# Waikawa Estuary (Marlborough)

## Fine Scale Monitoring 2016

Prepared
for

**Marlborough
District
Council**

**July
2016**

**Cover Photo: Waikawa Estuary seagrass bed and fine scale site**


Waikawa Estuary

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Prepared for
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by

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# WAIKAWA ESTUARY - EXECUTIVE SUMMARY

Waikawa Estuary is a small (3.4ha), shallow, well-flushed, seawater-dominated, meso-tidal (tidal range ~1m), river delta type estuary that opens via a wide mouth to Waikawa Bay in Queen Charlotte Sound. The catchment has a mix of regenerating bush and urban landuse, and while the estuary has been highly modified, it still supports regionally rare seagrass dominated intertidal flats. It is one of the key estuaries in Marlborough District Council's (MDC's) long-term coastal monitoring programme. This report summarises the results of the first year of fine scale baseline monitoring (January 2016) from one intertidal site within the estuary. The following table summarises fine scale monitoring results, condition ratings, issues, and monitoring and management recommendations.

## FINE SCALE MONITORING RESULTS

- Seagrass cover was high (80-100% ) and macroalgae cover was low (<5%) at the fine scale site.
- Sediment mud content (mean 25% mud), and sediment oxygenation (aRPD 1-2cm), rated as a "moderate risk of ecological impacts".
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations at both sites and rated as having a "low risk of ecological impacts".
- The metals Cu, Cd, Cr, Ni, Pb, Zn, and the metalloid As, as well as most of the semi-volatile organic contaminants were at low concentrations, a risk indicator rating of "low" or "very low". However, concentrations of mercury (Hg), the organochlorine pesticide DDT and the boat antifoulant tributyl tin exceeded guidelines for toxicity to benthic biota, a risk indicator rating of "high".
- The macroinvertebrate community consisted of a mixed assemblage of species, dominated by bivalves and polychaetes. In terms of mud and organic enrichment, the NZ AMBI scores (range 1.3-1.8) indicated a community dominated by both sensitive, and moderately tolerant taxa and overall good ecological condition with respect to these potential stressors (risk rating "low"). These good scores likely reflect the actions of the high seagrass cover at the site mitigating the negative effects of elevated mud concentrations.

## RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

| | | | |
|---|---|---|---|
| 🟦 | Low | 🟨 | Moderate |
| ⬜ | Very Low | 🟧 | High |

| Indicator | Site A (mid-estuary) | | | |
|---|---|---|---|---|
| | 2016 | 2021 | 2026 | 2031 |
| Sediment Mud Content | 🟨 | | | |
| aRPD (Sediment Oxygenation) | 🟨 | | | |
| TOC (Total Organic Carbon) | 🟦 | | | |
| TN (Total Nitrogen) | 🟦 | | | |
| Invertebrate Mud/Org Enrichment | 🟦 | | | |
| Metals (Cd, Cr, Cu, Ni, Pb, Zn) & As | 🟦 | | | |
| Metals (Hg) | 🟧 | | | |
| Most Semi-Volatile Organic Compounds (SVOCs) | ⬜ | | | |
| SVOCs (DDT and Tributyl Tin) | 🟧 | | | |

## ESTUARY CONDITION AND ISSUES

The results indicate that the highly modified Waikawa Estuary expressed few eutrophication and muddiness symptoms, had a relatively balanced macroinvertebrate community, and the presence of high value seagrass beds. Toxicants that typify urban stormwater discharges (e.g. Cu, Pb, Zn and PAHs) were only present in low concentrations and posed no toxicity threat to aquatic life. Elevated sediment concentrations of mercury, DDT and tributyl tin showed historic toxicant inputs exceeded thresholds used to indicate potential toxic impacts to benthic biota.

## RECOMMENDED MONITORING AND MANAGEMENT

Waikawa Estuary is a relatively small and highly modified tidal delta estuary, with high cultural significance to Te Ātiawa o Te Waka-a-Māui, and high human use ecological values. It has therefore been identified by MDC as a priority for monitoring. To support management decisions, a combined approach of broad and fine scale monitoring is applied to provide robust information on current estuary condition and trends over time. The following monitoring recommendations are proposed by Wriggle for consideration by MDC. Repeat fine scale sampling at 5 yearly intervals in conjunction with broad scale habitat mapping (next scheduled for 2021).

# 1. INTRODUCTION

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 Marlborough District Council's State of the Environment Estuary monitoring programme. Recently, Marlborough District Council (MDC) prepared a coastal monitoring strategy which established priorities for a long-term coastal and estuarine monitoring programme (Tiernan 2012). The assessment identified Waikawa Estuary as a priority for monitoring.

The estuary monitoring 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 estuaries in the region to major issues (see Table 1) and appropriate monitoring design. To date, neither estuary specific nor region-wide EVAs have been undertaken for the Marlborough region and therefore the vulnerability of Waikawa to issues has not yet been fully assessed. However, recent reports have documented selected ecologically significant marine sites in Marlborough (Davidson et al. 2011) and summarised known pressures, state, and trends of environmental health in Picton Bays (Newcombe and Johnston 2016).
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 Waikawa Estuary was undertaken first in 2016 (Stevens and Robertson 2016).
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 Waikawa Estuary, was undertaken first in 2016 and is the subject of this report.

In 2015, MDC commissioned Wriggle Coastal Management to undertake fine scale baseline monitoring of Waikawa Estuary in Queen Charlotte Sound. The current report provides fine scale monitoring results for sampling undertaken on 18 January 2016.

Waikawa Estuary is a small (3.4ha), highly-modified, shallow, well-flushed, seawater-dominated, meso-tidal (tidal range ~1m), river delta type estuary that opens via a wide mouth to Waikawa Bay in Queen Charlotte Sound. The estuary catchment is predominantly regenerating coastal forest (previously logged) with urban and commercial/industrial development in the lower reaches, and it is not considered particularly susceptible to either sediment accumulation or eutrophication effects because of its open coastal nature and strong tidal flushing.

Historically the estuary encompassed the entire head of Waikawa Bay and covered approximately 10ha, with the Waikawa Stream discharging to the estuary via two main branches, one to the east and one to the west. Alluvial deposits built up on the seaward margins of the main freshwater inflows and comprised a range of sediment sizes from fine silts to 100mm pebbles (Stephenson 1977). Although the estuary is relatively well sheltered, Waikawa Bay is exposed to north-north-east winds and has a fetch of 5-7kms, and wind-driven waves from this direction influence the estuary makeup. Wave action sorts sediments to create an exposed berm and fan of coarse material on the upper foreshore area by removing fines and depositing them in the lower tidal reaches. The deposited fines then establish a relatively uniform pattern consisting of an intermediate strip of unvegetated intertidal sand and mud flats on the upper flats, with extensive beds of seagrass (*Zostera*) lower in the tidal range, and below this, coarser sands in lower intertidal tidal and shallow subtidal zone. Regular exposure to small waves from ferry, ship and boat wakes which travel into the head of the bay contribute to ongoing sediment sorting.

Although much modified by the development of the Waikawa marina, the same broad sequence of estuary habitat described above is still apparent. The marina displaced the entire western part of the estuary, and diverted the western branch of Waikawa Stream into the eastern branch. This combined stream is now straightened and channelised (primarily for flood management purposes), and flows through residential developments and out along the marina's eastern mole reclamation where it discharges into Waikawa Estuary (Figure 1). The flood delta of Waikawa Stream has extensive deposits of coarse material that deposit on the western edge of the estuary (true right of the Waikawa Stream channel) to create a raised bar that channels most of the flow into the bay. The main freshwater influence on the estuary flats is from a small unnamed side stream ('Centre' Stream) that flows from the south across the predominantly sandy intertidal flats of the estuary. The remainder of the upper estuary margin is highly modified and provides little direct public access to the estuary.

In terms of human values, the 2012 Deed of Settlement of Historic Claims specifically addresses the very high cultural value to Te Ātiawa o Te Waka-a-Māui of Waikawa Estuary and its surrounds. More recent values are associated with residential housing and commercial activities (e.g. boat haul out and wharf to the east, marina and associated facilities including accommodation to the west). The estuary provides obvious amenity and aesthetic value, as well as providing important ecological habitat.

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

### 1. Fine Sediment

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly 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 2007a, 2010b, 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/Biomass | 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 Potential 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" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (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 the same 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 and overseas estuary data and presented in the NZ estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). 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 condition thresholds or ratings used for the Waikawa Estuary fine scale monitoring programme are summarised in Table 2, with detailed background notes explaining the use and justifications for each indicator presented in the NZ ETI (Robertson et al. 2016a and 2016b). The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of estuaries throughout NZ. Work to refine and document these relationships is ongoing.

