Wriggle coastalmanagement

# Jacobs River Estuary

## Fine Scale Monitoring of Highly Eutrophic Arms 2011/2012

Prepared for **Environment Southland**

**October 2012**

**Cover Photo: Pourakino Arm, Jacobs River Estuary.**

Aparima Arm - Jacobs River Estuary.

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## Fine Scale Monitoring of Highly Eutrophic Arms 2011/2012

Prepared for
Environment Southland

By

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# JACOBS RIVER ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the baseline 2012 fine scale monitoring of two eutrophic, poorly flushed, intertidal sites (Pourakino Arm and Aparima Arm) within Jacobs River Estuary, a medium-sized "tidal lagoon" type estuary (area 720ha), discharging to the sea at Riverton. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. The following sections summarise monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

## FINE SCALE RESULTS

- The sites were dominated by mud, and were poorly oxygenated (RPD was at the surface).
- The rate of sedimentation (infilling with mud) was in the low-moderate category in 2011-2012.
- The invertebrate community was dominated by surface feeding, mud and organic enrichment tolerant species, living on the surface macroalgal layer. Very few species were present within the underlying anoxic and sulphide-rich muds.
- Sediment nutrients and organic carbon were moderately elevated, and heavy metals were below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity), and similar to those measured at the other fine scale sites in Jacobs River Estuary.

## CONDITION RATINGS

Eutrophic Site D = Pourakino Arm
Eutrophic Site E = Aparima Arm

| | Fine Scale Monitoring Sites (located in the well flushed central basin) | | | | | | | | | | | | | | | Eutrophic Sites | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Site A (Central basin) | | | | | Site B (Southern Flats) | | | | | Site C (Pourakino Arm) | | | | | D | E |
| | 2003 | 2004 | 2005 | 2006 | 2011 | 2003 | 2004 | 2005 | 2006 | 2011 | 2003 | 2004 | 2005 | 2006 | 2011 | 2012 | 2012 |
| Sediment Oxygenation (RPD) | Fair | Fair | Fair | Fair | High/Poor | Fair | Fair | Fair | Fair | High/Poor | Fair | Fair | Fair | Fair | High/Poor | High/Poor | High/Poor |
| Invertebrates: Mud Tolerance | Very good | Good | Good | Very good | Very good | Good | Good | Good | Good | Good | Fair | Fair | Fair | Fair | Fair | Fair | Fair |
| TOC (Total Organic Carbon) | Very good | Good | Good | Good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Good | Fair |
| Total Nitrogen | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Very good | Fair | Fair |
| Total Phosphorus | Good | Fair | Fair | Fair | Fair | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Fair | Fair |
| Metals (Cd, Cu, Cr, Ni, Pb, Zn) | 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 | Good | Good |
| Invertebrates: Organic Enrichment Tolerance | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good |

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

## ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the fine scale monitoring (i.e. sedimentation, eutrophication, and toxicity), the 2012 results indicate that the poorly flushed Pourakino Arm, and the Northern Flats of the Aparima Arm are excessively muddy, have elevated nutrients and nuisance macroalgal growths, and very 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 mean the ability of the estuary to assimilate nutrient and sediment loads from the catchment is exceeded. Toxicity (indicated by heavy metals) was low and similar to other sites in the estuary.

## RECOMMENDED MONITORING AND MANAGEMENT

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

To address these issues, it is recommended that catchment nutrient and sediment guideline criteria be developed for each estuary type in Southland in a prioritised fashion, with Jacobs River Estuary as the second priority behind New River Estuary. Assessing the extent to which current catchment loads meet guideline criteria will enable ES to sustainably manage the estuary and its surroundings. If the approach is followed and successfully executed, the estuary will flourish and provide sustainable human use and ecological values in the long term. If catchment loads exceed the estuary's assimilative capacity, it will continue to degrade.

In order to assess ongoing trends in the fine scale condition of the estuary it is recommended that the newly established eutrophic sites be monitored in Feb. 2013, 2014 and again in Feb. 2016. This will coincide with when the 5 yearly fine scale trend monitoring at the three existing central basin sites falls due. Broad scale sedimentation rate, seagrass, and macroalgal monitoring should continue annually, and broad scale mapping every 5 years (next due in 2013).

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 Jacobs River Estuary consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002):

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (Table 1) and appropriate monitoring design. A preliminary EVA has been completed for Jacobs 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, and changes to these habitats over time, was undertaken in 2003 (Robertson et al. 2003), and repeated in 2008 (Stevens and Robertson 2008).
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (Table 2) including sedimentation plate monitoring (established in 2011). This component, which provides detailed information on the condition of the Jacobs River Estuary, has been undertaken in 2003, 2004, 2005, 2006 (Robertson and Stevens 2006), and 2011 (Robertson and Stevens 2011).

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

The results of the recent annual broad scale macroalgal monitoring (Stevens and Robertson 2010, 2011, 2012), in conjunction with the monitoring undertaken from 2002-2011, has highlighted the presence of extensive and increasing eutrophication and sedimentation problems in the natural settling areas within the Aparima and Pourakino Arms of Jacobs River Estuary. The increased eutrophication symptoms (very low sediment oxygenation and sulphide-rich sediments, smothering macroalgae, rapid soft mud accumulation) correlate with increased catchment nutrient loads over the last 10 years (see ES 2012).

These symptoms have not been as conspicuous in the fine scale monitoring results to date because the sites are located on the relatively well flushed sandy intertidal flats 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 2011).

Therefore, in response to the eutrophication and sedimentation problems evident in the natural settling areas within Jacobs River Estuary, and following preliminary synoptic fine scale assessment undertaken in the Waihopai Arm of New River Estuary in February 2011 which indicated significant degradation in these settling areas (see Robertson and Stevens 2011a), detailed fine scale assessment of the natural settling areas within both Aparima and Pourakino Arms was undertaken using the NEMP approach (Robertson et al. 2002). Sampling was undertaken in late January 2012 and results are presented in the current report.

Jacobs River Estuary is a moderate sized “tidal lagoon” type estuary (area 720ha) situated at the confluence of the Pourakino and Aparima Rivers that discharges to the sea at Riverton. The estuary is shallow (mean depth ~2m) and has a mixture of poorly flushed and well flushed areas. It drains a primarily agricultural catchment bordered by a mix of vegetation and landuses (predominantly grazed pasture and urban). Human use of the estuary is high and is used for walking, shellfish collecting, boating, fishing, duck shooting, bird watching, bathing, and white-baiting.

The estuary has extensive sand and mudflats, seagrass, and saltmarsh areas. Habitat diversity is moderate with tidal flats and saltmarsh providing important habitat for native fish, birdlife and tidal flat organisms. However, as a consequence of historical drainage, extensive weed growth, intensive farming in the catchment, and the grazing of margins, poorly flushed parts of the estuary are now relatively vulnerable to eutrophication and sedimentation. This is exacerbated in the Pourakino Arm by the natural constriction of the Narrows” (see Figure 1.)

Catchment development is evident in moderately degraded water quality entering the estuary, common nuisance blooms of macroalgae (*Ulva* and *Gracilaria*), and accumulations of deep soft muds. As a consequence, the estuary has several very eutrophic arms.

Therefore, it has been recommended that management actions be taken to improve the situation.

# 1. Introduction (Continued)

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

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

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

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

# 2. METHODS

## FINE SCALE MONITORING

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

In addition to the existing three fine scale sites located in the dominant sandy intertidal flats of Jacobs River Estuary, two additional fine scale sampling sites (Figure 1, Appendix 2) were selected in mid-low water habitat within the eutrophic natural settling areas of the estuary (areas with abundant macroalgal growth and muddy anoxic, sulphide-rich sediment). These eutrophic areas represent ~1/3rd of the total estuary habitat. At each eutrophic site, a 20m x 8m area in the lower intertidal was marked out and divided into 10 equal sized plots. Within each plot, a random position was defined, and the following sampling undertaken:

**Physical and chemical analyses**

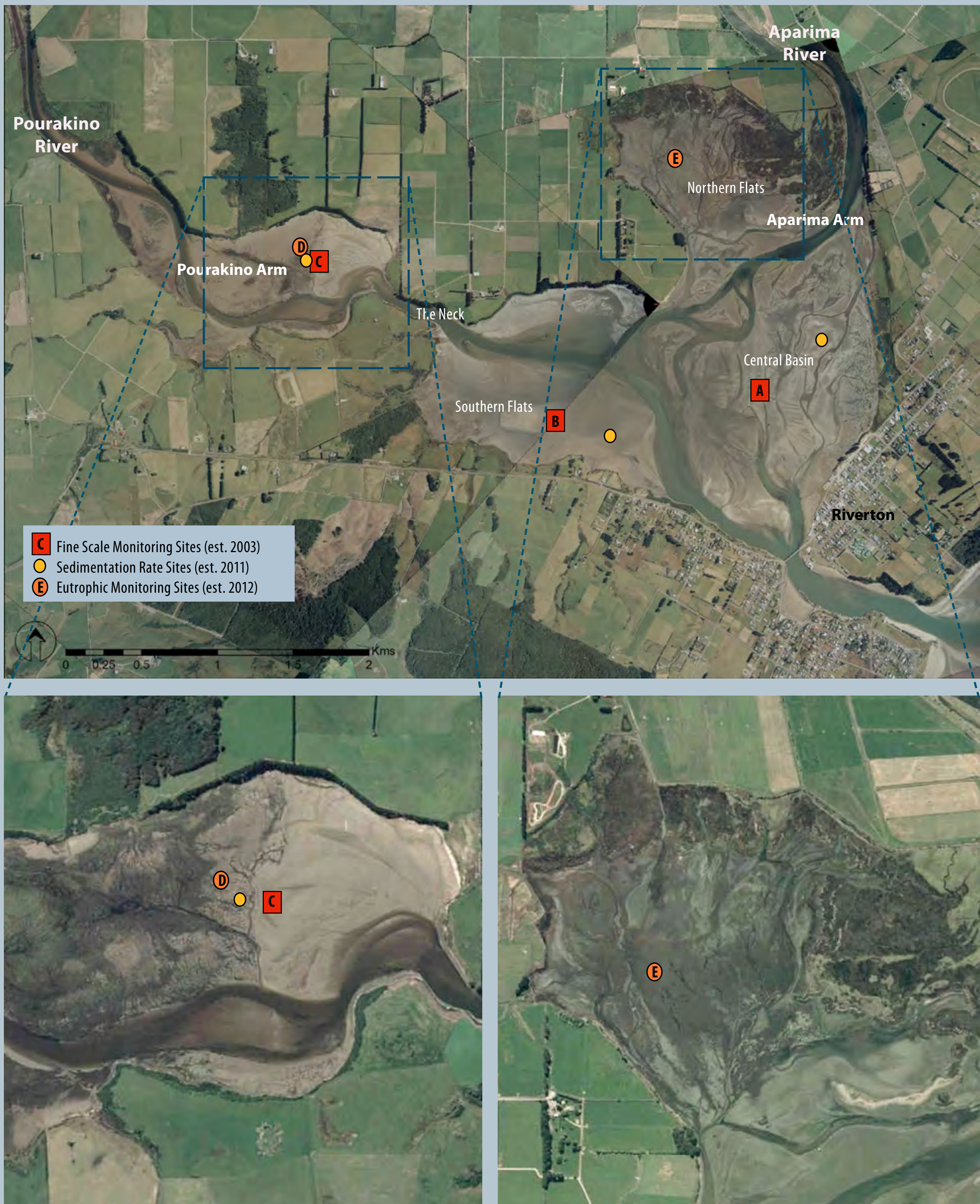
- One core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average redox potential discontinuity (RPD) depth (i.e. depth to light grey/black anoxic layer) recorded.
- At each site, three samples (2 a composite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

