Manawatu Estuary
Fine Scale Monitoring 2016-17

June 2017

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Prepared for:

Abby Matthews
Science Manager
Horizons Regional Council

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Prepared by:

Barry Robertson and Leigh Stevens
Wriggle Limited
PO Box 1622
Nelson 7040
www.wriggle.co.nz
Telephone 0275 417 935 or 021 417 936

CONTACT	**24 hr Freephone 0508 800 800**		**help@horizons.govt.nz**		**www.horizons.govt.nz**
SERVICE CENTRES	**Kairanga** Cnr Rongotea and Kairanga-Bunnythorpe Roads Palmerston North **Marton** Hammond Street **Taumarunui** 34 Maata Street	**REGIONAL HOUSES**	**Palmerston** North 11-15 Victoria Avenue **Wanganui** 181 Guyton Street	**DEPOTS**	**Levin** 11 Bruce Road **Taihape** Torere Road Ohotu **Woodville** 116 Vogel Street
POSTAL ADDRESS	Horizons Regional Council, Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442				F 06 9522 929

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Cover Photo: Sampling at Site B, Manawatu Estuary, January 2017

Manawatu Estuary intertidal flats, January 2017

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

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MANAWATU ESTUARY - EXECUTIVE SUMMARY

This report summarises the fine scale monitoring undertaken in January 2017 at two benthic sites (Sites A and B) established in dominant firm mud sand habitat in Manawatu Estuary, a shallow, short residence, tidal river estuary (SSRTRE) that flows into the Tasman Sea. It is one of the key estuaries in Horizons Regional Council's (HRC's) long-term coastal monitoring programme. Monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations are presented below.

FINE SCALE MONITORING RESULTS

- Macroalgae and seagrass were absent at both Sites A and B.
- Sediment mud content was at moderate to high levels (17% to 27% mud).
- Sediment oxygenation was moderate (aRPD 2cm depth).
- The indicators of organic and nutrient enrichment were at "low" levels.
- Sediment toxicant indicators, heavy metals (Cd, Cu, Cr, Ni, Pb, Hg, Zn) and metalloids (As), were at concentrations that were not expected to pose toxicity threats to aquatic life.
- The macroinvertebrate community index (NZH AMBI) results indicated a "moderate-poor" ecological condition rating at both Sites A and B (i.e. a "transitional to impoverished" type macroinvertebrate community, typical of large tidal river estuaries).
- The macroinvertebrate community was dominated at both sites by species tolerant of mud and organic enrichment, in particular the tube-dwelling corophioid amphipod *Paracorophium,* which is often present in muddy upper estuary areas with regular low salinity conditions, and the small estuarine snail *Potamopyrgus estuarinus* (limited to brackish upper estuary conditions).
- Also observed during both the 2016 broad scale and 2017 fine scale surveys, was the presence of turbid, green-tinged estuary waters indicating excessive nutrient and chlorophyll *a* concentrations (19mg/l chlorophyll *a* in 2016) in the main estuary channel.

BENTHIC RISK INDICATOR RATINGS

(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

🟦	Low	🟨	Moderate
⬜	Very Low	🟧	High

Manawatu Estuary	Site A				Site B			
	2017	2018	2019	2024	2017	2018	2019	2024
Sediment Mud Content	🟨				🟨			
Sediment Oxygenation (aRPD or RP)	🟨				🟨			
TOC (Total Organic Carbon)	⬜				⬜			
TN (Total Nitrogen)	🟦				🟦			
Invertebrate Mud/Organic Enrichment	Mod-High				Mod-High			
Metals (Cd, Cu, Cr, Ni, Pb, Hg, Zn) & As	Low-Very Low				Low-Very Low			

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, indicated:

- A low level of expression for eutrophication symptoms (i.e. nuisance macroalgal growth) on the intertidal flats but a potential for phytoplankton blooms in stratified bottom water in the upper estuary during summer low flow periods.
- A moderate level of expression for muddiness accompanied by reduced sediment oxygenation and a relatively impoverished type macroinvertebrate community, dominated by freshwater tolerant taxa.

Such findings are relatively common in large tidal river estuaries with developed catchments, high nutrient and sediment loads, and frequent low salinity conditions. Because of the strong flushing in such estuaries, fine sediment and nutrients largely pass directly through the estuary to the open coastal waters where they are expected to strongly influence the coastal ecology.

Manawatu Estuary - Executive Summary (continued)

RECOMMENDED MONITORING AND MANAGEMENT

Manawatu Estuary has been identified by HRC as a priority for monitoring because of its high ecological and human use values. It has been assessed as having a low susceptibility to eutrophication and a moderate susceptibility to excessive fine sediment inputs reflecting current estimated loads and its highly flushed nature. In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the fine scale component of the long term programme. The recommendation for ongoing monitoring to meet this requirement for the Manawatu Estuary is as follows:

Fine Scale Monitoring

- Complete the remaining 2 consecutive years of annual summer (i.e. December-February) of baseline fine scale monitoring of intertidal sites (including sedimentation rate measures) in Manawatu Estuary undertaken in 2018 and 2019 (preferably during a summer, low flow period).
- To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a summer, prolonged low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 3-4 sites in the main channel of the estuary.
- To characterise the potential for excessive sedimentation, it is recommended that sedimentation rates be assessed annually, using appropriately placed sediment plates, and the areal extent of muddy sediments be assessed at 5-10 yearly intervals (the latter assessed in broad scale monitoring).

Broad Scale Habitat Mapping

Undertake broad scale habitat mapping at 5 yearly intervals, focusing on the main issue of sediment. It is recommended that an estimate also be made of the historical extent of the estuary using combined information derived from historical maps, photos, descriptions, as well as any available survey or LIDAR data.

Catchment Landuse

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

Management

Overall, a step-wise management approach is recommended to cost effectively address the source of stressors, identify management targets, and guide management to help ensure that the assimilative capacity of the estuary is not exceeded so that the estuary can flourish and provide sustainable human use and ecological values in the long term. The data available to date suggest that management actions are required to minimise ongoing fine sediment impacts in the estuary in order to prevent deterioration in the estuary's ecological condition. While currently not a significant issue in the estuary itself, high nutrient concentrations flushing through the estuary may be contributing to impacts in coastal areas outside of the estuary.

As an initial step, it is recommended that the following management actions be considered by HRC:

- Determine the fine sediment (and nutrient) inputs to the estuary including relative inputs from dominant catchment land uses.
- Determine relevant sediment and nutrient guideline criteria for the estuary (e.g. under development ANZECC guidelines or NZ ETI) to maintain healthy estuary functioning.
- Determine any load reductions required to maintain health estuary functioning.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. A long-term objective of the Horizons Regional Council (HRC) is to incorporate all significant estuaries within their State of Environment monitoring framework through implementation of the NZ National Estuary Monitoring Protocol (NEMP, Robertson et al. 2002). While the region's estuaries have received relatively little attention, the Department of Conservation funded broad scale habitat mapping of the Whanganui River Estuary in 2009 (Stevens and Robertson 2009), and in late 2015 HRC commissioned an Ecological Vulnerability Assessment for all of the estuaries within the region to assess sediment and eutrophication risks, map dominant habitat features, and provide the Council with defensible monitoring recommendations and priorities (Robertson and Stevens 2016).

