coastalmanagement

# New River Estuary

## Fine Scale Monitoring of Highly Eutrophic Arms 2012/2013

Prepared for

**Environment Southland**

**October 2013**

**Cover Photo: Central Waihopai Arm, New River Estuary.**


Oioi (jointed wire rush) beds in upper Waihopai Arm, New River Estuary.

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By

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# Contents



## List of Tables



## List of Figures

# NEW RIVER ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the baseline 2012-2013 fine scale monitoring of two intertidal sites in eutrophic, poorly flushed areas of the Waihopai Arm (500ha) and Daffodil Bay Arm (160ha) within New River Estuary, a large (4,100ha) tidal lagoon estuary near Invercargill (with other fine scale results also presented for comparison). It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. The following sections summarise the fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

## FINE SCALE RESULTS

- In Daffodil Bay and the Waihopai Arm, sediments were very muddy (40-95% mud) and poorly oxygenated (Redox Potential Discontinuity - RPD layer at the surface).
- Mean sedimentation rates (infilling with mud) in Waihopai Arm since 2007 have been very high (14-34 mm/yr).
- At both sites the invertebrate community was dominated by mud and organic enrichment tolerant surface feeding species. Very few species were present within the underlying anoxic and sulphide-rich muds.
- Sediment nutrients and organic carbon were very elevated.
- Heavy metals were below the ANZECC (2000) ISQG-Low trigger values (i.e. low metal toxicity), but concentrations were much higher than at fine scale sites in the well flushed central basin of New River Estuary.

## CONDITION RATINGS

| | Fine Scale Monitoring Sites (located in the well flushed central basin) | | | | | | | | | | | | | | | Eutrophic Sites | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Site B (Shellbanks) | | | | | Site C (Daffodil Bay) | | | | | Site D (Lower Oreti) | | | | | E | E | W | F | F |
| Eutrophic Sites W & F = Waihopai Arm<br>Eutrophic Site E = Daffodil Bay | 2001 | 2003 | 2004 | 2005 | 2010 | 2001 | 2003 | 2004 | 2005 | 2010 | 2001 | 2003 | 2004 | 2005 | 2010 | 2012 | 2013 | 2011 | 2012 | 2013 |
| Inverts: Mud and Enrichment Tolerance | Good | Good | Good | Very Good | Good | Good | Good | Good | Very Good | Very Good | Good | Good | Good | Good | Good | Fair | High/Poor | High/Poor | Fair | Fair |
| Sediment Mud Content | Very Good | Very Good | Very Good | Good | Good | Good | Good | Good | Fair | Fair | Very Good | Very Good | Very Good | Very Good | Good | High/Poor | High/Poor | High/Poor | High/Poor | High/Poor |
| 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 | High/Poor | High/Poor |
| Total Organic Carbon (TOC) | 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 | High/Poor | High/Poor | Fair | High/Poor |
| Total Nitrogen (TN) | 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 | Good-Very Good | High/Poor | High/Poor | Fair |
| Total Phosphorus (TP) | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Fair | Fair | High/Poor | High/Poor | High/Poor |
| 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 | Good | Good |

**Key To Ratings**: Baseline est. | High/Poor | Fair | Good | Good-Very Good | Very Good

## ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the fine scale monitoring (i.e. sediment muddiness, eutrophication, and toxicity), the results indicate that the poorly flushed Waihopai Arm and Daffodil Bay are excessively muddy, have high nutrients and nuisance macroalgal growths, and contain sediments with toxic sulphides and poor sediment oxygenation. As a result, the macro-invertebrate 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 indicate the ability of the estuary to assimilate nutrient and sediment loads from the catchment is exceeded. Non-eutrophication related toxicity (indicated by heavy metals) was low, but higher than measured at other fine scale sites.

The cause of these extreme conditions is almost certainly attributable to excessive catchment nutrient input loads, exacerbated by the sheltered nature of these arms and their propensity to act as natural settling areas for fine, organic and nutrient enriched, sediment. Such enrichment encourages the growth of short-lived nuisance macroalgae which, in turn, degrades the existing habitat and has caused the loss of high value seagrass and healthy macro-invertebrate communities.

## 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). In response to these issues, ES is currently undertaking a comprehensive estuary sediment and trophic status assessment, including identification of appropriate management measures (e.g. nutrient and sediment load guidelines) for the estuary, as well as source tracking of catchment sediments and nutrients.

In order to assess ongoing trends in the fine scale condition of the estuary, it is recommended that the established eutrophic sites be monitored in Feb. 2014 and again in 2015 when the 5 yearly fine scale trend monitoring at the existing central basin sites falls due. Sedimentation rates, targeted seagrass monitoring, and estuary-wide macroalgal monitoring should continue annually, with broad scale mapping repeated 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** of the estuary to major issues (Table 1) and appropriate monitoring design. This component 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 2012).

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 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 has 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 annual broad scale macroalgal monitoring (Stevens and Robertson 2011, 2012, 2013), 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 intensification of catchment landuse over the last 10 years.

These eutrophication symptoms have not been conspicuous in the central basin fine scale monitoring results to date because the sites are located in the relatively well flushed intertidal margins 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). This monitoring was repeated in February 2013 and the results 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 it has also lost large areas through drainage and reclamation. The Waihopai Arm has been most affected with approximately 1,200ha (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 | |
|---|---|
| **Sediment** | Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived. |
| **Nutrients** | Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there. |
| **Disease Risk** | Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time. Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds. Diseases linked to pathogens include gastro-enteritis, 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 common-place 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 NEMP indicators** (shading signifies indicators used in this fine scale assessment).

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

# 2. METHODS

## FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the NEMP (Robertson et al. 2002) and provides detailed information on the condition of the estuary. Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary) 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 60m x30m area was marked out and divided into 12 equal sized plots. Ten plots were selected, and a random position defined within each where the following sampling was undertaken:

**Physical and chemical analyses.**

- Within each plot, 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 RPD depth recorded.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details in Appendix 3):
  - Grain size/Particle size distribution (% mud, sand, gravel).
  - Nutrients - total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC).
  - Trace metal contaminants (Cd, Cr, Cu, Ni, Pb, Zn). Analyses were based on whole sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

**Epifauna (surface-dwelling animals).**

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

**Infauna (animals within sediments).**

- One randomly placed sediment core was taken from each of ten plots using a 130mm diameter (area = 0.0133$m^2$) 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).

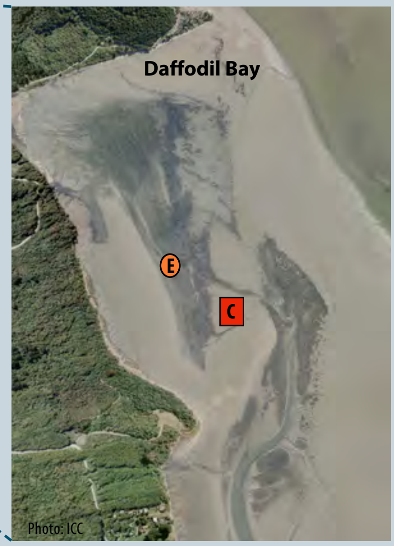
**Sedimentation Plate Deployment.**

Determining ongoing sedimentation rates involves measuring how much sediment builds up over buried plates over time. In 2007, three sites were established in the Waihopai Arm (see Stevens and Robertson 2007). At each site, four plates (20cm square concrete pavers) were buried ~30m apart in a square configuration deep in the sediments where stable substrate was located. In 2011, an additional 4 plates were buried at each of fine scale sites B, C and D in the central basin of the estuary, each located 5m, 10m, 20m, and 25m on a transect between two fine scale site corner pegs (see Stevens and Robertson 2011 for details).

Each plate position was logged by GPS and marked with adjacent wooden stakes. Plate depths are measured by clearing away surface debris or macroalgae, placing a 2m straight-edge on the sediment surface above each plate (to average out small surface irregularities), pushing a probe through the sediment until it hits the buried plate, and recording the mean depth from the sediment surface to the top of the buried plate (see Appendix 2 for data). Buried plates, measured every 1-5 years, will provide a long-term measure of mean sedimentation rates in the estuary.



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.**

## CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented below) has been proposed for New River Estuary (based on the ratings first developed for Southland's estuaries - e.g. Robertson & Stevens 2006). The ratings are based on relevant estuary monitoring data, guideline criteria, and expert opinion, and are regularly reviewed. They are screening tools 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).

## Wriggle Estuary Benthic Index (WEBI)

When representative sites are surveyed, soft sediment macrofauna can be used to represent benthic community health and classify estuary condition. The AZTI (AZTI-Tecnalia Marine Research Division, Spain) Marine Benthic Index (AMBI) (Borja et al. 2000) has previously been used to classify NZ estuary macrofauna, but because the AMBI ratings include non-estuarine habitats, and are primarily drawn from overseas data, an index specific to NZ estuaries has been developed by Wriggle. Robertson (2013) produced mud and organic matter sensitivity ratings for 99 NZ estuary taxa from estuaries throughout NZ with funding from Wriggle and 3 NZ Regional Councils (Southland, Wellington and Waikato). Each taxa was allocated one of 5 sensitivity groupings (see Appendix 3) for use within a new index, the "Wriggle Estuary Benthic Index" (WEBI) that calculates an integrated mud and organic enrichment rating for a site. The equation to calculate the WEBI biotic coefficient (BC) is:

$$BC = \{(0 \times \%Rating1) + (1.5 \times \%Rating2) + (3 \times \%Rating3) + (4.5 \times \%Rating4) + (6 \times \%Rating5)\}/100.$$

The WEBI has been verified in relation to both mud content and total organic carbon for a wide range of NZ estuary types and regions, and is a valuable extension to the NZ National Estuary Monitoring Protocol (Robertson et al. 2002). The WEBI is particularly useful in detecting temporal and spatial impact gradients related to sediment and eutrophication stressors. However, if toxicity levels (apart from toxicity related to eutrophic conditions, i.e. elevated sulphide or ammonia) exceed levels that cause biotic stress, its robustness can be reduced and interpretation of results needs to account for this.

