Wriggle

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Hutt Estuary

Fine Scale Monitoring 2016/17

Prepared for

Greater Wellington Regional Council

May 2017

Cover Photo: Collecting samples from Hutt Estuary Site A, 2017. Photo credit: Megan Oliver

Hutt Estuary intertidal flats near the Te Mome Stream mouth 2017

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Fine Scale Monitoring 2016/17

Prepared for
Greater Wellington Regional 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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HUTT ESTUARY - EXECUTIVE SUMMARY

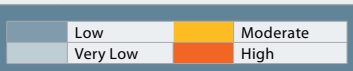
This report summarises fine scale monitoring undertaken at two shallow subtidal benthic sites (Sites A and B) in Hutt Estuary, a shallow, short residence, tidal river estuary (SSRTRE) that flows into Wellington Harbour at Petone. It has been identified by Greater Wellington Regional Council (GWRC) as a priority for monitoring, and is a key part of GWRC's long-term coastal monitoring programme being undertaken in a staged manner throughout the Wellington region. A three year monitoring baseline was established in dominant soft mud substrate in Hutt Estuary from 2010-12, with the first year of scheduled 5 yearly post-baseline monitoring undertaken on 27 January 2017. Monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations are presented below.

FINE SCALE MONITORING RESULTS

- Macroalgal cover at Sites A and B was low-moderate (<10%-30%) in 2010-2011, abundant (50%-100%) in 2012-2016 (see Stevens and Robertson 2016), but <5% in 2017.
- Seagrass was not recorded from the fine scale sites in 2010-12 or 2017.
- Sediment mud content was at moderate to high levels (23%-49% in 2017 and 19%-56% in 2010-12).
- Sediment oxygenation in 2017 was moderate (aRPD 1-2cm depth), consistent with 2010-12.
- Indicators of organic and nutrient enrichment (total organic carbon, total nitrogen and total phosphorus) were at "low-moderate" concentrations. There was a slight but significant decrease in TN at Site A in 2017 (p=0.05) compared to the 2010-12 baseline data.
- Indicators of sediment toxicants - (heavy metals (Sb, Cd, Cu, Cr, Ni, Pb, Hg, Zn and As) were all below concentrations expected to pose toxicity threats to aquatic life. There was a slight but significant increase in Cu at Site A in 2017 (p=0.05) compared to the 2010-12 baseline data.
- Comparisons of the 2010-12 baseline and 2017 data showed no statistically significant difference (p=0.05) in sediment mud content, sediment oxygenation, or total organic carbon.
- The macroinvertebrate community index (NZ Hybrid AMBI) results placed both Sites A and B in the "moderate to poor" ecological condition category (i.e. "transitional to impoverished" community). In 2017, there was a significant decrease in species richness at Site A, and a decrease in species richness and Shannon diversity at Site B (p=0.05) compared to the 2010-12 baseline data.
- The results showed the community at both sites was dominated by species tolerant of mud and organic enrichment, in particular the tube-dwelling corophioid amphipod *Paracorophium excavatum*, that is often present in muddy upper estuary areas with regular low salinity conditions. Other taxa that were present in moderate numbers were the capitellid polychaete *Capitella* sp., pipi (*Paphies australis*), and the small estuarine snail *Potamopyrgus estuarinus*.

BENTHIC RISK INDICATOR RATINGS

(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)



Hutt Estuary	Site A				Site B			
	2010	2011	2012	2017	2010	2011	2012	2017
Sediment Mud Content								
Sediment Oxygenation (aRPD or RP)								
TOC (Total Organic Carbon)								
TN (Total Nitrogen)								
Invertebrate Mud/Organic Enrichment								
Metals (Sb, Cd, Cu, Cr, Pb, Zn) & As								
Metal (Ni)								
Metal (Hg)	NA	NA	NA		NA	NA	NA	

ESTUARY CONDITION AND ISSUES

In terms of muddiness and organic enrichment, the various physical and chemical indicators, NZ Hybrid AMBI scores, and macroinvertebrate taxa analyses, all indicated a muddiness issue in the estuary with reduced sediment oxygenation. In some years, this was accompanied by nuisance macroalgal blooms. The 2017 results showed little evidence of a major shift towards a more degraded state since the 2010-12 baseline years.

