 1978). The RPD results showed that the depth of the RPD in Motupipi Estuary was relatively shallow at Site A (3cm depth) but much deeper at Site B (5 to >10cm depth). These RPD depths indicate that the sediments are likely to be well oxygenated at Site B in the eastern arm but only moderately oxygenated at Site A in the western arm. The presence of both sand-dominated sediments and infauna feeding voids and burrows below the RPD further support such indications.

RPD values at Site B fit the "good" to "very good" condition rating and indicate that the benthic invertebrate community was likely to be in a stable "normal" state. At Site A, the rating was "fair to good" and indicated a likely "transitional" community with fluctuating populations.

Figure 2. Sediment profiles, depths of RPD and predicted benthic community type.



2008 TOC RATING
Good

Organic Matter (TOC) (Figure 3)
The indicator of organic enrichment (TOC) at both sites was at moderately low concentrations (mean 1.2 % at both sites) and met the "good" condition rating. This reflects the well-flushed nature of much of the estuary area and a likely low-moderate load of organic matter (sourced primarily from phytoplankton and macroalgae) depositing on the sediments.

Total Phosphorus (TP) (Figure 4)
Total phosphorus (a key nutrient in the eutrophication process) was elevated to the "enriched" category at both sites (mean 573 mg/kg at Site A and 557 mg/kg at Site B). This means that the Motupipi Estuary sediments have a large store of P (sourced from both recent and historical catchment inputs), that could potentially fertilize nuisance algal growth. Currently, however, this is not occurring to a large extent, primarily because the reservoir of P is tightly bound within the sediments. Estuary sediments store P generally as iron (Fe) bound P which is only released to the water column at slow rates, unless conditions turn anoxic. Because anoxia is not common in the estuary at present (i.e. limited to the main channel in the middle and upper estuary), sediment P concentrations are likely to remain high for a long time unless conditions change. Excessive macroalgal growth in the middle and lower estuary (and excessive phytoplankton growth in the upper estuary) are the main threat leading to anoxic sediments. If a shift to widespread sediment anoxia occurred (e.g. from excessive nutrient loads from the catchment), the sediment P reservoir would suddenly be released to fuel even higher levels of nuisance algal growth and cause a major detrimental impact on estuarine ecology.

2008 TP RATING
Enriched

Total Nitrogen (TN) (Figure 6)
Total nitrogen (the other key nutrient in the eutrophication process) was at "low-moderate enrichment" levels at both sites (mean 730 mg/kg at Site A and 756 mg/kg at Site B). Unlike P, N is more mobile and in a healthy estuary a large amount of the N load is converted to nitrogen gas and liberated to the atmosphere. However, when the sediments become anoxic, the efficiency of this process is lowered and causes most of the N to stay within the estuary. So like P, N is suddenly much more available for nuisance algal growth when the sediment turns anoxic. The large increase in nuisance algal growth, in turn provides elevated organic matter to the sediments (i.e. rotting algae), which further exacerbates the anoxic condition. Clearly, once the "tipping point" to anoxic conditions occurs, a return to oxygenated conditions is difficult to achieve - even if catchment nutrient loads are reduced. In order to provide an early warning of such a threat, long term broad scale monitoring of macroalgae, phytoplankton and oxidation reduction potential (ORP) are being undertaken.
Another important point, is that the nutrient data identifies N as the nutrient most likely limiting eutrophication in the Motupipi Estuary (i.e. the ratio of TN:TP in the intertidal sediments was close to 1:1). Such data confirms N as the critical nutrient to address in any management actions designed to reduce macroalgal growth in the estuary.

2008 TN RATING
Low-Mod Enrichment

Sediment Biota
The benthic invertebrate community condition (a key indicator of response to both man-made and natural stressors) in the Motupipi Estuary was "unbalanced" at both Sites A and B, indicating a "slightly polluted" classification.