**WRIGGLE ESTUARY BENTHIC INDEX - WEBI (Mud and Organic Enrichment)**

| RATING | DEFINITION | BC | RECOMMENDED RESPONSE |
|---|---|---|---|
| Very Good | Intolerant of mud and organic matter | 0-1.2 | Monitor 5 yearly after baseline established |
| Good | Tolerant of slight mud and organic matter | 1.2-3.3 | Monitor 5 yearly after baseline established |
| Fair | Tolerant of moderate mud and organic matter | 3.3-5.0 | Monitor 5 yearly after baseline est. Initiate ERP |
| Poor | Tolerant of high mud and organic matter | 5.0-6.0 | Post baseline, monitor yearly. Initiate ERP |
| Very Poor | Very tolerant of high mud and organic matter | >6.0 | Post baseline, monitor yearly. Initiate ERP |
| Early Warning Trigger | Trend to more tolerant species | >3.3 | Initiate Evaluation and Response Plan |

## Sediment Mud Content

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

**SEDIMENT MUD CONTENT**

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

## 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 ERP |
| Very High | >10mm/yr | Monitor yearly. Manage source |
| Early Warning Trigger | Rate increasing | Initiate Evaluation and Response Plan |

## 2. Methods (Continued)

**Redox Potential Discontinuity (sediment oxygenation)**

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

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

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

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

**Total Organic Carbon**

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, which contribute to the release of excessive nutrients and have adverse impacts on biota - key symptoms of eutrophication. Hyland et al. (2005) recently expanded upon the Pearson and Rosenberg (1978) model (which describes benthic community response along an organic enrichment gradient) by using it as a conceptual basis for defining lower and upper thresholds in total organic carbon (TOC) concentrations corresponding to low versus high levels of benthic species richness in samples from seven coastal regions of the world. Specifically, it was shown that risks of reduced macrobenthic species richness from organic loading and other associated stressors in sediments should, in general, be relatively low where TOC values were <1%, and relatively high where values were >3.5%.

While not a direct measure of causality (i.e. it does not imply that the observed bioeffect was caused by TOC itself), it was anticipated that these TOC thresholds may serve as a general screening-level indicator, or symptom, of ecological stress in the benthos from related factors. Such factors may include high levels of ammonia and sulphide, or low levels of dissolved oxygen associated with the decomposition of organic matter, or the presence of chemical contaminants co-varying with TOC in relation to a common controlling factor such as sediment particle size. Magni et al. (2009) confirmed similar TOC categories for Mediterranean coastal lagoons (high values >2.8% TOC) and Robertson (2013) recently confirmed similar TOC categories for a wide range of NZ estuaries (high values at 2.3%).

Based on these newly available data, the TOC Condition Rating has been modified as follows:

| TOTAL ORGANIC CARBON CONDITION RATING | | |
|---|---|---|
| RATING | DEFINITION | RECOMMENDED RESPONSE |
| Very Good | <1% | Monitor at 5 year intervals after baseline established |
| Good | 1-1.5% | Monitor at 5 year intervals after baseline established |
| Fair | >1.5-2.5% | Monitor at 2 year intervals and manage source |
| Poor | >2.5% | 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 |

**Metals**

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

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

**Waihopai Arm eutrophic Site F (2013)**

# 3. RESULTS AND DISCUSSION

The results and discussion section is divided into an assessment of the key biotic indicator, macro-invertebrate condition, followed by an analysis of the primary environmental variables in relation to the key estuary problems that the fine scale monitoring is addressing: eutrophication, sedimentation and toxicity.

A summary of the 2013 monitoring results from eutrophic sites in the Waihopai Arm and Daffodil Bay is presented in Table 3 (detailed results presented in Appendix 2), along with summary results of the 2012 monitoring (Robertson and Stevens 2012) and the 2011 Waihopai Arm synoptic survey (Robertson and Stevens 2011). Table 3 also includes long term fine scale monitoring results (2001-2005 and 2010) from the central basin of the estuary - (see Robertson and Stevens 2010). Sedimentation rate monitoring results are summarised in Table 4 with detailed results in Appendix 2.

**Table 3. Summary of physical, chemical and macrofauna results (means) for eutrophic sites in New River Estuary (2011-2013), and central basin fine scale NEMP monitoring sites (2001-2010).**

| | Site | RPD | TOC[a] | Mud | Sand | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | TN | TP | Abundance | Species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cm | % | | | | mg/kg | | | | | | | | No./m² | No./core |
| Eutrophic 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 | 4436 | 5.7 |
| 2012 | 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 | 6790 | 9.3 |
| | 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 | 21820 | 7.7 |
| 2013 | NR E (Daffodil) | 0 | 1.5 | 39.6 | 59.9 | 0.5 | 0.08 | 22.0 | 11.6 | 15.3 | 5.4 | 48 | 1467 | 547 | 20098 | 7.5 |
| | NR F (Waihopai) | 0 | 3.4 | 80.8 | 17.9 | 1.4 | 0.13 | 36.3 | 22.0 | 28.0 | 13.2 | 107 | 3700 | 1413 | 16354 | 9.5 |
| Fine scale monitoring sites located in the relatively well flushed central basin of New River Estuary (see Robertson and Stevens (2010) for further details). | | | | | | | | | | | | | | | | |
| 2001 | NRE Fine Scale B | 3 | 0.30 | 1.2 | 98.8 | 0.1 | <0.100[b] | 8.4 | 3.6 | 0.7 | 4.3 | 15.4 | <250[c] | 216 | 4142 | 7.7 |
| | NRE Fine Scale C | 2 | 0.60 | 2.2 | 97.6 | 0.2 | <0.100[b] | 14.9 | 4.6 | 0.6 | 6.0 | 20.0 | <250[c] | 365 | 3164 | 10.9 |
| | NRE Fine Scale D | 3 | 0.28 | 1.2 | 98.2 | 0.6 | <0.100[b] | 12.3 | 3.6 | 0.5 | 5.2 | 17.4 | <250[c] | 232 | 9618 | 8.8 |
| 2003 | NRE Fine Scale B | 3 | 0.40 | 1.0 | 99.0 | 0.1 | <0.110[b] | 7.4 | 3.2 | 3.0 | 3.5 | 12.6 | 140 | 205 | 5098 | 10.3 |
| | NRE Fine Scale C | 2 | 0.48 | 2.6 | 97.4 | 0.1 | <0.180[b] | 15.9 | 4.6 | 4.3 | 8.2 | 19.6 | 122 | 393 | 2895 | 12.0 |
| | NRE Fine Scale D | 3 | 0.40 | 1.3 | 97.9 | 0.8 | <0.120[b] | 10.1 | 3.4 | 3.9 | 5.2 | 15.0 | 127 | 231 | 6354 | 8.9 |
| 2004 | NRE Fine Scale B | 3 | 0.45 | 0.8 | 99.2 | 0.1 | <1.00[c] | 5.5 | 2.5 | 1.1 | 3.9 | 47.1 | 128 | 208 | 1346 | 6.6 |
| | NRE Fine Scale C | 2 | 0.55 | 2.5 | 97.0 | 0.5 | <1.00[c] | 9.7 | 3.9 | 1.8 | 6.5 | 54.4 | 164 | 397 | 3556 | 10.7 |
| | NRE Fine Scale D | 3 | 0.43 | 0.8 | 98.8 | 0.4 | <1.00[c] | 6.6 | 2.6 | 1.4 | 4.6 | 57.2 | 158 | 233 | 6158 | 10.6 |
| 2005 | NRE Fine Scale B | 3 | 0.48 | 4.1 | 95.9 | 0.1 | <0.05[c] | 8.1 | 3.4 | 5.8 | 1.7 | 15.4 | 286 | 260 | 13632 | 9.5 |
| | NRE Fine Scale C | 2 | 0.54 | 5.7 | 94.2 | 0.1 | <0.05[c] | 11.4 | 4.5 | 7.8 | 2.3 | 22.0 | 263 | 415 | 6722 | 11.6 |
| | NRE Fine Scale D | 3 | 0.29 | 1.9 | 98.0 | 0.1 | <0.05[c] | 8.2 | 3.0 | 5.8 | 1.8 | 24.7 | 166 | 256 | 5188 | 9.0 |
| 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[c] | 250 | 1805 | 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[c] | 380 | 2970 | 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[c] | 330 | 8196 | 9.9 |

* Synoptic assessment based on analysis of single composite sample of chemistry and 3 macro-invertebrate cores.
[a] 2001-2005 TOC values estimated from AFDW as follows: Macroalgae (NZ) 1g AFDW as equivalent to 0.38 g TOC (± 26%) based on Lundquist and Pinkerton (2008).
[b] Methodology subsequently determined to be unreliable.
[c] Below method detection limit.

