coastalmanagement

New River Estuary

Fine Scale Monitoring of Highly Eutrophic Arms 2011/2012

Prepared for
Environment Southland
July 2012

Cover Photo: Central Waihopai Arm, New River Estuary.

Site for synoptic monitoring in Daffodil Bay, New River Estuary.

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By

Barry Robertson and Leigh Stevens

Wriggle Limited, PO Box 1622, Nelson 7040, Ph 0275 417 935, 021 417 936, www.wriggle.co.nz

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NEW RIVER ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the baseline 2012 fine scale monitoring of two eutrophic, poorly flushed, intertidal sites (Waihopai Arm and Daffodil Bay) within New River Estuary, a large (4,100ha) tidal lagoon estuary near Invercargill. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. The following sections summarise fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

FINE SCALE RESULTS

- The sites were dominated by mud, and were poorly oxygenated (Redox Potential Discontinuity at the surface).
- The rate of sedimentation (infilling with mud) in the Waihopai Arm has been very high from 2007-2012.
- The invertebrate community was dominated by surface feeding, mud and organic enrichment tolerant species. Very few species were present within the underlying anoxic and sulphide-rich muds.
- Sediment nutrients and organic carbon were very elevated, and while heavy metals were below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity), they were much greater than at the other fine scale sites in New River Estuary.

CONDITION RATINGS

Eutrophic Sites W & F = Waihopai Arm
Eutrophic Site E = Daffodill Bay Arm

	Fine Scale Monitoring Sites (located in the well flushed central basin)															Eutrophic Sites		
	Site B (Shellbanks)					Site C (Daffodil Bay)					Site D (Lower Oreti)					W	F	E
	2001	2003	2004	2005	2010	2001	2003	2004	2005	2010	2001	2003	2004	2005	2010	2011	2012	2012
Sediment Oxygenation (RPD)	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	High/Poor	Fair	Fair	Fair	Fair	Fair	High/Poor	High/Poor	High/Poor
Invertebrates: Mud Tolerance	Good	Good	Very good	Good	Good	Good	Good	Good	Good	Good	Fair	Fair	Fair	Fair	Fair	High/Poor	Fair	Fair
TOC (Total Organic Carbon)	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Fair	Fair	Good
Total Nitrogen	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	Very good	High/Poor	High/Poor	Fair
Total Phosphorus	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	High/Poor	High/Poor	Fair
Metals (Cd, Cu, Cr, Ni, Pb, Zn)	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good-Very Good	Good	Good	Good
Invertebrates: Organic Enrichment Tolerance	Good	Good	Good	Good	Good	Very good	Very good	Very good	Good	Good	Good	Good	Good	Good	Good	High/Poor	Good	Good

Key To Ratings: Baseline est. | High/Poor | Fair | Good | Good-Very Good | Very good | Not measured

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the fine scale monitoring (i.e. sedimentation, eutrophication, and toxicity), the 2012 results indicate that the poorly flushed Waihopai and Daffodil Bay Arms are excessively muddy, have high nutrients and nuisance macroalgal growths, and contain sediments with toxic sulphides and poor sediment oxygenation. As a result, the macroinvertebrate community is severely degraded with little animal life able to establish in the underlying sediments, while surface feeding species are few in number and limited to those tolerant of poor conditions. Such conditions limit the food availability for fish and birdlife, and mean the ability of the estuary to assimilate nutrient and sediment loads from the catchment is exceeded. Toxicity (indicated by heavy metals) was low, but higher than measured at other fine scale sites. Issues identified in other monitoring studies of New River Estuary include; loss of high value habitat, excessive muddiness in the main estuary, disease risk associated with shellfish consumption and bathing, and toxicity near urban stormwater drains.

RECOMMENDED MONITORING AND MANAGEMENT

Eutrophication and sedimentation have been identified as issues in New River Estuary since at least 1973 (Blakely 1973), with worsening conditions reported since 2007-2008 (Robertson and Stevens 2007, Stevens and Robertson 2008), as has been the case for several other Southland estuaries (e.g. Jacobs River Estuary, Waimatuku Estuary, and Waituna Lagoon).

To address these issues, it is recommended that catchment nutrient and sediment guideline criteria be developed for each estuary type in Southland in a prioritised fashion to derive thresholds protecting against adverse sediment and nutrient impacts. Assessment of the extent to which catchment loads meet guideline criteria will enable ES to sustainably manage the estuary and its surroundings. If catchment inputs can be assimilated by the estuary, it will flourish and provide sustainable human use and ecological values in the long term. If catchment loads exceed the estuary's assimilative capacity, it will continue to degrade. New River Estuary is recommended as the first priority for this work because of its current extent and rate of degradation.

In order to assess ongoing trends in the fine scale condition of the estuary it is also recommended that the newly established eutrophic sites be monitored in Feb. 2013, 2014 and again in 2015 when the 5 yearly fine scale trend monitoring at the existing central basin sites falls due. Broad scale sedimentation rate, seagrass, and macroalgal monitoring should continue annually, and broad scale mapping every 5 years (next due in 2017).

All photos by Wriggle except where noted otherwise.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. The process used for estuary monitoring and management by Environment Southland (ES) in New River Estuary consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002):

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (Table 1) and appropriate monitoring design. A preliminary EVA has been completed for New River Estuary and is reported on in Robertson and Stevens (2008).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component, which documents the key habitats within the estuary (Table 2), and changes to these habitats over time, was undertaken in 2002 (Robertson et al. 2002), and repeated in 2007 and 2012 (Robertson and Stevens 2007, Stevens and Robertson in press).
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (Table 2) including sedimentation plate monitoring. This component, which provides detailed information on the condition of the New River Estuary, has been undertaken in 2001, 2003, 2004, 2005 (Robertson and Stevens 2006) and 2010 (Robertson and Stevens 2010).

In addition, a series of condition ratings have been developed to help evaluate overall estuary condition and decide on appropriate monitoring and management actions. These ratings, described in Section 2, currently trigger annual monitoring of sedimentation rate and macroalgal growth in the estuary.

The results of the recent annual broad scale macroalgal monitoring (Stevens and Robertson 2011, 2012), in conjunction with the monitoring undertaken from 2002-2011, highlighted the presence of extensive and increasing eutrophication and sedimentation problems in the natural settling areas within Waihopai Arm and Daffodil Bay Arm of New River Estuary. The increased eutrophication symptoms (very low sediment oxygenation and sulphide-rich sediments, smothering macroalgae, rapid soft mud accumulation) correlate with increased catchment nutrient loads over the last 10 years.

These symptoms have not been conspicuous in the fine scale monitoring results to date because the sites are located in the relatively well flushed margins of the central basin of the estuary - the dominant habitat type in the estuary which was the focus of the original NEMP sampling design (see Figure 1, Robertson and Stevens 2010).

Therefore, in response to the eutrophication and sedimentation problems evident in the natural settling areas within New River Estuary, a preliminary synoptic fine scale assessment (unreplicated sampling from 3 areas showing varying degrees of eutrophic enrichment) was undertaken in the Waihopai Arm in February 2011 to evaluate estuary condition and determine if further investigation was necessary (see Robertson and Stevens 2011). The results showed sediments were enriched, anoxic and muddy, and contained a very degraded biological community characterised by small numbers of pollution tolerant species. The degraded areas were located in the parts of the estuary adversely affected by combined increases in macroalgal growth and muddy sediment evident from 2001-2011.

Consequently, in 2012 monitoring was expanded to undertake a more detailed fine scale assessment in natural settling areas within both the Waihopai and Daffodil Bay Arms using the NEMP approach (Robertson et al. 2002). Results of sampling undertaken in January 2012 are presented in the current report.

New River Estuary is a large "tidal lagoon" type estuary (area 4,100ha), discharging to the east end of Oreti Beach. Situated at the confluence of the Oreti and Waihopai Rivers, it drains a primarily agricultural catchment.

This shallow estuary (mean depth ~2m) is bordered by a mix of vegetation and landuses (urban, bush and grazed pasture). It has a wide range of habitats (extensive mudflats, seagrass and saltmarsh areas) but has also lost large areas through drainage and reclamation. The Waihopai Arm has been most affected with around 1200ha (75%) of the Arm reclaimed, greatly reducing its ability to filter, dilute, and assimilate nutrient and sediment inputs.

Invercargill City is also located adjacent to the Waihopai Arm and discharges its treated wastewater to the estuary. Nuisance blooms of macroalgae (*Ulva* and *Gracilaria*), exceedance of bathing and shellfish faecal bacterial guidelines, and sedimentation problems are common within the estuary.

As a consequence of the much reduced saltmarsh area, the estuary is expected to be more vulnerable to issues of eutrophication and sedimentation (given that saltmarsh acts to reduce nutrient and sediment impacts).

Despite the presence of these issues, human use and ecological values of large parts of the estuary are high. However, it has been recommended that management actions be taken to improve the situation in areas where the condition is poor.

1. Introduction (Continued)

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

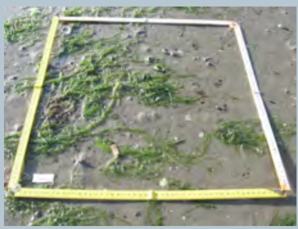
Major Estuary Issues	
Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance,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

Table 2. Summary of the broad and fine scale EMP indicators (shading signifies indicators used in the fine scale monitoring assessments)**.**

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

2. METHODS

FINE SCALE MONITORING



Quadrat for epifauna sampling.

Fine scale monitoring is based on the methods described in the NEMP (Robertson et al. 2002) and provides detailed information on the condition of the estuary. Using the outputs of the broad scale habitat mapping, representative sampling sites (usually one or two per estuary, or three or four for larger estuaries) are selected and samples collected and analysed for physical, chemical and biological variables.

For New River Estuary, two eutrophic fine scale sampling sites (Figure 1, Appendix 2) were selected in mid-low water habitat of the dominant substrate type (areas of abundant macroalgal growth, and muddy anoxic, sulphide-rich sediment). At each site, a 20m x 8m area in the lower intertidal was marked out and divided into 10 equal sized plots. Within each plot, a random position was defined, and the following sampling undertaken:

Physical and chemical analyses

- Within each sampling location, one core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average redox potential discontinuity (RPD) depth (i.e. depth to light grey/black anoxic layer) recorded.
- At each site, three samples (2 a composite from 4 plots, and 1 from 2 plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. All samples were kept in a chillybin in the field.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details in Appendix 1):
    - Grain size/Particle size distribution (% mud, sand, gravel).
    - Nutrients - total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC).
    - Trace metal contaminants (total recoverable Cd, Cr, Cu, Ni, Pb, Zn). Analyses were based on whole sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.

Epifauna (surface-dwelling animals)

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

Infauna (animals within sediments)

- One randomly placed sediment core was taken from each of 10 plots using a 130mm diameter (area = 0.0133m^2) PVC tube.
- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled plastic bag.
- Once all replicates had been collected at a site, the plastic bags were transported to a nearby source of seawater and the contents of the core were washed through a 0.5mm nylon mesh bag. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.
- The samples were then transported to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).

1. Waihopai Arm eutrophic Site F (2012) located adjacent to synoptic Site W (2011).

2. Daffodil Bay Arm eutrophic Site E and fine scale Site C.

Figure 1. Location of fine scale monitoring sites in New River Estuary (Photo LINZ).