In addition, and in recognition of the high ecological value of the Manawatu Estuary, HRC commissioned detailed broad scale habitat mapping which was undertaken in January 2016.

The estuary monitoring process consists of three components developed from the NEMP [see Robertson et al. 2002 for original programme design, and subsequent extensions for fine scale monitoring (see Robertson and Stevens 2015) and broad scale habitat mapping (see Stevens and Robertson 2015)] as follows:

- **Ecological Vulnerability Assessment (EVA)** of the estuary to major issues (see Table 1) and appropriate monitoring design. This component has been partially undertaken (includes assessment of vulnerabilities to sediment and eutrophication only but excludes other coastal resources and pressures), and is reported on in Robertson and Stevens (2016).
- **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. The inaugural broad scale habitat mapping was undertaken in Manawatu Estuary in January 2016 in tandem with the EVA (Stevens and Robertson 2016).
- **Fine Scale Monitoring (NEMP approach)** 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), was first undertaken in January 2017 and is the subject of this report.

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.

Manawatu Estuary

The Manawatu Estuary is a large (533ha), shallow, short residence, tidal river estuary (SSRTRE) located near Foxton. It has a large freshwater inflow which, when combined with the marine inflow, has a tidal influence that extends ~11km inland. The upper estuary is often stratified, largely confined within defined river channels and is characterised by low salinity surface waters. It is flanked by narrow bands of predominantly brackish aquatic plants then pasture. In contrast, the middle and lower reaches have large intertidal flats and saltmarsh. The estuary mouth is always open to the sea. The estuary catchment is extensively developed with land use predominantly sheep, beef and dairy farming, but also some urban.

The estuary is a high use area valued for its aesthetic appeal, bathing, boating, fishing, whitebaiting and beach access. Ecologically it is important for freshwater fish and internationally significant for birds. Although the natural vegetated margin is mostly lost and much of the upper estuary channelised, habitat diversity is moderate-high, with relatively extensive areas of saltmarsh remaining (161ha, 30%). It was designated a wetland of international importance under the Ramsar Convention in July 2005.

The estuary has a high nutrient load (estimated catchment N areal loading of 3,245 $mgN.m^{-2}.d^{-1}$ exceeds the guideline for low susceptibility tidal river estuaries of ~2000 $mgN.m^{-2}.d^{-1}$, Robertson et al. 2016), but despite this the estuary has low susceptibility to eutrophication. This is primarily because of its highly flushed nature, given that it is strongly channelised with very few poorly flushed areas, has high freshwater inflow, is strongly affected by tidal currents and is often turbid (mean 35 NTU). However, on occasions during low flows when the estuary is stratified, nuisance algal/macrophyte growth may occur. The presence of elevated chlorophyll *a* concentrations at times are likely attributable to phytoplankton blooms in saline bottom waters and from freshwater sources upstream of the estuary.

The current suspended sediment load (CSSL) is likely to be >10 times the estimated natural state SS load (NSSL), however the estuary is rated as only moderately vulnerable to muddiness issues as it is well-flushed.

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,
- direct physical effects e.g. gill abrasion in fish, compromised filter feeding (invertebrates including shellfish, and prey sighting (fish and birds),
- 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. Microbeads and plastics are a recently recognised concern. 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 Manawatu 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 of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water, or in the case of some SSRTRE type estuaries (e.g. Hutt Estuary, Wellington), shallow subtidal margins.

Within the selected intertidal sites, 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). Synoptic sampling was undertaken in 2016 as part of broad scale mapping (Stevens and Robertson 2016), and is also recommended for 2018.

For the Manawatu Estuary, two fine scale sampling sites, each 30m x 60m (Figure 1), were selected in the dominant estuary habitat (i.e. unvegetated intertidal flats in the lower estuary). Each site was marked out and divided into 12 equal sized plots. Within each plot, 10 of the 12 plots were selected, an arbitrary 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, redox potential (mV) will be directly measured with an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10cm depths below the surface in three representative 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.

Sorting sediment samples

Methods (continued)