## MACRO-INVERTEBRATE CONDITION

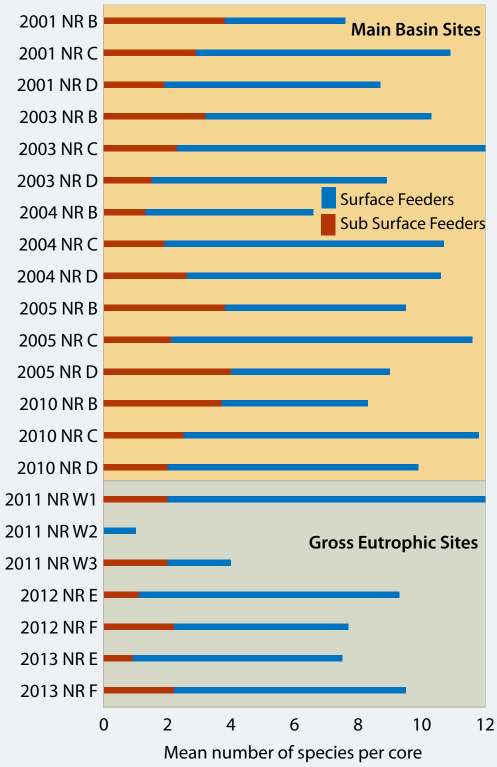
Macro-invertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong link with the sediments which, at the same time, are linked to the water column (Dauer et al. 2000). Because they integrate recent pollution history in the sediment, macro-invertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors at a community level.

The response of macro-invertebrates to stressors in New River Estuary has been examined in three steps:

1. Assessment of species richness, abundance and feeding types.
2. Assessment of the response of the macro-invertebrate community to increasing mud and organic matter over the 12 years of monitoring based on identified tolerance thresholds for NZ taxa (Robertson 2013).
3. Use of multivariate techniques to explore differences in the macro-invertebrate communities at the Waihopai and Daffodil Bay eutrophic sites, and the other New River Estuary fine scale monitoring sites.

**Species Richness, Abundance and Feeding Types**

Species richness (the mean number of species per core) in 2012 and 2013 respectively was 9.3 and 7.5 at Site E (Daffodil Bay), and 7.7 and 9.5 at Site F (Waihopai Arm). Compared to the central basin fine scale sites, there were generally fewer species per core at the gross eutrophic sites (Figure 2). The species present at the eutrophic sites were also biased towards those living on top of the sediment, or among the dense macroalgal cover present, with generally very few invertebrates living within the soft anoxic muds. This is reflected in Figure 2 which shows a reduced presence of subsurface feeders at the gross eutrophic sites compared with the main estuary basin sites.



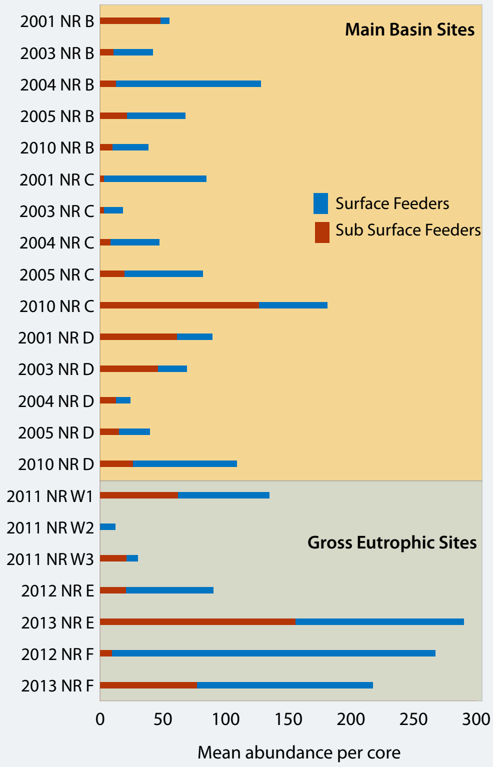




**Figure 2. Mean number of species and abundance per core plus feeding types, New River Estuary, 2001-2013.**

While the gross eutrophic sites generally had fewer species overall, and particularly fewer subsurface feeders compared to the central basin fine scale sites, mean abundance (number of individuals) per core was ~2.5 times higher (Figure 2, Table 3). Abundances at Site E were 90 and 267 in 2012 and 2013 respectively, and 290 and 218 at Site F, changes attributable primarily to variable numbers of amphipods. The combined indicators (low species richness and high (and variable) abundance) are a classic indicator of an unbalanced (degraded) community.

Also striking was the dominance of relatively mobile deposit feeders and surface scavengers at the gross sites. This is evident in Figure 3 which shows macro-invertebrate abundance was dominated by crustaceans (mostly small amphipods), and to a lesser extent gastropods and a small mud dwelling bivalve. Relatively few polychaetes were present.

Such findings are to be expected given the very muddy, anoxic sediment conditions, combined with decaying algae, which favour surface feeding organisms (particularly crustaceans, gastropods, bivalves and only some polychaetes), although it was notable that few mud crabs were present at the Waihopai Arm site. This, and the low frequency of subsurface animals that feed on deposits within the sediments, reflect the very poor sediment conditions encountered.

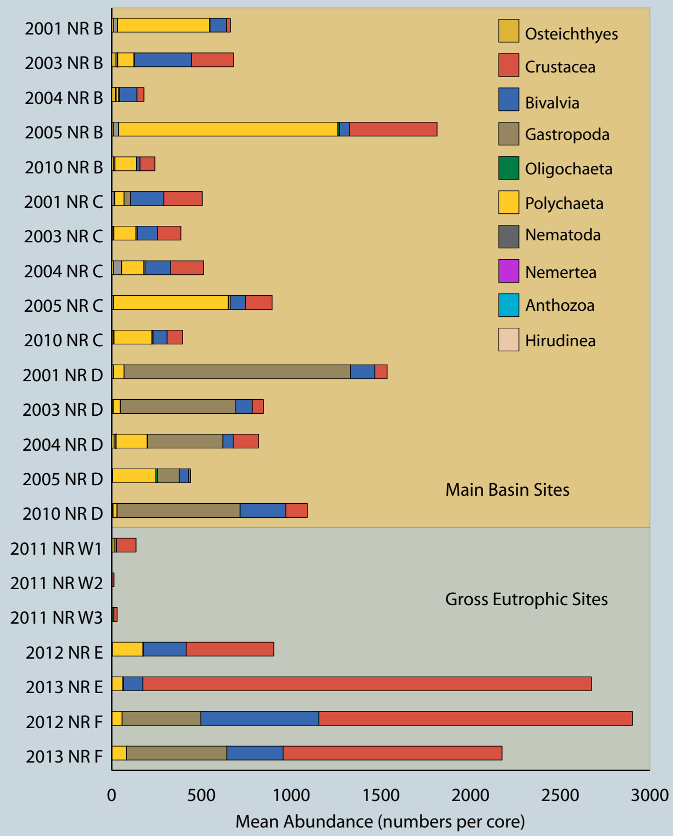



**Figure 3. Mean abundance of major infauna groups, New River Estuary, 2001-2013.**

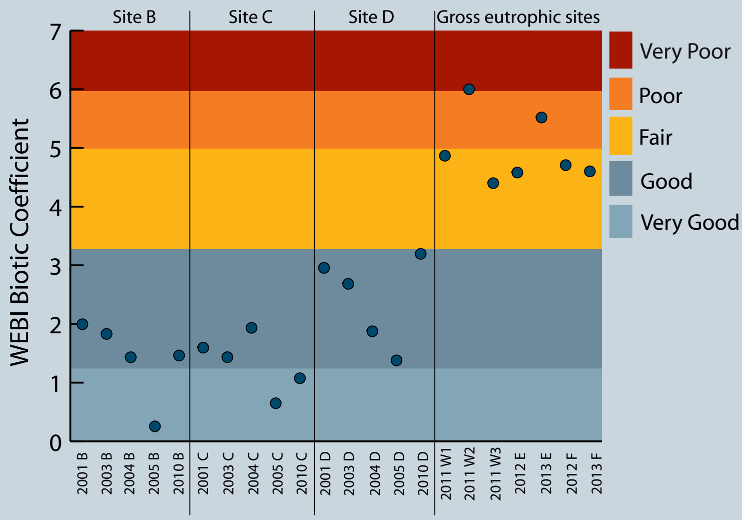



**Figure 4. WEBI mud and organic enrichment macro-invertebrate rating, New River Estuary, 2001-2013.**

### WEBI Mud and Orgaic Enrichment Index

The benthic invertebrate organic enrichment tolerance ratings (using the recently revised approach for NZ estuaries - see section on condition ratings) for the eutrophic arms of the New River Estuary (Sites E, F and W) ranged from 4-6 (Figure 4) and were in the "fair", "high" and "very high" categories. The dominance by mud and enrichment tolerant species at Sites E, F and W, supports the premise that the macro-invertebrate communities at these sites were degraded compared to those at the main basin sites.

Figure 3 highlights the dominance of species that live within the thick surface macroalgal layer that has a relatively low mud content. This provides a 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, Site W2 that rated in the "very high" category in 2011, 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 truly reflects the harsh conditions present which are displacing both the animal and plant communities that would normally be flourishing in the area.

As the macroalgal layers disappear due to seasonal influences and/or increased presence of toxic conditions, it is expected that the ratings will deteriorate further.

