coastalmanagement

# Waimea Inlet

## Fine Scale Monitoring 2013/14

Prepared
for

**Tasman
District
Council**

**June
2014**

**Cover Photo: Waimea Inlet.**

Waimea Inlet, Leigh Stevens and Ben Robertson near Site D, Hoddy Peninsula.

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Prepared for
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By

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All photos by Wriggle except where noted otherwise.

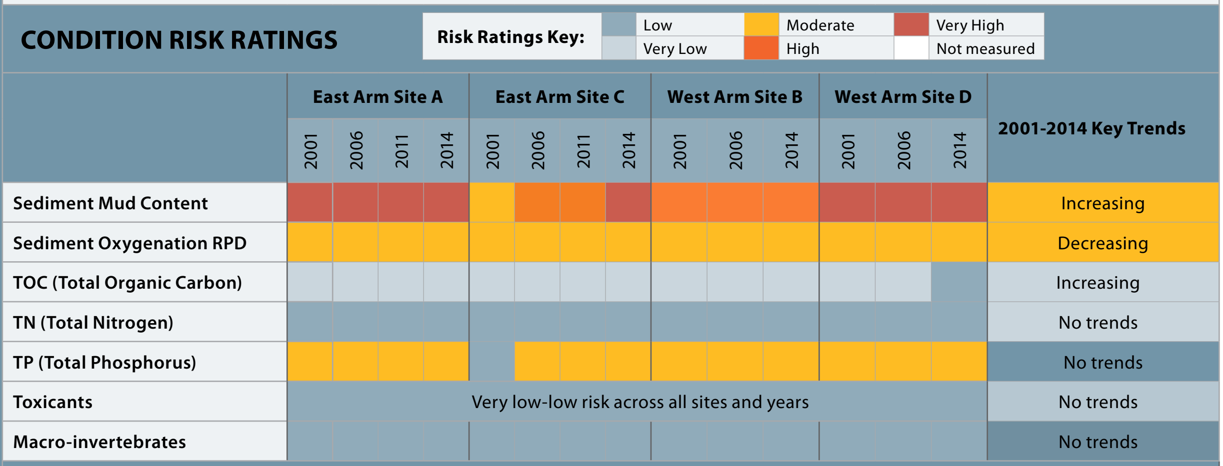
# WAIMEA INLET - EXECUTIVE SUMMARY

Waimea Inlet is one of the South Islands largest tidal lagoon estuaries (~3307ha intertidal area), located near Nelson City and Richmond in the Nelson/Tasman District. It is part of Tasman District Council's (TDC's) coastal State of the Environment (SOE) monitoring programme. This report summarises the results of four years of fine scale monitoring (2001, 2006, 2011, 2014) at four sites within Waimea Inlet. The monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations are presented below.

## FINE SCALE RESULTS

- Sediment mud content was relatively high, averaging 25-50%, and had increased by 23-176% from 2001.
- Sediment oxygenation (aRPD depth) in 2014 was "moderate" (1cm) and had reduced since 2001 (2-3cm).
- Although total organic carbon (TOC) was in the "low to very low" risk category in 2014, the results reflect a significant upward trend between 2001 and 2014 (range, 47-212% increase across all sites). Sediment nutrients, total nitrogen (TN) and total phosphorus (TP), were in the "low-moderate" risk categories and showed no significant trend of change at any site between 2001-2014.
- Macro-invertebrates consisted of a mixed assemblage of species. Statistical analysis showed no significant differences at a community level between 2001-2014, but at a micro or individual species level, there were significant differences. In particular, a significant reduction in species that were highly sensitive to mud/organic enrichment (e.g. pipi).
- Sediment toxicants (heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn), arsenic and semi-volatile organic compounds) were at concentrations that were not expected to pose toxicity threats to aquatic life.

## CONDITION RISK RATINGS



**Risk Ratings Key:**

| | | | | | |
|---|---|---|---|---|---|
| 🟦 | Low | 🟨 | Moderate | 🟥 | Very High |
| ⬜ | Very Low | 🟧 | High | □ | Not measured |

| | East Arm Site A | | | | East Arm Site C | | | | West Arm Site B | | | West Arm Site D | | | 2001-2014 Key Trends |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2001 | 2006 | 2011 | 2014 | 2001 | 2006 | 2011 | 2014 | 2001 | 2006 | 2014 | 2001 | 2006 | 2014 | |
| **Sediment Mud Content** | 🟥 | 🟥 | 🟥 | 🟥 | 🟨 | 🟧 | 🟧 | 🟥 | 🟧 | 🟧 | 🟧 | 🟥 | 🟥 | 🟥 | Increasing |
| **Sediment Oxygenation RPD** | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | Decreasing |
| **TOC (Total Organic Carbon)** | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | 🟦 | Increasing |
| **TN (Total Nitrogen)** | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | No trends |
| **TP (Total Phosphorus)** | 🟨 | 🟨 | 🟨 | 🟨 | 🟦 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | No trends |
| **Toxicants** | Very low-low risk across all sites and years | | | | | | | | | | | | | | No trends |
| **Macro-invertebrates** | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | No trends |

## ESTUARY CONDITION AND ISSUES

Overall, these 2001-2014 results from each of the four sites indicate that the dominant unvegetated habitat in Waimea Inlet is very muddy, has got progressively muddier since 2001, and has low-moderate levels of organic enrichment and toxicity. Although the sites have not shown any broad trends of change in the macro-invertebrate community since 2001, losses in mud sensitive organisms (e.g. pipi) have occurred since that time. Given the magnitude of the muddiness between the 2001 and 2014, it is recommended that annual monitoring be undertaken for the next two years to establish whether the deteriorating results observed in 2014 are truly representative of current conditions. This recommendation is supported by the findings of the broad scale mapping of soft muddy sediments and nuisance macroalgae (Stevens and Robertson 2014).

## RECOMMENDED MONITORING AND MANAGEMENT

In order to assess ongoing trends in the fine scale condition of the estuary it is recommended that sites A, C and D be monitored again (data collection only) in February 2015, and 2016 to establish a multi-year baseline, and undertake a full report of all data at the next scheduled 5 yearly monitoring interval (2020/21). Broad scale sedimentation rate monitoring should continue at annual intervals, and broad scale mapping every 5 years (next due in 2019).

Increased muddiness has been identified as a major issue in Waimea since at least 2010 (Stevens and Robertson 2010). To identify the sources of this issue, it is recommended that catchment inputs be assessed through a combination of modeling and monitoring and that a sediment reduction plan be instigated.

Overall, if the estuary and its surroundings are managed to ensure that the assimilative capacity for muds is not breached, then the estuary will flourish and provide sustainable human use and ecological values in the long term.

# 1. INTRODUCTION

**OVERVIEW**

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. These objectives, along with understanding change in condition/trends, are key objectives of Tasman District Council's State of the Environment Estuary monitoring programme. Recently, Tasman District Council (TDC) undertook a vulnerability assessment of the region's coastlines to establish priorities for a long-term monitoring programme (Robertson and Stevens 2012). The assessment identified the Waimea, Motueka Delta, Motupipi, Ruataniwha and Whanganui estuaries as priorities for monitoring.

For Waimea Inlet, the monitoring and management process consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) as follows:

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (see Table 1) and appropriate monitoring design. Both estuary specific (Stevens and Robertson 2010) and region-wide EVAs have been undertaken (Robertson and Stevens 2012) providing specific recommendations for Waimea Inlet.
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. Broad scale mapping of Waimea Inlet was undertaken in 2001 (Robertson et al. 2002), and historical vegetation cover assessed from 1946 and 1985 aerial photographs (Tuckey and Robertson 2003). Broad scale habitat mapping was repeated in 2006 (Clarke et al. 2008), and in 2014 (Stevens and Robertson 2014).
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Waimea Inlet, was undertaken in 2001 (Robertson et al. 2002) and 2006 (Gillespie et al. 2007). Additionally, sedimentation rates in the estuary have been monitored annually by TDC at ten sites since 2008 and sites A and C monitored in 2011.

In 2013, TDC commissioned Wriggle Coastal Management to undertake a repeat of the fine scale monitoring of Waimea Inlet previously undertaken in 2001(Robertson et al. 2002) and 2006 (Gillespie et al. 2007). The current report describes the 2014 fine scale results and compares them to the previous findings.

Waimea Inlet has been previously described as a relatively large-sized (~3,460ha), macrotidal (3.66m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary (Figure 1, Table 2, Robertson et al. 2002). It has two tidal openings, two main basins, and several tidal arms separated by causeways. The catchment (812km$^2$) is fully developed and dominated by high producing pasture, cropping/horticulture and exotic forestry, while much of the estuary margin is directly bordered by developed urban and rural land, roads, cycleway/walkway (Great Taste Trail), causeways, and seawalls.

The estuary, given it's complex shape, contains a wide variety of intertidal habitats. Data from previous mapping (Robertson et al 2002) include soft muds (1105ha), firm mud sands (801ha), firm and mobile sands (341ha), saltmarsh (234ha), seagrass (~34ha), cobble and gravel fields (252ha) and oyster and cockle beds (32ha). While dominated by intertidal sand and mudflats, the well flushed and often steeply incised estuary channels are deep and, particularly near the entrances, support a variety of cobble, gravel, sand, and biogenic (oyster, mussel, tubeworm) habitats.

Previously reported historical loss of high value vegetated habitat has been estimated for seagrass as 40% loss from 1990 to 1999, and native saltmarsh as 15% loss from 1946-2006 (based on Davidson and Moffat 1990, Tuckey and Robertson 2003, Clark et al. 2008). The loss of saltmarsh habitat has been attributed primarily to reclamation and drainage around margin areas, with shoreline modification (e.g. seawalls, bunds, roads) now greatly limiting natural saltmarsh expansion and restricting its capacity to migrate inland in response to predicted sea level rise. Consequently, future saltmarsh loss is highly likely. The cause of the seagrass loss is likely attributable to the unusually large extent of soft mud in the estuary (see later sections of this report) and its role in both smothering seagrass, and reducing available light through poor water clarity.

The estuary has moderate use and is valued for its aesthetic appeal, rich biodiversity, shellfish collection, bathing, waste assimilation, whitebaiting, fishing, boating, walking, and scientific appeal. The inlet is recognised as a valuable nursery area for marine and freshwater fish, an extensive shellfish resource, and is very important for birdlife. A small port is located at Mapua near the north western entrance.

A recent vulnerability assessment (Robertson and Stevens 2012) identified habitat loss, excessive muddiness, moderate disease risk, and changes in biota as a result of climate change, as the most significant issues in the estuary. Excessive muds and increasing eutrophication and sedimentation are most evident in the presence of localised areas of excessive macroalgal blooms with low sediment oxygenation and muddy, sulphide-rich sediments.

The Waimea Inlet is currently being monitored every five years and the results will help determine the extent to which the estuary is affected by major estuary issues (Table 1), both in the short and long term.

## Table 1. Summary of the major environmental issues affecting most New Zealand estuaries.

### 1. Sedimentation

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). 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 with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007, 2010, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include;

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

**Recommended Key Indicators:**

| Issue | Recommended Indicators | Method |
|---|---|---|
| Sedimentation | Soft Mud Area | GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time. |
| | Seagrass Area/biomass | GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time. |
| | Saltmarsh Area | GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time. |
| | Mud Content | Grain size - estimates the % mud content of sediment. |
| | Water Clarity/Turbidity | Secchi disc water clarity or turbidity. |
| | Sediment Toxicants | Sediment heavy metal concentrations (see toxicity section). |
| | Sedimentation Rate | Fine scale measurement of sediment infilling rate (e.g. using sediment plates). |
| | 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). |

### 2. Eutrophication

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. 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 (Anderson et al. 2002, Valiela et al. 1997).

**Recommended Key Indicators:**

| Issue | Recommended Indicators | Method |
|---|---|---|
| Eutrophication | Macroalgal Cover | Broad scale mapping - macroalgal cover/biomass over time. |
| | Phytoplankton (water column) | Chlorophyll a concentration (water column). |
| | Sediment Organic and Nutrient Enrichment | Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations. |
| | Water Column Nutrients | Chemical analysis of various forms of N and P (water column). |
| | Redox Profile | Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potenial Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial. |
| | 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). |

## Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

### 3. 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 (e.g. Stewart et al. 2008). 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. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). 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.

**Recommended Key Indicators:**

| Issue | Recommended Indicators | Method |
|---|---|---|
| Disease Risk | Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc. | Bathing water and shellfish disease risk monitoring (Council or industry driven). |

### 4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

**Recommended Key Indicators:**

| Issue | Recommended Indicators | Method |
|---|---|---|
| Toxins | Sediment Contaminants | Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples. |
| | Biota Contaminants | Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish). |
| | 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). |

### 5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, 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 such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being 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 (IPCC 2007 and 2013, Kennish 2002).

**Recommended Key Indicators:**

| Issue | Recommended Indicators | Method |
|---|---|---|
| Habitat Loss | Saltmarsh Area | Broad scale mapping - estimates the area and change in saltmarsh habitat over time. |
| | Seagrass Area | Broad scale mapping - estimates the area and change in seagrass habitat over time. |
| | Vegetated Terrestrial Buffer | Broad scale mapping - estimates the area and change in buffer habitat over time. |
| | Shellfish Area | Broad scale mapping - estimates the area and change in shellfish habitat over time. |
| | Unvegetated Habitat Area | Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types. |
| | Sea level | Measure sea level change. |
| | Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges | Various survey types. |

# 2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" that assign a relative level of risk (e.g. very low, low, moderate, high, very high) of specific indicators adversely affecting intertidal estuary condition have been proposed (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within a risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data. However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

The indicators and risk ratings used for the Waimea Inlet fine scale monitoring programme are summarised in Table 2, and detailed background notes explaining the use and justifications for each indicator are presented in Appendix 4.

**Table 2. Summary of estuary condition risk indicator ratings used in the present report.**

| INDICATOR | RISK RATING | | | | |
|---|---|---|---|---|---|
| | Very Low | Low | Moderate | High | Very High |
| **Apparent Redox Potential Discontinuity (aRPD)** | >10cm depth below surface | 3-10cm depth below sediment surface | 1-<3cm depth below sediment surface | 0-<1cm depth below sediment surface | Anoxic conditions at surface |
| **Sediment Mud Content (%mud)** | <2% | 2-5% | >5-15% | >15-25% | >25% |
| **Macro-invertebrate Enrichment Index (WEBI)** | 0-1.2<br>Intolerant of enriched conditions | >1.2-3.3<br>Tolerant of slight enrichment | >3.3-5.0<br>Tolerant of moderate enrichment | >5.0-6.0<br>Tolerant of high enrichment | >6.0<br>Azoic (devoid of invertebrate life) |
| **Total Organic Carbon (TOC)** | <0.5% | 0.5-<1% | 1-<2% | 2-<3.5% | >3.5% |
| **Total Nitrogen (TN)** | <250mg/kg | 250-1000mg/kg | >1000-2000mg/kg | >2000-4000mg/kg | >4000mg/kg |
| **Total Phosphorus (TP)** | <100mg/kg | 100-300mg/kg | >300-500mg/kg | >500-1000mg/kg | >1000mg/kg |
| **Metals** | <0.2 x ISQGLo | 0.2 x ISQGLo to 0.5 x ISQGLo | >0.5 x ISQGLo to ISQGLo | ISQGLo to ISQGHi | >ISQGHi mg/kg |

# 3. METHODS

## FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary, but varies with estuary size) are selected and samples collected and analysed for the following variables.

- Salinity, Oxygenation (apparent Redox Potential Discontinuity - aRPD), Grain size (% mud, sand, gravel).
- Organic Matter: Total organic carbon (TOC).
- Nutrients: Total nitrogen (TN), Total phosphorus (TP).
- Heavy metals and metalloids: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn).
- Macro-invertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: these are measured in certain estuaries where a risk has been identified.

For the Waimea Inlet, four fine scale sampling sites (Figure 3) were selected in unvegetated, mid-low water mudflats (Robertson et al. 2002) (note; in 2011 only sites A and C were sampled). At all sites, a 60m x 30m area in the lower intertidal was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each (precise locations are in Appendix 1), and the following sampling undertaken:

### Physical and chemical analyses.

- Within each plot, one random core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average apparent Redox Potential Discontinuity (aRPD) depth recorded.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. All samples were kept in a chillybin in the field. For semi-volatile organic contaminants (SVOCs), a composite sample was collected from each of the 4 sites (by subsampling each of the 10 replicates).
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details of lab methods and detection limits in Appendix 1):
    - Grain size/Particle size distribution (% mud, sand, gravel).
    - Nutrients - total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC).
    - Trace metals (Cd, Cr, Cu, Ni, Pb, Zn, Hg), arsenic, and semi-volatile organic compounds (SVOCs). Analyses were based on whole sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

### Epifauna (surface-dwelling animals).

Visually conspicuous epifauna within the 60m x 30m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species were identified and allocated a SACFOR abundance category based on percentage cover (Appendix 1, Table A), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Appendix 1, Table B). Species size determined both the quadrat size and SACFOR density rating applied, while photographs were taken and archived. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal/microalgal cover.

### Infauna (animals within sediments).

- One randomly placed sediment core (130mm diameter (area = 0.0133$m^2$) PVC tube) was taken from each of ten plots.
- The core tube was manually driven 150mm into the sediments, and the core transferred to 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).
- Infauna data analysis is discussed in Section 4.

