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Waikanae Estuary

Fine Scale Monitoring 2016/17

Prepared for

Greater Wellington Regional Council

May 2017

Cover Photo: Royal spoonbills feeding in Waikanae Estuary, January 2017

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by

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WAIKANAE ESTUARY - EXECUTIVE SUMMARY

This report summarises fine scale monitoring undertaken at one benthic intertidal site (Site A) in the upper reaches of Waikanae Estuary, a shallow, short residence, tidal river estuary (SSRTRE) on the Kapiti coast. It has been identified by Greater Wellington Regional Council (GWRC) as a priority for monitoring, and is a key part of GWRC's long-term coastal monitoring programme being undertaken in a staged manner throughout the Wellington region. A three year monitoring baseline was established in firm mud sand habitat in Waikanae Estuary from 2010-2012, with the first year of scheduled 5 yearly post-baseline monitoring undertaken on 29 January 2017. Monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations are presented below.

FINE SCALE MONITORING RESULTS

- No macroalgae or seagrass was recorded from Site A in 2017. These features were also absent in 2010-2012, and were relatively uncommon in the estuary as a whole (Stevens and Robertson 2015).
- Sediment mud content in 2017 was relatively low (11.2% to 15.0% mud) compared with the 2010-2012 baseline years (15.3% to 47.7% mud).
- Sediment oxygenation in 2017 was moderate (aRPD 2-4cm depth), consistent with that measured in the 2010-2012 baseline years.
- Indicators of organic and nutrient enrichment (total organic carbon, total nitrogen and total phosphorus) were at low or very low concentrations in 2017. This was also the situation in 2010 and 2011, but these indicators were rated "moderate" in 2012.
- Indicators of sediment toxicants in 2017 - (heavy metals Cd, Cu, Cr, Ni, Pb, Hg, Zn and arsenic) were all at concentrations not expected to pose toxicity threats to aquatic life. Nickel concentrations were slightly higher in 2012 and 2017 compared to 2010 and 2011.
- The estuary macroinvertebrate community index (NZ HybAMBI) characterised Site A as a "transitional" type community ("moderate" ecological risk rating) in all years.
- Comparisons of the 2010-2012 baseline and 2017 post baseline data showed no statistically significant difference (p=0.05) in sediment mud content, sediment oxygenation, indicators of organic and nutrient enrichment, indicators of sediment toxicants, or the NZ HybAMBI.
- However there was a significant difference between baseline and post-baseline years in macroinvertebrate species abundance. The results showed two species tolerant of mud and brackish water (the estuarine snail *Potamopyrgus estuarinus* and the amphipod *Paracorophium excavatum*), were responsible for the greatest differences between each of the baseline years and 2017. An increased marine influence in 2017 was postulated as the main cause for this difference.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Key: Low | Moderate | Very Low | High

Indicator	Waikanae Estuary Site A			
	2010	2011	2012	2017
Sediment Mud Content	High	Moderate	High	Low
Sediment Oxygenation (aRPD or RP)	Low	Low	Moderate	Low
TOC (Total Organic Carbon)	Very Low	Very Low	Moderate	Very Low
TN (Total Nitrogen)	Low	Low	Moderate	Low
Invertebrate Mud/Organic Enrichment	Moderate	Moderate	Moderate	Moderate
Metals (Cd, Cu, Cr, Hg, Pb, Zn) & As	Low or Very Low	Low or Very Low	Low or Very Low	Low or Very Low
Metals (Ni)	Low	Low	Moderate	Moderate

ESTUARY CONDITION AND ISSUES

In terms of muddiness and organic enrichment, the various physical and chemical indicators, NZ Hybrid AMBI scores, and macroinvertebrate taxa analyses, all indicated an intermittent muddiness issue in the upper estuary, accompanied with reduced sediment oxygenation. It is likely that in some years when the marine influence is strong (e.g. 2017), the muddiness issue is masked by the deposition of marine sands, but the influence is not sufficient to facilitate a shift towards a less mud tolerant community. The 2017 results showed no deterioration of estuary condition since the 2010-2012 baseline years.

Waikanae Estuary - Executive Summary (continued)

RECOMMENDED MONITORING AND MANAGEMENT

Based on the 2017 monitoring results and risk indicator ratings, particularly those related to fine sediment, the following monitoring recommendations are proposed by Wriggle for consideration by GWRC:

Fine Scale Monitoring

Continue fine scale monitoring at five yearly intervals (next scheduled for 2022).

Broad Scale Habitat Mapping, Including Macroalgae

Continue broad scale habitat mapping at 10 yearly intervals, unless obvious changes are observed in the interim, focusing on the main issue of fine sediment. Next monitoring recommended for January 2025. Undertake macroalgal mapping 5 yearly (next monitoring recommended for January 2020).

Eutrophication and Sedimentation Monitoring

To better assess current symptoms of sedimentation, it is recommended that annual monitoring be continued for low cost key indicators of RPD, sedimentation rate and grain size at Site A, with additional sites established in the upper and lower estuary. At the same time, quickly assess macroalgal cover of the whole estuary. If issues are present, undertake macroalgal mapping and synoptic sampling to characterise chlorophyll *a* concentrations in surface water and bottom water (downstream pool).

Catchment Landuse

Track and map key broad scale changes in catchment landuse (5 yearly).

Recommended Management

The combined results from the broad scale and fine scale monitoring (Stevens and Robertson 2015, Robertson and Stevens 2010, 2011, 2012, and the current report) identify fine sediment as the major current stressor in Waikanae Estuary (noting that disease risk is addressed separately by GWRC). Although elevated fine sediment inputs have likely been occurring since the first human development of the catchment, the broad and fine scale monitoring results highlight an intermittent muddiness issue in the upper estuary. To address this issue, it is recommended that the following be considered:

- Develop a conceptual outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, high and existing) and, through stakeholder involvement, identify an appropriate "target" estuary condition.
- Following this initial step, undertake a detailed investigation of fine sediment sources through the application of a catchment based land use/sediment yield model to predict sediment sources under different land use patterns.
- Apply an estuary model that predicts how the estuary retains and distributes sediment under various input load scenarios, incorporating variable states of marine influence.
- Using the results of the above investigations, and other appropriate monitoring data, identify sediment input load guideline criteria required for fine sediment infilling to meet a target state.
- Explore catchment management and estuary restoration options, and develop a plan to achieve targets.

Fine scale Site A showing muddy sand sediments

Upper estuary looking towards adjacent beach and ocean

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. In 2007, Greater Wellington Regional Council (GWRC) identified a number of estuaries in its region as immediate priorities for long term monitoring and initiated monitoring of key estuaries in a staged manner. The estuaries currently monitored include; Porirua Harbour, Lake Onoke, and Whareama, Hutt and Waikanae estuaries. Risk assessments have also been undertaken to establish management priorities for a number of other estuaries (Robertson and Stevens 2007a,b,c).

Within NZ, the approach for monitoring estuary condition follows the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a and b). It consists of three components as follows:

- **Ecological Vulnerability Assessment (EVA)** of the estuary to major issues (see Table 1) and appropriate monitoring design. This component has been completed for Waikanae Estuary and is reported on in Robertson and Stevens (2007b).
- **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. Preliminary broad scale intertidal mapping of Waikanae Estuary was undertaken in 2006 (Stevens and Robertson 2006), and a full assessment undertaken in 2015 (Robertson and Stevens 2015). Annual mapping of macroalgal cover has been undertaken from 2010 to 2014 (see Stevens and Robertson 2014).
- **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 an estuary across a three year baseline and subsequently every five years, commenced in 2010 and is reported on in Robertson and Stevens (2010, 2011, 2012). The first year of impact monitoring was undertaken on 29 January 2017 and is the subject of this report. Sedimentation rates in the estuary have been monitored annually since 2010 (see Stevens 2017).

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of risk indicator ratings have also been developed and are described in Section 2. The current report describes the 2017 fine scale results and compares them to the previous findings.