### Multivariate Analysis

Multivariate techniques were also used to explore the difference between the macro-invertebrate communities at the various New River Estuary sampling sites. Figure 5 (NMDS Plot) shows differences exist in the benthic invertebrate communities at the cleaner, less disturbed, low mud content sites (Sites B, C and D) and the muddy, eutrophic sites (Sites W, E and F). Further exploration of the data also shows 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.

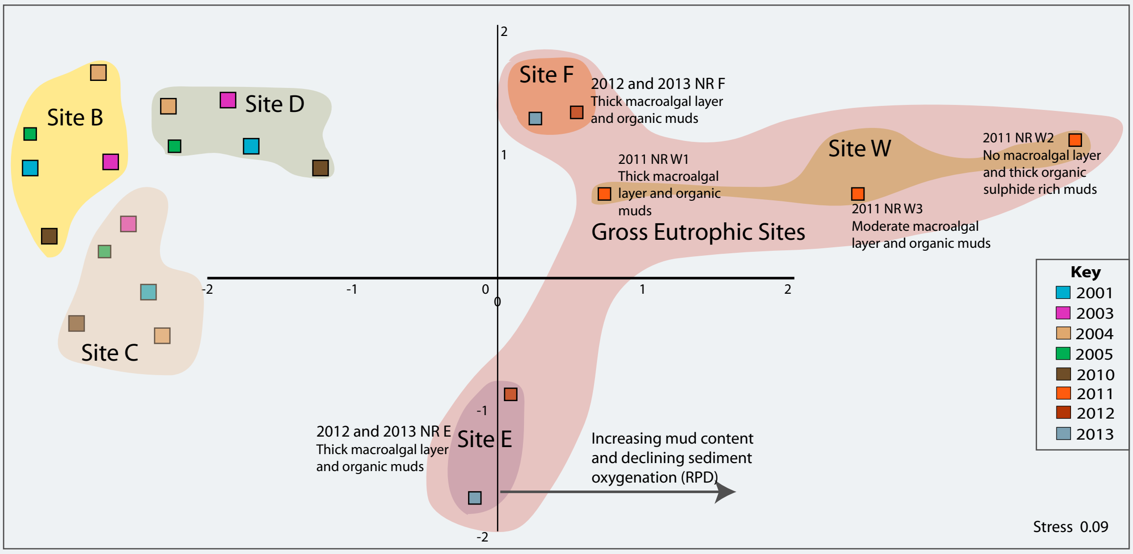



**Figure 5. NMDS plot showing the relationship among mean samples in terms of similarity in macro-invertebrate community composition for New River Estuary Sites B, C, D, W, E, F for 2001-2013. The plot shows the mean of each of the 10 (or 12 in 2001) replicate samples for each site and is based on Bray 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.

Overall, the results of the macro-invertebrate analysis indicate that the communities at the gross eutrophic sites (E, F and W) in Daffodil Bay and Waihopai Arm differed considerably from those at sites in the main basin. In particular, they were dominated by surface feeding, enrichment tolerant taxa that existed primarily within the surface macroalgal layer, rather than within the underlying anoxic muddy sediments.

**Waihopai Arm - extensive smothering macroalgal cover over previously healthy seagrass beds.**

## PRIMARY ENVIRONMENTAL VARIABLES

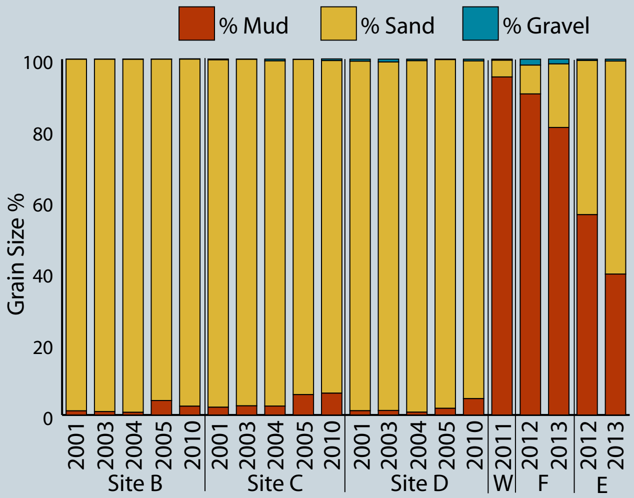



**Figure 6. Grain size results, New River Estuary, 2001-2013.**

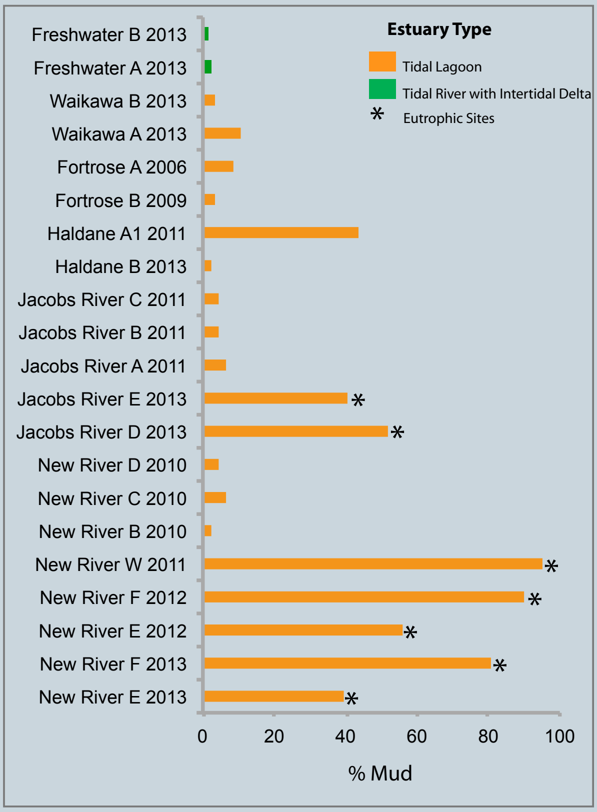



**Figure 7. Percentage of mud at fine scale sites in Southland estuaries.**

The next step is to explore the primary environmental variables that are most likely to be driving the macrobenthic response in relation to the key issues of sedimentation, eutrophication, and toxicity.

The primary variables are related to sediment ***muddiness*** - in particular sediment grain size (often the primary controlling factor) and sedimentation rate; and ***eutrophication***, commonly assessed by sediment RPD depth (a measure of both available oxygen and the presence of eutrophication related toxicants such as ammonia and sulphide), organic matter (measured as TOC), and nutrients (Dauer et al. 2000, Magni et al. 2009). The influence of non-eutrophication related ***toxicity*** is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs assessed where inputs are likely, or metal concentrations are found to be elevated.

## SEDIMENT INDICATORS

### Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments, unless in naturally erosion-prone catchments with few wetland filters, generally have a very low mud content (e.g. ~1% mud at Freshwater Estuary, Stewart Island). In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >30% mud). This is not spread evenly throughout the estuary, with mud commonly accumulating where salinity driven flocculation occurs, or in areas experiencing low energy tidal currents and waves i.e. upper estuary intertidal margins and deeper subtidal basins. Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

The grain size results (Figure 6) show that the gross eutrophic sites were dominated by very high mud contents i.e. 80-95% mud in the Waihopai Arm (Sites W and F), and 40-56% mud at Daffodil Bay (Site E). These mud results are similar to or above those recorded for eutrophic sites in Jacobs River Estuary (Figure 7), and fall in the "poor" condition rating.

In contrast, the main basin sites (Sites B, C and D) were dominated by sands (>94% sand in all years), a "good-fair" condition rating, with results similar to those from the central basin areas of other estuaries in Southland (Figure 7).

Waihopai Arm eutrophic Site F (2013) showing recent deposits of fine muds on the surface, and underlying black, sulphide-rich anoxic sediments.

**Table 4. Sedimentation rate monitoring results, New River Estuary, February 2007-February 2013.**

| SITE | Overall Rate (mm/yr) | SEDIMENTATION RATE CONDITION RATING |
|---|---|---|
| 2007-2013 | | |
| Waihopai Upper | 14.6 | VERY HIGH |
| Waihopai Central | 33.7 | VERY HIGH |
| Bushy Point | -2.7 | VERY LOW |
| 2011-2013 | | |
| NRE Fine Scale B | -9.6 | VERY LOW |
| NRE Fine Scale C | -0.1 | VERY LOW |
| NRE Fine Scale D | 16.1 | VERY HIGH |

### Sedimentation Rate

Mean annual rates of sedimentation measured at buried plates in New River Estuary are presented in Table 4, with cumulative changes above each plate shown in Figures 8 and 9.

In the central and upper Waihopai Arm, sedimentation rates measured over the past 6 years were "very high" (33.7 and 14.6mm/yr respectively), well above pre-European rates of <1mm/year, and recent historical estimates from this part of the estuary (3mm/yr from 1906-1967, and 12.7-16.4mm/yr from 1967-2007 - Robertson and Stevens 2007).

Although little change was evident at these sites from 2012-2013, Figure 8 shows that large pulses of fine sediment have deposited over very short time periods (e.g. 50-60mm in 2009-2010), and the fine sediment has remained. The thickness of fine sediment deposits shown to significantly alter macrobenthic community structure in NZ is as low as 3mm (Lohrer et al. 2004). Because the Waihopai Arm deposits are many times greater than this, and have occurred rapidly, the resident macro-invertebrate community would almost certainly have been smothered or displaced, while the rapid loss of seagrass from this part of the estuary is also likely to be strongly related to sediment impacts. While almost certainly sourced from the catchment, ES is currently undertaking work to track the source of fine sediments (and nutrients) within the estuary.