Hutt Estuary - Executive Summary (continued)

RECOMMENDED MONITORING AND MANAGEMENT

Based on the 2017 monitoring results and risk indicator ratings, as well as previous broad scale monitoring reports, the following monitoring recommendations are proposed by Wriggle for consideration by GWRC:

Fine Scale Monitoring.

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

Broad Scale Habitat Mapping.

Continue broad scale habitat mapping at 10 yearly intervals, unless obvious changes are observed in the interim. Next monitoring recommended for Jan-Mar 2026.

Sedimentation Rate Monitoring.

Although fine sediment has not been identified as a priority issue in the estuary, it is recommended that sediment plates established in the estuary in 2010 be measured annually if other monitoring is being undertaken in the vicinity of the estuary, and a single composite sediment sample be analysed for grain size.

Intensive Investigations.

In addition to the above routine SOE monitoring of long term fine scale and broad scale elements, to defensibly address the likely cause of macroalgal growths and subtidal habitat degradation, it is recommended that the following intensive investigations be considered:

1. Identify catchment sediment and nutrient sources (e.g. catchment wide nutrient inputs or localised sources), and derive a guideline limit for nutrient inputs (likely to be nitrogen) as the first step, followed by identification of major sources and their subsequent reduction to meet the guideline. The key steps in such an approach are as follows:
   - Assign catchment nutrient load guideline criteria to the estuary based on available catchment load/estuary response information from other relevant estuaries.
   - Estimate catchment nutrient loads to the estuary using available catchment models and stream monitoring data.
   - Determine the extent to which the estuary meets guideline catchment load criteria.
   - Assess the potential for requiring more detailed assessments of priority catchments (e.g. estuary response modelling, stream and tributary monitoring, catchment load modelling).
   - Develop plans for targeted management or restoration of priority catchments.

   GWRC is currently investigating the sources of nutrients in the Hutt River catchment with a focus on nitrogen. Preliminary results from work by GWRC and GNS indicate that in addition to catchment sources, groundwater is a significant source of nitrogen to the river. Although these investigations are currently centred around the occurrence of cyanobacteria blooms in the Hutt River, the information will also be relevant to macroalgal blooms in the estuary.
2. Design and implement a subtidal mapping and monitoring programme to define the spatial extent of degraded subtidal habitat, and the extent of any biological impacts that may be occurring. Particular focus should be given to the impact of dredging in the lower estuary on the accumulation and settlement of organic material and fine muds.

1. INTRODUCTION

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

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

- **Ecological Vulnerability Assessment (EVA)** of the estuary to major issues (see Table 1) and appropriate monitoring design. This component has been completed for Hutt Estuary and is reported on in Robertson and Stevens (2007b).
- **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. Broad scale intertidal mapping of a small part of Hutt Estuary was undertaken in 2004 (Stevens and Robertson 2004), and in Waiwhetu Stream in 2009 and 2012 (Stevens and Robertson 2009, 2012). In addition, mapping of macroalgal cover has been undertaken annually since 2010 (e.g. Stevens and O'Neill-Stevens 2017). Detailed broad scale intertidal habitat mapping (plus a synoptic assessment of subtidal habitat in the lower estuary) was undertaken in the summer of 2015/16 (Stevens and Robertson 2016).
- **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of an estuary across a three year baseline and subsequently every five years, commenced in 2010 and is reported on in Robertson and Stevens (2010, 2011, 2012). The first year of impact monitoring was undertaken on 27 January 2017 and is the subject of this report. Sedimentation rates in the estuary have been monitored annually since 2010 (see Stevens 2017).

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

Hutt Estuary

The Hutt Estuary is a moderate-sized (3km long) "shallow, short residence tidal river (SSRTRE)" type estuary which drains into Wellington Harbour at Petone. Saltwater extends up to 3km inland (230m downstream of the Ewens Bridge) and the water column is often stratified (freshwater overlying denser saline bottom water).

The estuary has been highly modified from its original state, when it was a "shallow, intertidal dominated estuary (SIDE)". In 1909 it was much larger and included several large lagoon arms and extensive intertidal flats and saltmarsh vegetation (Figure 1) (Bell 1910). Over the next 50 years, most of the intertidal flats and lagoon areas were reclaimed and the estuary was trained to flow in one channel between artificial rip-rap (quarried boulder) banks. The terrestrial margin, which was originally vegetated with natural coastal shrub and forest species, was replaced for urban and industrial land uses.