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

| **RISK INDICATOR RATINGS / ETI BANDS** (indicate risk of adverse ecological impacts) | | | | |
|---|---|---|---|---|
| **INDICATOR** | Very Low Risk - Band A | Low Risk - Band B | Moderate Risk - Band C | High Risk - Band D |
| **Apparent Redox Potential Discontinuity (aRPD)**** | Unreliable | Unreliable | 0.5-2cm | <0.5cm |
| **Redox Potential (mV) upper 3cm***** | >+100 | -50 to +100 | -50 to -150 | >-150 |
| **Sediment Mud Content (%mud)*** | <5% | 5-10% | >10-25% | >25% |
| **Macroinvertebrate Enrichment Index (NZ AMBI) ****** | 0-1.0<br>None to minor stress on benthic fauna | >1.0-2.5<br>Minor to moderate stress on fauna | >2.5-4.0<br>Moderate to high stress on fauna | >4.0<br>Persistent, high stress on benthic fauna |
| **Total Organic Carbon (TOC)*** | <0.5% | 0.5-<1% | 1-<2% | >2% |
| **Total Nitrogen (TN)*** | <250mg/kg | 250-1000 mg/kg | >1000-2000 mg/kg | >2000 mg/kg |
| **Metals** | <0.2 x ISQG Low | 0.2 - 0.5 x ISQG Low | 0.5 x to ISQG Low | >ISQG Low |

*NZ ETI (Robertson et al. 2016b), **Hargrave et al. (2008), ***Robertson (2016), Keeley et al. (2012), ****Robertson et al. (2016).

# 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 (Redox Potential Discontinuity depth - aRPD or RPmV), Grain size (% mud, sand, gravel).
- Organic Matter and Nutrients: Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP).
- Heavy metals and metalloids: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), Zinc (Zn), mercury (Hg) and arsenic (As).
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: these are measured in certain estuaries where a risk has been identified.

For the Waikawa Estuary, one fine scale sampling site (Site A, Figure 1) was selected in the mid-low water, seagrass zone, the most sensitive high value intertidal habitat type within the estuary. At the site a 15m x 30m area was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and the following sampling undertaken:

### Physical and chemical analyses

- Within each plot, one random core was collected to a depth of at least 100mm and photographed alongside a ruler. 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 chilly bin in the field.
- 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 and As), and semi-volatile organic compounds (SVOCs). Analyses were based on whole sample fractions. Organic compounds are 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.

### Infauna (animals within sediments) and epifauna and epiflora (surface-dwelling animals and plants)

- From each of 10 plots 1 randomly placed sediment core (130mm diameter (area = $0.0133m^2$) tube) was taken.
- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled 0.5mm nylon mesh bag. Once all replicates had been collected at a site, the bags were transported to a nearby source of seawater and fine sediments were washed from the core. 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 sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).
- Conspicuous epifauna and epiflora visible on the sediment surface within the 15m x 30m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epibiota species are identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix 1), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Table B, Appendix 1). Species size or growth form determines both the quadrat size and SACFOR density rating applied, while photographs are taken and archived for future reference. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal and microalgal cover.

# 3. Methods (continued)

Waikawa Estuary
Base Photos: LINZ Dec 2011
Estuary Clip: MDC 2013

Figure 1. Waikawa Estuary - location of fine scale monitoring sites.

# 4. RESULTS AND DISCUSSION

A summary of the results of the 18 January 2016 fine scale intertidal monitoring of Waikawa Estuary is presented in Table 3, with detailed results in Appendices 2 and 3. Analysis and discussion of the results are presented as two main steps; firstly, exploring the primary environmental variables that are most likely to be driving the ecological response in relation to the key issues of sedimentation, eutrophication and toxicity, and secondly, investigating the biological response using the macroinvertebrate community.

**Table 3. Summary of fine scale physical, chemical, plant growth and macrofauna results (means), Waikawa Estuary, January 2016.**

| Site | aRPD | Salinity | TOC | Mud | Sand | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | As | Hg | TN | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | ppt | % | | | | mg/kg | | | | | | | | | |
| 2016 A | 1.5 | 33 | 0.63 | 24.6 | 73.1 | 2.3 | 0.042 | 10.5 | 26.3 | 7.2 | 18.9 | 55.0 | 3.2 | 0.202 | 533 | 227 |

| Site | Seagrass Cover | Macoalgal Cover | Macrofauna Abundance | Macrofauna Richness |
|---|---|---|---|---|
| | (%) | (%) | Individuals/m$^2$ | Species/core |
| 2016 A | 80-100% cover | <5% | 3,285 | 9.9 |

Data for semi-volatile organic compounds are presented in Appendix 3.

## ENVIRONMENTAL VARIABLES

The primary environmental variables that are most likely to be influencing the ecological response in relation to the key potential issues of sedimentation, eutrophication and toxicity are as follows:

- For sedimentation or sediment muddiness, the variables are sediment mud content (often the primary controlling factor) and sedimentation rate.
- For eutrophication, the primary variable is macroalgal biomass and is supported by measures of organic matter (measured as TOC), nutrients, sediment RPD depth (either directly measured ORP, or aRPD, a qualitative measure of both available oxygen and the presence of eutrophication related toxicants such as ammonia and sulphide) (Dauer et al. 2000, Magni et al. 2009) and seagrass cover.
- The influence of non-eutrophication related toxicity is primarily indicated by concentrations of heavy metals, with organic toxicants (e.g. DDT) are generally only assessed where inputs are likely, or metal concentrations are found to be elevated.

**Typical muddy sand low tide sediments Site A**

**Typical high water coarse sediments**

# 4. Results and Discussion (continued)

## 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 are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island), unless they are naturally erosion-prone with few wetland filters (e.g. Whareama Estuary, Wairarapa). 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%).

The January 2016 monitoring results showed that Waikawa Estuary Site A had moderate sediment mud contents (21-26% mud) indicative of a “moderate” ecological risk rating (Table 3, Figure 2).

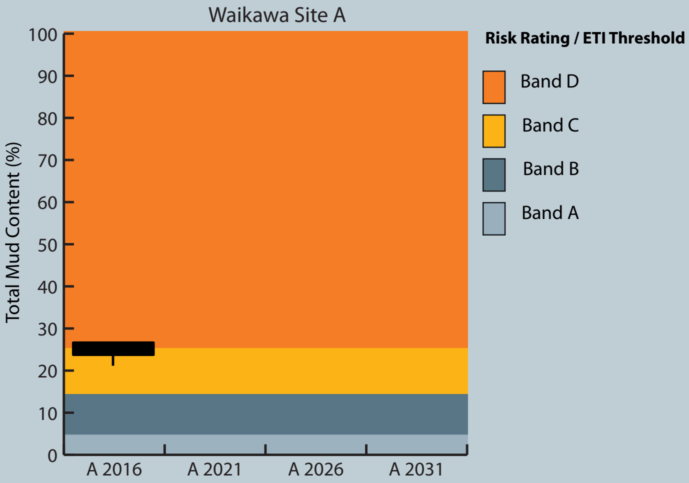


**Figure 2. Mean mud content (median, interquartile range, total range, n=3), Jan. 2016.**

**Close-up of sediment at 2-4cm depth Site A**

## EUTROPHICATION INDICATORS

The variables used to assess eutrophication impacts are macroalgae, sediment mud content, aRPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and seagrass.

### Macroalgae

A primary symptom of estuary eutrophication is the growth of opportunistic macroalgae which are highly effective at utilising excess nitrogen. When present at nuisance levels it can adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh.

The presence of <5% cover of macroalgae (*Gracilaria chilensis, Ulva lactuca*) at Site A, combined with the other eutrophication indicators, indicates a low expression of primary eutrophication symptoms.

### Sediment Grain Size (% Mud)

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, the moderate mud contents, and hence lowered sediment permeability at Site A indicate sediment oxygenation is likely to be moderately reduced.

### Apparent Redox Potential Discontinuity (aRPD)

The depth of the aRPD boundary indicates the extent of oxygenation within sediments. Currently, a condition rating for the direct measurement of redox potential is under development (Robertson et al. 2016b). Initial findings indicate that the recommended NZ estuary aRPD and redox potential thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Table 2 and Figure 3).

The 2016 results show that the mean aRPD depth was 1-2cm at Site A, indicating a “moderate” risk of ecological impacts (Figure 3).

# 4. Results and Discussion (continued)

Typical sediment core at Site A showing shallow RPD layer and seagrass at the surface

## Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and 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 NZ AMBI biotic coefficient (see the following macroinvertebrate condition section)], then elevated TN, TP and TOC concentrations provide strong supporting information to indicate that loadings are exceeding the assimilative capacity of the estuary.

The 2016 results for Site A showed TOC (<0.7%) and TN (<600mg/kg) were in the "low" ecological risk indicator rating, while TP (rating not yet developed) was relatively low at 210-250mg/kg (Figures 4, 5 and 6).

## Seagrass

Where present the extent of seagrass (*Zostera muelleri*) on the sediment surface acts to mitigate or offset the negative symptoms of eutrophication and muddiness by:

- enhancing sediment oxygenation through diffusion of oxygen from the seagrass roots,
- trapping and stabilising the sediment to improve water clarity and erosion,
- providing food and habitat for biota,
- absorbing nutrients and slowing water flow,
- reducing toxic effects of sulphides when present at low-moderate concentrations (high sulphide concentrations reduce seagrass production or are lethal to seagrass).