Downstream of the obvious mud deposition zone in the Waihopai Arm, the Bushy Point site was dominated by clean sands and showed no obvious signs of sediment degradation despite previously relatively large deposits of sand (Figure 8). This is likely due to a combination of the low mud content of the sediments and flood/tidal scouring of the site quickly removing and redepositing surface sediments (e.g. 88mm of sediment has been removed over the past 2 years). The condition rating at this site was "very low".

The sediment plates established at fine scale monitoring sites in the central basin in 2011 showed no results of concern. Sites B and C were both rated "very low" and reflected slight erosion of sands. Site D, while rated "very high" in terms of the change in sediment height, simply reflects localised mobile sands and gravels being redeposited by the prevalent southwest winds and associated wave fetch that spreads sediment across the intertidal flats at this site.

Given the intensively developed pastoral nature of the catchment, and the elevated sediment yields expected from such landuse areas, the high sediment mud content and the very elevated rates of mud deposition in both Daffodil Bay and the Waihopai Arm, are not unexpected.

Taken in combination, the results indicate that sediment mud content and deposition rates are both likely to be major drivers of degraded macrobenthic condition at the Waihopai Arm and Daffodil Bay sites.

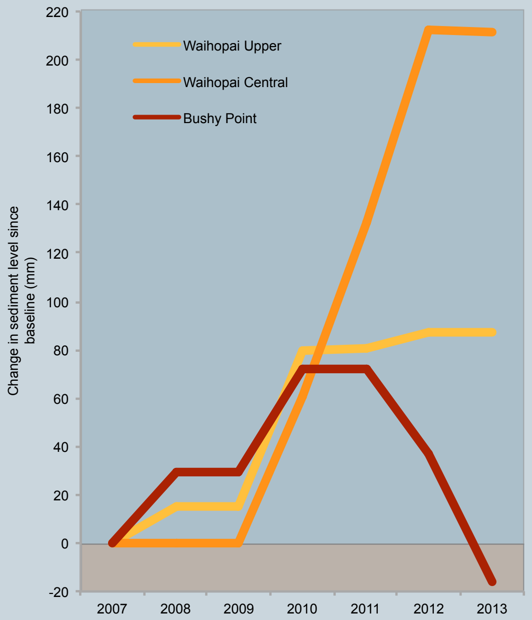



**Figure 8. Change in sediment levels over buried plates in the Waihopai Arm 2007-2013.**

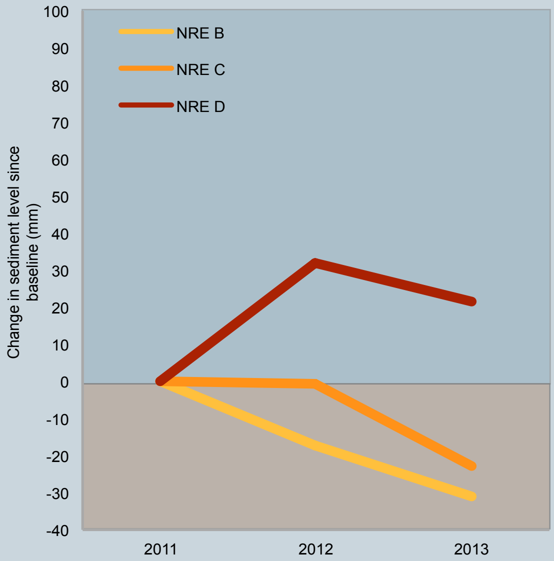



**Figure 9. Change in sediment levels over buried plates at Sites B, C, and D 2011-2013.**

CLUES model estimates, based on 2001 catchment land use, give an areal sediment load to New River Estuary of 10g.m$^{-2}$.d$^{-1}$. Because of the relatively large freshwater flows to the estuary, and its high rate of tidal flushing, a large portion of this is expected to be flushed directly out to sea. Recent work by Green (2009) in Tauranga Harbour estimated 75% of catchment derived sediment was flushed directly to sea. If 25% of catchment sediment inputs were retained in New River and spread evenly over the entire estuary, it would equate to a mean infilling rate of ~1mm/yr.

However, past monitoring shows most retained sediment settles in muddy parts of the estuary. Evenly spreading 25% of catchment sediment inputs over just the muddy parts of the estuary gives a mean infilling rate of ~7mm/yr. This is similar to the ~10mm/yr rate estimated from lead and caesium core dating from 1967-2001 in the Waihopai Arm. However, measured rates over the past 5 years (2007-2012) of 29mm/yr, and lead and caesium coring rates from 2001-2007 of 28mm/yr, suggest a significant increase in catchment sediment inputs since 2001. This is likely to have directly contributed to the current assimilative capacity of the soft mud settlement areas being exceeded.

**Macroalgal growths smothering seagrass beds in the upper Waihopai Arm (2013)**

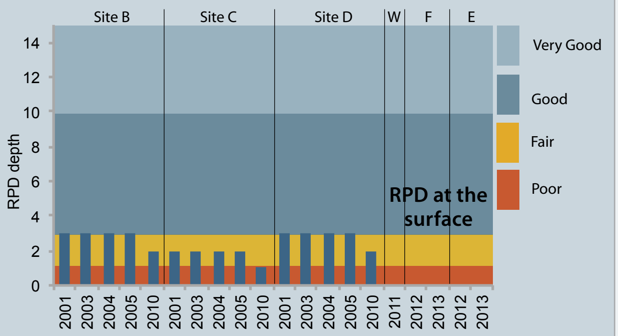



Figure 10. Redox Potential Discontinuity (RPD) depth at intertidal sites, 2001-2013.

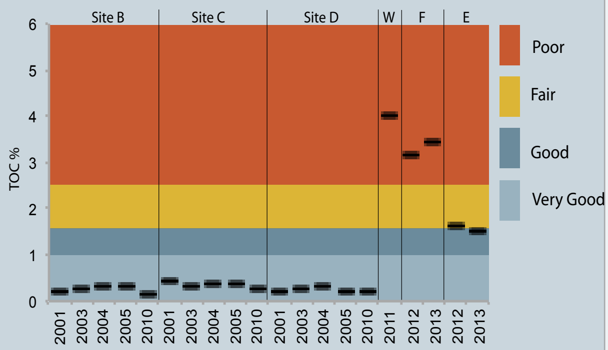



Figure 11. Total organic carbon (mean and range) at intertidal sites, 2001-2013.

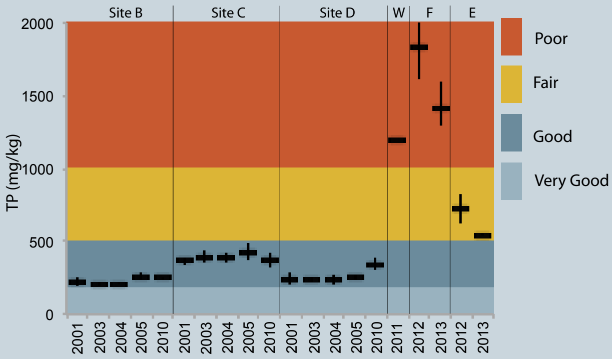



Figure 12. Total phosphorus (mean and range) at intertidal sites, 2001-2013.

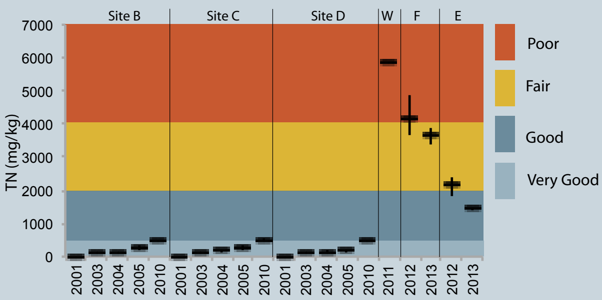



Figure 13. Total nitrogen (mean and range) at intertidal sites, 2001-2013.

## EUTROPHICATION INDICATORS

The primary variables indicating eutrophication impacts are grain size, RPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal cover.

### Grain Size

This indicator has been discussed in the sediment section and is not repeated here. However, in relation to eutrophication, the very high mud content at the eutrophic sites indicates upper sediment oxygenation is likely to be poor, while sediment bound nutrients and metals, most strongly associated with fine sediments, are likely to be elevated.

### Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the degree of sediment oxygenation. Figure 10 shows the Waihopai and Daffodil Bay eutrophic sites were very poorly oxygenated with the RPD depth at the surface (0cm), and often associated with sulphur bacterial mats at the surface. Such shallow RPD values fit the "poor" condition rating, with the benthic invertebrate community likely to be restricted to 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) provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow RPD, excessive algal growth, high WEBI biotic coefficient), 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 11-13) indicate very elevated concentrations of TOC, TP and TN compared with fine scale sites in the less eutrophic parts of the estuary. Note, a change in the TN methodology used in 2012, likely underestimates TN compared to other values by 10-40%.

### Macroalgal Cover

Each eutrophic arm site had 100% nuisance macroalgal cover (see Stevens and Robertson 2013) which was having a significant adverse impact.

The above results confirm the eutrophic nature of these estuary arms and the oversupply of sediment nutrients to the estuary. 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.

