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Whangarae Estuary

Fine Scale Monitoring 2016

Prepared for

Marlborough District Council

July 2016

Cover Photo: Whangarae Estuary main basin


Whangarae Estuary

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Prepared for
Marlborough District Council

by

Barry Robertson and Leigh Stevens

Wriggle Limited, PO Box 1622, Nelson 7040, Ph 0275 417 935, 021 417 936, www.wriggle.co.nz

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WHANGARAE ESTUARY - EXECUTIVE SUMMARY

Whangarae Estuary is a relatively unmodified, moderate-sized (124ha), macrotidal (3.1m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary located within Croiselles Harbour on the east side of Tasman Bay. It has a single narrow tidal opening, a central basin and three small arms. The catchment is >95% native scrub/forest, and the estuary is perceived to be near pristine. 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 (March 2016) from two intertidal sites within the inlet. The following table summarises fine scale monitoring results, condition ratings, issues, and monitoring and management recommendations.

FINE SCALE MONITORING RESULTS

- Macroalgae was not growing at either fine scale site and was relatively uncommon in the estuary as a whole.
- Sediment mud content was rated "low-moderate" at Site A (mean 14% mud) and "high" at Site B (mean 72% mud).
- Sediment oxygenation (aRPD) was ~3cm at Site A (i.e. "moderate risk of ecological impacts") and ~1.5cm at Site B (i.e. "low 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.
- Sediment toxicants, heavy metals (Cd, Cu, Pb, Hg, Zn and arsenic) and semi-volatile organic compounds, were at concentrations that were not expected to pose toxicity threats to aquatic life. However, chromium and nickel concentrations exceeded ANZECC (2000) ISQG High limits, indicating a high risk of toxicity threats to aquatic life (e.g. benthic macroinvertebrates), despite the likely cause being attributable to natural catchment geological sources.
- Macroinvertebrates consisted of a mixed assemblage of species, with a "good" nutrient and organic enrichment rating. However, at both sites, but particularly at Site B, the abundance of macroinvertebrates compared with other NZ estuaries outside of Tasman/Marlborough was low, a fact which is likely attributable to the elevated natural metal concentrations of many Tasman/Marlborough estuaries.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

	Low		Moderate
	Very Low		High

Indicator	Site A (mid-estuary)				Site B (upper estuary)			
	2015/16	2016/17	2017/18	2022/23	2015/16	2016/17	2017/18	2022/23
Sediment Mud Content								
aRPD (Sediment Oxygenation)								
TOC (Total Organic Carbon)								
TN (Total Nitrogen)								
Invertebrate Mud/Organic Enrichment								
Metals (Cd, Cu, Hg, Pb, Zn) & As								
Metals (Cr, Ni)								
Semi-Volatile Organic Compounds								

ESTUARY CONDITION AND ISSUES

The results indicate that, apart from the naturally potentially toxic levels of metals, the estuary currently has a muddiness issue. Given the existing bush-dominated catchment, the cause of the muddiness is likely attributable to historical inputs when the catchment was logged. As such, any monitoring focus should be on confirmation that the muddiness is not increasing, and that there is a solid ecological baseline of monitoring data which can be used as a reference for assessing change in both Whangarae Inlet and other more-impacted Marlborough estuaries.

RECOMMENDED MONITORING AND MANAGEMENT

Because Whangarae Inlet is a moderate-sized tidal lagoon estuary with high ecological and human use values, situated in a largely undeveloped catchment, this estuary has been identified by MDC as a priority for monitoring. Fine scale monitoring, in conjunction with sedimentation rate monitoring and broad scale habitat mapping, provides valuable information on current estuary condition and trends over time, particularly in relation to the sedimentation issue identified in the estuary. The following monitoring recommendations are proposed by Wriggle for consideration by MDC.

Complete a three year annual baseline of fine scale monitoring. It is recommended that the second year of baseline monitoring of intertidal sites (including sedimentation rate measures) be undertaken in the period Jan-March 2017. Once the baseline has been established, a recommendation will be made on the frequency of any subsequent fine scale monitoring, likely to be repeat sampling at 5-10 yearly intervals.

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 Whangarae 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 Whangarae to issues has not yet been fully assessed. However, a recent report has documented selected ecologically significant marine sites in Marlborough (Davidson et al. 2011).
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 Whangarae 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 Whangarae Estuary, was undertaken first in 2016 and is the subject of this report.

In 2015, MDC commissioned Wriggle Coastal Management to undertake the first year of a three year fine scale monitoring baseline of Whangarae Estuary. The current report provides the 21 March 2016 fine scale monitoring results. When the full three years of baseline data has been collected, the combined data will be fully analysed and compared with estuary condition ratings in order to assess the overall estuary condition, identify any issues and recommend ongoing monitoring and management.

Whangarae Estuary is a moderate-sized (124ha), relatively unmodified, shallow, well-flushed, seawater-dominated, tidal lagoon type estuary that is open to the sea via a narrow entrance mouth. The estuary is located approximately 5km south-east of Cape Soucis in Tasman Bay and forms the south-western arm of Croiselles Harbour. It is fed by one main stream, Castor Stream, and several smaller streams. Much of the estuary catchment is regenerating coastal forest that has all been logged in the past. Around the estuary fringes are some small areas of pasture as well as stands of the regionally rare swamp maire tree, representing one of the few known sites of its kind in the South Island. Apart from the south-eastern hillside and estuary edge, most of the bush catchment is privately owned. *Spinifex*, a regionally rare sand dune plant grows on the south-east sand-spit, along with other native coastal and sand-inhabiting plants. Currently, Whangarae Estuary provides habitat for several regionally rare bird species, including the banded rail and fern bird (Davidson at al. 2011).

The area is also of high cultural value to Maori. The Ngāti Kōata Deed of Settlement for historical Treaty of Waitangi claims formally recognises the traditional, historical, cultural and spiritual association of Ngāti Kōata with Whangarae Estuary (and surrounds) and provides for formal cultural, financial and commercial redress resulting from acts or omissions by the Crown prior to 21 September 1992.

Whangarae Estuary is currently being monitored every 5-10 years and the results will help determine the extent to which the estuary is affected by major estuary issues (Table 1), both in the short and long term.

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

1. Sedimentation

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. 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 Whangarae 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 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), **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 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 Whangarae Estuary, two fine scale sampling sites (Figure 1) were selected in unvegetated mid-low water habitat in the south of the estuary. Site A was located in the sand dominated flats representative of much of the main basin, and Site B in an upper estuary deposition zone dominated by fine muds. At each site a 60m 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 which are not normalised to allow direct comparison with ANZECC (2000) Guidelines for Fresh and Marine Water Quality.
- 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 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 60m 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)

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

Sediment Accumulation

To determine the future sedimentation rate, a simple method of measuring how much sediment builds up over a buried plate over time is used. Once a plate has been buried and levelled, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. These are then measured over time (commonly annually) to assess net sediment accrual.