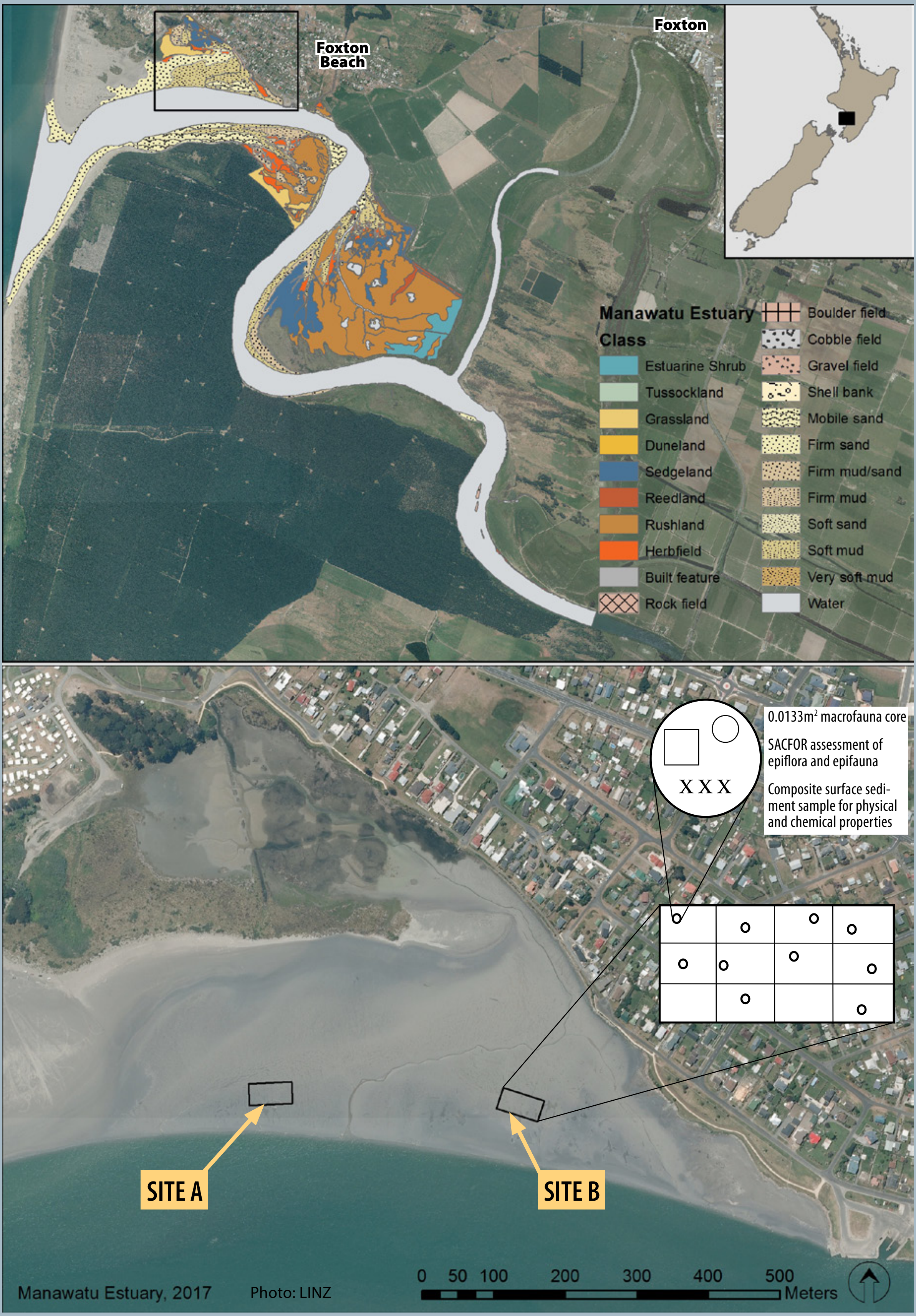

Figure 1. Manawatu Estuary location of sediment plates and monitoring sites.

Methods (continued)

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

From each of 10 plots, 1 arbitrarily 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).
- 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 30m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna 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 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.

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 sediment accrual.

Two sites, each with four plates (20cm square concrete paving stones) were established in January 2017 in Manawatu Estuary at fine scale Sites A and B (Figure 1), with Site B representing the muddier deposition zone and Site A the main estuary basin. Plates were buried deeply in the sediments where stable substrate was located and positioned 5m apart in a linear configuration along the 30m long downstream edge of each fine scale site. 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.

Marking sediment plate site

Digging hole for sediment plate

Positioning sediment plate

4. RESULTS AND DISCUSSION

A summary of the results of the first year of baseline fine scale monitoring of Manawatu Estuary (Sites A and B), undertaken on 30-31 January 2017, 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. Mean fine scale physical, chemical and vegetation (n=3), and macrofauna (n=10) results, Manawatu Estuary, 30-31 January 2017.

Site Year	aRPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%													
A 2017	2	NA	0.3	19.0	80.8	0.2	0.018	10.5	4.7	8.8	5.5	32.3	3.4	0.037	<500	367
B 2017	2	NA	0.3	22.9	76.9	0.3	0.020	9.8	4.5	8.7	5.4	32.7	3.1	0.022	<500	370

Site Year	Seagrass Cover	Macroalgal Cover	Macrofauna Abundance	Macrofauna Richness
	(%)	(%)	Mean Individuals/m^2	Mean Species/core
A 2017	-	-	14,754	6.3
B 2017	-	-	22,436	6.8

NA = Not Assessed

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.

SEDIMENT INDICATORS

4.1.1 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%).

Results showed the Manawatu Estuary fine scale sites had moderate to high sediment mud contents (17-27%) that were similar at each site (Table 3, Figure 2).

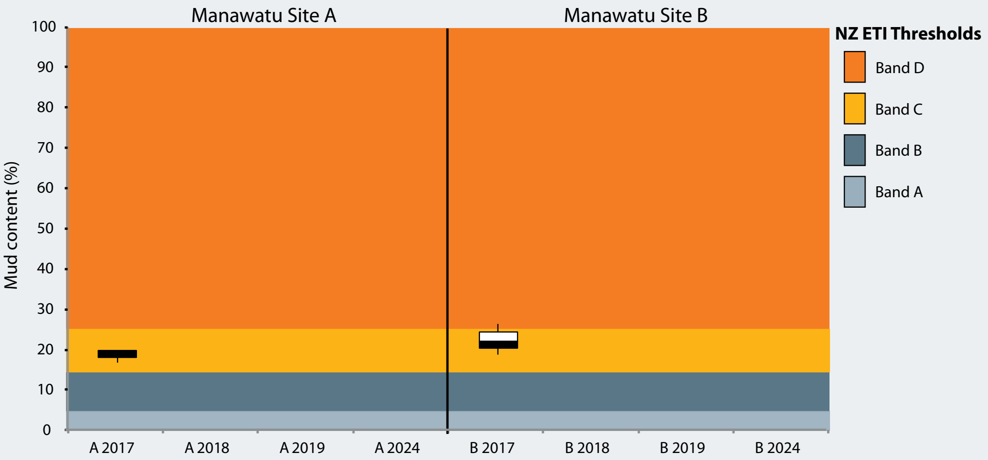

Figure 2. Mean mud content (median, interquartile range, total range, n=3), Manawatu Estuary 2017.

Site A (downstream) showed slightly sandier sediments compared with Site B, which was likely attributable to its closer proximity to ocean-derived sands. The overall moderate mud content fits the Band C rating, and indicates *"moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost, especially if nutrient levels are elevated"* (Robertson et al. 2016b).

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

The presence of opportunistic macroalgae on the sediment surface (or entrained within sediment) can increase sediment organic matter and nutrients which can lead to a degraded sediment ecosystem (Robertson et al. 2016b).

In contrast, seagrass (*Zostera muelleri*) can mitigate or offset the negative symptoms of eutrophication and muddiness by maintaining sediment oxygenation and increasing bed stability, with losses providing a clear indication of a shift towards a more degraded estuary state.

Results at both Sites A and B in 2017 showed there was no seagrass present and <5% cover of opportunistic macroalgae (Figure 3). Such findings indicate low levels of eutrophication at the site and unsuitable conditions for seagrass growth. The 2016 broad scale mapping (Stevens and Robertson 2016) also showed low growth of both seagrass and macroalgae in the estuary in January 2016.

Figure 3. Photo illustrating the absence of opportunistic macroalgae and seagrass at fine scale Site A (left) and Site B (right), Manawatu Estuary 2017.

Results and Discussion (continued)

Sediment Mud Content

This indicator has been discussed in Section 4.1.1 and is not repeated here. However, in relation to eutrophication, the moderate to high mud contents at both sites indicate sediment oxygenation is likely to be moderate due to infilling of interstitial spaces limiting atmospheric and aquatic exchange.

Apparent Redox Potential Discontinuity (aRPD)

The depth of the aRPD boundary provides an indirect measure of the extent of oxygenation within sediments. Currently, the condition rating for this indicator is under development (Robertson et al. 2016b) pending the results of a PhD study in which aRPD and redox potential (RP) measured directly 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).