**Epifauna (surface-dwelling animals)**

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

**Infauna (animals within sediments)**

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




1. Pourakino Arm eutrophic Site D and fine scale Site C.

2. Aparima Arm eutrophic Site E.

**Figure 1. Location of fine scale monitoring sites in Jacobs River Estuary (Photo ES).**

Central Basin sedimentation rate site in Jan. 2012

### Sedimentation Rate

Determining the sedimentation rate from now and into the future involves a simple method of measuring how much sediment builds up over buried plates over time. Once a plate has been buried, levelled, and the elevation measured, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. Locations (Figure 1) and methods for deployment are presented in Robertson and Stevens 2011). In the future, these depths will be measured every 1-5 years and, over the long term, will provide a measure of rate of sedimentation in representative parts of the estuary.

Pourakino Arm sedimentation rate site in Jan. 2012.

## CONDITION RATINGS

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

**Sedimentation Rate**

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

**SEDIMENTATION RATE CONDITION RATING**

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

## 2. Methods (Continued)

**Benthic Community Mud Tolerance**

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

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

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

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

**BENTHIC COMMUNITY MUD TOLERANCE RATING**

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

**Redox Potential Discontinuity**

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

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

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

**RPD CONDITION RATING**

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

**Total Organic Carbon**

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

**TOTAL ORGANIC CARBON CONDITION RATING**

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

# 2. Methods (Continued)

**Total Phosphorus**

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

**TOTAL NITROGEN CONDITION RATING**

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

**Benthic Community Organic Enrichment Tolerance**

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

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

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

**BENTHIC COMMUNITY ORGANIC ENRICHMENT TOLERANCE RATING**

| ENRICHMENT TOLERANCE RATING | DEFINITION | BC | RECOMMENDED RESPONSE |
|---|---|---|---|
| Very Low | Unpolluted | 0-1.2 | Monitor at 5 year intervals after baseline established |
| Low | Slightly polluted | 1.2-3.3 | Monitor 5 yearly after baseline established |
| Moderate | Moderately polluted | 3.3-5.0 | Monitor 5 yearly after baseline est. Initiate ERP |
| High | Heavily polluted | 5.0-6.0 | Post baseline, monitor yearly. Initiate ERP |
| Very High | Azoic (devoid of life) | >6.0 | Post baseline, monitor yearly. Initiate ERP |
| Early Warning Trigger | Trend to slightly polluted | >1.2 | Initiate Evaluation and Response Plan |

**Metals**

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

**METALS CONDITION RATING**

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

# 3. RESULTS AND DISCUSSION

A summary of the 29 January 2012 eutrophic zone monitoring results is presented alongside the long term fine scale monitoring results (2003-2006 baseline and 2011 results - Robertson and Stevens 2011) in Table 3. Sedimentation rate monitoring results are presented in Table 4, and detailed macroinvertebrate results in Table 5. The results and discussion section is divided into three subsections based on the key estuary problems that the fine scale monitoring is addressing: sedimentation, eutrophication, and toxicity.

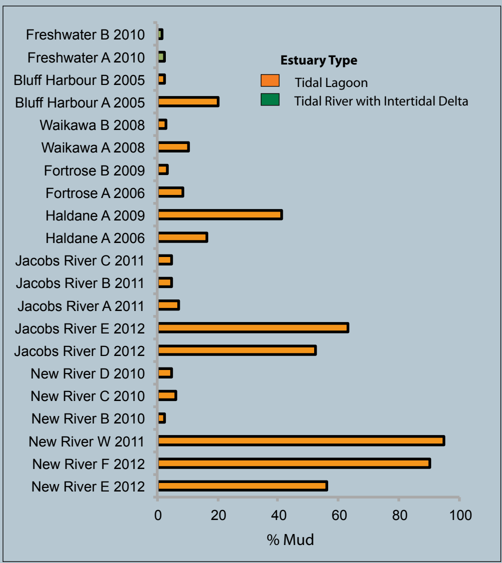



**Figure 2. Percent mud content at Southland fine scale monitoring sites.**

## SEDIMENTATION

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

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

**Table 3. Physical, chemical and macrofauna results (as means) for main basin Jacobs River Estuary sites (2003-2011) and eutrophic arms (2012).**

| Year | Site | RPD | TOC | Mud | Sand | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | TN | TP | Abundance | Mean Species No. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cm | % | | | | mg/kg | | | | | | | | No./m² | per core | per site |
| Sites located in the relatively well flushed central basin of Jacobs River Estuary | | | | | | | | | | | | | | | | | |
| 2003 | JRE Fine Scale A | Data collected by Cawthron - unable to be provided. | 0.9 | 1.0 | 98.8 | 0.22 | 0.48* | 14.70 | 24.0 | 8.36 | 12.08 | 73.1 | 121 | 495 | 4508 | 8 | 21 |
| 2003 | JRE Fine Scale B | | 0.4 | 2.8 | 96.5 | 0.71 | 0.19* | 11.90 | 6.19 | 4.44 | 5.90 | 17.3 | 147 | 203 | 3870 | 12 | 24 |
| 2003 | JRE Fine Scale C | | 0.7 | 4.0 | 95.3 | 0.80 | 0.11* | 10.43 | 5.57 | 3.87 | 4.72 | 17.4 | 222 | 276 | 5453 | 10 | 20 |
| 2004 | JRE Fine Scale A | | 1.1 | 0.8 | 98.8 | 0.45 | <1.0 | 10.27 | 23.2 | 2.90 | 11.10 | 83.1 | 149 | 464 | 7335 | 14 | 23 |
| 2004 | JRE Fine Scale B | | 0.6 | 3.9 | 95.1 | 1.05 | <1.0 | 6.93 | 5.8 | 1.64 | 5.57 | 50.7 | 252 | 198 | 6780 | 15 | 28 |
| 2004 | JRE Fine Scale C | | 0.8 | 6.4 | 92.8 | 0.81 | <1.1 | 7.16 | 4.91 | 1.61 | 4.87 | 51.6 | 249 | 267 | 9330 | 12 | 22 |
| 2005 | JRE Fine Scale A | | 1.0 | 4.9 | 94.7 | 0.46 | <0.05 | 9.87 | 23.7 | 11.90 | 3.22 | 52.3 | 255 | 508 | 6105 | 12 | 21 |
| 2005 | JRE Fine Scale B | | 0.6 | 6.2 | 93.0 | 0.75 | <0.05 | 8.21 | 6.61 | 6.40 | 1.85 | 19.2 | 262 | 248 | 5693 | 15 | 32 |
| 2005 | JRE Fine Scale C | | 0.7 | 8.7 | 90.7 | 0.59 | <0.05 | 7.89 | 5.66 | 5.40 | 1.81 | 20.0 | 358 | 336 | 7013 | 13 | 24 |
| 2006 | JRE Fine Scale A | | 1.0 | 1.5 | 98.0 | 0.50 | 0.10 | 8.87 | 21.67 | 11.33 | 2.90 | 56.3 | 140 | 577 | 6188 | 13 | 26 |
| 2006 | JRE Fine Scale B | | 0.9 | 7.7 | 92.1 | 0.20 | 0.10 | 7.13 | 6.47 | 6.00 | 1.73 | 19.0 | 250 | 219 | 5828 | 16 | 26 |
| 2006 | JRE Fine Scale C | | 1.0 | 13.6 | 85.9 | 0.57 | 0.10 | 7.47 | 6.47 | 5.33 | 2.03 | 21.3 | 333 | 389 | 4163 | 10 | 22 |
| 2011 | JRE Fine Scale A | 0 | 0.1 | 6.9 | 92.9 | 0.23 | 0.07 | 10.60 | 25.0 | 13.20 | 3.43 | 58.3 | <500 | 500 | 9421 | 11 | 24 |
| 2011 | JRE Fine Scale B | 1 | 0.2 | 4.8 | 94.8 | 0.37 | 0.02 | 7.03 | 6.17 | 5.73 | 1.71 | 16.8 | <500 | 204 | 6098 | 17 | 30 |
| 2011 | JRE Fine Scale C | 1 | 0.2 | 4.7 | 94.6 | 0.63 | 0.02 | 6.97 | 5.13 | 4.90 | 1.65 | 16.8 | <500 | 233 | 18715 | 15 | 23 |
| Sites located in relatively poorly flushed sheltered arms of Jacobs River Estuary | | | | | | | | | | | | | | | | | |
| 2012 | JRE D (Pourakino) | 0 | 1.2 | 52.4 | 46.9 | 1.1 | 0.12 | 17.2 | 30.7 | 15.4 | 5.4 | 65.0 | 1433 | 640 | 18120 | 10 | 17 |
| 2012 | JRE E (Aparima) | 0-0.5 | 2.7 | 63.0 | 36.0 | 1.0 | 0.09 | 22.3 | 25.7 | 16.2 | 6.2 | 54.3 | 3133 | 823 | 11272 | 8 | 16 |

*denotes unreliable chemical results

## 3. Results and Discussion (Continued)

**Mud dominated sediments in the Pourakino Arm.**

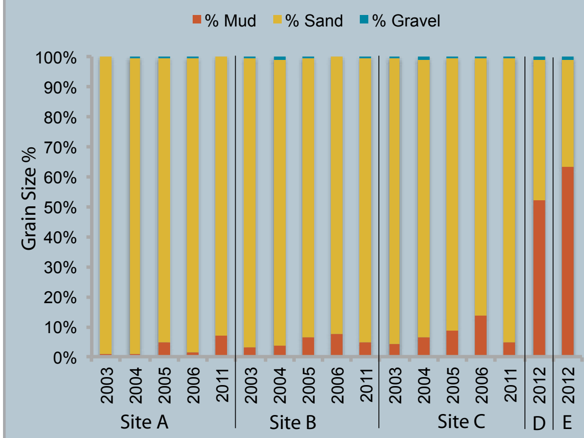



**Figure 3. Grain size, Jacobs River Estuary.**

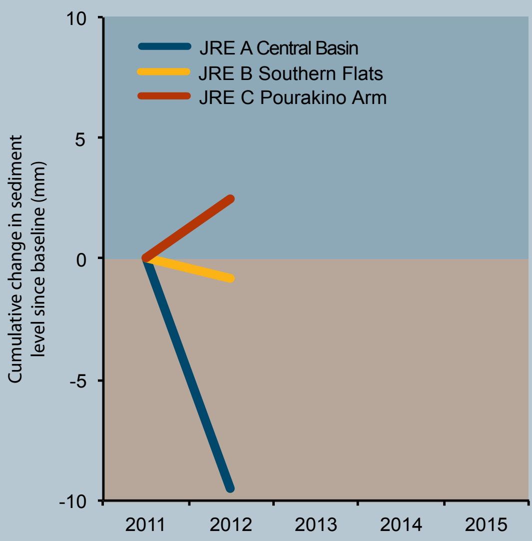



**Figure 4. Cumulative change in sediment levels over buried plates in Jacobs River Estuary, 2011 to 2012.**

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

### Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The monitoring results for all Jacobs River Estuary sites (Figure 3) show that the Pourakino and Aparima eutrophic zone sediments (Sites D and E) were dominated by mud (52-63% mud), whereas the main intertidal basin sites were dominated by sands (>90% sand in all years).