Two sites, each with four plates (20cm square concrete paving stones) were established in March 2016 in Whangarae Estuary at fine scale Sites A and B (Figure 1). Plates were buried deeply in the sediments where stable substrate was located and positioned 2m apart in a linear configuration along the baseline of each fine scale site. To ensure plate stability, steel waratahs (0.8 or 1.6m long) were driven into the sediments until firm substrate was encountered beneath the plates, and the plates placed on these. Steel reinforcing rod was also placed horizontally next to each buried plate to enable relocation with a metal detector.

The GPS positions of each plate were logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded (Appendix 2). In the future, these depths will be measured annually and, over the long term, will provide a measure of the rate of sedimentation in the estuary.

4. RESULTS AND DISCUSSION

A summary of the results of the 21 March 2016 fine scale intertidal monitoring of Whangarae 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, vegetation, and macrofauna results (means), Whangarae Estuary, March 2016.

Site	aRPD	Salinity	TOC	Mud	Sand	Gravel	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	TN	TP
	cm	ppt	%				mg/kg									
2016 A	3.0	32	0.19	13.6	85.0	1.4	5.5	0.02	79.0	9.2	0.01	43.3	4.0	50.3	<500	697
2016 B	1.5	32	0.57	72.0	27.5	0.5	6.1	0.03	104.3	13.1	0.03	68.3	6.1	48.7	633	703

Site	Seagrass Biomass	Macoalgal Biomass	Macrofauna Abundance	Macrofauna Richness
	(g.m^{-2} wet weight)	(g.m^{-2} wet weight)	Individuals/m^2	Species/core
2016 A	0	10	3949	11.3
2016 B	0	0	897	5.4

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 and), 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 biomass and 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.

Fine scale Site A showing muddy sand sediments

Fine scale Site B showing typical soft mud sediments

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 March 2016 monitoring results showed that the two Whangarae Estuary sites had contrasting sediment mud contents (Table 3, Figure 2). The upper estuary deposition zone Site B had the highest mud concentrations (mean 72% mud) indicative of a "high" ecological risk rating, while the more centrally located and well flushed Site A having lower mud concentrations (mean 13.6%), indicative of a "low-moderate" ecological risk rating.

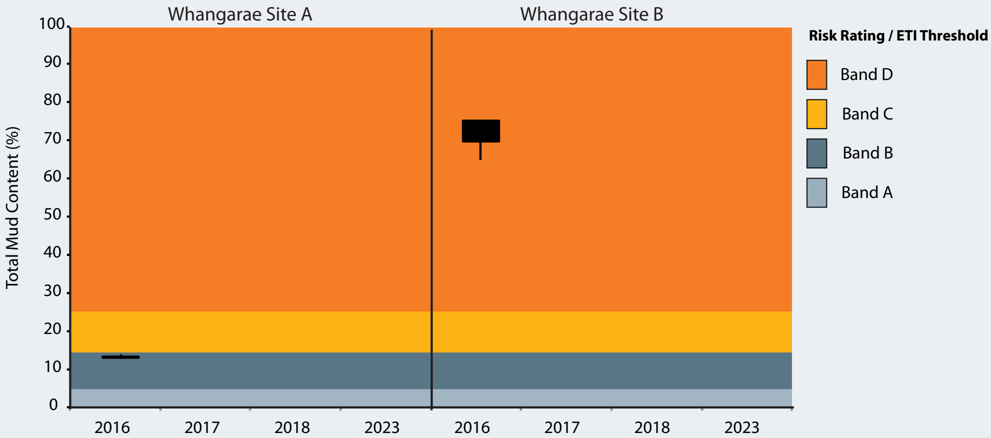

Figure 2. Mean mud content (median, interquartile range, total range, n=3), March 2016.

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*) at Site A, and its absence at Site B, combined with the other eutrophication indicators, indicates a low expression of eutrophication symptoms at the fine scale sites.

Sediment Mud Content

The above discussion of this indicator is not repeated here, however, in relation to eutrophication, the high mud contents at Site B indicate sediment oxygenation is likely to be relatively poor.

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 (RP) is under development (Robertson et al. 2016b). 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 3).

Figure 3 shows the aRPD depths for the two Whangarae Estuary sampling sites for March 2016.

4. Results and Discussion (continued)

The results show that the aRPD depth was 1.5cm at the muddy Site B, indicating a “moderate” risk of ecological impacts (Figure 3) and 3cm at Site A indicating a likely “low” risk of ecological impacts. Such conditions indicate that both Sites A and B have suitable habitat in terms of redox potential for a range of sensitive taxa but this habitat is likely to be more spatially restricted at Site B, which is likely to be reflected as a comparative reduction in the abundance of taxa sensitive to mud and organic enrichment (see Biotic Index section).

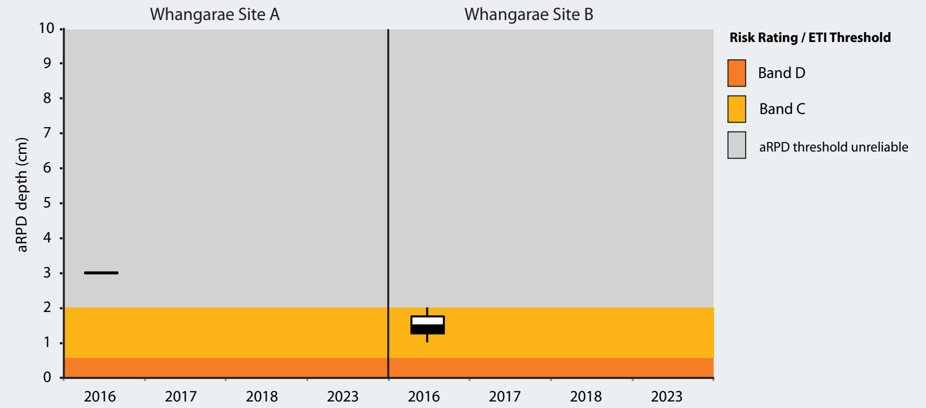

Figure 3. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3), March 2016.

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 RPD, 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 both sites showed TOC (<0.7%) and TN (<700mg/kg) were in the “very-low” to “low” ecological risk indicator rating, while TP (rating not yet developed) was relatively low at 660-750mg/kg (Figures 4, 5 and 6). Like mud and redox potential, the most impacted site (i.e. the site with the highest TOC, TN and TP concentrations) was the upper estuary Site B.