Waikanae Estuary

Waikanae Estuary is a moderate-sized (2km long, 40-50m wide, 1-2m deep) "shallow, short residence, tidal river (SSRTRE) type estuary which drains onto a broad flat (dissipative) beach just north of Paraparaumu. As is typical in such situations, the majority of the estuary area consists of a long, shallow lagoon type estuary running along the back of the beach parallel to the sea. This results from the continual action of ocean currents from the north that generate a sandspit that pushes the mouth progressively southwards. However, in the case of the Waikanae Estuary, this lower part of the estuary is periodically lost when the channel naturally realigns, or opens more directly to the sea at the north end before progressively migrating south. In addition, floodgates restrict tidal action and flushing to a large historical estuarine arm. Such instability greatly diminishes ecological values in the lower estuary by limiting the potential for long-term estuarine communities to establish. The middle and upper estuary in the main arm are, however, much more stable (including some saltmarsh and tidal flats) and, consequently, have been targeted for the fine scale monitoring programme. There are also various freshwater lakelets around the margins.

Like other moderate-sized tidal river estuaries, the Waikanae is usually freshwater dominated at low tide and at high tide consists of a freshwater layer on top of saline bottom water. Plant and animal life is therefore restricted to those that tolerate such regular salinity extremes.

Human and ecological use of the estuary is high. It is one of very few sizable estuary/wetland areas in the southwestern North Island, and is a nationally significant wetland habitat for waders, seabirds and waterfowl, both local and migratory. More wild birds reportedly visit Waikanae Estuary Scientific Reserve than any other area in the Wellington province. In terms of human use, the estuary is a local focal point for conservation, walking, picnicking, boating, fishing, paddling, bird watching, bathing, and white-baiting. The estuary receives moderate inputs of nutrients and sediment from the large catchment and tertiary treated wastewater from the Paraparaumu Treatment Plant (via Mazengarb Drain) (Robertson and Stevens 2007b).

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

1. Sediment Changes

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 considering 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 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:
  - Statistical measures be used to refine indicator ratings where information is lacking.
  - 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.
  - The outputs stimulate discussion regarding what the acceptable level of risk is, and managing it.

The indicators and condition ratings used for the Waikanae Estuary 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 NZ estuaries. 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 - Band A	Low - Band B	Moderate - Band C	High - 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 None to minor stress on benthic fauna	>1.0-2.5 Minor to moderate stress on fauna	>2.5-4.0 Moderate to high stress on fauna	>4.0 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), ** and *** Hargrave et al. (2008), ***Robertson (in prep.), 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 subsequent extensions (e.g. Robertson et al. 2016b) and provides detailed information on indicators of chemical and biological condition within 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) with 1-2 sites per estuary (although this varies depending on estuary size or complexity). The recently developed NZ ETI (Robertson et al. 2016b) also requires assessment of sediment condition in the primary mud deposition zone of estuaries where eutrophic conditions are most likely to be first expressed.

Within the selected intertidal site samples are 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), Mercury (Hg), Nickel (Ni), Zinc (Zn) plus Arsenic (As). Analyses are based on non-normalised whole sample fractions to allow direct comparison with ANZECC (2000) Guidelines.
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: measured in certain estuaries where a risk has been identified.

Synoptic water samples from estuary surface and bottom waters and subtidal sediment samples also provide very useful information to support intertidal assessments where estuaries include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted).

For the Waikanae Estuary, one fine scale sampling site (Wkne A) measuring 15m x 60m (Figure 1), was established in unvegetated, mid-low water habitat of the upper estuary depositional flats in 2010 (Robertson and Stevens 2010). When sampled the site is marked out and divided into 12 equal sized plots and within each area, ten plots selected, a random position defined within each, and sampling undertaken as described in the following sections:

Physical and chemical analyses

- At each site, average apparent Redox Potential Discontinuity (aRPD) depth was recorded within each plot. In future, it is proposed that redox potential (mV) be directly measured with an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10cm depths below the surface in three plots.
- 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 for chemical analysis. All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1).
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

3. Methods (continued)

Figure 1. Location of fine scale sampling sites, Waikanae Estuary, Kapiti coast.

Infauna (animals within sediments) and epiflora/fauna (surface dwelling plants and animals)

From each of 10 plots, 1 randomly placed sediment core [130mm diameter (area = 0.0133m2) 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).
- Where present, macroalgae and seagrass vegetation (including roots) was collected within each of three representative 0.0625m2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured.
- Conspicuous epifauna visible on the sediment surface within the 15m x 60m 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 percent-age 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 determines both the quadrat size and SACFOR density rating applied, while photographs were taken and archived for future refer-ence. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal and microalgal cover.

4. RESULTS AND DISCUSSION

A summary of the results of the 29 January 2017, and the 2010, 2011 and 2012 fine scale intertidal monitoring of Waikanae Estuary is presented in Table 3, with detailed results in Table 5 and 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. Mean fine scale physical, chemical and vegetation (n=3), and macrofauna (n=10) results, Waikanae Estuary, 2010-2012 and January 2017.

Year Site	aRPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2010 A	2.8	<1	0.5	26.7	72.7	0.6	0.036	11.3	7.0	9.4	10.0	44.3	NA	NA	567	333
2011 A	5.0	<1	0.4	18.0	81.3	0.7	0.033	12.3	6.3	9.5	9.5	40.7	NA	NA	633	377
2012 A	1.0	<1	1.7	38.7	60.7	0.5	0.053	14.8	8.7	11.6	10.7	49.3	NA	NA	1433	523
2017 A	3.0	1	0.3	13.2	83.8	3.0	0.034	13.7	8.6	11.9	11.1	49.3	3.1	0.034	<500	377

Year Site	Seagrass Biomass and Cover	Macroalgal Biomass and Cover	Macrofauna Abundance	Macrofauna Richness
	$g.m^{-2}$ wet weight (%)	$g.m^{-2}$ wet weight (%)	Individuals/m^2	Species/core
2010 A	0	0	33,287	8.2
2011 A	0	0	18,828	7.1
2012 A	0	0	24,910	7.3
2017 A	0	0	5,248	6.4

NA = Not Assessed. Note, minor corrections have been made to baseline abundance and richness results reported in Robertson and Stevens (2012).

Primary Environmental Variables

The primary environmental variables that are most likely to be driving 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 variables are organic matter (measured as TOC and macroalgal biomass), nutrients, sediment oxygenation [either directly measured as redox potential, or by measuring the redox potential discontinuity depth (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).
- The influence of non-eutrophication related toxicity is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs generally only assessed where inputs are likely, or metal concentrations are found to be elevated.

The relationship between environmental factors and spatio-temporal influences in Waikanae Estuary has been examined in two steps:

- One way ANOVA (p=0.05) was used to assess if there was a significant difference between means for any two years at Site A, for each environmental factor.
- The ANOVA analysis was followed by a Tukey post hoc test to determine if there was a significant difference between 2017 data (i.e. "post baseline" data) and all of the baseline years 2010-2012 and, if there was a significant difference between all of the years, was the 2017 data also outside of the baseline data range. If the latter was true, then it was concluded that there had been a significant change between the post baseline year and the baseline years for that particular variable.

The results of these analyses are presented in Table 4.

Table 4. Summary of One-Way ANOVA (p=0.05) and Tukey post hoc tests for physical and chemical data for Site A (2010-2012 and 2017) in Waikanae Estuary.