As a result, the estuary now has extremely low habitat diversity. High value habitats such as tidal flats, saltmarsh and seagrass beds are virtually absent. Instead the estuary is dominated by lower value subtidal sands and mud, and artificial seawalls. Several small streams which discharge into the estuary have also been highly modified, however, recent steps have been undertaken to improve conditions in the lower Waiwhetu Stream (Stevens and Robertson 2009, 2012).

The estuary currently receives high inputs of nutrients and sediment from the large catchment and consequently growths of green nuisance macroalgae are common along its banks, and the bed near the mouth is muddy and enriched.

Hutt Estuary - historical extent 1909 (from Bell 1910) and present day.

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

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007a, 2010b, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sedimentation	Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
	Seagrass Area/Biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Mud Content	Grain size - estimates the % mud content of sediment.
	Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
	Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
	Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

2. Eutrophication

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll *a* concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

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

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

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

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural storm-water 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, polychlo-rinated 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 pollut-ants, 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 Hutt 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 SSRTRE type estuaries like Hutt, shallow subtidal margins. The recently developed NZ ETI (Robertson et al. 2016b) also requires assessment of sediment condition in the primary mud deposition zone of estuaries where eutrophic conditions are most likely to be first expressed.

Within the selected intertidal site samples are collected and analysed for the following variables.

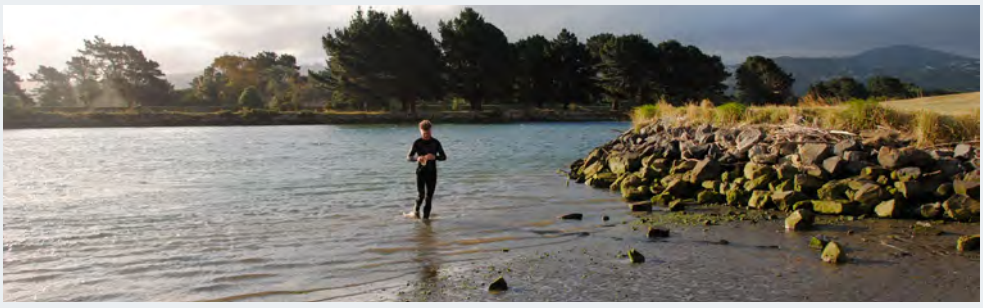
- Salinity, Oxygenation (Redox Potential Discontinuity depth - aRPD or RPmV),
- Grain size (% mud, sand, gravel).
- Organic Matter and Nutrients: Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP).
- Heavy metals and metalloids: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), Zinc (Zn) plus Arsenic (As). Analyses are based on non-normalised whole sample fractions to allow direct comparison with ANZECC (2000) Guidelines.
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: measured in certain estuaries where a risk has been identified.

Synoptic water samples from estuary surface and bottom waters and subtidal sediment samples also provide very useful information to support intertidal assessments where estuaries include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted). This was undertaken in Hutt Estuary in 2016 (Stevens and Robertson 2016).

For the Hutt Estuary, two fine scale sampling sites (Figure 1) were established in shallow subtidal margin habitat in 2010 (Robertson and Stevens 2010) along a 20m long transect aligned parallel to the shore. When sampled the site was marked out and at 2m intervals along each transect, ten sampling points were selected 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 three representative plots. In future, it is proposed that redox potential (mV) be directly measured with an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10cm depths below the surface in three plots.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core for chemical analysis. All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1).
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.



Upper estuary Site B

3. Methods (continued)

Figure 1. Location of fine scale monitoring sites and sediment plates in Hutt Estuary.

3. Methods (continued)

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

From each of 10 plots, 1 randomly placed sediment core [130mm diameter (area = 0.0133m2) tube] was taken.

- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled 0.5mm nylon mesh bag. Once all replicates had been collected at a site, the bags were transported to a nearby source of seawater and fine sediments were washed from the core. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.
- The samples were sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).
- Where present, macroalgae and seagrass vegetation (including roots) was collected within each of three representative 0.0625m2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured.
- Because the cores are collected from subtidal habitat, conspicuous surface epifauna are not enumerated at the current sampling sites.

Collecting sediment samples at Site A 2017. Photo credit: Megan Oliver

4. RESULTS AND DISCUSSION

A summary of the results of the 27 January 2017, and the 2010, 2011 and 2012 fine scale monitoring of Hutt Estuary is presented in Table 3, with detailed results in Table 5 and Appendices 2 and 3. Analysis and discussion of the results are presented as two main steps; firstly, exploring the primary environmental variables that are most likely to be driving the ecological response in relation to the key issues of sedimentation, eutrophication and toxicity, and secondly, investigating the biological response using the macroinvertebrate community.