Compared with fine scale sites in other tidal lagoon type estuaries in Southland, the Pourakino and Aparima Arm mud contents were very high (Figure 2). Such findings are not unexpected given the intensively developed pastoral nature of the catchment and the elevated sediment yields expected from such landuse areas. Estimated areal sediment loads to Jacobs River Estuary are 18.3g.m$^{-2}$.d$^{-1}$ (based on CLUES model estimates), which is nearly twice the areal load to the nearby similarly affected New River Estuary. Both estuaries have extensive muddy, anoxic, eutrophic zones within their borders.

### Sedimentation Rate

Table 4 presents the January 2012 sedimentation rate monitoring results for the 12 plates buried in Jacobs River Estuary, with summary data from 2011-2012 presented in Figure 4.

Although the results are very much preliminary, reflecting only 1 year of monitoring, sediment rates in the main central basin of the estuary (Sites A and B) were rated in the "very low" category. From Feb. 2011 to Jan. 2012, both sites showed a decrease in sediment which is attributed to wave driven movement of surface sediments common in the main estuary basin. At Site C, in the muddy, eutrophic and macroalgae covered upper Pourakino Arm, there was a "moderate" increase in sediment recorded.

The results reflect the obvious differences between the sites. The well flushed main basin sites remain dominated by sands, with muds not accumulating on the estuary surface. In contrast, large parts of the sheltered arms of the estuary are smothered in deep soft, sulphide-rich muds and excessive macroalgal growth. The source of fine muds is almost certainly from the surrounding Pourakino and Aparima catchments rather than the sea. While ongoing monitoring of sedimentation rates will measure changes into the future, the prevailing conditions indicate the assimilative capacity of the settling basins within the estuary are currently being exceeded and that there has already been a significant input of muddy sediments into the estuary.

# 3. Results and Discussion (Continued)

**Table 4. Sedimentation rate monitoring results, Jacobs River Estuary, February 2011 - January 2012.**

| SITE | PLATE | Mean Sediment Depth (mm) | | | | | Change (mm) | | | | Site Mean (mm/yr) | | | | Overall Rate (mm/yr) | SEDIMENTATION RATE CONDITION RATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20-Feb-2011 | 29-Jan-2012 | 2013 | 2014 | 2015 | 2011-2012 | 2012-2013 | 2013-2014 | 2014-2015 | 2011-2012 | 2011-2013 | 2011-2014 | 2011-2015 | 2011-2012 | |
| JRE A Lower Aparima Arm | 1 | 202 | 190 | | | | -12 | | | | -9.5 | | | | -9.5 | VERY LOW |
| | 2 | 256 | 238 | | | | -18 | | | | | | | | | |
| | 3 | 231 | 220 | | | | -11 | | | | | | | | | |
| | 4 | 232 | 235 | | | | 3 | | | | | | | | | |
| JRE B Western Central Basin | 1 | 102 | 98 | | | | -4 | | | | -0.8 | | | | -0.8 | VERY LOW |
| | 2 | 199 | 184 | | | | -15 | | | | | | | | | |
| | 3 | 196 | 200 | | | | 4 | | | | | | | | | |
| | 4 | 194 | 206 | | | | 12 | | | | | | | | | |
| JRE C Upper Pourakino Arm | 1 | 105 | 115 | | | | 10 | | | | +2.5 | | | | +2.5 | MODERATE |
| | 2 | 90 | 90 | | | | 0 | | | | | | | | | |
| | 3 | 107 | 107 | | | | 0 | | | | | | | | | |
| | 4 | 120 | 120 | | | | 0 | | | | | | | | | |

Thick beds of *Gracilaria* that contribute to trapping and deposition of fine muds in the Upper Pourakino Arm.

**Macro-invertebrate Community**

Sediment mud content is a major determinant of the structure of the benthic invertebrate community. This section examines this relationship in Jacobs River Estuary in three steps by:

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

As previously explained, ten core samples were analysed at each of the gross eutrophic sites, Pourakino Arm (Sites D) and Aparima Arm (Site E), for the presence of macroinvertebrates. The samples were taken from the dominant habitat type in each arm, i.e. muddy, anoxic, sulphide rich sediments overlain with a thick layer of partially decaying macroalgae.

The 2012 results (Appendix 3) indicate a community that was dominated by crustacea, gastropods and bivalves, which was different to the community composition at the other fine scale sites measured previously in Jacobs River Estuary (Figure 5), except for Site C in 2011. These differences are attributed to the poor sediment conditions at the eutrophic sites and the fact that they were overlain with a thick layer of decaying algae. The proximity to large areas of macroalgal cover in the Pourakino Arm was the likely explanation for the large numbers of gastropods (primarily *Potamopyrgus* sp.) found at Site C in 2011.

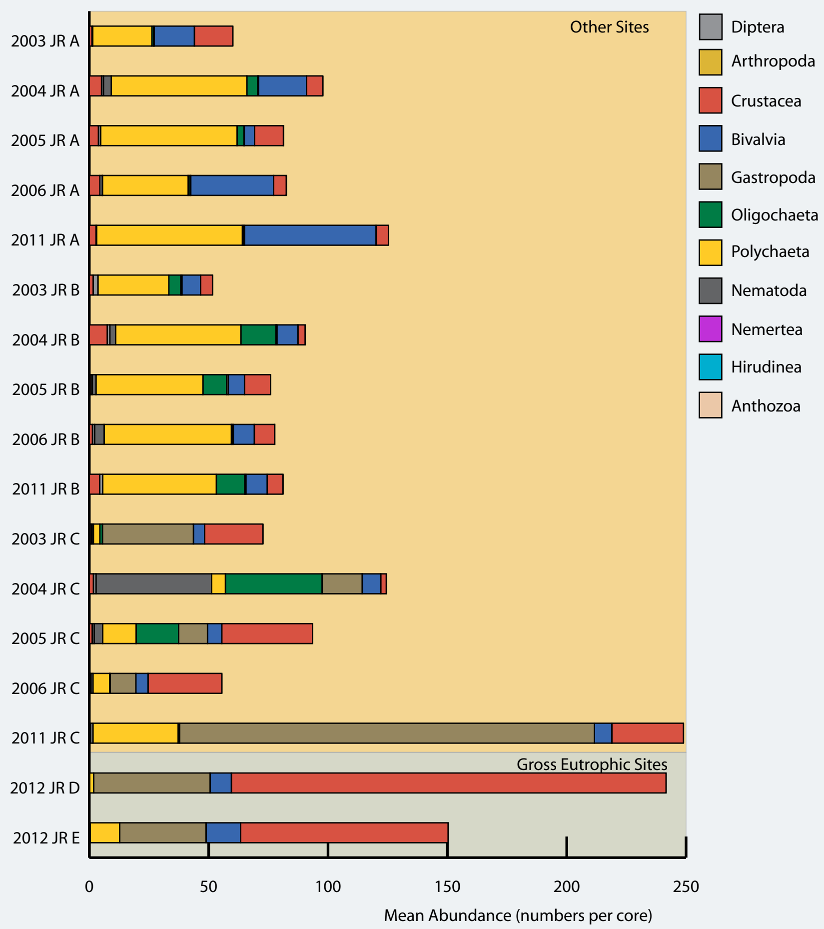



**Figure 5. Mean abundance of major infauna groups, Jacobs River Estuary, 2003-2012.**

Such conditions favour surface feeding organisms (particularly crustacea, gastropods, bivalves and some polychaetes), rather than subsurface animals that feed on deposits within the sediments (Figure 6). In particular, the gross eutrophic sites included the following taxa in relatively large numbers:

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

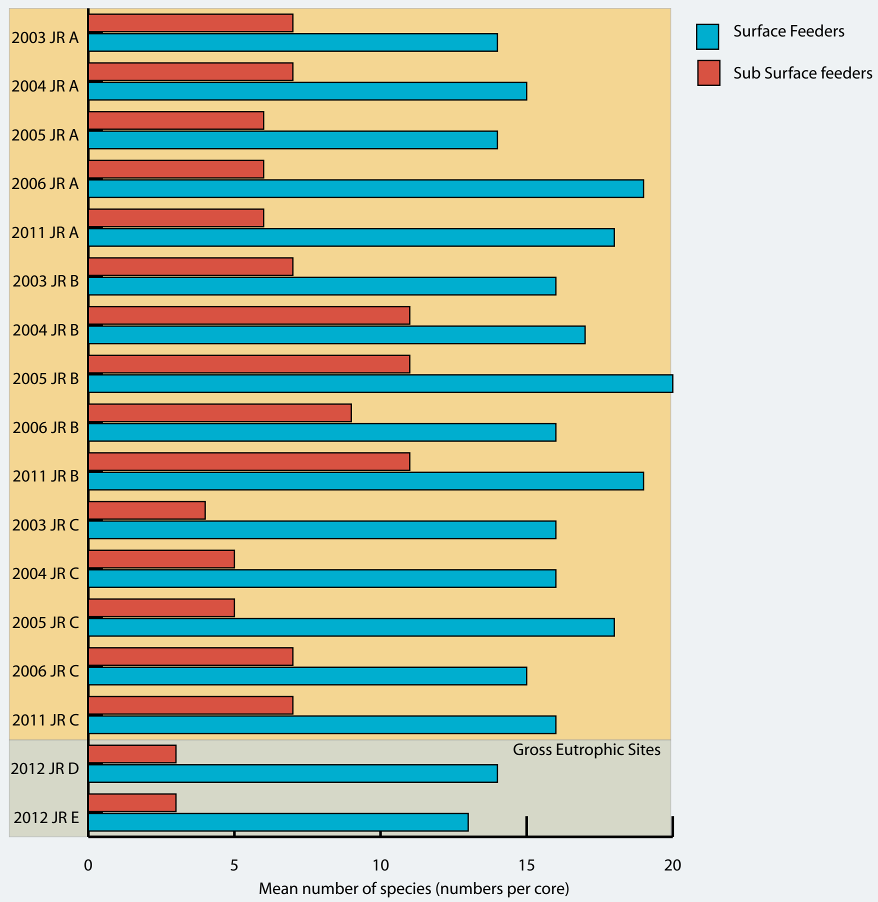



**Figure 6. Mean number of species within surface and subsurface feeding groups, Jacobs River Estuary, 2003-2012.**

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

**Table 5. Macrofauna abundance per core for Jacobs River Estuary Gross Eutrophic Site D and E (2012). Organic enrichment (AMBI) and mud (MUD) tolerance ratings also shown.** (NA=tolerance not yet ascribed).