Daffodil Bay Arm eutrophic Site E showing surface sulphides (centre).

Waihopai Arm eutrophic Site F.

2. Methods (Continued)

Waihopai Arm sedimentation rate site in 2007.

Sedimentation Rate

Determining the sedimentation rate from now and into the future involves a simple method of measuring how much sediment builds up over buried plates 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. Locations (Figure 1) and methods for deployment are presented in Robertson and Stevens 2007). In the future, these depths will be measured every 1-5 years and, over the long term, will provide a measure of rate of sedimentation in representative parts of the estuary.

Waihopai Arm sedimentation rate site in 2010.

CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented below) have been proposed for New River Estuary (based on the ratings developed for Southland's estuaries - e.g. Robertson & Stevens 2006). The ratings are based on a review of estuary monitoring data, guideline criteria, and expert opinion. They are designed to be used in combination with each other (usually involving expert input) when evaluating overall estuary condition and deciding on appropriate management. The condition ratings include an "early warning trigger" to highlight rapid or unexpected change, and each rating has a recommended monitoring and management response. In most cases initial management is to further assess an issue and consider what response actions may be appropriate (e.g. develop an Evaluation and Response Plan - ERP).

Sedimentation Rate

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

SEDIMENTATION RATE CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Low	<1mm/yr (typical pre-European rate)	Monitor at 5 year intervals after baseline established
Low	1-2mm/yr	Monitor at 5 year intervals after baseline established
Moderate	2-5mm/yr	Monitor at 5 year intervals after baseline established
High	5-10mm/yr	Monitor yearly. Initiate Evaluation & Response Plan
Very High	>10mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

2. Methods (Continued)

Benthic Community Index (Mud Tolerance)

Soft sediment macrofauna can also be used to represent benthic community health in relation to the extent of mud tolerant organisms compared with those that prefer sands. Using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) a "mud tolerance" rating has been developed similar to the "organic enrichment" rating identified below.

The equation to calculate the Mud Tolerance Biotic Coefficient (MTBC) is a s follows;

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

The characteristics of the above-mentioned mud tolerance groups (SS, S, I, M and MM) are summarised in Appendix 2.

BENTHIC COMMUNITY MUD TOLERANCE RATING

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

Redox Potential Discontinuity

The RPD is the grey layer between the oxygenated yellow-brown sediments near the surface and the deeper anoxic black sediments. It is an effective ecological barrier for most but not all sediment-dwelling species. A rising RPD will force most macrofauna towards the sediment surface to where oxygen is available. The depth of the RPD layer is a critical estuary condition indicator in that it provides a measure of whether nutrient enrichment in the estuary exceeds levels causing nuisance anoxic conditions in the surface sediments. The majority of the other indicators (e.g. macroalgal blooms, soft muds, sediment organic carbon, TP, and TN) are less critical, in that they can be elevated, but not necessarily causing sediment anoxia and adverse impacts on aquatic life. Knowing if the surface sediments are moving towards anoxia (i.e. RPD close to the surface) is important for two main reasons:

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

The tendency for sediments to become anoxic is much greater if the sediments are muddy. In sandy porous sediments, the RPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1 cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

RPD CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	>10cm depth below surface	Monitor at 5 year intervals after baseline established
Good	3-10cm depth below sediment surface	Monitor at 5 year intervals after baseline established
Fair	1-3cm depth below sediment surface	Monitor at 5 year intervals. Initiate 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

Total Organic Carbon

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

TOTAL ORGANIC CARBON CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<1%	Monitor at 5 year intervals after baseline established
Good	1-2%	Monitor at 5 year intervals after baseline established
Fair	2-5%	Monitor at 2 year intervals and manage source
Poor	>5%	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

2. Methods (Continued)

Total Phosphorus

In shallow estuaries like New River the sediment compartment is often the largest nutrient pool in the system, and phosphorus exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL PHOSPHORUS CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<200mg/kg	Monitor at 5 year intervals after baseline established
Good	200-500mg/kg	Monitor at 5 year intervals after baseline established
Fair	500-1000mg/kg	Monitor at 2 year intervals and manage source
Poor	>1000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Total Nitrogen

In shallow estuaries like New River, the sediment compartment is often the largest nutrient pool in the system, and nitrogen exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL NITROGEN CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<500mg/kg	Monitor at 5 year intervals after baseline established
Good	500-2000mg/kg	Monitor at 5 year intervals after baseline established
Fair	2000-4000mg/kg	Monitor at 2 year intervals and manage source
Poor	>4000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Benthic Community Index (Organic Enrichment Tolerance)

Soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). The AZTI (AZTI-Tecnalia Marine Research Division, Spain) Marine Benthic Index (AMBI) (Borja et al. 2000) has been verified successfully in relation to a large set of environmental impact sources (Borja, 2005) and geographical areas (in N and S hemispheres) and so is used here. However, although the AMBI is particularly useful in detecting temporal and spatial impact gradients care must be taken in its interpretation. In particular, its robustness can be reduced when only a very low number of taxa (1–3) and/or individuals (<3 per replicate) are found in a sample; in low-salinity locations; and naturally enriched sediments. The equation to calculate the AMBI Biotic Coefficient (BC) is as follows;

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

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

BENTHIC COMMUNITY ORGANIC ENRICHMENT TOLERANCE RATING			
ENRICHMENT TOLERANCE RATING	DEFINITION	BC	RECOMMENDED RESPONSE
Very Low	Intolerant of enriched conditions	0-1.2	Monitor at 5 year intervals after baseline established
Low	Tolerant of slight enrichment	1.2-3.3	Monitor 5 yearly after baseline established
Moderate	Tolerant of moderate enrichment	3.3-5.0	Monitor 5 yearly after baseline est. Initiate ERP
High	Tolerant of high enrichment	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very High	Azoic (devoid of invertebrate life)	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend to slight enrichment	>1.2	Initiate Evaluation and Response Plan

Metals

Heavy metals provide a low cost preliminary assessment of toxic contamination 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

3. RESULTS AND DISCUSSION

A summary of the 27 January 2012 eutrophic zone monitoring results is presented in Table 3 alongside the long term fine scale monitoring results (2001-2005 baseline and 2010 results - Robertson and Stevens 2010), and the 2011 synoptic survey (Robertson and Stevens 2011). Sedimentation rate monitoring results are presented in Table 4, and detailed macroinvertebrate results in Table 5. The results and discussion section is divided into three subsections based on the key estuary problems that the fine scale monitoring is addressing: sedimentation, eutrophication, and toxicity.

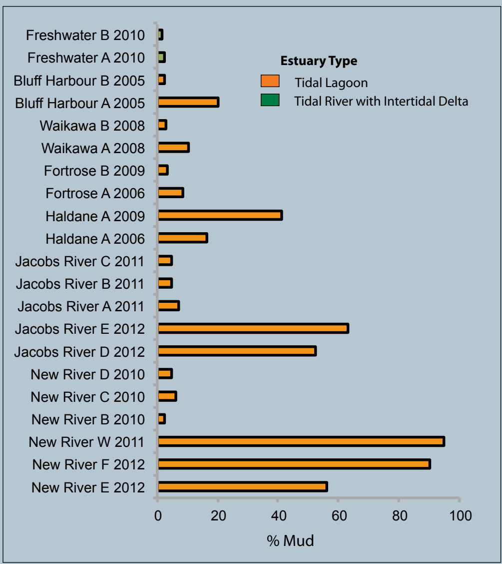


Figure 2. Percent mud content at Southland fine scale monitoring sites.

SEDIMENTATION

Accelerated soil erosion from developed catchments is a major issue for tidal lagoon estuaries in NZ as they form a sink for fine suspended sediments. NZ estuaries are particularly sensitive to increased muddiness given the facts that they are generally sand dominated, have a diverse and healthy biology, and have a short history of catchment development. Increased muddiness results in reduced sediment oxygenation, production of toxic sulphides, increased nuisance macroalgal growth, and a shift towards a degraded invertebrate and plant community. Such a change reduces feeding grounds and habitat for bird and fish species. If the input of fine sediment exceeds the assimilative capacity of the estuary, then the estuary will rapidly infill, high value habitat will be lost, and their value for fish, birdlife and humans be greatly reduced.

Sediments containing high mud content (i.e. around 30% mud with a grain size <63μm) are now typical in NZ estuaries that drain developed catchments. In such mud-impacted estuaries, the muds are generally concentrated in areas that experience low energy tidal currents and waves i.e. the intertidal margins of the upper reaches of estuaries (e.g. Waihopai Arm, New River Estuary sites W, E, F, Jacobs River Estuary sites D, E - Figure 2).

Table 3. Physical, chemical and macrofauna results for main basin New River Estuary (2001-2010 and 2012 as means) and synoptic samples from Waihopai Arm New River Estuary (2011 - one chemical sample and 3 macroinvertebrate core samples).

Year	Site	RPD	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	Species
		cm	%				mg/kg								No./m²	No./core
Sites located in the relatively well flushed central basin of New River Estuary																
2001	NRE Fine Scale B	3	0.30	1.2	98.8	0.1	0.100	8.4	3.6	0.7	4.3	15.4	<250	216	4131	7.7
	NRE Fine Scale C	2	0.60	2.2	97.6	0.2	0.100	14.9	4.6	0.6	6.0	20.0	<250	365	3156	10.9
	NRE Fine Scale D	3	0.28	1.2	98.2	0.6	0.100	12.3	3.6	0.5	5.2	17.4	<250	232	9594	8.8
2003	NRE Fine Scale B	3	0.40	1.0	99.0	0.1	0.110	7.4	3.2	3.0	3.5	12.6	140	205	5085	10.3
	NRE Fine Scale C	2	0.48	2.6	97.4	0.1	0.180	15.9	4.6	4.3	8.2	19.6	122	393	2888	12.0
	NRE Fine Scale D	3	0.40	1.3	97.9	0.8	0.120	10.1	3.4	3.9	5.2	15.0	127	231	6338	8.9
2004	NRE Fine Scale B	3	0.45	0.8	99.2	0.1	1.000	5.5	2.5	1.1	3.9	47.1	128	208	1343	6.6
	NRE Fine Scale C	2	0.55	2.5	97.0	0.5	1.000	9.7	3.9	1.8	6.5	54.4	164	397	3548	10.7
	NRE Fine Scale D	3	0.43	0.8	98.8	0.4	1.000	6.6	2.6	1.4	4.6	57.2	158	233	6143	10.6
2005	NRE Fine Scale B	3	0.48	4.1	95.9	0.1	0.050	8.1	3.4	5.8	1.7	15.4	286	260	13598	9.5
	NRE Fine Scale C	2	0.54	5.7	94.2	0.1	0.050	11.4	4.5	7.8	2.3	22.0	263	415	6750	12.2
	NRE Fine Scale D	3	0.29	1.9	98.0	0.1	0.050	8.2	3.0	5.8	1.8	24.7	166	256	3293	6.4
2010	NRE Fine Scale B	2	0.17	2.5	97.5	<0.1	0.018	7.6	3.6	5.5	1.5	16.7	<500	250	1800	8.3
	NRE Fine Scale C	1	0.24	6.1	93.5	0.5	0.023	10.5	4.6	7.4	2.0	21.0	<500	380	2962	11.8
	NRE Fine Scale D	2	0.22	4.6	94.9	0.5	0.028	10.3	4.3	7.1	2.1	21.0	<500	330	8175	9.9
Sites located in relatively poorly flushed sheltered arms of New River Estuary																
2011	NR W (Waihopai)	0	4.0	95.0	4.7	0.3	0.153	33.0	25.0	30.0	14.7	113.0	5900	1200	2250	4.0
2012	NR F (Waihopai)	0	3.1	90.2	8.1	1.7	0.160	36.3	23.3	31.3	14.3	118.0	4133	1837	24262	7.7
	NR E (Daffodil)	0	1.6	56.3	43.3	0.4	0.120	24.3	14.9	19.5	7.1	58.7	2200	720	6975	9.3

3. Results and Discussion (Continued)

Sand dominated sediments at Bushy Point.