Table 3. Mean fine scale physical, chemical and vegetation (n=3), and macrofauna (n=10) results, Hutt Estuary, 2010-12 and January 2017.

Site Year	aRPD	Salinity	TOC	Mud	Sand	Gravel	Sb	Cd	Cr	Cu	Pb	Hg	Ni	Zn	As	TN	TP
	cm	ppt	%				mg/kg										
A 2010	1.2	30	0.9	51.0	48.5	0.6	0.15	0.040	13.1	8.7	15.3	NA	11.1	61.3	NA	1467	420
A 2011	3.5	20.5	1.0	42.5	52.2	5.3	0.07	0.052	13.5	8.8	16.3	NA	11.2	61.0	NA	1267	457
A 2012	2.0	NA	1.2	28.4	61.7	10.0	0.10	0.077	15.0	10.0	15.5	NA	12.4	71.3	NA	1233	483
A 2017	2.0	NA	1.0	34.6	60.0	5.4	0.17	0.053	15.0	12.4	17.3	0.073	13.8	70.0	5.1	800	450
B 2010	2.8	30	0.7	35.3	62.6	2.1	0.09	0.038	13.7	9.3	17.0	NA	12.1	69.3	NA	1157	427
B 2011	3.0	17.6	0.6	35.0	59.2	5.8	0.08	0.053	14.8	8.9	17.8	NA	11.7	65.3	NA	867	427
B 2012	1.0	NA	1.0	22.7	68.8	8.5	0.13	0.055	15.6	10.5	17.6	NA	13.0	74.7	NA	1067	503
B 2017	1.0	NA	1.0	26.6	72.8	0.7	0.10	0.046	14.0	11.1	16.7	0.082	12.5	69.7	4.6	800	437

Site Year	Seagrass Cover	Macroalgal Cover	Macrofauna Abundance	Macrofauna Richness
	(%)	(%)	Mean Individuals/m^2)	Mean Species/core
A 2010	-	10%	23,886	8.7
A 2011	-	20-30%	27,427	11.7
A 2012	-	80-100%	8,213	10.7
A 2017	-	<5%	22,303	6.7
B 2010	-	<10%	20,244	10.0
B 2011	-	20-30%	6,681	8.0
B 2012	-	50-80%	8,313	9.0
B 2017	-	<5%	35,916	7.3

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.

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

4. Results and Discussion (continued)

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

The results of these analyses are presented in Table 4.

Table 4. Summary of One-Way ANOVA (p=0.05) and Tukey post hoc tests for physical and chemical data for Sites A and B (2010-12 and 2017) in Hutt Estuary.

Variable	Hutt Site A			Hutt Site B		
	ANOVA F, P value		Post hoc test (Tukey)	ANOVA F, P value		Post hoc test (Tukey)
TOC	F = 8.83, P < 0.0001.	Significant	Not significant	F = 8.297, P < 0.0001.	Significant	Not significant
Mud	F = 26.05, P < 0.001.	Significant	Not Significant	F = 3.24, P = 0.03.	Significant	Not Significant
Antimony	F = 6.89, P < 0.001.	Significant	Not significant	F = 11.11, P < 0.0001.	Significant	Not Significant
Cadmium	F =97.78, P < 0.001.	Significant	Not Significant	F =5.08, P =0.005.	Significant	Not Significant
Chromium	F =16.43, P < 0.001.	Significant	Not Significant	F =15.70, P < 0.001.	Significant	Not Significant
Copper	F =31.56, P < 0.001.	Significant	Significant difference 2017 data outside baseline range	F =16.92, P < 0.001.	Significant	Not Significant
Nickel	F =21.42, P < 0.001.	Significant	Not Significant	F =17.92, P < 0.001.	Significant	Not Significant
Lead	F =4.21, P =0.012.	Significant	Not Significant	F =1.88, P = 0.12.	Not Significant	Not Significant
Zinc	F =47.15, P < 0.001.	Significant	Not Significant	F =20.02, P < 0.001.	Significant	Not Significant
RPD	F =71.65, P < 0.001.	Significant	Not Significant	F =69.54, P < 0.001.	Significant	Not Significant
TN	F =19.79, P < 0.001.	Significant	Significant difference 2017 data outside baseline range	F = 3.08, P = 0.039.	Significant	Not Significant
TP	F = 27.45, P < 0.001.	Significant	Not Significant	F = 11.50, P < 0.001.	Significant	Not Significant

Note: **ANOVA F and P value.** Is there a significant difference between at least two of the years means? (p=0.05)
Post hoc test (Tukey P=0.05). Is the difference between 2017 data and all of the baseline years 2010-2012 significant? Are 2017 data outside of the baseline data range?