# 3. Methods (Continued)

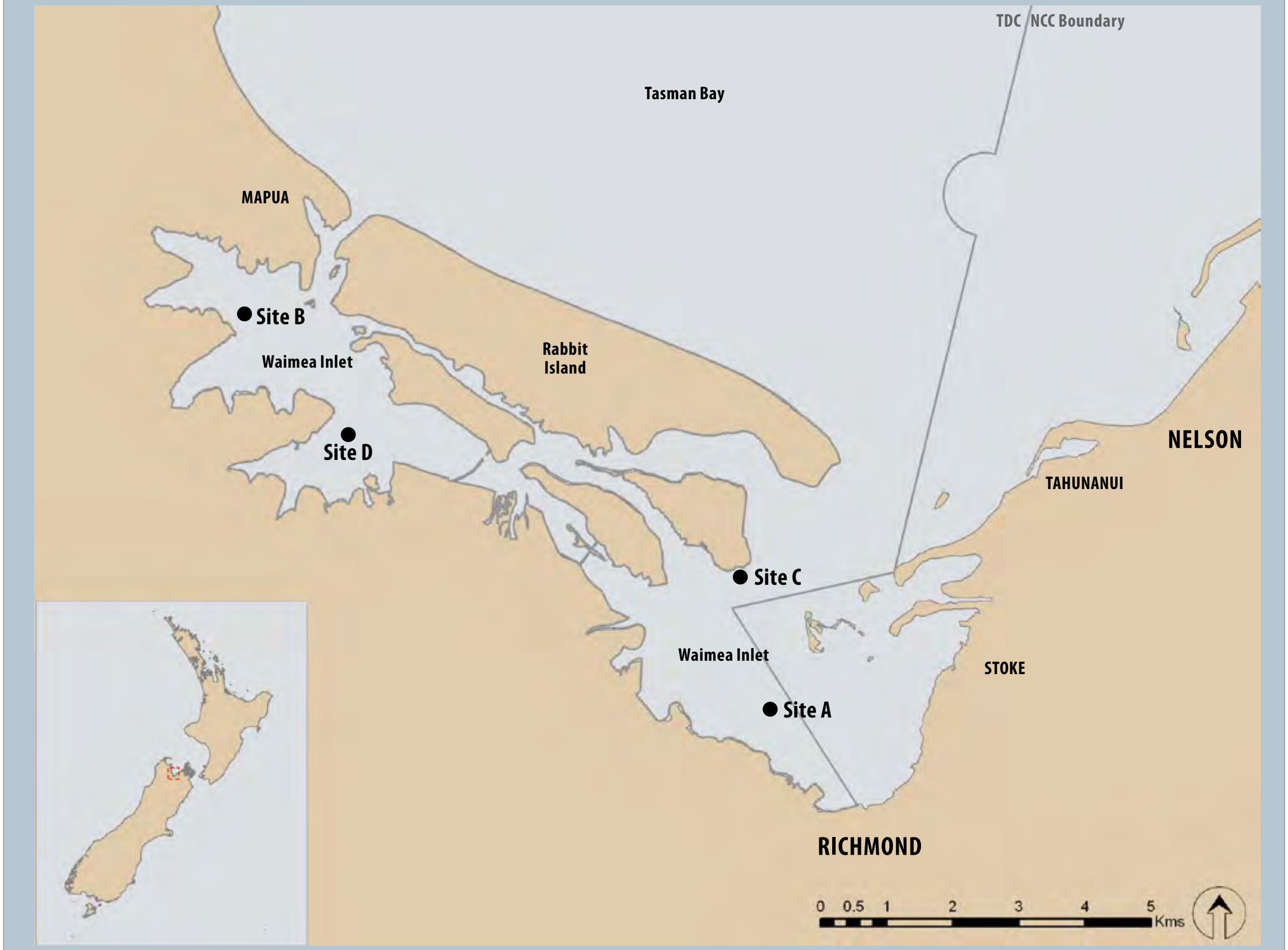


Figure 1. Waimea Inlet - location of fine scale monitoring sites.

# 4. RESULTS AND DISCUSSION

A summary of the results of the 11-12 March 2014 fine scale monitoring of Waimea Inlet, together with the 2001, 2006 fine scale results, is presented in Table 3, with detailed results in Appendices 2 and 3. Data collected from two of the fine scale sites in 2011 are also included.

**Table 3. Summary of physical, chemical[a] and macrofauna results (means) for four fine scale sites (2001-2014).**

| Site | aRPD | Salinity | TOC [b] | Mud | Sand | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | TN | TP | Abundance | Richness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | ppt | % | | | | mg/kg | | | | | | | | No./core | Species/core |
| 2001 A | 3 | - | 0.27 | 28.2 | 69.2 | 2.6 | <0.2 | 69.0 | 10.3 | 64.6 | 4.6 | 43.8 | 608 | 436 | 62.9 | 10.8 |
| 2001 B | 3 | - | 0.21 | 15.9 | 83.7 | 0.4 | <0.2 | 44.6 | 8.8 | 72.3 | 6.3 | 38.4 | 533 | 480 | 32.7 | 9.7 |
| 2001 C | 3 | - | 0.16 | 9.6 | 89.5 | 0.9 | 0.4 | 61.3 | 7.0 | 58.3 | 7.7 | 34.5 | 522 | 273 | 78.6 | 12.6 |
| 2001 D | 3 | - | 0.42 | 40.5 | 56.8 | 2.7 | 0.5 | 95.2 | 12.3 | 94.2 | 11.3 | 50.2 | 783 | 539 | 61.9 | 12.5 |
| 2006 A | 2 | - | 0.38 | 34.1 | 65.0 | 1.1 | <0.1 | 48.9 | 8.0 | 65.3 | 6.4 | 35.2 | 473 | 457 | 46.6 | 8.9 |
| 2006 B | 2 | - | 1.16 | 20.1 | 79.8 | 0.2 | <0.1 | 31.8 | 6.7 | 69.1 | 5.1 | 27.8 | 354 | 515 | 24.2 | 7.4 |
| 2006 C | 2 | - | 0.42 | 21.8 | 77.5 | 0.7 | <0.1 | 42.5 | 8.0 | 61.7 | 6.0 | 28.6 | 553 | 381 | 80.6 | 12.1 |
| 2006 D | 2 | - | 0.45 | 33.2 | 64.1 | 2.7 | <0.1 | 55.2 | 9.5 | 89.5 | 6.5 | 34.6 | 485 | 509 | 57.5 | 11.9 |
| 2011 A | 1 | - | 0.49 | 43.5 | 55.9 | 0.7 | <0.1 | 55.0 | 9.3 | 70.0 | 7.9 | 39.0 | 375 | 493 | 67.8 | 12.0 |
| 2011 C | 1 | - | 0.50 | 33.2 | 64.1 | 2.7 | <0.1 | 55.2 | 9.5 | 89.5 | 6.5 | 34.6 | 485 | 509 | 103.8 | 15.3 |
| 2014 A | 1 | 30 | 0.54 | 42.7 | 56.9 | 0.3 | 0.03 | 51.7 | 9.8 | 74.0 | 7.4 | 40.0 | 700 | 437 | 33.8 | 9.4 |
| 2014 B | 2 | 30 | 0.38 | 25.2 | 74.6 | 0.2 | 0.02 | 31.7 | 7.4 | 75.3 | 5.6 | 32.0 | 500 | 493 | 14.6 | 8.0 |
| 2014 C | 1 | 30 | 0.54 | 26.6 | 72.4 | 1.0 | 0.02 | 51.0 | 9.3 | 72.7 | 6.8 | 37.7 | 733 | 370 | 57.5 | 11.7 |
| 2014 D | 1 | 30 | 0.62 | 50.1 | 47.8 | 2.1 | 0.03 | 58.3 | 10.4 | 95.3 | 7.0 | 41.0 | 700 | 530 | 32.4 | 9.4 |

[a] Data for arsenic, mercury and semi-volatile organic compounds are presented in Appendix 3.

[b] 2001-2011 TOC values estimated from AFDW as follows: 1g AFDW as equivalent to 0.2 g TOC (± 100%) based on a preliminary analysis of NZ estuary data.

## PRIMARY ENVIRONMENTAL VARIABLES

The first step in the data analysis was to explore the primary environmental variables that are most likely to be driving the macrobenthic response in relation to the key issues of sedimentation, eutrophication, and toxicity. These are related to both the risk indicator ratings as presented in Table 2, as well as to changes over time.

The primary variables are related to sediment ***muddiness*** - in particular sediment mud content (often the primary controlling factor) and sedimentation rate; and ***eutrophication***, commonly assessed by sediment aRPD depth (a qualitative measure of both available oxygen and the presence of eutrophication related toxicants such as ammonia and sulphide), organic matter (measured as TOC), and nutrients (Dauer et al. 2000, Magni et al. 2009, Robertson 2013). The influence of non-eutrophication related ***toxicity*** is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs assessed where inputs are likely, or metal concentrations are found to be elevated.

### SEDIMENT INDICATORS

### Sediment Mud Content

Sediment mud content (i.e. % grain size <63µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments, unless naturally erosion-prone with few wetland filters, are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island). In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >25% mud) in the primary sediment settlement areas e.g. where salinity driven flocculation occurs, or in areas that experience low energy tidal currents and waves (i.e. upper estuary intertidal margins and deeper subtidal basins). Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

The 2014 monitoring results for sediment mud content (Table 3) show sites A, C and D fall within the “very high” risk indicator rating, with site B at the very upper end of the “high” rating (Figure 2).

Validated Mann-Kendall trend analyses (Figure 2) showed a uniform increase in mud content at sites A, B and C between 2001-2014 (i.e. all overlaid *P*<0.05; Figure 2), and an overall increase in mud content at Site D, although the variability in the data set meant a statistically significant trend was not present for site D. Since 2001, the mud content of sediments reflected an overall increase of 57% at Site A, 58% at Site B, 176% at Site C, and 24% at Site D.

# 4. Results and Discussion (Continued)

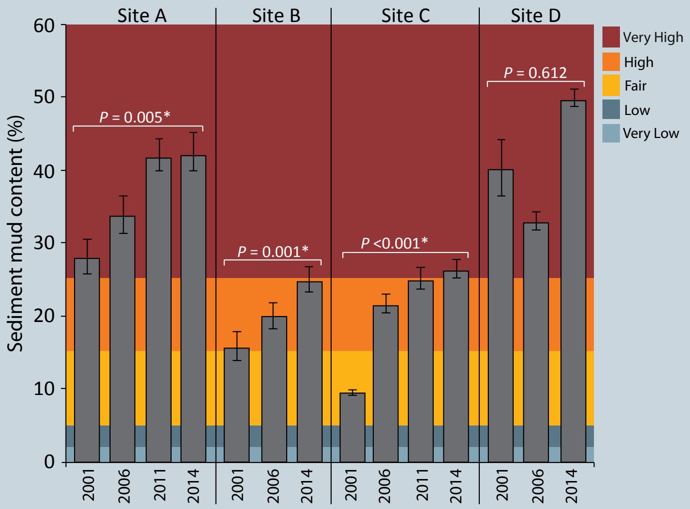


**Figure 2. Mean sediment mud content (±SE, n=3), Waimea Inlet, 2001-2014.**
*** denotes a significant upward trend in mud content between 2001 and 2014.**

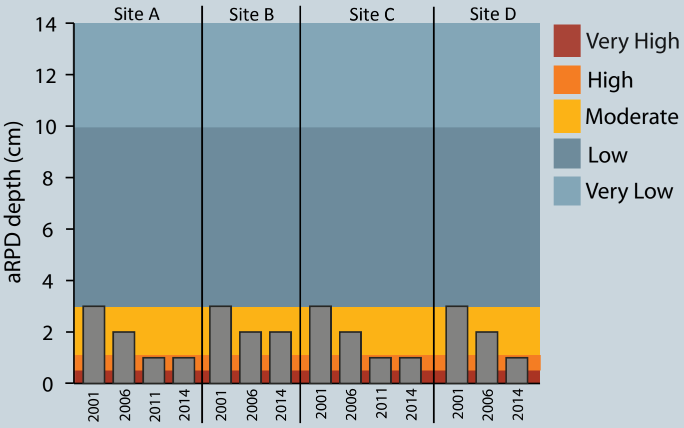


**Figure 3. Mean apparent Redox Potential Discontinuity (aRPD) depth at intertidal sites, 2001-2014.**

The trend analysis results show there has been a clear decline in substrate condition, and the risk indicator ratings highlight that a likely consequence is adverse impacts to benthic macro-invertebrates (investigated further on pages 10-12).

The reason for this upward trend in mud content is currently unclear but may possibly reflect an increase in the mud proportion of sediment inputs to the estuary since 2001 (e.g. increased land development, changing climate patterns), the release and transport of mud from old *Spartina* beds (an exotic rush that covered much of the inlet before it was almost eradicated), and/or ongoing erosion of estuary margins.

## EUTROPHICATION INDICATORS

The primary variables associated with eutrophication impacts are sediment mud content, aRPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal cover. These are discussed below, with the exception of macroalgal cover which is assessed in the broad scale report (Stevens and Robertson 2014).

### Sediment Grain Size (% Mud)

This indicator has been discussed in the sediment section above and is not repeated here. However, in relation to eutrophication, the very high mud content at all sites indicates upper sediment oxygenation is likely to be reduced, and depending on catchment sources, sediment bound organic matter, nutrients and metals may be elevated.

### Apparent Redox Potential Discontinuity (aRPD)

The depth of the aRPD boundary indicates the extent of oxygenation within sediments. Figure 3 shows the aRPD depths for the four Waimea sampling sites. In 2014, the aRPD depth was shallow (1cm) at sites A, C and D, a "high" risk indicator rating, and 2cm, "moderate" at site B. The aRPD has reduced at all sites compared to results for 2001-2006 (2-3cm). However, because the sediment coloration was only slightly grey below the aRPD depth, it is likely that redox levels were not strongly reducing. Consequently, an overall moderate aRPD rating for 2014 results is indicated, which suggests that the benthic invertebrate community was likely to be in a "transitional" state.

# 4. Results and Discussion (Continued)

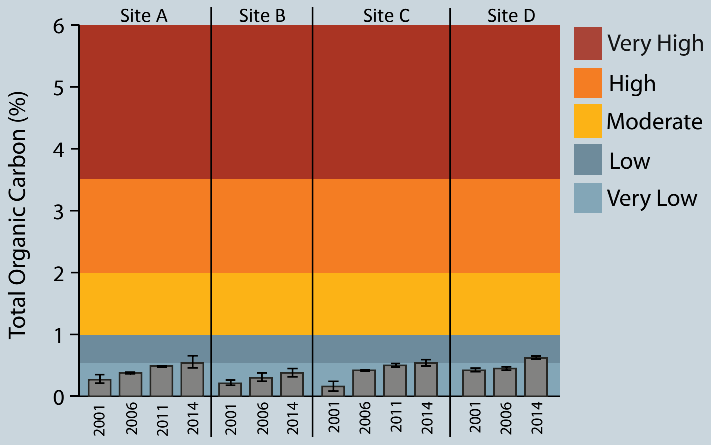


**Figure 4. Mean total organic carbon (±SE, n=3) at intertidal sites, 2001-2014.**

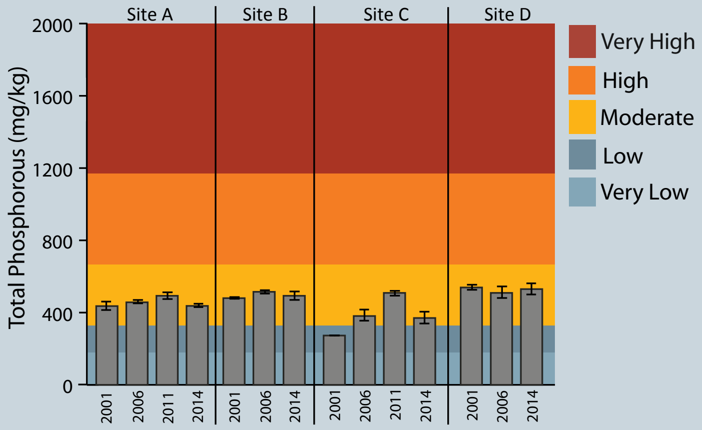


**Figure 5. Mean total phosphorus (±SE, n=3) at intertidal sites, 2001-2014.**

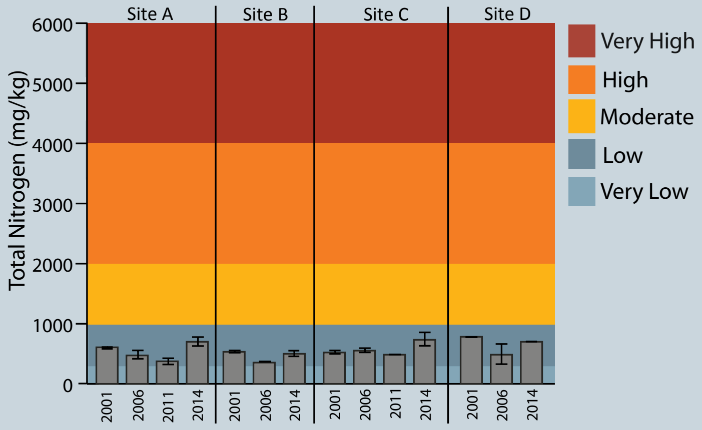


**Figure 6. Mean total nitrogen (±SE, n=3) at intertidal sites, 2001-2014.**

The primary driver of the decline in aRPD from 2001 to 2014 is the increased mud content (Figure 2) at the sites, rather than macroalgal enrichment due to the generally low macroalgal cover present at the fine scale sites.

**Total Organic Carbon and Nutrients**

The concentrations of sediment organic matter (TOC) and to a limited extent, nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow aRPD, excessive algal growth, high WEBI biotic coefficient - see the macro-invertebrate condition section below), then TN, TP and TOC concentrations provide a good indication that loadings are exceeding the assimilative capacity of the estuary. However, a low TOC, TN, or TP concentration does not in itself indicate an absence of eutrophication symptoms. It may be that the estuary, or part of an estuary, may have reached a eutrophic condition and exhausted the available nutrient supply. Obviously, the latter case is likely to better respond to input load reduction than the former.

The 2014 results showed TOC (~0.5%) and TN (~500mg/kg) were in the “low” risk indicator rating, while TP was rated “moderate” (Figures 4, 5, and 6). The low TOC levels reflect the well-flushed nature of much of the estuary, and a likely moderate load of organic matter, sourced primarily from the catchment. Although the TOC results show a significant increase across all sites between 2001 and 2014 (i.e. 100% for Site A, 81% for Site B, 212% for Site C, and 47% for Site D; Man-Kendall $P<0.05$ at all sites), and correspond to a shift from a “very low” to “low” risk indicator rating at Sites A, C and D, this may reflect a change in methods. In 2014 TOC was measured directly, while previous analyses have used a less reliable measure of ash free dry weight and a standard conversion factor to estimate TOC.

No significant trend was detected in sediment TN and TP concentrations between 2001-2014 (Man-Kendall $P>0.05$ at all sites).

Overall, the physico-chemical results indicate that the substrate conditions at the sites were as follows:

- very muddy
- moderately oxygenated
- low organic carbon concentrations
- low-moderate nutrient concentrations

# 4. Results and Discussion (Continued)

## BENTHIC MACRO-INVERTEBRATE COMMUNITY

Benthic macro-invertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong linkage to sediments and, secondarily, to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987). Because they integrate recent pollution history in the sediment, macro-invertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macro-invertebrates to stressors in Waimea Inlet has been examined in three steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macro-invertebrate community among fine scale sites sampled between 2001-2014.
2. Assessment of species richness, abundance, diversity and major infauna groups.
3. Assessment of the response of the macro-invertebrate community to increasing mud and organic matter over the 13 years of monitoring based on identified tolerance thresholds for NZ taxa (Robertson 2013).

### Macro-invertebrate Community Ordination

Principle Coordinates Analysis (PCO) shows that, based on between-year species abundance data collected over the period 2001-2014, the invertebrate community at Sites B and D appeared somewhat distinct from one another, while the community at Sites A and C appeared to maintain a similar structure (Figure 7). However, despite these apparent differences, and the temporal trends in physico-chemical conditions, subsequent statistical analyses revealed no significant differences at any site (i.e. PERMANOVA $P>0.05$ for all sites, for all between-year comparisons), indicating negligible structural changes to the invertebrate community over this period.