Figure 3.. Total Organic Carbon

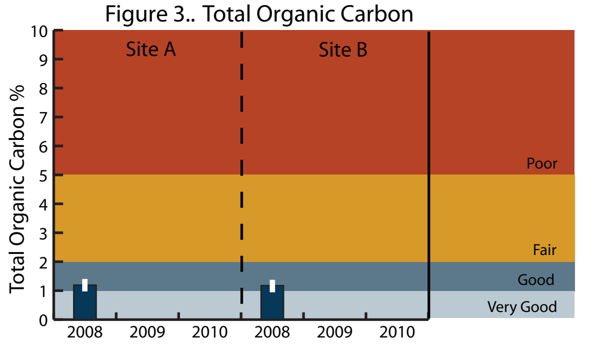


Figure 4. Total Phosphorus

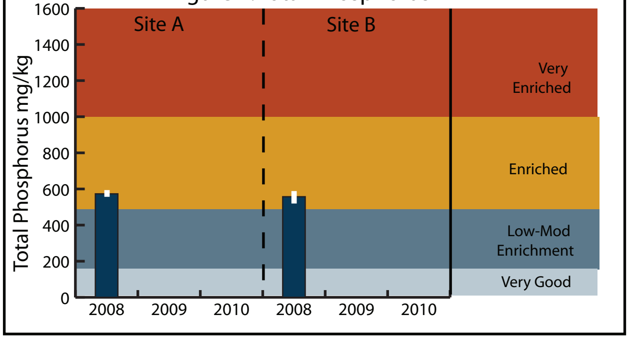


Figure 5. Grain Size

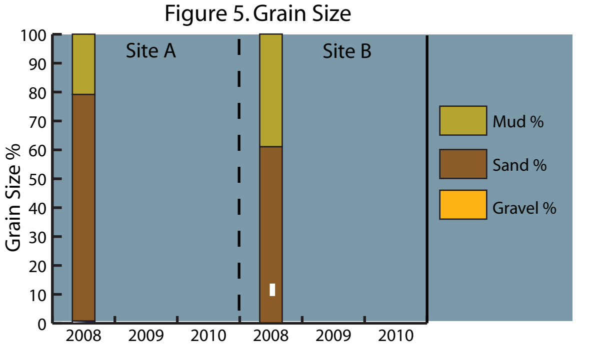


Figure 6. Total Nitrogen

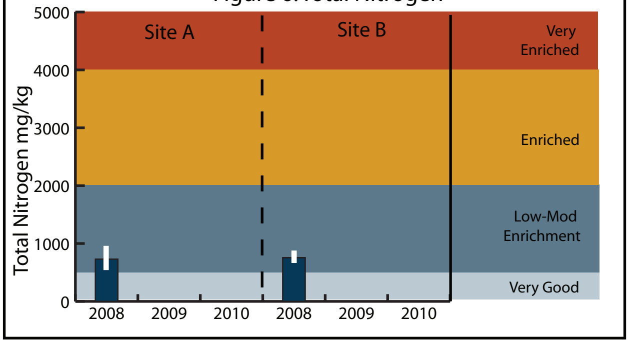


Figure 7. Cadmium

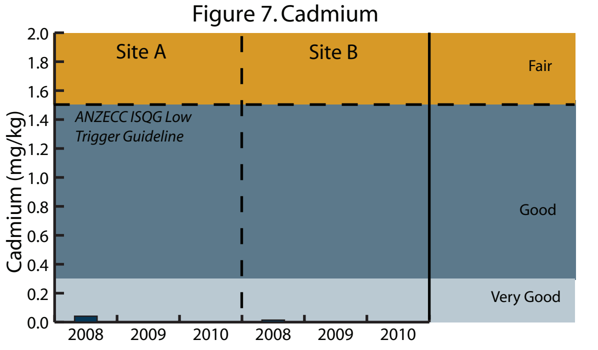


Figure 8. Chromium

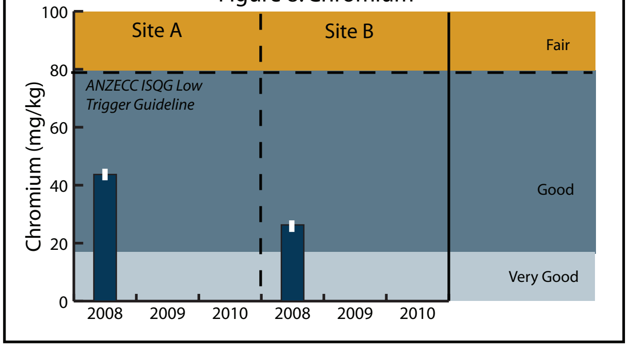


Figure 9. Copper

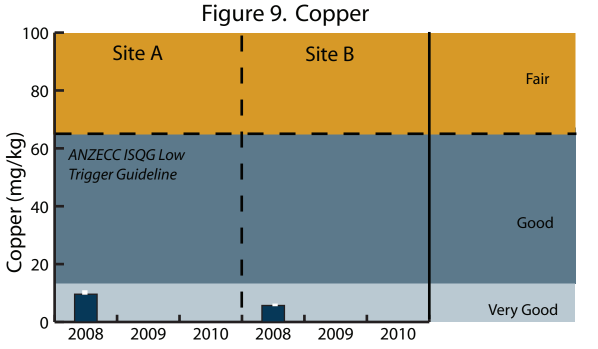


Figure 10. Lead

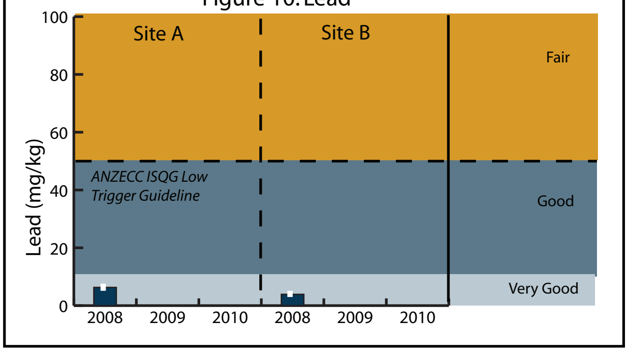


Figure 11. Nickel

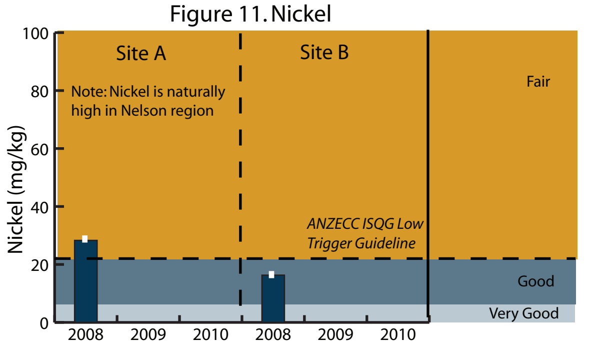
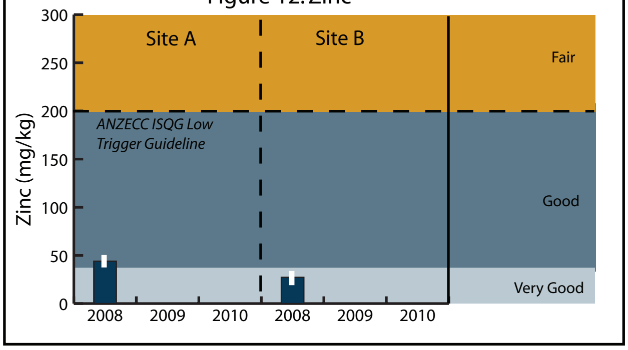


Figure 12. Zinc

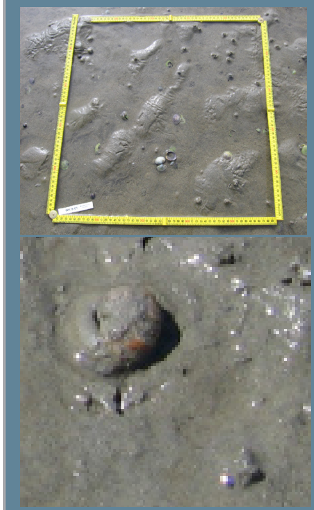


3. Results and Discussion (Continued)

2008
Benthic Community
RATING

Unbalanced
Slightly Polluted

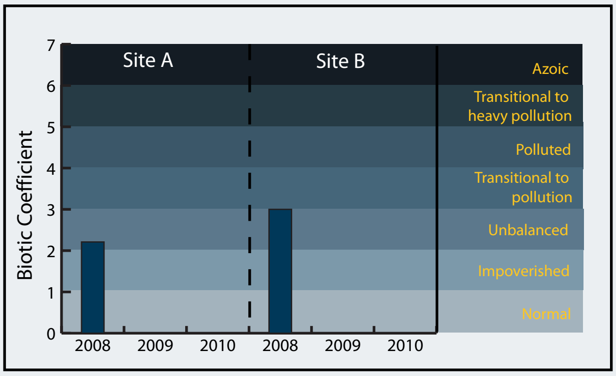
Site A



Site B

Photograph showing the much drier nature of sediments at Site B.

Figure 13. Benthic community condition rating for Motupipi Estuary sites A and B



At Site A in the Western Arm, the community was dominated by a mix of suspension and surface and subsurface deposit feeders that prefer low to moderately enriched sands (or muddy sands that remain relatively wet), and a moderately shallow RPD. The community included very few species that were very sensitive to organic enrichment and present under unpolluted conditions (i.e. Group I types - see Appendix 3). Instead, it was dominated by species either tolerant of, or indifferent to, enrichment (Groups II and III) but also included second order opportunistic species (Group IV) and a few first order opportunists (Group V organisms which are commonly found in very unbalanced situations). The dominant infaunal species included the cockle *Austrovenus stutchburyi*, with its attached anemone (*Edwardsia* sp.), the wedge shell *Macomona liliana*, the capitellid polychaete *Heteromastus filiformis*, and unidentified spionid and maldanid polychaetes. Birds and fish prey on most of these species, with