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%).

The 2017 monitoring results for sediment mud content at both Hutt sites (Table 3, Figure 2) were at relatively high levels (mean 34.6 and 26.6% mud respectively at Sites A and B, i.e. Band D) but were within the range of the data for the baseline years (mean 28.4-51.0 and 22.7-35.3% mud respectively at sites A and B, i.e. Bands C and D). The variable mud content between years is likely attributable to scouring of fine sediments from the sites during flood events.

The data for all years at both sites (i.e. 2010-2012 and 2017) showed that mean mud content differed between at least two years (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the post baseline 2017 data and all of the baseline 2010-2012 data. These results indicate that there has been no significant change from the baseline and therefore, no associated change is expected to the benthic macroinvertebrate community attributable to this indicator.

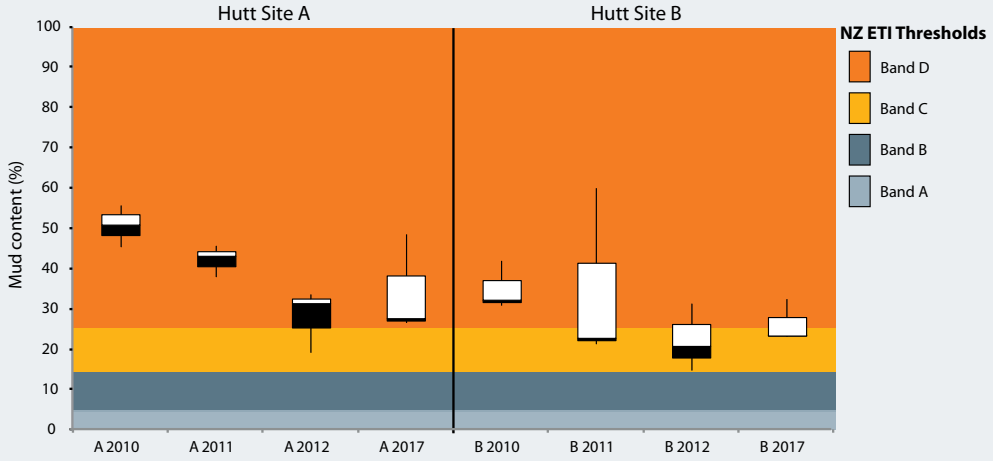


Figure 2. Mean mud content (median, interquartile range, total range, n=3), Hutt Estuary 2010-12 and 2017.

4.1.2 Eutrophication

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

Macroalgae and Seagrass

The presence of opportunistic macroalgae on the sediment surface or entrained in the sediment, can provide organic matter and nutrients to the sediment which can lead to a degraded sediment ecosystem (Robertson et al. 2016b). In addition, seagrass (*Zostera muelleri*) cover and biomass on the sediment surface is also measured when present because seagrass can mitigate or offset the negative symptoms of eutrophication and muddiness. When seagrass losses occur it provides a clear indication of a shift towards a more degraded estuary state.

Seagrass has not been recorded from either Site A or B as part of fine scale monitoring in the estuary in 2010-12 or 2017, indicating the sites currently do not have conditions or habitat suitable for seagrass growth.

Figure 3 summarises the percentage cover of opportunistic macroalgae recorded from Sites A and B over the 2010-12 baseline, and in 2017. The results show macroalgal cover is variable, with very little growth recorded in 2010 and 2017, but high cover in 2011 and 2012. Macroalgae, when present, is dominated by dense luxuriant growths of the green alga *Ulva intestinalis* which grows prolifically along the shallow subtidal margins of the main river channel where the fine scale sites are located (see photos on the following page for examples). It is likely that growth is promoted by river flows providing a regular supply of nutrients, as well as helping to maintain sediment oxygenation and flush fine sediments from plant fronds. However, regular flood flows also serve to dislodge macroalgae and occasionally scour the sites clean. Loss from flood scouring is considered to be the most likely reason for variable presence of macroalgae at the fine scale sites.