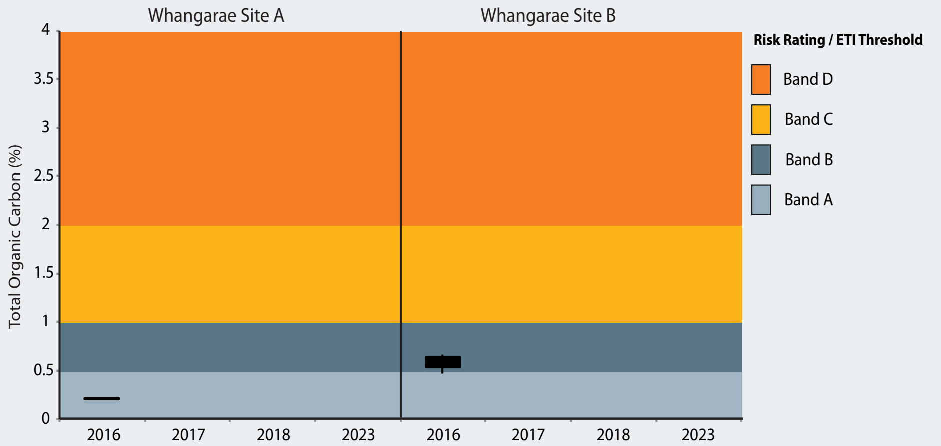

Figure 4. Mean total organic carbon (median, interquartile range, total range, n=3), March 2016.

Seagrass

When present seagrass (*Zostera muelleri*) cover and biomass on the sediment surface can mitigate or offset the negative symptoms of eutrophication and muddiness. No seagrass was present at fine scale sites in Whangarae.

Overall, the results for the sediment and eutrophication environmental variables indicate low-moderate to highly muddy sediments, with low organic and nutrient contents and moderate levels of sediment oxygenation. The upper estuary Site B was muddier, more enriched and less oxygenated than the main basin estuary site.

4. Results and Discussion (continued)

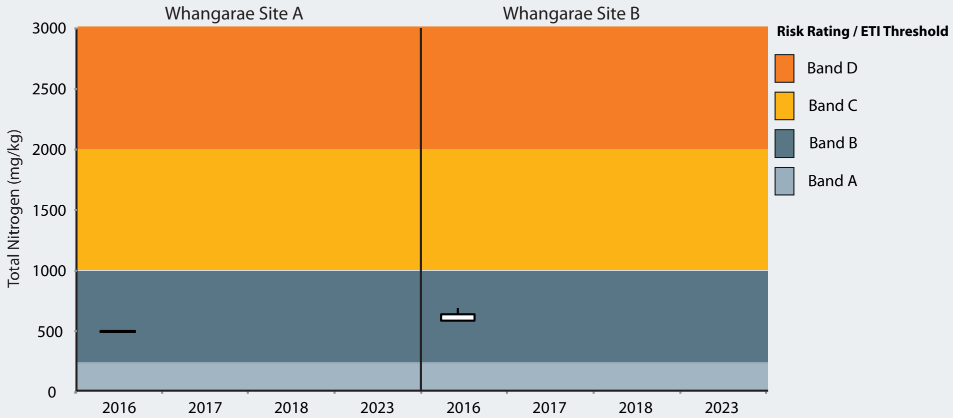

Figure 5. Mean total nitrogen (median, interquartile range, total range, n=3), March 2016.

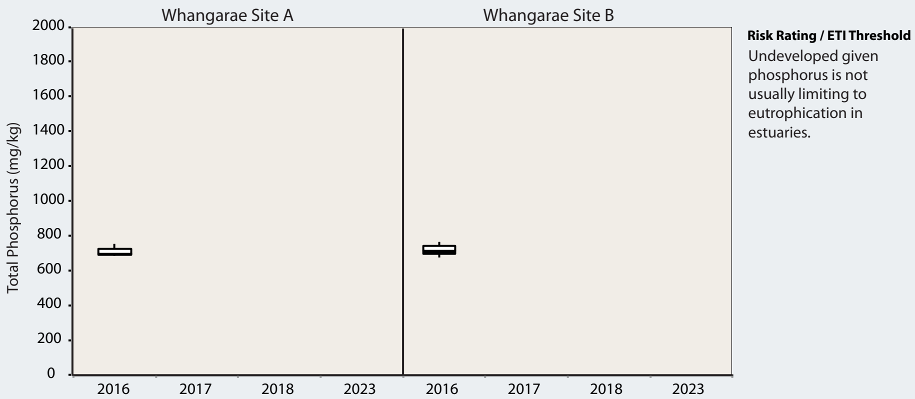

Figure 6. Mean total phosphorus (median, interquartile range, total range, n=3), March 2016.

TOXICITY INDICATORS

In March 2016, the heavy metals Cd, Cu, Hg, Pb, Zn and arsenic, used as indicators of potential toxicants, were present at "very low" to "low" concentrations with all non-normalised values 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) Sites A and B, March 2016.

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
March 2016 A 1-4 *	0.0183	79	9.4	44	4.2	52	6.1	0.012
March 2016 A 4-8 *	0.0203	79	9.1	44	4.1	50	5.7	0.010
March 2016 A 9-10 *	0.0203	82	9.3	45	4.1	52	5.1	<0.010
March 2016 B 1-4 *	0.0324	99	12.9	66	6.2	48	6.3	0.029
March 2016 B 4-8 *	0.0335	101	12.8	66	6.0	49	6.1	0.023
March 2016 B 9-10 *	0.0335	117	14.2	76	6.3	52	6.3	0.023
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
[b] ISQG-Low	1.5	80	65	21	50	200	20	0.15
[b] ISQG-High	10	370	270	52	220	410	70	1

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

However, chromium and nickel were present at both sites at concentrations exceeding (or close to exceeding for two replicates at Site A) the ISQG Low trigger, and for nickel at Site B, the ISQG-High limits. This is likely attributable to elevated inputs in run-off from the geologically nickel and chromium enriched catchment (Robinson et al. 1996, Rattenbury et al. 1998), and the high affinity of heavy metals for muds acting to transport and sequester them into estuarine sediments (Whitehouse et al. 1999). In such cases as this, where the ISQG limit is exceeded and the likely cause is natural, the revised ANZECC (2000) guidelines (Simpson et al. 2013) recommend no further action.

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), and pthalates (Appendix 1 describes the analytical methods and Appendix 2 presents the results in full). The results indicate that all analytes were found to be less than the analytical detection limits and, for the organochlorine pesticides (which were analysed at trace levels), were less than the revised ANZECC (2000) guideline (Simpson et al. 2013) SQG values and therefore unlikely to cause toxicity to benthic macrofauna.

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 Whangarae 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 data for March 2016 showed that Site B had lower species richness (4-8 per core), abundance (6-16 per core) and Shannon diversity (0.89-1.24) than Site A - species richness (6-15 per core), abundance (21-80 per core) and Shannon diversity (1.14-1.5). The data also showed that species richness, and particularly abundance, at both Sites A and B, while similar to those from within the region, were relatively low compared to most other estuaries outside of the natural nickel and chromium-enriched sediments of the Tasman/Marlborough region (Figure 8).