Variable	**ANOVA F and P value.** Is there a significant difference between at least two of the years means? (p=0.05)		**Post hoc test (Tukey P=0.05).** Is the difference between 2017 and all baseline years (2010-2012) significant? Is 2017 data outside of the baseline data range?
TOC	F = 52.37, P < 0.001.	Significant	Not significant
Mud	F = 40.23, P < 0.001.	Significant	Not Significant
Cadmium	F =92.28, P < 0.001.	Significant	Not Significant
Chromium	F =138.93, P < 0.001.	Significant	Significant, but still within the range of baseline data
Copper	F =88.90 P < 0.001.	Significant	Not Significant
Nickel	F =197.90, P < 0.001.	Significant	Not Significant
Lead	F =14.43, P < 0.001.	Significant	Not Significant
Zinc	F =81.95, P < 0.001.	Significant	Not Significant
RPD	F =17.13, P < 0.001.	Significant	Not Significant
TN	F =66.98, P < 0.001.	Significant	Not Significant
TP	F = 210.41, P < 0.001.	Significant	Not Significant

SEDIMENT INDICATORS

4.1.1 Muddiness (or Sedimentation)

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 2017 monitoring results for sediment mud content (Table 3, Figure 2) were at relatively low levels (11.2 to 15% mud) compared with the baseline years (15.3 to 47.7% mud). Single sediment samples collected at Site A in 2014-2016 (Stevens 2017) and included in Figure 2 show a decrease in mud content related to observed increases in marine sands deposited at the site over this period.

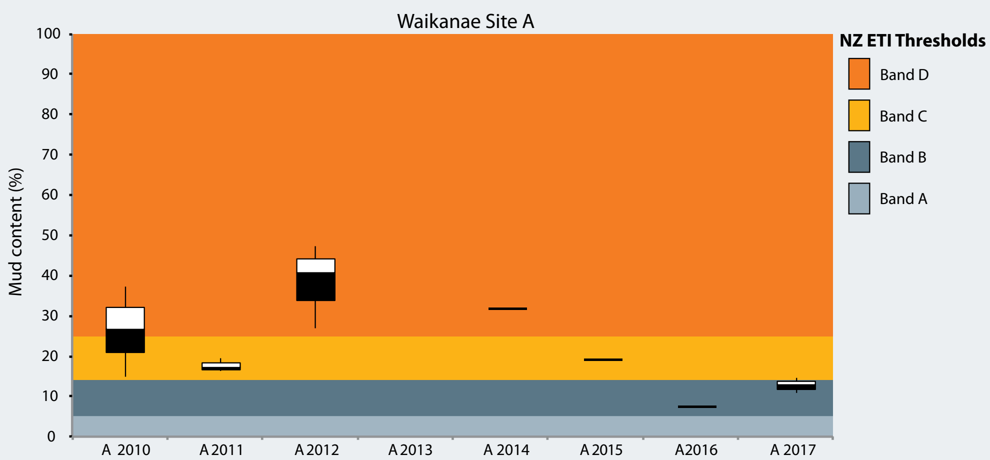

Figure 2. Mean mud content (median, interquartile range, total range, n=3), Waikanae Estuary 2010-2012 and 2017. 2014-2016 data single composite samples sourced from Stevens (2017).

4. Results and Discussion (continued)

The fine scale data for all years (i.e. 2010-2012 and 2017) showed that mean mud content differed between at least two years (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between all of the "baseline" 2010-2012 data and the "post baseline" 2017 data. These results indicate that there has been no significant change from the baseline and therefore, no associated change is expected to the benthic macroinvertebrate community attributable to this indicator. Field observations indicate the lower mud contents in 2011 and 2017 are attributable to greater deposition of marine sands into the upper estuary in these years.

Sediment accrual at Site A has been monitored annually since 2010 and shows a mean annual average sedimentation rate of 23.2mm/year (Stevens 2017), a risk rating of "high", with changes in the annual site average ranging from a low of -1.8mm/yr (2017) to a high of +45mm/yr (2011). The consistently high rate of sedimentation is an obvious stressor to the benthic community and will have a strong influence on community structure.

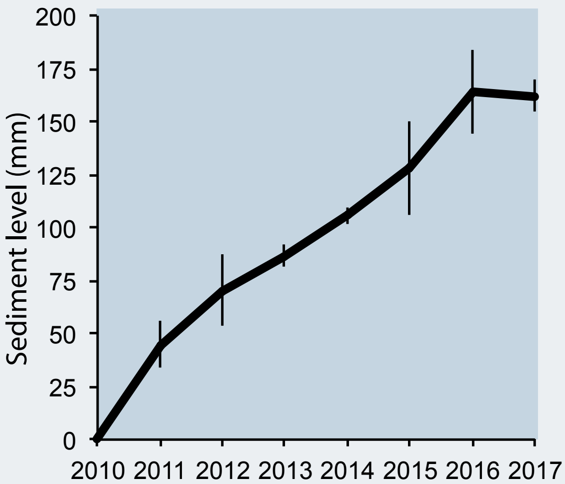

Figure 3. Change in mean sediment level over buried plates (± annual range), Waikanae Estuary, 2010 to 2017.

4.1.2 Eutrophication

The primary variables indicating eutrophication impacts are sediment mud content, aRPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal and seagrass cover.

Macroalgae and Seagrass

There was no opportunistic macroalgae or seagrass growing at Site A in 2017 and it has not been observed at the site during annual summer sampling from 2010-2017. This likely represents unsuitable conditions for seagrass growth, and indicates low levels of eutrophication at the site. It is noted though that phytoplankton blooms have been recorded from the estuary indicating it is at times impacted by elevated nutrient inputs.

Sediment Mud Content

This indicator has been discussed in Section 4.1.1 and is not repeated here. However, in relation to eutrophication, sediment oxygenation is likely to be relatively poor in years when the mud content at the site is elevated.

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the extent of oxygenation within sediments. Currently, the condition rating for redox potential is under development (Robertson et al. 2016b) pending the results of a PhD study in which apparent Redox Potential (aRPD) (an indirect measure) and redox potential (RP) directly measured with an ORP electrode and meter are being assessed for a gradient of eutrophication symptoms. Initial findings indicate that the recommended NZ estuary aRPD and RP thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Table 2 and Figure 4).

4. Results and Discussion (continued)

Figure 4 shows the aRPD depths from the surface for Site A in 2017, and the baseline years 2010-2012. In 2017, the aRPD depth was at a moderate depth (2-4cm). The data for all years (i.e. 2010-12 and 2017) showed that aRPD differed between at least two years (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the "post baseline" 2017 data and all of the "baseline" 2010-2012 data. These results indicate that sediment oxygenation was likely to support a moderate range of species. In the future, redox potential will be directly measured through a vertical profile, which will enable a more accurate assessment of sediment oxygenation conditions.

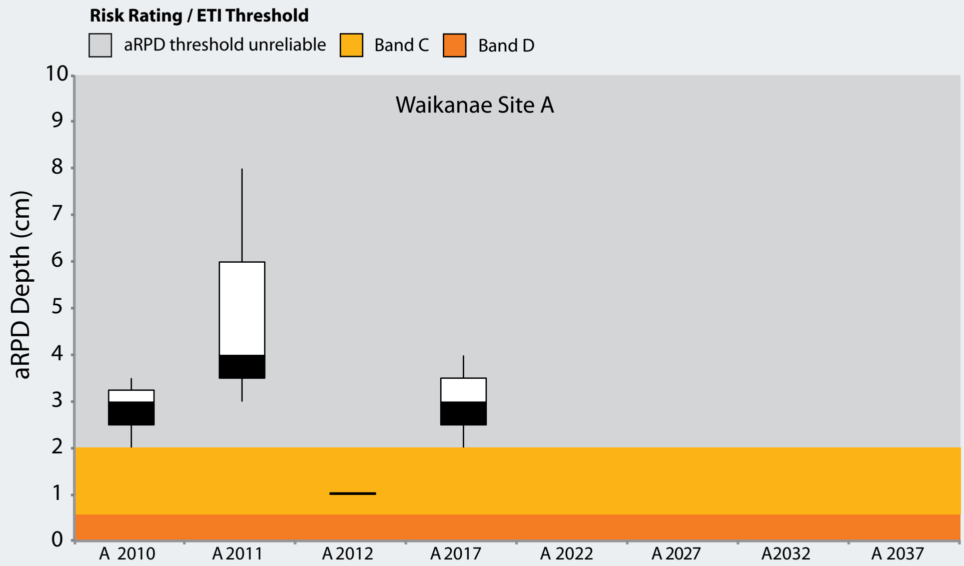

Figure 4. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=10), Waikanae Estuary 2010-2012 and 2017.