Figure 7 shows the relationship among samples in terms of similarity in macro-invertebrate community composition at Sites A, B, C and D for the sampling period 2001-2014. The plot shows the means of the 3 replicate samples for each site (1 rep for Sites A and C in 2011) and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves an unconstrained multivariate data analysis method, in this case principle coordinates analysis (PCO) using PERMANOVA version 1.0.5 (PRIMER-e v6.1.15). The analysis plots the site 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(s) depends on how good a representation it is of actual dissimilarities (i.e. how much of the variation in the data matrix is explained by the first two PCO axis). For the present plots, the cumulative variation explained was >60% for all sites, indicating a good representation of the abundance matrix. Finally, PERMANOVA tests for statistical significant differences in the invertebrate communities among samples, which, for all sites in the present dataset, reflected no significant ($P>0.05$) structural changes over the sampling period 2001-2014.

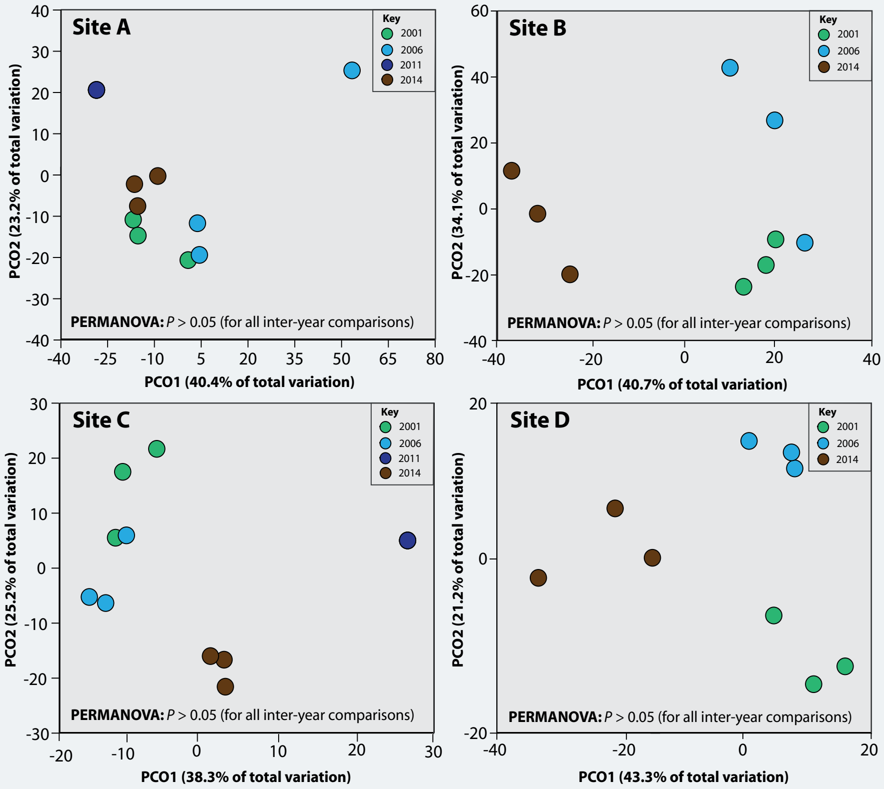


**Figure 7. Principle coordinates analysis (PCO) ordination plots reflecting structural differences in the macro-invertebrate community at each site, Waimea Inlet, 2001-2014.**

# 4. Results and Discussion (Continued)

### Species Richness, Abundance, Diversity and Infauna Groups

Species richness (the mean number of species per core) in 2014 was 9.4 at Site A, 8 at Site B, 11.7 at Site C, and 9.4 at Site D, while species abundance (the mean number of individuals per core) was 33.8 at Site A, 14.6 at Site B, 57.5 at Site C, and 32.4 at Site D (Table 3, Figure 8). The Shannon diversity index was similar for most sites and years and ranged from 1.74-2.09. Mann-Kendall analysis detected no clear directional trends for either species richness, abundance or Shannon diversity index across all sites between 2001-2014 (see Figure 8). The abundance of each of the major infauna groups are compared in Figure 9, and shows dominance by polychaetes, crustacea, bivalves and gastropods. The most notable difference between sites was that Site B had lower overall species richness and abundance compared to the other sites. This most likely reflects its relatively high position on the shore compared to the other sites, effectively increasing its natural stress exposure (i.e. salinity, wave exposure, temperature, desiccation). Consequently, analysis of Site B data should be considered separately or, if a more representative site can be identified, then relocation would be an option.

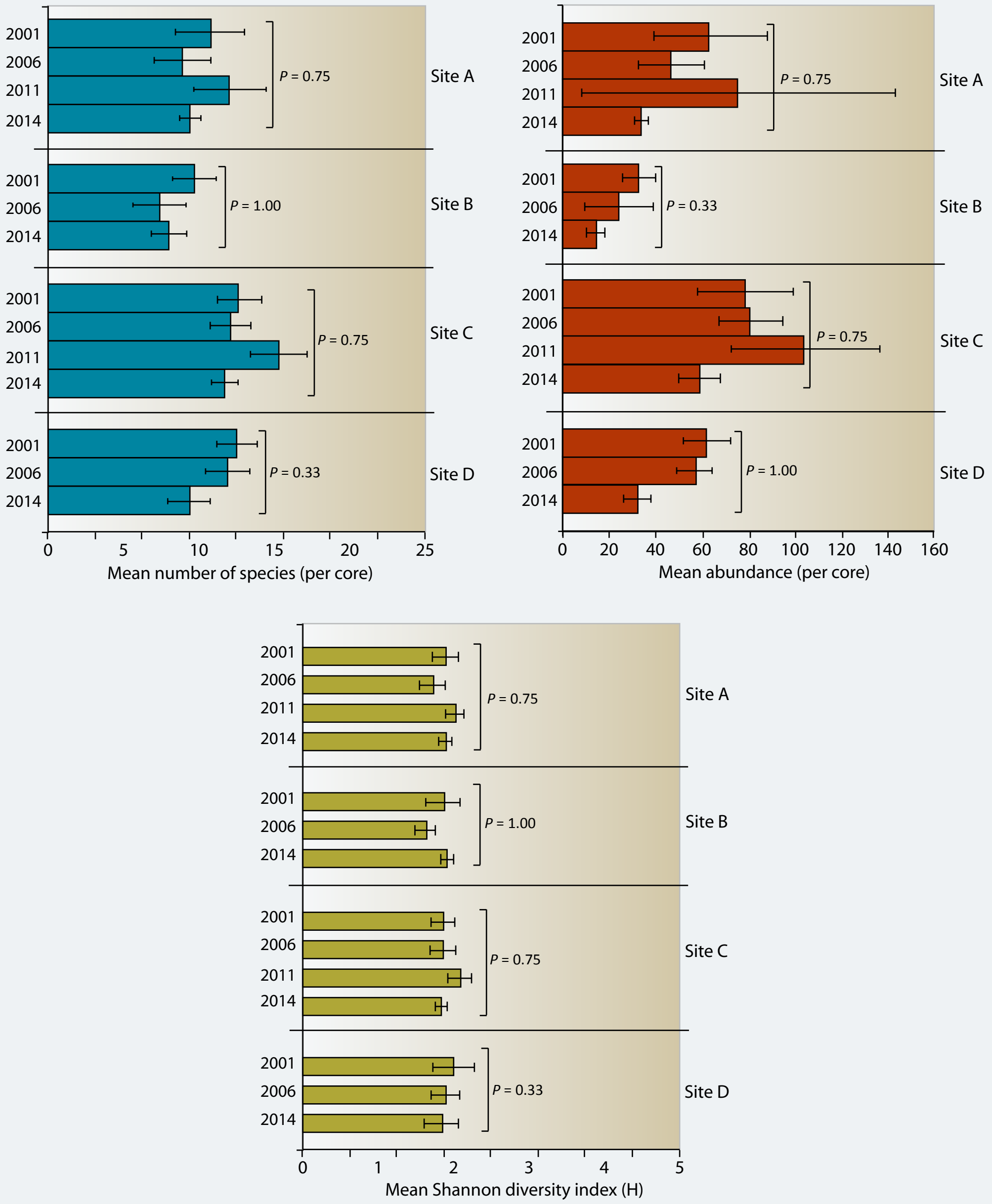


**Figure 8. Mean number of species, abundance per core, and Shannon diversity index (±SE, n=3), Waimea Inlet, 2001-2014.** **Note: Overlaid Mann-Kendall *P*>0.05 for all sites, indicate no significant differences in either species richness, abundance or Shannon diversity index between 2001 and 2014.**

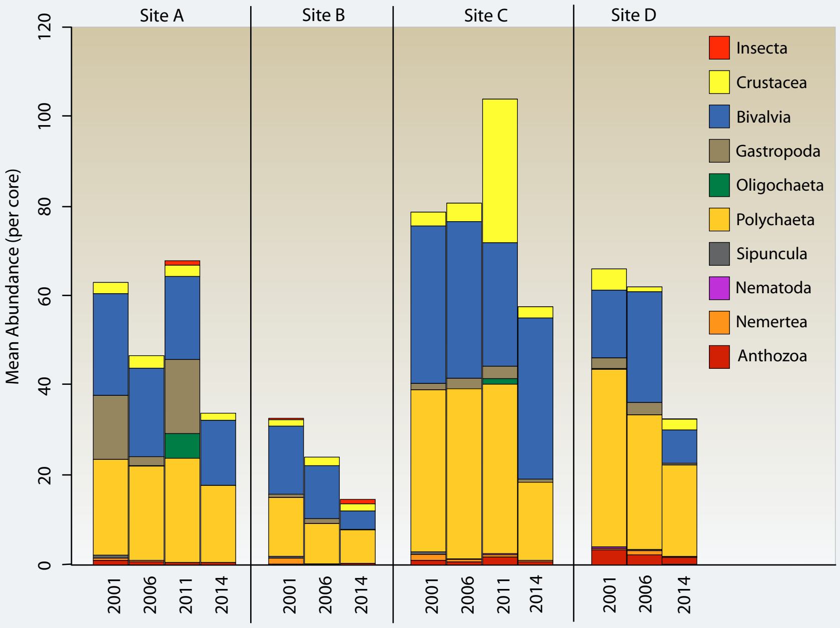


**Figure 9. Mean abundance of major infauna groups (n=3), Waimea Inlet, 2001-2014.**

Overall, the results using whole community, rather than species level approaches, indicates negligible changes to the invertebrate community structure between 2001-2014. The following section explores the community composition in more detail, specifically in relation to the observed elevated mud and TOC concentrations.

### Macro-invertebrate Community in Relation to Mud and Organic Enrichment

Organic matter and mud are major determinants of the structure of the benthic invertebrate community. The previous section has already established that there were no clear trends of change in species abundance, richness or diversity between 2001 and 2014, despite an obvious increasing trend in mud and TOC contents and a decline in aRPD. The following analyses explore the macrofaunal results in greater detail using two steps as follows:

#### 1. WEBI Mud and Organic Enrichment Index

The first approach is undertaken by using the WEBI mud/organic enrichment rating (Appendix 4), which is basically the AMBI (Borja at al. 2000) approach but modified by using the sensitivity ratings for NZ macrofauna (Robertson 2013). The WEBI approach is clearly is an improvement on the AMBI approach for NZ estuary macrofauna, but because it still relies on the AMBI formula, and therefore does not directly account for species richness, its results must be considered alongside a range of other relevant indicators before a reliable conclusion is reached.

WEBI biotic coefficients, and mud and organic enrichment tolerance ratings, for the Waimea fine scale sites are presented in Figure 10. Coefficients ranged from 2-3, and were all in the “low” risk indicator category (i.e. a transitional type community indicative of low levels of organic enrichment and moderate mud concentrations). The WEBI values showed no clear trend of change between 2001-2014, despite a significant trend of increasing mud, and possibly TOC at all sites over this period. The WEBI findings are consistent with statistical results showing no significant change in the macro-invertebrate community between 2001 and 2014 (Mann-Kendall/PERMANOVA, *P*>0.05 for all sites).

#### 2. Individual Species Changes

The most reliable approach at this stage is by assessing changes in abundance of individual species within each of the 5 major mud/enrichment tolerance groupings (i.e. “very sensitive to organic enrichment” group through to “1st-order opportunistic species“ group) (Robertson 2013). Although Figure 10 provides little support for mud/organic enrichment changing the macroinvertebrate community, Figure 11 and Table 4 do. Table 4 shows major reductions in the abundance of certain species in 4 major enrichment tolerance groupings between 2001 and 2014, particularly Group 1 organisms (highly sensitive species), where there was an 85% reduction (8 species in 2001, to 1 in 2014).

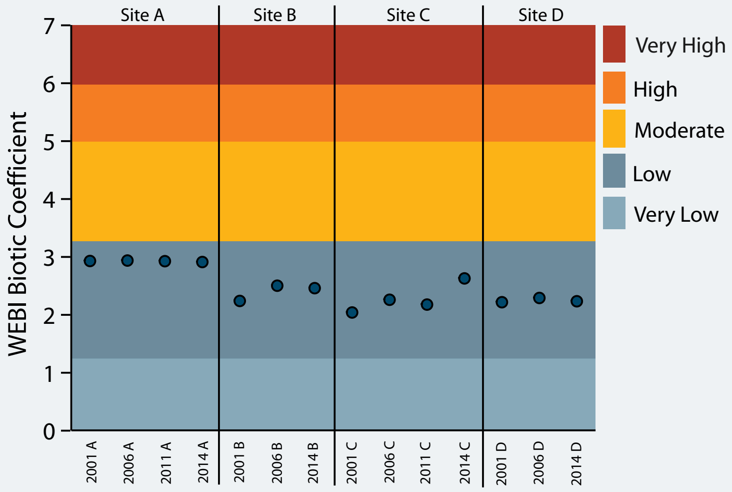


**Figure 10. Benthic invertebrate mud/organic enrichment tolerance rating (±SE, n=3), 2001-2014.**

The identity of the individual species that have been lost over time can be assessed from Figure 11 and supported by a more detailed examination of the macro-invertebrate data using univariate SIMPER (PRIMER-e) analysis. They show for example, the following losses of highly sensitive species:

- *Aonides* sp., a small surface deposit-feeding, endemic, spionid polychaete that is not very mobile and prefers to live in fine sands. It has an important ecological role as a sediment bioturbator, effectively oxygenating sediments, but is very sensitive to changes in the silt/clay content of the sediment. The abundance of *Aonides* declined from a mean of 2.7 across all sites in 2001, to 1 in 2006, and zero in 2011 and 2014.
- *Soletellina* sp., a brittle shelled, deposit-feeding, endemic, bivalve mollusc in the family Psammobiidae, known as sunset shells, that is intolerant of eutrophic or muddy conditions. The abundance of *Soletellina* declined from a mean of 1.2 across all sites in 2001, to 0.2 in 2006, and zero in 2011 and 2014.
- *Paphies australis* (pipi) is an endemic bivalve that is intolerant of mud, tolerant of moderate wave action, and commonly inhabits coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. The abundance of *Paphies* declined from a mean of 1 across all sites in 2001, to 0.2 in 2006, and zero in 2011 and 2014.

**Table 4. Percent change in mean species numbers in each enrichment tolerance group, Waimea Inlet.**

| Mud/Organic Enrichment Tolerance Group | % Change in Number of Species across all sites between 2001 and 2014 |
|---|---|
| 1. Very sensitive to mud/organic enrichment. | 87.5% reduction |
| 2. Indifferent to mud/organic enrichment (slightly unbalanced). | 31.6% reduction |
| 3. Tolerant to excess mud/organic enrichment (unbalanced situations). | 33.3% reduction |
| 4. 2nd-order opportunistic species (slight to pronounced unbalanced). | 33.3% reduction |
| 5. 1st-order opportunistic species (pronounced unbalanced situations). | 0.0% reduction |

These results emphasize the importance of using a multi-criteria approach rather than a single biotic index for assessing estuary condition. They highlight the issue that the WEBI rating (which is based on the AMBI approach) does not take species diversity into account and therefore likely underestimates mud/organic enrichment response (e.g. six Group 1 species with an abundance of 4 individuals each, rates the same as a single Group 1 species with an abundance of 24, effectively stating that one sensitive species is as good as six; refer to Appendix 3 for details on species tolerance groupings). Currently research is being undertaken at Otago University to address this issue.

Overall, the findings indicate that the dominant unvegetated habitat in Waimea Inlet (i.e soft mud) has high mud concentrations (20-55% mud and trending upward), low to moderate levels of the eutrophication indicators (TOC <1%) and sediment oxygenation (aRPD) and a transitional type macrofaunal community that has lost significant numbers of species sensitive to mud and organic enrichment.