cockles forming a key part in the oystercatchers diet. Compared with the intertidal mudflats in other NZ estuaries, the community diversity at Site A was relatively good (mean 12.4 species per core - Figure 14) and mean abundance was low-moderate at 3,500/m2 (Figure 15). Epifauna (surface dwelling organisms) at Site A were typical of estuarine muddy sites in that they included the cockle and 4 snail species including the mud snail *Amphibola crenata*.

At Site B in the Eastern Arm, which is muddier, well-oxygenated, but also much drier than Site A (given its mid-tide rather than low-mid position), the community was quite different. As might be expected, it was dominated by deposit feeders that are tolerant of mud but also capable of surviving periods when the sediments dry out. Like Site A, the community included very few species that were very sensitive to organic enrichment and present under unpolluted conditions (i.e. Group I types). Instead, it was dominated by species either tolerant of, or indifferent to, enrichment (Groups II and III) but also included a few first order opportunists (Group V organisms which are commonly found in very unbalanced situations). The dominant species included; the generally pollution-tolerant oligochaete worms, the small burrowing bivalve *Arthritica bifurca*, the small amphipod *Paracorophium* sp. and the mud snail *Amphibola crenata*. Birds and fish prey on most of these species, with the mud snail likely to be the dominant food source. Compared with the intertidal mudflats in other NZ estuaries, the community diversity at Site B was more (mean 6.4 species per core - Figure 14) and mean abundance was low at 1,800/m^2 (Figure 15). This is most probably due to the relatively higher position in the tidal range compared with the other NZ sites which were mid-low water sites. Epifauna (surface dwelling organisms) at Site B was limited to only one species, the mud snail *Amphibola crenata*, probably a response to the drier conditions at Site B.