Outside of the fine scale sites, broad scale macroalgal mapping undertaken annually in the estuary since 2010 (see Stevens and O'Neill-Stevens 2017, Stevens and Robertson 2015) has shown opportunistic macroalgae is consistently present throughout the estuary, but is not causing significant nuisance conditions.

4. Results and Discussion (continued)

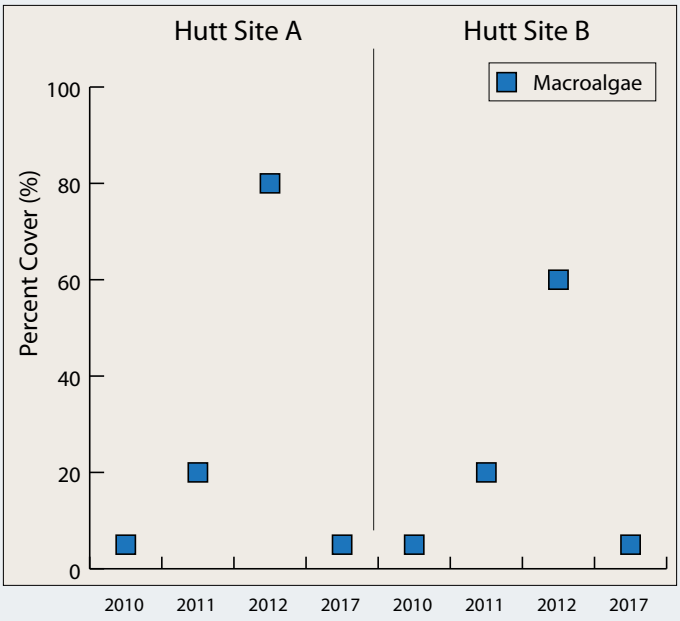
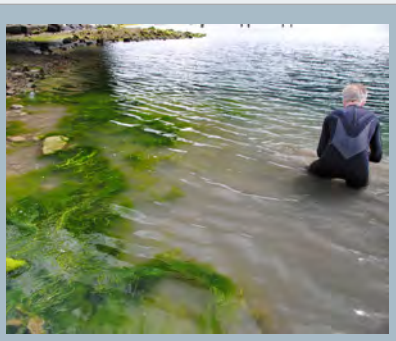


Figure 3. Percent cover of opportunistic macroalgae, Hutt Estuary 2010-12 and 2017.

2010 - low macroalgal growth

2011 - low-moderate macroalgal growth



2012 - high macroalgal growth

2015 - very high macroalgal growth

2015 - very high macroalgal growth

2017 - very low macroalgal growth after recent flooding

Variable macroalgal presence at fine scale Site A, Hutt River, 2010-2017.

Sediment Mud Content

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, the high mud contents at both sites indicate sediment oxygenation is likely to be relatively poor.

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, and the baseline years 2010-2012. In 2017, the aRPD depth was relatively shallow (1cm) at Site B and at more variable and deeper (1-3cm) at Site A.

Analysis of all data showed that aRPD differed between at least two years (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between baseline 2010-12 data and the 2017 post baseline data at either site. These results indicate that sediment oxygenation was likely to support a moderate range of species. In the future, RP will be directly measured through a vertical profile, which will enable a more accurate assessment of sediment oxygenation conditions.