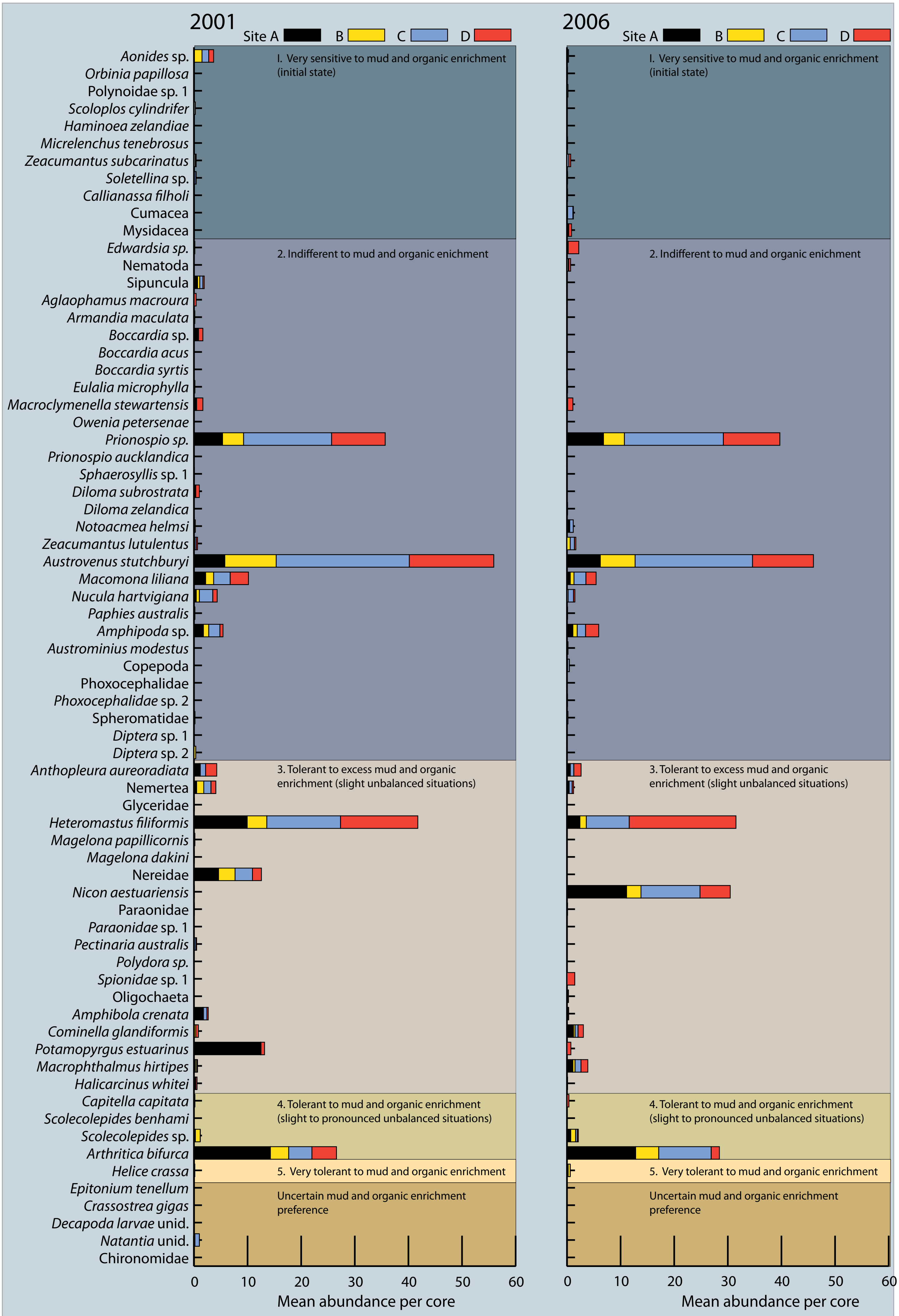


**Figure 11. Mud and organic enrichment sensitivity of macro-invertebrates, Waimea Inlet, 2001-2014 (see Appendix 4 for sensitivity details).**

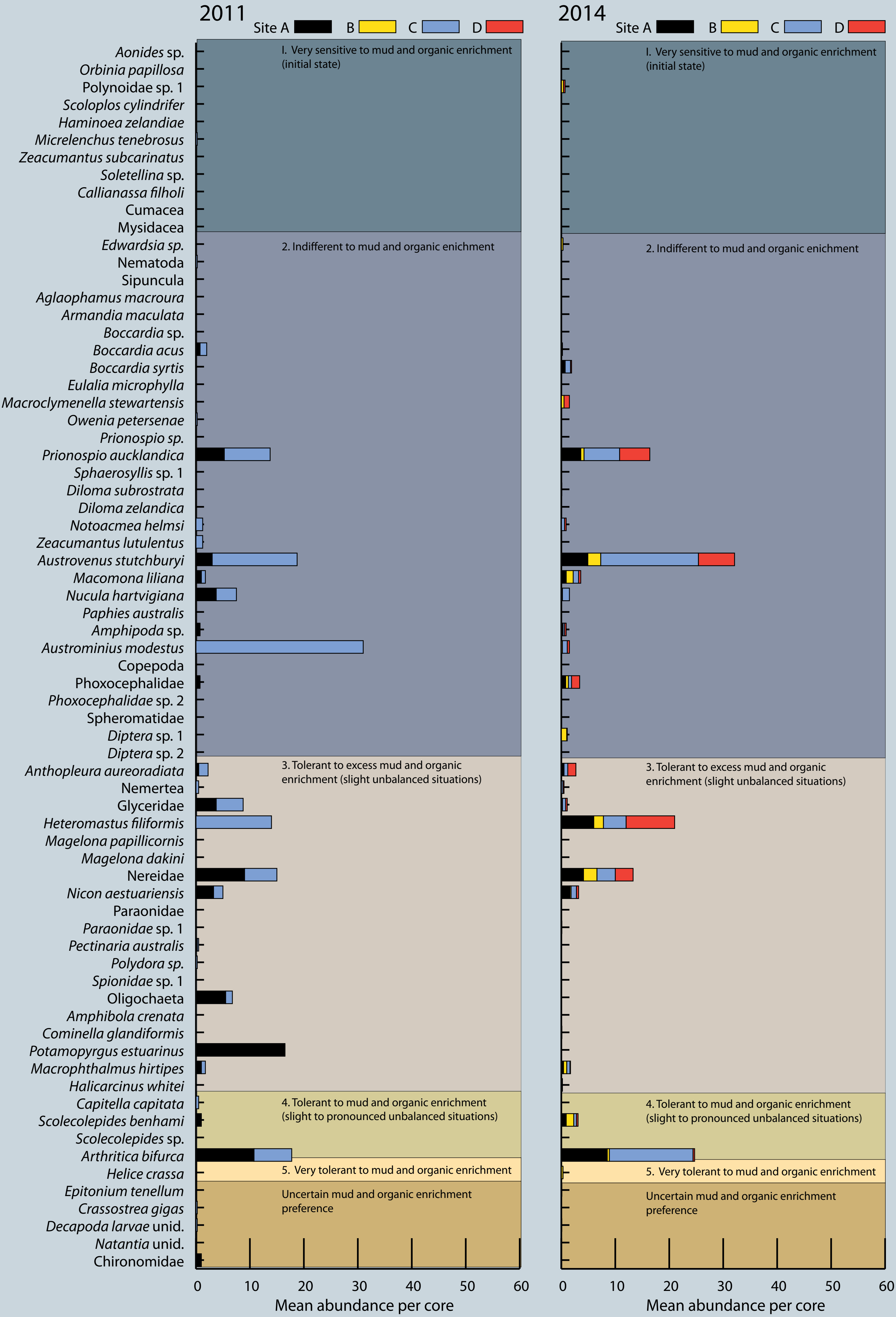


**Figure 11(continued). Mud and organic enrichment sensitivity of macro-invertebrates, Waimea Inlet, 2001-2014 (see Appendix 4 for sensitivity details).**

# 4. Results and Discussion (Continued)

## TOXICITY INDICATORS

In 2014, the heavy metals Cd, Cr, Cu, Pb, Zn, used as an indicator of potential toxicants, were present at "very low" to "moderate" concentrations across all fine scale sites, with all non-normalised values below the ANZECC (2000) ISQG-Low trigger values (Figure 12). Note that cadmium levels prior to 2014 reflect high detection limits rather than high concentrations. The 2014 results also showed that concentrations of the heavy metal mercury and the metalloid arsenic were also well below the ANZECC (2000) ISQG Low limit (Appendix 2) and therefore, like most of the metal results, posed no toxicity threat to aquatic life.

However, nickel was present across all sites at concentrations exceeding the ISQG High limits, and significant increases at sites A and C were observed between 2001 and 2014. Chromium was also present at elevated concentrations. This is likely attributable to elevated inputs in run-off from the geologically nickel and chromium enriched catchment (Robinson et al. 1996, Rattenbury et al. 1998), and the high affinity of heavy metals for muds acting to transport and sequester them into estuarine sediments (Whitehouse et al. 1999).

In such cases as this, where the ISQG high limit is exceeded and the likely cause is natural, the ANZECC (2000) guidelines recommend further investigation to examine factors controlling bioavailability.

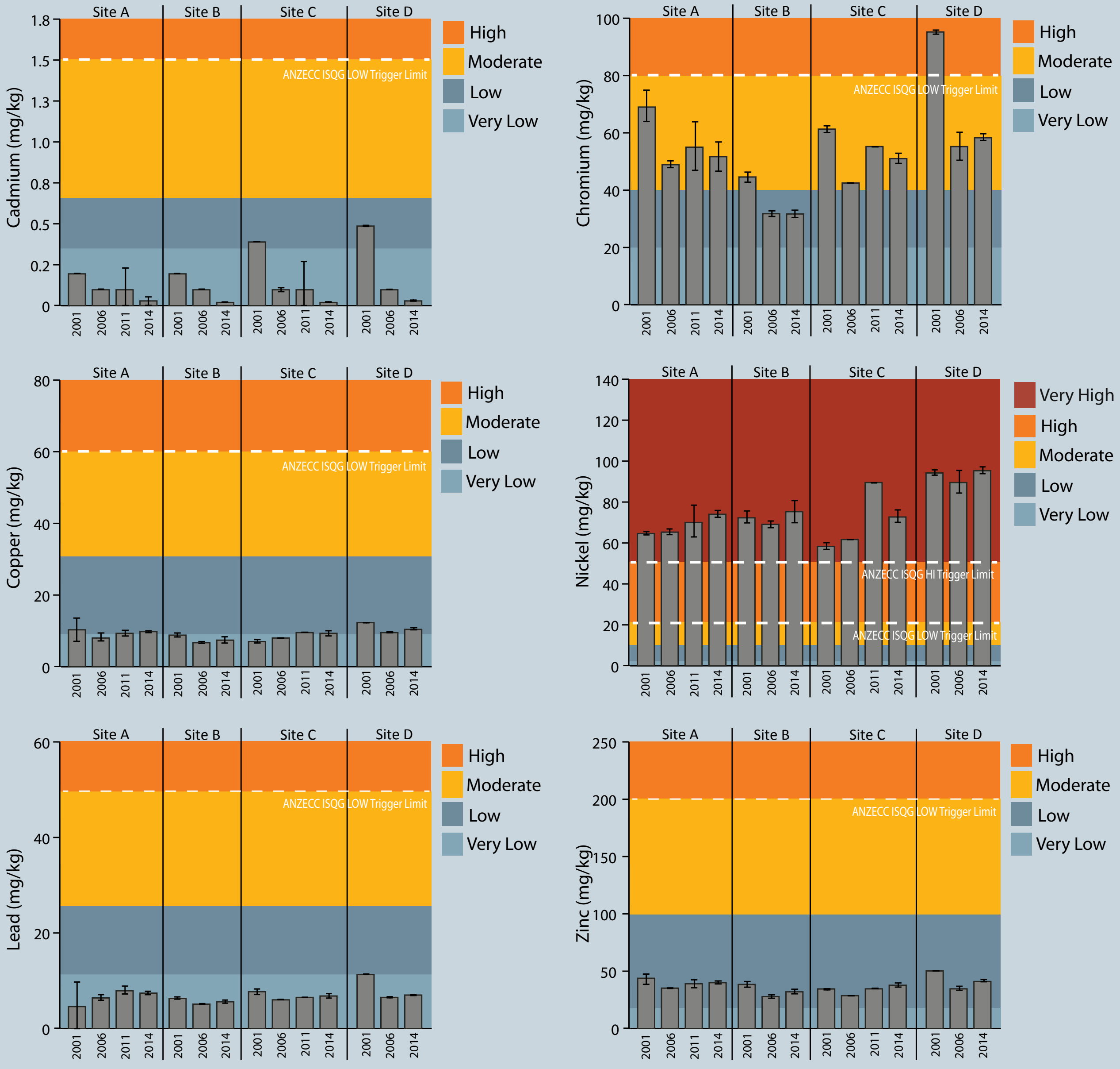


**Figure 12. Sediment metal concentrations (±SE, n=3), Waimea Inlet (2001-2013).**

# 4. Results and Discussion (Continued)

Semi-volatile organic compounds (SVOCs) were also analysed to screen for key pollutants including organochlorine pesticides (OCPs), polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs), and pthalates (Appendix 1 describes the analytical methods and Appendix 2 presents the results in full).

All analytes were found to be less than the analytical detection limits and the ANZECC (2000) ISQG Low or High trigger values, and therefore unlikely to cause toxicity to benthic macrofauna.

# 5. SUMMARY AND CONCLUSIONS

Fine scale monitoring results of estuary condition within Waimea Inlet in 2014, and supported by 2001, 2006 and 2011 results, showed the following key findings:

- The sediment mud content in 2014 was relatively high at 25-50% mud, and had increased significantly by 23-176% at the four sites since 2001.
- Sediment oxygenation in 2014 was "moderate" as indicated by aRPD depth (1cm) but had declined since 2001 (2-3cm).
- Although TOC was in the "low to very low" risk category in 2014, the results reflect a significant upward trend across all sites between 2001 and 2014 (47-212% increase). Sediment nutrient concentrations, TN and TP, were in the "low-moderate" risk categories and showed no significant trend of change at any site.
- Macro-invertebrates consisted of a mixed assemblage of species, dominated by polychaetes, crustacea, bivalves and gastropods, spread across all sites between 2001-2014.
- Statistical analysis of the results showed no significant differences in the communities at each site at a macro or community level between 2001-2014 (as indicated by trend analysis of species abundance, richness and diversity data, PERMANOVA analysis, and WEBI mud/organic enrichment indices), but significant differences were present at a micro or individual species level. In particular, there was a large reduction in species that were highly sensitive to mud/organic enrichment (e.g. pipi) from 2001 to 2014.
- Sediment toxicants (heavy metals (Cd, Cr, Cu, Hg, Pb, Zn), arsenic and semi-volatile organic compounds) were at concentrations that were not expected to pose toxicity threats to aquatic life. Nickel, while likely from a natural source, exceeded the ISQG high toxicity limit (ANZECC 2000) and therefore requires further investigation to examine factors controlling bioavailability.

Overall, these 2001-2014 results from each of the four sites indicate that the dominant unvegetated habitat in Waimea Inlet is very muddy, has got progressively muddier since 2001, and has low-moderate levels of organic enrichment and toxicity. Although it has not show any broad trends of change in the macro-invertebrate community since 2001, significant losses in mud sensitive organisms (e.g. pipi) have occurred since that time.

# 6. MONITORING

Waimea Inlet has been identified by TDC as a priority for monitoring, and is a key part of TDC's coastal monitoring programme being undertaken in a staged manner throughout the Tasman district. Based on the 2014 monitoring results and risk indicator ratings, particularly related to fine sediment, it is recommended that monitoring continue as follows:

- **Fine Scale Monitoring**. Sampling of fine scale sites A, B, C and D have now been completed for 2001, 2006 and 2014). It is recommended that for the next two years TDC collect data only (no reporting), from sites A, C and D (excluding heavy metals, SVOCs, mercury and arsenic) to establish a multi-year baseline, and undertake a full report of all data at the next scheduled 5 yearly monitoring interval (2020/21).
- **Broad Scale Habitat Mapping, Including Macroalgae.** Continue with the programme of 5 yearly broad scale habitat mapping. Next monitoring due in February/March 2019. Undertake a rapid visual assessment of macroalgal growth annually, and initiate broad scale macroalgal mapping if conditions appear to be worsening over the 5 years before broad scale mapping is repeated.
- **Sedimentation Rate Monitoring**. Because sedimentation is a priority issue in the estuary it is recommended that sediment plate depths be measured annually, and new plates be deployed in the highly eutrophic locations where sediment is rapidly accumulating.
- **Sediment Source Monitoring.** Identify catchment sources of fine sediment to the estuary, using both modeling and monitoring methods.
- **Sediment Transport and Deposition Monitoring Within Estuary.** Monitor transport/deposition patterns of sediment within the estuary and losses to the ocean using modeling and monitoring methods, and use this and other appropriate monitoring data to identify appropriate sediment input load guideline criteria to reduce infilling to a more natural rate.

# 7. MANAGEMENT

The combined results from the 2014 fine scale and broad scale reports (Stevens and Robertson 2014) identify sedimentation as a major issue in Waimea Inlet. To address this issue, it is recommended that a staged investigation be undertaken as follows, once initial monitoring results for sediment source identification and transport and deposition patterns within the estuary have been undertaken.

1. Identify options for reducing existing areas of fine sediment within the estuary, particularly options that dramatically reduce resuspension and replace muddy areas with high ecological value habitat.
2. Develop a sediment input load reduction plan to meet sedimentation targets for the estuary.

# 8. ACKNOWLEDGEMENTS

This survey and report has been undertaken with the support and assistance of Trevor James (Resource Scientist, TDC). His review of this report was much appreciated.

# 9. REFERENCES

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# APPENDIX 1. DETAILS ON ANALYTICAL METHODS

| Indicator | Laboratory | Method | Detection Limit |
|---|---|---|---|
| Infauna Sorting and ID | CMES | Coastal Marine Ecology Consultants (Gary Stephenson) * | N/A |
| Grain Size | R.J Hill | Wet sieving, gravimetric (calculation by difference). | 0.1 g/100g dry wgt |
| Total Organic Carbon | R.J Hill | Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser). | 0.05g/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 mercury | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | <0.27 mg/kg dry wgt |
| Total recoverable arsenic | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | <10 mg/kg dry wgt |
| Total recoverable phosphorus | R.J Hill | Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2. | 40 mg/kg dry wgt |
| Total nitrogen | R.J Hill | Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser). | 500 mg/kg dry wgt |
| Organochlorine Pesticides | R.J. Hill | Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270 | |
| Organonitro/phosphorus Pesticides | R.J. Hill | Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270 | |
| Dry Matter (Env) | R.J. Hill | Dried at 103°C (removes 3-5% more water than air dry) | |

* 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 macro-invertebrates 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.

## Epifauna (surface-dwelling animals).

## SACFOR Percentage Cover and Density Scales (after Marine Nature Conservation Review - MNCR).

| **A.** PERCENTAGE COVER | Growth Form | | |
|---|---|---|---|
| | i. Crust/Meadow | ii. Massive/Turf | SACFOR Category |
| >80 | S | - | S = Super Abundant |
| 40-79 | A | S | A = Abundant |
| 20-39 | C | A | C = Common |
| 10-19 | F | C | F = Frequent |
| 5-9 | O | F | O = Occasional |
| 1-4 | R | O | R = Rare |
| <1 | - | R | |

- Whenever percentage cover can be estimated for an attached species, it should be used in preference to the density scale.
- The massive/turf percentage cover scale should be used for all species except those classified under crust/meadow.
- Where two or more layers exist, for instance foliose algae overgrowing crustose algae, total percentage cover can be over 100%.