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 2010-2012 and 2017 results showed TOC and TN were usually in the "low" or "very low" risk indicator ratings, except for 2011 when they were in the "moderate" rating, whereas TP (rating not yet developed) was relatively low at 310-540mg/kg (Figures 5, 6 and 7).

The data for all years (i.e. 2010-2012 and 2017) showed that TOC, TN and TP differed between at least two years (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the "baseline" 2010-2012 data and the "post baseline" 2017 data.

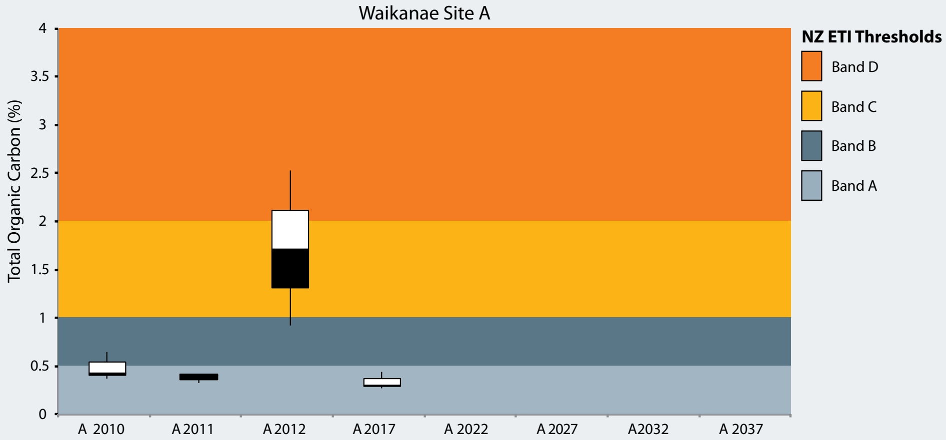

Figure 5. Mean total organic carbon (median, interquartile range, total range, n=3), 2010-12 and 2017.

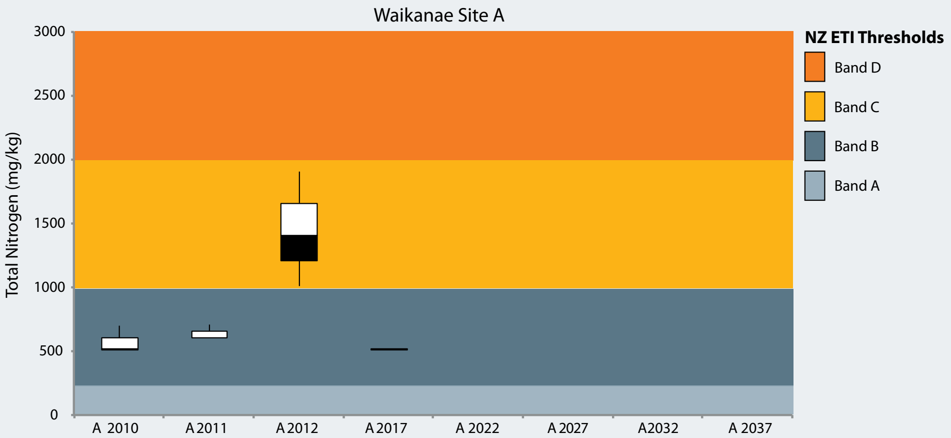

Figure 6. Mean total nitrogen (median, interquartile range, total range, n=3), 2010-12 and 2017.

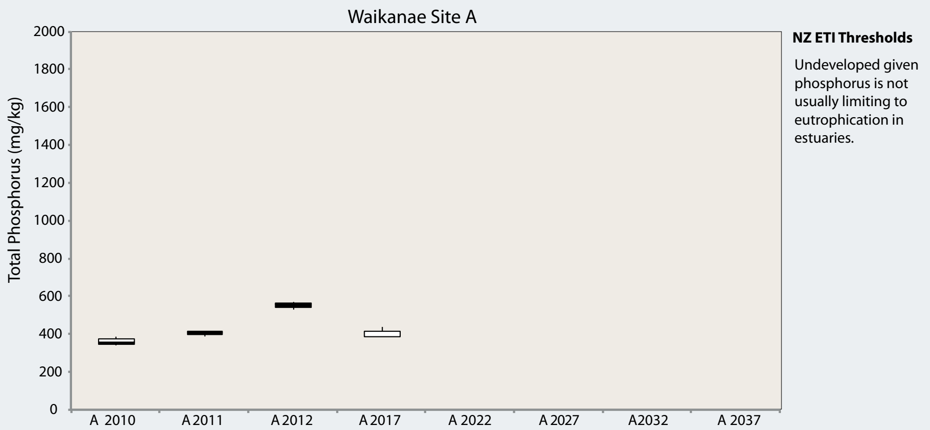

Figure 7. Mean total phosphorus (median, interquartile range, total range, n=3), 2010-12 and 2017.

4.1.3 Toxicity

Both the 2017 and the 2010-2012 results for heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn and arsenic (indicators of potential toxicants) were present at "very low" to "low" concentrations, or "moderate" in the case of nickel in 2012 and 2017. All non-normalised values were below the ANZECC (2000) ISQG-Low trigger values (Table 5), and therefore posed no significant toxicity threat to aquatic life. The data also showed that for all years metals differed between at least two years (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the "baseline" 2010-2012 data and the "post baseline" 2017 data.

Table 5. Indicator toxicant results, Waikanae Estuary, Site A, 2010-2012 and 2017.

Year	Site /Rep*	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
		mg/kg							
2010	Wkne A 1-4	0.036	11.0	6.7	9.3	9.4	43	NA	NA
2010	Wkne A 5-8	0.034	11.0	6.8	9.2	9.6	43	NA	NA
2010	Wkne A 9-10	0.037	12.0	7.6	9.8	11.0	47	NA	NA
2011	Wkne A 1-4	0.031	12.4	6.5	9.7	9.7	41	NA	NA
2011	Wkne A 5-8	0.035	12.8	6.7	10.0	10.0	42	NA	NA
2011	Wkne A 9-10	0.033	11.6	5.7	8.7	8.8	39	NA	NA
2012	Wkne A 1-4	0.052	15.0	8.9	11.8	11.5	50	NA	NA
2012	Wkne A 5-8	0.058	14.2	9.1	11.5	11.2	50	NA	NA
2012	Wkne A 9-10	0.049	15.2	8.0	11.4	9.5	48	NA	NA
2017	Wkne A 1-4	0.037	14.0	8.9	12.0	11.6	51	3.2	0.039
2017	Wkne A 5-8	0.028	13.4	8.1	11.8	10.4	47	3.0	0.029
2017	Wkne A 9-10	0.038	13.8	8.8	12.0	11.4	50	3.1	0.033
Condition Thresholds (ANZECC 2000 criteria, 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
[a]ISQG-Low		1.5	80	65	21	50	200	20	0.15
[a]ISQG-High		10	370	270	52	220	410	70	1

[a]ANZECC 2000, *composite samples, mean of 2-4 samples.

4.1.4 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 disturbance 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 Waikanae Estuary has been examined in 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 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).

Macroinvertebrate Community Ordination

Principle Coordinates Analysis (PCO), based on species abundance data for Site A (2010-2012 and 2017), showed that the macroinvertebrate community in the "baseline" years was significantly different from the "post baseline" year 2017 (i.e. PERMANOVA P<0.0001, Figure 8).

4. Results and Discussion (continued)

Vector overlays of environmental variables (based on Pearson correlations) are also presented in order to provide information in relation to the potential influence of environmental factors at the site over the years. The results clearly identify differences in mud content, nutrients, TOC and aRPD depth as a likely explanation of the differences in invertebrate community structure within the site for each of the years, but no clear environmental variable explaining the difference between the community in 2017 compared with those in 2010, 2011 and 2012. Comparison of the faunal results with abiotic factors using the BIOENV procedure (correlates rank values of faunal similarities between sites with rank Euclidean distances based on environmental factors between sites) indicated that, at Site A, the combination of TOC, aRPD, mud, TN and TP was well correlated with the faunal results (Spearman correlation coefficient r=0.774).