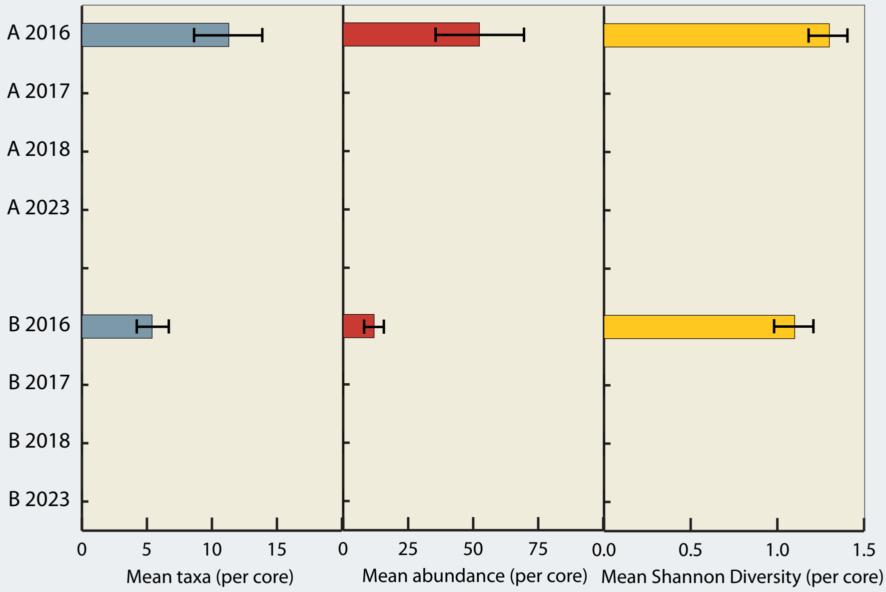

Figure 7. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Whangarae Estuary, March 2016.

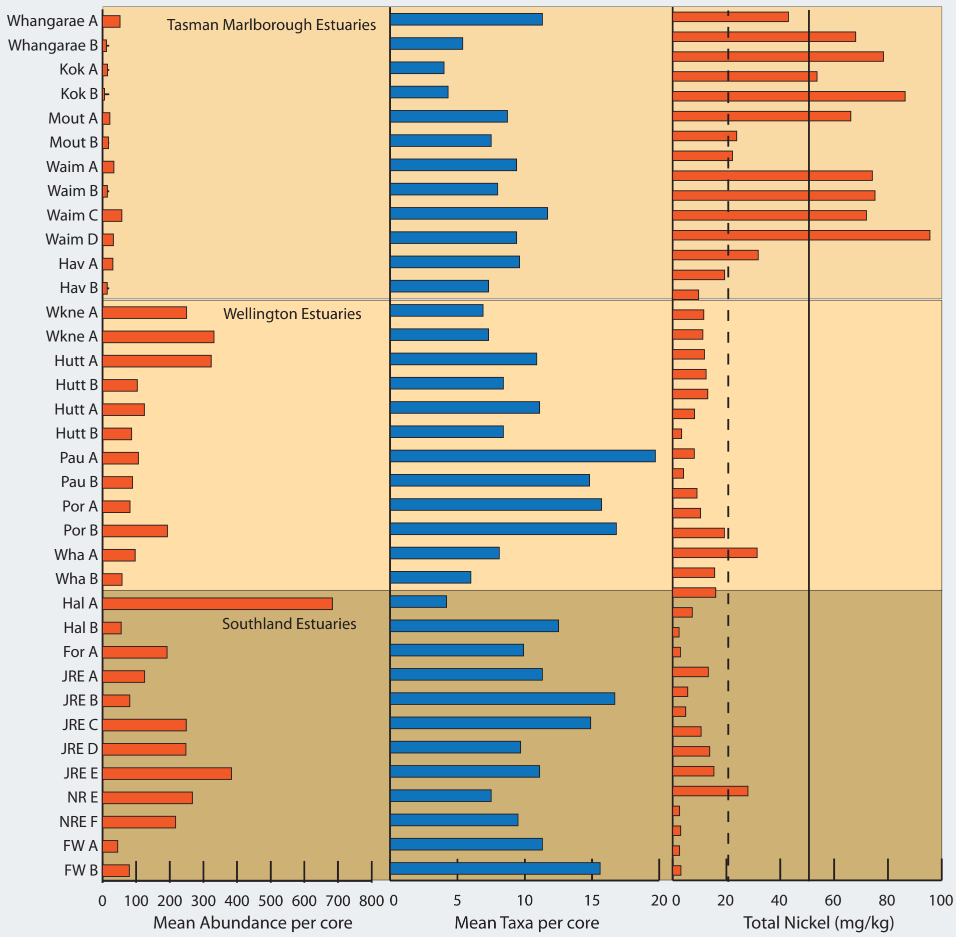

Figure 8. Mean abundance, mean taxa, and total recoverable nickel concentrations at two Whangarae Estuary sites, and a range of other sites from typical NZ tidal lagoon estuaries (Wriggle Coastal Management database). **Dashed and solid lines are ANZECC ISQG Low and High nickel trigger values respectively.**

Figure 9 shows that although the community at both sites was dominated by polychaetes, bivalves and crustacea, the sand dominated Site A had greater abundances than the mud dominated Site B, particularly with regard to polychaetes and bivalves.

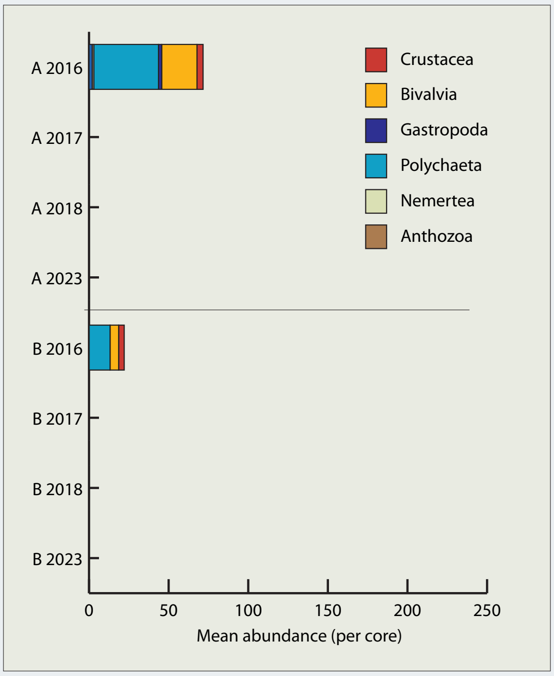

Figure 9. Mean abundance of major infauna groups (n=10), Whangarae Estuary, March 2016.

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 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.