### B. DENSITY SCALES

| SACFOR size class | | | | Density | | | | |
|---|---|---|---|---|---|---|---|---|
| i | ii | iii | iv | $0.25m^2$ | $1.0m^2$ | $10m^2$ | $100m^2$ | $1,000m^2$ |
| <1cm | 1-3cm | 3-15cm | >15cm | (50x50cm) | (100x100cm) | (3.16x3.16m) | (10x10m) | (31.6x31.6m) |
| S | - | - | - | >2500 | >10,000 | | | |
| A | S | - | - | 250-2500 | 1000-9999 | >10,000 | | |
| C | A | S | - | 25-249 | 100-999 | 1000-9999 | >10,000 | |
| F | C | A | S | 1-9 | 10-99 | 100-999 | 1000-9999 | >10,000 |
| O | F | C | A | | 1-9 | 10-99 | 100-999 | 1000-9999 |
| R | O | F | C | | | 1-9 | 10-99 | 100-999 |
| - | R | O | F | | | | 1-9 | 10-99 |
| - | - | R | O | | | | | 1-9 |
| - | - | - | R | | | | | <1 |

# APPENDIX 1. DETAILS ON ANALYTICAL METHODS (CONTINUED)

### Station Locations

| **Waimea Site A** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| NZTM EAST | 1615288.02 | 1615289.96 | 1615286.23 | 1615288.77 | 1615296.82 | 1615296.82 | 1615297.42 | 1615298.16 | 1615309.95 | 1615307.71 |
| NZTM NORTH | 5425955.20 | 5425966.53 | 5425983.54 | 5426005.01 | 5426007.55 | 5425989.20 | 5425971.75 | 5425954.01 | 5425958.33 | 5425978.17 |
| **Waimea Site B** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| NZTM EAST | 1607350.52 | 1607358.52 | 1607364.45 | 1607373.69 | 1607363.07 | 1607355.90 | 1607349.28 | 1607341.55 | 1607331.21 | 1607337.97 |
| NZTM NORTH | 5431843.52 | 5431860.34 | 5431874.14 | 5431887.66 | 5431892.48 | 5431876.90 | 5431860.76 | 5431846.83 | 5431850.69 | 5431863.52 |
| **Waimea Site C** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| NZTM EAST | 1614913.99 | 1614895.85 | 1614878.55 | 1614865.34 | 1614865.22 | 1614879.39 | 1614892.13 | 1614907.02 | 1614915.31 | 1614901.50 |
| NZTM NORTH | 5428008.02 | 5428001.29 | 5428003.10 | 5427996.37 | 5427987.48 | 5427991.20 | 5427991.80 | 5427999.01 | 5427988.92 | 5427987.36 |
| **Waimea Site D** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| NZTM EAST | 1608914.86 | 1608910.80 | 1608906.50 | 1608903.43 | 1608914.98 | 1608916.21 | 1608922.72 | 1608922.60 | 1608931.69 | 1608932.19 |
| NZTM NORTH | 5430110.64 | 5430093.92 | 5430078.56 | 5430062.83 | 5430061.60 | 5430078.93 | 5430095.77 | 5430110.02 | 5430101.17 | 5430086.06 |

# APPENDIX 2. 2014 DETAILED RESULTS

### Physical and Chemical results for Waimea Inlet (Sites A, B, C and D), 2001, 2006, 2011 and 2014.

| Site | Reps [b] | RPD | Salinity | TOC [f] | Mud | Sand | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | Hg | As | TN | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cm | ppt | % | | | | mg/kg | | | | | | | | | |
| 2001A-01 [c] | 1-4 | 3 | - | 0.20 | 28.4 | 68.3 | 3.3 | <0.2 | 72.5 | 8.9 | 65.5 | 1.7 | 42.3 | - | - | 625 | 461 |
| 2001A-02 | 5-8 | 3 | - | 0.28 | 26.1 | 71.8 | 2.1 | <0.2 | 63.5 | 8.5 | 64.3 | 2.1 | 40.5 | - | - | 600 | 416 |
| 2001A-03 | 9-12 | 3 | - | 0.34 | 30.3 | 67.3 | 2.4 | <0.2 | 71.0 | 13.5 | 64.0 | 10.0 | 48.5 | - | - | 600 | 430 |
| 2001B-01 | 1-4 | 3 | - | 0.22 | 17.8 | 81.5 | 0.7 | <0.2 | 44.5 | 9.3 | 71.5 | 6.9 | 38.8 | - | - | 600 | 472 |
| 2001B-02 | 5-8 | 3 | - | 0.21 | 14.4 | 85.4 | 0.3 | <0.2 | 43.5 | 9.5 | 71.8 | 5.8 | 38.0 | - | - | 500 | 479 |
| 2001B-03 | 9-12 | 3 | - | 0.21 | 15.5 | 84.2 | 0.3 | <0.2 | 45.8 | 7.6 | 73.8 | 6.4 | 38.5 | - | - | 500 | 488 |
| 2001C-01 | 1-4 | 3 | - | 0.17 | 9.9 | 89.2 | 0.9 | 0.5 | 53.0 | 6.3 | 51.8 | 6.9 | 31.3 | - | - | 500 | 256 |
| 2001C-02 | 5-8 | 3 | - | 0.15 | 9.3 | 90.0 | 0.7 | 0.4 | 63.3 | 6.9 | 57.8 | 7.6 | 34.5 | - | - | 500 | 277 |
| 2001C-03 | 9-12 | 3 | - | 0.15 | 9.7 | 89.3 | 1.0 | 0.3 | 67.8 | 7.8 | 65.3 | 8.5 | 37.8 | - | - | 567 | 287 |
| 2001D-01 | 1-4 | 3 | - | 0.35 | 40.9 | 57.3 | 1.8 | 0.5 | 92.3 | 12.3 | 92.5 | 11.3 | 49.5 | - | - | 850 | 546 |
| 2001D-02 | 5-8 | 3 | - | 0.40 | 36.9 | 59.8 | 3.4 | 0.5 | 93.0 | 12.0 | 95.8 | 11.8 | 49.5 | - | - | 700 | 542 |
| 2001D-03 | 9-12 | 3 | - | 0.52 | 43.7 | 53.4 | 3.0 | 0.5 | 100.3 | 12.5 | 94.3 | 11.0 | 51.5 | - | - | 800 | 529 |
| 2006A-01 [d] | 1-4 | 2 | - | 0.34 | 33.9 | 64.7 | 1.5 | <0.1 | 49.0 | 7.8 | 65.3 | 6.4 | 34.5 | - | - | 480 | 464 |
| 2006A-02 | 5-8 | 2 | - | 0.39 | 33.0 | 66.2 | 1.0 | <0.1 | 47.3 | 7.6 | 62.8 | 6.2 | 33.5 | - | - | 443 | 453 |
| 2006A-03 | 9-10 | 2 | - | 0.41 | 35.3 | 64.1 | 0.7 | <0.1 | 50.5 | 8.5 | 68.0 | 6.7 | 37.5 | - | - | 495 | 456 |
| 2006B-01 | 1-4 | 2 | - | 0.26 | 20.6 | 79.3 | 0.2 | <0.1 | 32.8 | 7.0 | 70.0 | 5.2 | 29.3 | - | - | 350 | 526 |
| 2006B-02 | 5-8 | 2 | - | 0.28 | 18.3 | 81.6 | 0.1 | <0.1 | 31.8 | 6.6 | 69.8 | 5.0 | 27.0 | - | - | 353 | 511 |
| 2006B-03 | 9-10 | 2 | - | 0.37 | 21.5 | 78.4 | 0.2 | <0.1 | 31.0 | 6.6 | 67.5 | 5.3 | 27.0 | - | - | 360 | 510 |
| 2006C-01 | 1-4 | 2 | - | 0.36 | 21.4 | 77.5 | 1.0 | <0.1 | 42.8 | 7.4 | 57.8 | 5.7 | 27.3 | - | - | 585 | 376 |
| 2006C-02 | 5-8 | 2 | - | 0.45 | 21.2 | 78.2 | 0.6 | <0.1 | 41.3 | 7.8 | 60.3 | 5.8 | 28.0 | - | - | 505 | 361 |
| 2006C-03 | 9-10 | 2 | - | 0.46 | 22.8 | 76.7 | 0.7 | <0.1 | 43.5 | 9.0 | 67.0 | 6.3 | 30.5 | - | - | 570 | 406 |
| 2006D-01 | 1-4 | 2 | - | 0.49 | 34.2 | 65.2 | 0.7 | <0.1 | 56.0 | 9.3 | 89.5 | 6.2 | 34.0 | - | - | 463 | 508 |
| 2006D-02 | 5-8 | 2 | - | 0.36 | 33.3 | 64.4 | 2.2 | <0.1 | 54.0 | 9.3 | 88.0 | 6.2 | 34.8 | - | - | 518 | 509 |

# APPENDIX 2. 2014 DETAILED RESULTS (CONTINUED)

| Site | Reps[b] | RPD | Salinity | TOC[f] | Mud | Sand | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | Hg | As | TN | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cm | ppt | % | | | | mg/kg | | | | | | | | | |
| 2006D-03 | 9-10 | 2 | - | 0.49 | 32.0 | 62.8 | 5.3 | <0.1 | 55.5 | 10.0 | 91.0 | 7.1 | 35.0 | - | - | 475 | 510 |
| 2011A-01[e] | 1-4 | 1 | - | 0.48 | 41 | 58.4 | 0.6 | 0.09 | 55 | 9.3 | 70 | 7.9 | 39 | - | - | 360 | 470 |
| 2011A-02 | 1-4 | 1 | - | 0.5 | 42.6 | 57.2 | 0.2 | 0.1 | 55 | 9.3 | 70 | 7.9 | 39 | - | - | 420 | 460 |
| 2011A-03 | 1-4 | 1 | - | 0.5 | 44 | 55.2 | 0.9 | 0.1 | 55 | 9.3 | 70 | 7.9 | 39 | - | - | 360 | 510 |
| 2011C-01 | 1-4 | 1 | - | 0.48 | 24.1 | 75.7 | 0.2 | 0.1 | 49 | 8.9 | 64 | 6.3 | 33 | - | - | 440 | 390 |
| 2011C-02 | 1-4 | 1 | - | 0.5 | 26.2 | 73.3 | 0.5 | 0.2 | 49 | 8.9 | 64 | 6.3 | 33 | - | - | 320 | 410 |
| 2011C-03 | 1-4 | 1 | - | 0.52 | 26.3 | 69.8 | 4 | 0.4 | 49 | 8.9 | 64 | 6.3 | 33 | - | - | 400 | 400 |
| 2014A-01 | 1-4 | 1 | 30 | 0.59 | 44.9 | 54.7 | 0.3 | 0.02 | 53 | 10.5 | 77 | 7.9 | 42 | 0.04 | 5.5 | 800 | 470 |
| 2014A-02 | 5-8 | 1 | 30 | 0.53 | 42.8 | 56.8 | 0.2 | 0.03 | 50 | 9.6 | 72 | 7.2 | 39 | 0.03 | 5.1 | 700 | 420 |
| 2014A-03 | 9-12 | 1 | 30 | 0.51 | 40.3 | 59.3 | 0.3 | 0.03 | 52 | 9.4 | 73 | 7.2 | 39 | 0.02 | 5 | 600 | 420 |
| 2014B-01 | 1-4 | 2 | 30 | 0.41 | 24.1 | 75.8 | 0.1 | 0.01 | 32 | 7.4 | 76 | 5.6 | 32 | 0.01 | 5.5 | 500 | 480 |
| 2014B-02 | 5-8 | 2 | 30 | 0.36 | 24.5 | 75.5 | 0.1 | 0.02 | 31 | 7.3 | 74 | 5.6 | 32 | 0.02 | 5.6 | 500 | 490 |
| 2014B-03 | 9-12 | 2 | 30 | 0.38 | 27 | 72.4 | 0.4 | 0.02 | 32 | 7.5 | 76 | 5.6 | 32 | 0.02 | 5.8 | 500 | 510 |
| 2014C-01 | 1-4 | 1 | 30 | 0.54 | 27.9 | 70.1 | 2.1 | 0.02 | 46 | 9.1 | 67 | 6.9 | 36 | 0.02 | 4.9 | 600 | 340 |
| 2014C-02 | 5-8 | 1 | 30 | 0.51 | 25.7 | 74 | 0.4 | 0.02 | 53 | 9.5 | 75 | 6.8 | 39 | 0.02 | 5.6 | 900 | 390 |
| 2014C-03 | 9-12 | 1 | 30 | 0.56 | 26.3 | 73.2 | 0.4 | 0.02 | 54 | 9.3 | 76 | 6.7 | 38 | 0.02 | 5.7 | 700 | 380 |
| 2014D-01 | 1-4 | 1 | 30 | 0.63 | 57.6 | 41.8 | 0.4 | 0.03 | 59 | 10.7 | 95 | 7.1 | 42 | 0.02 | 6.7 | 700 | 510 |
| 2014D-02 | 5-8 | 1 | 30 | 0.6 | 44.5 | 53.8 | 1.7 | 0.03 | 59 | 10.3 | 97 | 7 | 41 | 0.02 | 6.2 | 700 | 560 |
| 2014D-03 | 9-12 | 1 | 30 | 0.63 | 48.1 | 47.8 | 4.2 | 0.02 | 57 | 10.2 | 94 | 6.8 | 40 | 0.02 | 6.1 | 700 | 520 |
| ISQG-Low[a] | - | - | - | - | - | - | - | 1.5 | 80 | 65 | 21 | 50 | 200 | 0.15 | 20 | - | - |
| ISQG-High[a] | - | - | - | - | - | - | - | 10 | 370 | 270 | 52 | 220 | 410 | 1 | 70 | - | - |

[a] ANZECC 2000.

[b] composite samples.

[c] results from Robertson et al. 2002.

[d] results from Gillespie et al. 2007.

[e] unpublished 2011 Cawthron data.

[f] 2001-2011 TOC values estimated from AFDW as follows: 1g AFDW as equivalent to 0.2 g TOC (± 100%) based on a preliminary analysis of NZ estuary data.

### Epifauna and macroalgal cover (0.25m$^2$ quadrats, Waimea Estuary SitesA, B, C and D, 2014).

| Group | Family | Species | Common name | Scale | Class | A | B | C | D |
|---|---|---|---|---|---|---|---|---|---|
| Bivalves | *Mytilidae* | *Mytilus galloprovincialis* | Blue mussel | # | iii | - | R | - | - |
| Topshells | *Amphibolidae* | *Amphibola crenata* | Mudflat snail | # | ii | R | - | O | C |
| | *Buccinidae* | *Cominella glandiformis* | Mudflat whelk | # | ii | R | R | R | R |
| | *Trochidae* | *Diloma subrostrata* | Grooved topshell | # | ii | O | O | - | O |
| | *Buccinidae* | *Zeacumantus lutulentus* | Spire shell | # | ii | O | F | O | O |
| Limpets | *Lottiidae* | *Notoacmaea helmsi* | Estuarine limpet | # | i | - | - | - | O |
| Red algae | *Gracilariaceae* | *Gracilaria sp. ?secundata* | Gracilaria weed | % | ii | R | R | - | C |
| Green algae | *Ulvaceae* | *Ulva lactuca* | Sea lettuce | % | i | - | - | - | O |

# APPENDIX 2. 2013 DETAILED RESULTS (CONTINUED)

**Non-normalised semi volatile organic compounds (SVOCs) in Waimea Inlet, 2014. Note: results are for a single composite sample for each site, with no analysed compound present at detectable levels (all reported as mg/kg d.w.).**

| GROUP | Organic Chemical | Waimea A 2014 | Waimea B 2014 | Waimea C 2014 | Waimea D 2014 |
|---|---|---|---|---|---|
| **Organochlorine Pesticides** | *Aldrin* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *alpha-BHC* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *beta-BHC* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *delta-BHC* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *gamma-BHC (Lindane)* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *cis-Chlordane* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *trans-Chlordane* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *2,4'-DDD* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *4,4'-DDD* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *2,4'-DDE* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *4,4'-DDE* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *2,4'-DDT* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *4,4'-DDT* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Dieldrin* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Endosulfan I* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Endosulfan II* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Endosulfan sulphate* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Endrin* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Endrin aldehyde* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Endrin ketone* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Heptachlor* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Heptachlor epoxide* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Hexachlorobenzene* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Methoxychlor* | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| | *Total Chlordane [(cis+trans)*100/42]* | < 0.002 | < 0.002 | < 0.002 | < 0.002 |
| **Organonitro & phosphorus Pesticides** | *Acetochlor* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Alachlor* | < 0.006 | < 0.006 | < 0.006 | < 0.006 |
| | *Atrazine* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Atrazine-desethyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Atrazine-desisopropyl* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Azaconazole* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Azinphos-methyl* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Benalaxyl* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Bitertanol* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Bromacil* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Bromopropylate* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Butachlor* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Captan* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Carbaryl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Carbofuran* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Chlorfluazuron* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Chlorothalonil* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Chlorpyrifos* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Chlorpyrifos-methyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Chlortoluron* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Cyanazine* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Cyfluthrin* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Cyhalothrin* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Cypermethrin* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Deltamethrin (including Tralomethrin)* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Diazinon* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Dichlofluanid* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Dichloran* | < 0.03 | < 0.03 | < 0.03 | < 0.03 |
| | *Dichlorvos* | < 0.010 | < 0.010 | < 0.010 | < 0.010 |
| | *Difenoconazole* | < 0.013 | < 0.013 | < 0.012 | < 0.014 |
| | *Dimethoate* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Diphenylamine* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |

# APPENDIX 2. 2013 DETAILED RESULTS (CONTINUED)

| GROUP | Organic Chemical | Waimea A 2014 | Waimea B 2014 | Waimea C 2014 | Waimea D 2014 |
|---|---|---|---|---|---|
| **Organonitro & phosphorus Pesticides (continued)** | *Diuron* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Fenpropimorph* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Fluazifop-butyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Fluometuron* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Flusilazole* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Fluvalinate* | < 0.007 | < 0.007 | < 0.006 | < 0.007 |
| | *Furalaxyl* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Haloxyfop-methyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Hexaconazole* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Hexazinone* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *IPBC (3-Iodo-2-propynyl-n-butylcarbamate)* | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| | *Kresoxim-methyl* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Linuron* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Malathion* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Metalaxyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Methamidophos* | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| | *Metolachlor* | < 0.006 | < 0.006 | < 0.006 | < 0.006 |
| | *Metribuzin* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Molinate* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Myclobutanil* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Naled* | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| | *Norflurazon* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Oxadiazon* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Oxyfluorfen* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Paclobutrazol* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Parathion-ethyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Parathion-methyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Pendimethalin* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Permethrin* | < 0.003 | < 0.003 | < 0.003 | < 0.003 |
| | *Pirimicarb* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Pirimiphos-methyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Prochloraz* | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| | *Procymidone* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Prometryn* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Propachlor* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Propanil* | < 0.03 | < 0.03 | < 0.03 | < 0.03 |
| | *Propazine* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Propiconazole* | < 0.007 | < 0.007 | < 0.006 | < 0.007 |
| | *Pyriproxyfen* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Quizalofop-ethyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Simazine* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Simetryn* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Sulfentrazone* | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| | *TCMTB [2-(thiocyanomethylthio)benzothiazole,Busan]* | < 0.018 | < 0.018 | < 0.017 | < 0.02 |
| | *Tebuconazole* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Terbacil* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Terbumeton* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Terbuthylazine* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Terbuthylazine-desethyl* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Terbutryn* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Thiabendazole* | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| | *Thiobencarb* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Tolylfluanid* | < 0.005 | < 0.005 | < 0.005 | < 0.005 |
| | *Triazophos* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Trifluralin* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |
| | *Vinclozolin* | < 0.009 | < 0.009 | < 0.009 | < 0.010 |