Figure 4 shows the aRPD depths from the surface for Sites A and B in 2017, were the same (i.e. 2cm). These results indicate that sediment oxygenation was likely to support a moderate range of species. In the future, redox potential will be measured directly, which will enable a more accurate assessment of sediment oxygenation conditions.

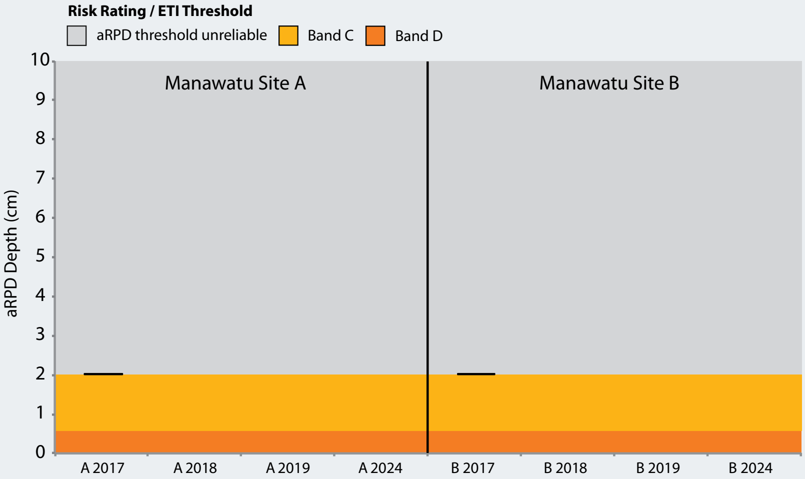

Figure 4. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3), Manawatu Estuary 2017.

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 2017 results showed TOC and TN were in the “low” or “very low” risk indicator ratings at both sites, whereas TP (rating not yet developed) was relatively low at <400mg/kg (Figures 5, 6 and 7).

Dark anoxic layer at 2cm depth, Site A

Dark anoxic layer at 2cm depth, Site B

Monitoring site

Results and Discussion (continued)

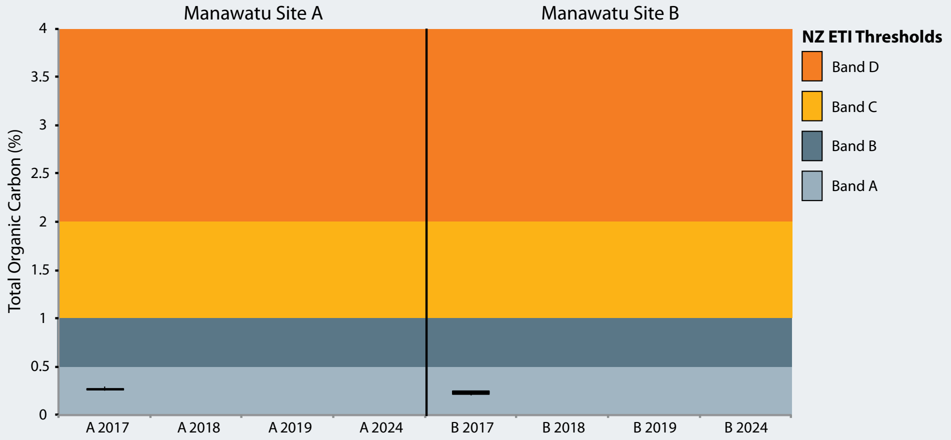

Figure 5. Mean total organic carbon (median, interquartile range, total range, n=3), Manawatu Estuary 2017.

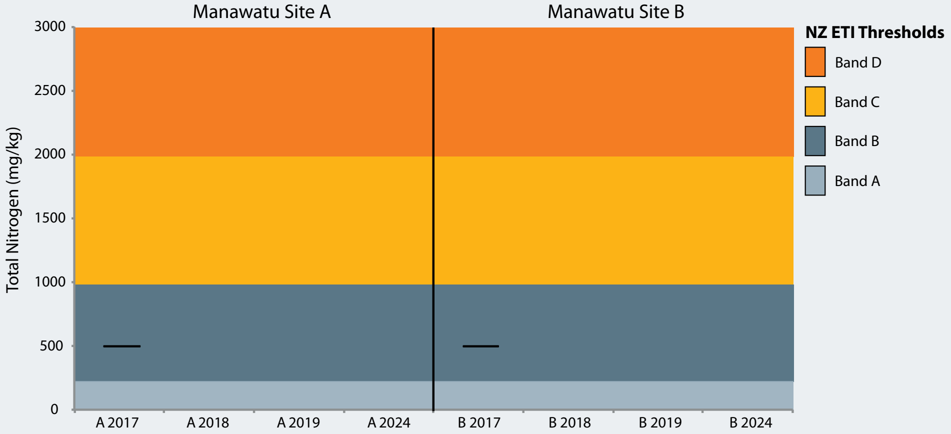

Figure 6. Mean total nitrogen (median, interquartile range, total range, n=3), Manawatu Estuary 2017.

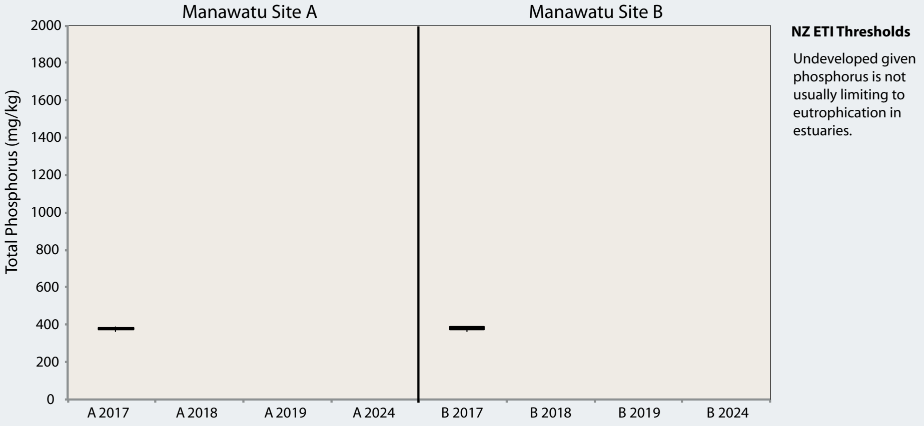

Figure 7. Mean total phosphorus (median, interquartile range, total range, n=3), Manawatu Estuary 2017.

Results and Discussion (continued)

4.1.3 Toxicity

Results for heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn and the metalloid As, used as indicators of potential toxicants, were rated as "very low" to "low" for all parameters. All non-normalised values were below the ANZECC (2000) ISQG-Low trigger values (Table 4) and therefore posed no toxicity threat to aquatic life.

Table 4. Indicator toxicant results for Manawatu Estuary, 2017.