| Phyla | Species | AMBI | MUD | 2012 JR D | 2012 JR E |
|---|---|---|---|---|---|
| NEMERTEA | *Nemertea sp.#2* | III | 3 | 0.1 | 0.4 |
| POLYCHAETA | *Aglaophamus macroura* | II | NA | 0.2 | 0.0 |
| | *Nicon aestuariensis* | III | 4 | 0.8 | 3.0 |
| | *Polydora* sp.#1 | I | 2 | 0.0 | 0.1 |
| | *Prionospio aucklandica* | IV | 3 | 0.6 | 0.0 |
| | *Scolecolepides benhami* | III | 5 | 0.1 | 9.2 |
| GASTROPODA | *Amphibola crenata* | NA | NA | 0.0 | 0.1 |
| | *Potamopyrgus* sp. or spp. | III | 4 | 48.8 | 36.1 |
| BIVALVIA | *Arthritica sp.#1* | III | 3 | 8.1 | 14.4 |
| | *Austrovenus stutchburyi* | III | 2 | 0.6 | 0.0 |
| | *Paphies australis* | II | 1 | 0.2 | 0.1 |
| CRUSTACEA | Amphipoda sp.#1 | NA | NA | 17.3 | 8.5 |
| | Amphipoda sp.#2 | NA | NA | 13.0 | 0.7 |
| | Amphipoda sp.#7 | NA | NA | 115.0 | 38.5 |
| | *Austrohelice crassa* | NA | 5 | 0.0 | 0.1 |
| | *Exosphaeroma planulum* | NA | NA | 3.1 | 3.7 |
| | *Halicarcinus whitei* | NA | NA | 0.5 | 0.3 |
| | *Macrophthalmus hirtipes* | NA | 3 | 6.1 | 2.1 |
| | *Paracorophium excavatum* | III | 5 | 26.9 | 33.0 |
| | *Pseudaega punctata* | NA | NA | 0.2 | 0.0 |

When compared to the other less muddy fine scale monitoring sites in the main basin of Jacobs River Estuary (Sites A and B), the macroinvertebrate mud tolerance rating was in the fair range at the gross eutrophic sites, indicating a community dominated by mud tolerant taxa (Figure 7). The similarity of Site C to the eutrophic sites likely reflects the higher mud content evident at Site C compared to Sites A and B.

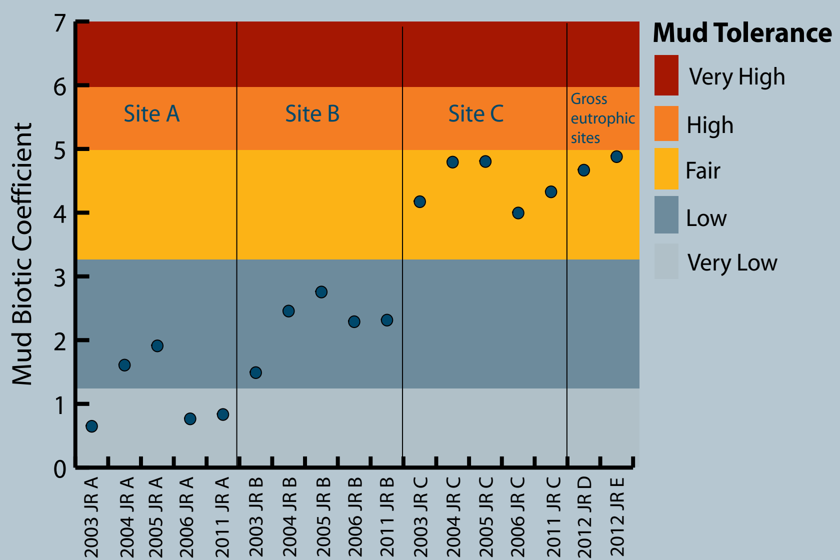



**Figure 7. Mud tolerance macroinvertebrate rating.**

Multivariate techniques were also used to explore whether the macroinvertebrate communities at the gross eutrophic sites differed from the less disturbed fine scale sites in Jacobs River Estuary (Figure 8). Figure 8 shows that the results of the multivariate analysis (NMDS Plot) clearly portray the difference in the benthic invertebrate communities between the cleaner, less disturbed, low mud content sites (Sites A,B, and C) and the muddy, eutrophic sites (Sites D and E). Data from other studies (Robertson and Stevens 2012a) showed that macrofauna communities were more diverse and abundant where there was a thick macroalgal layer over anoxic sulphide rich sediments (as at the Jacobs River sites D and E), compared to the sites with thick anoxic muds and no macroalgal layer.

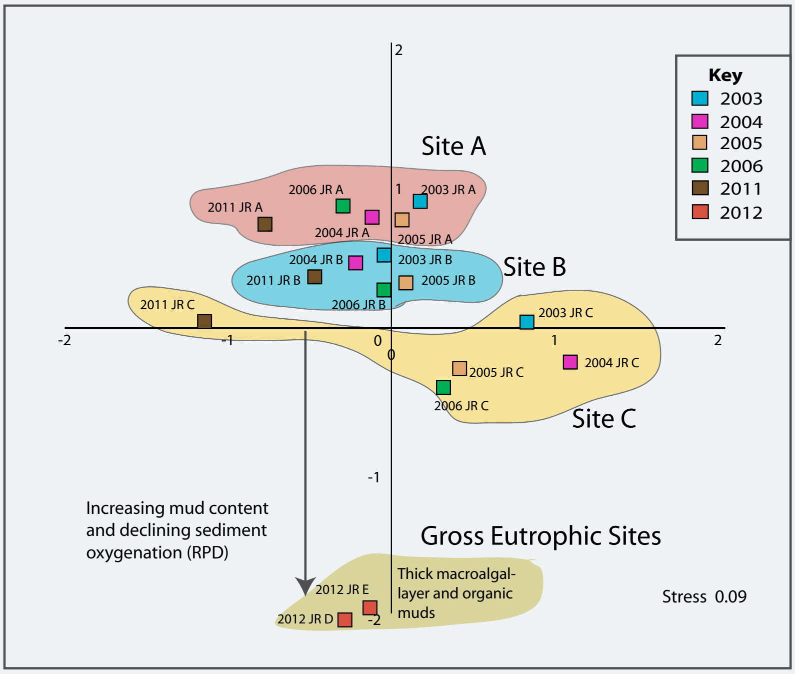
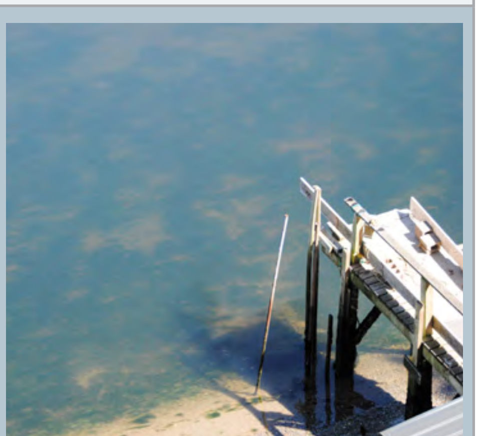



**Figure 8. NMDS plot showing the relationship among mean samples in terms of similarity in macro-invertebrate community composition for Jacobs River Estuary Sites A, B, C, D, and E and for 2003-2012. The plot shows the mean of each of the 10 (or 12 in 2003) replicate samples for each site and is based 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.

**Pourakino Arm Site D showing thick muddy macroalgal cover.**

**Aparima Arm Site E showing thin macroalgal cover overlaying surface muds.**



**Luxuriant subtidal growth in the Aparima River.**

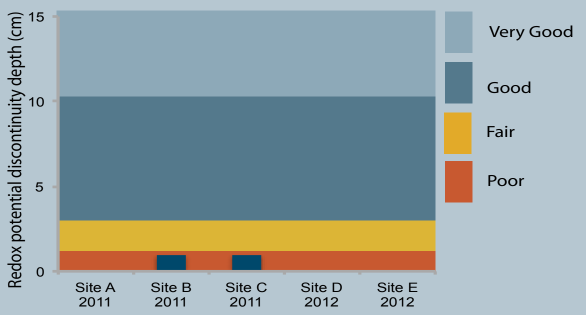



**Figure 9. Redox potential discontinuity depth (RPD) at intertidal sites, 2011-2012.**

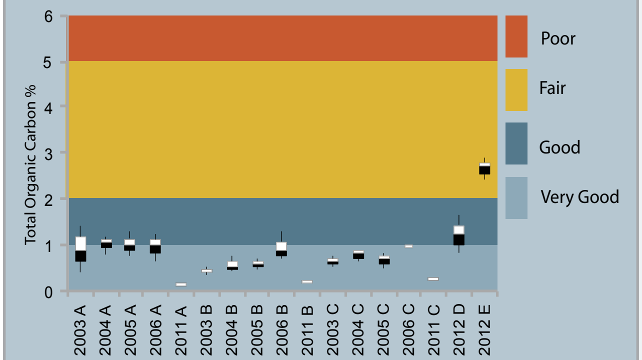



**Figure 10. Total organic carbon (median, upper and lower quartiles, range) at intertidal sites, 2003-2012.**

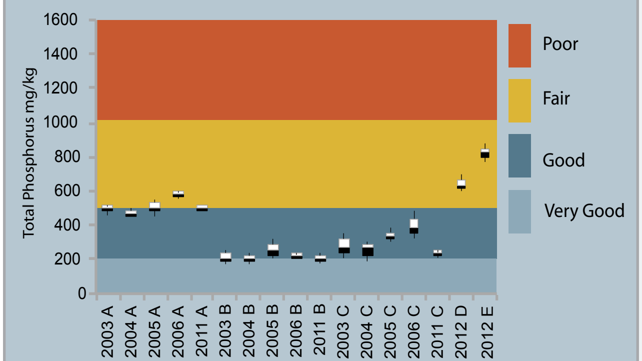



**Figure 11. Total phosphorus (median, upper and lower quartiles, range) at intertidal sites, 2003-2012.**

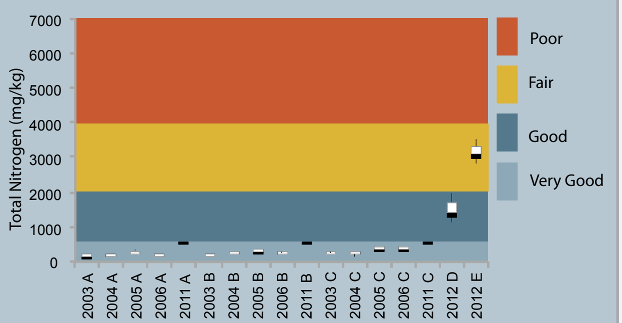



**Figure 12. Total nitrogen (median, upper and lower quartiles, range) at intertidal sites, 2003-2012.**

## EUTROPHICATION

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. In tidal lagoon estuaries like Jacobs River, as organic input to the sediment increases the sediments become deoxygenated, nuisance algal growth becomes abundant, the number of suspension-feeders (e.g. bivalves and certain polychaetes) declines, and deposit-feeders (e.g. opportunistic polychaetes) increase (Pearson and Rosenberg 1978). The primary fine scale indicators of eutrophication are grain size, RPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and the community structure of certain sediment-dwelling animals. The broad scale indicators are the percentages of the estuary covered by macroalgae and soft muds (Stevens and Robertson, 2008).