# APPENDIX 2. 2013 DETAILED RESULTS (CONTINUED)

**Infauna (numbers per 0.01327m² core)** **(Note NA = Not Assigned)**

**Waimea Inlet Sites A and B, 11-12 March 2014**

| Group | Species | WIBI | A-01 | A-02 | A-03 | A-04 | A-05 | A-06 | A-07 | A-08 | A-09 | A-10 | B-01 | B-02 | B-03 | B-04 | B-05 | B-06 | B-07 | B-08 | B-09 | B-10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ANTHOZOA | *Anthopleura aureoradiata* | 3 |  |  |  | 1 | 1 | 1 |  | 1 | 1 |  |  |  |  |  |  |  |  |  |  |  |
|  | *Edwardsia* sp. | 2 |  |  |  |  |  |  |  |  |  |  | 1 |  | 1 |  |  |  |  | 1 |  |  |
| NEMERTEA | Nemertea | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| POLYCHAETA | *Boccardia acus* | 2 | 1 |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Boccardia syrtis* | 2 | 2 | 2 | 1 |  |  |  |  |  |  | 1 |  | 1 |  |  |  |  |  |  |  |  |
|  | Glyceridae | 3 |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Heteromastus filiformis* | 3 | 7 | 4 | 2 | 11 | 1 | 7 | 5 | 7 | 5 | 11 | 1 |  | 1 |  | 1 | 2 | 2 |  | 6 | 5 |
|  | *Macroclymenella stewartensis* | 2 |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 2 |  |  | 1 |  |  |  |
|  | Nereidae | 3 | 9 | 9 | 2 | 2 | 4 | 7 | 1 | 1 | 4 | 2 | 1 | 2 | 1 | 2 |  | 4 |  | 1 | 1 | 13 |
|  | *Nicon aestuariensis* | 3 |  |  | 2 |  | 3 | 2 | 1 | 3 | 2 | 3 |  | 1 |  |  | 1 |  |  |  |  |  |
|  | *Paraonidae sp. 1* | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Polynoidae sp. 1* | 1 |  |  |  |  |  |  |  |  |  |  | 1 | 1 |  | 1 | 1 |  |  |  |  |  |
|  | *Prionospio sp.* | 2 | 4 | 2 | 2 | 3 | 2 | 2 | 2 | 8 | 5 | 6 |  | 2 |  |  | 2 | 1 |  | 1 |  |  |
|  | *Scolecolepides benhami* | 4 |  |  |  |  | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 |  | 2 | 1 |  | 3 | 1 | 3 |
| GASTROPODA | *Cominella glandiformis* | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |
|  | *Diloma subrostrata* | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Epitonium tenellum* | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Notoacmea helmsi* | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| BIVALVIA | *Arthritica bifurca* | 4 | 2 | 2 | 10 | 12 | 14 | 8 | 12 | 13 | 8 | 4 |  |  |  | 1 |  | 1 |  |  | 1 | 1 |
|  | *Austrovenus stutchburyi* | 2 | 5 | 10 | 4 | 3 | 6 | 4 | 6 | 5 | 2 | 4 | 2 | 5 | 2 | 2 | 4 | 2 | 2 | 1 | 1 | 3 |
|  | *Macomona liliana* | 2 | 1 |  |  |  | 2 | 3 | 1 |  | 2 |  | 2 |  |  | 1 | 3 | 2 | 1 |  |  | 4 |
|  | *Nucula hartvigiana* | 2 |  |  |  |  |  | 1 |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |
| CRUSTACEA | Amphipoda *sp.* | 2 |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Austrominius modestus* | 2 |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  | 1 |  |  |  |  |  |
|  | Decapoda *larvae unid.* | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Halicarcinus whitei* | NA |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Helice crassa* | 5 |  |  |  |  |  |  |  |  |  |  | 2 |  |  | 1 |  |  |  |  |  |  |
|  | *Macrophthalmus hirtipes* | 3 |  |  | 1 | 1 |  |  | 1 | 1 |  |  |  | 1 | 1 |  |  | 1 |  | 1 | 2 |  |
|  | Phoxocephalidae | 2 | 2 | 1 |  | 1 | 1 |  |  |  | 1 | 2 |  | 1 |  | 2 | 1 |  |  |  | 1 |  |
| INSECTA | Diptera sp. 1 | 2 |  |  |  |  |  |  |  |  |  |  | 1 | 3 | 2 | 1 |  |  | 2 | 1 |  |  |
| **Total individuals in sample** |  |  | **33** | **30** | **24** | **40** | **37** | **36** | **32** | **40** | **32** | **34** | **12** | **22** | **9** | **13** | **17** | **14** | **8** | **9** | **13** | **29** |
| **Total species in sample** |  |  | **9** | **7** | **8** | **11** | **10** | **10** | **10** | **9** | **11** | **9** | **9** | **12** | **7** | **9** | **10** | **8** | **5** | **7** | **7** | **6** |

# APPENDIX 2. 2013 DETAILED RESULTS (CONTINUED)

**Infauna (numbers per 0.01327$m^2$ core)** **(Note NA = Not Assigned)**

**Waimea Inlet Sites C and D, 11-12 March 2014**

| Group | Species | WIBI | C-01 | C-02 | C-03 | C-04 | C-05 | C-06 | C-07 | C-08 | C-09 | C-10 | D-01 | D-02 | D-03 | D-04 | D-05 | D-06 | D-07 | D-08 | D-09 | D-10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ANTHOZOA | *Anthopleura aureoradiata* | 3 |  | 2 | 1 | 1 |  |  |  | 2 | 1 |  | 2 | 1 | 2 | 2 |  |  | 2 | 2 | 3 | 1 |
|  | *Edwardsia* sp. | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| NEMERTEA | Nemertea | 3 |  | 2 | 1 |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 1 |  |  |  |
| POLYCHAETA | *Boccardia acus* | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Boccardia syrtis* | 2 | 2 |  | 2 | 1 |  |  | 1 | 1 | 3 |  |  |  |  |  | 1 |  |  | 1 |  |  |
|  | Glyceridae | 3 |  | 1 |  | 1 | 1 |  |  | 3 |  |  |  |  | 1 |  |  |  | 1 | 1 |  |  |
|  | *Heteromastus filiformis* | 3 | 2 | 1 | 4 | 2 | 5 | 1 | 6 | 3 | 8 | 10 | 10 | 3 | 6 | 6 | 7 | 17 | 4 | 13 | 15 | 9 |
|  | *Macroclymenella stewartensis* | 2 |  |  |  |  |  |  |  |  |  |  | 1 | 1 | 2 | 1 |  | 1 | 1 | 1 | 1 | 1 |
|  | Nereidae | 3 | 4 | 2 | 9 | 2 | 7 | 4 | 2 | 1 | 1 | 2 | 6 | 1 |  | 2 | 4 | 3 | 6 | 6 | 4 | 1 |
|  | *Nicon aestuariensis* | 3 |  | 2 |  | 3 |  |  | 1 | 1 | 1 | 2 |  |  | 1 |  |  | 1 | 1 |  |  | 1 |
|  | *Paraonidae sp. 1* | 3 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Polynoidae sp. 1* | 1 |  |  |  |  |  |  |  |  |  |  |  | 1 |  | 1 |  |  |  | 1 |  |  |
|  | *Prionospio* sp. | 2 | 8 | 10 | 9 | 5 | 4 | 2 | 9 | 8 | 8 | 3 | 5 | 1 | 3 |  | 17 | 3 |  | 11 | 8 | 8 |
|  | *Scolecolepides benhami* | 4 | 1 | 1 |  |  |  | 1 | 1 |  |  | 1 | 1 | 1 |  |  |  | 1 |  |  |  |  |
| GASTROPODA | *Cominella glandiformis* | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Diloma subrostrata* | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |
|  | *Epitonium tenellum* | NA | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Notoacmea helmsi* | 2 |  |  |  |  | 1 |  | 1 | 1 |  | 3 |  | 1 | 1 |  |  |  | 1 |  |  |  |
| BIVALVIA | *Arthritica bifurca* | 4 | 13 | 16 | 2 | 44 | 17 | 10 | 3 | 13 | 21 | 16 |  |  |  |  |  |  | 1 | 1 | 1 |  |
|  | *Austrovenus stutchburyi* | 2 | 14 | 16 | 16 | 8 | 26 | 15 | 14 | 26 | 29 | 17 | 7 | 4 | 7 | 6 | 5 | 7 | 7 | 6 | 7 | 11 |
|  | *Macomona liliana* | 2 |  | 1 | 2 | 1 |  | 1 | 1 | 1 | 2 | 1 | 1 |  | 1 |  |  |  | 1 |  | 1 |  |
|  | *Nucula hartvigiana* | 2 |  |  |  | 1 | 1 | 3 | 2 | 1 | 5 |  |  |  |  |  |  |  |  |  |  |  |
| CRUSTACEA | Amphipoda *sp.* | 2 |  |  |  | 1 |  |  | 1 |  |  | 1 |  |  |  |  |  |  | 3 |  |  |  |
|  | *Austrominius modestus* | 2 |  | 1 | 2 |  |  | 2 |  |  | 4 |  |  |  | 2 |  | 2 |  |  |  |  |  |
|  | Decapoda *larvae unid.* | NA |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
|  | *Halicarcinus whitei* | NA |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Helice crassa* | 5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Macrophthalmus hirtipes* | 3 | 1 |  | 1 |  | 1 |  | 1 | 1 |  | 1 |  |  |  |  |  |  |  | 1 |  |  |
|  | Phoxocephalidae | 2 | 2 | 1 |  | 1 | 1 |  |  |  |  | 1 | 2 |  |  | 1 |  |  | 2 | 5 | 4 | 1 |
| INSECTA | Diptera sp. 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |
| **Total individuals in sample** |  |  | **49** | **57** | **49** | **71** | **64** | **39** | **43** | **62** | **83** | **58** | **36** | **14** | **29** | **19** | **36** | **33** | **31** | **49** | **44** | **33** |
| **Total species in sample** |  |  | **11** | **14** | **11** | **13** | **10** | **9** | **13** | **13** | **11** | **12** | **10** | **9** | **13** | **7** | **6** | **7** | **13** | **12** | **9** | **8** |

# APPENDIX 3. INFAUNA CHARACTERISTICS

| Group and Species | | WEBI Group * | Details |
|---|---|---|---|
| Anthozoa | *Anthopleura aureoradiata* | 3 | Mud flat anemone, attaches to cockle shells and helps to reduce the rate at which cockles accumulate parasites. It can also grow in small vertical shafts of its own an inch or more deep, fastened to small stones. Grows up to 10mm, intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al., 2001). It has green plant cells in its tissues that convert solar energy to food. |
| | *Edwardsia* sp.#1 | 2 | A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions. |
| Nemertea | Nemertea sp. | 3 | Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions. |
| Polychaeta | *Boccardia acus* | 2 | A slender, surface deposit-feeding worm, most often encountered boring on cockles. It creates sock-like (U-shaped) borings divided into 2 arms by a central partition of debris. Occurs only in New Zealand. |
| | *Boccardia syrtis* | 2 | A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Some species very sensitive to organic enrichment and usually present under unenriched conditions. |
| | *Capitella capitata* | 4 | A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments. |
| | Glyceridae | 3 | Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15 cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions and low salinity. |
| | *Heteromastus filiformis* | 3 | Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15 cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species. |
| | *Macroclymenella stewartensis* | 2 | A sub-surface, deposit-feeder that is usually found in tubes of fine sand or mud. This species is found throughout the sediment to depths of 15cm and potentially has a key role in the reworking and turn-over of sediment. This worm may modify the sediment conditions, making it more suitable for other species (Thrush et al. 1988). Common at low water in estuaries. Intolerant of anoxic conditions. |
| | Nereidae | 3 | Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of elevated sulphide concentrations. |
| | *Nicon aestuariensis* | 3 | A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate mud content sediments. |
| | Paraonidae sp.#1 | 3 | Slender burrowing worms, selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands to a depth of 15cm. Sensitive to changes in the mud content of the sediment. Some species of Aricidea are associated with sediments with high organic content. |

# APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group and Species | | WEBI Group * | Details |
|---|---|---|---|
| Polychaete | Polynoidae | 1 | The polynoid scale worms are dorsoventrally flattened predators. Lower intertidal and subtidal to deep sea throughout New Zealand. Conspicuous but never abundant. |
| | *Scolecolepides benhami* | 4 | A Spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary. |
| | *Prionospio* sp. | 2 | Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was renamed to *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001). |
| Gastropoda | *Cominella glandiformis* | 3 | Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds. |
| | *Diloma subrostrata* | 2 | Endemic, mudflat top shell, lives on mudflats, but prefers a more solid substrate such as shells, stones etc. Feeds on the film of microscopic algae on top of the sand. |
| | *Epitonium tenellum* | NA | A small ectoparasitic sea snail, a marine gastropod mollusk in the family Epitoniidae, the wentletraps, which feeds on the anemone Anthopleura. |
| | *Notoacmea helmsi* | 2 | Endemic to NZ, a small grazing limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds and sensitive to pollution. |
| Bivalvia | *Arthritica bifurca* | 4 | A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition. |
| | *Austrovenus stutchburyi* | 2 | Family Veneridae. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects. 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. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community who are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macro-invertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). |
| | *Macomona liliana* | 2 | A deposit feeding wedge shell. This species lives at depths of 5–10cm 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. |
| | *Nucula hartvigiana* | 2 | A small deposit feeding nut clam of the family Nuculidae (<5mm), is endemic to New Zealand. It is found intertidally and in shallow water, especially in Zostera sea grass flats. Often abundant in top few cm, together with the New Zealand cockle, Austrovenus stutchburyi, but is not as abundant. Like Arthritica, this species feeds on organic particles within the sediment using a plug-like foot, which it uses for motion in mud deposits. Intolerant of organic enrichment. |

# APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

| Group and Species | | WEBI Group * | Details |
|---|---|---|---|
| Crustacea | *Amphipoda* sp. 1 | 2 | An unidentified amphipod species. |
| | *Austrominius modestus* | 2 | Small acorn barnacle (also known as *Elminius modestus*). Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones. A filter feeder that prefers sandy substrate. |
| | *Decapoda larvae unid.* | NA | Unidentified decapod larvae. |
| | *Halicarcinus whitei* | 3 | Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments. |
| | *Helice crassa* | 5 | Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content. |
| | *Macrophthalmus hirtipes* | 5 | The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. |
| | Phoxocephalidae | 2 | A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism. |
| Insecta | *Diptera* sp. 1 | 2 | An unknown dipteran or fly larvae. |

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

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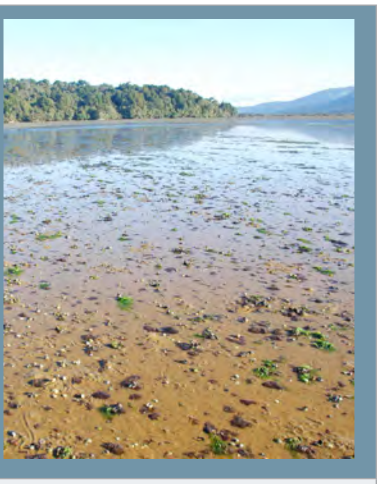
# APPENDIX 4.

# ESTUARY CONDITION RISK RATINGS FOR KEY INDICATORS

DEVELOPED BY WRIGGLE COASTAL MANAGEMENT

JUNE 2014



## GUIDELINES FOR USE

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality. In order to facilitate this process, "risk indicator ratings" have been proposed that assign a relative level of risk of adversely affecting estuarine conditions (e.g. very low, low, moderate, high, very high) to each indicator. Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within a risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data. However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

The indicators and risk ratings used in the Waimea Inlet fine scale monitoring programme, and their justifications, are summarised in the following sections.

# APPENDIX 4.  ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 1. SEDIMENT PERCENT MUD CONTENT

In their natural state, most NZ estuaries would have been dominated by sandy or shelly substrates, while most NZ beaches are dominated by sandy substrates due to their relatively high wave exposure.  In estuaries or beaches not naturally prone to muddy conditions, a significant shift towards elevated concentrations of mud (grain size <63um) is likely to result in detrimental and difficult to reverse changes in biotic community composition, and adverse impacts to human uses and values (e.g. through reduced water clarity and increased muddiness).  Consequently, mud content can indicate where changes in land management may be needed.

Subsequent to the development of NEMP (Robertson et al. 2002) which uses sediment grain size as one indicator of sediment condition, the relationships between sediment mud content, the benthic macrofaunal community, sediment cohesiveness or stickiness, and organic carbon concentration have been further defined (see supporting evidence below).  This included a widespread Wriggle funded study of NZ estuarine habitats (Robertson 2013) which found estuarine sediments with low to intermediate mud concentrations (i.e. 2-25% mud) were more likely to have a diverse and abundant macroinvertebrate assemblage and low organic enrichment (<1% TOC) than muddier sediments. Based on this, and other supporting work, the associated characteristics of the sediment % mud content indicator can be summarised as follows:

**"% Mud Content" Characteristics**

- Sediments are relatively incohesive at mud contents below 20-30% (i.e. are not sticky and are relatively firm to walk on), but become cohesive and "sticky" at higher mud contents (i.e. you begin to sink into the muds).
- There is a marked shift in the macroinvertebrate assemblage when mud content exceeds 25-30% to one dominated by mud tolerant and/or species of intermediate tolerance.  This shift is most apparent when elevated mud content is contiguous with high total organic carbon (TOC) concentrations.
- As % mud content increases, the concentrations of organic carbon and nutrients (total organic carbon and total nitrogen) also generally increase, particularly for estuaries with highly developed catchments.  As a consequence, such sediments are often poorly oxygenated and, when present in intertidal flats of tidal lagoon estuaries (particularly in poorly flushed areas), are often overlain with dense nuisance macroalgal blooms.
- In typical NZ shallow tidal lagoon estuaries, muddy sediments (>40% mud) and elevated nitrogen loadings ($100mgN.m^{-2}.d^{-1}$), commonly coincide with dense macroalagal cover (>80% cover) and gross eutrophic conditions (TOC >3%, RPD at surface).  Similar gross eutrophic conditions occur in shallow coastal lagoons or ICOLLs where conditions are not too turbid, but the minimum mud content at which they occur is expected to be much less than for tidal lagoon estuaries.  In narrow tidal river estuaries, which are well flushed and lack large settling basins, such gross eutrophic conditions are rare.

These characteristics indicate that NZ estuary sediments with a widespread mud content of greater than 20-30% are likely to have a degraded macroinvertebrate community, and sediments that are non-cohesive (soft and muddy).  Such impacts are most significant if such conditions are occurring in estuaries with a naturally low mud content.  Of particular importance are the typical NZ shallow, tidal lagoon and ICOLL estuaries.