For the two fine scale sites in Whangarae Estuary, the NZ AMBI biotic coefficients were 1.3 (Site A) and 3.8 (Site B) and were in the "low" to "moderate" ecological condition category (i.e. a "slightly unbalanced" to "transitional" type community indicative of low levels of organic enrichment and moderate to high mud concentrations) (Figure 10). As expected, the muddier and more organically enriched upper Site B, had consistently higher NZ AMBI biotic coefficients than the more marine influenced, and sand dominated main basin Site A.

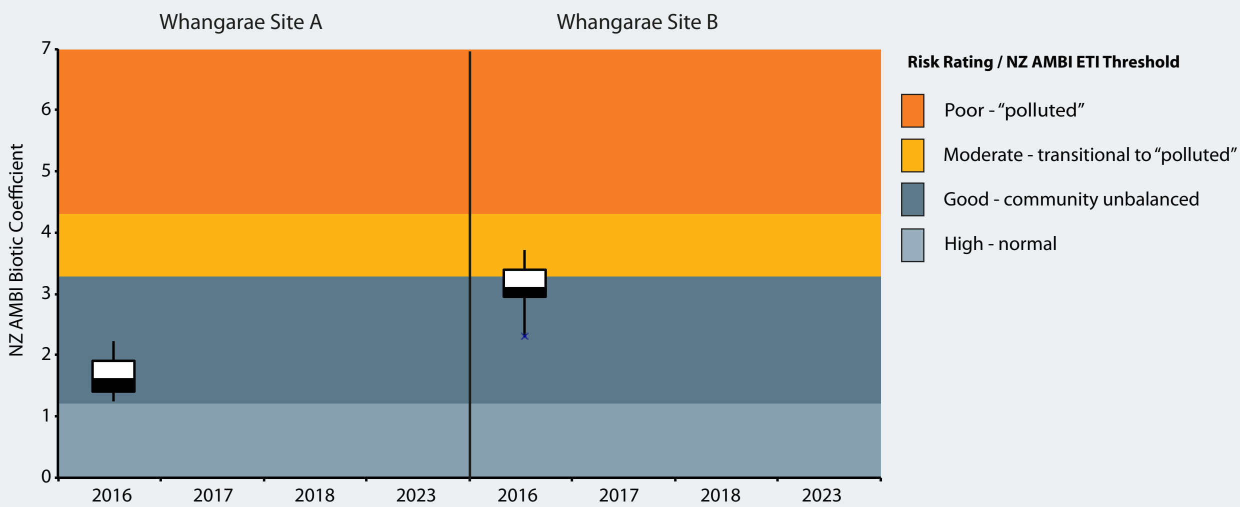

Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Whangarae Estuary, March 2016.

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 11). The results clearly show the cause of the difference in NZ AMBI results between the two sites to be as follows:

- the lack of any Group 1 taxa (i.e. "very sensitive to mud and organic enrichment") at the muddy Site B,
- the accompanying much lower abundance and diversity of Group 2 (i.e. "indifferent to mud and organic enrichment") and Group 3 ("tolerant of mud and organic enrichment") sensitivity categories at Site B.

In terms of individual taxa, Site A had consistently high numbers of cockles (*Austrovenus stutchburyi) and* wedge shells (*Tellina liliana*) distributed throughout the site, whereas these bivalves were less common at Site B. Site A also had elevated numbers of the very sensitive Maldanid polychaetes, and the slightly less sensitive polychaete *Prionospio aucklandica*.

In addition, as could be expected from sites with "low-moderate" to "high" levels of muddiness, both Sites A and B had a few taxa from Groups 4 and 5 (i.e. "tolerant and very tolerant to mud and organic enrichment " respectively) sensitivity groupings. The fact that the muddier Site B did not show a much greater population of tolerant taxa was perhaps attributable to it's low organic content or elevated nickel and chromium concentrations.

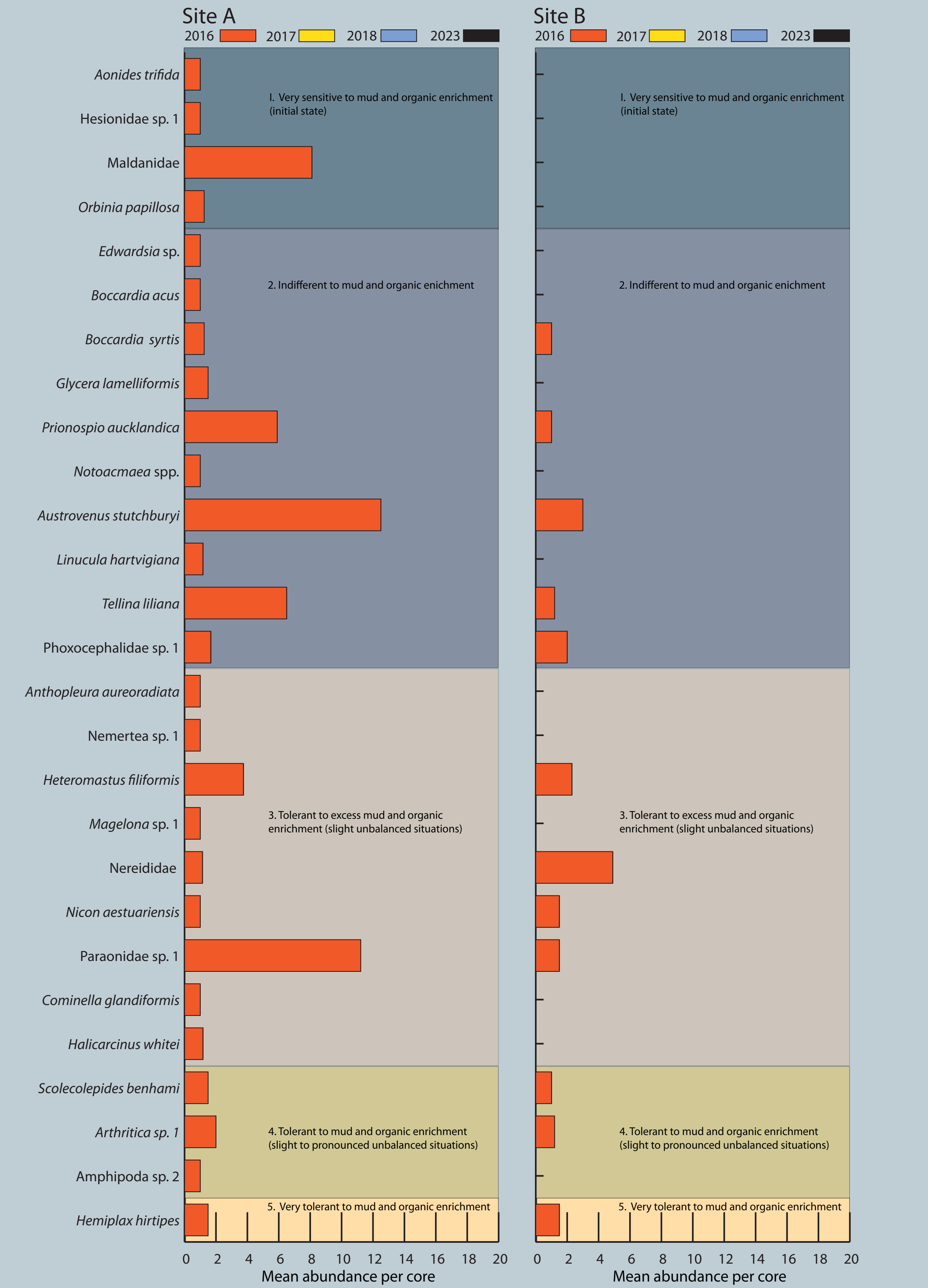

Figure 11. Mud and organic enrichment sensitivity of macroinvertebrates, Whangarae Estuary, March 2016 (see Appendix 3 for sensitivity details).