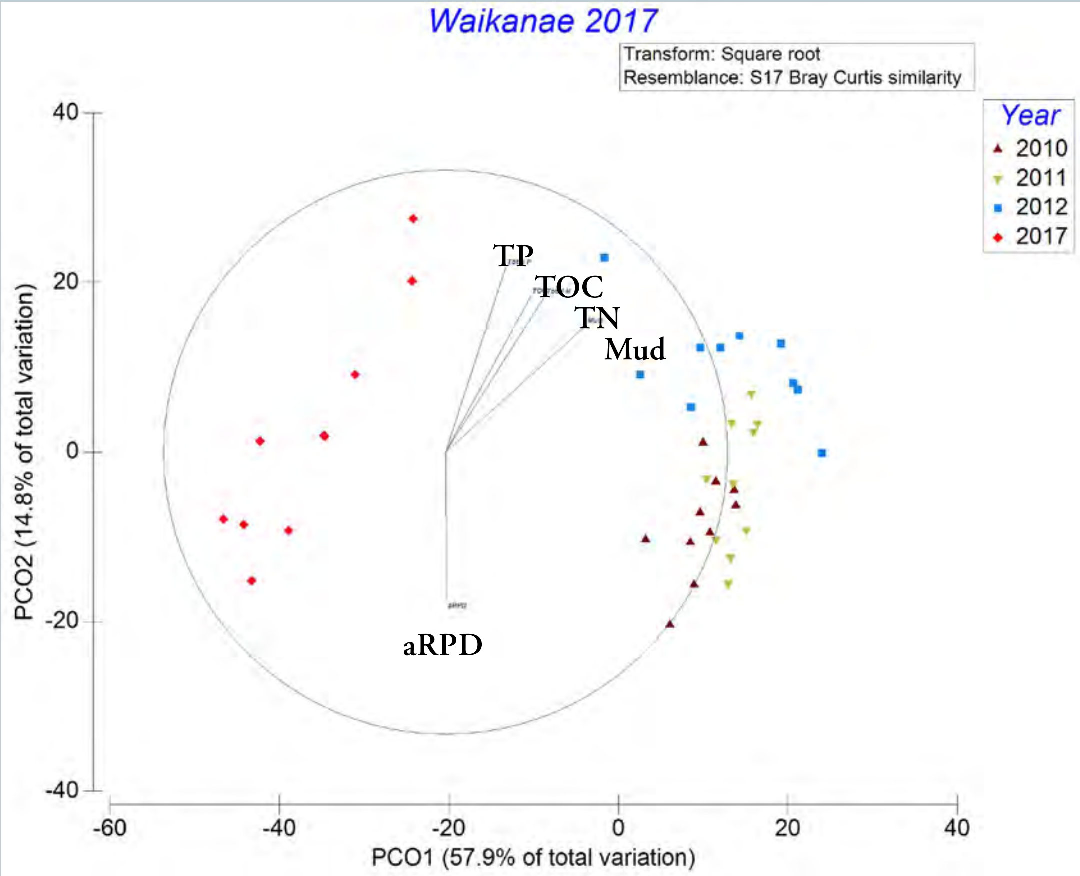

Figure 8. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at Site A Waikanae Estuary, 2010-12 and 2017 and the key environmental variables of mud, TN, TP, TOC, and aRPD.

Figure 8 shows the relationship among samples in terms of similarity in macroinvertebrate community composition at Site A, for the sampling period 2010-2012 and 2017. The plot shows the 10 replicate samples for Site A in each year, 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 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 axes). For the present plots, the cumulative variation explained was >70%, indicating a good representation of the abundance matrix.

PERMANOVA, testing for statistical significant differences in the invertebrate communities among samples, reflected highly significant ($P<0.0002$) structural changes between years for all Site A data.

The environmental vector overlays, based on Pearson correlations, show preliminary exploratory information on the strength of environmental relationships with their length in relation to the circle boundary indicating the magnitude of the strength.

4. Results and Discussion (continued)

Species Richness, Abundance, Diversity, and Infauna Groups

The next step was to assess whether simple univariate whole community indices, i.e. species richness, abundance and Shannon diversity at each site (Figure 9), could explain the differences between years indicated by the PCO analysis. The data for all years (i.e. 2010-12 and 2017) at Site A showed that species abundance was significantly different between at least two years (Table 6 ANOVA results), but richness and Shannon diversity did not differ. The Tukey post-hoc test (p=0.05) found there was a significant difference between the "post baseline" 2017 data and all of the 2010-2012 "baseline" for abundance, but no significant difference for species richness or Shannon diversity. This is reflected visually in Figure 9 which shows a large drop in abundance in 2017, but little change in the other measures.

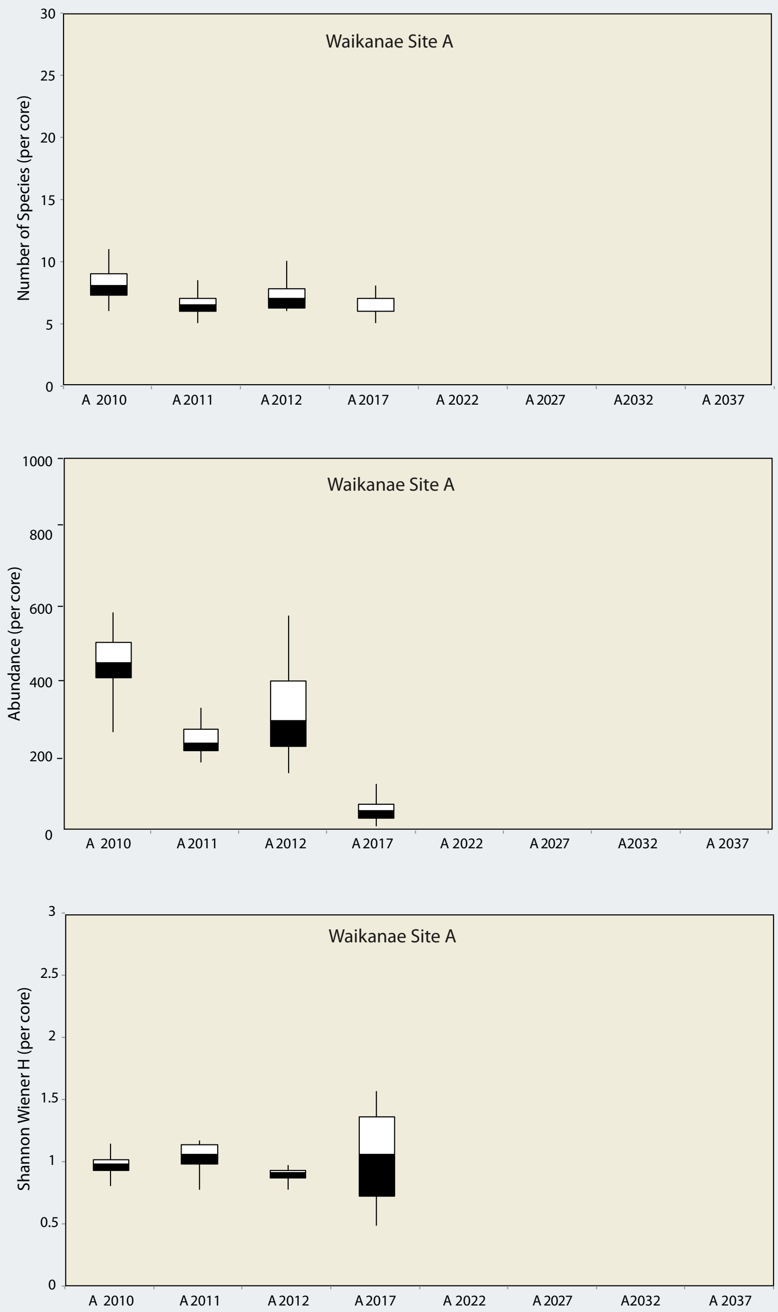

Figure 9. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Waikanae Estuary, 2010-2012 and 2017.