## SUPPORTING EVIDENCE

### 1. Mud Content - Relationship to Macroinvertebrate Community

A review of monitoring data from 25 typical NZ estuaries (shallow, short residence time estuaries) (Wriggle database 2009-2014) confirmed a "high" risk of reduced macrobenthic species richness for NZ estuaries when mud values were >25-30% mud and a "very high" risk at >55% (this last value is more tentative given the low number of data-points beyond this mud content) (Figure 1).  This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of mud content) by the increasing dissimilarity in the macrobenthic community as mud contents increase above 25-30% mud (Figure 2).

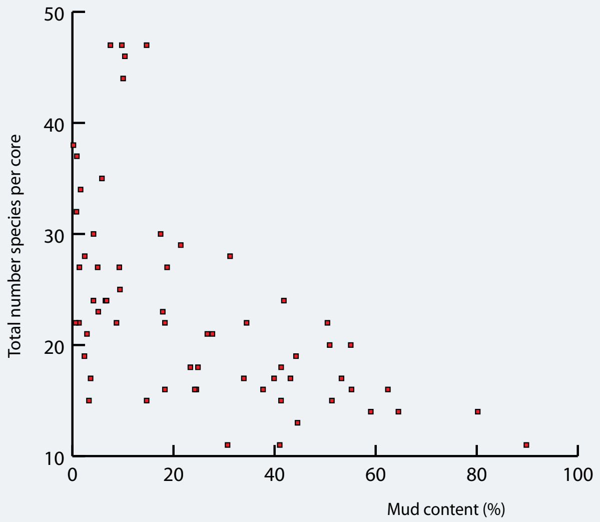


**Figure 1.  Sediment mud content and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types.  (Wriggle Coastal Management database 2009-14).**

# APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 1. SEDIMENT PERCENT MUD CONTENT (CONTINUED)

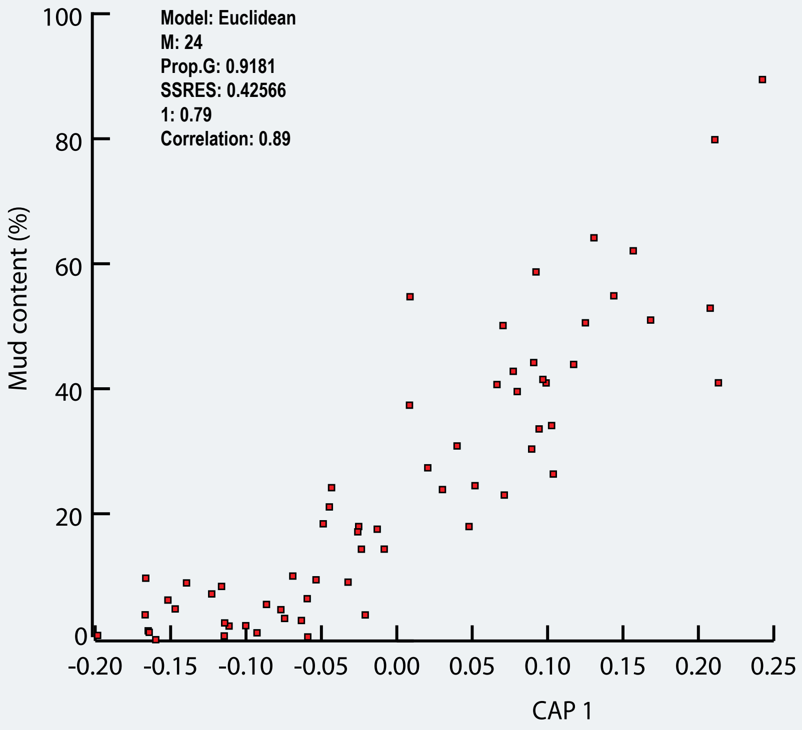


**Figure. 2. Canonical analysis of the principal coordinates (CAP) for the effect of sediment mud content (exclusively) on the macroinvertebrate assemblages from 25 typical NZ estuaries (i.e. CAP1) among sites. Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.**

### 2. Mud Content - Relationship to Sediment Cohesiveness

Studies show that sediments become "cohesive" or sticky once the % mud content increases above approximately 20-30% mud depending on such factors as the clay content (Houwing 2000).

### 3. Mud Content- Relationship to Gross Nuisance Conditions

The trophic response to muddy sediments under elevated nitrogen loadings, in this case macroalgal cover, has been explored for 15 shallow tidal lagoon estuaries in NZ (tidal lagoon type with flushing potentials <0.1 days, mean depth 0.5-2m, intertidal flats >50% estuary area). The results (Figure 3) showed that where mud content was greater than 40% and the nitrogen load to the estuary was greater than 100mgN.m$^{-2}$.d$^{-1}$, macroalagal cover was greater than 80% and was accompanied by gross eutrophic conditions (mud content >30%, TOC >3%, RPD at surface).

Similar gross eutrophic conditions have been found to occur in shallow coastal lagoons or ICOLLs where conditions are not too turbid (e.g. Hoopers Inlet, Waituna Lagoon), but the minimum mud content at which they occur is expected to be much less than for tidal lagoon estuaries. Further work is however required to confirm this.

The trophic response to muddy sediments under elevated nitrogen loadings, in this case macroalgal cover, has been explored for 5 shallow tidal river estuaries in NZ (tidal river type with flushing potentials <0.1 days, mean depth 0.5-2m, intertidal flats <5% estuary area). In these narrow, well flushed, tidal river estuaries, where intertidal area is small and therefore the opportunity for nuisance macroalgal growth limited, such gross eutrophic conditions were rare (Figure 4).

# APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 1. SEDIMENT PERCENT MUD CONTENT (CONTINUED)

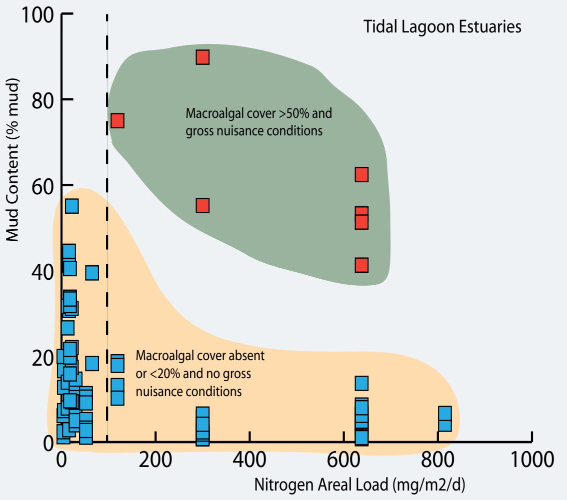


**Figure 3. Mud content of sediment and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 15 typical NZ tidal lagoon estuaries (shallow, residence time <3d, >50% of estuary intertidal) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013, Robertson et al. 2002).**

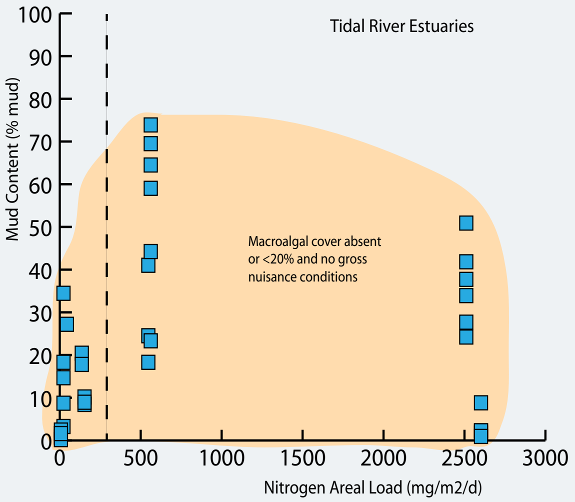


**Figure 4. Mud content of sediment and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 5 typical NZ tidal river estuaries (data sourced from Wriggle Coastal Management monitoring reports 2006-2013).**

### RECOMMENDED SEDIMENT MUD CONTENT RISK RATING (INTERIM)

It is recommended that the estuary sediment-macroinvertebrate-mud thresholds (primarily adapted from Robertson 2013) be used to provide an interim indicator of estuary risk based on the magnitude of likely impact on sediment biota from measured % mud content as follows:

**Estuary Condition Risk Rating (Interim): Sediment Mud Content**

| Risk Rating | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| Sediment Mud Content (% mud) | <2% | 2-5% | >5-15% | >15-25% | >25% |

Clearly, this rating is intended for the determination of site-specific conditions at monitoring sites, not for whole estuary assessments (unless representative sites have been monitored over the whole estuary).

### RECOMMENDED RESEARCH

Undertake extensive grain size validation monitoring of the following habitat types: firm muddy sand, soft mud, and very soft mud to confirm and refine the measured range of % mud found in each these broad scale monitoring categories from estuaries throughout NZ.
Undertake further studies in typical NZ estuaries on % mud and the incidence of:

- gross eutrophic conditions,
- adverse impacts to macroinvertebrates, seagrass, saltmarsh, fish, and/or birds.

### References

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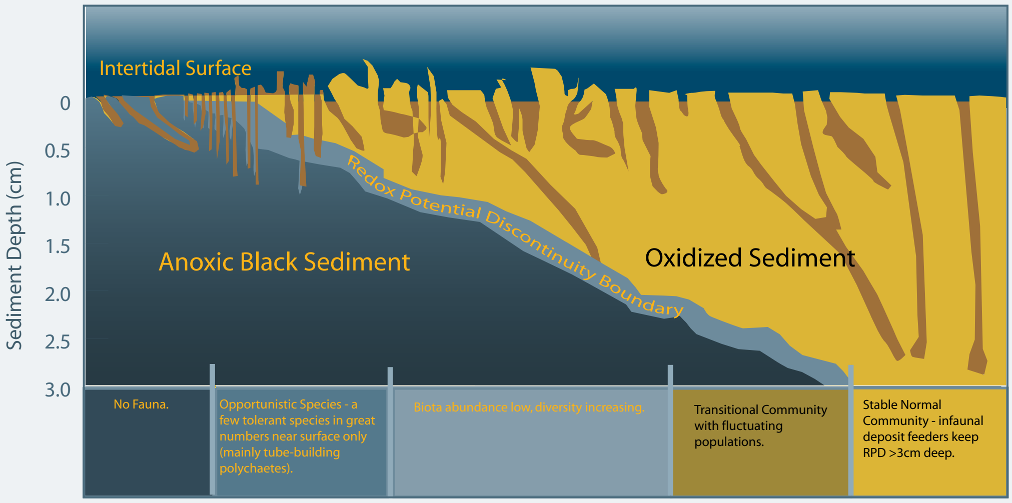
## 2. REDOX POTENTIAL DISCONTINUITY (RPD) DEPTH

Redox Potential Discontinuity (RPD) depth measures the transition between oxygenated sediments near the surface and deeper anoxic sediments. It is a primary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Anoxic sediments contain toxic sulphides, which support very little aquatic life, and 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 worsen sediment conditions. In sandy porous sediments, the RPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

The RPD layer 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. Pearson and Rosenberg (1978) developed a useful organic enrichment tool that indicates the likely benthic macrofauna community that is supported at a particular site based on the measured RPD depth (see Figure below for summary). This tool has been used extensively to date to help interpret intertidal monitoring data in New Zealand and its relationship to organic enrichment. However, it is important to note that this tool was based primarily on studies conducted in stable subtidal sediments of coastal estuaries and embayments rather than the more unstable intertidal sediments of beach habitat or shallow, well-flushed estuaries commonly found in NZ.



**An indication of the likely benthic community supported at measured RPD depths (adapted from Pearson and Rosenberg 1978).**

In addition, a recent study (Gerwing et al. 2013) describe two common methods for measuring RPD as follows:

- **Visual assessment** (often by digital imaging e.g. Munari et al. 2003) based on the assumption that in the absence of oxygen, ferrous sulphides produced by microbial sulphate reduction precipitate as Fe-sulphides, which produce a grey or black coloration of the sediment, which signifies the RPD depth (Valdemarsen et al. 2009). When redox measurements (Eh) are not considered simultaneously, the RPD is termed the apparent RPD (aRPD) (Birchenough et al. 2012).
- **Redox potential (Eh) measurements** represent a bulk measurement that reflects the occurrence of multiple redox equilibria at the surface of an electrode and reflects a system's tendency to receive or donate electrons. Electrodes are inserted either vertically or horizontally at different depths (Rosenberg et al. 2001, Diaz & Trefry 2006) into the sediment. The depth of the RPD is identified as the zone where conditions change from oxidizing to reducing or the transition from positive to negative mV readings (Birchenough et al. 2012).

Gerwing et al. (2013) compared the methods and found similar results for stable subtidal (Rosenberg et al. 2001) and deep sea sediments (Diaz & Trefry 2006), but different results for relatively dynamic intertidal sediments.

Such findings, indicate two important points:

1. The use of the Pearson-Rosenberg (1978) approach for assessing macrobenthic response to organic enrichment in dynamic, shallow intertidal sediments (i.e. the dominant habitats in most NZ estuaries and beaches) has yet to be proven, and
2. The appropriate RPD method for use in such intertidal sediments and its relationship with biotic indicators needs to be identified.

# APPENDIX 4. ESTUARY CONDITION RISK RATINGS - (CONTINUED)

## 2. REDOX POTENTIAL DISCONTINUITY (RPD) DEPTH (CONTINUED)

### RECOMMENDED RPD RISK RATING (INTERIM)

In the interim period prior to the results of proposed Otago University research being available (see recommended research section below), it is recommended that the RPD risk rating be based on aRPD results and predicted ecological response bands similar to those proposed by Pearson-Rosenberg (1978) as presented in the Table below. In addition, it is recommended that other indicators are used to further assess sediment oxygenation if the aRPD indicates a high/very high risk of ecological impacts. The measurement of redox potential and/or various sulphur fractions are the most common approaches.

**Estuary and Beach Condition Risk Indicator Rating (Interim): Apparent RPD Depth**

| Risk Rating | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| aRPD depth (cm) | >10cm | 3-10cm | 1-<3cm | 0-<1cm | Anoxic at surface |

### RECOMMENDED RESEARCH

Clearly, there is an urgent requirement for a direct comparison between both RPD methods (visual and redox) for intertidal and subtidal estuary and beach habitats in NZ, and particularly the relationship between the RPD depth measured by each, and other indicators, especially biotic factors such as macroinvertebrates and macroalgal cover, and environmental factors such as sulphur species. This is to be included as part of Wriggle sponsored PhD research being undertaken by Ben Robertson (commenced in June 2014).

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*Veldemarsen T., Kristensen E., and Holmer M. 2009. Metabolic threshold and sulfide-buffering in diffusion controlled marine sediments impacted by continuous organic enrichment. Biogeochemistry 95: 335-353.*

# APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 3. TOTAL ORGANIC CARBON (TOC) AND RELATED NUTRIENTS

Estuaries with a high sediment organic content can result in anoxic sediments and bottom water, which contribute to the release of excessive nutrients and have adverse impacts on biota - key symptoms of eutrophication. Elevated sediment organic content (measured as total organic carbon, TOC) is generally caused by excessive plant growth within an estuary, or from catchment inputs (including point sources). In NZ's shallow, short residence time estuaries (SSRTEs), decaying macroalgae, seagrass and saltmarsh vegetation are the major sources of sediment TOC. In in deep, long residence time estuaries (DLRTEs), the major source is phytoplankton.

Hyland et al. (2005) recently expanded upon the Pearson and Rosenberg (1978) model (which describes benthic community response along an organic enrichment gradient) by using it as a conceptual basis for defining lower and upper thresholds in TOC concentrations corresponding to low versus high levels of benthic species richness in samples from seven coastal regions of the world. Specifically, it was shown that risks of reduced macrobenthic species richness from organic loading and other associated stressors in sediments should, in general, be relatively low where TOC values were <1%, and relatively high where values were >3.5%.

While not a direct measure of causality (i.e. it does not imply that the observed bioeffect was caused by TOC itself), it was anticipated that these TOC thresholds may serve as a general screening-level indicator, or symptom, of ecological stress in the benthos from related factors. Such factors may include high levels of ammonia and sulphide, or low levels of dissolved oxygen associated with the decomposition of organic matter, or the presence of chemical contaminants co-varying with TOC in relation to a common controlling factor such as sediment particle size. Subsequently, the TOC threshold values have been confirmed by several sources:

- Analysis of TOC sediment data collected in EMAP-Virginian Province Study indicated that TOC values in the 1 to 3% range were associated with impacted benthic communities, while values less than 1% were not (Paul et al. 1999).
- Magni et al. (2009) confirmed a high risk of reduced macrobenthic species richness for Mediterranean coastal lagoons when TOC values were >2.8%.
- A review of monitoring data from 25 typical NZ estuaries (SSRTEs) (Wriggle database 2009-2014) confirmed a "high" risk of reduced macrobenthic species richness when TOC values were >2% and a "very high" risk at >3.5% (this last value is more tentative given the low number of data-points beyond this TOC concentration) (Figure 1). This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of TOC content, Figure 2) by the increasing dissimilarity in the macrobenthic community as TOC concentrations increase above 2%.

### SUPPORTING EVIDENCE

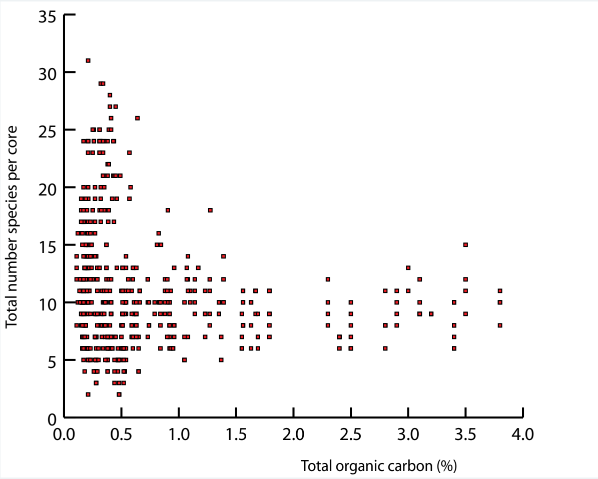

**Figure 1. Sediment TOC concentrations and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).**

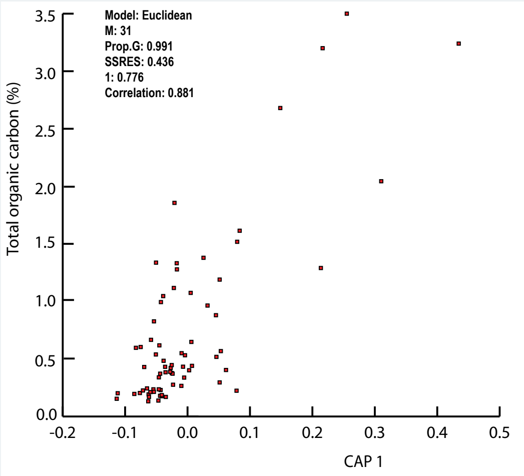

**Figure 2. Canonical analysis of the principal coordinates (CAP) for the effect of total organic carbon content, on the macroinvertebrate assemblages from 12 typical NZ estuaries (i.e. CAP1) among sites.**

**Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.**

# APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 3. TOTAL ORGANIC CARBON (TOC) AND RELATED NUTRIENTS (CONTINUED)

Data from 12 estuaries scattered throughout NZ, and representing most NZ estuary types were reviewed in relation to TOC and nutrients (Figure 3). Total nitrogen was found to be very strongly correlated with TOC ($r^2 = 0.90$). Total phosphorus was less strongly correlated ($r^2 = 0.68$), but preliminary analysis of the data suggests a likely explanation for the variability at elevated P concentrations. Surface P concentrations can become elevated if P that is released from intense sulphate reduction process at depth in sediment, is trapped by iron oxyhydroxides in the surface oxygenated layer. This process is likely to be expressed in a variable way, being most intense in situations with dense macroalgal cover, and less intense where macroalgal cover is moderate (Figure 3).