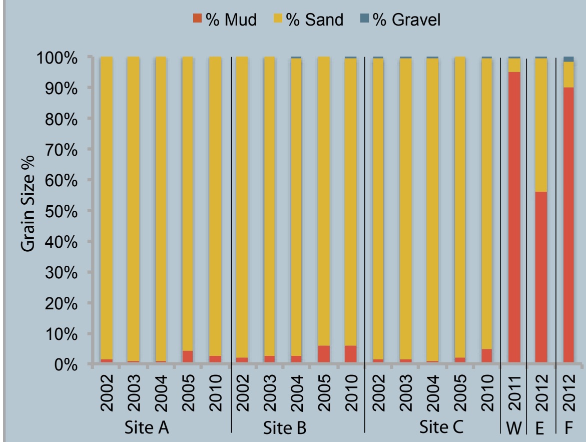


Figure 3. Grain size, New River Estuary.

In contrast, the main intertidal flats of developed estuaries (e.g. New River Estuary sites B, C, D, and Jacobs River Estuary sites A, B, C - Figure 2) are usually characterised by sandy sediments low in mud content (2-10% mud) reflecting their exposure to wind-wave disturbance. In order to assess sedimentation in the Waihopai and Daffodil Bay Arms of New River Estuary, a number of indicators have been used: grain size, sedimentation rate, and presence of mud tolerant invertebrates.

Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results for all New River Estuary sites (Figure 3) show that the Waihopai Arm (Sites W and F) and Daffodil Bay (Site E) sediments were dominated by mud (56-95% mud), whereas the main basin sites (Sites A, B and C) were dominated by sands (>93% sand in all years). Compared with fine scale sites in other tidal lagoon type estuaries in Southland, the Waihopai and Daffodil Arm mud contents were very high (Figure 2). Such findings are not unexpected given the very high rates of infilling with muds in the Waihopai Arm (Stevens and Robertson 2011), the intensively developed pastoral nature of the catchment, and the elevated sediment yields expected from such landuse areas. Estimated areal sediment loads to New River Estuary are 10g.m^{-2}.d^{-1} (based on CLUES model estimates), which equates to a mean rate of estuary infilling of 3mm/yr, assuming 80% retention in the estuary (as typically reported for tidal lagoon estuaries, e.g. Martin and Whitfield 1983).

Table 4. Sedimentation rate monitoring results, New River Estuary, February 2007- January 2012.

	Sediment Depth (mm)					Change (mm)				Site Mean (mm/yr)					Overall Rate (mm/yr)	SEDIMENTATION RATE CONDITION RATING
SITE	27-Feb-2007	19-Feb-2009	10-Feb-2010	18-Feb-2011	27-Jan-2012	2007-2009	2009-2010	2010-2011	2011-2012	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2007-2011	
Waihopai Upper	403	445	496	496	500	42	51	0	4	15.0	15.0	49.8	0.5	7.0	17.5	VERY HIGH
Waihopai Upper	290	331	368	366	370	41	37	-2	4							
Waihopai Upper	325	327	387	400	412	2	60	13	12							
Waihopai Upper	270	305	356	347	355	35	51	-9	8							
Waihopai Central	280	279	316	401	490	-1	37	85	89	0.4	0.4	59.8	72.0	79.7	41.0	VERY HIGH
Waihopai Central	382	395	458	506	585	13	63	48	79							
Waihopai Central	295	282	342	426	497	-13	60	84	71							
Waihopai Central	400	404	483	554	?	4	79	71	-							
Bushy Point	226	253	270	264	230	27	17	-6	-34	29.8	29.8	12.3	0.3	-35.0	7.4	HIGH
Bushy Point	265	381	396	412	356	116	15	16	-56							
Bushy Point	240	323	328	330	305	83	5	2	-25							
Bushy Point	265	277	289	278	253	12	12	-11	-25							
NRE Fine Scale B				178	162				-16					-17.0	-17.0	VERY LOW
NRE Fine Scale B				122	102				-20							
NRE Fine Scale B				205	189				-16							
NRE Fine Scale B				190	174				-16							
NRE Fine Scale C				116	115				-1					-0.3	-0.3	VERY LOW
NRE Fine Scale C				194	189				-5							
NRE Fine Scale C				135	135				0							
NRE Fine Scale C				197	202				5							
NRE Fine Scale D				177	225				48					32.3	32.3	VERY HIGH
NRE Fine Scale D				120	150				30							
NRE Fine Scale D				118	162				44							
NRE Fine Scale D				208	215				7							

3. Results and Discussion (Continued)

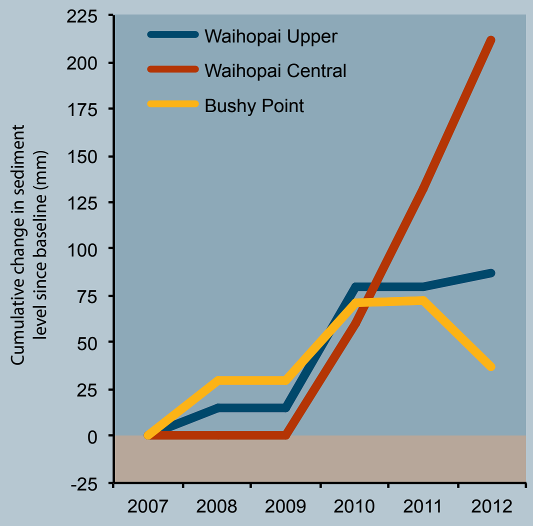


Figure 4. Cumulative change in sediment levels over buried plates in the Waihopai Arm from 2007 to 2012.

Deposition of fine muds in the Upper Waihopai Arm with anoxic and sulphide-rich underlying sediments.

Sedimentation Rate

Table 4 presents the January 2012 sedimentation rate monitoring results for the 12 plates buried in the Waihopai Arm, with summary data from 2007-2012 presented in Figure 4.

Sediment rates in the upper and central Waihopai Arm remain in the "very high" category. From Feb. 2011 to Jan. 2012, a mean annual increase of 80mm was recorded from the Waihopai Central site. This is an overall increase of 212mm over 5 years of monitoring (mean 41mm/yr), almost all of which has deposited in the last 2 years (Figure 4). Deposition has been so rapid that the site marker pegs initially set 190mm above the sediment surface have all been completely buried. While sites were re-pegged in 2011, one sediment plate could not be relocated in 2012 as its replacement peg could not be found.

The Upper Waihopai site showed a smaller increase (7mm) over the 2011-2012 period, but an overall increase of 87mm over the past 5 years (mean 17.5mm/yr). While much lower than the Central site, this deposition, when compared to pre-european rates of <1mm/year, is excessively high.

Overall, deposition at the Waihopai Upper and Central sites has consistently increased since 2007 and fine muds now smother the estuary surface (see sidebar photos). These increases have coincided with a shift to eutrophic sediment conditions and excessive macroalgal growth, clearly indicating the assimilative capacity in this part of the estuary is being exceeded.

In contrast, the nearby Bushy Point sediments remain dominated by clean sands and show no obvious signs of sediment degradation. Significant flood scouring of the site was evident in January 2012, which was reflected in an overall loss of sediment from the site (mean loss of 35mm over the previous 12 months). Of concern was the steady migration towards this site of the thick macroalgal cover dominating surface sediments in the Waihopai Arm, particularly as this surface growth greatly increases the rate of sediment deposition and associated habitat degradation.

The results clearly show that sediment deposition in the Waihopai Arm remains at unacceptably high levels with deposition rates well above recent historical estimates, and significant adverse effects being evident. While almost certainly sourced from the catchment, source tracking of fine sediments could be undertaken to confirm sediment origins.

Preliminary results from the newly established sedimentation plates at the fine scale monitoring sites on the main intertidal flats of the estuary are variable (Table 4). Site B "Shellbanks" in the lower east of the estuary showed a net loss of sediment, attributed to wave driven movement of surface sediments. Site C "Daffodil Bay" in the west showed no significant change, while Site D "Lower Oreti" showed a relatively large increase. This appeared to be a combination of recent flood deposition of sand and gravel on intertidal flats where the Oreti River discharges into New River Estuary, combined with a prolonged period of strong southwest winds and associated wave fetch spreading sediment across the intertidal flats. The increased sediment at Site D from 2011 to 2012 does not yet represent a significant deterioration in sediment quality.

Macro-invertebrate Community

Sediment mud content is a major determinant of the structure of the benthic invertebrate community. The 2012 results (Appendix 3) indicate a community that was dominated by crustacea, bivalves and gastropods, which was different to the community composition at the other fine scale sites measured previously in New River Estuary (Figure 5). These differences are attributed to the poor sediment conditions at the eutrophic sites and the fact that they were overlain with a thick layer of decaying algae. Such gross conditions were extensive, covering ~190ha in the Waihopai Arm, and ~40ha in Daffodil Bay, and were also displacing high value seagrass beds from these areas.

The following section examines this relationship in New River Estuary in three steps by:

1. Comparing the mean abundance of major macroinvertebrate groups, and the number of species in the surface and subsurface feeding types, with other estuary sites to see if there are any major differences (Figures 5 and 6).
2. Using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) to assess the mud tolerance of the New River Estuary macro-invertebrate community over the 11 years of monitoring (Figure 7).
3. Using multivariate techniques to explore whether the macro-invertebrate communities at each of the Waihopai and Daffodil Bay eutrophic sites differ from the other estuary sites (Figure 8).

As previously explained, ten core samples were analysed at each of the gross eutrophic sites, Waihopai Arm (Sites F) and Daffodil Bay (Site E), for the presence of macroinvertebrates. The samples were taken from the dominant habitat type in each arm, i.e. muddy, anoxic, sulphide rich sediments overlain with a thick layer of partially decaying macroalgae. Three cores were also collected as part of the 2011 preliminary assessment of the Waihopai Arm eutrophic site (Sites 2011 NR W 1,2,3 in Figure 5).