Figure 14. Mean total abundance of macrofauna at Motupipi Estuary compared with other NZ estuaries (Source Robertson et al. 2002, Robertson and Stevens 2006)

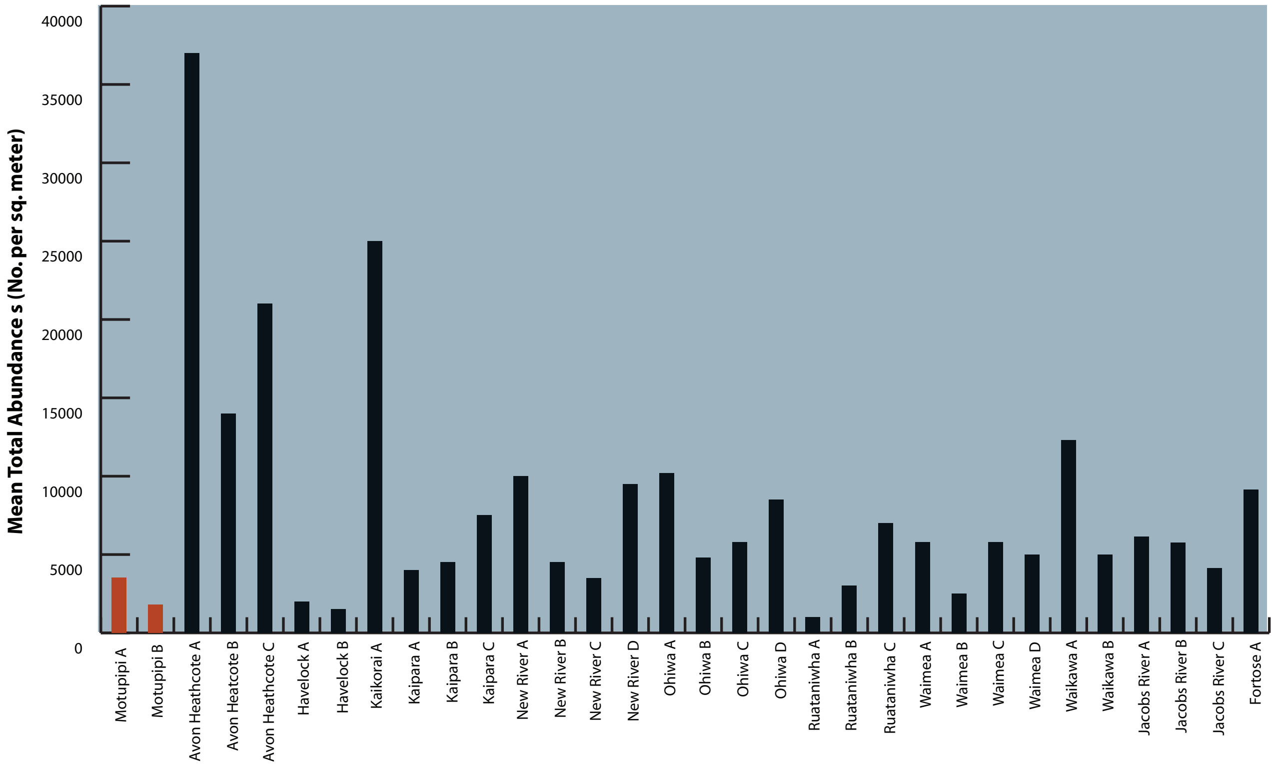
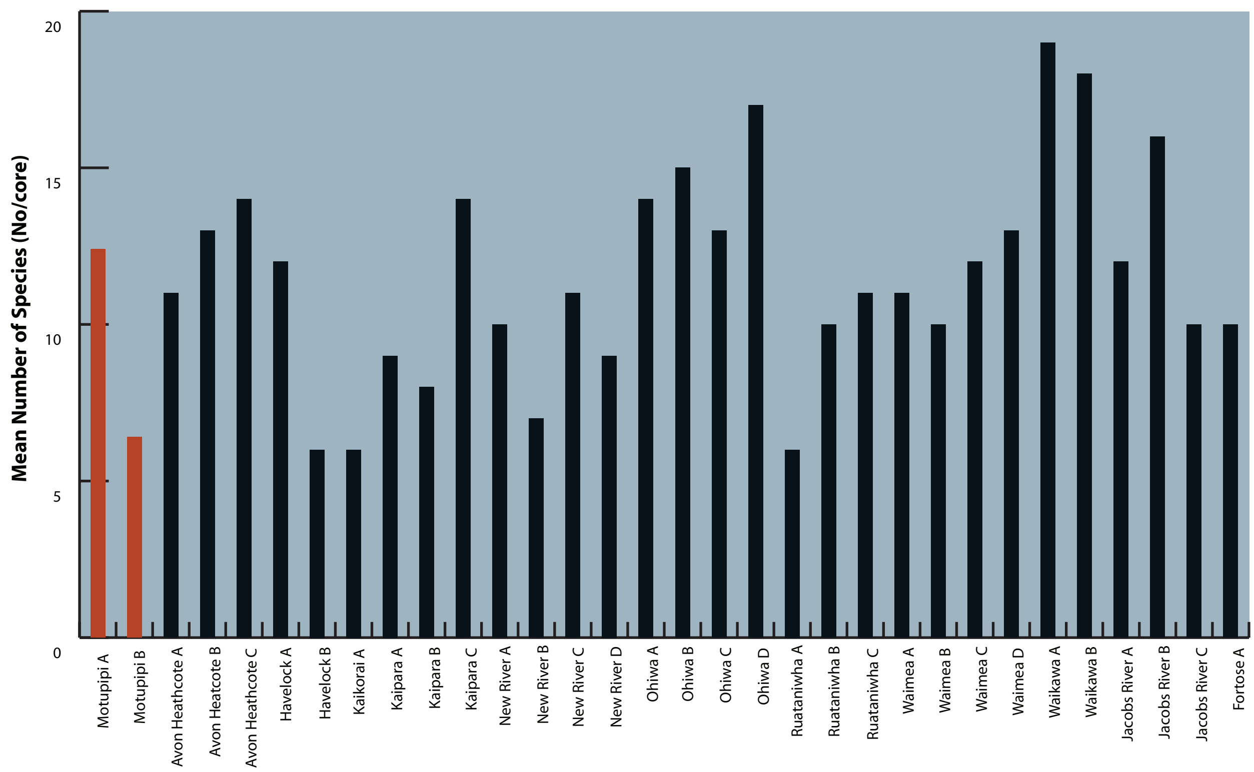