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for the two long term intertidal monitoring sites within Whangarae Estuary in March 2016, showed the following key findings:

Physical and Chemical Condition

- Macroalgae was <5% at the fine scale sites, and was relatively uncommon in the estuary generally (Stevens and Robertson 2016), indicating low levels of eutrophication.
- Sediment mud content was rated "low-moderate" at Site A (mean 14% mud) and "high" at Site B (mean 72% mud) indicating a muddiness issue in the upper estuary.
- Sediment oxygenation (aRPD) was ~3cm at Site A (i.e. "moderate risk of ecological impacts") and ~1.5cm at Site B (i.e. "low risk of ecological impacts").
- Sediment organic matter and nutrient concentrations were low (TOC <0.7% and TN <700mg/kg, i.e. "low-moderate risk of ecological impacts"), while TP was unrated but relatively low at 660-750mg/kg. Like mud and redox potential, the most impacted site (i.e. the site with the highest TOC, TN and TP concentrations) was the upper estuary Site B.
- Sediment toxicants, heavy metals (Cd, Cu, Pb, Hg, Zn and arsenic) and semi-volatile organic compounds, were at concentrations that were not expected to pose toxicity threats to aquatic life. However, chromium and nickel concentrations exceeded ANZECC (2000) ISQG High limits, indicating a high risk of toxicity threats to aquatic life (e.g. benthic macroinvertebrates), despite the likely cause being attributable to natural catchment geological sources. In such cases as this, where the ISQG high limit is exceeded and the likely cause is natural, the ANZECC (2000) guidelines recommend further investigation to examine factors controlling metal bioavailability.

Biological Condition

- The macroinvertebrate community consisted of a mixed assemblage of species, dominated at both sites by polychaetes, bivalves and gastropods. In terms of mud and organic enrichment, the NZ AMBI scores indicated a community dominated by both sensitive, and moderately tolerant taxa and overall good ecological condition with respect to these potential stressors. However, at both sites, but particularly at Site B, there was low species richness, abundance and diversity. Compared to other estuaries outside of the Tasman/Marlborough region, the abundance of macroinvertebrates was particularly low, a fact which is likely attributable to the elevated natural metal concentrations in Whangarae Inlet (and many other Tasman/Marlborough estuaries).

In summary, the results for the site representing the majority of the mid-low water estuary habitat (i.e. Site A) indicated moderately muddy conditions, with low organic and nutrient contents, moderate levels of sediment oxygenation, high levels of potentially toxic metals (from natural sources), and a relatively depauperate, mud-tolerant macroinvertebrate community that is common to many estuaries in the Tasman/Marlborough region. In contrast, the results for Site B (which represents the more localised upper estuary mud deposition zone and hence an early warning indicator of a muddiness issue), indicated highly muddy conditions, and an even more depauperate macroinvertebrate community, but similar low organic and nutrient contents, moderate levels of sediment oxygenation and high levels of potentially toxic metals (from natural sources). The results indicate that, apart from the naturally potentially toxic levels of metals, the estuary currently has a muddiness issue. However, given the existing bush-dominated catchment, the cause of the muddiness is likely attributable to historical inputs when the catchment was logged. As such, any monitoring focus should be on confirmation that the muddiness is not increasing, and that there is a solid ecological baseline of monitoring data which can be used as a reference for assessing change in both Whangarae Estuary and other more-impacted, Marlborough estuaries.

6. MONITORING

RECOMMENDED MONITORING

Whangarae Estuary has been identified by MDC as a priority for monitoring because of its relatively unmodified condition, high ecological and human use values, and because its estuary type means it is very vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of MDC's coastal monitoring programme being undertaken in a staged manner throughout the region. The present report addresses the fine scale intertidal component of the long term programme. The recommendation for ongoing monitoring for this component is as follows.

Fine Scale Monitoring

Fine scale intertidal sampling of Sites A and B has now been undertaken for one baseline year (March 2016). It is recommended that fine scale intertidal monitoring of the two established sites (including sedimentation rate measures) be undertaken for the next two years to establish a robust baseline of estuary condition. As the SVOCs and pesticide toxicant indicators showed a low risk, it is recommended that these be excluded from subsequent baseline monitoring.

Once the baseline has been established, a recommendation will be made on the frequency of any subsequent fine scale monitoring.

Broad Scale Habitat Mapping

As addressed separately by Stevens and Robertson (2016), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals unless obvious changes are observed in the interim (next scheduled for 2026).

RECOMMENDED 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. We are also very grateful to Roy and Twinkle Te Kotua for their warm welcome to Whangarae, and for sharing their vast knowledge of the estuary with us, and to Megan Southwick and Sally O'Neill for help with the field sampling.

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

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
Semivolatile Organic Compounds	R.J Hill	Sonication extraction, GPC cleanup (if required), GC-MS FS analysis.	0.3-30 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 (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	1-9	10-99	100-999	1000-9999	>10,000
O	F	C	A		1-9	10-99	100-999	1000-9999
R	O	F	C			1-9	10-99	100-999
-	R	O	F				1-9	10-99
-	-	R	O					1-9
-	-	-	R					<1

APPENDIX 2. 2015/16 DETAILED RESULTS

Fine Scale Site Boundaries

Whangarae Site A	1	2	3	4	**Whangarae Site B**	1	2	3	4
NZTM EAST	1651846	1651873	1651900	1651867	NZTM EAST	1652162	1652192	1652191	1652152
NZTM NORTH	5450140	5450127	5450181	5450197	NZTM NORTH	5449779	5449777	5449717	5449725