Year/Site /Rep*	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
	mg/kg							
2017 A 1-4 *	3.6	0.019	11.0	5.0	5.6	0.024	9.0	33
2017 A 4-8 *	3.3	0.019	10.3	4.5	5.4	0.065	8.6	32
2017 A 9-10 *	3.4	0.017	10.2	4.6	5.4	0.023	8.7	32
2017 B 1-4 *	3.2	0.019	10.2	4.6	5.6	0.023	9.0	34
2017 B 4-8 *	3.1	0.023	9.9	4.5	5.4	0.019	8.7	33
2017 B 9-10 *	2.9	0.017	9.3	4.4	5.1	0.023	8.4	31
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)								
Band A Very Low Risk	<4	<0.3	<16	<13	<10	<0.03	<4.2	<40
Band B Low Risk	4 - 10	0.3 - 0.75	16 - 40	13 - 32.5	10 - 25	0.03 - 0.075	4.2 - 10.5	40 - 100
Band C Moderate Risk	10 - 20	0.75 - 1.5	40 - 80	32.5 - 65	25 - 50	0.075 - 0.15	10.5 - 21	100 - 200
Band D High Risk	>20	>1.5	>80	>65	>50	>0.15	>21	>200
[a] ISQG-Low	20	1.5	80	65	50	0.15	21	200
[a] ISQG-High	70	10	370	270	220	1	52	410

[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 the Manawatu Estuary will be analysed in detail once sufficient baseline monitoring data are 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 Step 3, simple univariate whole community indices, i.e. species richness, abundance and diversity are presented for each site (Figure 8) and in the future when more data are available, will be used to help explain any differences between years indicated by other analyses.

The 2017 data for Sites A and B showed that species richness, abundance and Shannon diversity were similar at both sites, portraying a low species richness and moderately high abundance, typical of tidal river estuaries.

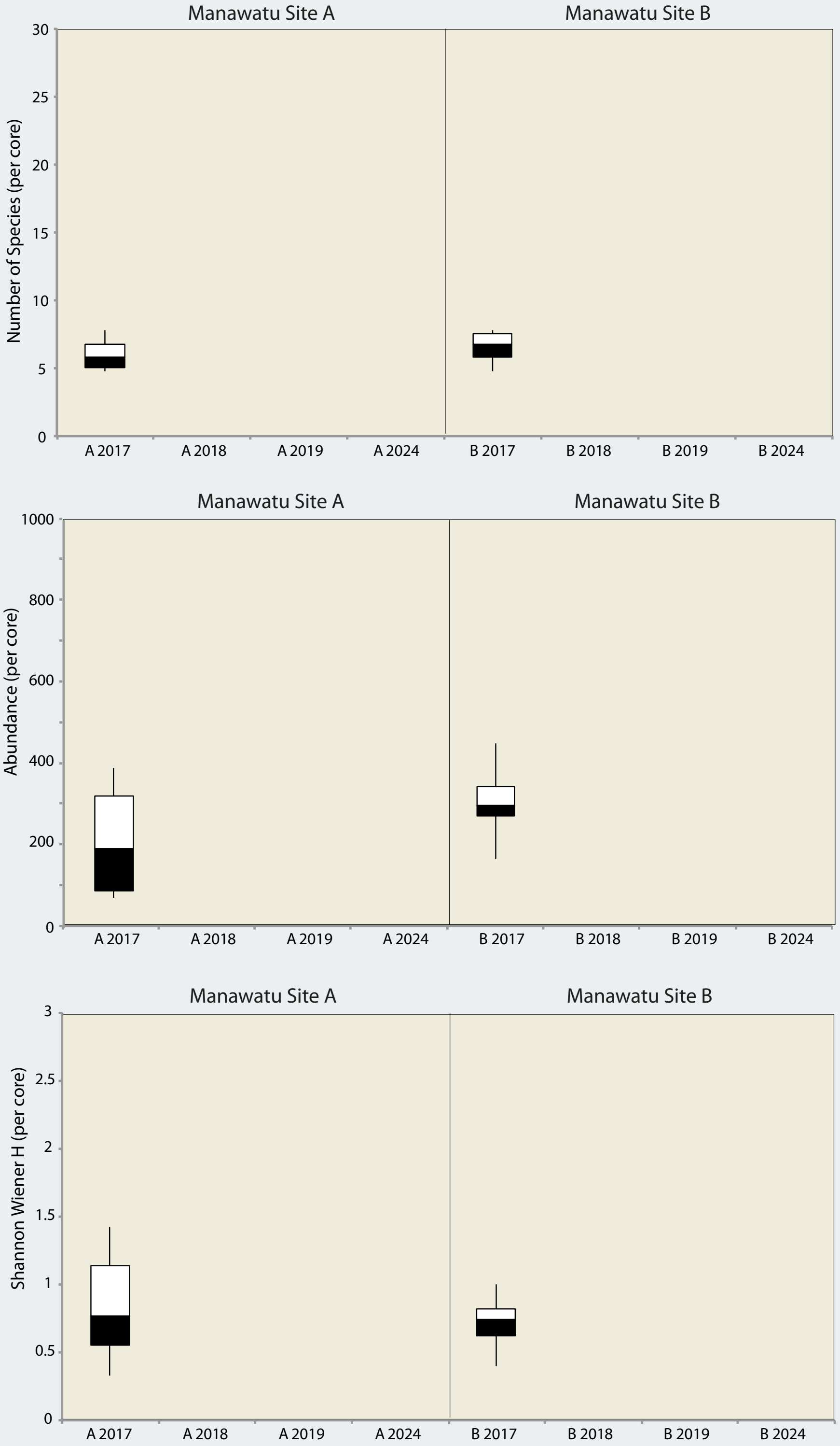

Figure 8. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Manawatu Estuary, 2017.

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

A. Mud and Organic Enrichment Index (NZ AMBI)

Step 4 is undertaken by using the NZ AMBI and NZ Hybrid 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” [high to good status] macrofauna community; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an “unbalanced” to “transitional to polluted” [good to moderate” status] macrofauna community; and >3% to 4% TOC reflected a “transitional to polluted” to “polluted” [moderate to poor status] macrofauna community.

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 the Manawatu Estuary, the NZ Hybrid AMBI biotic coefficients were relatively similar, with medians of 4.48 at Site A and 4.43 at Site B (Figure 9). The coefficients indicate that both Sites A and B were rated in “moderate-poor” ecological condition (i.e. an unbalanced to impoverished type community, with limited sub-surface organisms, indicative of moderate-high mud concentrations, possibly accompanied by organic enrichment and/or a high freshwater influence).