Figure 15. Mean number of species, Motupipi Estuary compared with other NZ estuaries



3. Results and Discussion (Continued)

TOXICITY

2008 TOXICITY RATING
Good
Very Good

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at very low concentrations at both sites (Figures 7 to 12) with all values well below the ANZECC (2000) ISQG-Low trigger values, except for nickel and chromium which are known to be naturally high throughout the Nelson region. Metals met the "very good" condition rating for cadmium, copper and lead at both sites and zinc at Site B. Metals met the "good" condition rating for chromium at both sites, nickel at Site B and zinc at Site A. Metals met the "fair" condition rating for nickel at Site A. These results indicate that widespread toxicity is not an issue in the Motupipi.

SEDIMENTATION OF FINE SEDIMENT

Soil erosion is a major issue in NZ and the resulting suspended sediment impacts are of particular concern in tidal lagoon estuaries like the Motupipi because they have a central basin which forms a sink for fine sediments. The result can cause impacts such as; increased muddiness and turbidity, shallowing, more nutrients, changes in saltmarsh and seagrass habitats, less oxygen, increased organic matter degradation by anoxic processes (e.g. sulfate reduction), and alterations to fish and invertebrate communities. The primary fine scale indicators of fine sediment deposition are grain size and sedimentation rate. The broad scale indicator is the area of soft mud (the results of which are presented in an accompanying report - Stevens and Robertson 2008).

Grain Size (Figure 5)

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The 2008 monitoring results show that although both sites were dominated by sandy sediments (53-85% sand), the mud fraction was also very significant (12-46% mud content), particularly in the Eastern Arm Site B (34-47%mud). The site closest to the sea, Site A, had the least amount of mud. The eastern arm, however, is not all dominated by soft mud like at Site B. Stevens and Robertson (2008) found Site B type sediments occupy approximately one third of the eastern arm - the remainder is dominated by sandy sediments. The source of the mud to the eastern arm is unknown but is likely to be predominantly from Motupipi River inputs.

Rate of Sedimentation

The rate of sedimentation for the Motupipi Estuary has yet to be determined. Sedimentation plates were deployed in the estuary in September 2007 to enable long term monitoring of sedimentation rates.

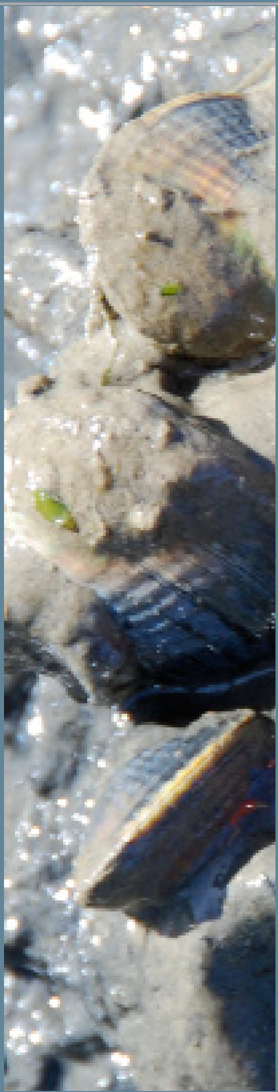
SEDIMENTATION PLATE DEPLOYMENT

The location of the 12 sedimentation plates buried in soft muddy sediments in Motupipi Estuary are shown in Figure 1, while the distance (mm) from the sediment surface to the buried plate, and the height of the two marker stakes (mm) 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. Sedimentation plate locations and height and depth details