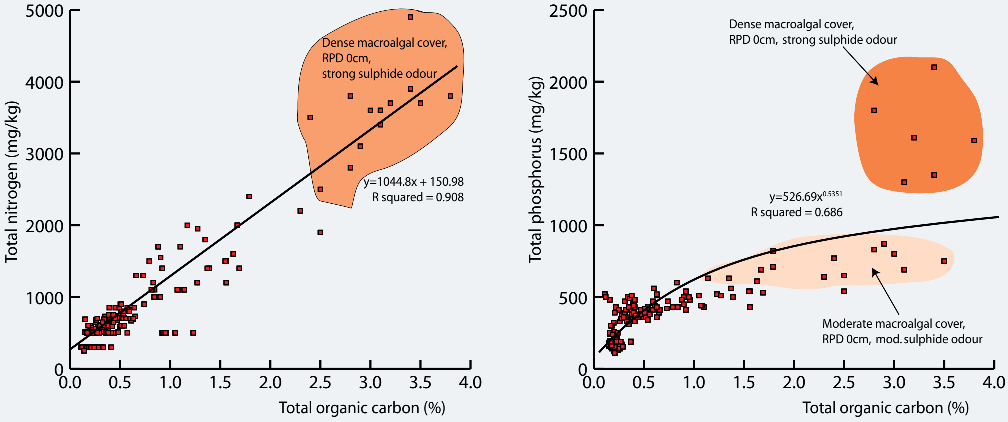

**Figure 2. Sediment TOC and TN, and sediment TOC and TP concentrations from 12 estuaries scattered throughout NZ, and representing most NZ estuary types (Wriggle Coastal Management database 2009-2013).**

### RECOMMENDED TOC AND RELATED NUTRIENTS RISK RATING (INTERIM)

In order to assess the likely risk of estuary ecological condition being affected by the sediment TOC concentration it is recommended that the following thresholds be used.

**Estuary Condition Risk Indicator Rating: TOC and Related Nutrients (TN and TP)**

| Indicator | Risk Rating | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|---|
| **Primary** | **Total Organic Carbon** | <0.5% | 0.5-1% | 1-2% | 2-3.5% | >3.5% |
| **Secondary** | **Total Nitrogen** | <250mg/kg | 250-1000mg/kg | 1000-2000mg/kg | 2000-4000mg/kg | >4000mg/kg |
| | **Total Phosphorus** | <100mg/kg | 100-300mg/kg | 300-500mg/kg | 500-1000mg/kg | >1000mg/kg |

However, it is emphasised that in order to assess the condition of NZ estuaries using TOC, a multi-criteria approach (physical, chemical and biotic indicators) is recommended, so that TOC concentration measurements are supported by related indicators, in particular mud content, RPD, macroinvertebrates, macroalgal cover, and the secondary indicators TP and TN.

### RECOMMENDED RESEARCH

- Undertake studies to further expand the sediment macroinvertebrate/TOC relationships for NZ estuaries into highly eutrophic habitats, particularly those with >3.5% TOC concentrations.
- Develop a list of macrobenthic species sensitivities to TOC concentrations under varying mud, redox, and heavy metal concentrations.

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# APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 4. TOXICANTS (HEAVY METALS ETC)

Many urban estuaries have sediments contaminated with toxicants, both heavy metals and hydrophobic organic compounds (ANZECC 2000). Heavy metals provide a low-cost preliminary assessment of toxic contamination, and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for other major contaminant classes: pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

The ANZECC (2000) sediment criteria (Interim Sediment Quality Guidelines - ISQG) have been developed on the basis that "guideline numbers are trigger values that, if exceeded, prompt further action as defined by the decision tree". The first-level screening compares the trigger value with the measured value for the total contaminant concentration in the sediment. If the trigger value (ISQGLow) is exceeded, then this triggers either management/remedial action, or further investigation to consider natural background levels and the fraction of the contaminant that is bioavailable (or can be transformed and mobilised in a bioavailable form).

If the natural background concentration is less than the ISQG High trigger then it is considered a low risk and no action is recommended. If the natural background concentration is greater than ISQG High trigger then it is considered a risk and further investigation is recommended.

### RECOMMENDED TOXICANT RISK RATING

In order to assess the likely risk of estuary ecological condition being affected by the sediment toxicant concentration it is recommended that the following thresholds be used, (broadly based on the ANZECC (2000) sediment quality guidelines).

**Estuary Condition Risk Indicator Rating: Toxicants**

| Risk Rating | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| **Toxicant (e.g. heavy metals)** | <0.2 x ISQGLow | 0.2 x ISQGLow to 0.5 x ISQGLow | >0.5 x ISQGLow to ISQGLow | ISQGLow to ISQGHigh | >ISQGHigh |
| | | | | | |
| **Actions** | No action | No action | Monitor trends | Further investigate if not due to high natural background levels. | Further investigation recommended. |

### RECOMMENDED RESEARCH

- Undertake studies to further expand the sediment macroinvertebrate/toxicant relationships for NZ estuaries.
- Develop a list of macrobenthic species sensitivities to various toxicant concentrations under varying mud, redox, and TOC concentrations.

### References

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

# APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 5. MACROINVERTEBRATE COMMUNITY

Because of their proven ability to indicate and integrate complex environmental conditions, soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). Such a classification is particularly useful given the fact that most estuaries are dominated by soft sediments. However, assessing estuarine condition by macroinvertebrates is difficult due to the high variability of natural conditions in estuaries and their often modified nature. Importantly, the use of this approach must include an awareness of it's advantages and disadvantages (Table 1).

Table 1. Advantages and disadvantages of using macroinvertebrates to assess ecological quality.

| **Advantages** (Dauvin 2007) | **Disadvantages** (Rakocinski and Zapfe 2005) |
|---|---|
| • Sedentary nature and therefore inability to avoid water/sediment quality conditions.<br>• Relatively long life spans.<br>• High species diversity with different tolerances to stress.<br>• Important in water/sediment biogeochemical cycling. | • Static expression of an ecological condition.<br>• Not directly linked to changes in ecological function.<br>• May not be specific with respect to different kinds of stressors.<br>• Subject to underlying taxonomic changes across estuarine gradients.<br>• Labour intensive.<br>• Not applied consistently across biogeographic provinces. |

As a by-product of the development of macroinvertebrate/estuary condition indicator relationships, a large number of macroinvertebrate biotic indices (sometimes associated with other environmental or biological variables) have been developed and used to assess estuary condition. These range from simple univariate indices, such as species richness (number of species), and diversity indices (e.g. Shannon diversity index, H'), to more complex functional indices, multimetric indices (e.g. BQI: Biological Quality Index) and multivariate approaches (e.g. M-AMBI: Multivariate-AMBI) (see list in Borja et al. 2012).

These indices, result in a single number which summarises the complex estuary condition and is statistically supported by a wide range of physical, chemical and biological measures. The development of these indices reflect the facts that biological communities are a product of their environment, and organisms can be grouped according to different habitat preferences and pollution tolerance. Most of the estuarine biotic indices are only used in a limited way at present, but AMBI and multivariate AMBI (M-AMBI), BQI (and its various adaptations), B-IBI, and Infaunal Trophic Index (ITI) are currently widely used throughout the world (Borja et al. 2012). However, a recent review (Borja et al. 2012) concluded that no single biotic index can correctly assess the estuary condition, and that a multi-criteria approach is favoured.

Within NZ, there have been several approaches to the development of macroinvertebrate/estuary condition relationships based on the response of NZ species to estuarine variables. The most common environmental variables for which taxa responses have been identified are: mud content (Norkko et al. 2002, Robertson 2013), heavy metals (Rodil et al. 2013), and redox and organic matter (Robertson 2013). A summary of the approaches and results, in order of their development, are presented below.

- **Mud Sensitivity Ratings** - based on the environmental condition indicator of % mud. From a limited dataset of 14 upper North Island estuaries, as well as short-term laboratory experiments, a macroinvertebrate-mud sensitivity rating (based on % mud) was estimated for 38 taxa, of which 13 were able to be statistically modelled, and 25 assessed through visual interpretation of the raw macroinvertebrate abundance data (Norkko et al. 2002, Thrush et al. 2003). These species ratings have been subsequently used to assess benthic macroinvertebrate community condition in relation to muddiness in estuaries throughout NZ (e.g. see Gibbs and Hewitt 2004, Hailes and Hewitt 2012). However, in a national context, such ratings potentially lack strong regional transferability and are limited in terms of the number of taxa with assigned ratings. As such, their use in assessing estuary condition at any particular site needs to be supported by information that indicates that: i. the estuary in question fits within the upper North Island estuary type classification used to produce the ratings, ii. that due regard is given to taxa that have not yet been rated for sensitivity and, iii. that the ratings are only used to assess sensitivity to sediment mud content. Use of a multi-metric approach is required to gain a true indication of the factors driving a particular macroinvertebrate assemblage, particularly the inclusion of indicators of eutrophication and toxicity.

- **Local Trophic Biotic Index (TBI)** - based on the environmental condition indicators of % mud and metal concentrations. Rodil et al. (2013) developed the local traits based index (TBI) primarily to predict the response of the macrofauna community to metal gradients. They assigned macroinvertebrate species from 84 intertidal soft-sediment sites from three Auckland harbour estuaries (Mahurangi, Waitemata, and Manukau), into one of 29 functional groupings. Correlation strengths between the number of taxa and individuals in each of the 29 functional groups were evaluated and related to sediment mud content (using the Mahurangi data) and metal content (using the Waitemata/Manukau data). Based on these correlations, seven functional groups were retained for use in the TBI, due to their observed responsiveness to both mud and metals in two independent data sets. The utility of the TBI was then verified using independent data from >100 additional Auckland estuary sites and results from these upper North Island estuaries showed the TBI responded to changes in sediment mud percentage and heavy metal contaminant concentration gradients at levels below international toxicity thresholds, and therefore successfully tracked the most relevant local stressors. The rating results were also compared with results from two other indices; the AMBI, which is designed to respond to mud and organic enrichment), and the B-IBI which evaluates the ecological condition of a sample by comparing values of benthic community attributes to reference values expected under non-degraded conditions in similar habitat types (Weisberg et al. 1997).

## 5. MACROINVERTEBRATE COMMUNITY (CONTINUED)

The results from the AMBI showed that this indicator performed well for the job it was designed to do (i.e. predict response to organic enrichment). The AMBI coefficients were in the low range (1-4, indicating undegraded states), which was expected given that all the sites experienced low levels of organic enrichment (expert opinion rather than measured). They also predictably showed that the increased AMBI scores (indicative of degrading health) were associated with declines in the abundances of sensitive species and declines in species diversity.

The results from the B-IBI, which was calculated using well known metrics of species abundance, diversity and the abundance of sensitive species, carnivores and deposit feeders, were correlated with gradients of increasing muddiness, although B-IBI was unsuccessful at distinguishing reference sites from known degraded sites. It calculated 58% of the sites correctly as uncontaminated, and it was not closely related to the mud gradient. Concordance between the two indices was also relatively poor.

Although a promising tool, before the TBI can be applied nationally, it needs to be tested for other estuaries outside of the upper North Island, and also for other environmental factors known to influence macrofauna in NZ estuaries, particularly organic enrichment indicators (e.g. TOC, TN, macroalgal cover, RPD). Therefore, although this rating is likely to be useful in the Auckland region where metal toxicity and muddiness are key stressors, its wider use in other NZ estuaries where organic enrichment, muddiness and low metal concentrations are more evident, is currently unproven.

- **Mud and Organic Carbon Sensitivity Ratings.** Robertson (2013) used organic enrichment, grain size and macroinvertebrate data from 135 sites in 25 estuaries scattered throughout NZ, and representing most NZ estuary types, to produce mud and organic sensitivity ratings for NZ estuarine macroinvertebrates. The results confirmed sediment mud content and TOC as co-varying ($R^2 = 0.706$; $P = 0.001$) key drivers of the macroinvertebrate community (noting that all sites had metals concentrations below ANZECC ISQG toxicity thresholds). Mud/organic enrichment sensitivity ratings (5 sensitivity groupings) were subsequently established through statistical modelling for a total of 42 species, with a further 56 species assessed through visual interpretation of the raw data. These results were then used as inputs to the AMBI biotic coefficient equation to produce an integrated mud and organic enrichment rating - the “Wriggle Estuary Benthic Index” (WEBI) for available NZ data.

### RECOMMENDATIONS FOR MACROINVERTEBRATE INDICATORS FOR NZ ESTUARIES

It is strongly recommended that only NZ macroinvertebrate/physico-chemical variable relationships be used to assess estuary condition in NZ. This is because the physical conditions of most NZ estuaries (dominated by largely intertidal, well-flushed, shallow, short residence time estuary types and absence of midwater saltmarsh), differ greatly from the majority of the overseas estuaries types and the associated datasets (dominated by marine/estuarine subtidal data) which have been used to derive international biotic indices.

Further, in order to assess the ecological condition of NZ estuaries using macroinvertebrates, particularly in relation to three of the major estuary stressors, i.e. muddiness, eutrophication and toxicity, a multi-criteria approach using physical, chemical and biotic indicators is recommended. This approach is recommended because the response of NZ estuary macroinvertebrate taxa to these issues has not yet been reflected in any one integrated biotic indice. This recommended approach should include the following:

1. Measure key physical and chemical indicators of NZ estuary condition (e.g. TOC, TN, redox/RPD, grain size, heavy metals) and compare the monitoring data with established physico-chemical/macroinvertebrate response relationships for representative NZ estuaries. For example:
    - TOC concentration versus species richness (see preceding TOC Rating section)
    - TOC concentration versus macroinvertebrate community similarity (see preceding TOC Rating section, i.e. CAP Plot)
    - Mud content versus species richness (see preceding Mud Content Rating section)
    - Mud content versus macroinvertebrate community similarity (see preceding Mud Content Rating section, i.e. CAP Plot)
    - Toxic contaminant (e.g. heavy metals) concentration versus macroinvertebrate community similarity (these relationships will be developed once sufficient monitoring data from a range of NZ estuaries has been collected - the current data set held by Wriggle does not include high toxicity sites).
2. Use the mud/organic enrichment sensitivity ratings (5 sensitivity groupings, Gp1-Gp5) established by Robertson (2013) for NZ estuary taxa, as inputs to the AMBI biotic coefficient equation (until a more appropriate local equation has been derived). This so called “Wriggle Estuary Benthic Index” (WEBI) calculates an integrated mud and organic enrichment rating for a site using the following AMBI equation and the ratings indicated in the table below;

    Biotic Coefficient (BC) = {(0 x %Rating Gp1) + (1.5 x %Rating Gp2) + (3 x %Rating Gp3) + (4.5 x %Rating Gp4) + (6 x %Rating Gp5)}/100.
    Verify the WEBI score in relation to the measured physical and chemical results and thresholds for TOC and mud content.

    At sites where toxicity is present, the use of the TBI mentioned above is recommended, particularly as a screening tool.
3. Finally, assess changes in abundance of individual species, preferably in relation to their sensitivity to relevant stressors, e.g. the 5 major mud/enrichment tolerance groupings (i.e. “very sensitive to organic enrichment” group through to “1st-order opportunistic species“ group) (Robertson 2013). This final analysis is vital, given the tendency for community indices and statistical approaches to mask potentially important changes at a species level.

# APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

## 5. MACROINVERTEBRATE COMMUNITY (CONTINUED)

### RECOMMENDED MACROINVERTEBRATE RISK RATING

In order to assess the likely risk of estuary ecological condition being affected by excessive muddiness or organic enrichment, it is recommended that the following thresholds be used.

**Estuary Condition Risk Indicator Rating: WEBI Mud and Organic Enrichment**

| Risk Rating | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| Macro-invertebrate Enrichment Index (WEBI) | 0-1.2<br>Intolerant of enriched conditions | >1.2-3.3<br>Tolerant of slight enrichment | >3.3-5.0<br>Tolerant of moderate enrichment | >5.0-6.0<br>Tolerant of high enrichment | >6.0<br>Azoic (devoid of invertebrate life) |

The characteristics of the ecological groups (G1, G2, G3, G4 and G5) are summarised as follows:

- Group 1. Species very sensitive to mud and organic enrichment and present under unpolluted conditions (initial state).
- Group 2. Species indifferent to mud and organic enrichment.
- Group 3. Species tolerant to excess mud and organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalanced situations).
- Group 4. Species tolerant of mud and organic enrichment (slight to pronounced unbalanced situations).
- Group 5. Species tolerant of mud and organic enrichment (pronounced unbalanced situations).

3. If the toxicity levels (apart from toxicity related to eutrophic conditions, i.e. elevated sulphide or ammonia) exceed levels that cause biotic stress, it is recommended that the TBI be used and the scores be verified in relation to the measured results and thresholds for toxic contaminants and mud content.

### RECOMMENDED RESEARCH

- Because opportunistic macroalgae are the predominant source of elevated organic matter (and therefore eutrophication symptoms) in NZ shallow, intertidally dominated estuaries, with very short residence times (SSRTEs) (i.e. NZ's dominant estuary type) it is recommended that further studies be undertaken to establish the relationship between macroalgal cover and the macroinvertebrate community. Such a study should aim to provide a predictive tool for macroinvertebrate response to macroalgal cover.
- Because NZ estuarine ecology is susceptible to the influence of fine sediments and nutrients, research is required to investigate the combined influence of fine sediment and nutrient loads on macroinvertebrates in NZ shallow estuaries. Such a study should aim to provide a predictive tool for macroinvertebrate response to nutrient and fine sediment input loads to key estuary types and estuary habitats (particularly SSRTEs).
- Development of macrobenthic biotic indices for each of the major estuary issues of muddiness, organic enrichment and toxicity. Research is required to tease the apart covariance between these issues so that macrobenthic response relationships can be derived for mud content alone, TOC/redox at varying mud contents, then TOC/redox, toxicants at varying mud contents. Careful site selection to minimise the influence of other variables (e.g. tide height, freshwater influence, resuspension, etc) is recommended in the design.

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