Fine Scale Station Locations

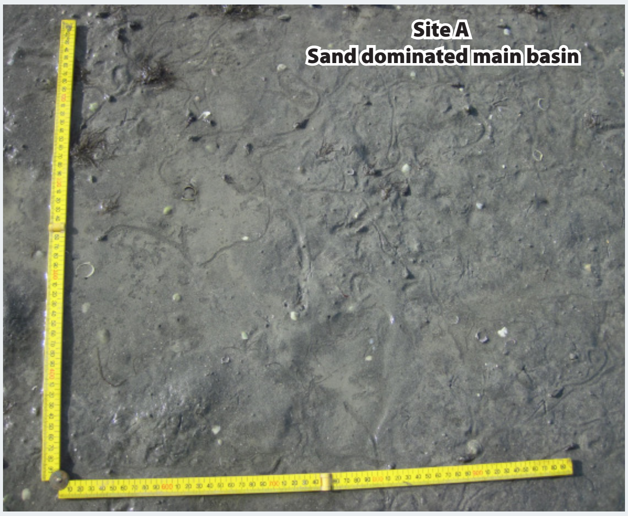
Whangarae Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1651852	1651859	1651865	1651869	1651881	1651876	1651868	1651863	1651873	1651878
NZTM NORTH	5450146	5450159	5450172	5450186	5450182	5450168	5450156	5450143	5450139	5450151
Whangarae Site B	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1652165	1652164	1652161	1652161	1652170	1652172	1652173	1652173	1652183	1652184
NZTM NORTH	5449770	5449760	5449748	5449735	5449731	5449742	5449759	5449768	5449763	5449748

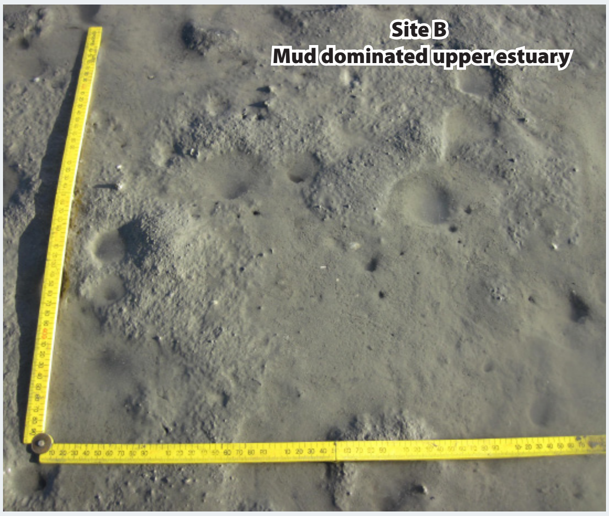
Whangarae Estuary sediment plate and peg locations and depth of plate (mm) below surface

Site A Sed Plates (Firm Muddy Sand)	NZTM East	NZTM North	Height/Depth (mm) March 2016	**Site B Sed Plates** (Very Soft Mud)	NZTM East	NZTM North	Height/Depth (mm) March 2016
Peg 1	1651846	5450140	+150	Peg 1	1652162	5449779	+150
Plate 1	1651851	5450138	-106	Plate 1	1652168	5449780	-62
Plate 2	1651856	5450136	-101	Plate 2	1652173	5449779	-85
Peg 2	1651860	5450134	+100	Peg 2	1652177	5449778	+100
Plate 3	1651865	5450131	-84	Plate 3	1652182	5449778	-96
Plate 4	1651867	5450129	-72	Plate 4	1652186	5449778	-82
Peg 3	1651873	5450127	+100	Peg 3	1652192	5449777	+100

Epifauna abundance and macroalgal cover at fine scale sites, March 2016

Group	Family	Species	Common name	Scale	Class	A	B
Topshells	Amphibolidae	*Amphibola crenata*	Estuary mud snail	#	ii	-	F
	Buccinidae	*Cominella glandiformis*	Mudflat whelk	#	ii	-	F
	Trochidae	*Diloma subrostrata*	Grooved topshell	#	ii	C	-
	Buccinidae	*Zeacumantus lutulentus*	Spire shell	#	ii	C	F
Red algae	Gracilariaceae	*Gracilaria* sp. ?*secundata*	Gracilaria weed	%	ii	R	-





Appendix 2. 2015/16 Detailed Results (continued)

Physical and Chemical Results for Whangarae Estuary (Sites A and B), March 2016

Note; metal concentrations include all sediment fractions.

Year/Site/Rep	RPD	Salinity	TOC	Mud	Sand	Gravel	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	TN	TP
	cm	ppt	%				mg/kg									
March 2016 A 1-4 *	3	32	0.19	13.3	85.3	1.4	6.0	0.018	78	9.3	0.012	43	4.1	51	<500	740
March 2016 A 4-8 *	3	32	0.20	13.3	85.9	0.8	5.6	0.020	78	9.0	0.01	43	4.0	49	<500	670
March 2016 A 9-10 *	3	32	0.18	14.1	83.9	1.9	5.0	0.020	81	9.2	< 0.010	44	4.0	51	<500	680
March 2016 B 1-4 *	1	32	0.65	75.7	24.2	0.1	6.2	0.032	98	12.7	0.029	65	6.1	47	700	750
March 2016 B 4-8 *	1.5	32	0.60	75.1	24.5	0.4	6.0	0.033	100	12.6	0.023	65	5.9	48	600	700
March 2016 B 9-10 *	2	32	0.45	65.1	33.8	1.1	6.2	0.033	115	14.0	0.023	75	6.2	51	600	660
ISQG-Low [a]	-	-	-	-	-	-	20	1.5	80	65	0.15	21	50	200	-	-
ISQG-High [a]	-	-	-	-	-	-	70	10	370	270	1	52	220	410	-	-

[a] ANZECC 2000. *composite samples.

Non-normalised semi volatile organic compounds (SVOCs) in Whangarae Estuary, 2016.

Note: results are for a single composite sample for each site, with no analysed compound present at detectable levels (all reported as mg/kg d.w.).

GROUP	Organic Chemical	WHE A 2016	WHE B 2016
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*	< 0.8	< 0.9
	1,3-Dichlorobenzene	< 0.8	< 0.9
	1,4-Dichlorobenzene	< 0.8	< 0.9
	Hexachlorobutadiene	< 0.8	< 0.9
	Hexachloroethane	< 0.8	< 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*	< 9	< 10
	C10 - C14	< 20	< 20
	C15 - C36	< 40	< 40
	Total hydrocarbons (C7 - C36)	< 70	< 70

Appendix 2. 2015/16 Detailed Results (continued)

Non-normalised semi volatile organic compounds (SVOCs) in Whangarae Estuary, 2016.

Note: results are for a single composite sample for each site, with no analysed compound present at detectable levels (all reported as mg/kg d.w.).