### Redox Potential Discontinuity (RPD)

The depth of the RPD boundary provides an indication of the level of sediment oxygenation. The results (Figure 9) showed the 2012 RPD depth at the Pourakino and Aparima Arm eutrophic sites was at, or very near, the surface (0-0.5cm), reflecting very poorly oxygenated sediments. These RPD ratings were similar to those measured at the main basin fine scale sites in 2011. Such shallow RPD values fit the "poor" condition rating (see Section 2), with the benthic invertebrate community likely to be dominated by a few pollution-tolerant species that live near the surface.

### Total Organic Carbon and Nutrients

The concentrations of sediment nutrients (total nitrogen - TN and phosphorus - TP) and organic matter (total organic carbon - TOC) also provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow RPD, excessive algal growth, low biotic index), then N, P 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 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 Jacobs River Estuary (Sites D and E), the results (Figures 10-12) indicate elevated concentrations of TOC, TP and TN compared with fine scale sites in less eutrophic parts of the estuary. Note, a changed TN method in 2012 is likely to underestimate TN compared to previous values by 10-40%. Combined with the very high macroalgal cover (Site D=100%, Site E (10-100%) recorded in 2012, and the shallow RPD depths, these results confirm the eutrophic nature of these estuary arms and the oversupply of sediment nutrients in the area.

**Macro-invertebrate Organic Enrichment Index**

The benthic invertebrate organic enrichment tolerance ratings for the eutrophic arm sites in Jacobs River Estuary (JR D and JR E) were in the "low" category (Figure 13). However, because the sediment cores had only a very few sediment dwelling species (Figure 6), Type I "very sensitive" organisms were only present at the surface, and many of the surface species (particularly Amphipoda) that dominated the eutrophic samples have not yet been ascribed tolerances to organic enrichment (Table 5), the AMBI is considered to currently under-represent the extent of sediment degradation at the Jacobs River eutrophic sites.

Instead, the "low" rating (indicating only slight organic enrichment) is attributed to the presence of a thick surface macroalgal layer with a relatively low mud content. This supports a 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. Beneath this surface macroalgal layer, few animals are able to survive.

The impact caused to the sediment community by enrichment is most apparent when comparing species composition over time from JR C in the Pourakino Arm (Figure 1). Here, the shift to increased eutrophication, particularly from 2006 onwards, has seen a classical corresponding pollution response (e.g. Warwick 1986) of increased abundance of smaller opportunistic species and decreased community biomass and diversity (Figure 5). This site, along with the eutrophic site JR D, now show clear signs of ecological stress.

The presence of significant adverse sediment impacts in Jacobs River Estuary is supported by data from New River Estuary (Robertson and Stevens 2012a) which showed that where very anoxic muds are present without an oxygenated surface macroalgal layer, the community had a "very high" AMBI rating, indicating a significantly degraded macroinvertebrate community. Although areas with such conditions were present in Jacobs River Estuary, the 2012 monitoring focused on the dominant habitat of the eutrophic arms which were areas with surface macroalgae.

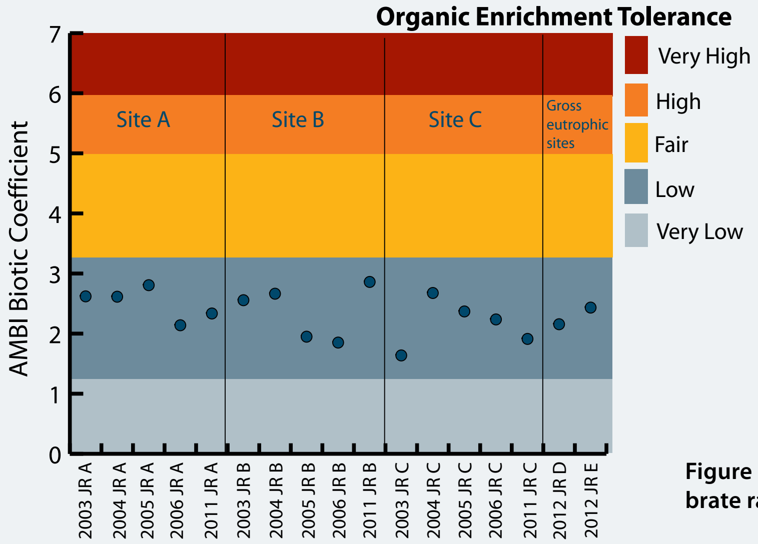



**Figure 13. Organic enrichment macro-invertebrate rating, Jacobs River Estuary, 2003-2012.**

**Pourakino Arm**

**Aparima Arm, thick macroalgal cover (centre) and site patchiness (right)**

## TOXICITY

Heavy metals (Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at moderate concentrations at the Pourakino and Aparima Arm eutrophic sites D and E, with all non-normalised values below the ANZECC (2000) ISQG-Low trigger values (Figure 14). However, these concentrations were generally higher than those measured at the main basin sites during 2003-2011. Such conditions indicate a moderate accumulation of heavy metals in the sediments of the Pourakino and Aparima Arms of the estuary.

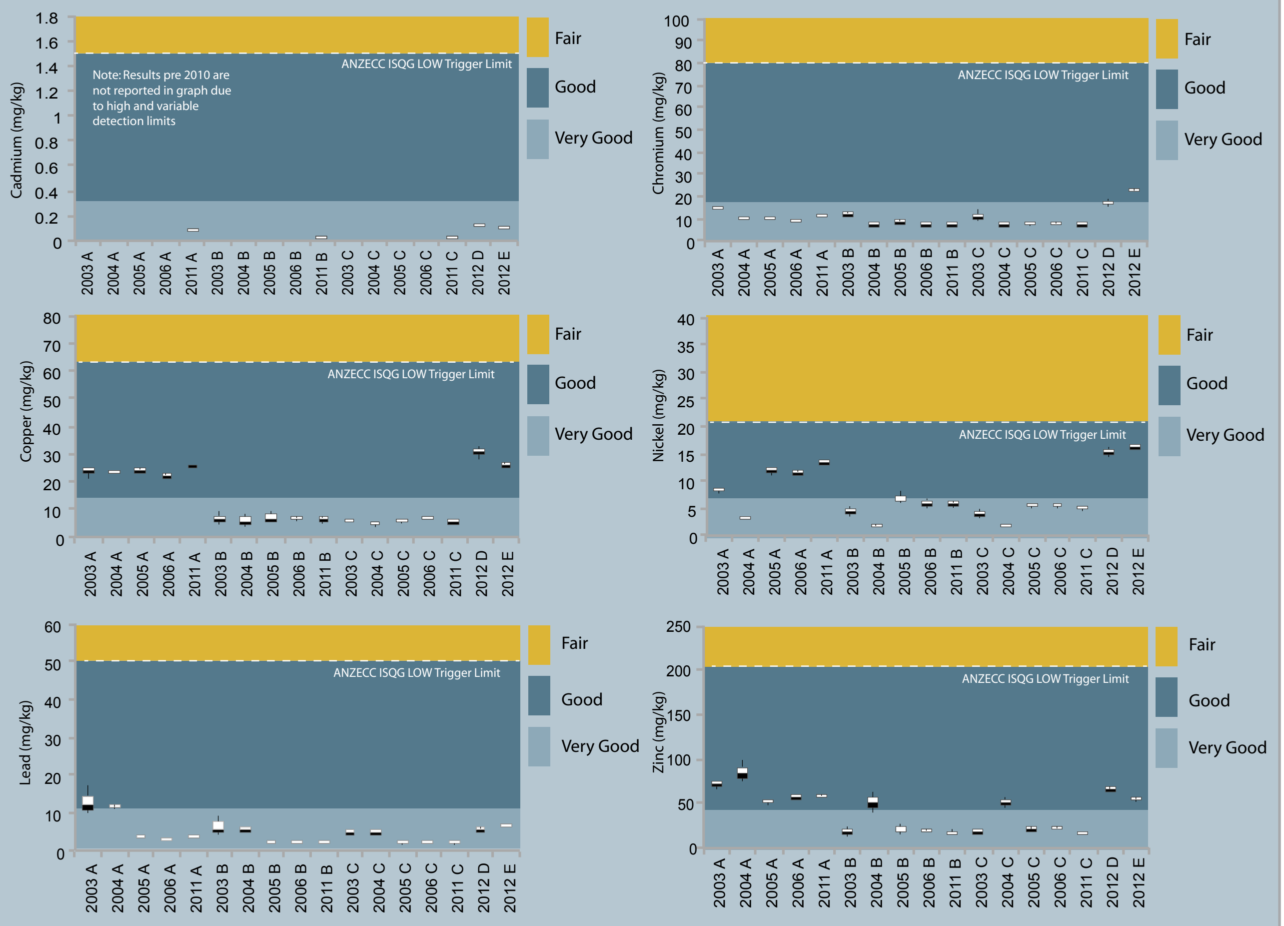
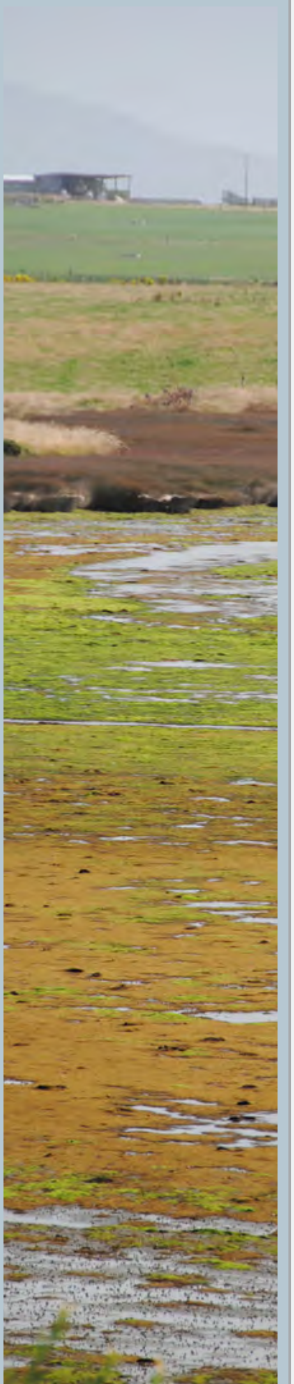



**Figure 14. Sediment metal concentrations, (median, upper and lower quartiles, range) Jacobs River Estuary (2003-2012).**


**Pourakino Arm Site D showing deep soft anoxic muds present beneath macroalgae.**

# 4. CONCLUSIONS



The 2012 results indicate that the poorly flushed Pourakino and Aparima Arms of the estuary are excessively muddy, have high nutrients and nuisance macroalgal growths, and very poor sediment oxygenation. As a result, the macroinvertebrate community is dominated by surface feeding species that are tolerant of such poor conditions. Such conditions limit the food availability for fish and birdlife, and mean the capacity of the estuary to assimilate nutrient and sediment loads from the catchment is exceeded in the upper arm settlement zones. Toxicity (indicated by heavy metals) was low, but higher than measured at other fine scale sites.