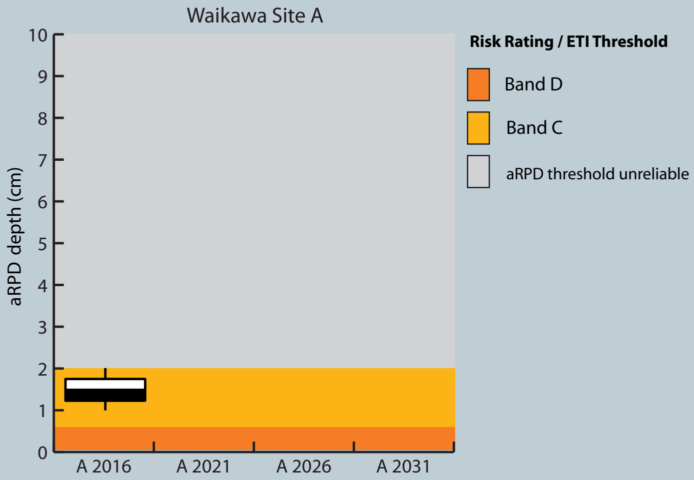


Figure 3. Mean aRPD depth, (median, interquartile range, total range, n=3), Jan. 2016.

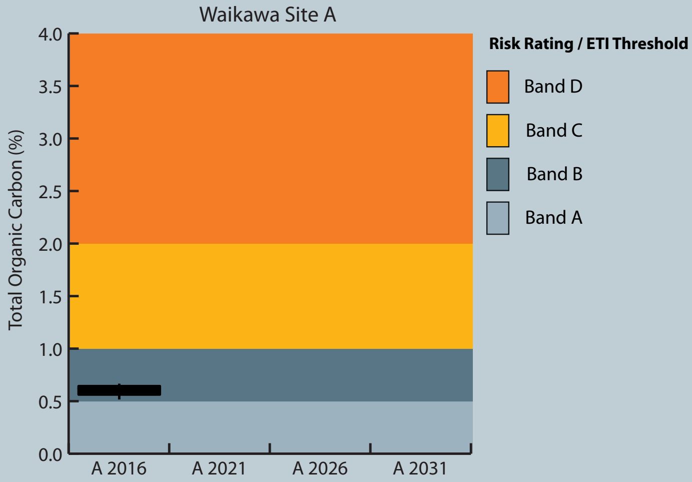


Figure 4. Mean total organic carbon (median, interquartile range, total range, n=3), Jan. 2016.

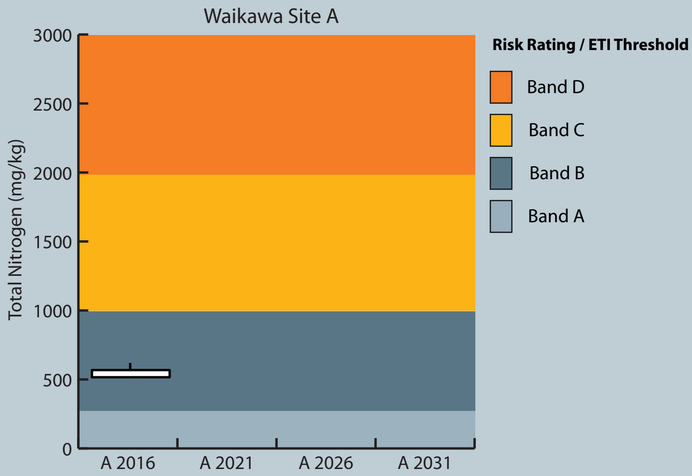
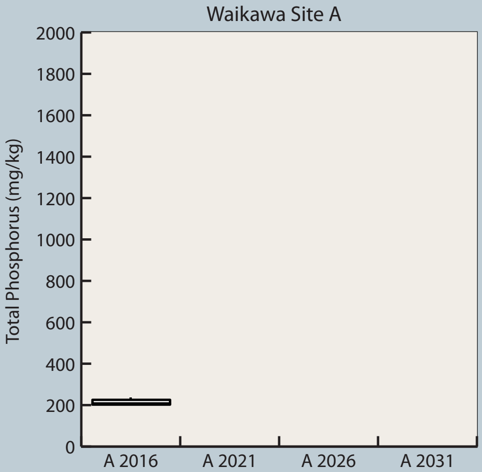


Figure 5. Mean total nitrogen (median, interquartile range, total range, n=3), Jan. 2016.

# 4. Results and Discussion (continued)

In relation to estuarine benthic ecology, the presence of healthy seagrass beds is therefore expected to result in a more diverse macroinvertebrate community (including taxa sensitive to mud and organic enrichment) than would be found in non-vegetated sites. However, it is also well-known that certain mud-related conditions can cause loss of seagrass beds; for example, when the water clarity is reduced to a level that limits light to the beds, or the mud content becomes too high causing the beds to become unstable and erode (Wolanski 2013). Clearly, such loss is more likely where exposure to bed stress is most prevalent, particularly shallow intertidal areas exposed to wind and wave turbulence.



**Risk Rating / ETI Threshold**
Undeveloped given phosphorus is not usually limiting to eutrophication in estuaries

**Figure 6. Mean total phosphorus (median, interquartile range, total range, n=3), Jan. 2016.**

The presence of 80-100% cover of seagrass (*Zostera muelleri*) at Site A in Waikawa Estuary, combined with the results for other eutrophication indicators, indicates the likely presence of a diverse ecological community.

Overall, the results for the sediment and eutrophication environmental variables indicate that the sediment conditions were moderately muddy, with low expression of eutrophication symptoms.

### TOXICITY INDICATORS

In 2016, the metals Cd, Cr, Cu, Ni, Pb, Zn, and the metalloid As used as indicators of potential toxicants, were present at "very low" to "low" concentrations with all total metal concentrations below the revised ANZECC (2000) ISQG-Low trigger values (Simpson et al. 2013) (Table 4), and therefore posed no toxicity threat to aquatic life.

**Table 4. Sediment metal concentrations (excluding gravel fraction), Jan. 2016.**

| Year/Site/Rep | Cd | Cr | Cu | Ni | Pb | Zn | As | Hg |
|---|---|---|---|---|---|---|---|---|
| | mg/kg | | | | | | | |
| Jan 2016 A 1-4 * | 0.037 | 11.2 | 29.8 | 7.7 | 18.8 | 55.4 | 3.7 | 0.106 |
| Jan 2016 A 4-8 * | 0.048 | 11.5 | 22.6 | 7.9 | 16.8 | 56.4 | 3.4 | 0.179 |
| Jan 2016 A 9-10 * | 0.045 | 9.7 | 28.7 | 6.6 | 22.6 | 57.5 | 2.8 | 0.339 |
| **Condition Thresholds** (ANZECC 2000 criteria, risk ratings Very Low, <0.2 x ISQG Low; Low, 0.2 - 0.5 x ISQG Low; Moderate, 0.5 x to ISQG Low; High, >ISQG Low) | | | | | | | | |
| [a] Band A Very Low Risk | <0.3 | <16 | <13 | <4.2 | <10 | <40 | <4 | <0.03 |
| [a] Band B Low Risk | 0.3 - 0.75 | 16 - 40 | 13 - 32.5 | 4.2 - 10.5 | 10 - 25 | 40 - 100 | 4 - 10 | 0.03 - 0.075 |
| [a] Band C Moderate Risk | 0.75 - 1.5 | 40 - 80 | 32.5 - 65 | 10.5 - 21 | 25 - 50 | 100 - 200 | 10 - 20 | 0.075 - 0.15 |
| [a] Band D High Risk | >1.5 | >80 | >65 | >21 | >50 | >200 | >20 | >0.15 |
| [b] ISQG-Low | 1.5 | 80 | 65 | 21 | 50 | 200 | 20 | 0.15 |
| [b] ISQG-High | 10 | 370 | 270 | 52 | 220 | 410 | 70 | 1 |

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

The normalised concentrations indicate that most analytes were found to be less than the analytical detection limits and the revised ANZECC sediment guidelines (Simpson et al. 2013). Sneddon (2010) also reported Waikawa Bay SVOCs and metals (Cr, Cu,Ni, Pb, Zn) at concentrations below ISQG-Low trigger values. However the ANZECC guidelines were exceeded for the following potentially toxic contaminants within Waikawa Estuary (Table 5, see also following page):

**Table 5. SVOCs (DDT and TBT) exceeding ANZECC criteria, Jan. 2016.**

| Organic Chemical | 2,4'-DDD + 4,4'-DDD | 4,4'-DDE | Total DDT Isomers | Tributyltin (as Sn) |
|---|---|---|---|---|
| [a] Normalised to 1% TOC | 0.0051 | 0.0029 | 0.0111 | 0.0095 |
| [b] ISQG-Low | 0.0035 | 0.0014 | 0.0012 | 0.0090 |
| [b] ISQG-High | 0.0090 | 0.0070 | 0.0050 | 0.0700 |

*Composite samples [a] Approximate ecological risk ratings (high risk corresponding with the ISQG-Low trigger) based on [b]. [b] Revised ANZECC (2000) criteria (Simpson et al. 2013): < ISQG-Low indicates the frequency of adverse effects is very low. > ISQG-High concentration indicates adverse biological effects are expected to occur more frequently.