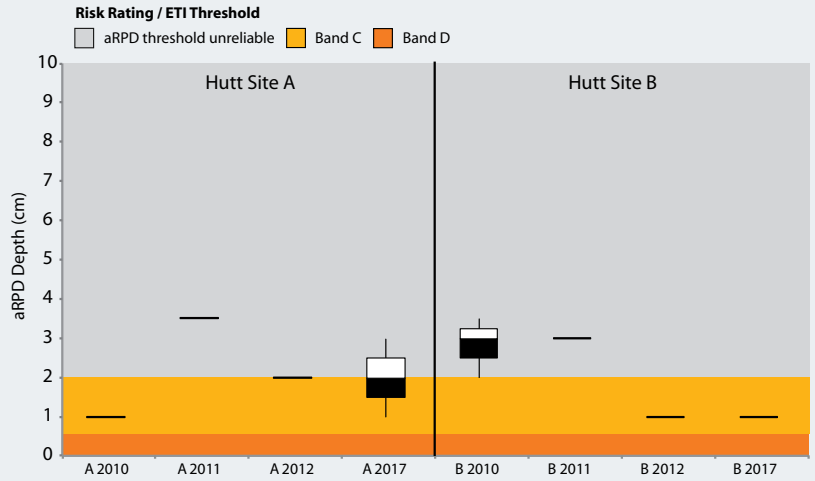


Figure 4. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3), Hutt Estuary 2010-12 and 2017.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated and eutrophication symptoms are present [i.e. shallow aRPD, excessive algal growth, high NZ AMBI biotic coefficient (see the following macroinvertebrate condition section)], then elevated TN, TP and TOC concentrations provide strong supporting information to indicate that loadings are exceeding the assimilative capacity of the estuary.

The 2010-2012 and 2017 results for TOC and TN were in the "low" or "moderate" risk indicator ratings at both sites, whereas TP (rating not yet developed) was relatively low at 420-503mg/kg (Figures 5, 6 and 7).

Analysis of data for all years (i.e. 2010-2012 and 2017) at both sites showed that TOC, TP, and TN differed between at least two years (Table 4 ANOVA results). However, the Tukey post-hoc test (p=0.05) indicated the only significant difference between the baseline 2010-12 data and the 2017 post baseline data was for a decrease in TN at Site A in 2017.

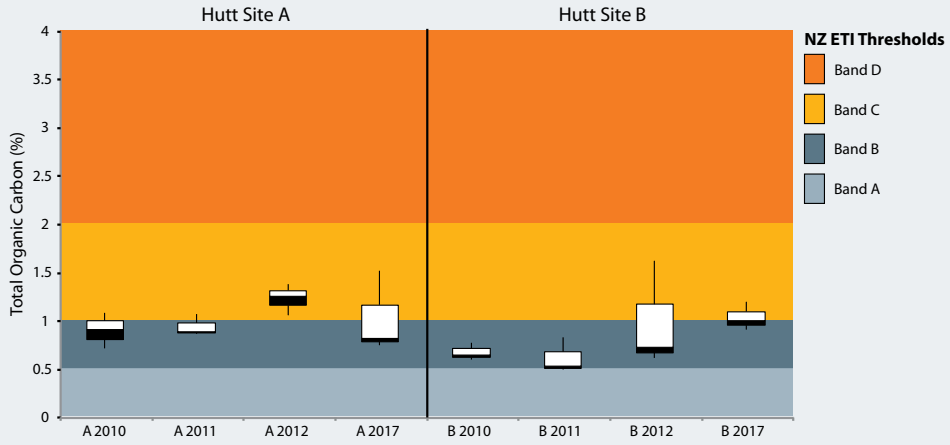


Figure 5. Mean total organic carbon (median, interquartile range, total range, n=3), 2010-12 and 2017.

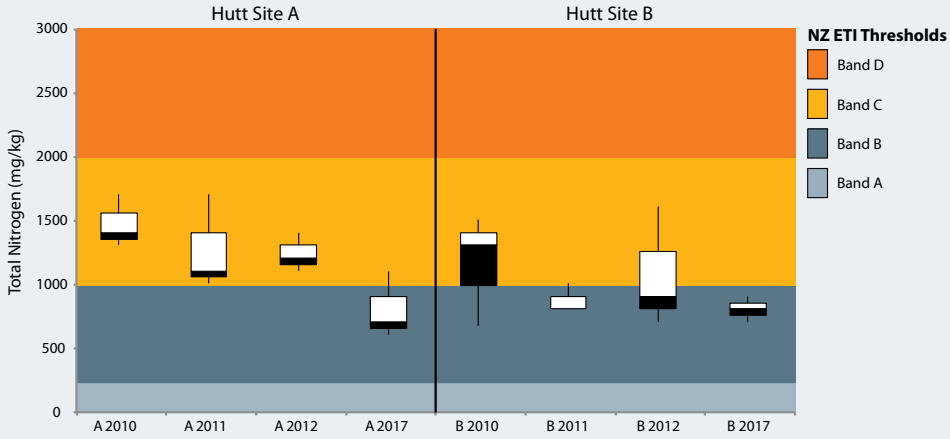


Figure 6. Mean total nitrogen (median, interquartile range, total range, n=3), 2010-12 and 2017.