Table 6. Summary of One-Way ANOVA (p=0.05) and Tukey post hoc tests for macroinvertebrate data, Waikanae Estuary Site A, 2010-12 and 2017.

Variable	**ANOVA F and P value.** Is there a significant difference between at least two of the years means? (p=0.05)		**Post hoc test (Tukey P=0.05).** Is the difference between 2017 and all baseline years (2010-2012) significant? Is 2017 data outside of the baseline data range?
Mean No. Species	F = 2.57, P = 0.069.	Not Significant	Not Significant
Mean Abundance	F = 25.45, P <0.001.	Significant	Significant, decline in species abundance
Shannon Wiener (H)	F = 0.98, P = 0.40.	Not Significant	Not Significant

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

A. 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 responsiveness 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 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.

The median NZ AMBI biotic coefficients for Waikanae Estuary for 2010, 2011, 2012 and 2017 were 3.7, 3.6, 4.0 and 4.3 respectively. The results identified Site A to be in the "moderate" ecological condition category (i.e. a "transitional to polluted" type macroinvertebrate community).

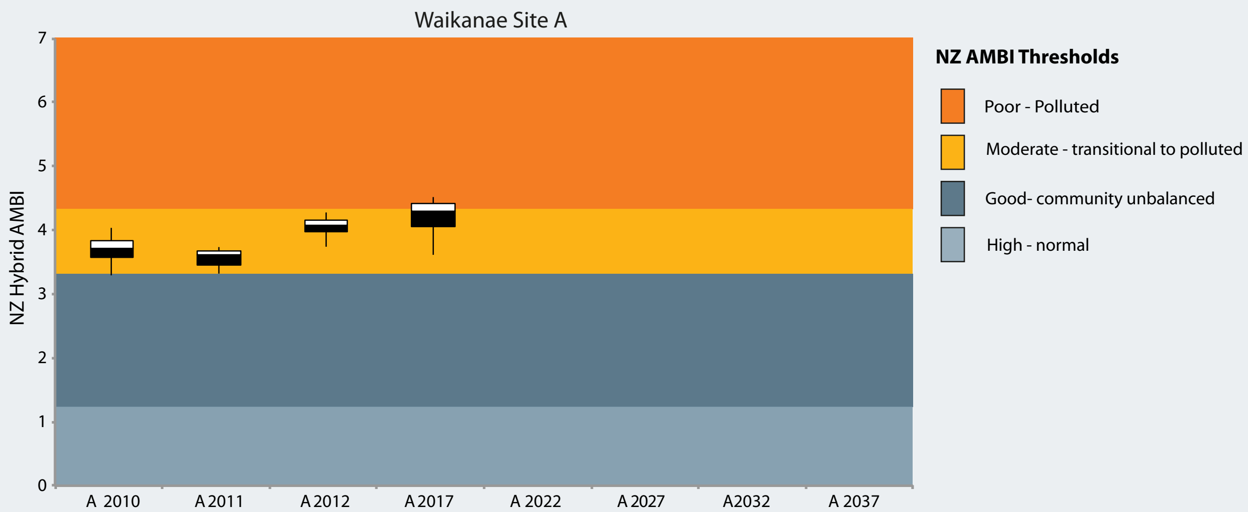

Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Waikanae Estuary, 2010-2012 and 2017.

B. Taxonomic Groups and Individual Species

This step compares the structure of the macrofaunal community at Site A over time, firstly in terms of its general taxonomic grouping, and secondly in terms of individual taxa. The aim of this final step is to identify the taxa that are responsible for any observed macrofaunal differences between years (i.e. results of PCO ordinations, univariate and NZH AMBI-RI analyses) and to hypothesize on potential reasons based on their individual sensitivity to stressors.

1. Taxonomic Groups

Table 7 shows that in the baseline years (2010-2012) the community was dominated by gastropods, crustaceans, and polychaete worms, with nematode and nemertean worms also recorded. In 2017, crustacea were dominant to polychaetes, with very few gastropods and no nematode or nemertean worms. Bivalves and insects were present in low numbers throughout the sampling period. Such findings provide a preliminary insight into the taxonomic composition of Site A, and differences between years.

Table 7. Summary of major taxa groupings data, Waikanae Estuary Site A, 2010-12 and 2017.

Major Taxa Group	2010	2011	2012	2017
	Mean abundance per core			
Bivalvia (e.g. cockles)	1	4	1	1
Crustacea (e.g. amphipods)	181	92	219	59
Gastropoda (snails)	234	142	99	2
Insecta (insects)	2	0	1	5
Nematoda (round worms)	1	1	0	0
Nemertea (ribbon worms)	1	1	0	0
Polychaeta (bristle worms)	32	24	17	15

2. Dominant Taxa

Figure 11 illustrates mean abundance between years for 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, Robertson et al. 2015).

The plot shows that the macroinvertebrate community in all years was dominated by species tolerant of mud and organic enrichment (i.e. Groups 3 and 4), with only a few species (at low abundances) in the highly sensitive Groups 1 and 2 or the highly tolerant Group 5. The dominant taxa for each year were as follows:

- **Site A 2010.** The dominant taxa were, respectively, the small estuarine snail *Potamopyrgus estuarinus* (limited to brackish upper estuary conditions) (mean abundance 231.7 per core) and the tube-dwelling corophioid amphipod *Paracorophium excavatum* (mean abundance 177.8 per core).
- **Site A 2011.** As in 2010, the dominant taxa in 2011 were, respectively, *Potamopyrgus estuarinus* (mean abundance 140.7 per core) and *Paracorophium excavatum* (mean abundance 81.8 per core).
- **Site A 2012.** In 2012, the dominant taxa were the same as in 2010 and 2011 but their order of dominance reversed, i.e. *Paracorophium excavatum* (mean abundance 210.8 per core) and *Potamopyrgus estuarinus* (mean abundance 97.7 per core).
- **Site A 2017.** In 2017, there were very few estuarine snails and instead the dominant taxa were *Paracorophium excavatum* (mean abundance 81.8 per core) and, at a much lower abundance, the polychaete *Scolecolepides benhami*.

The Similarity Percentages procedure (SIMPER) (PRIMER-e) (Clarke 1993) was also applied to indicate which taxa contributed most to the difference in macroinvertebrate community structure between baseline years 2010-2012 and post baseline 2017. As expected, the results clearly indicate that *Potamopyrgus estuarinus* and *Paracorophium excavatum* were responsible for the greatest differences between each of the baseline years and 2017.