- **Mercury** was historically a constituent in many herbicides, fungicides and antifouling agents, but is no longer used in these products. As there are no obvious current likely sources of mercury to the estuary, its exceedance of the ISQG Low value is likely related to these historical inputs. Mercury is a persistent contaminant known to bioaccumulate and poses a health issue at high concentrations.
- **Total DDT** (i.e. DDT plus its two breakdown metabolites DDD and DDE) exceeded the ISQG High value (indicating a high potential for toxicity effects). DDT is a highly persistent organochlorine pesticide, is readily adsorbed to soils and sediments, and because of its lipophilic properties, can bioaccumulate, especially in predatory birds. 'Booster' agents such as DDT, organomercurial, organolead and arsenical compounds were used in antifouling paints in the 1950's, but were subsequently withdrawn from use in the early 1960's. Agricultural DDT use effectively ceased in the 1970's, and was banned in urban areas in the late 1980s. However, because of its of its persistence (tentative half life can range from 22 days to 30 years), substantial sources of DDT remain in the NZ environment and are carried into the waterways in stormwater and agricultural runoff (Stephenson et al. 2008). Ongoing inputs of DDT to the estuary from streambed sediments, earthworks and land runoff are therefore possible. The presence of detectable DDT and the DDT breakdown products DDD and DDE indicates that historic inputs of DDT are degrading into less toxic forms.
- **Organotins** are highly toxic and persistent contaminants sourced (in a marine sediment context) almost certainly from marine antifouling paints where they were historically included as a biocide. While organotins were banned on recreational vessels in NZ in 1988, and a global ban of the use of organotin compounds in anti-fouling paints entered into force under the IMO International Convention on the Control of Harmful Anti-fouling Substances in September 2008, they are slow to degrade. The half-life of TBT in aerobic sediments has been estimated to be 2.5–3 years (de Mora et al. 1995), but may be tens of years in anaerobic sediments (Dowson et al. 1996). Because TBT degrades to DBT (a less toxic form), the ratio of DBT:TBT can be used to indicate degradation progress. Low ratios are assumed to be indicative of 'fresh' inputs of TBT (e.g. Michel et al., 2001, Stewart 2002), and high ratios indicate degradation of past inputs i.e. no fresh source. The current results show a DBT:TBT ratio of 1.5, indicating degradation is occurring in the absence of fresh inputs. This is consistent with previous results from the estuary (Stewart 2002) and bans on marine TBT use.

## BENTHIC MACROINVERTEBRATE COMMUNITY

Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong primary linkage to sediments and secondary linkage to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987, Robertson et al. 2016). Because they integrate recent pollution history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macroinvertebrates to stressors in Waikawa Estuary will be analysed in detail once sufficient baseline monitoring data is available. This analysis will include four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (v.6) package will be used to evaluate and compare the relative importance of different environmental factors and their influence on the identified macrobenthic communities.
3. Assessment of species richness, abundance, diversity and major infauna groups.
4. Assessment of the response of the macroinvertebrate community to increasing mud and organic matter among fine scale sites over time, based on identified tolerance thresholds for NZ taxa (NZ AMBI, Robertson et al. 2015, Robertson et al. 2016).

At this stage, with only one year of monitoring data, this section of the report will present and interpret data in relation to steps 3 and 4 only.

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

In this step, simple univariate whole community indices, i.e. species richness, abundance and diversity at each site (Figure 7) are presented for each site, and in the future when more data is available, will be used to help explain any differences between years indicated by other analyses.

The Site A 2016 data showed moderate species richness (7-18 per core), abundance (24-63 per core) and Shannon diversity (0.8-1.4). Figure 8 shows that the community at Site A was dominated by bivalves and polychaetes, but also included crustacea, gastropods, starfish, nemerteans and one burrowing anemone.

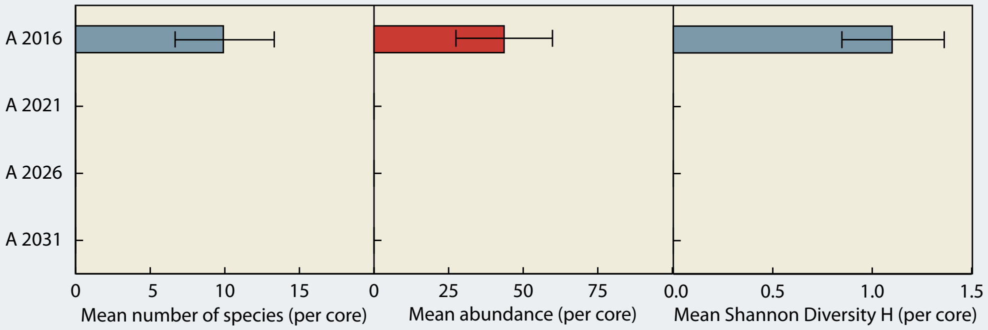


**Figure 7. Mean number of species, abundance, and Shannon Diversity index per core (±SE, n=10), Waikawa Estuary, Jan. 2016.**

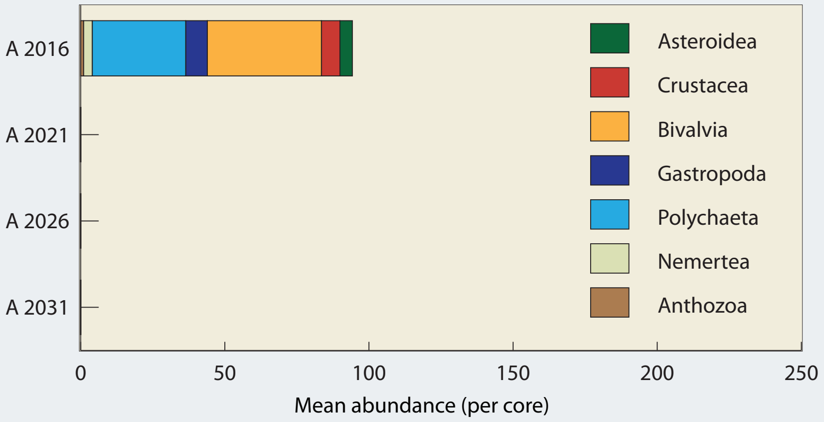


**Figure 8. Mean abundance of major infauna groups (n=10), Waikawa Estuary, Jan. 2016.**

### Macroinvertebrate Community in Relation to Mud and Organic Enrichment

### 1. Mud and Organic Enrichment Index (NZ AMBI)

This step is undertaken by using the NZ AMBI (Robertson et al. 2016), a benthic macroinvertebrate index based on the international AMBI approach (Borja et al. 2000) which includes several modifications to strengthen its responsive to anthropogenic stressors, particularly mud and organic enrichment as follows:

- integration of previously established, quantitative ecological group classifications for NZ estuarine macrofauna (Robertson et al. 2015),
- addition of a meaningful macrofaunal component (taxa richness), and
- derivation of classification-based and breakpoint-based thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents). The latter was used to evaluate the applicability of existing AMBI condition bands, which were shown to accurately reflect benthic condition for the >100 intertidal NZ estuarine sites surveyed: 2% to ~30% mud reflected a "normal" to "impoverished" macrofauna community, or "high" to "good" status; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an "unbalanced" to "transitional to polluted" macrofauna community, or "good" to "moderate" status; and >3% to 4% TOC reflected a "transitional to polluted" to "polluted" macrofauna community, or "moderate" to "poor" status.

In addition, the NZ AMBI was successfully validated ($R^2$ values >0.5 for mud, and >0.4 for total organic carbon) for use in shallow, intertidal dominated estuaries New Zealand-wide.

# 4. Results and Discussion (continued)

For the fine scale site in Waikawa Estuary, the NZ AMBI biotic coefficients ranged from 1.3-1.8 and were in the "good - community unbalanced" ecological condition category (Figure 9), which likely reflects the actions of the high seagrass cover at the site mitigating the negative effects of elevated mud concentrations.

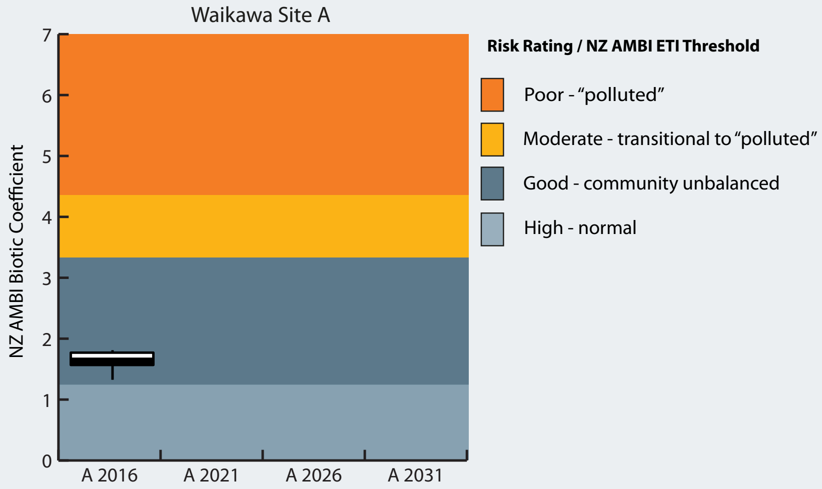


**Figure 9. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Waikawa Estuary, Jan. 2016.**

### 2. Individual Species

To further explore the macroinvertebrate community in relation to taxa sensitivities to mud and organic enrichment, a comparison was made of the mean abundances of individual taxa within the 5 major mud/enrichment tolerance groupings (i.e. "very sensitive to organic enrichment" group through to "1st-order opportunistic species" group) (Figure 10). The results clearly show that the groups with the highest numbers of taxa and abundances were the 3 most sensitive groups (i.e. Gps 1-3), which explains the low NZ AMBI scores for the site.