# 3. Results and Discussion (Continued)

**TOXICITY INDICATORS**

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 Arm eutrophic sites E, F and W, with all non-normalised values (except nickel) below the ANZECC (2000) ISQG-Low trigger values (Figure 14). Concentrations were much higher than those measured at the main basin sites during 2002-2010 and indicate a moderate accumulation of heavy metals associated with the muddy sediments of the Waihopai and Daffodil Bay arms of the estuary. However, with the exception of nickel, concentrations remained below the ISQG-low criteria, indicating metal toxicity related stress to macrobenthos is unlikely.

In contrast, the presence of widespread sulphide-rich and oxygen depleted sediments observed in the Waihopai and Daffodil Bay arms of the estuary suggest that toxicity effects related to elevated levels of sediment ammonia or sulphide are highly likely to exist.

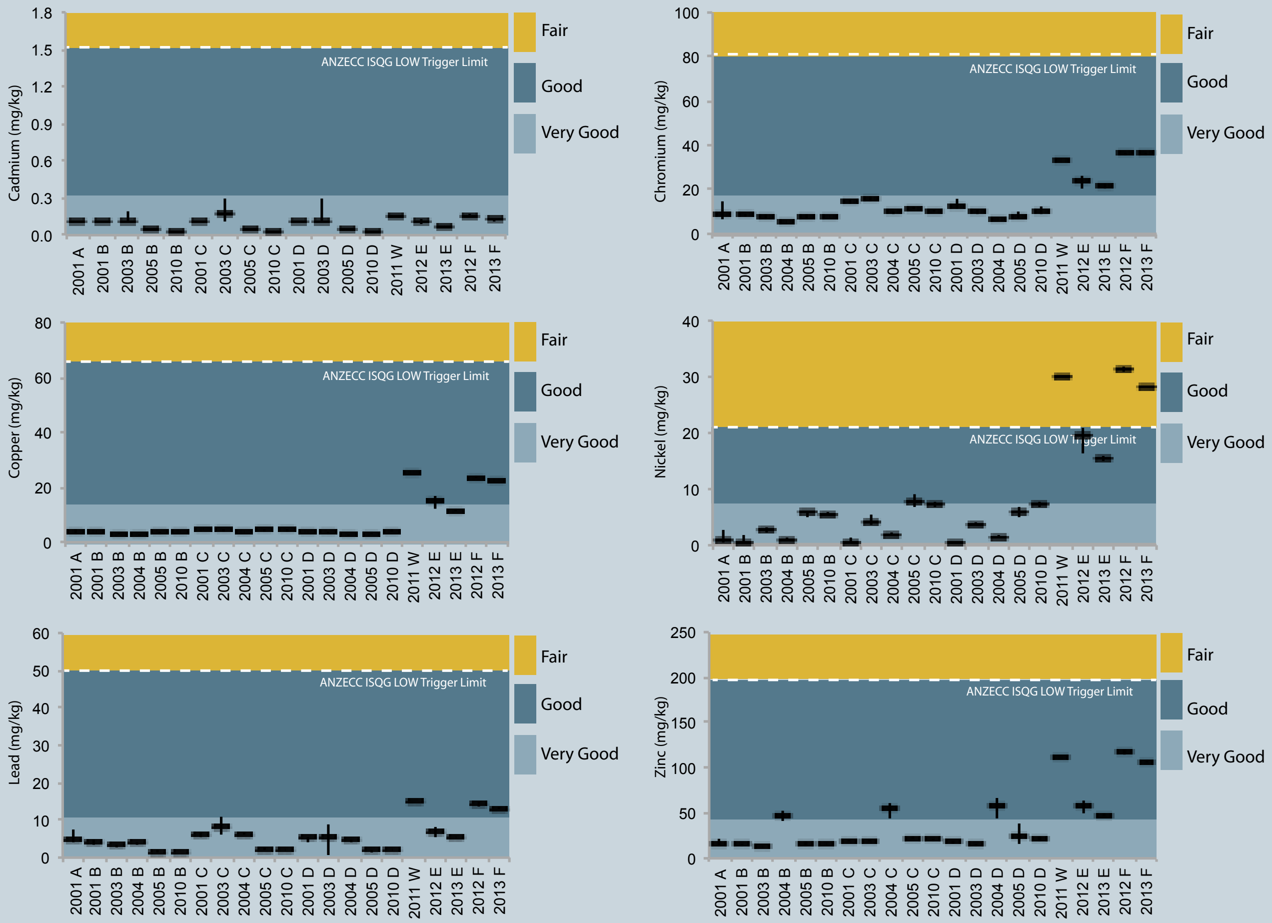



**Figure 14. Sediment metal concentrations, (mean and range) New River Estuary (2001-2013).**

**Extensive macroalgal cover in the Waihopai Arm (2013)**

# 4. CONCLUSIONS

The results of the 2011-2013 fine scale monitoring of New River Estuary, confirm that the Waihopai Arm and Daffodil Bay intertidal flats are highly eutrophic and dominated by soft muds. The primary evidence for this is as follows (also see summary table below):

- The macro-invertebrate communities at the Daffodil Bay and Waihopai Arm gross eutrophic sites differed considerably from sites in the main basin of the estuary. In particular, they were dominated by surface feeding, enrichment tolerant taxa that live primarily within the surface nuisance macroalgal layer, rather than in the underlying anoxic muddy sediments.
- Analysis of the physico-chemical characteristics of the sediment at the gross eutrophic sites showed very elevated mud contents (40-95%), organic matter, and nutrient concentrations (TOC, TN and TP), and very low sediment oxygenation (RPD depth - 0cm). Toxicity (indicated by heavy metals) was low, but higher than measured at the other fine scale sites. However, other forms of toxicity, in particular elevated sulphide and ammonia levels, were almost certainly present at these sites, given the muddy anoxic conditions.

Such enrichment by muds and nutrients, encourages the growth of short-lived nuisance macroalgae which, in turn, degrades the existing habitat causing the loss of high value seagrass and healthy macro-invertebrate communities. These findings are supported by the broad scale mapping results (2001-2013), in particular:

- In the Waihopai Arm, seagrass (a very high value habitat) has declined by 85% since 2001 with a further 50% reduction between 2012 and 2013.
- In Daffodil Bay, the area of nuisance macroalgal cover (>50% cover) has increased 470% from 9ha in 2001 to 43ha in 2012.

The presence of muddy, highly eutrophic areas in estuaries, limits the food availability for fish and birdlife, and means the capacity of the estuary to assimilate nutrient and sediment loads from the catchment is exceeded. The cause of these extreme conditions is almost certainly attributable to excessive catchment nutrient input loads, exacerbated by the sheltered nature of these arms and their propensity to act as natural settling areas for fine, organic and nutrient enriched sediment.

| Indicator | Gross Eutrophic Arm Sites 2011-2013 | Central Estuary Fine Scale Sites 2001-2010 |
|---|---|---|
| **Oxygen Content (RPD)** | RPD at 0cm - anoxic to the surface. | RPD 2-3cm, oxygenated surface sediments. |
| **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 80-100% 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 (40-95% mud). | Relatively low (<6% mud) but increasing. |
| **Sedimentation Rate** | Mean rates very high for Waihopai Arm (14-34mm/yr) over the past 6 years. | Rates variable but suggest no significant adverse deposition at fine scale sites. |
| **Heavy Metals** | Heavy metals concentrations elevated compared to main estuary basin sites, 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. |

# 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 2014 and again in February 2015 when the 5 yearly fine scale trend monitoring falls due for the main basin sites.

**Macroalgal and Seagrass Monitoring**

Continue with the programme of annual broad scale mapping of macroalgae. Next monitoring due in February 2014. 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 continue to be measured annually.

# 6. MANAGEMENT

Eutrophication and excessive 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, ES is currently undertaking a comprehensive estuary sediment and trophic status assessment, including identification of appropriate management measures (e.g. nutrient and sediment load guidelines) for the estuary, as well as source tracking of catchment sediments and nutrients.

# 7. ACKNOWLEDGEMENTS

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Anoxic sulphide-rich sediments in the Waihopai Arm (2013)

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# APPENDIX 1. ANALYTICAL METHODS

| Indicator | Laboratory | Method | Detection Limit |
|---|---|---|---|
| Infauna Sorting and ID | CMEC | Coastal Marine Ecology Consultants (Gary Stephenson) * | N/A |
| Grain Size | R.J Hill | Wet sieving (2mm and 63µm sieves), gravimetry (calculation by difference). | 0.1 g/100g dry wgt |
| 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 | R.J Hill | Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser) | 500 mg/kg dry wgt |

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

### 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 East | 1239260 | 1239264 | 1239266 | 1239270 | 1239273 | 1239276 | 1239280 | 1239283 | 1239286 | 1239289 |
| NZTM North | 4842402 | 4842406 | 4842408 | 4842412 | 4842414 | 4842419 | 4842418 | 4842415 | 4842412 | 4842415 |
| | | | | | | | | | | |
| **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 East | 1241172 | 1241177 | 1241181 | 1241184 | 1241186 | 1241194 | 1241191 | 1241191 | 1241189 | 1241187 |
| NZTM North | 4846405 | 4846404 | 4846396 | 4846392 | 4846385 | 4846389 | 4846394 | 4846398 | 4846404 | 4846413 |