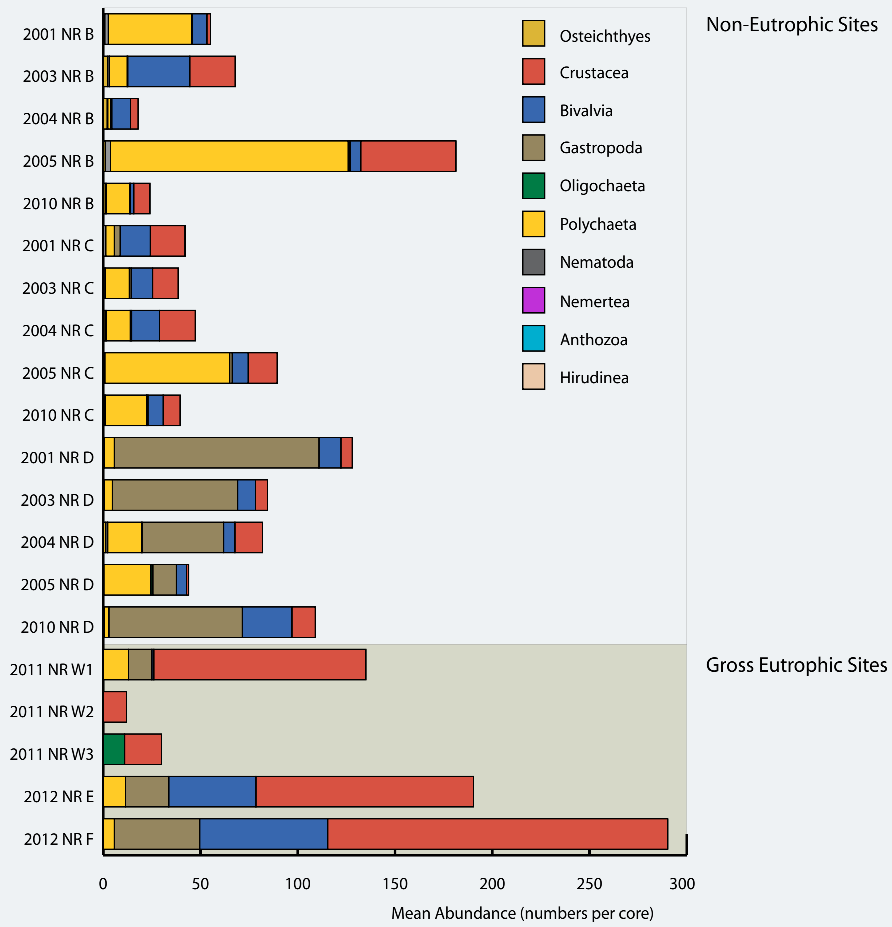


Figure 5. Mean abundance of major infauna groups, New River Estuary, 2001-2012.

Muddy, anoxic sediment conditions, combined with decaying algae, favour surface feeding organisms (particularly crustacea, gastropods, bivalves and some polychaetes), rather than subsurface animals that feed on deposits within the sediments (Figure 6). The gross eutrophic sites included the following taxa in relatively large numbers:

- The tube-dwelling crustacean amphipod *Paracorophium excavatum*, which is the dominant corophioid amphipod in the South Island. *Paracorophium* is well-known as a major primary coloniser (and hence indicator) of disturbed estuarine intertidal flats (Ford et al. 1999). Examples of common disturbances are: macroalgal mats settling on the tidal flats as a result of coastal eutrophication, and mud deposition after mobilisation of fine sediments from exposed soil surfaces in the catchment. In these situations, *Paracorophium* can become very abundant and, through its burrowing activities, increases oxygen exchange, which in turn helps mitigate the effect of the disturbance.
- The scavenging predator isopod, *Exospheroma* sp. lives and burrows in the top 2cm of the sediment, and rarely grows more than 5mm in length.
- The small deposit-feeding bivalve *Arthritica bifurca*, that prefers living in muddy-sand habitats, but is tolerant to a broad range of mud contents. These bivalves do not grow more than 5mm in size and feed at a depth of greater than 2cm.
- The small native estuarine snails *Potamopyrgus sp*. that require brackish conditions for survival. They feed on decomposing animal and plant matter, bacteria and algae, and while tolerant of muds, are intolerant of anoxic sediments.
- The surface deposit feeding spionid polychaete *Scolecolepides benhami*. This spionid is very tolerant of mud, fluctuating salinities, organic enrichment and toxicants (e.g. heavy metals). It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards the low water mark.

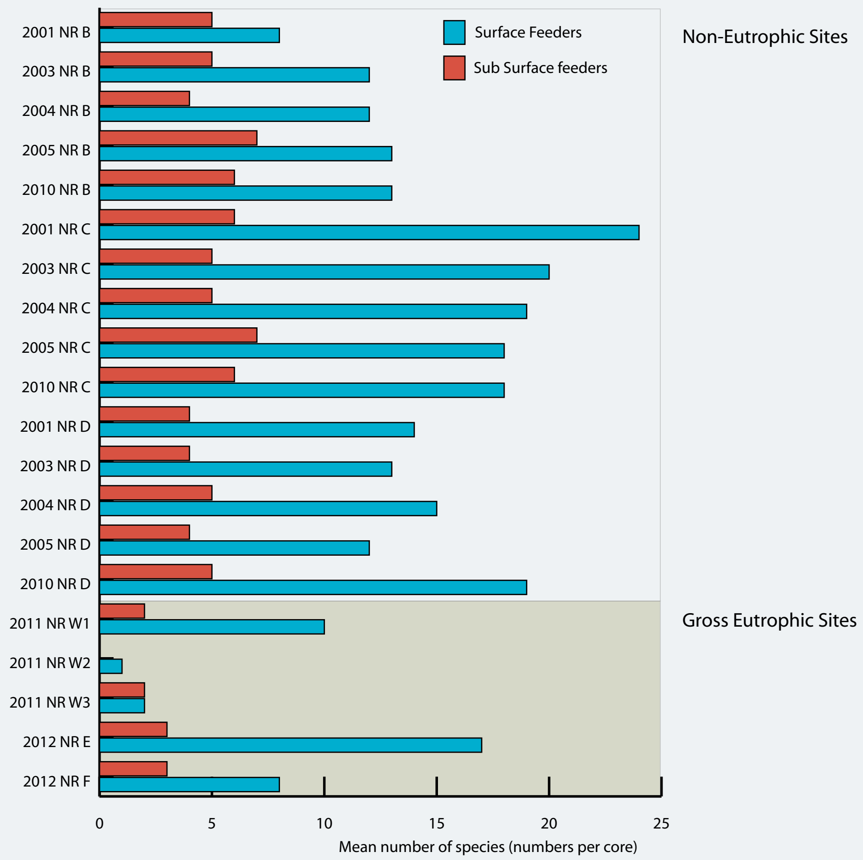


Figure 6. Mean number of species within surface and subsurface feeding groups, New River Estuary, 2001-2012.

These taxa are widely acknowledged to respond in a characteristic manner to disturbance and are sensitive to pollution. Studies on the response of invertebrates to increased clay/silt sediments (Norkko et al., 2001, and the results from a wide range of NZ estuaries (Robertson and Stevens 2013, in press), have identified all the dominant taxa as tolerant to, or preferring, increased mud content (Table 5: MUD Groups 3-5).

Table 5. Macrofauna abundance per core for New River Estuary Gross Eutrophic Site E and F (2012) and organic enrichment (AMBI) and mud (MUD) tolerance ratings. (NA=tolerance not yet ascribed).

Taxa	AMBI	AMBI Group	MUD Group	2012 NR E	2012 NR F
NEMERTEA	Nemertea sp.#2	III	3	0.1	0
POLYCHAETA	*Boccardia (Paraboccardia) syrtis*	IV	3	0.05	0
	Capitella sp.#1	V	3	0.2	0.2
	Nicon aestuariensis	III	4	1.85	1
	Prionospio aucklandica	IV	3	0.4	0
	Scolecolepides benhami	III	5	8.9	4.5
GASTROPODA	*Cominella glandiformis*	NA	3	0.05	0
	Notoacmaea helmsi	NA	2	0.2	0
	Potamopyrgus sp. or spp.	III	4	21.95	43.9
BIVALVIA	*Arthritica sp.#1*	III	3	43.05	65.8
	Austrovenus stutchburyi	III	2	1.7	0
CRUSTACEA	Amphipoda sp.#1	NA	NA	5.55	4.7
	Amphipoda sp.#2	NA	NA	14.1	0
	Amphipoda sp.#7	NA	NA	24.9	48.5
	Austrohelice crassa	NA	5	0.2	0.4
	Exosphaeroma planulum	NA	NA	15.65	31.3
	Halicarcinus varius	NA	NA	0.5	0
	Halicarcinus whitei	NA	NA	0.1	0
	Macrophthalmus hirtipes	NA	3	5.9	0.1
	Paracorophium excavatum	III	5	44.9	89.8

When compared to the other less muddy fine scale monitoring sites in New River estuary (Sites B, C and D), the macroinvertebrate mud tolerance rating was in the fair to very high range at the gross eutrophic sites, indicating a community dominated by mud tolerant taxa (Figure 7).

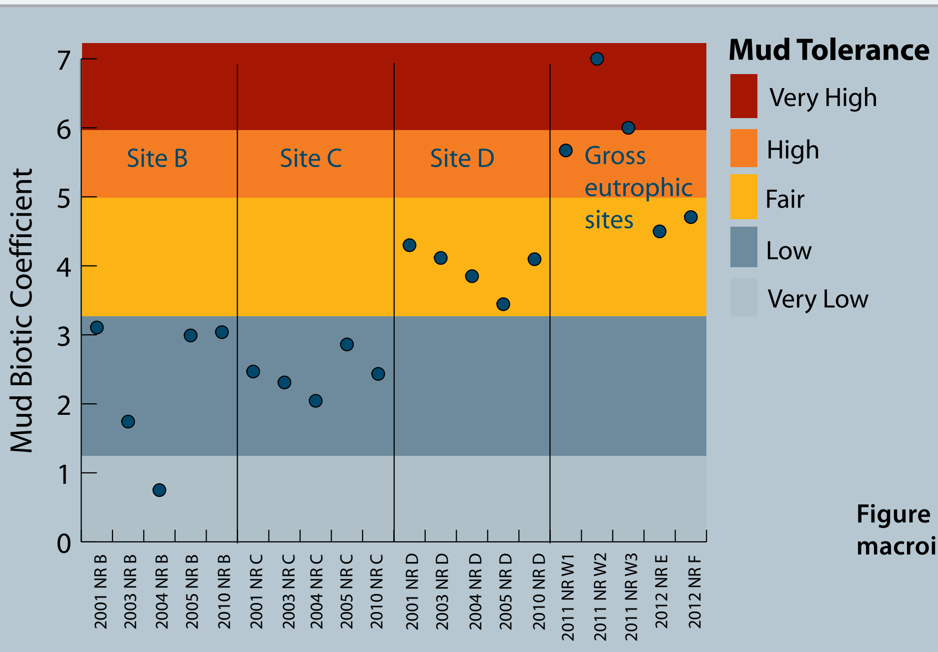


Figure 7. Mud tolerance macroinvertebrate rating.

3. Results and Discussion (Continued)

Multivariate techniques were also used to explore whether the macro-invertebrate communities at the gross eutrophic sites differed from the less disturbed fine scale sites in New River Estuary (Figure 8). Figure 8 shows that the results of the multivariate analysis (NMDS Plot) clearly portray the difference in the benthic invertebrate communities between the cleaner, less disturbed, low mud content sites (Sites B, D and C) and the muddy, eutrophic sites (Sites E, F and W). Further exploration of the data also showed that the macrofauna community was less disturbed where there was a thick macroalgal layer over anoxic sulphide rich sediments, compared to the sites with thick anoxic muds and no macroalgal layer.