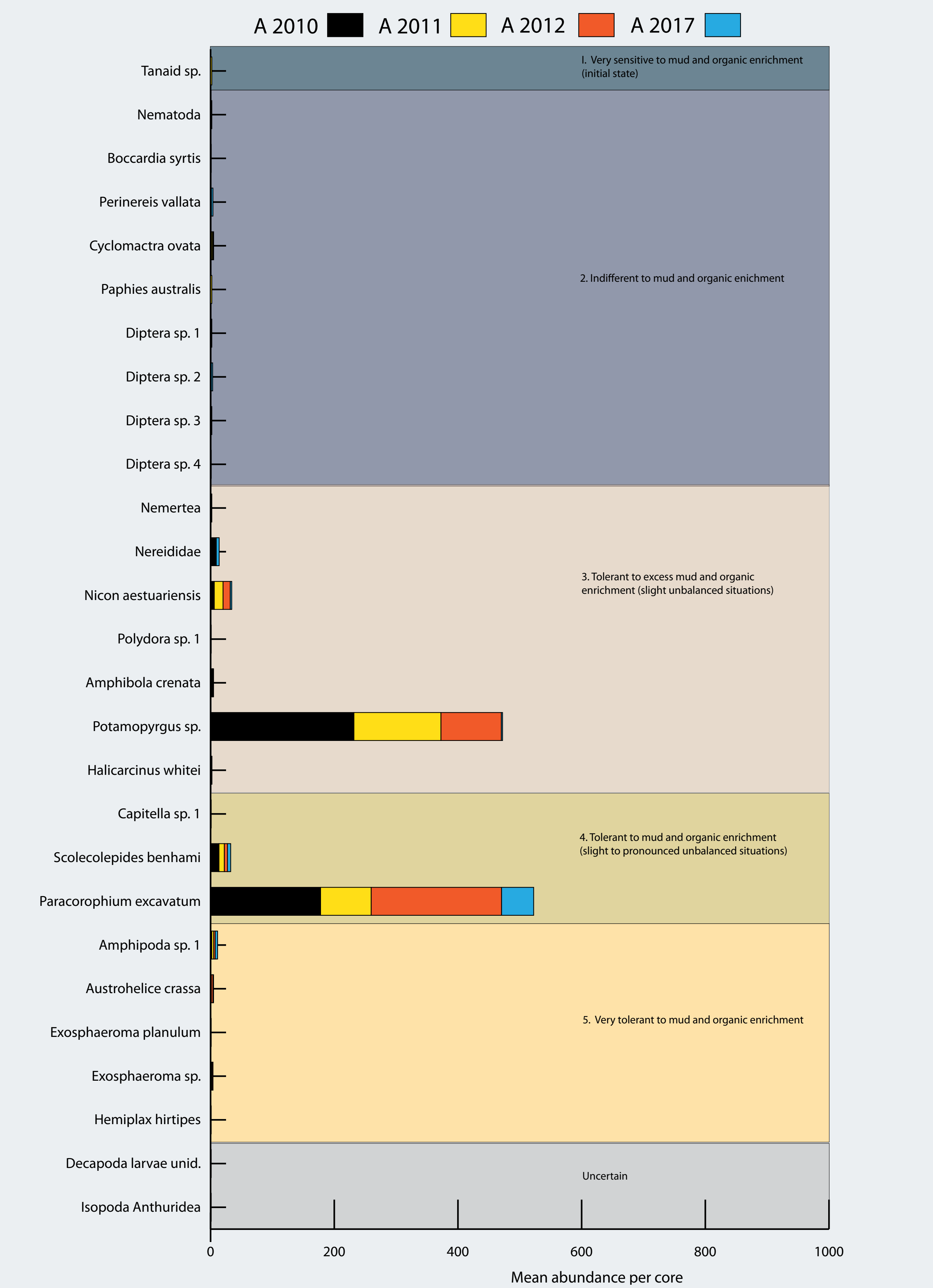

Figure 11. Mud and organic enrichment sensitivity of macroinvertebrates, Waikanae Estuary, 2010-12 and 2017 (see Appendix 3 for sensitivity details).

4. Results and Discussion (continued)

Table 8. Dominant species of macroinvertebrate taxa in Waikanae Estuary.

Potamopyrgus estuarinus	Small estuarine snail, requiring brackish conditions for survival. Endemic to NZ. Common in upper estuary tidal flats adjacent to freshwater inflows. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.	
Paracorophium excavatum	A tube-dwelling corophioid amphipod that lives in the top 2cm - endemic to NZ. It is a suspension feeder that uses the long setae to trap suspended organic matter. Found mainly in NZ east coast habitats and is sensitive to metals. Also very strong mud preference. Often present in muddy upper estuaries with regular low salinity conditions.	
Nicon aestuariensis	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate mud content sediments.	

In addition, the presence of high numbers of the brackish preferring snail *P. estuariensis* in the baseline years (mean abundance >90 per core) and very low numbers in 2017 (mean abundance 2 per core), provides an indication that an increased marine influence on the site in the immediate period leading up to the 2017 monitoring event was the likely reason for the differences observed. This influence likely manifested as increased salinity and sandiness at the site.

Table 9. Species causing the greatest contribution to the difference between macroinvertebrate community structure between years at Site A (SIMPER Analysis - cutoff for low contributions 90%).

Species	**NZH AMBI**	**2010 Av.Abund**	**2011 Av.Abund**	**Contribution %**
Paracorophium excavatum	4	177.8	81.8	44.51
Potamopyrgus estuarinus	3	231.7	140.7	42.26
Nicon aestuariensis	3	5.2	14.3	3.78
Species	**NZH AMBI**	**2010 Av.Abund**	**2012 Av.Abund**	**Contribution %**
Potamopyrgus estuarinus	3	231.7	97.7	53.21
Paracorophium excavatum	4	177.8	210.8	34.95
Nereididae	3	9.1	0	3.17
Species	**NZH AMBI**	**2011 Av.Abund**	**2012 Av.Abund**	**Contribution %**
Paracorophium excavatum	4	81.8	210.8	55.04
Potamopyrgus estuarinus	3	140.7	97.7	36.13
Species	**NZH AMBI**	**2010 Av.Abund**	**2017 Av.Abund**	**Contribution %**
Potamopyrgus estuarinus	3	231.7	0.2	58.46
Paracorophium excavatum	4	177.8	52	34.1
Species	**NZH AMBI**	**2011 Av.Abund**	**2017 Av.Abund**	**Contribution %**
Potamopyrgus estuarinus	3	140.7	0.2	64.12
Paracorophium excavatum	4	81.8	52	21.23
Nicon aestuariensis	3	14.3	2	5.64
Species	**NZH AMBI**	**2012 Av.Abund**	**2017 Av.Abund**	**Contribution %**
Potamopyrgus estuarinus	4	210.8	52	56.2
Paracorophium excavatum	3	97.7	0.2	32.74
Nicon aestuariensis	3	11.6	2	4.03

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for the long term intertidal monitoring site within Waikanae Estuary showed the following key findings:

Physical and Chemical Condition

Overall, the results for the sediment and eutrophication environmental variables indicate that sediment conditions at Site A over the period 2010-2012 and 2017 have been variable, but there was no significant change between baseline and post baseline years. In general, the conditions can be described as:

- low-high muddiness, with 2017 having the lowest mud content which was attributed to an increased presence of marine-derived sands.
- moderate sediment oxygenation.
- low-moderate organic carbon and nutrient concentrations.
- an absence of opportunistic macroalgae.
- indicators of sediment toxicants (Cd, Cu, Cr, Ni, Pb, Hg, Zn and arsenic) were at concentrations that were not expected to pose toxicity threats to aquatic life.

Biological Condition

These findings of no significant change in environmental variables between baseline and post baseline years were supported by the macroinvertebrate data. In particular, it was reflected in the abundance of mud and organic enrichment sensitive taxa between sites and years as portrayed by the NZ Hybrid AMBI biotic coefficients (i.e. no significant difference between baseline and post baseline years). The results identified Site A in all years to be in the "moderate" ecological condition category (i.e. a "transitional" type community). However, for species abundance data, there was a significant difference between "baseline" and "post baseline" years. In terms of the individual taxa causing these differences, the results clearly indicate that the reduced abundance of the estuarine snail *Potamopyrgus estuarinus* and the amphipod *Paracorophium excavatum* in 2017 were responsible for the greatest differences from the baseline years. Both taxa prefer brackish conditions with moderate mud contents. An increased marine influence in 2017 was postulated as the main cause for this difference (i.e. a shift to a greater presence of marine-derived sands, lower mud content and possibly increased salinity in the period leading up to the 2017 monitoring event). Such variability in marine influence is common in estuaries like Waikanae, where there is a migrating mouth, and the upper estuary tidal flats are situated adjacent to the main beach.

6. RECOMMENDED MONITORING

Waikanae Estuary has been identified by GWRC as a priority for monitoring, and is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout the Wellington region. Based on the 2017 monitoring results and risk indicator ratings, particularly those related to fine sediment, the following monitoring recommendations are proposed by Wriggle for consideration by GWRC:

Fine Scale Monitoring
Continue fine scale monitoring at five yearly intervals (next scheduled for 2022).

Broad Scale Habitat Mapping, Including Macroalgae
Continue broad scale habitat mapping at 10 yearly intervals, unless obvious changes are observed in the interim, focusing on the main issue of fine sediment. Next monitoring recommended for January 2025. Undertake macroalgal mapping 5 yearly (next monitoring recommended for January 2020).