In terms of individual taxa, consistently high numbers of cockles (*Austrovenus stutchburyi*) and the spionid polychaete *Prionospio aucklandica*, as well as moderate numbers of pipi (*Paphies australis*) and wedge shells (*Tellina liliana*), were distributed throughout the site.

In addition, as could be expected from a site with moderate to high levels of muddiness, one or two taxa from the Grp 4 and 5 sensitivity groupings (i.e. "tolerant" and "very tolerant to mud and organic enrichment " respectively) were present.

Fine scale Site A showing pipi and cockle

Fine scale Site A showing typical seagrass cover

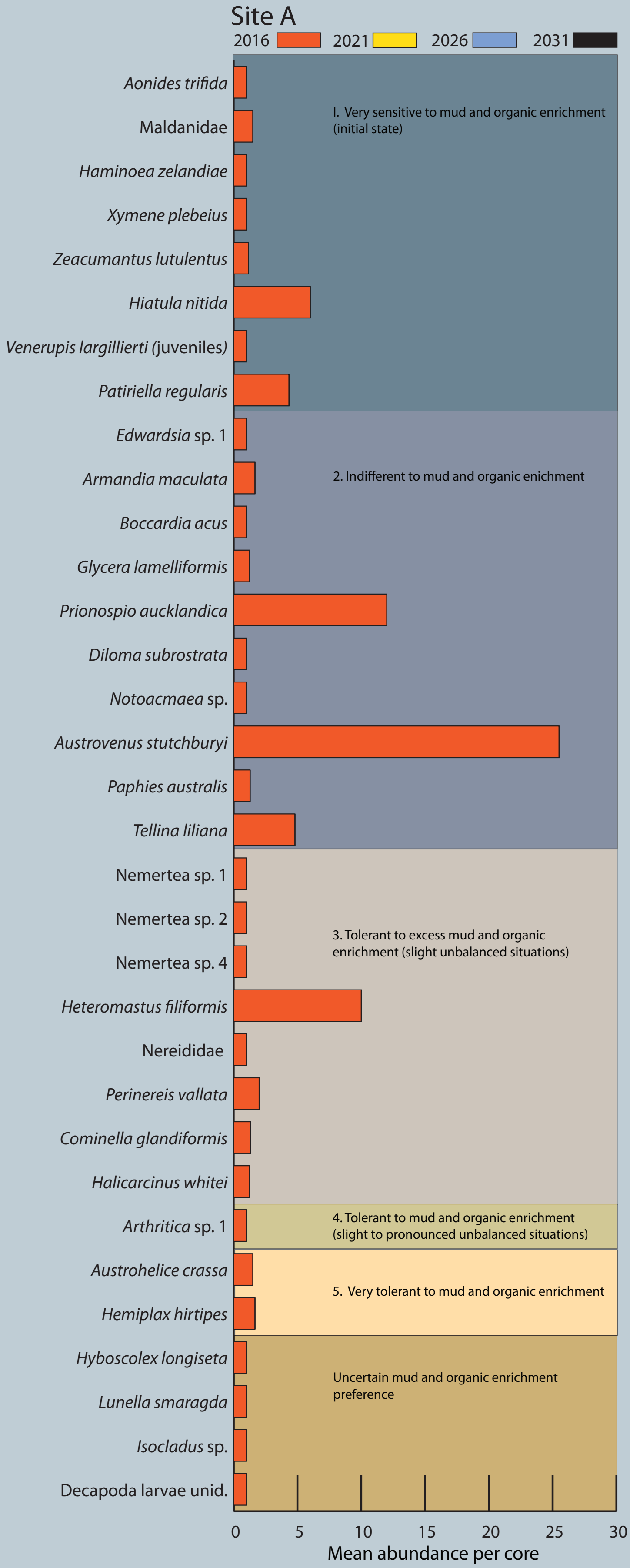


**Figure 10. Mud and organic enrichment sensitivity of macroinvertebrates, Waikawa Estuary, Jan. 2016 (see Appendix 3 for sensitivity details).**

# 5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for the long term intertidal monitoring site within Waikawa Estuary in January 2016, showed the following key findings:

**Physical and Chemical Condition**

- Macroalgae was <5% at the fine scale site, and was relatively uncommon in the estuary generally (Stevens and Robertson 2016), indicating low levels of eutrophication.
- Sediment mud content (mean 25% mud) and sediment oxygenation (aRPD 1-2cm) were indicative of a "moderate risk of ecological impacts".
- Sediment organic matter and nutrient concentrations were rated "low" (TOC <0.7% and TN <600mg/kg i.e. "low-moderate risk of ecological impacts"), while TP was unrated but relatively low at 210-250mg/kg.
- Sediment toxicants, heavy metals (Cd, Cr, Cu, Pb, Ni, Zn), the metalloid arsenic (As), and most semi-volatile organic compounds, were at concentrations that were not expected to pose toxicity threats to aquatic life. However the ANZECC Low trigger guideline was exceeded for the heavy metal mercury (historically used in antifouling paints), as well as the antifouling biocide tributyl tin (banned in NZ on recreational vessels in 1988 and internationally in 2008). In addition, the highly persistent organochlorine pesticide DDT (also used in antifoulants, and banned from NZ in 1989), and its two breakdown products, DDD and DDE, was present at levels exceeding the ISQG High trigger guideline (i.e. high toxicity risk level).
- Seagrass (*Zostera muelleri*) cover was high (80-100%) which, combined with the other eutrophication indicators, indicates the likely presence of a diverse ecological community.

**Biological Condition**

The macroinvertebrate community consisted of a mixed assemblage of species, dominated by bivalves and polychaetes. In terms of mud and organic enrichment, the NZ AMBI scores (range 1.3-1.8 at Site A) indicated a community dominated by both sensitive, and moderately tolerant taxa and overall good ecological condition with respect to these potential stressors. These good scores likely reflect the actions of the high seagrass cover at the site mitigating the negative effects of elevated mud concentrations.

The results indicate that the highly modified Waikawa Estuary expressed few eutrophication and muddiness symptoms, had a relatively balanced macroinvertebrate community, and the presence of high value seagrass beds. Toxicants that typify urban stormwater discharges (e.g. Cu, Pb, Zn and PAHs) were only present in low concentrations and posed no toxicity threat to aquatic life. Elevated sediment concentrations of mercury, DDT and tributyl tin showed historic toxicant inputs exceeded thresholds used to indicate potential toxic impacts to benthic biota.

**Waikawa Estuary (eastern margin)**

# 6. MONITORING

## MONITORING

Waikawa Estuary is a relatively small and highly modified tidal delta estuary, with high cultural significance to Te Ātiawa o Te Waka-a-Māui, and high human use and ecological values. It has therefore been identified by MDC as a priority for monitoring. However it is not considered particularly susceptible to either sediment accumulation or eutrophication effects because of its open coastal nature and strong tidal flushing.

To support management decisions, a combined approach of broad and fine scale monitoring is applied to provide robust information on current estuary condition and trends over time. The present report addresses the fine scale intertidal component of the long term programme, with the following monitoring recommendations proposed by Wriggle for consideration by MDC:

### Fine Scale Monitoring

Three years of annual monitoring is commonly recommended to establish a robust baseline against which future change can be measured. In this instance the January 2016 fine scale intertidal monitoring results identified legacy contaminants (i.e. Hg, TBT and DDT) as the primary fine scale issue in the estuary. Because of their high affinity with fine sediments, and the relatively small extent of intertidal mud in the estuary (8%), and the low susceptibility of the estuary to sediment accumulation or eutrophication effects, it is recommended that fine scale intertidal monitoring be repeated 5 yearly.

### Broad Scale Habitat Mapping

As addressed separately by Stevens and Robertson (2016), it is recommended that broad scale habitat mapping be undertaken at 5-10 yearly intervals unless obvious changes are observed in the interim (next scheduled for consideration in 2021).

## MANAGEMENT

Using the results of the above investigations, it is recommended that the Council identify, through stakeholder involvement, an appropriate "target" estuary condition and determine management strategies to maintain or achieve the target condition.

# 7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with the support and assistance of Steve Urlich (Coastal Scientist, MDC). His review of this report was much appreciated. Many thanks also to Ian Shapcott (Te Atiawa Trust) for sharing his time and thoughts on Waikawa Estuary.