GROUP	Organic Chemical	WHE A 2016	WHE B 2016
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
	cis-Chlordane	< 0.0010	< 0.0010
	trans-Chlordane	< 0.0010	< 0.0010
	2,4'-DDD	< 0.0010	< 0.0010
	4,4'-DDD	< 0.0010	< 0.0010
	2,4'-DDE	< 0.0010	< 0.0010
	4,4'-DDE	< 0.0010	< 0.0010
	2,4'-DDT	< 0.0010	< 0.0010
	4,4'-DDT	< 0.0010	< 0.0010
	Total DDT Isomers	< 0.006	< 0.006
	Dieldrin	< 0.0010	< 0.0010
	Endosulfan I	< 0.0010	< 0.0010
	Endosulfan II	< 0.0010	< 0.0010
	Endosulfan sulphate	< 0.0010	< 0.0010
	Endrin	< 0.0010	< 0.0010
	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
Polycyclic Aromatic Hydro-carbons	*Acenaphthene*	< 0.5	< 0.5
	Acenaphthylene	< 0.5	< 0.5
	Anthracene	< 0.5	< 0.5
	Benzo[a]anthracene	< 0.5	< 0.5
	Benzo[a]pyrene (BAP)	< 0.5	< 0.5
	Benzo[b]fluoranthene + Benzo[j]fluoranthene	< 0.5	< 0.5
	Benzo[g,h,i]perylene	< 0.5	< 0.5
	Benzo[k]fluoranthene	< 0.5	< 0.5
	1&2-Chloronaphthalene	< 0.5	< 0.5
	Chrysene	< 0.5	< 0.5
	Dibenzo[a,h]anthracene	< 0.5	< 0.5
	Fluoranthene	< 0.5	< 0.5
	Fluorene	< 0.5	< 0.5
	Indeno(1,2,3-c,d)pyrene	< 0.5	< 0.5
	2-Methylnaphthalene	< 0.5	< 0.5
	Naphthalene	< 0.5	< 0.5
	Phenanthrene	< 0.5	< 0.5
	Pyrene	< 0.5	< 0.5
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

Appendix 2. 2015/16 Detailed Results (continued)

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

Whangarae Estuary Sites A and B, March 2016

	Species	NZ AMBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
ANTHOZOA	*Anthopleura aureoradiata*	3								1												
	Edwardsia sp.	2										1										
NEMERTEA	Nemertea sp. 1	3										1										
POLYCHAETA	*Aonides trifida*	1					1	1														
	Boccardia acus	2					1															
	Boccardia syrtis	2			1		1		2	1			1				1	1				
	Glycera lamelliformis	2						2				1										
	Hesionidae sp. 1	1		1																		
	Heteromastus filiformis	3	8	2			3	2	4	1	6	4	4	1	2	2	2	3	1	3	2	3
	Magelona sp. 1	3	1								1											
	Maldanidae	1	2	7	6	2	12	6	20		15	3										
	Nereididae	3		1	1	1	1		1	2		1	5	8	2	6	4	7	3	5	3	6
	Nicon aestuariensis	3	1																1	2		
	Orbinia papillosa	1		1	1	2		1														
	Paraonidae sp. 1	3	12	6	9		5	1	22	22	14	10	1				3		1	1		
	Prionospio aucklandica	2	7	6	6	4	6	4	9	8	4	5		1		1						1
	Scolecolepides benhami	4	1	2									1	1		1						
GASTROPODA	*Cominella glandiformis*	3		1																		
	Notoacmaea spp.	2	1						1	1	1											
BIVALVIA	*Arthritica* sp. 1	4	1							2		3	1		1			1		2	1	
	Austrovenus stutchburyi	2	11	5	19	8	13	9	12	7	19	22		1								5
	Linucula hartvigiana	2	1		1		1	1	1	2												
	Tellina liliana	2	3	4	7	4	9	5	6	14	7	6	1					2	1		1	1
CRUSTACEA	Amphipoda sp. 2	4	1							1												
	Halicarcinus whitei	3	2	1				1	1	1		1										
	Hemiplax hirtipes	5											1	1	1		1		2	3		
	Phoxocephalidae sp. 1	2	2	4				1	1	1	1							2				
Total species in sample			**15**	**13**	**9**	**6**	**11**	**12**	**12**	**14**	**9**	**12**	**8**	**6**	**4**	**4**	**5**	**6**	**6**	**6**	**4**	**5**
Total individuals in sample			**54**	**41**	**51**	**21**	**53**	**34**	**80**	**64**	**68**	**58**	**15**	**13**	**6**	**10**	**11**	**16**	**9**	**16**	**7**	**16**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group	Group and Species	NZ AMBI Group	Details
Anthozoa	*Anthopleura aureoradiata*	3	Mud flat anemone, attaches to cockle shells and helps to reduce the rate at which cockles accumulate parasites. It can also grow in small vertical shafts of its own an inch or more deep, fastened to small stones. Grows up to 10mm, intolerant of low salinity, high-turbidity and increasing silt/clay sediment content (Norkko et al. 2001). It has green plant cells in its tissues that convert solar energy to food.
	Edwardsia sp.1	2	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
Polychaeta	*Aonides* sp.#1	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.
	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.
	Boccardia syrtis	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Some species very sensitive to organic enrichment and usually present under unenriched conditions.
	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.
	Hesionidae	1	Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The NZ species are little known.
	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. Mito-chondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	Magelona sp. 1	3	The Magelonidae is a small family of polychaete worms, with around 70 species described worldwide. *Magelona* sp. 1 is a thin, thread-like segmented worm that reaches lengths of up to 8-10 cm. It forms fragile tubles in clean to muddy sand on the lower shore.
	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 habi-tats. 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.
	Orbinia papillosa	1	Endemic orbiniid. Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.

Appendix 3. Infauna Characteristics (continued)

Group	Species	NZ AMBI Group	Details
Polychaeta	Paraonidae	3	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15cm and appear to be sensitive to changes in the mud content of the sediment. Some species of *Aricidea* are associated with sediments with high organic content
Polychaeta	*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.
Polychaeta	*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	*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.
Gastropoda	*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.
Bivalvia	*Arthritica bifurca*	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
Bivalvia	*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).
Bivalvia	*Linucula hartvigiana*	2	Small deposit feeder. Nut clam of the family Nuculidae (<5mm), is endemic to NZ. Often abundant in top few cm. It is found intertidally and in shallow water, especially in *Zostera* eel grass flats. It is often found together with the NZ cockle, *Austrovenus stutchburyi*, but is not as abundant. Like *Arthritica* this species feeds on organic particles within the sediment. Has a plug-like foot, which it uses for motion in mud deposits. **Intolerant of organic enrichment**. High abundance in Porirua Harbour near sea (Railway and Boatshed sites). None in Freshwater Estuary.
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.

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ AMBI Group	Details
Crustacea	Amphipoda	Sp 2 = 4	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 340 millimetres (0.039 to 13 in) 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.
	Halicarcinus whitei	3	Another 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.*
	Phoxocephalidae sp.1	2	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.

* 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 Whangarae Estuary samples (March 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.