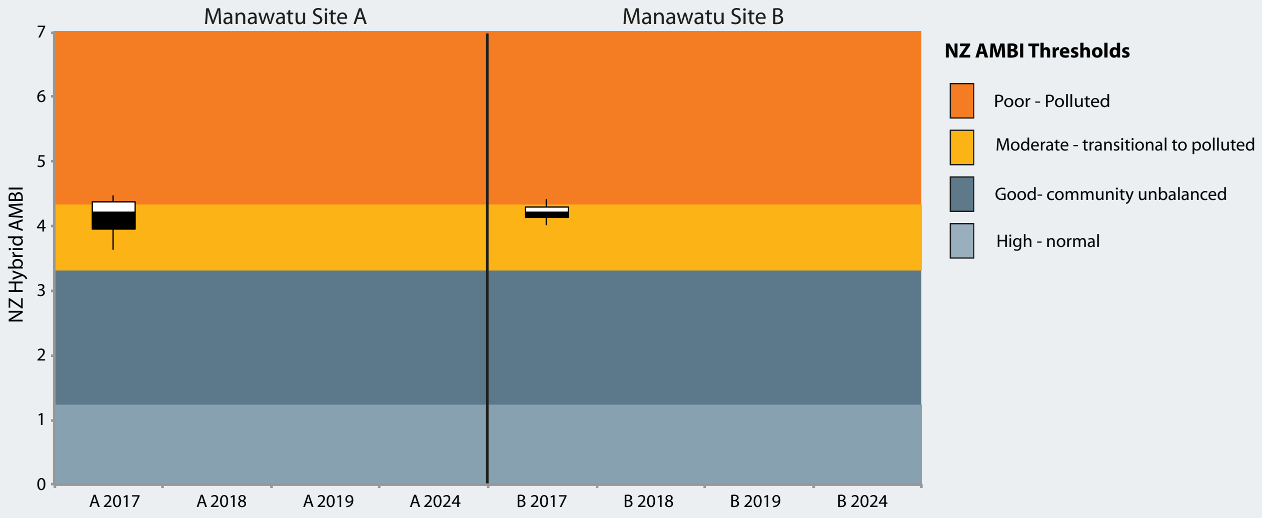

Figure 9. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Manawatu 2017.

B. Taxonomic Groups and Individual Species

This step compares the structure of the macrofaunal community within each site, firstly in terms of their general taxonomic grouping and secondly in terms of individual taxa. The aim of this step is to identify the taxa that are responsible for any observed macrofaunal differences between the sites and to hypothesize on potential reasons based on their individual sensitivity to stressors.

1. Taxonomic Groups

Broad taxonomic groupings (Table 5) provide a preliminary insight into the diversity of the dominant intertidal habitat in Manawatu Estuary. It shows that sites A and B were very similar but had relatively low diversity, with 4-5 major taxa groups and 12-14 taxa in total. Abundances across each major taxa group were also similar but consistently higher at Site B (Table 5). Table 3 showed overall species richness per core was relatively low (Site A: 6.3, Site B: 6.8), but abundance was relatively high (Site A: 14,754/m^2, Site B: 22,436/m^2).

Table 5. Summary of major taxa groupings data for Manawatu Estuary.

Major Taxa Group	A 2017		B 2017	
	Richness	Mean abundance/core	Richness	Mean abundance/core
Nemertea	0	0	1	0.1
Polychaeta	4	3.4	2	3.6
Gastropoda	1	26.5	2	51.5
Bivalvia	4	6.8	3	7.0
Crustacea	5	159.5	4	236.2
Total/site	14	196.2	12	298.4

2. Dominant Taxa

Figure 10 shows a comparison of the mean abundances of taxa across each of the 5 major mud/enrichment tolerance groupings (i.e. Group 1 "very sensitive to organic enrichment" through to Group 5 "1st-order opportunistic species", Robertson 2013, Robertson et al. 2015).

The plots show that the macroinvertebrate community was dominated at both sites by species tolerant of mud and organic enrichment (i.e. Groups 3 and 4), with only a few species (at low abundances) in the higher sensitivity Group 2 or the highly tolerant Group 5. Also of significance, was the fact that there were no taxa belonging to the highly sensitive Group 1 category. Because the site is not highly enriched, the absence of species from this group is likely to reflect the combined influence of elevated muds, a strong regular freshwater influence, and intermittent physical disturbance from flood scouring. The dominant taxa at both Sites A and B were:

- The tube-dwelling crustacean amphipod *Paracorophium*. *Paracorophium* is well-known as a primary coloniser (and hence indicator) of disturbed estuarine intertidal flats. Examples of common disturbances are macroalgal mats settling on the tidal flats as a result of coastal eutrophication, and mud deposition after mobilisation of fine sediments from exposed soil surfaces in the catchment. In these situations, *Paracorophium* can become very abundant and, through its burrowing activities, increases oxygen exchange which in turn mitigates the effect of the disturbance.

- The small estuarine snail *Potamopyrgus estuarinus,* often present in muddy upper estuary areas with regular low salinity conditions.

Paracorophium excavatum

Potamopyrgus estuarinus

Other taxa that were present in moderate numbers were the small deposit feeding bivalve *Arthritica* sp., two neriid polychaetes and undetermined amphipod species. Adult pipi, cockles and trough shells were also present at low numbers, but were relatively large when present.