Waikawa Estuary at high tide (view looking toward Waikawa Stream).

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# APPENDIX 1. DETAILS ON ANALYTICAL METHODS

## 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 |
| >80 | S | - |
| 40-79 | A | S |
| 20-39 | C | A |
| 10-19 | F | C |
| 5-9 | O | F |
| 1-4 | R | O |
| <1 | - | R |

| SACFOR Category |
|---|
| S = Super Abundant |
| A = Abundant |
| C = Common |
| F = Frequent |
| O = Occasional |
| R = Rare |

- 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 | 0.25$m^2$ | 1.0$m^2$ | 10$m^2$ | 100$m^2$ | 1,000$m^2$ |
| <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 |

## Sediment analyses

| Indicator | Lab. | Method | Detection Limit |
|---|---|---|---|
| Infauna Sorting and ID | CMES | Coastal Marine Ecology Consultants (Gary Stephenson)*. | N/A |
| Dry Matter (Env) | R.J Hill | Dried for 16 hours at 103°C (removes 3-5% more water than air dry). | 0.10 g/100g as rcvd |
| 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, SPE cleanup, GPC cleanup (if required), dual column GC-ECD. | 0.0010-0.006 mg/kg dry wgt |
| Polycyclic Aromatic Hydrocarbons | R.J Hill | Sonication extraction, SPE cleanup, GC-MS SIM analysis US EPA 8270C. [KBIs:5784,4273,2695]. | 0.002-0.010 mg/kg dry wgt |
| Semivolatile Organic Compounds | R.J Hill | Sonication extraction, GPC cleanup (if required), GC-MS FS analysis. | 0.3-30 mg/kg dry wgt |
| Tributyl Tin | R.J Hill | Solvent extraction, ethylation, SPE cleanup, GC-MS SIM analysis. | 0.003-0.007 mg/kg dry wgt |
| Total Petroleum Hydrocarbons | R.J Hill | Sonication extraction in DCM, Silica cleanup, GC-FID analysis. US EPA 8015B/MfE Petroleum Industry Guidelines. [KBIs:5786,2805,10734] | 8-60 mg/kg dry wt |

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

# APPENDIX 2. 2015/16 DETAILED RESULTS

## Fine Scale Site Boundaries

| **Whangarae Site A** | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| NZTM EAST | 1687096 | 1687097 | 1687127 | 1687126 |
| NZTM NORTH | 5430967 | 5430952 | 5430956 | 5430971 |

## Fine Scale Station Locations

| **Waikawa Site A** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| NZTM EAST | 1687098 | 1687108 | 1687115 | 1687123 | 1687124 | 1687118 | 1687111 | 1687102 | 1687101 | 1687110 |
| NZTM NORTH | 5430965 | 5430964 | 5430964 | 5430969 | 5430962 | 5430961 | 5430962 | 5430959 | 5430954 | 5430957 |

## Seagrass (*Zostera muelleri*) Cover and Biomass at Site A, January 2016

| Year/Site/Rep | Seagrass Cover | Macoalgal Cover |
|---|---|---|
| | % | % |
| 2016 A 1-4 | 80-100 | <5 |
| 2016 A-4-8 | 80-100 | <5 |
| 2016 A-9-10 | 80-100 | <5 |

## Epifauna abundance and macroalgal cover at Site A, January 2016

| Group | Family | Species | Common name | Scale | Class | Site A |
|---|---|---|---|---|---|---|
| Bivalves | Veneridae | *Austrovenus stutchburyi* | Cockle | # | iii | A |
| Topshells | Buccinidae | *Cominella glandiformis* | Mudflat whelk | # | ii | F |
| | Trochidae | *Diloma subrostrata* | Grooved topshell | # | ii | C |
| | Haminoeidae | *Haminoea zelandiae* | Bubble shell | # | ii | R |
| | Buccinidae | *Zeacumantus lutulentus* | Spire shell | # | ii | C |
| Red algae | Gracilariaceae | *Gracilaria* sp. ?*secundata* | Gracilaria weed | % | ii | R |
| Green algae | Ulvaceae | *Ulva lactuca* | Sea lettuce | % | ii | R |

## Physical and Chemical Results for Waikawa Estuary (Site A), January 2016

| Year/Site/Rep | RPD | Salinity | TOC | Mud | Sand | Gravel | Cd | Cr | Cu | Ni | Pb | Zn | As | Hg | TN | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | ppt | % | | | | mg/kg | | | | | | | | | |
| Jan 2016 A 1-4 * | 1.8 | 33 | 0.55 | 20.9 | 75.4 | 3.7 | 0.036 | 10.9 | 29 | 7.5 | 18.3 | 54 | 3.6 | 0.103 | <500 | 210 |
| Jan 2016 A 4-8 * | 1.8 | 33 | 0.7 | 26.4 | 72.1 | 1.4 | 0.047 | 11.2 | 22 | 7.7 | 16.4 | 55 | 3.3 | 0.174 | 600 | 250 |
| Jan 2016 A 9-10 * | 1 | 33 | 0.65 | 26.4 | 71.9 | 1.7 | 0.044 | 9.5 | 28 | 6.4 | 22 | 56 | 2.7 | 0.33 | 500 | 220 |
| ISQG-Low [a] | - | - | - | - | - | - | 1.5 | 80 | 65 | 21 | 50 | 200 | 20 | 0.15 | - | - |
| ISQG-High [a] | - | - | - | - | - | - | 10 | 370 | 270 | 52 | 220 | 410 | 70 | 1 | - | - |

[a] ANZECC 2000. *composite samples.

# Appendix 2. 2015/16 Detailed Results (continued)

**Semi volatile organic compounds (SVOCs) in Waikawa Estuary, 2016 (normalised to 1% TOC).**

Note: results are for a single composite sample for each site (all reported as mg/kg d.w.). Revised ANZECC (2000) sediment criteria (see Simpson et al. 2013). ISQG Low and High values are reported where they are available (with exceedances of ISQG Low in Yellow and ISQG High in Red).

| GROUP | Organic Chemical | Site A (non normalised) | Site A (normalised to 1% TOC) | ANZECC ISQG Low | ANZECC ISQG High | Comment |
|---|---|---|---|---|---|---|
| **Organochlorine Pesticides** | *Aldrin* | < 0.0010 | < 0.0010 | | | |
| | *alpha-BHC* | < 0.0010 | < 0.0010 | | | |
| | *beta-BHC* | < 0.0010 | < 0.0010 | | | |
| | *delta-BHC* | < 0.0010 | < 0.0010 | | | |
| | *gamma-BHC (Lindane)* | < 0.0010 | < 0.0010 | 0.0009 | 0.0014 | |
| | *cis-Chlordane* | < 0.0010 | < 0.0010 | | | |
| | *trans-Chlordane* | < 0.0010 | < 0.0010 | | | |
| | *2,4'-DDD* | < 0.0010 | < 0.0010 | | | |
| | *4,4'-DDD* | 0.0032 | 0.0051 | | | |
| | *2,4'-DDD plus 4,4'-DDD* | 0.0032 | 0.0051 | 0.0035 | 0.009 | |
| | *2,4'-DDE* | < 0.0010 | < 0.0010 | | | |
| | *4,4'-DDE* | 0.0018 | 0.0029 | 0.0014 | 0.007 | |
| | *2,4'-DDT* | < 0.0010 | < 0.0010 | | | |
| | *4,4'-DDT* | 0.002 | 0.0032 | | | |
| | *Total DDT Isomers* | 0.007 | 0.0111 | 0.0012 | 0.005 | |
| | *Dieldrin* | < 0.0010 | < 0.0010 | 0.0028 | 0.007 | |
| | *Endosulfan I* | < 0.0010 | < 0.0010 | | | |
| | *Endosulfan II* | < 0.0010 | < 0.0010 | | | |
| | *Endosulfan sulphate* | < 0.0010 | < 0.0010 | | | |
| | *Endrin* | < 0.0010 | < 0.0010 | 0.0027 | 0.060 | |
| | *Endrin aldehyde* | < 0.0010 | < 0.0010 | | | |
| | *Endrin ketone* | < 0.0010 | < 0.0010 | | | |
| | *Heptachlor* | < 0.0010 | < 0.0010 | | | |
| | *Heptachlor epoxide* | < 0.0010 | < 0.0010 | | | |
| | *Hexachlorobenzene* | < 0.0010 | < 0.0010 | | | |
| | *Methoxychlor* | < 0.0010 | < 0.0010 | | | |
| | *Total Chlordane [(cis+trans)*100/42]* | < 0.002 | < 0.002 | 0.0045 | 0.009 | |
| **Polycyclic Aromatic Hydrocarbons** | *Acenaphthene* | < 0.003 | < 0.003 | 0.016 | 0.5 | |
| | *Acenaphthylene* | < 0.003 | < 0.003 | 0.044 | 0.64 | |
| | *Anthracene* | 0.008 | 0.0127 | 0.085 | 1.1 | |
| | *Benzo[a]anthracene* | 0.029 | 0.0460 | 0.261 | 1.6 | |
| | *Benzo[a]pyrene (BAP)* | 0.04 | 0.0635 | 0.43 | 1.6 | |
| | *Benzo[b]fluoranthene + Benzo[j] fluoranthene* | 0.045 | 0.0714 | | | |
| | *Benzo[g,h,i]perylene* | 0.026 | 0.0413 | | | |
| | *Benzo[k]fluoranthene* | 0.021 | 0.0333 | | | |
| | *Chrysene* | 0.029 | 0.0460 | 0.384 | 2.8 | |
| | *Dibenzo[a,h]anthracene* | 0.005 | 0.0079 | 0.063 | 0.26 | |
| | *Fluoranthene* | 0.071 | 0.1127 | 0.6 | 5.1 | |
| | *Fluorene* | < 0.003 | < 0.003 | | | |
| | *Indeno(1,2,3-c,d)pyrene* | 0.026 | 0.0413 | | | |
| | *Naphthalene* | < 0.011 | < 0.011 | | | |
| | *Phenanthrene* | 0.025 | 0.0397 | | | |
| | *Pyrene* | 0.062 | 0.0984 | 0.665 | 2.6 | |
| | *Total PAHs* | 0.39 | 0.619 | 10 | 50 | |