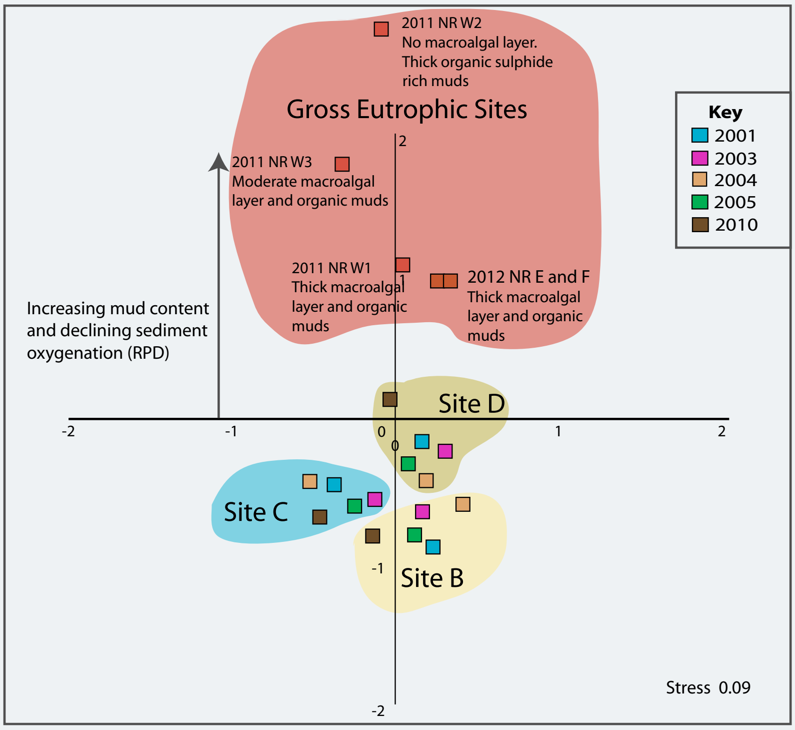


Figure 8. NMDS plot showing the relationship among mean samples in terms of similarity in macro-invertebrate community composition for New River Estuary Sites B, C, D, W, E and F for 2001-2012. The plot shows the mean of each of the 10 (or 12 in 2001) replicate samples for each site and is based on Bray Curtis dissimilarity and fourth root transformed data.

The approach involves multivariate data analysis methods, in this case non-metric multidimensional scaling (NMDS) using PRIMER version 6.1.10. The analysis basically plots the site, year and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities i.e. how low the calculated stress value is. Stress values greater than 0.3 indicate that the configuration is no better than arbitrary, and we should not try and interpret configurations unless stress values are less than 0.2.


Site NR F Waihopai Arm


Site NR F Waihopai Arm


Site NR E Daffodil Bay

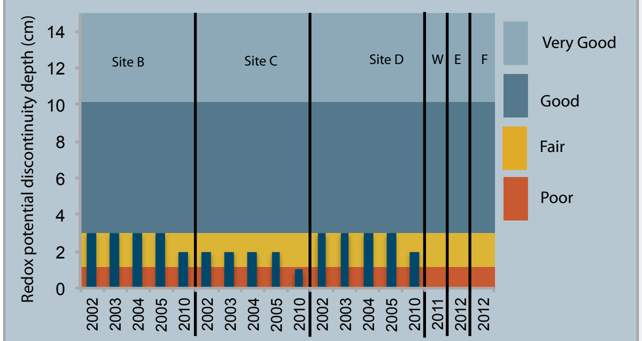


Figure 9. Redox potential discontinuity depth (RPD) at intertidal sites, 2001-2012.

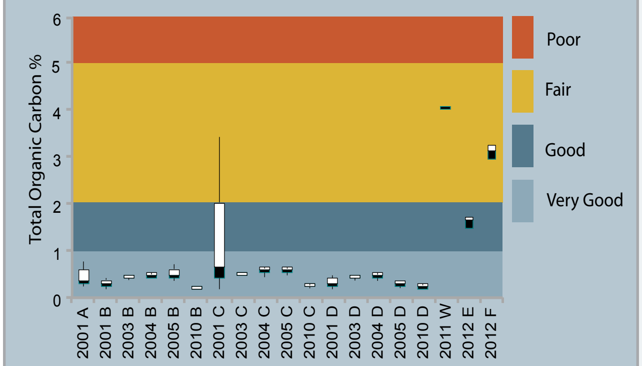


Figure 10. Total organic carbon (median, upper and lower quartiles, range) at intertidal sites, 2001-2012.

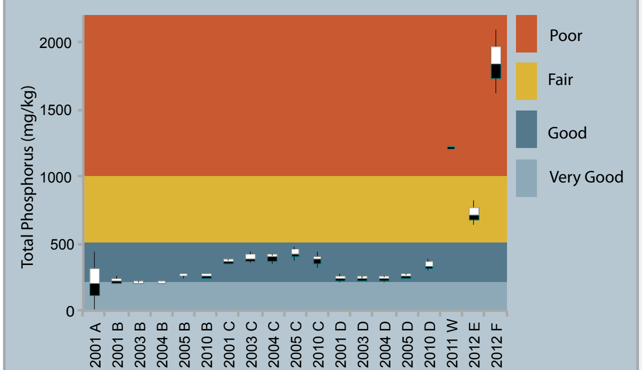


Figure 11. Total phosphorus (median, upper and lower quartiles, range) at intertidal sites, 2001-2012.

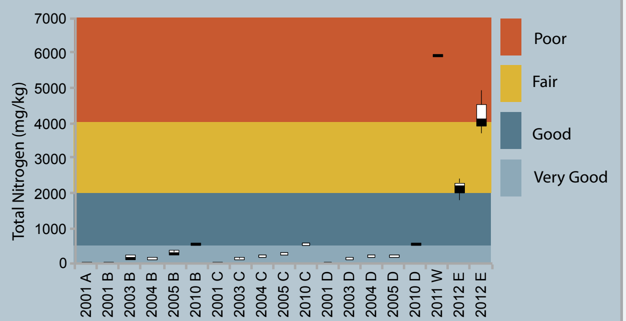


Figure 12. Total nitrogen (median, upper and lower quartiles, range) at intertidal sites, 2001-2012.

EUTROPHICATION

The primary fine scale indicators of eutrophication are grain size, RPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and the community structure of certain sediment-dwelling animals. The broad scale indicators are the percentages of the estuary covered by macroalgae and soft muds (Stevens and Robertson, in press). In tidal lagoon estuaries like New River, as organic input to the sediment increases the sediments become deoxygenated, nuisance algal growth becomes abundant, the number of suspension-feeders (e.g. bivalves and certain polychaetes) declines, and deposit-feeders (e.g. opportunistic polychaetes) increase (Pearson and Rosenberg 1978).

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary provides an indication of the level of sediment oxygenation. The results (Figure 9) showed the 2012 RPD depth at the Waihopai and Daffodil Bay eutrophic sites was at the surface (0cm), reflecting very poorly oxygenated sediments. These RPD ratings were much shallower than those measured at the main basin fine scale sites during 2002-2010. Such shallow RPD values fit the "poor" condition rating (see Section 2), with the benthic invertebrate community likely to be dominated by a few pollution-tolerant species that live near the surface.

Total Organic Carbon and Nutrients

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

In relation to the eutrophic arms of the New River Estuary (Sites E, F and W), the results (Figures 10-12) indicate very elevated concentrations of TOC, TP and TN compared with fine scale sites in less eutrophic parts of the estuary. Note, a changed TN method in 2012 is also likely to underestimate TN compared to previous values by 10-40%. Combined with the 100% macroalgal cover recorded at both sites in 2012, and the shallow RPD depths, these results confirm the eutrophic nature of these estuary arms and the oversupply of sediment nutrients in the area. Such excessive organic input, sourced either from outside the estuary or growing within it in response to high nutrient loads, is a principal cause of physical and chemical degradation and of faunal change in estuarine and near-shore benthic environments.

Macro-invertebrate Organic Enrichment Index

The benthic invertebrate organic enrichment tolerance ratings for the eutrophic arms of the New River Estuary (Sites E, F and W) ranged from 3-7 (Figure 13) and were in the "low" and "very high" categories.

However, the AMBI is considered to currently under-represent the extent of sediment degradation at the New River eutrophic sites. This is because the sediment cores had only a very few sediment dwelling species (Figure 6), contained no Type I "very sensitive" organisms, and many of the surface species (particularly Amphipoda) that dominated the eutrophic samples have not yet been ascribed tolerances to organic enrichment (Table 5). Instead, the "low" rating (indicating only slight organic enrichment) is attributed to the presence of a thick surface macroalgal layer with a relatively low mud content. This provides a temporary surface refuge and supports a diverse community of surface feeding organisms with varying tolerances to organic enrichment as they are not constantly exposed to the degraded (anoxic and sulphide-rich) conditions in the underlying sediment.

In contrast, the site that rated in the "very high" category lacked surface macroalgal growths which appeared to have been unable to survive in the sulphide rich anoxic sediments. In the absence of a surface refuge, very few species were present, and the rating reflects the harsh conditions present which are displacing both the animal and plant communities that would normally be flourishing in the area.

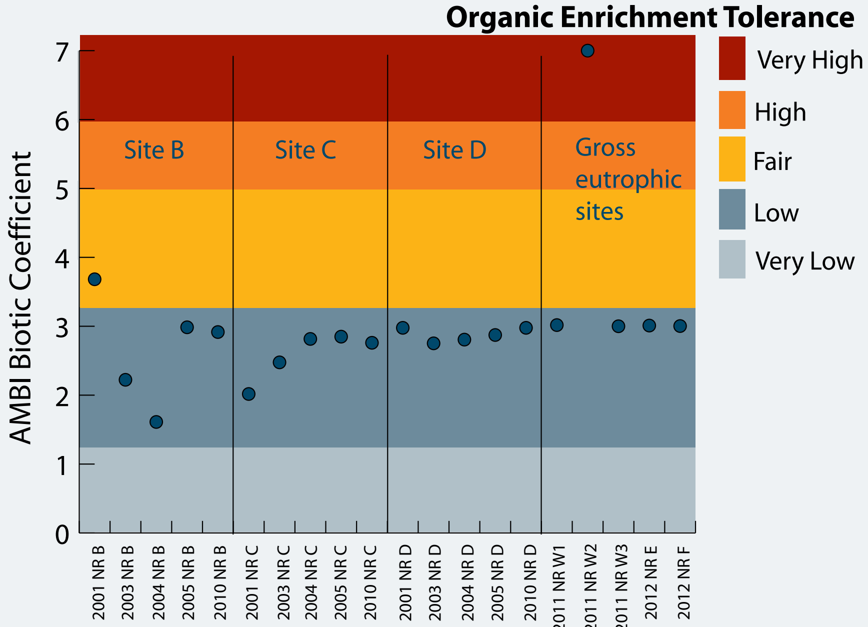
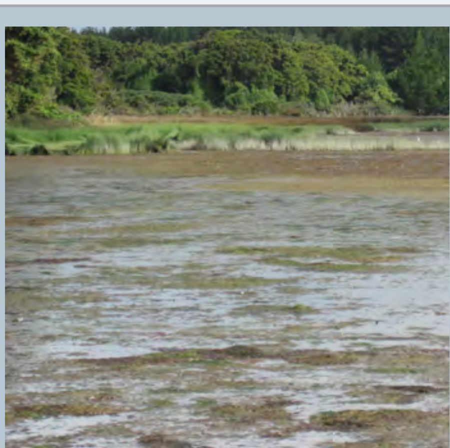
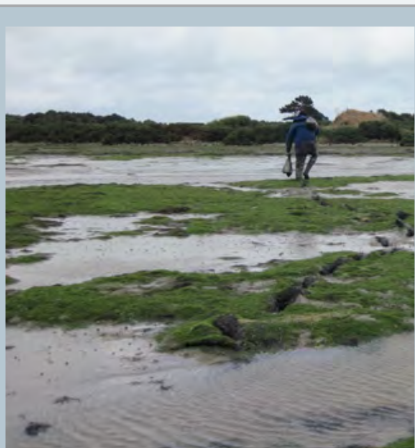


Figure 13. Organic enrichment macro-invertebrate rating, New River Estuary, 2001-2012.