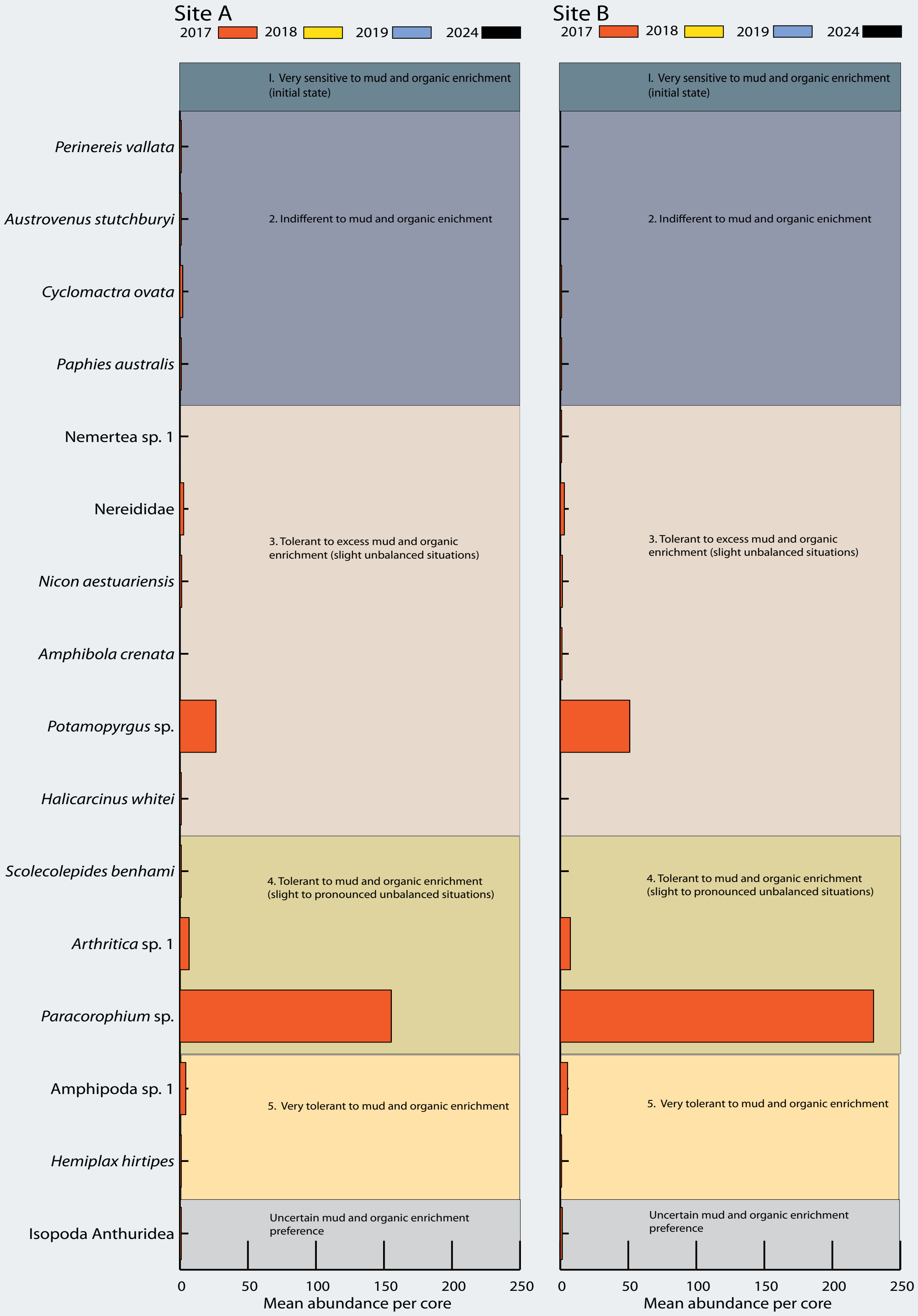

Figure 10. Mud and organic enrichment sensitivity of macroinvertebrates, Manawatu Estuary, 2017 (see Appendix 3 for sensitivity details).

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for the long term intertidal monitoring Sites A and B within Manawatu Estuary in 2017, showed the following key findings:

Overall, the 2017 results for the sediment and eutrophication environmental variables indicate that Site A and B were similar to each other. In general, the sediment conditions can be described as:

- Moderate-high muddiness (17-27% mud).
- Moderate sediment oxygenation (2cm aRPD).
- Low organic carbon and nutrient concentrations.
- Low macroalgal growth.
- Relatively low indicators of toxicity with heavy metals (Cd, Cu, Cr, Ni, Pb, Hg, Zn and As) at concentrations that were not expected to pose toxicity threats to aquatic life.
- A “moderate-poor” ecological condition rating based on the macroinvertebrate community index (NZ Hybrid AMBI) results which classified both Sites A and B as having a “transitional to impoverished” type macroinvertebrate community, typical of large tidal river estuaries exposed to fluctuating freshwater inflows and elevated nutrient and sediment loads.
- The macroinvertebrate community was dominated at both sites by species tolerant of mud and organic enrichment, in particular the tube-dwelling corophioid amphipod *Paracorophium*, which is often present in muddy upper estuary areas with regular low salinity conditions, and the small estuarine snail *Potamopyrgus estuarinus* (limited to brackish upper estuary conditions).

These results likely reflect the strong flushing of the estuary where the primary stressors (i.e. fine sediment, nutrients, Robertson and Stevens 2016) largely pass directly through the estuary to the open sea, while poor clarity and regular high river flows limit the establishment of intertidal nuisance macroalgal growth. As measured during the 2016 broad scale assessment (Stevens and Robertson 2016), the presence of green subtidal waters was also evident in 2017 and indicate that excessive nutrient and chlorophyll *a* concentrations in the main estuary channel continue to be a significant issue.

6. MONITORING AND MANAGEMENT

Manawatu Estuary has been identified by HRC as a priority for monitoring because of its high ecological and human use values. It has been assessed as having a low susceptibility to eutrophication and a moderate susceptibility to excessive fine sediment inputs reflecting current estimated loads and its highly flushed nature. In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the fine scale component of the long term programme. The recommendation for ongoing monitoring to meet this requirement for the Manawatu Estuary is as follows:

Fine Scale Monitoring

- Complete the remaining 2 consecutive years of annual summer (i.e. December-February) of baseline fine scale monitoring of intertidal sites (including sedimentation rate measures) in Manawatu Estuary undertaken in 2018 and 2019 (preferably during a summer, low flow period).
- To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a summer, prolonged low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 3-4 sites in the main channel of the estuary.
- To characterise the potential for excessive sedimentation, it is recommended that sedimentation rates be assessed annually, using appropriately placed sediment plates, and the areal extent of muddy sediments be assessed at 5-10 yearly intervals (the latter assessed in broad scale monitoring).

6. Monitoring and Management (continued)

Broad Scale Habitat Mapping
Undertake broad scale habitat mapping at 5 yearly intervals, focusing on the main issue of sediment. It is recommended that an estimate also be made of the historical extent of the estuary using combined information derived from historical maps, photos, descriptions, as well as any available survey or LIDAR data.

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

Management
Overall, a step-wise management approach is recommended to cost effectively address the source of stressors, identify management targets, and guide management to help ensure that the assimilative capacity of the estuary is not exceeded so that the estuary can flourish and provide sustainable human use and ecological values in the long term. The data available to date suggest that management actions are required to minimise ongoing fine sediment impacts in the estuary in order to prevent deterioration in the estuary's ecological condition. While currently not a significant issue in the estuary itself, high nutrient concentrations flushing through the estuary may be contributing to impacts in coastal areas outside of the estuary.

As an initial step, it is recommended that the following management actions be considered by HRC:

- Determine the fine sediment and nutrient inputs to the estuary including relative inputs from dominant catchment land uses. This can be readily undertaken in the first instance using existing catchment models such as CLUES, and extensions incorporating refined sediment or nutrient yields for specific land use activities e.g. Green et al. (2014).
- Determine relevant sediment and nutrient guideline criteria for the estuary (e.g. under development ANZECC guidelines or NZ ETI) to maintain healthy estuary functioning.
- Determine any load reductions required to maintain health estuary functioning by comparing current catchment loads with what could be achieved under best landuse soil conservation practices and, through stakeholder involvement, identify an appropriate "target" estuary condition, sediment loads to achieve that condition, and any catchment management changes needed to meet the target. For example, ensuring Good Management Practices (GMPs) are being implemented within the catchment. This step may require additional detailed investigation of fine sediment sources, transport, deposition and export within the estuary, to provide underpinning information upon which to base management decisions.
- If the Council determined it a priority to know the previous state of the estuary (was it always muddy or has it become muddier more recently?), or wished to relate changes to specific time periods e.g. following Maori or European settlement in the region, or known land clearance events, a range of forensic techniques are available (e.g. radioactive isotopes, lead, carbon, pollen analyses) to assess historical sediment rates.
- Undertake similar assessments for other relevant stressors e.g. disease causing organisms, as appropriate.

7. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g/100g dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg/kg dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt
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 Manawatu Estuary samples (January 2017).

Evaluation Criterion	Staff	Assessor	Outcome
>95% picking efficiency (10% of samples randomly assessed)	Reuben Lloyd (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

Station Locations (NZGD2000 NZTM) **Manawatu Estuary, 30-31 January 2017.**

SITE A	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
NZTM East	1788734	1788747	1788764	1788778	1788780	1788765	1788751	1788734	1788735	1788752
NZTM North	5517645	5517645	5517647	5517646	5517636	5517635	5517635	5517635	5517627	5517627
SITE B	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
NZTM East	1789084	1789101	1789113	1789132	1789127	1789112	1789097	1789081	1789078	1789091
NZTM North	5517632	5517628	5517625	5517621	5517614	5517618	5517618	5517621	5517613	5517611

Site Boundaries (NZGD2000 NZTM)

SITE A	CornerA01	CornerA02	CornerA03	CornerA04
NZTM East	1788727	1788725	1788787	1788787
NZTM North	5517648	5517619	5517620	5517650

SITE B	CornerB01	CornerB02	CornerB03	CornerB04
1788765	1789082	1789069	1789127	1789140
5517635	5517639	5517612	5517598	5517623

SEDIMENT PLATE LOCATIONS (NZGD2000 NZTM) Sediment plates located on downstream edge of fine scale site.

SITE A							
Station	CornerPegA01	SedA01	SedA02	SedPegA15m	SedA03	SedA04	CornerPegA02
	0m	5m	10m	15m	20m	25m	30m
NZTM East	1788727	1788726	1788727	1788727	1788726	1788727	1788725
NZTM North	5517648	5517643	5517639	5517634	5517629	5517623	5517619
Peg height/Plate depth	100	-81	-89	50	-113	-90	100

SITE B							
Station	CornerPegB01	SedB01	SedB02	SedPegB15m	SedB03	SedB04	CornerPegB02
	0m	5m	10m	15m	20m	25m	30m
NZTM East	1789082	1789080	1789078	1789076	1789074	1789072	1789069
NZTM North	5517639	5517636	5517631	5517626	5517621	5517617	5517612
Peg height/Plate depth	100	-99	-79	50	-83	-93	100

Physical and chemical results for Manawatu Estuary, 30-31 January 2017.

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
		cm	ppt	%				mg/kg									
Site A	1-4	2	NA	0.32	19.8	80.1	0.1	0.019	11	5.0	9.0	5.6	33	3.6	0.024	<500	380
Site A	5-8	2	NA	0.29	20	79.8	0.2	0.019	10.3	4.5	8.6	5.4	32	3.3	0.065	<500	370
Site A	9-10	2	NA	0.28	17.2	82.6	0.2	0.017	10.2	4.6	8.7	5.4	32	3.4	0.023	<500	350
Site B	1-4	2	NA	0.28	26.9	72.7	0.4	0.019	10.2	4.6	9.0	5.6	34	3.2	0.023	<500	380
Site B	5-8	2	NA	0.26	22.5	77.3	0.2	0.023	9.9	4.5	8.7	5.4	33	3.1	0.019	<500	380
Site B	9-10	2	NA	0.23	19.2	80.6	0.2	0.017	9.3	4.4	8.4	5.1	31	2.9	0.023	<500	350
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.

Seagrass, macroalgal cover,and macrofauna results for Manawatu Estuary, 30-31 January 2017.

Site Year	Seagrass Cover	Macroalgal Cover	Macrofauna Abundance	Macrofauna Richness
	(%)	(%)	Mean Individuals/m^2	Mean Species/core
A 2017	-	-	14,754	6.3
B 2017	-	-	22,436	6.8

Appendix 2. 2016/17 Detailed Results (continued)

Manawatu Estuary (Site A and Site B) 2017. Infauna (numbers per 0.01327m² core) (Note 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	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
Nemertea	Nemertea sp. 1	3																1				
Polychaeta	Nereididae	3		1	3	4	3	6	2	2	1	3	3	7	1	1	2	2	1	6	4	3
	Nicon aestuariensis	3						2	1	1				1			2			1		2
	Perinereis vallata	2			1							1										
	Scolecolepides benhami	4					1			1	1											
Gastropoda	*Amphibola crenata*	3														1	1	1		2		
	Potamopyrgus sp.	3	17	21	35	21	18	23	20	36	41	33	51	44	32	13	47	71	49	56	86	61
Bivalvia	*Arthritica* sp. 1	4	5	4	1	1	17	14	4	13	1		25	3	6	2	8	1		19	2	1
	Austrovenus stutchburyi	2							1													
	Cyclomactra ovata	2								3	2	1					1			1		
	Paphies australis	2						1									1					
Crustacea	Amphipoda sp. 1	5	13	3	7	1	4	4	1	2		4	16	4	8	3		5	3	3	6	1
	Halicarcinus whitei	3						1														
	Isopoda Anthuridea	NA			1								2	1	1				1			2
	Hemiplax hirtipes	5	1													1		1	1			
	Paracorophium spp.	4	247	351	161	298	33	267	31	21	34	110	209	206	417	217	207	301	89	173	213	271
Total species in sample			**5**	**5**	**7**	**5**	**6**	**8**	**7**	**8**	**6**	**6**	**6**	**7**	**6**	**7**	**8**	**8**	**6**	**8**	**5**	**7**
Total individuals in sample			**283**	**380**	**209**	**325**	**76**	**318**	**60**	**79**	**80**	**152**	**306**	**266**	**465**	**238**	**269**	**383**	**144**	**261**	**311**	**341**

Note *Paracorophium lucasi* and *P. excavatum* have been previously recorded sympatrically at Foxton (e.g. Stevens and Hogg 2003) but were unable to be distinguished as part of this work.

Stevens, M.I., and Hogg, I.D. 2003. Population genetic structure of New Zealand's endemic corophiid amphipods: evidence for allopatric speciation . The Linnean Society of London, Biological Journal of the Linnean Society, 2004, 81, 119–133.

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
Polychaeta	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.
	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 sp.	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	*Arthritica* sp. 1	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
	Austrovenus stutchburyi	2	Family Veneridae which is a family of bivalves which are very sensitive to organic enrichment. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects. Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community who are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). Prefers sand with some mud.
	Cyclomactra ovata	2	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water.

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 (polytech) 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 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	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.

* 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.

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horizons
regional council

11-15 Victoria Avenue
Private Bag 11 025
Manawatu Mail Centre
Palmerston North 4442

T 0508 800 800
F 06 952 2929
help@horizons.govt.nz
www.horizons.govt.nz