Eutrophication and Sedimentation Monitoring
To better assess current symptoms of sedimentation, it is recommended that annual monitoring be continued for low cost key indicators of RPD, sedimentation rate and grain size at Site A, with additional sites established in the upper and lower estuary. At the same time, quickly assess macroalgal cover of the whole estuary. If issues are present, undertake macroalgal mapping and synoptic sampling to characterise chlorophyll *a* concentrations in surface water and bottom water (downstream pool).

Catchment Landuse
Track and map key broad scale changes in catchment landuse (5 yearly).

7. RECOMMENDED MANAGEMENT

The combined results from the broad scale and fine scale monitoring (Stevens and Robertson 2015, Robertson and Stevens 2010, 2011, 2012, Stevens 2017, and the current report) identify fine sediment as the major current stressor in Waikanae Estuary (noting that disease risk is addressed separately by GWRC). Although elevated fine sediment inputs have likely been occurring since the first human development of the catchment, the broad and fine scale monitoring results highlight an intermittent muddiness issue in the upper estuary. To address this issue, it is recommended that the following be considered:

- Develop a conceptual outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, high and existing) and, through stakeholder involvement, identify an appropriate "target" estuary condition.
- Following this initial step, undertake a detailed investigation of fine sediment sources through the application of a catchment based land use/sediment yield model to predict sediment sources under different land use patterns.
- Apply an estuary model that predicts how the estuary retains and distributes sediment under various input load scenarios, incorporating variable states of marine influence.
- Using the results of the above investigations, and other appropriate monitoring data, identify sediment input load guideline criteria required for fine sediment infilling to meet a target state.
- Explore catchment management and estuary restoration options, and develop a plan, to achieve targets.

8. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Laboratory analyses

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
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 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.

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	$0.25m^2$	$1.0m^2$	$10m^2$	$100m^2$	$1,000m^2$
<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	3-24	10-99	100-999	1000-9999	>10,000
O	F	C	A	1-2	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)

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 key 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 Waikanae Estuary samples (January 2017).

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	Barry Robertson (Wriggle)	Barry Robertson (Wriggle))	PASS
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.

APPENDIX 2. 2016/17 DETAILED RESULTS

Fine Scale Station Locations

Waikanae Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1769248	1769251	1769253	1769260	1769262	1769260	1769257	1769252	1769257	1769261
NZTM NORTH	5473364	5473346	5473337	5473317	5473319	5473333	5473345	5473364	5473368	5473355

Epifauna abundance and macroalgal cover for Waikanae Estuary (Site A), January 2017

Group	Family	Species	Common name	Scale	Class	A
Gastropoda	Tateidae	*Potamopyrgus estuarinus*	Estuary mud snail	#	ii	C

Physical and Chemical Results for Waikanae Estuary (Site A), January 2017

Site/Rep/Year	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
Wkne A 1-4* 2017	2	NA	0.42	15	82.1	2.8	0.037	14	8.9	12	11.6	51	3.2	0.039	<500	410
Wkne A 5-8* 2017	3	NA	0.25	11.2	88.4	0.4	0.028	13.4	8.1	11.8	10.4	47	3	0.029	<500	360
Wkne A 9-10* 2017	4	NA	0.28	13.3	80.9	5.9	0.038	13.8	8.8	12	11.4	50	3.1	0.033	<500	360
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.

Infauna (numbers per 0.01327m² core) Waikanae Estuary January 2017. NA=Not Assigned

Group	Species	NZH AMBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10
Nemertea	Nemertea	3										
Nematoda	Nematoda	2										
Polychaeta	*Boccardia syrtis*	2										
	Capitella sp. 1	4										
	Nereididae	3	8	7	4	5	3	3	5	4	2	7
	Nicon aestuariensis	3		1	2	4		2	6	2	2	1
	Perinereis vallata	2					2	3				
	Polydora sp. 1	3										
	Scolecolepides benhami	4	12	3	2		3	8	4	6	5	4
Gastropoda	*Amphibola crenata*	3										
	Potamopyrgus sp.	3										2
Bivalvia	*Cyclomactra ovata*	2								1		
	Paphies australis	2										
Crustacea	Amphipoda sp. 1	5	2	1	1	12		1	6	5	3	
	Austrohelice crassa	5				1			1			
	Decapoda larvae unid.	NA										
	Exosphaeroma planulum	5									1	
	Exosphaeroma sp.	5										
	Halicarcinus whitei	3										
	Isopoda anthuridea	NA					1					
	Hemiplax hirtipes	5										
	Paracorophium excavatum	4	45	57	72	115	33	18	114	38	23	5
	Tanaid sp.	1										
Insecta	Diptera sp. 1	2		1		1						
	Diptera sp. 2	2	2			1	4	2	3		3	1
	Diptera sp. 3	2									1	
	Diptera sp. 4	2	1									
Total species in sample			**6**	**6**	**5**	**7**	**6**	**7**	**7**	**6**	**8**	**6**
Total individuals in sample			**70**	**70**	**81**	**139**	**46**	**37**	**139**	**56**	**40**	**20**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		NZ Hyb AMBI Gp*	Details
Nemertea	Nemertea sp. 1	3	Ribbon or Proboscis worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda	2	Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5mm mesh sieve. Generally reside in the upper 2.5cm of sediment. Intolerant of anoxic conditions.
Polychaeta	*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. Very sensitive to organic enrichment and usually present under unenriched conditions.
	Capitella sp. 1	4	A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments. Commonly *Capitella capitata*.
	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.
	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.
	Perinereis vallata	2	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
	Polydora sp. 1	3	A Spionid. Polydora-group have many NZ species. Difficult to identify unless complete and in good condition. The Polydora group of species specialise in boring into shells. *Boccardia acus* bores into the upper exposed shell of the cockle *Austrovenus stutchburyi*. Several other Polydora group species live free in tubes in the sand. The tubes of the most widely-occurring species, *Boccardia syrtis*, form a visible fine turf on sandstone reefs and on some sand flats.
	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.
Gastropoda	*Amphibola crenata*	3	A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria.
	Potamopyrgus estuarinus	3	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
Bivalvia	*Cyclomactra ovata*	2	Trough shell of the family Mactridae, endemic to NZ. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water.

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Bivalvia	*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 (5% mud).
Crustacea	Amphipoda sp. 1	5	Amphipoda is an order of malacostracan crustaceans with no carapace and generally with laterally compressed bodies. The name amphipoda means “different-footed”, and refers to the different forms of appendages, unlike isopods, where all the legs are alike. Of the 7,000 species, 5,500 are classified into one suborder, Gammaridea. The remainder are divided into two or three further suborders. Amphipods range in size from 1 to 340mm and are mostly detritivores or scavengers. They live in almost all aquatic environments. Amphipods are difficult to identify, due to their small size, and the fact that they must be dissected. As a result, ecological studies and environmental surveys often lump all amphipods together. Species sensitivities to muds and organic enrichment differs.
	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.
	Exosphaeroma sp.	5	Small seaweed dwelling isopod. Isopods are an order of peracarid crustaceans, including familiar animals such as woodlice and pill bugs. The name Isopoda derives from the Greek iso meaning "same" and pod meaning "foot".
	Halicarcinus whitei	3	A species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Isopoda anthuridea	NA	Anthuroidea is a superfamily of isopod crustaceans, formerly treated as a suborder, Anthuridea. The group is characterised by "an elongate cylindrical” body form.
	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*.
	Paracorophium sp.	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites we get very few.
	Tanaid	1	Tanaids (order Tanaidacea) make up a minor crustacean group within the class Malacostraca. There are about 940 species in this order. Tanaids are small, shrimp-like creatures ranging from 0.5 to 120 millimetres (0.020 to 4.7 in) in adult size, with most species being from 2 to 5 millimetres. Most are marine, but some are also found in freshwater coastal habitat or estuaries. The majority of species are bottom-dwellers in shallow water environments. Optimum Range 10-15% mud (found in 0-100% mud)
Insecta	Diptera sp.	2	Fly or midge larvae - species unknown.

* 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.