Site	No	Date	NZMG East	NZMG North	Plate depth (mm)	Height of stake (mm)	Height of stake (mm)
Upper West Arm	1	27/9/07	2496407	6040764	248	190 (north)	190 (south)
Upper West Arm	2	27/9/07	2496429	6040776	215	190 (north)	190 (south)
Upper West Arm	3	27/9/07	2496442	6040753	190	190 (north)	190 (south)
Upper West Arm	4	27/9/07	2496422	6040737	210	190 (north)	190 (south)
Upper East Arm	1	26/9/07	2497860	6040405	205	190 (west)	190 (east)
Upper East Arm	2	26/9/07	2497842	6040385	205	190 (west)	190 (east)
Upper East Arm	3	26/9/07	2497817	6040394	200	190 (west)	190 (east)
Upper East Arm	4	26/9/07	2497832	6040419	210	190 (west)	190 (east)

4. SUMMARY



The first year of fine scale monitoring results for a range of physical, chemical and biological indicators of estuary condition show that the dominant habitat (i.e. unvegetated sandflat) in the Motupipi Estuary was generally in a good - moderate condition.

In terms of the eutrophication indicators, the results were in the low-moderate category for sediment oxygenation (RPD), nitrogen and organic matter, but phosphorus was in the moderate category. As expected from such conditions, the benthic community health was unbalanced giving it a "slightly polluted" classification. The shallow nature of the RPD in the western arm and the relatively muddy sediments at both sites indicate a need for caution. If enrichment continues (particularly in combination with an increased mud content, sediment anoxia could get worse and result in sediment nutrients becoming much more available for nuisance algal growth. Under such conditions, a return to oxygenated sediment conditions is difficult to achieve - even if catchment nutrient loads are reduced. Because nutrient loads to the estuary are high and parts of the estuary are already anoxic, it is recommended that nutrient load management be instigated (as recommended in the recent vulnerability assessment - Robertson and Stevens 2008) and long term monitoring be continued. The TN:TP ratio in the intertidal sediments indicated nitrogen as the key nutrient to target for minimising eutrophication symptoms.

The extent of contamination with toxic substances was rated "very good to good" reflecting the low levels of heavy metals in the intertidal sediments (except for nickel and chromium which is known to be naturally elevated in the region).

In terms of deposition of fine sediments, the grain size results were interesting in that they showed that both sites, but particularly the eastern arm, were relatively muddy (12-46% mud). Such findings, confirm the results of the estuary vulnerability assessment (Robertson and Stevens 2008) that increasing muddiness is an issue in the estuary that requires ongoing monitoring and source management. Sedimentation plates were deployed during this study to provide a means of monitoring sedimentation rates. Broad scale habitat mapping of the area of soft sediments in the estuary (which was undertaken in December 2007 and reported separately - Stevens and Robertson 2008), provides the other key long term monitoring indicator of muddiness.

5. MONITORING

Motupipi Estuary has been identified by TDC as a priority for monitoring, and is a key part of TDC's existing estuary monitoring programme being undertaken in a staged manner throughout the Nelson/Golden Bay region. Based on the 2008 monitoring results and condition ratings, it is recommended that monitoring continue as outlined below:

- **Fine Scale Monitoring**. Complete the four years of the annual scheduled baseline monitoring in Motupipi Estuary to Jan-Feb 2011. After the four year baseline is completed, reduce monitoring to five yearly intervals or as deemed necessary based on the condition ratings.
- **Sedimentation Rate Monitoring**. Measure the depths of the existing 8 sediment plates in January-March 2009 while doing the fine scale monitoring. At the same time, it is recommended that four new plates should be deployed in the area of very soft and anoxic muds adjacent to the old Rototai landfill. Following the 2009 monitoring, it is recommended that the depth of all plates be measured annually thereafter.

6. MANAGEMENT

The fine scale monitoring reinforced the need for management of nutrient and fine sediment sources entering the estuary. It is recommended that options be considered for the following (as identified in the estuary vulnerability assessment - Robertson and Stevens 2008):

Identify and Implement Catchment BMPs

Catchment runoff was identified as one of the major stressors in Motupipi Estuary. To prevent avoidable inputs, best management practices (BMPs) should be identified and implemented to reduce runoff of sediment, nutrients and pathogens from catchment "hotspots". TDC and Landcare Research, with Foundation for Research Science and Technology Envirolink funding, are currently working with farmers in the catchment to identify catchment nutrient sources and "hotspots", and to implement BMPs for reducing nutrient mobilisation and runoff to surface and groundwater.

Set Limits on Nutrient Inputs

Because nutrient input was both high and strongly related to the eutrophication symptoms, it is recommended that catchment nutrient inputs be reduced. Currently the nitrogen input (as estuary areal load) is likely to be in the range 60-100 $mg.m^{-2}.d^{-1}$ which is elevated when compared with the 50 $mg.m^{-2}.d^{-1}$ upper limit suggested by Heggie (2006) for ensuring no eutrophication of temperate Australian estuaries. A Total Daily Maximum Load to the estuary of about 50 kgN/day (as opposed to the current input of 60-100 kg/day) is suggested as a preliminary guideline.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from various people, local farmers who provided access to the estuary, and staff of Tasman District Council. In particular, the support and feedback of Trevor James, Rob Smith (both from TDC) and local resident Fred Winter, was much appreciated.