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

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

| Indicator | Gross Eutrophic Arm Sites 2011-2012 | Central Estuary Fine Scale Sites 2003-2011 |
|---|---|---|
| **Oxygen Content (RPD)** | RPD at 0-1cm - anoxic to surface in the Pourakino. Very limited oxtygenation (0.5cm at Aparima sites with no smothering macroalgal cover. Sulphide-rich sediments. | RPD at 0-1cm in 2011 (anecdotally lower than in the 2003-2006 period) - anoxic to surface at Site A, oxygenated surface sediments at Sites B and C. Sediments generally not sulphide-rich. |
| **Macrofauna** | Dominated by surface feeding organisms only, especially when a surface macroalgal layer was present. The underlying sediments were so toxic (high sulphides) and low in oxygen, that animal life had difficulty establishing within the sediments. | Relatively diverse fauna with wide range of feeding groups. |
| **Macroalgae** | The vast majority of the sites had 100% cover of thick macroalgae. A relatively abundant fauna was found in the layer of decaying macroalgae on the sediment surface wherever it was present. | Relatively low abundance of macroalgae on surface. |
| **Nutrients and Organic Matter** | Concentrations of nitrogen, phosphorus and organic carbon in the sediments were generally elevated ("good" - "fair" condition ratings). "Good" ratings may reflect exhaustion of sediment nutrient supply. | Concentrations of nitrogen, phosphorus and organic carbon in the sediments were relatively low ("very good" to "fair" condition rating). |
| **Mud Content** | Very elevated (52-63% mud). | Relatively low (1-14% mud). |
| **Sedimentation Rate** | Baseline established in 2011. "Moderate" increase in first year (2.5mm/yr) but longer monitoring period needed. | Baseline established in 2011. Initial results indicate no significant adverse deposition at fine scale sites. |
| **Heavy Metals** | Concentrations of heavy metals were elevated compared to sites in the main estuary basin, but still less than ANZECC (2000) ISQG-Low trigger values. | Concentrations of heavy metals were relatively low and all less than ANZECC (2000) ISQG-Low trigger values. |

It is expected that these extreme conditions that occur at the Pourakino and Aparima sites are due to the sheltered nature of these arms and their propensity to act as natural settling areas for fine sediment and macroalgae sourced from both within and outside the estuary. Because these areas provide an early warning of siltation and eutrophication problems to the wider estuary, and are already showing significant and rapid degradation, it is recommended that the Pourakino and Aparima Arm sites be included in the long term monitoring estuary programme.

## 5. MONITORING

Jacobs 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 Pourakino and Aparima Arm Sites D and E in February 2013, 2014 and again in February 2016 when the 5 yearly fine scale trend monitoring falls due.

**Macroalgal and Seagrass Monitoring.**
Continue with the programme of annual broad scale mapping of macroalgae. Next monitoring due in February 2013. In addition, in order to assess changes in seagrass cover, 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 2013.

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

## 6. MANAGEMENT

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

To address these issues, it is recommended that catchment nutrient and sediment guideline criteria be developed for each estuary type in Southland in a prioritised fashion (e.g. Robertson and Stevens 2011). New River Estuary is recommended as the first priority, with the results being applied to Jacobs River Estuary to quickly assess the extent to which current catchment loads are likely to meet likely guideline criteria. If the catchment inputs are at or below guideline criteria, the estuary is expected to flourish and provide sustainable human use and ecological values in the long term. If catchment loads exceed the estuary's assimilative capacity, it will continue to degrade.

## 7. ACKNOWLEDGEMENTS

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

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# APPENDIX 1. ANALYTICAL METHODS

| Indicator | Laboratory | Method | Detection Limit |
|---|---|---|---|
| Infauna Sorting and ID | CMES | Coastal Marine Ecology Consultants (Gary Stephenson) * | N/A |
| Grain Size | R.J Hill | Air dry (35 degC, sieved to pass 2mm and 63um sieves, gravimetric - (% sand, gravel, silt) | N/A |
| Total Organic Carbon | R.J Hill | Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser). | 0.05 g/100g dry wgt |
| Total recoverable cadmium | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 0.01 mg/kg dry wgt |
| Total recoverable chromium | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 0.2 mg/kg dry wgt |
| Total recoverable copper | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 0.2 mg/kg dry wgt |
| Total recoverable nickel | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 0.2 mg/kg dry wgt |
| Total recoverable lead | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 0.04 mg/kg dry wgt |
| Total recoverable zinc | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 0.4 mg/kg dry wgt |
| Total recoverable phosphorus | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 40 mg/kg dry wgt |
| Total nitrogen | Cawthron | APHA 21st Edn 4500N C | 50 mg/kg dry wgt |

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

# APPENDIX 2. 2012 DETAILED RESULTS

### Station Locations

| Pourakino Site D | JRE D 1 | JRE D 2 | JRE D 3 | JRE D 4 | JRE D 5 | JRE D 6 | JRE D 7 | JRE D 8 | JRE D 9 | JRE D 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| NZTM_E | 1212894 | 1212893 | 1212893 | 1212892 | 1212886 | 1212886 | 1212886 | 1212886 | 1212878 | 1212879 |
| NZTM_N | 4856503 | 4856507 | 4856513 | 4856520 | 4856520 | 4856514 | 4856507 | 4856502 | 4856502 | 4856507 |
| | | | | | | | | | | |
| **Aparima Site E** | **JRE E 1** | **JRE E 2** | **JRE E 3** | **JRE E 4** | **JRE E 5** | **JRE E 6** | **JRE E 7** | **JRE E 8** | **JRE E 9** | **JRE E 10** |
| NZTM_E | 1215311 | 1215313 | 1215316 | 1215322 | 1215327 | 1215325 | 1215320 | 1215318 | 1215319 | 1215323 |
| NZTM_N | 4857085 | 4857090 | 4857092 | 4857096 | 4857094 | 4857092 | 4857089 | 4857086 | 4857080 | 4857082 |

### Physical and Chemical Results for Jacobs River Estuary (Sites D and E), 29 January 2012.

| Site | Reps* | RPD | Salinity | TOC | Mud | Sands | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | TN | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cm | ppt | % | | | | mg/kg | | | | | | | |
| Jacobs River D | 1-4 | 0 | NA | 1.67 | 60.9 | 39 | < 0.1 | 0.120 | 19.1 | 33 | 16.3 | 6.2 | 68 | 2000 | 690 |
| Jacobs River D | 5-8 | 0 | NA | 1.14 | 48 | 50.5 | 1.6 | 0.120 | 17.3 | 31 | 15.5 | 5.4 | 65 | 1100 | 630 |
| Jacobs River D | 9-10 | 0 | NA | 0.83 | 48.4 | 51.1 | 0.5 | 0.109 | 15.1 | 28 | 14.4 | 4.5 | 62 | 1200 | 600 |
| Jacobs River E | 1-4 | 0 | NA | 2.9 | 63.8 | 35.9 | 0.3 | 0.093 | 22.0 | 25.0 | 16.0 | 6.2 | 55 | 3100 | 870 |
| Jacobs River E | 5-8 | 0.5 | NA | 2.4 | 59.3 | 40 | 0.7 | 0.088 | 22.0 | 25.0 | 15.6 | 6.0 | 52 | 3500 | 770 |
| Jacobs River E | 9-10 | 0.25 | NA | 2.8 | 65.9 | 32.2 | 1.9 | 0.094 | 23.0 | 27.0 | 16.9 | 6.4 | 56 | 2800 | 830 |

* composite samples

# APPENDIX 2. 2012 DETAILED RESULTS (CONTINUED)

**Epifauna and macroalgal cover within 0.25m² quadrats, Jacobs River Estuary Sites D and E, 29 Jan. 2012.**

| Site | | RPD depth (cm) | COMMENT | EPIFAUNA (No/0.25m² quadrat) | | MACROALGAE (percent cover) | |
|---|---|---|---|---|---|---|---|
| **Pourakino Arm** | Rep. | | | *Amphibola crenata* | *Potamopyrgus* spp. | *Gracilaria chilensis* | *Ulva intestinalis* |
| Jacobs River D | 1 | 0 | | | | 100 | |
| Jacobs River D | 2 | 0 | | | | 100 | |
| Jacobs River D | 3 | 0 | | | | 100 | 5 |
| Jacobs River D | 4 | 0 | | | | 100 | |
| Jacobs River D | 5 | 0 | | | | 100 | |
| Jacobs River D | 6 | 0 | | | | 100 | 5 |
| Jacobs River D | 7 | 0 | strong sulphide odour | | | 100 | |
| Jacobs River D | 8 | 0 | strong sulphide odour | | | 100 | 5 |
| Jacobs River D | 9 | 0 | strong sulphide odour | | | 100 | 1 |
| Jacobs River D | 10 | 0 | | | | 100 | |
| **Aparima Arm** | Rep. | RPD | | *Amphibola crenata* | *Potamopyrgus* spp. | *Gracilaria chilensis* | *Ulva intestinalis* |
| Jacobs River E | 1 | 0 | | 2 | | 80 | 0 |
| Jacobs River E | 2 | 0 | | 1 | | 70 | 15 |
| Jacobs River E | 3 | 0 | | 0 | | 75 | 10 |
| Jacobs River E | 4 | 0 | | 0 | | 80 | 0 |
| Jacobs River E | 5 | 0.5 | | 2 | | 10 | 5 |
| Jacobs River E | 6 | 0.5 | | 10 | | 10 | 10 |
| Jacobs River E | 7 | 0.5 | | 5 | | 0 | 0 |
| Jacobs River E | 8 | 0.5 | | 3 | 1 | 15 | 10 |
| Jacobs River E | 9 | 0.5 | | 3 | | 15 | 10 |
| Jacobs River E | 10 | 0 | | 0 | | 100 | 0 |