Site NR F Waihopai Arm



Site NR E Daffodil Bay



Macroalgal patchiness, Waihopai Arm

TOXICITY

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at moderate concentrations at the Daffodil Bay and Waihopai eutrophic sites E, F and W, with all non-normalised values (except nickel) below the ANZECC (2000) ISQG-Low trigger values (Figure 14). However, these concentrations were much higher than those measured at the main basin sites during 2002-2010. Such conditions indicate a moderate accumulation of heavy metals in the sediments of the Waihopai and Daffodil Bay Arms of the estuary.

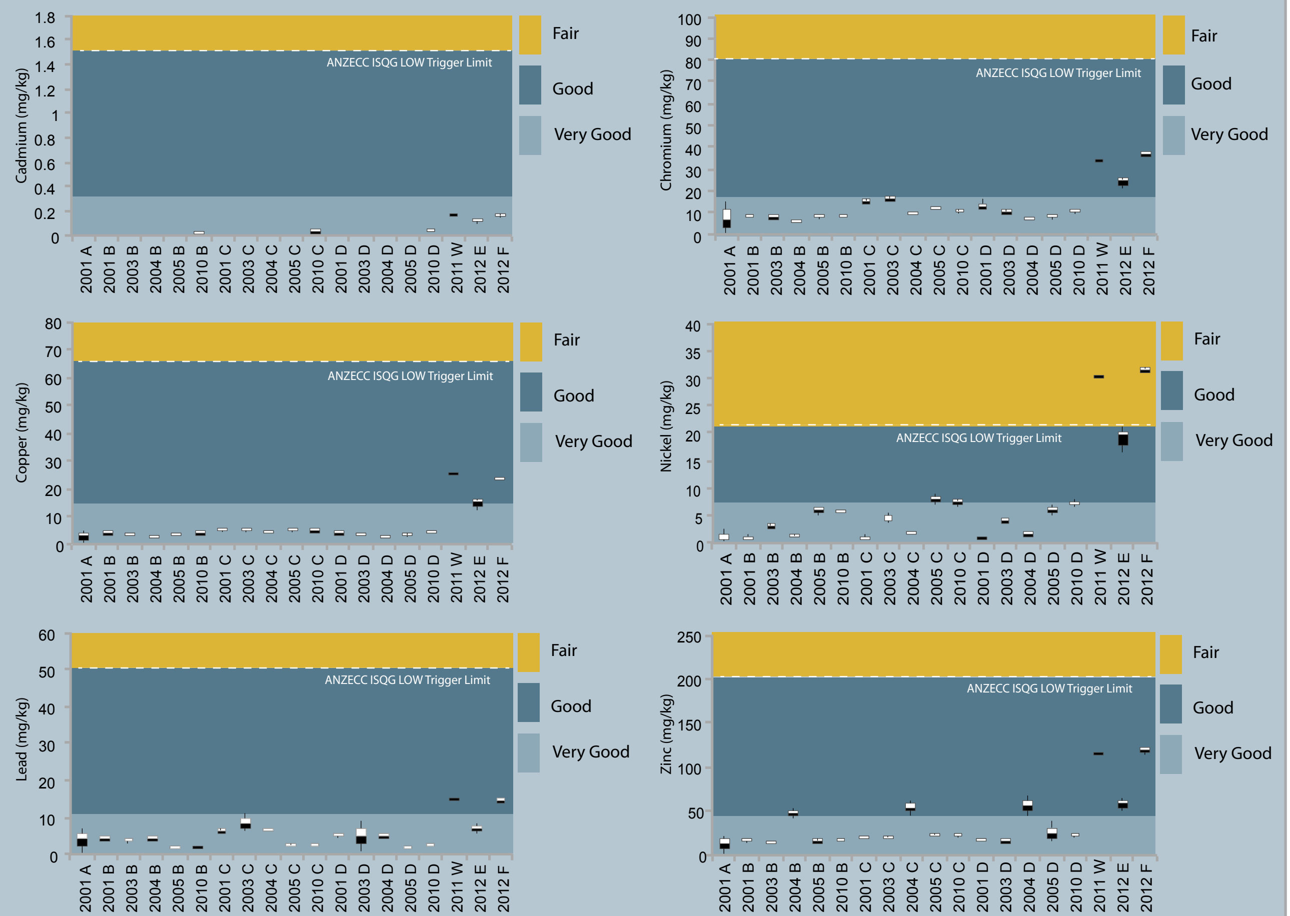


Figure 14. Sediment metal concentrations, (median, upper and lower quartiles, range) New River Estuary (2001-2012).

Site NR E Daffodil Bay

4. CONCLUSIONS

In relation to the key issues addressed by the fine scale monitoring (i.e. sedimentation, eutrophication and toxicity), the 2012 results indicate that the poorly flushed Waihopai and Daffodil Bay Arms of the estuary are excessively muddy, have high nutrients and nuisance macroalgal growths, and very poor sediment oxygenation. As a result, the macroinvertebrate community is severely degraded with little animal life able to establish in the underlying sediments, while surface feeding species are few in number and limited to those tolerant of poor conditions. Such conditions limit the food availability for fish and birdlife, and mean the ability of the estuary to assimilate nutrient and sediment loads from the catchment is exceeded. Toxicity (indicated by heavy metals) was low, but higher than measured at other fine scale sites.

Issues identified in other monitoring studies of New River Estuary include; loss of high value habitat, excessive muddiness in the main estuary, disease risk associated with shellfish consumption and bathing, and toxicity near urban stormwater drains.

The results confirm the presence of significant areas of gross eutrophic conditions in sheltered estuary arms. Results are as summarised below, and compared with earlier results for sites in the main body of the estuary, as follows:

Indicator	Gross Eutrophic Arm Sites 2011-2012	Central Estuary Fine Scale Sites 2001-2010
Oxygen Content (RPD)	RPD at 0cm - anoxic to surface	RPD 2-3cm, oxygenated surface sed.
Macrofauna	Dominated by surface feeding organisms only, especially when a surface macroalgal layer was present. The underlying sediments were so toxic (high sulphides) and low in oxygen, that animal life had difficulty establishing within the sediments.	Relatively diverse fauna with wide range of feeding groups.
Macroalgae	The vast majority of the sites had 100% cover of thick macroalgae. A relatively abundant fauna was found in the layer of decaying macroalgae on the sediment surface wherever it was present.	Low abundance of macroalgae on surface.
Nutrients and Organic Matter	Concentrations of nitrogen, phosphorus and organic carbon in the sediments were extremely elevated ("fair" to "poor" condition rating).	Concentrations of nitrogen, phosphorus and organic carbon in the sediments were relatively low ("good" to "very good" condition rating).
Mud Content	Very elevated (56-95% mud).	Relatively low (<6% mud).
Sedimentation Rate	High to Very High mean rate (7-41mm/yr) over the past 5 years. Annual deposition of 60-80mm/yr for each of the past 3 years at Waihopai Central site.	Baseline established in 2011. Initial results variable but indicate no significant adverse deposition at fine scale sites.
Heavy Metals	Heavy metals concentrations elevated compared to sites in the main estuary basin, but still less than ANZECC (2000) ISQG-Low trigger values (except for nickel).	Concentrations of heavy metals were relatively low and all less than ANZECC (2000) ISQG-Low trigger values.

The presence of these extreme conditions at the Waihopai and Daffodil Bay sites is predominantly due to the sheltered nature of these arms and their propensity to act as natural settling areas for fine sediment and macroalgae.

Monitoring has shown these areas have undergone significant and rapid degradation over the past five years, with conditions much worse than previously seen in the estuary. As such they provide clear evidence that significant siltation and eutrophication problems are occurring, and serve as an early warning that if management action is not taken, these problems will continue to worsen and begin to impact on the wider estuary.

It is therefore recommended that the Waihopai and Daffodil Bay sites be included in the long term monitoring estuary programme, and that catchment nutrient and sediment guideline criteria be developed for the estuary. The development of nutrient and sediment guideline criteria for New River Estuary is scheduled to be undertaken in 2012/13.

5. MONITORING

New River Estuary has been identified by Environment Southland as a high priority for monitoring, and is a key part of their coastal monitoring programme being undertaken in a staged manner throughout the Southland region. The future monitoring recommendations are outlined as follows:

Fine Scale Monitoring.

Monitor Daffodil Bay and Waihopai Arm Sites E and F in February 2013, 2014 and again in February 2015 when the 5 yearly fine scale trend monitoring falls due.

Macroalgal and Seagrass Monitoring.

Continue with the programme of annual broad scale mapping of macroalgae. Next monitoring due in February 2013. In addition, in order to assess changes in seagrass cover (particularly in the Waihopai Arm), it is recommended that seagrass cover be monitored annually in priority areas in tandem with the macroalgal monitoring.

Broad Scale Habitat Mapping.

Continue with the programme of 5 yearly broad scale habitat mapping. Next monitoring due in February/March 2017.

Sedimentation Rate Monitoring.

Because sedimentation is a priority issue in the estuary it is recommended that sediment plate depths be measured annually.

6. MANAGEMENT

Eutrophication and sedimentation have been identified as major issues in New River Estuary since at least 1973 (Blakely 1973), with worsening conditions reported since 2007-2008 (Robertson and Stevens 2007, Stevens and Robertson 2008), as has been the case for several other Southland estuaries (e.g. Jacobs River, Waimatuku and Waituna Lagoon).

To address these issues, it was recommended in 2011 that catchment nutrient and sediment guideline criteria be developed for each estuary type in Southland in a prioritised fashion to derive thresholds protecting against adverse sediment and nutrient impacts. Assessment of the extent to which catchment loads meet guideline criteria will enable ES to sustainably manage the estuary and its surroundings. If catchment inputs can be assimilated by the estuary, it will flourish and provide sustainable human use and ecological values in the long term. If catchment loads exceed the estuary's assimilative capacity, it will continue to degrade. New River Estuary was identified as the first priority for this work because of its current extent and rate of degradation, and will be undertaken in 2012/13.