8. REFERENCES

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

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

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

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

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

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

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

Robertson, B., and Stevens, L. 2007. Waikawa Estuary 2007a, Monitoring, Macroalgal Mapping & Historical Sediment Coring. Prepared for Environment Southland.

Robertson, B., and Stevens, L. 2008. Motupipi Estuary Vulnerability Assessment and Monitoring Recommendations. Prepared for Tasman District Council.

Stevens, L., and Robertson, B. 2008. Motupipi Estuary 2007 - Broad scale habitat mapping. Prepared for Tasman District Council.

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

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

APPENDIX 2. 2008 DETAILED RESULTS

Physical and chemical results for Motupipi Estuary, January 2008.

Estuary	Site	Rep.	RPD	Salinity	AFDW	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
			cm	ppt@15^{0}C	%				mg/kg							
Motupipi	A	01	3	27	2.10	12.7	85.6	1.7	0.046	44	10.0	29	6.3	46	630	580
Motupipi	A	02	3	27	1.90	16.3	83.6	0.1	0.036	43	9.1	27	6.0	42	570	570
Motupipi	A	03	3	27	2.80	33.6	66.0	0.5	0.042	44	9.8	29	6.5	44	990	570
Motupipi	B	01	>10	30	2.30	33.9	66.0	0.1	0.018	27	6.3	17	4.2	29	870	550
Motupipi	B	02	>10	30	2.60	46.5	53.5	0.1	0.014	26	5.8	16	3.9	28	720	600
Motupipi	B	03	>10	30	1.80	36.6	63.4	0.1	0.011	26	5.0	16	3.6	25	680	520

Station Locations

Motupipi A	MotA-1	MotA-2	MotA-3	MotA-4	MotA-5	MotA-6	MotA-7	MotA-8	MotA-9	MotA-10
NZMG260 East	2496431	2496425	2496419	2496413	2496414	2496421	2496431	2496438	2496439	2496433
NZMG260 North	6041019	6041017	6041008	6041007	6041002	6041004	6041013	6041020	6041014	6041012

Motupipi B	MotB-1	MotB-2	MotB-3	MotB-4	MotB-5	MotB-6	MotB-7	MotB-8	MotB-9	MotB-10
NZMG260 East	2497945	2497896	2497892	2497894	2497901	2497905	2497909	2497907	2497919	2497920
NZMG260 North	6040514	6040600	6040581	6040571	6040567	6040584	6040600	6040614	6040613	6040599

Epifauna (numbers per 0.25m^2 quadrat) and Macroalgae (percent cover per 0.25m^2 quadrat)

Motupipi A

Scientific name Common name	MotA-01	MotA-02	MotA-03	MotA-04	MotA-05	MotA-06	MotA-07	MotA-08	MotA-09	MotA-10
Amphibola crenata Mud snail	0	1	0	4	5	1	2	3	3	7
Austrovenus stutchburyi Cockle	0	0	1	0	0	0	0	0	0	0
Cominella glandiformis Mudflat whelk	0	0	0	0	0	0	0	1	0	0
Diloma subrostrata Mudflat topshell	0	0	0	0	0	1	0	1	0	0
Zeacumantus lutulentus Spire shell	2	0	1	0	2	0	0	0	1	1

Motupipi B

Scientific name Common name	MotB-01	MotB-02	MotB-03	MotB-04	MotB-05	MotB-06	MotB-07	MotB-08	MotB-09	MotB-10
Amphibola crenata Mud snail	2	4	2	2	5	1	1	2	1	0

APPENDIX 2. 2008 DETAILED RESULTS

Infauna (numbers per 0.01327m² core)