# APPENDIX 2. 2013 DETAILED RESULTS

### Physical and Chemical Results for New River Estuary (Sites E and F), 21 and 26 February 2013.

| 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 | 1.56 | 41.5 | 58.4 | 0.1 | 0.075 | 23 | 12 | 15.8 | 5.6 | 48 | 150 | 540 |
| New River E | 5-8 | 0 | NA | 1.55 | 39.2 | 60.5 | 0.3 | 0.077 | 21 | 11.6 | 15.1 | 5.2 | 48 | 150 | 540 |
| New River E | 9-10 | 0 | NA | 1.37 | 38.1 | 60.7 | 1.2 | 0.078 | 22 | 11.3 | 15 | 5.3 | 49 | 140 | 560 |
| New River F | 1-4 | 0 | NA | 3.8 | 83.5 | 14.3 | 2.3 | 0.115 | 36 | 22 | 28 | 13.3 | 107 | 380 | 1,590 |
| New River F | 5-8 | 0 | NA | 3.4 | 75.1 | 23.3 | 1.6 | 0.133 | 37 | 22 | 28 | 13.4 | 107 | 390 | 1,350 |
| New River F | 9-10 | 0 | NA | 3.1 | 83.8 | 16 | 0.2 | 0.128 | 36 | 22 | 28 | 12.9 | 108 | 340 | 1,300 |

* composite samples

# APPENDIX 2. 2013 DETAILED RESULTS (CONTINUED)

**Sedimentation rate monitoring results, New River Estuary, February 2007- February 2013.**

| | Sediment Depth (mm) | | | | | | Change (mm) | | | | | Site Mean (mm/yr) | | | | | | Overall Rate | SEDIMENTATION RATE CONDITION RATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | 27 Feb 2007 | 19 Feb 2009 | 10 Feb 2010 | 18 Feb 2011 | 27 Jan 2012 | 26 Feb 2013 | 2007-2009 | 2009-2010 | 2010-2011 | 2011-2012 | 2012-2013 | 2007-2008 | 2008-2009 | 2009-2010 | 2010-2011 | 2011-2012 | 2012-2013 | (mm/yr) | |
| Waihopai Upper | 403 | 445 | 496 | 496 | 500 | 499 | 42 | 51 | 0 | 4 | -1 | 15.0 | 15.0 | 49.8 | 0.5 | 7.0 | 0.3 | **14.6** | **VERY HIGH** |
| Waihopai Upper | 290 | 331 | 368 | 366 | 370 | 363 | 41 | 37 | -2 | 4 | -7 | | | | | | | | |
| Waihopai Upper | 325 | 327 | 387 | 400 | 412 | 412 | 2 | 60 | 13 | 12 | 0 | | | | | | | | |
| Waihopai Upper | 270 | 305 | 356 | 347 | 355 | 364 | 35 | 51 | -9 | 8 | 9 | | | | | | | | |
| Waihopai Central | 280 | 279 | 316 | 401 | 490 | * | -1 | 37 | 85 | 89 | - | 0.4 | 0.4 | 59.8 | 72.0 | 79.7 | -0.5 | **33.7** | **VERY HIGH** |
| Waihopai Central | 382 | 395 | 458 | 506 | 585 | 588 | 13 | 63 | 48 | 79 | 3 | | | | | | | | |
| Waihopai Central | 295 | 282 | 342 | 426 | 497 | 493 | -13 | 60 | 84 | 71 | -4 | | | | | | | | |
| Waihopai Central | 400 | 404 | 483 | 554 | * | * | 4 | 79 | 71 | - | - | | | | | | | | |
| Bushy Point | 226 | 253 | 270 | 264 | 230 | 181 | 27 | 17 | -6 | -34 | -49 | 29.8 | 29.8 | 12.3 | 0.3 | -35.0 | -53.0 | **-2.7** | **VERY LOW** |
| Bushy Point | 265 | 381 | 396 | 412 | 356 | 300 | 116 | 15 | 16 | -56 | -56 | | | | | | | | |
| Bushy Point | 240 | 323 | 328 | 330 | 305 | 256 | 83 | 5 | 2 | -25 | -49 | | | | | | | | |
| Bushy Point | 265 | 277 | 289 | 278 | 253 | 195 | 12 | 12 | -11 | -25 | -58 | | | | | | | | |
| NRE Fine Scale B | | | | 178 | 162 | 153 | | | | -16 | -9 | | | | | -17.0 | -14.0 | **-9.6** | **VERY LOW** |
| NRE Fine Scale B | | | | 122 | 102 | 93 | | | | -20 | -9 | | | | | | | | |
| NRE Fine Scale B | | | | 205 | 189 | 170 | | | | -16 | -19 | | | | | | | | |
| NRE Fine Scale B | | | | 190 | 174 | 155 | | | | -16 | -19 | | | | | | | | |
| NRE Fine Scale C | | | | 116 | 115 | 108 | | | | -1 | -7 | | | | | -0.3 | -22.5 | **-0.1** | **VERY LOW** |
| NRE Fine Scale C | | | | 194 | 189 | 109 | | | | -5 | -80 | | | | | | | | |
| NRE Fine Scale C | | | | 135 | 135 | 134 | | | | 0 | -1 | | | | | | | | |
| NRE Fine Scale C | | | | 197 | 202 | 200 | | | | 5 | -2 | | | | | | | | |
| NRE Fine Scale D | | | | 177 | 225 | 227 | | | | 48 | 2 | | | | | 32.3 | -10.8 | **16.1** | **VERY HIGH** |
| NRE Fine Scale D | | | | 120 | 150 | 133 | | | | 30 | -17 | | | | | | | | |
| NRE Fine Scale D | | | | 118 | 162 | 152 | | | | 44 | -10 | | | | | | | | |
| NRE Fine Scale D | | | | 208 | 215 | 197 | | | | 7 | -18 | | | | | | | | |

* Data is missing as sediment deposition was so rapid between 2011 and 2012 that the site marker pegs initially set 190mm above the sediment surface were completely buried at one site and consequently one sediment plate could not be relocated. The three remaining sites were re-pegged in 2012, but only two of the pegged sites could be found when monitored in 2013.

**Epifauna and macroalgal cover (0.25m² quadrats, New River Estuary Sites E and F, 21 and 26 February 2013).**

| **Site** | | RPD depth (cm) | **Epifauna (no/0.25m² quadrat)** | **Macroalgae (percent cover)** | |
|---|---|---|---|---|---|
| **Daffodil Bay** | Rep. | | *Amphibola crenata* | *Gracilaria chilensis* | *Ulva intestinalis* |
| New River E | 1 | 0 | | 100 | 50 |
| New River E | 2 | 0 | 4 | 100 | 50 |
| New River E | 3 | 0 | | 100 | 50 |
| New River E | 4 | 0 | | 100 | 50 |
| New River E | 5 | 0 | 1 | 100 | 50 |
| New River E | 6 | 0 | 1 | 100 | 50 |
| New River E | 7 | 0 | 8 | 100 | 50 |
| New River E | 8 | 0 | | 100 | 50 |
| New River E | 9 | 0 | 1 | 100 | 50 |
| New River E | 10 | 0 | | 100 | 50 |
| **Waihopai Arm** | Rep. | RPD | *Amphibola crenata* | *Gracilaria chilensis* | *Ulva intestinalis* |
| New River F | 1 | 0 | | 100 | 50 |
| New River F | 2 | 0 | | 100 | 50 |
| New River F | 3 | 0 | | 100 | 50 |
| New River F | 4 | 0 | | 100 | 50 |
| New River F | 5 | 0 | | 100 | 50 |
| New River F | 6 | 0 | | 100 | 50 |
| New River F | 7 | 0 | | 100 | 50 |
| New River F | 8 | 0 | | 100 | 50 |
| New River F | 9 | 0 | | 100 | 50 |
| New River F | 10 | 0 | 1 | 100 | 50 |

# APPENDIX 2. 2013 DETAILED RESULTS (CONTINUED)

**Macro-invertebrate infauna for New River Estuary Sites E (Daffodil Bay) and F (Waihopai Arm), 21 and 26 February 2013.**