**Macroinvertebrate Infauna for Jacobs River Estuary (Sites D and E), 29 January 2012 - numbers per core.**

| | Species | AMBI | MUD | JRE D-01 | JRE D-02 | JRE D-03 | JRE D-04 | JRE D-05 | JRE D-06 | JRE D-07 | JRE D-08 | JRE D-09 | JRE D-10 | JRE E-01 | JRE E-02 | JRE E-03 | JRE E-04 | JRE E-05 | JRE E-06 | JRE E-07 | JRE E-08 | JRE E-09 | JRE E-10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NEMERTEA | Nemertea sp.#2 | III | 3 | | | | | 1 | | | | | | | 1 | | | | 1 | | 1 | 1 | |
| POLYCHAETA | *Aglaophamus macroura* | II | NA | | | | 1 | | | | | 1 | | | | | | | | | | | |
| | *Nicon aestuariensis* | III | 4 | 1 | 1 | 1 | | 3 | | | | | 2 | 5 | 1 | 3 | 7 | 2 | 1 | 4 | 1 | 3 | 3 |
| | *Polydora* sp.#1 | ! | 2 | | | | | | | | | | | | | 1 | | | | | | | |
| | *Prionospio aucklandica* | IV | 3 | 1 | | 2 | | 2 | | | | | 1 | | | | | | | | | | |
| | *Scolecolepides benhami* | III | 5 | | 1 | | | | | | | | | 1 | | 8 | 27 | 9 | 11 | 6 | 21 | 3 | 6 |
| GASTROPODA | *Amphibola crenata* | NA | NA | | | | | | | | | | | | | | | 1 | | | | | |
| | *Potamopyrgus* sp. or spp. | II | 4 | 47 | 52 | 45 | 36 | 50 | 72 | 33 | 61 | 50 | 42 | 42 | 46 | 26 | 29 | 10 | 30 | 19 | 47 | 79 | 33 |
| | *Arthritica* sp.#1 | I | 3 | 17 | 11 | 10 | 6 | 6 | 9 | 8 | 5 | 5 | 4 | 17 | 15 | 18 | 46 | 1 | 10 | 8 | 9 | 9 | 11 |
| | *Austrovenus stutchburyi* | I | 2 | 3 | | | | | | 2 | 1 | | | | | | | | | | | | |
| BIVALVIA | *Paphies australis* | II | 1 | | | 1 | | | | 1 | | | | | 1 | | | | | | | | |
| | *Amphipoda* sp.#1 | NA | NA | 8 | 17 | 14 | 15 | 7 | 11 | 35 | 19 | 20 | 27 | 20 | | 1 | | | | | | | 64 |
| CRUSTACEA | Amphipoda sp.#2 | NA | NA | 39 | 13 | 8 | 11 | 1 | 20 | 5 | 10 | 2 | 21 | | | 2 | | | | | | | 5 |
| | Amphipoda sp.#7 | NA | NA | 141 | 130 | 93 | 178 | 31 | 171 | 70 | 151 | 107 | 78 | 211 | 41 | 56 | 34 | | | | | 1 | 42 |
| | *Austrohelice crassa* | NA | 5 | | | | | | | | | | | | 1 | | | | | | | | |
| | *Exosphaeroma planulum* | NA | NA | 7 | 3 | 6 | 1 | | 4 | 1 | 4 | 2 | 3 | 19 | 4 | 2 | 6 | | | | | | 6 |
| | *Halicarcinus whitei* | NA | NA | | 1 | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | 3 |
| | *Macrophthalmus hirtipes* | NA | 3 | 5 | 6 | 7 | 9 | 3 | 12 | 4 | 5 | 3 | 7 | 2 | 1 | 5 | 3 | 4 | 1 | 1 | 1 | 2 | 1 |
| | *Paracorophium excavatum* | III | 5 | 15 | 19 | 12 | 32 | 4 | 16 | 30 | 65 | 60 | 16 | 63 | 30 | 47 | 83 | 19 | 6 | 7 | 5 | 45 | 25 |
| | *Pseudaega punctata* | NA | NA | | | | | | | 1 | 1 | | | | | | | | | | | | |
| **Total individuals** | | | | **284** | **254** | **199** | **289** | **108** | **316** | **191** | **323** | **251** | **201** | **380** | **141** | **169** | **235** | **46** | **60** | **45** | **85** | **143** | **199** |
| **Total species** | | | | **11** | **11** | **11** | **9** | **10** | **9** | **12** | **11** | **10** | **10** | **9** | **10** | **11** | **8** | **7** | **7** | **6** | **7** | **8** | **11** |

# APPENDIX 3. INFAUNA CHARACTERISTICS

| Group and Species | | Organic Enrichment Tolerance-AMBI Group ***** | Mud Tolerance **** | Details |
|---|---|---|---|---|
| Hirudinea | Hirudinea sp.1 | NA | NA | Unidentified leech. Leeches are most common in warm, protected shallows where there is little disturbance from currents. Free-living leeches avoid light and generally hide and are active or inactive under stones or other inanimate objects, among aquatic plants, or in detritus. Some species are most active at night. Silted substrates are unsuitable for leeches because they cannot attach. Some species can tolerate mild pollution. |
| Anthozoa | *Anthopleura aureoradiata* | II | S<br>Optimum range 5-10% mud,* distribution range 0-15%* | Mud flat anemone, attaches to cockle shells and helps reduce the rate at which cockles accumulate parasites. Grows up to 10 mm, intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al., 2001). Very tolerant to a range of Polycyclic Aromatic Hydrocarbons (PAH's). *Anthopleura* are also tolerant to UV light, because they have mycosporine-like amino acids in their tissue which act like a biological sunscreen. It has green plant cells in its tissues that convert solar energy to food. Its column is rough with warts. |
| | *Edwardsia* sp.#1 | II | NA | A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions. |
| Nemertea | Nemertea sp. | III | I | Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions. Optimum range 55-60% mud,* distribution range 0-95%* |
| Nematoda | Nematoda sp | III | M<br>Mud tolerant. | Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5 mm mesh sieve. Generally reside in the upper 2.5 cm of sediment. Intolerant of anoxic conditions. |
| Polychaeta | *Aglaophamous macroura.* | II | NA | A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate. Feeding type is carnivorous. Significant avoidance behaviour by other species. Feeds on *Heteromastus filiformis, Orbinia papillosa* and *Scoloplos cylindrifer* etc. |
| | *Aonides oxycephala* | III | SS<br>Optimum range 0-5% mud*, distribution range 0-80%**. | A small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10 cm. Although Aonides is free-living, it is not very mobile and prefers to live in fine sands. Aonides is very sensitive to changes in the silt/clay content of the sediment. **But is generally tolerant of organically enriched situations.** In general, polychaetes are important prey items for fish and birds. |
| | *Boccardia (Paraboccardia) syrtis)* | IV | S<br>Optimum range 10-15% mud,* distribution range 0-50%* | A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Some species very sensitive to organic enrichment and usually present under unenriched conditions. Mud Tolerance; Optimum range 10-15% mud,* distribution range 0-50%*. Often found in organically enriched conditions - e.g Waihopai Arm, New River Estuary and Wellington Harbour. |
| | *Capitella capitata* | V | I | A blood red capitellid polychaete which is **very pollution tolerant.** Common in suphide rich anoxic sediments. Optimum mud range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *H. filiformis* |
| | *Capitellethus zeylanicus* | V | I | A capitellid polychaete. |
| | Cirratulidae | 4 | I | Subsurface deposit feeder that prefers muddy sands. Small sized, tolerant of slight to unbalanced situations. Mud Tolerance; Optimum range 10-15% mud**, distribution range 5-70%**. |

## APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group and Species | | Organic Enrichment Tolerance-AMBI Group ***** | Mud Tolerance **** | Details |
|---|---|---|---|---|
| Polychaeta | Glyceridae | II | I<br>Optimum range 10-15% mud,* distribution range 0-95%* | Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15 cm. They are distinguished by having 4 jaws on a long eversible pharynx. **Intolerant of anoxic conditions. Prefer 10-15% mud but found in wide range. Intolerant of low salinity.** |
| | Hesionidae | II | NA (likely SS) | Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The New Zealand species are little known. Relatively uncommon. Prefer sand. |
| | *Heteromastus filiformis* | IV | I<br>Optimum range 10-15% mud,* distribution range 0-95%* | Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15 cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate to high organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species. |
| | *Microspio maori* | III | I<br>Expect optimum range in 0-20% mud. | A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in low numbers in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary very abundant (5% mud, moderate organic enrichment). Prey items for fish and birds. |
| | *Nicon aestuariensis* | III | M<br>Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. | A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. **Prefers to live in moderate mud content sediments.** |
| | *Orbinia papillosa* | I | S<br>Optimum range 5-10% mud,* distribution range 0-50%* | Family Orbiniidae. Live in sandy or fine sand sediments. Do not have a burrow. A large non-selective deposit feeder. Endemic orbiniid. Without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant. Prefers 5-10% mud but found from 0-50% mud. Sensitive to changes in sedimentation rate. Low numbers in Bluff Harbour (2-20% mud), New River Estuary (1-6% mud). |
| | Paraonidae sp.#1 | III | I | Slender burrowing worms, selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands to a depth of 15cm. Sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content. **Aricidea prefer 35-40% mud (range 0-70% mud).** |
| | *Pectinaria australis* | I | NA | Subsurface deposit-feeding/herbivore. Lives in a cemented sand grain cone-shaped tube. Feeds head down with tube tip near surface. Prefers fine sands to muddy sands. Mid tide to coastal shallows. Belongs to Family Pectinariidae. Often present in NZ estuaries. **Density may increase around sources of organic pollution and eelgrass beds. Intolerant of anoxic conditions.** |
| | *Perinereis camiguinoides.* | III | 4 | An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers sandy, muddy sand, sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation. Mud Tolerance; Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. |

## APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group and Species | | Organic Enrichment Tolerance-AMBI Group ***** | Mud Tolerance **** | Details |
|---|---|---|---|---|
| Polychaeta | Polydora sp | I | S<br>Optimum range 10-15% mud,* distribution range 0-50%* | A Spionid. Polydora-group have many NZ species. Difficult to identify unless complete and in good condition. The Polydora group of species specialise in boring into shells. *Boccardia acus* bores into the upper exposed shell of the cockle *Austrovenus stutchburyi*. Several other Polydora group species live free in tubes in the sand. The tubes of the most widely-occurring species, *Boccardia syrtis*, form a visible fine turf on sandstone reefs and on some sand flats. |
| Polychaeta | *Prionospio aucklandica* originally *Aquilaspio aucklandica.* | IV | I<br>Optimum range 65-70% mud* or 20-50%**, distribution range 0-95%*. Sensitive to changes in sediment mud content. | Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was originally *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A suspension feeding spionid (also capable of detrital feeding) that **prefers living in muddy sands (65-70% mud) but does not like higher levels.** But animals found in 0-95% mud. **Commonly an indicator of increase in mud content. Tolerant of organically enriched conditions.**<br>Common in Freshwater estuary (<1% mud). Present in Waikawa (10% mud), Jacobs River Estuary (5-10% muds). |
| Polychaeta | Sabellidae sp.#1 | I | NA | Sabellids are not usually present in intertidal sands, though some minute forms do occur low on the shore. They are referred to as fan or feather-duster worms and are so-called from the appearance of the feeding appendages, which comprise a crown of two semicircular fans of stiff filaments projected from their tube. |
| Polychaeta | *Scolecolepides benhami* | III | MM<br>Optimum range 25-30% mud,* distribution range 0-100%* | A Spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. **Strong Mud Preference but prefers moderate mud content (25-30% mud).** But also found in 0-100% mud environments. Rare in Freshwater Estuary (<1% mud) and Porirua Estuary (5-10% mud). Common in Whareama (35-65% mud), Fortrose Estuary (5% mud), Waikanae Estuary 15-40% mud. Moderate numbers in Jacobs River Estuary (5-10% muds) and New River Estuary (5% mud).A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary. |
| Polychaeta | *Scoloplos cylindrifer* | I | S<br>Optimum range 0-5% mud,* distribution range 0-60%* | Originally, *Haploscoloplos cylindrifer.* Belongs to Family Orbiniidae which are thread-like burrowers without head appendages. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. **Prefers 0-5% mud (range 0-60% mud). Pollution and mud intolerant**. |
| Polychaeta | Syllidae | II | S<br>Optimum range 25-30% mud,* distribution range 0-40%* | Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers mud/sand sediments (25-30% mud). |
| Polychaeta | *Sphaerosyllis* sp | II | 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. Mud Tolerance; Optimum range 25-30% mud,* distribution range 0-40%*. |

## APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group | Species | Organic Enrichment Tolerance-AMBI Group ***** | Mud Tolerance **** | Details |
|---|---|---|---|---|
| Gastropoda | *Amphibola crenata* | NA | NA | A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria. |
| | *Cominella glandiformis* | NA | SS<br>Optimum range 5-10% mud*, distribution range 0-10%**. | Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds. **Strong Sand Preference. Optimum mud range 5-10% mud. Distribution range 0-10%**.** |
| | *Diloma subrostrata* | NA | SS | The mudflat top shell, lives on mudflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ. Feeds on the film of microscopic algae on top of the sand. **Strong Sand Preference** . **Optimum mud range 5-10% mud. Distribution range 0-15%**.** |
| | *Notoacmaea helmsi* | I | SS<br>Optimum range 0-5% mud*, distribution range 0-10%**. | Endemic to NZ. Small grazing limpet attached to stones and shells in intertidal zone. **Intolerant of anoxic surface muds and sensitive to pollution. Strong sand preference 0-5% mud (range 0-10% mud).** Present in Porirua Harbour 4-5% mud, Freshwater Estuary <1% mud. A few in Fortrose (5% mud). |
| | *Potamopyrgus antipodarum* | II | M<br>Tolerant of muds. | Endemic to NZ. Small snail that can live in freshwater as well as brackish conditions. In estuaries *P. antipodarum* can tolerate up to 17-24% salinity. Shell varies in color (gray, light to dark brown). Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds but can tolerate organically enriched conditions. Tolerant of muds. Populations in saline conditions produce fewer offspring, grow more slowly, and undergo longer gestation periods. |
| | *Potamopyrgus estuarinus* | NA | M<br>Tolerant of muds. | Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feed on decomposing animal and plant matter, bacteria, and algae. **Intolerant of anoxic surface muds. Tolerant of muds.** |
| Bivalvia | *Arthritica bifurca* | III | I | A small sedentary deposit feeding bivalve, preferring a moderate mud content. Lives greater than 2cm deep in the muds. **Prefers 55-60% mud (range 5-70% mud).** |
| | *Austrovenus stutchburyi* | III | S | Family Veneridae. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. **Can live in both mud and sand but is sensitive to increasing mud - prefers low mud content (5-10% but can be found in 0-60% mud). Rarely found below the RPD layer.** Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. |
| | *Macomona liliana* | II | S | A deposit feeding wedge shell. This species lives at depths of 5–10 cm in the sediment and uses a long inhalant siphon to feed on surface deposits and/or particles in the water column. Rarely found beneath the RPD layer. Adversely affected at elevated suspended sediment concentrations. Sand Preference: **Prefers 0-5% mud (range 0-60% mud).** |
| | *Mactra Ovata (Cyclomactra ovata)* | I | NA | Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water. Mud Tolerance; prefers 0-10% mud (range 0-80%). |

## APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group | Species | Organic Enrichment Tolerance-AMBI Group ***** | Mud Tolerance **** | Details |
|---|---|---|---|---|
| Bivalvia | *Paphies australis* | II | SS (adults) S or M (Juveniles) | The pipi is endemic to New Zealand. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7 m. **Optimum mud range 0-5% mud and very restricted to this range.** Strong sand preference (adults optimum range 0-5% mud*, distribution range 0-5% mud**).<br>Juveniles often found in muddier sediments.<br>Common at mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud. |
| | *Perrierina turneri* | II | S | A small relatively uncommon bivalve. Found in Waikawa, Jacobs and Haldane Estuaries. Prefers sand or slightly muddy sand. |
| | *Solletellina* | I | NA | *Soletellina* is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells. |
| Oligichaeta | Oligochaete sp. | I ? | MM | Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species. Optimum mud range 95-100% mud*, distribution range 0-100%**. |
| Crustacea | *Amphipoda sp.1* | NA | NA | An unidentified amphipod. |
| | *Austrominius modestus* | II | NA | Small acorn barnacle (also named *Elminius modestus)*. Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones. |
| | *Colorostylis* sp.#1 | NA | 2 | *Colorostylis lemurum* is a cumacean that feeds on detritus and small organisms, making small feeding pits in the sediment surface and spending much of its time on the sediment surface. It has been reported as sensitive to lead (Hewitt et al. 2009) and to prefer low sediment mud content (<5% Anderson et al. 2007). Surface deposit feeder |
| | Copepoda | NA | NA | Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat and they constitute the biggest source of protein in the oceans. Usually have six pairs of limbs on the thorax. The benthic group of copepods (Harpactacoida) have worm-shaped bodies. |
| | Cumacea | NA | NA | Cumacea is an order of small marine crustaceans, occasionally called hooded shrimps. Some species can survive in water with a lower salinity rate, like in brackish water (e.g. estuaries). Most species live only one year or less, and reproduce twice in their lifetime. Cumaceans feed mainly on microorganisms and organic material from the sediment. Species that live in the mud filter their food, while species that live in sand browse individual grains of sand. |
| | *Decapoda (larvae)* | NA | NA | Unidentified crab larvae. |
| | *Exosphaeroma* sp. | NA | NA | Small seaweed dwelling isopod. |
| | *Halicarcinus cookii* | NA | NA | Pillbox crab. NZ hymenosomatids are generally sub-littoral, although H. cookii, H. varius, H. pubescens and H. innominatus can inhabit shores as high as the lower mid-littoral zone depending on algal cover. H. cookii is endemic to New Zealand. It is an opportunistic carnivore and scavenger, with a diet consisting of molluscs, polychaetes and especially amphipods. |
| | *Halicarcinus whitei* | NA | NA | Pillbox crabs are usually found on the sand and mudflats but may also be encountered under stones on the rocky shore. |

## APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group | Group and Species | Organic Enrichment Tolerance-AMBI Group ***** | Mud Tolerance **** | Details |
|---|---|---|---|---|
| Crustacea | *Helice crassa* | NA | MM | Endemic, burrowing mud crab. Helice crassa concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content. Optimum Range 95-100% mud (found in 5-100% mud)*. |
| | *Lysiosquilla* sp | NA | NA | *Lysiosquilla spinosa*, or New Zealand burrowing mantis shrimp, is a mantis shrimp of the family Lysiosquillidae, endemic to New Zealand. It attains a maximum length of 75 mm (3 in). A common crustacean on harbour or estuarine flats, either in muddy sand or low water Zostera beds. Found throughout New Zealand. It excavates vertical burrows which it leaves at high tide, for short periods, especially at night. The female has an irregular red band along the back flanked with dark green. the male has a sparse pepper-coloured pattern on the body. |
| | *Macrophthalmus hirtipes* | NA | I Optimum range 45-50% mud, distribution range 0-95%*. | The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. |
| | *Mysidacea* sp.1 | II | NA | Mysidacea is a group of small, shrimp-like creatures. They are sometimes referred to as opossum shrimps. Wherever mysids occur, whether in salt or fresh water, they are often very abundant and form an important part of the normal diet of many fishes |
| | Natantia unid. | III | NA | True shrimps are small, swimming, decapod crustaceans usually classified in the suborder Natantia, found widely around the world in both fresh and salt water. |
| | Ostracoda | NA | NA | Ostracoda is a class of the Crustacea, sometimes known as the seed shrimp because of their appearance. They are typically around 1 millimetre. The body of an ostracod is encased by two valves, superficially resembling the shell of a clam. |
| | *Paracorophium excavatum* | III | MM | 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. Optimum Range 95-100% mud (found in 40-100% mud) in upper Nth. Is. estuaries. In Sth. Is. and lower Nth. Is. common in Waikanae Estuary (15-40% mud), Haldane Estuary (25-35% mud) and in Fortrose Estuary (4% mud).<br>Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites like Whareama A and B (30-70% mud) we get very few. |
| | *Pseudaega punctata* | NA | NA | *Pseudaega punctata* is a carnivorous biting isopod of the family Euridicidae. A truly marine species that swims about hunting for food when the tide is in and lies buried in the sand when the tide is out. |
| | Spheromatidae | III | NA | Sphaeromatidae is a family of isopods. |
| | *Tenagomysis* sp.#1 | II | NA | *Tenagomysis* is a genus of mysid shrimps in the family Mysidae. At least nine of the fifteen species known are from New Zealand. |
| Coleoptera | Elmidae Larvae | NA | NA | An unknown water beetle in the family Elmidae. |
| Diptera | Muscidae sp. | NA | NA | Muscidae is a family of flies found in the superfamily Muscoidea some of which are commonly known as house flies or stable flies due to their synanthropy, are worldwide in distribution and contain almost 4,000 described species in over 100 genera. |

## APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

NA=Not Allocated

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

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

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

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

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

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

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

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

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

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