7. ACKNOWLEDGEMENTS

Many thanks to Ben Robertson (Wriggle) for assistance with fieldwork and macrofauna sample processing. This survey and report has been undertaken with the support and assistance from Greg Larkin (Coastal Scientist, Environment Southland).

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APPENDIX 1. ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Air dry (35 degC, sieved to pass 2mm and 63um sieves, gravimetric - (% sand, gravel, silt)	N/A
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05 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	Cawthron	APHA 21st Edn 4500N C	50 mg/kg dry wgt

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

APPENDIX 2. 2012 DETAILED RESULTS

Station Locations

Daffodil Bay Site E	NRE E 1	NRE E 2	NRE E 3	NRE E 4	NRE E 5	NRE E 6	NRE E 7	NRE E 8	NRE E 9	NRE E 10
NZTM_E	1239260	1239264	1239266	1239270	1239273	1239276	1239280	1239283	1239286	1239289
NZTM_N	4842398	4842402	4842404	4842408	4842410	4842415	4842415	4842420	4842423	4842425
Waihopai Site F	**NRE F 1**	**NRE F 2**	**NRE F 3**	**NRE F 4**	**NRE F 5**	**NRE F 6**	**NRE F 7**	**NRE F 8**	**NRE F 9**	**NRE F 10**
NZTM_E	1241201	1241205	1241210	1241206	1241200	1241194	1241190	1241190	1241185	1241184
NZTM_N	4846389	4846394	4846404	4846407	4846406	4846399	4846401	4846410	4846411	4846407

Physical and Chemical Results for New River Estuary (Sites D and E), 27 January 2012.

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg							
New River E	1-4	0	NA	1.35	44.4	55.1	0.5	0.09	21.0	12.2	16.5	5.6	50.0	1800	630
New River E	5-8	0	NA	1.79	62.8	36.9	0.3	0.13	26.0	15.9	21.0	7.6	62.0	2400	710
New River E	9-10	0	NA	1.79	61.7	38.0	0.3	0.13	26.0	16.5	21.0	8.0	64.0	2400	820
New River F	1-4	0	NA	3.40	88.4	9.2	2.4	0.17	36.0	24.0	32.0	14.8	120.0	4900	2100
New River F	5-8	0	NA	3.20	90.0	8.8	1.2	0.16	37.0	23.0	31.0	14.3	120.0	3700	1610
New River F	9-10	0	NA	2.80	92.3	6.3	1.4	0.15	36.0	23.0	31.0	13.7	114.0	3800	1800

* composite samples

Epifauna and macroalgal cover within 0.25m² quadrats, New River Estuary Sites E and F, 27 Jan. 2012.

Site		RPD depth (cm)	EPIFAUNA (No/0.25m² quadrat)		MACROALGAE (percent cover)		
Daffodil Bay	Rep.		*Amphibola crenata*	*Potamopyrgus* spp.	*Gracilaria chilensis*	*Ulva intestinalis*	Fine reds
New River E (strong H_2S odour)	1	0	3		95	1	
New River E	2	0		1	100	2	
New River E	3	0			100	1	1
New River E	4	0			100	5	1
New River E	5	0			100	1	1
New River E	6	0			100	1	1
New River E	7	0			100	5	2
New River E	8	0			100	1	1
New River E	9	0			100	1	2
New River E	10	0			100	1	2
Waihopai Arm	Rep.	RPD	*Amphibola crenata*	*Potamopyrgus* spp.	*Gracilaria chilensis*	*Ulva intestinalis*	Fine reds
New River F	1	0			100	100	5
New River F	2	0			90	80	
New River F	3	0			95	10	
New River F	4	0			100	40	
New River F	5	0			100	50	
New River F	6	0			95	50	
New River F	7	0			95	80	
New River F	8	0			95	70	
New River F	9	0			100	50	
New River F	10	0	1		100	80	

APPENDIX 2. 2012 DETAILED RESULTS (CONTINUED)

Macroinvertebrate Infauna for New River Estuary (Sites E and F), 27 January 2012 - numbers per core.

Taxa	AMBI	AMBI	MUD	NRE E-01	NRE E-02	NRE E-03	NRE E-04	NRE E-05	NRE E-06	NRE E-07	NRE E-08	NRE E-09	NRE E-10	NRE F-01	NRE F-02	NRE F-03	NRE F-04	NRE F-05	NRE F-06	NRE F-07	NRE F-08	NRE F-09	NRE F-10
NEMERTEA	Nemertea sp.#2	III	3			1					1												
POLYCHAETA	*Boccardia (Paraboccardia) syrtis*	IV	2				1																
	Capitella sp.#1	V	3	2																	1	1	
	Nicon aestuariensis	III	4		9	1	1	3	2	3	3	1	4	1		3		1	2	1	1	1	
	Prionospio aucklandica	IV	3	3		2					3												
	Scolecolepides benhami	III	5	16	18	13	3	22	17	9	13	9	13	5	1	6	3	3	11	5	5	6	
GASTROPODA	*Amphibola crenata*	NA	NA																				
	Cominella glandiformis	NA	3					1															
	Notoacmaea helmsi	NA	2			1		1		1			1										
	Potamopyrgus sp. or spp.	III	4											45	37	9	56	73	91	36	4	3	85
BIVALVIA	*Arthritica sp.#1*	III	3	4	18	26	17	18	7	33	12	16	52	33	92	99	124	74	93	51	61	105	106
	Austrovenus stutchburyi	III	2	4	5	4	4	7	2	4	2		2										
CRUSTACEA	Amphipoda sp.#1	NA	NA	9	2	10		13	6	14	3	14	20	1				3	14	13	14		2
	Amphipoda sp.#2	NA	NA	2	2	24	17	47	54	42	2	55	37										
	Amphipoda sp.#7	NA	NA	2	1		3	1		3	2	1		13	37	19	82	26	129	28	129	70	105
	Austrohelice crassa	NA	5																2	2			
	Exosphaeroma planulum	NA	NA											23	22	11	27	16	28	1	112	5	68
	Halicarcinus varius	NA	NA				1	5	1		1		2										
	Halicarcinus whitei	NA	NA	1	1																		
	Macrophthalmus hirtipes	NA	3	3	8	11	8	17	9	13	14	18	16					1					
	Paracorophium excavatum	III	5											18	89	37	141	7	87	4	221	196	98
Total individuals in sample				**46**	**64**	**93**	**55**	**135**	**98**	**122**	**56**	**114**	**147**	**139**	**278**	**184**	**433**	**204**	**457**	**141**	**548**	**387**	**464**
Total species in sample				**10**	**9**	**10**	**9**	**11**	**8**	**9**	**11**	**7**	**9**	**8**	**6**	**7**	**6**	**9**	**9**	**9**	**9**	**8**	**6**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Hirudinea	Hirudinea sp.1	NA	NA	Unidentified leech. Leeches are most common in warm, protected shallows where there is little disturbance from currents. Free-living leeches avoid light and generally hide and are active or inactive under stones or other inanimate objects, among aquatic plants, or in detritus. Some species are most active at night. Silted substrates are unsuitable for leeches because they cannot attach. Some species can tolerate mild pollution.
Anthozoa	*Anthopleura aureoradiata*	II	SS Optimum range 5-10% mud,* distribution range 0-15%*	Mud flat anemone, attaches to cockle shells and helps reduce the rate at which cockles accumulate parasites. Grows up to 10 mm, intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al., 2001). Very tolerant to a range of Polycyclic Aromatic Hydrocarbons (PAH's). *Anthopleura* are also tolerant to UV light, because they have mycosporine-like amino acids in their tissue which act like a biological sunscreen. It has green plant cells in its tissues that convert solar energy to food. Its column is rough with warts.
	Edwardsia sp.#1	II	NA	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.	III	I Optimum range 55-60% mud,* distribution range 0-95%*	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp	III	M Mud tolerant.	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 0.5 mm mesh sieve. Generally reside in the upper 2.5 cm of sediment. Intolerant of anoxic conditions.
Polychaeta	*Abarenicola affinis*	III	NA	An endemic species that belongs to Family Arenicolidae. Lower shore, burrowing in medium to fine, sheltered sands and discharging a pile of sandy coils on the surface. *Abarenicola affinis* thrives in organically enriched sediments. The once well-known *Abarenicola affinis* population of Wellington's Petone Beach has dwindled greatly in number since the closure of an abattoir outfall, and now Otago Harbour may have New Zealand's biggest population of lugworms.
	Aglaophamous macroura.	II	NA	A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate. Feeding type is carnivorous. Significant avoidance behaviour by other species. Feeds on *Heteromastus filiformis, Orbinia papillosa* and *Scoloplos cylindrifer* etc.
	Aonides oxycephala	III	SS Optimum range 0-5% mud*, distribution range 0-80%**.	A small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10 cm. Although Aonides is free-living, it is not very mobile and prefers to live in fine sands. Aonides is very sensitive to changes in the silt/clay content of the sediment. **But is generally tolerant of organically enriched situations.** In general, polychaetes are important prey items for fish and birds.
	Boccardia (Paraboccardia) syrtis)	IV	S Optimum range 10-15% mud,* distribution range 0-50%*	A small surface deposit-feeding spionid. Prefers low 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. Some species very sensitive to organic enrichment and usually present under unenriched conditions. Mud Tolerance; Optimum range 10-15% mud,* distribution range 0-50%*. Often found in organically enriched conditions - e.g Waihopai Arm, New River Estuary and Wellington Harbour.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaeta	*Capitella capitata*	V	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *H. filiformis*	A blood red capitellid polychaete which is **very pollution tolerant.** Common in suphide rich anoxic sediments.
	Glyceridae	II	I Optimum range 10-15% mud,* distribution range 0-95%*	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15 cm. They are distinguished by having 4 jaws on a long eversible pharynx. **Intolerant of anoxic conditions. Prefer 10-15% mud but found in wide range. Intolerant of low salinity.**
	Heteromastus filiformis	IV	I Optimum range 10-15% mud,* distribution range 0-95%*	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. Shows a preference for areas of moderate to high organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	Microspio maori	III	S Expect optimum range in 0-20% mud.	A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in low numbers in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary very abundant (5% mud, moderate organic enrichment). Prey items for fish and birds.
	Nereidae	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of high sulphide concentrations.
	Nicon aestuariensis	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. **Prefers to live in moderate mud content sediments.**
	Orbinia papillosa	1	S Optimum range 5-10% mud,* distribution range 0-50%*	Family Orbiniidae. Live in sandy or fine sand sediments. Do not have a burrow. A large non-selective deposit feeder. Endemic orbiniid. Without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant. Prefers 5-10% mud but found from 0-50% mud. Sensitive to changes in sedimentation rate. Low numbers in Bluff Harbour (2-20% mud), New River Estuary (1-6% mud).
	Owenia petersenae	II	NA	Oweniidae. Members of the Oweniidae have characteristic tubes which are considerable longer than the animal and are composed of shell fragments and sand grains which are stacked on top of each other. Oweniids often remain intact within their tubes and must be carefully removed for proper examination. *O. fusiformis* is currently thought to include a variety of species. Normally a suspension feeder, but is capable of detrital feeding. Is a cosmopolitan species frequently abundant on sandflats. **Are classified as intermediate type species along organic enrichment gradients (Pearson and Rosenberg 1978).**