| Group | Species | WEBI | 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 | 3 | | | | | | | | | | | | | | | | | | | | |
| POLYCHAETA | *Boccardia syrtis* | 2 | | | | | | | | | | | | | | | | | | | | |
| | *Capitella* sp.#1 | 4 | | | | | | | | | | | | | | | | | | | | |
| | *Nereidae (unidentified juveniles)* | 3 | | | | | | | | | | | | | | | 3 | 2 | 5 | 1 | 1 | |
| | *Nicon aestuariensis* | 3 | 1 | | | | | | 1 | 1 | | | 4 | 2 | 1 | 2 | 1 | | 4 | 3 | | 3 |
| | *Prionospio aucklandica* | 2 | 3 | 3 | 7 | 2 | 10 | 4 | 15 | 2 | 1 | 8 | | | | | | | | | | |
| | *Scolecolepides benhami* | 4 | | 1 | | 1 | | | | | | 1 | 5 | 4 | 7 | 9 | 3 | 5 | 9 | 2 | 5 | |
| OLIGOCHAETA | Oligochaeta | 3 | | | | | | | | | | | | 1 | | | | 1 | | | | |
| GASTROPODA | *Amphibola crenata* | 3 | 1 | 1 | 1 | | | | | | | | | 2 | | | 2 | | 1 | | | 1 |
| | *Cominella glandiformis* | 3 | | | | | | | | | | | | | | | | | | | | |
| | *Notoacmaea helmsi* | 2 | | | | 1 | | | | | | | | | | | | | | | | |
| | *Potamopyrgus* sp. or spp. | 3 | | | | | | | | | | | 61 | 59 | 74 | 43 | 52 | 32 | 26 | 101 | 39 | 65 |
| BIVALVIA | *Arthritica* sp.#1 | 4 | 2 | 7 | | 1 | 2 | 26 | 7 | 23 | 3 | 24 | 45 | 42 | 59 | 6 | 15 | 30 | 20 | 26 | 23 | 48 |
| | *Austrovenus stutchburyi* | 2 | | | 3 | 1 | | | | 1 | | | | | | | | | | | | |
| | *Cyclomactra ovata* | 2 | | | | | 1 | | | | | | | | | | | | | | | |
| | *Macomona liliana* | 2 | | | 3 | | 1 | 1 | | | | | | | | | | | | | | |
| | *Mytilus galloprovincialis* | NA | | | | 2 | | | | | | | | | | | | | | | | |
| CRUSTACEA | Amphipoda sp.#1 | 5 | 220 | 192 | 186 | 268 | 139 | 387 | 215 | 121 | 28 | 111 | 4 | 7 | 2 | 1 | 1 | | | 1 | 1 | 1 |
| | Amphipoda sp.#2 | 4 | 88 | 43 | 32 | 86 | 52 | 79 | 39 | 48 | 25 | 44 | | | | | | | | | | |
| | Amphipoda sp.#7 | 5 | | 1 | | | 1 | | | | | | 100 | 107 | 77 | 30 | 26 | | 31 | 87 | 50 | 103 |
| | *Austrohelice crassa* | 5 | | | | | | | | | | 1 | 3 | 1 | 1 | | | | | 2 | | 1 |
| | *Exosphaeroma planulum* | 5 | | | | | | | | | | | 18 | 12 | 20 | 2 | 2 | 2 | 8 | 39 | 8 | 5 |
| | *Halicarcinus varius* | 3 | 1 | | 1 | 2 | 1 | | | | | | | | | | | | | | | |
| | *Halicarcinus whitei* | 3 | | | | | | | | | | | | | | | | | | | | |
| | *Macrophthalmus hirtipes* | 5 | 2 | 10 | 5 | 8 | 13 | 12 | 15 | 9 | 5 | 9 | | | | | | | | | 2 | |
| | *Palaemon affinis* | NA | | | | 1 | | | | | | | | | | | | | | | | |
| | *Paracorophium excavatum* | 4 | | | | | | | | | | | 42 | 77 | 47 | 126 | 22 | 89 | 19 | 11 | 12 | 12 |
| | *Tenagomysis* sp.#1 | 2 | | | | | | | | | | | 1 | | 1 | | | 3 | 3 | | | |
| **Total individuals per core** | | | **318** | **258** | **238** | **373** | **220** | **509** | **292** | **205** | **62** | **198** | **283** | **314** | **289** | **219** | **127** | **164** | **126** | **273** | **141** | **239** |
| **Total species per core** | | | **8** | **8** | **8** | **11** | **9** | **6** | **6** | **7** | **5** | **7** | **10** | **11** | **10** | **8** | **10** | **8** | **10** | **10** | **9** | **9** |

# APPENDIX 3. INFAUNA CHARACTERISTICS

| Group | Species | WEBI Group * | Details |
|---|---|---|---|
| Hirudinea | Hirudinea sp.1 | 4 | 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. |
| Anthozoa | *Edwardsia* sp.#1 | 2 | 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. | 3 | Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions. |
| Nematoda | Nematoda sp. | 1 | 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* | 1 | 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. Otago Harbour may have New Zealand's biggest population of lugworms. |
| | *Aglaophamous macroura* | 2 | 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* | 1 | 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 sediments. In general, polychaetes are important prey items for fish and birds. |
| | *Boccardia syrtis* | 2 | 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. |
| | *Capitella capitata* | 4 | A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments. |
| | Glyceridae | 3 | 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 and low salinity. |
| | *Heteromastus filiformis* | 3 | 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 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* | 1 | A small, common, intertidal spionid. Prey items for fish and birds. |
| | Nereidae | 3 | 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 elevated sulphide concentrations. |

# APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group and Species | | WEBI Group * | Details |
|---|---|---|---|
| Polychaeta | *Nicon aestuariensis* | 3 | 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 | 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. |
| | *Owenia petersenae* | 2 | 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. |
| | Paraonidae sp.#1 | 3 | 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. |
| | *Pectinaria australis* | 3 | 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 | 2 | 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. |
| | Polynoidae | 1 | The polynoid scale worms are dorsoventrally flattened predators. Lower intertidal and subtidal to deep sea throughout New Zealand. Conspicuous but never abundant. |
| | *Prionospio aucklandica* | 2 | 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). |
| | *Scolecolepides benhami* | 4 | 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. 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. |
| | *Scoloplos cylindrifer* | 1 | 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. Pollution and mud intolerant. |
| | Sphaerosyllis sp.#1 | 2 | Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers sandy sediments. |
| Gastropoda | *Amphibola crenata* | 3 | 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* | 3 | 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. |

# APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group | Group and Species | WEBI Group * | Details |
|---|---|---|---|
| Gastropoda | *Diloma subrostrata* | 2 | 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. |
| | *Notoacmaea helmsi* | 2 | Endemic to NZ. Small grazing limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds and sensitive to pollution. |
| | *Potamopyrgus estuarinus* | 3 | 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. |
| Bivalvia | *Arthritica bifurca* | 4 | A small sedentary deposit feeding bivalve, preferring a moderate mud content. Lives greater than 2cm deep in the muds. |
| | *Austrovenus stutchburyi* | 2 | 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. 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 | 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. |
| | *Macomona liliana* | 2 | 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. |
| | *Mactra Ovata (Cyclomactra ovata)* | 2 | 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. Often present in upper estuaries so tolerates brackish water. |
| | *Mytilus galloprovincialis* | NA | *Mytilus galloprovincialis* (blue mussel) is an invasive species and is now common throughout NZ. It is dark blue or brown to almost black. Common in estuaries, often on rocks but also can be found on sands. It is able to outcompete and displace native mussels and become the dominant mussel species in certain localities because it may grow faster than native mussels, be more tolerant to air exposure and have a reproductive output of between 20% and 200% greater than that of indigenous species. Prefers sandy environments with substrate for attachment. |
| | *Paphies australis* | 2 | 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. Common at mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud. |
| | *Perna canaliculus* | NA | The New Zealand green-lipped mussel (also known as *Perna canaliculus*, the New Zealand mussel the greenshell mussel, or kuku, or kutai) is a bivalve mollusc in the family Mytilidae. It has great importance as a cultivated species for New Zealand and is endemic to New Zealand. Intolerant of eutrophic or muddy conditions. |
| | *Solletellina* | 1 | *Soletellina* is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells. |
| Oligichaeta | Oligochaete sp. | 3 | Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species. |

# APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group and Species | | WEBI Group * | Details |
|---|---|---|---|
| Crustacea | *Amphipoda* sp.1 | 5 | An unidentified amphipod. |
| | *Austrominius modestus* | 2 | Small acorn barnacle (also named *Elminius modestus)*. Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones. |
| | *Callianassa filholi* | 2 | Ghost shrimp, Decapoda, endemic to NZ. Makes long, semi-permanent burrows between low water of neap and spring. Up to 5 cm long and 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. |
| | *Colurostylis lemurum* | 1 | A cumacean that prefers sandy environments. Cumacea is an order of small marine crustaceans, occasionally called hooded shrimp. Their unique appearance and uniform body plan makes them easy to distinguish from other crustaceans. |
| | Copepoda | 2 | 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 | 1 | 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. |
| | *Decapoda* (larvae) | NA | Unidentified crab larvae. |
| | *Exosphaeroma* sp. | 5 | Small seaweed dwelling isopod. |
| | *Halicarcinus varius* | 3 | Pillbox crabs are usually found on the sand and mudflats but may also be encountered under stones on the rocky shore. *Halicarcinus varius* (10mm) has a pear-shaped carapace, its upper half covered in small hairs. Males have hairy nippers. Its colour varies from white/green to yellow, found in sheltered areas on brown seaweeds or under stones. |
| | *Helice crassa* | 5 | Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content. |
| | *Macrophthalmus hirtipes* | 5 | 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. |
| | *Melita* sp. | NA | A genus from the Meletidae family of Gammarid amphipods. |
| | *Mysidacea* sp.1 | 1 | 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. |
| | *Natantia* sp. | 2 | True shrimps are small, swimming, decapod crustaceans usually classified in the suborder Natantia, found widely around the world in both fresh and salt water. |
| | *Palaemon affinis* | NA | Palaemonidae is a family of crustaceans of the order Decapoda. They belong to the infraorder Caridea, which contains the true shrimp; while some freshwater palaemonid species are known as "prawns", the family belongs to the suborder Pleocyemata like all true shrimp, whereas the true prawns are members of the suborder Dendrobranchiata. |
| | *Paracorophium excavatum* | 4 | A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. |

# APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group and Species | | WEBI Group * | Details |
|---|---|---|---|
| | Spheromatidae | 2 | Sphaeromatidae is a family of isopods. |
| | *Tenagomysis* sp.#1 | 2 | *Tenagomysis* is a genus of mysid shrimps in the family Mysidae. At least nine of the fifteen species known are from New Zealand. |
| Osteichthyes | *Peltorhamhus novaezelandiae* | 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. | 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. |

* Wriggle Estuary Biotic Index (WEBI).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.