# Appendix 2. 2015/16 Detailed Results (continued)

## Semi volatile organic compounds (SVOCs) in Waikawa Estuary, 2016 (normalised to 1% TOC) (continued)

| GROUP | Organic Chemical | Site A (non normalised) | Site A (normalised to 1% TOC) | ANZECC ISQG Low | ANZECC ISQG High | Comment |
|---|---|---|---|---|---|---|
| **Phenols** | *4-Chloro-3-methylphenol* | < 5 | < 5 | | | |
| | *2-Chlorophenol* | < 1.0 | < 1.0 | | | |
| | *2,4-Dichlorophenol* | < 1.0 | < 1.0 | | | |
| | *2,4-Dimethylphenol* | < 3 | < 3 | | | |
| | *3 & 4-Methylphenol (m- + p-cresol)* | < 3 | < 3 | | | |
| | *2-Methylphenol (o-Cresol)* | < 1.0 | < 1.0 | | | |
| | *2-Nitrophenol* | < 5 | < 5 | | | |
| | *Pentachlorophenol (PCP)* | < 30 | < 30 | | | |
| | *Phenol* | < 1.0 | < 1.0 | | | |
| | *2,4,5-Trichlorophenol* | < 1.0 | < 1.0 | | | |
| | *2,4,6-Trichlorophenol* | < 1.0 | < 1.0 | | | |
| **Haloethers** | *Bis(2-chloroethoxy) methane* | < 0.5 | < 0.5 | | | |
| | *Bis(2-chloroethyl)ether* | < 0.5 | < 0.5 | | | |
| | *Bis(2-chloroisopropyl)ether* | < 0.5 | < 0.5 | | | |
| | *4-Bromophenyl phenyl ether* | < 0.5 | < 0.5 | | | |
| | *4-Chlorophenyl phenyl ether* | < 0.5 | < 0.5 | | | |
| **N Containing Compounds** | *2,4-Dinitrotoluene* | < 1.0 | < 1.0 | | | |
| | *2,6-Dinitrotoluene* | < 1.0 | < 1.0 | | | |
| | *Nitrobenzene* | < 0.5 | < 0.5 | | | |
| | *N-Nitrosodi-n-propylamine* | < 0.9 | < 0.9 | | | |
| | *N-Nitrosodiphenylamine + Diphenylamine* | < 0.9 | < 0.9 | | | |
| **Plasticizers (Phthalates)** | *Bis(2-ethylhexyl)phthalate* | < 5 | < 5 | | | |
| | *Butylbenzylphthalate* | < 1.0 | < 1.0 | | | |
| | *Di(2-ethylhexyl)adipate* | < 1.0 | < 1.0 | | | |
| | *Diethylphthalate* | < 1.0 | < 1.0 | | | |
| | *Dimethylphthalate* | < 1.0 | < 1.0 | | | |
| | *Di-n-butylphthalate* | < 1.0 | < 1.0 | | | |
| | *Di-n-octylphthalate* | < 1.0 | < 1.0 | | | |
| **Other Halogenated Compounds** | *1,2-Dichlorobenzene* | < 0.9 | < 0.9 | | | |
| | *1,3-Dichlorobenzene* | < 0.9 | < 0.9 | | | |
| | *1,4-Dichlorobenzene* | < 0.9 | < 0.9 | | | |
| | *Hexachlorobutadiene* | < 0.9 | < 0.9 | | | |
| | *Hexachloroethane* | < 0.9 | < 0.9 | | | |
| | *1,2,4-Trichlorobenzene* | < 0.5 | < 0.5 | | | |
| **Other Potentially Toxic Compounds** | *Benzyl alcohol* | < 10 | < 10 | | | |
| | *Carbazole* | < 0.5 | < 0.5 | | | |
| | *Dibenzofuran* | < 0.5 | < 0.5 | | | |
| | *Isophorone* | < 0.5 | < 0.5 | | | |
| **Total Petroleum Hydrocarbons** | *C7 - C9* | < 11 | < 11 | | | |
| | *C10 - C14* | < 30 | < 30 | | | |
| | *C15 - C36* | < 50 | < 50 | | | |
| | *Total hydrocarbons (C7 - C36)* | < 80 | < 80 | 280 | 550 | |
| **Tributyl Tin** | *Dibutyltin (as Sn)* | 0.009 | 0.0142 | | | |
| | *Monobutyltin (as Sn)* | < 0.007 | < 0.007 | | | |
| | *Tributyltin (as Sn)* | 0.006 | 0.0095 | 0.009 | 0.07 | |
| | *Triphenyltin (as Sn)* | < 0.003 | < 0.003 | | | |

# Appendix 2. 2015/16 Detailed Results (continued)

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

### Waikawa Estuary Site A, January 2016

| | Species | NZ AMBI | A-01 | A-02 | A-03 | A-04 | A-05 | A-06 | A-07 | A-08 | A-09 | A-10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ANTHOZOA | *Edwardsia* sp. 1 | 2 | | | | | | | | | | 1 |
| NEMERTEA | Nemertea sp. 1 | 3 | | | | | | | | 1 | 1 | 1 |
| | Nemertea sp. 2 | 3 | | | 1 | | | | | | | |
| | Nemertea sp. 4 | 3 | | | | | | | | | 1 | |
| POLYCHAETA | *Aonides trifida* | 1 | | | | | | | | | 1 | |
| | *Armandia maculata* | 2 | | 1 | | | | | | | 3 | 1 |
| | *Boccardia acus* | 2 | | | | | | | | | 1 | |
| | *Glycera lamelliformis* | 2 | | 1 | | | | | 1 | 2 | | 1 |
| | *Heteromastus filiformis* | 3 | | | | | | | | 10 | | |
| | *Hyboscolex longiseta* | NA | | | | | | | | 1 | | |
| | Maldanidae | 1 | | | 2 | | | | 1 | 1 | | 2 |
| | Nereididae | 3 | | | | | | | | | 1 | 1 |
| | *Perinereis vallata* | 3 | | | | | 3 | | | | 1 | 2 |
| | *Prionospio aucklandica* | 2 | | | | | | | | 12 | | |
| GASTROPODA | *Cominella glandiformis* | 3 | 1 | 3 | 1 | 1 | 1 | | | | 1 | |
| | *Diloma subrostrata* | 2 | | 1 | | 1 | 1 | | | 1 | 1 | |
| | *Haminoea zelandiae* | 1 | | | | | | 1 | | | | |
| | *Lunella smaragda* | NA | | | | | 1 | | | | 1 | |
| | *Notoacmaea* sp. | 2 | | | | | | | 1 | | 1 | |
| | *Xymene plebeius* | 1 | | 1 | | | | | | | | |
| | *Zeacumantus lutulentus* | 1 | 1 | 1 | | | 1 | 1 | | 1 | 2 | |
| BIVALVIA | *Arthritica* sp. 1 | 4 | | | | | | 1 | | | | |
| | *Austrovenus stutchburyi* | 2 | 36 | 39 | 11 | 9 | 9 | 45 | 47 | 26 | 18 | 15 |
| | *Hiatula (Soletellina) nitida* | 1 | | | | | | | 6 | | | |
| | *Paphies australis* | 2 | 1 | 1 | 1 | | | 2 | 1 | | 1 | 2 |
| | *Tellina liliana* | 2 | 2 | 3 | 6 | 6 | 3 | 8 | 4 | 5 | 5 | 6 |
| | *Venerupis largillierti* (juveniles) | 1 | | | | | 1 | | | 1 | 1 | |
| CRUSTACEA | *Austrohelice crassa* | 5 | | | | 2 | | 1 | | | | |
| | *Halicarcinus whitei* | 3 | 1 | | 1 | | | 2 | | 1 | | |
| | *Hemiplax hirtipes* | 5 | 1 | 2 | | 1 | | 1 | | 1 | 4 | |
| | *Isocladus* sp. | NA | | | 1 | | | | | | | |
| | Decapoda larvae unid. | NA | | | | | | | 1 | | | |
| ASTEROIDEA | *Patiriella regularis* | 1 | | | | 5 | 4 | | | | 4 | |
| **Total species in sample** | | | **7** | **10** | **8** | **7** | **9** | **9** | **8** | **13** | **18** | **10** |
| **Total individuals in sample** | | | **43** | **53** | **24** | **25** | **24** | **62** | **62** | **63** | **48** | **32** |