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaeta	Paraonidae sp.#1	III	NA	Slender burrowing worms, selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands to a depth of 15cm. Sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content. **Aricidea prefer 35-40% mud (range 0-70% mud).**
	Pectinaria australis	I	NA	Subsurface deposit-feeding/herbivore. Lives in a cemented sand grain cone-shaped tube. Feeds head down with tube tip near surface. Prefers fine sands to muddy sands. Mid tide to coastal shallows. Belongs to Family Pectinariidae. Often present in NZ estuaries. **Density may increase around sources of organic pollution and eelgrass beds. Intolerant of anoxic conditions.**
	Phyllodocidae	II	NA	The phyllodocids are a colourful family of long, slender, and very active carnivorous worms characteristically possessing enlarged dorsal and ventral cirri which are often flattened and leaf-like (paddleworms). They are common intertidally and in shallow waters.
	Polydora sp	I	S Optimum range 10-15% mud,* distribution range 0-50%*	A Spionid. Polydora-group have many NZ species. Difficult to identify unless complete and in good condition. The Polydora group of species specialise in boring into shells. *Boccardia acus* bores into the upper exposed shell of the cockle *Austrovenus stutchburyi*. Several other Polydora group species live free in tubes in the sand. The tubes of the most widely-occurring species, *Boccardia syrtis*, form a visible fine turf on sandstone reefs and on some sand flats.
	Polynoidae	II	NA	The polynoid scale worms are dorsoventrally flattened predators. Lower intertidal and subtidal to deep sea throughout New Zealand. Conspicuous but never abundant.
	Prionospio aucklandica originally *Aquilaspio aucklandica.*	IV	I Optimum range 65-70% mud* or 20- 50%**, distribution range 0-95%*. Sensitive to changes in sediment mud content.	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was originally *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A suspension feeding spionid (also capable of detrital feeding) that **prefers living in muddy sands (65-70% mud) but does not like higher levels.** But animals found in 0-95% mud. **Commonly an indicator of increase in mud content. Tolerant of organically enriched conditions.** Common in Freshwater estuary (<1% mud). Present in Waikawa (10% mud), Jacobs River Estuary (5-10% muds).
	Sabellidae sp.#1	I	NA	Sabellids are not usually present in intertidal sands, though some minute forms do occur low on the shore. They are referred to as fan or feather-duster worms and are so-called from the appearance of the feeding appendages, which comprise a crown of two semicircular fans of stiff filaments projected from their tube.
	Scolecolepides benhami	III	MM Optimum range 25-30% mud,* distribution range 0-100%*	A Spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. **Strong Mud Preference but prefers moderate mud content (25-30% mud).** But also found in 0-100% mud environments. Rare in Freshwater Estuary (<1% mud) and Porirua Estuary (5-10% mud). Common in Whareama (35-65% mud), Fortrose Estuary (5% mud), Waikanae Estuary 15-40% mud. Moderate numbers in Jacobs River Estuary (5-10% muds) and New River Estuary (5% mud).A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary.
	Scolelepis (Microspio) sp	III	NA	A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary (5% mud),

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Polychaeta	*Scoloplos cylindrifer*	I	S Optimum range 0-5% mud,* distribution range 0-60%*	Originally, *Haploscoloplos cylindrifer.* Belongs to Family Orbiniidae which are thread-like burrowers without head appendages. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. **Prefers 0-5% mud (range 0-60% mud).** **Pollution and mud intolerant**.
	Syllidae	II	S Optimum range 25-30% mud,* distribution range 0-40%*	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers mud/sand sediments (25-30% mud).
Gastropoda	*Amphibola crenata*	NA	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	SS Optimum range 5-10% mud*, distribution range 0-10%**.	Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds. **Strong Sand Preference. Optimum mud range 5-10% mud.**
	Diloma subrostrata	NA	SS Optimum range 5-10% mud*, distribution range 0-15%**.	The mudflat top shell, lives on mudflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ. Feeds on the film of microscopic algae on top of the sand. **Strong Sand Preference . Optimum mud range 5-10% mud.**
	Notoacmaea helmsi	I	SS Optimum range 0-5% mud*, distribution range 0-10%**.	Endemic to NZ. Small grazing limpet attached to stones and shells in intertidal zone. **Intolerant of anoxic surface muds and sensitive to pollution.** **Strong sand preference 0-5% mud (range 0-10% mud).** Present in Porirua Harbour 4-5% mud, Freshwater Estuary <1% mud. A few in Fortrose (5% mud).
	Potamopyrgus estuarinus	NA	M Tolerant of muds.	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.**
Bivalvia	*Arthritica bifurca*	III	I Optimum range 55-60% mud*, or 20-40%***, distribution range 5-70%**.	A small sedentary deposit feeding bivalve, preferring a moderate mud content. Lives greater than 2 cm deep in the muds. **Prefers 55-60% mud (range 5-70% mud).**
	Austrovenus stutchburyi	II	S Prefers sand with some mud (optimum range 5-10% mud* or 0-10% mud**, distribution range 0-85% mud**).	Family Veneridae. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. **Can live in both mud and sand but is sensitive to increasing mud - prefers low mud content (5-10% but can be found in 0-60% mud). Rarely found below the RPD layer.** Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns.
	Hunkydora australica novozelandica	NA	NA	Belongs to the Family Myochamidae, large marine bivalves of the Pholadomyoida order. The valves are unequal, the left valve flat, and the right convex, and overlapping the left. DOC threat classification 7 - range restricted.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Bivalvia	*Macomona liliana*	II	S Prefers sand with some mud (optimum range0-5% mud* distribution range 0-40% mud**).	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. Adversely affected at elevated suspended sediment concentrations. Sand Preference: **Prefers 0-5% mud (range 0-60% mud).**
Bivalvia	*Mactra Ovata (Cyclomactra ovata)*	I	NA	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water. Mud Tolerance; prefers 0-10% mud (range 0-80%).
Bivalvia	*Nucula hartvigiana*	I	S Optimum range 0-5% mud,* distribution range 0-60%*	Small deposit feeder. Nut clam of the family Nuculidae (<5mm), is endemic to New Zealand. Often abundant in top few cm. It is found intertidally and in shallow water, especially in *Zostera* sea grass flats. It is often found together with the New Zealand cockle, *Austrovenus stutchburyi*, but is not as abundant. Like *Arthritica* this species feeds on organic particles within the sediment. Has a plug-like foot, which it uses for motion in mud deposits. **Intolerant of organic enrichment.** Prefers 0-5% mud (range 0-60%). High abundance in Porirua Harbour near sea (Railway and Boatshed sites). None in Freshwater Estuary.
Bivalvia	*Paphies australis*	II	SS (adults) S or M (Juveniles) Strong sand preference (adults optimum range 0-5% mud*, distribution range 0-5% mud**). Juveniles often found in muddier sediments.	The pipi is endemic to New Zealand. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7 m. **Optimum mud range 0-5% mud and very restricted to this range.** Common at mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud.
Bivalvia	*Solletellina*	I	NA	*Soletellina* is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells.
Oligichaeta	Oligochaete sp.	I ?	MM Optimum range 95-100% mud*, distribution range 0-100%**.	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Crustacea	*Amphipoda sp.1*	NA	NA	An unidentified amphipod.
Crustacea	*Austrominius modestus*	II	NA	Small acorn barnacle (also named *Elminius modestus)*. Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		Organic Enrichment Tolerance-AMBI Group *****	Mud Tolerance ****	Details
Crustacea	*Callianassa filholi*	NA	NA	Ghost shrimp, Decapoda, endemic to NZ. Makes long, semi-permanent burrows between low water of neap and spring. Up to 5 cm long it is pale milk white with coral pink. Not able to walk on a firm surface. A male and a female normally occupy a burrow. When feeding the shrimp moves close to one of the entrances.
	Copepoda	NA	NA	Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat and they constitute the biggest source of protein in the oceans. Usually have six pairs of limbs on the thorax. The benthic group of copepods (Harpactacoida) have worm-shaped bodies.
	Cumacea	NA	NA	Cumacea is an order of small marine crustaceans, occasionally called hooded shrimps. Some species can survive in water with a lower salinity rate, like in brackish water (e.g. estuaries). Most species live only one year or less, and reproduce twice in their lifetime. Cumaceans feed mainly on microorganisms and organic material from the sediment. Species that live in the mud filter their food, while species that live in sand browse individual grains of sand.
	Decapoda (larvae)	NA	NA	Unidentified crab larvae.
	Exosphaeroma sp.	NA	NA	Small seaweed dwelling isopod.
	Flabellifera	NA	NA	Flabellifera is the second largest isopod suborder.
	Macrophthalmus hirtipes	NA	I Optimum range 45-50% mud, distribution range 0-95%*.	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
	Mysidacea sp.1	II	NA	Mysidacea is a group of small, shrimp-like creatures. They are sometimes referred to as opossum shrimps. Wherever mysids occur, whether in salt or fresh water, they are often very abundant and form an important part of the normal diet of many fishes
Osteichthyes	*Peltorhamhus novaezelandiae*	NA	NA	Juvenile common sole. The young of many adult flatfish species are strongly dependent on estuarine areas. In New River Estuary many juvenile flatfish inhabit the small channels at low tide and are preyed on by other fish. Flatfish depend on benthic invertebrates as a food source with a diet consisting of mainly small crabs, worms and crustaceans. Flatfish are fast growing and are a relatively dependable fishery from year to year.
Pycnogonidae	Pycnogonid sp.	I	NA	Sea spiders either walk along the bottom with their stilt-like legs or swim just above it using an umbrella pulsing motion. Most are carnivorous and feed on cnidarians, sponges, polychaetes and bryozoans. Sea spiders are generally predators or scavengers. They will often insert their proboscis, a long appendage used for digestion and sucking food into its gut, into a sea anemone and suck out nourishment. The sea anemone, large in comparison to its predator, almost always survives this ordeal. Studies have shown that adult taste preferences depend on what the animals were fed as young.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

NA=Not Allocated

* Preferred and distribution ranges based on findings from the Whitford Embayment in the Auckland Region (Norkko et al. 2001).
** Preferred and distribution ranges based on findings from 19 North Island estuaries (Gibbs and Hewitt 2004).
*** Preferred and distribution ranges based on findings from Thrush et al. (2003)

**** Tolerance to Mud Codes are as follows (from Gibbs and Hewitt, 2004, Norkko et al. 2001) :

1 = SS, strong sand preference.
2 = S, sand preference.
3 = I, prefers some mud but not high percentages.
4 = M, mud preference.
5 = MM, strong mud preference.

***** AMBI Sensitivity to Organic Enrichment Groupings (from Borja et al. 2000)

Group I. Species very sensitive to organic enrichment and present under unpolluted conditions (initial state). They include the specialist carnivores and some deposit-feeding tubicolous polychaetes.

Group II. Species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.

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

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

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

The distribution of these ecological groups, according to their sensitivity to pollution stress, provides a Biotic Index with 5 levels, from 0 to 6.