Motupipi A and B																						
Group	**Species**	**AMBI Group**	Motu A-01	Motu A-02	Motu A-03	Motu A-04	Motu A-05	Motu A-06	Motu A-07	Motu A-08	Motu A-09	Motu A-10	Motu B-01	Motu B-02	Motu B-03	Motu B-04	Motu B-05	Motu B-06	Motu B-07	Motu B-08	Motu B-09	Motu B-10
ANTHOZOA	*Edwardsia sp.#1*	II	9	12	4	3	12	5	2	5	12	9	4	4	2	1	2					1
NEMERTEA	*Nemertea sp.#1*	III	2			1			1	1	1	1										
	Nemertea sp.#2	III	1					1														
NEMATODA	*Nematoda sp.*	III					1											1				
POLYCHAETA	*Boccardia (Paraboccardia) acus*	I									1											
	Boccardia (Paraboccardia) syrtis	I				1																
	Capitella capitata	V	4		1	1		1			1				2	1			2			1
	Glycera sp.#1	II								1												
	Heteromastus filiformis	IV	5	9	2	9	2	3	6	1		1										
	Maldanidae sp.#1	NA	3	3	1	4	1	4	15	4	3											
	Nicon aestuariensis	III	2	2	1	1	1	2	1				1		1		1	1				1
	Orbiniidae sp.#1	I		1					1		1											
	Paraonidae sp.#1	III														1						
	Polynoidae sp.#1	NA	1	1	1	1			1	1	2											
	Scolecolepides benhami	III								1					1							
	Spionidae sp.#1	NA	12	4	2	16	4	6	7	5	6	1				1						
	Spionidae sp.#2	NA				1																
	Syllidae sp.#1	II								1												
OLIGOCHAETA	Oligochaeta sp.	NA		2						1			12		4	13	7	22	1	21	2	17
GASTROPODA	*Amphibola crenata*	NA											1		5	3	6	3				3
	Cominella glandiformis	NA	1					1	2	1												
	Notoacmaea helmsi	NA								1												
	Potamopyrgus estuarinus	NA															1				1	1
	Zeacumantus lutulentus	NA	2			1						1										
BIVALVIA	*Arthritica sp.#1*	III				6	1				5		3	2	1			1			3	4
	Austrovenus stutchburyi	NA	26	12	7	11	1	13	12	7	14	4										
	Macomona liliana	NA	7	3	3	7		4	10	10	7	1										
CRUSTACEA	*Austrominius modestus*	NA									5											
	Copepoda sp.#1	NA			1																	
	Exosphaeroma sp.#1	NA																			1	
	Halicarcinus innominatus	NA				1																
	Helice crassa	NA						2					1	1		1		2		1		
	Macrophthalmus hirtipes	NA				1		1	1			3										
	Paracorophium spp.	NA											1	5	39	2	4	4	1	1	3	1
	Phoxocephalidae sp.#1	I	1			1	1			1	1				1							
INSECTA	Diptera sp.#1	NA			4			1		1		1										
	Diptera sp.#2	NA											1				1				1	1
Total species in sample			14	10	11	17	9	13	12	16	13	9	8	4	9	8	7	7	3	3	6	9
Total individuals in sample			76	49	27	66	24	44	59	42	59	22	24	12	56	23	22	34	4	23	11	30

NA=Not Allocated

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		AMBI Group	Details
Anthozoa	*Edwardsia* sp.#1	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 sp.#1, sp 2	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.
Polychaeta	*Boccardia (Paraboccardia) syrtis*	I	A small surface deposit-feeding spionid. Prefers low-mod mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions. 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 suphide rich anoxic sediments.
	Glycera sp	II	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15 cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions. Often present in muddy conditions. Intolerant of low salinity.
	Heteromastus filiformis	IV	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15 cm, and prefers a muddy-sand substrate. Despite being a capitellid, *Heteromastus* is not opportunistic and does not show a preference for areas of high organic enrichment as other members of this polychaete group do.
	Maldanidae	NA	Bamboo worms. Probably *Macroclymenella* sp., 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 15 cm and potentially has a key role in the re-working and turn-over of sediment. This worm may modify the sediment conditions, making it more suitable for other species (Thrush et al., 1988). Macroclymenella is common in estuaries. Intolerant of anoxic conditions.
	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.
	Orbiniidae sp	I	Unsure of species, possibly *Orbinia papillosa*. Found only in fine and very fine sands. Pollution and mud intolerant.
	Paraonidae sp	III	*Aricidea* sp., a paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15 cm 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 (Lim and Hong, 1997).
	Polynoidae sp	NA	Scaleworms.
	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.
	Spionidae sp	NA	An unknown spionid polychaete. Feed at the sediment-water interface - as either deposit or suspension feeders.
	Syllidae	II	Small slender worms with 3 antenna. Present in sandy sediments.
Oligochaeta	Oligochaete sp.	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.
Insecta	Diptera sp.	NA	Fly or midge larvae - species unknown.

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		AMBI Group	Details
Gastropoda	*Amphibola crenata*	NA	A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria.
	Cominella glandiformis	NA	Endemic to NZ. A carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds.
	Notoacmaea helmsi	NA	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds.
	Potamopyrgus estuarinus	NA	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feed on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds.
	Zeacumantus lutulentus	NA	A medium-sized mud snail. Endemic to the North Island and the northern half of the South Island of NZ. Very common on intertidal mudflats. On the mudflats, these snails plough their way across the surface, leaving recognizable trails. Each snail passes huge quantities of mud through its gut as it extracts organic matter from the mud.
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 stutchburyi	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 5–10 cm 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.
Crustacea	*Austrominius modestus*	NA	Small acorn barnacle. Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones.
	Copepoda *sp.*	NA	Very small crustaceans usually having six pairs of limbs on the thorax. The benthic group of copepods (Harpactacoida) have worm-shaped bodies.
	Exosphaeroma sp.	NA	Small isopod.
	Halicarcinus innominatus	NA	Pillbox crabs are usually found on the sand and mudflats but may also be encountered under stones on the rocky shore. *Halicarcinus innominatus* has an oval carapace and long forelegs. It is usually brown with patterns that extend onto its smooth legs. Common with the green-lipped mussel.
	Helice crassa	NA	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level.
	Macrophthalmus hirtipes	NA	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
	Paracorophium sp.	NA	Brackish water amphipod common in estuary mudflats. Considered to be a non-selective surface deposit feeder.
	Phoxocephalidae sp.	I	A family of amphipods.

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.