# APPENDIX 3. INFAUNA CHARACTERISTICS

| Group and Species | | NZ AMBI Group | Details |
|---|---|---|---|
| **Anthozoa** | *Edwardsia* sp.1 | 2 | A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions. |
| **Nemertea** | Nemertea sp. | 3 | Ribbon or proboscis worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions. |
| **Polychaeta** | *Aonides trifida* | 1 | Small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. *Aonides* is free-living, not very mobile and strongly prefers to live in fine sands; also very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds. |
| | *Armandia maculata* | 2 | Common subsurface deposit-feeding/herbivore, non-tube dwelling, Family Opheliidae. Found inter- and sub-tidally in bays and sheltered beaches. A good coloniser and explorer. |
| | *Boccardia acus* | 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. Very sensitive to organic enrichment and usually present under unenriched conditions. |
| | *Glycera lamelliformis* | 2 | Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15cm. 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 15cm, 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. |
| | *Hyboscolex longiseta* | 1 | A small polychaete of the Scalibregmatidae family called "red maggot" worm because of its dark wine red colouration. Burrows in soft sediments. |
| | Maldanidae | 1 | Bamboo worms are large, blunt-ended, cylindrical worms and feed as bulk consumers of sediment using a balloon-like proboscis. Most bamboo worms live below the surface in flimsy sediment tubes. They process copious amounts of sediment and deposit it in earthworm-like surface casts. |
| | Nereididae | 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. |
| | *Perinereis vallata* | 2 | An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers sandy, muddy sand, sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation. |
| | *Prionospio aucklandica* | 2 | Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was renamed to *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that is common at low water mark in harbours and estuaries. |

# Appendix 3. Infauna Characteristics (continued)

| Group and Species | | NZ AMBI Group | Details |
|---|---|---|---|
| **Gastropoda** | *Cominella glandiformis* | 3 | *Cominella glandiformis*, or the mud whelk or mud-flat whelk is a species of predatory sea snail, a marine gastropod mollusc in the family Buccinidae, the true whelks. 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 | The mudflat top shell, lives on sandflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ and feeds on the film of microscopic algae on top of the sand. Has a strong sand preference. |
| | *Haminoea zelandiae* | 1 | The white bubble shell, is a species of medium-sized sea snail or bubble snail, a marine opisthobranch gastropod mollusc in the family Haminoeidae, the bubble snails. This bubble snail is common on intertidal mudflats in sheltered situations associated with eel grass. This species is endemic to New Zealand. It is found around the North Island and the northern part of the South Island. Mud Tolerance; prefers 0-20% mud. |
| | *Lunella smaragda* | NA | *Lunella smaragda* (cats eye) is an endemic species found both at the intertidal and low subtidal rocky shores and soft substrates (including seaweeds) of New Zealand. |
| | *Notoacmea* spp. | 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. |
| | *Xymene plebeius* | 1 | Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds. |
| | *Zeacumantus lutulentus* | 2 | Belongs to the Family Muricidae, or murex snails, which are a large and varied taxonomic family of small to large predatory sea snails. |
| **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 which is a family of bivalves which are very sensitive to organic enrichment. 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 macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). |
| | *Hiatula (Soletellina) nitida* | 2 | Soletellina is a genus of bivalve molluscs in the family Psammobiidae, known as sunset shells. Intolerant of eutrophic or muddy conditions. |
| | *Paphies australis* | 2 | The pipi is endemic to NZ. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7m. Common at the mouth of Motupipi Estuary, Freshwater Estuary (<1% mud), a few at Porirua B (polytech) 5% mud. |

## Appendix 3. Infauna Characteristics (continued)

| Group and Species | | NZ AMBI Group | Details |
|---|---|---|---|
| **Bivalvia** | *Tellina 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. |
| | *Venerupis largillierti* | 1 | *Venerupis* is a genus of marine bivalve molluscs in the family Veneridae, commonly known as carpet shells. |
| **Crustacea** | *Austrohelice 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. |
| | Decapoda larvae unid. | NA | The decapods or Decapoda (literally means “ten footed”) are an order of crustaceans within the class Malacostraca, including many familiar groups, such as crayfish, crabs, lobsters, prawns and shrimp. Most decapods are scavengers. It is estimated that the order contains nearly 15,000 species in around 2,700 genera, with approximately 3,300 fossil species. Nearly half of these species are crabs, with the shrimps (~3000 species) and Anomura (including hermit crabs, porcelain crabs, squat lobsters: ~2500 species), making up the bulk of the remainder. |
| | *Halicarcinus whitei* | 3 | A species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments. |
| | *Hemiplax 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. Previously *Macrophthalmus hirtipes*. |
| | *Isocladus* sp. | NA | A common estuarine isopod. |
| **Asteroidea** | *Patiriella regularis* | 2 | A common starfish. |

* NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al. (2015).
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.

# Appendix 3. Macroinvertebrate QAQC

Macroinvertebrate sampling, sorting, identification and enumeration follows the general principles laid out in the protocol for processing, identification and quality assurance of New Zealand marine benthic invertebrate samples proposed by Hewitt et al. (2014). However, because the draft protocol does not address many important aspects for ensuring taxonomic consistency or required resolution, and provides limited explanation or support for many recommended procedures, Wriggle have instead adopted the following approach:

1. All sample processing follows the standard protocol guidance, and uses experienced sample sorters to cross check 10% of each others samples to ensure >95% of animals are being collected.
2. Species identification is conducted by a highly competent and experienced estuary taxonomist (Gary Stephenson, Coastal Marine Ecological Consultants - CMEC) who has a demonstrated ability to reliably and consistently identify all of the NZ species for which there are sensitivity data, and which are used in determining biological indices e.g. AMBI-NZ.
3. Where any identifications are uncertain, they are evaluated against a comprehensive in-house reference collection of specimens from throughout NZ that have been compiled specifically by CMEC for this purpose.
4. Where this does not resolve uncertainty, specific taxonomic expertise is sought from either NIWA or Te Papa to further resolve uncertainty.
5. In addition, species lists published by other providers from comparable locations are also assessed to highlight any potential differences in identifications or naming, or where regionally specific animals may potentially be mis-classified. Any discrepancies are noted in the reports provided.
6. Consistency in nomenclature is provided by reference to the most up to date online publications.
7. Taxa from NZ groups that are relatively poorly understood, or for which identification keys are limited (e.g. amphipods), are identified to the lowest readily identifiable groupings (i.e. Family or Genus) and consistently labelled and held in the in-house CMEC reference collection. Until species sensitivity information and taxonomic capacity are further developed for such groups, there is little defensible support for the further enumeration of such groups for the current SOE monitoring purposes.
8. The suggested requirement of Hewitt et al. (2014) that 10% of all samples be assessed for independent QAQC by another taxonomist is not supported in the absence of a list of taxa (relevant for SOE monitoring purposes) that taxonomic providers are expected to be able to readily identify to defined levels, combined with a minimum defined standard of competence for taxonomists to undertake QAQC assessments, and a defined process for resolving potential disagreements between taxonomic experts.

For the current work, no specimens were collected that could not be reliably identified and, consequently, no additional taxonomic expertise was sought from either NIWA or Te Papa. The following table summarise the QAQC for Waikawa Estuary samples (January 2016).

| Evaluation Criterion | Staff | Assessor | Outcome |
|---|---|---|---|
| >95% picking efficiency (10% of samples randomly assessed) | Reuben McKay (Wriggle) | Leigh Stevens (Wriggle) | PASS |
| Enumeration of individuals (<10% difference in repeat counts) | Gary Stephenson (CMEC) | Gary Stephenson (CMEC) | PASS |
| Enumeration of common taxa (<10% difference in repeat counts) | Gary Stephenson (CMEC) | Gary Stephenson (CMEC) | PASS |
| Taxonomic identification possible with current expertise | Gary Stephenson (CMEC) | Gary Stephenson (CMEC) | PASS |
| Identification consistent with in-house reference collection | Gary Stephenson (CMEC) | Gary Stephenson (CMEC) | PASS |
| External validation to resolve any identification uncertainty | Gary Stephenson (CMEC) | Gary Stephenson (CMEC) | NOT REQUIRED |
| Comparison of site data with published data from other providers | Gary Stephenson (CMEC) | Gary Stephenson (CMEC) | NO DATA AVAIL. |
| Nomenclature checked against latest online publications | Gary Stephenson (CMEC) | Gary Stephenson (CMEC) | PASS |

*Hewitt, J.E., Hailes, S.F. and Greenfield, B.L. 2014. Protocol for processing, identification and quality assurance of New Zealand marine benthic invertebrate samples. Prepared for Northland Regional Council by NIWA. NIWA Client Report No: HAM2014-105.*