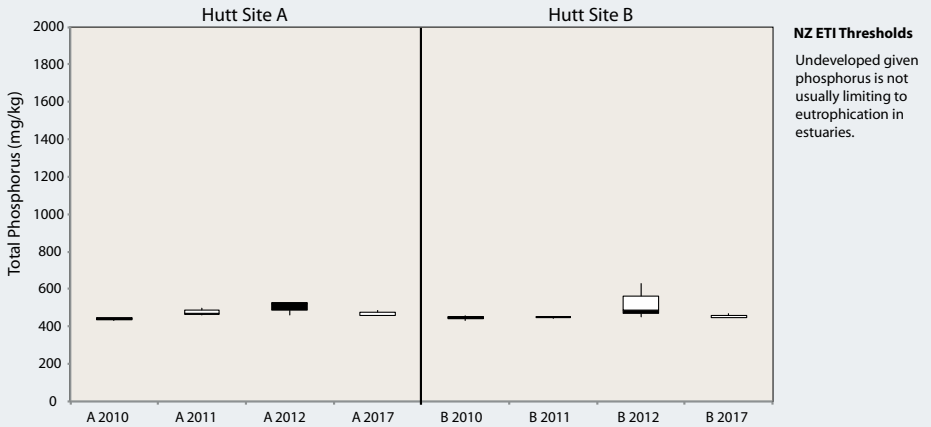


Figure 7. Mean total phosphorus (median, interquartile range, total range, n=3), 2010-12 and 2017.

4. Results and Discussion (continued)

4.1.3 Toxicity

At both sites A and B the 2017 and the 2010-2012 results for heavy metals Sb, Cd, Cr, Cu, Pb, Zn and As (indicators of potential toxicants) were present at concentrations rated "very low" to "low", with Hg and Ni rated "moderate". All non-normalised values were below the ANZECC (2000) ISQG-Low trigger values (Table 5), and therefore posed no significant toxicity threat to aquatic life.

Analysis of the data showed that for all years metals differed between at least two years (Table 4 ANOVA results), except for lead at Site B. Tukey post-hoc tests indicated copper at Site A was the only metal where a significant difference was detected between the baseline 2010-12 data and the 2017 post baseline data (increase in 2017).

Table 5. Indicator toxicant results for Hutt Estuary, 2010-12 and 2017.

Year	Site /Rep*	Sb	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
		mg/kg								
2010	Hutt A 1-4	0.11	0.041	13.0	8.7	11.0	15.0	60	Not assessed	
2010	Hutt A 5-8	0.22	0.036	13.0	8.7	11.0	15.0	62		
2010	Hutt A 9-10	0.11	0.043	13.0	8.8	11.0	16.0	62		
2011	Hutt A 1-4	0.07	0.046	13.9	8.3	11.3	16.2	60		
2011	Hutt A 5-8	0.07	0.057	14.0	9.4	11.4	17.1	62		
2011	Hutt A 9-10	0.08	0.053	12.5	8.8	10.9	15.6	61		
2012	Hutt A 1-4	0.11	0.080	14.9	10.2	12.4	15.9	74		
2012	Hutt A 5-8	0.09	0.080	15.3	9.9	12.7	16.4	75		
2012	Hutt A 9-10	0.11	0.070	14.7	9.8	12.0	14.1	65		
2017	Hutt A 1-4	0.09	0.043	13.6	10.4	12.4	15.5	67	4.7	0.063
2017	Hutt A 5-8	0.29	0.054	16.6	14.3	16.1	16.3	68	5.5	0.076
2017	Hutt A 9-10	0.12	0.061	14.9	12.6	13.0	20.0	75	5.0	0.080
2010	Hutt B 1-4	0.08	0.033	13.0	9.0	12.0	16.0	68	Not assessed	
2010	Hutt B 5-8	0.09	0.041	14.0	9.4	12.0	18.0	71		
2010	Hutt B 9-10	0.11	0.039	14.0	9.6	12.0	17.0	69		
2011	Hutt B 1-4	0.09	0.075	16.1	10.2	12.2	20.0	67		
2011	Hutt B 5-8	0.07	0.041	14.2	8.2	11.5	17.1	63		
2011	Hutt B 9-10	0.07	0.042	14.2	8.4	11.5	16.2	66		
2012	Hutt B 1-4	0.12	0.071	17.1	12.0	13.9	19.8	82		
2012	Hutt B 5-8	0.19	0.055	15.0	10.7	12.4	17.2	73		
2012	Hutt B 9-10	0.08	0.038	14.8	8.9	12.8	15.9	69		
2017	Hutt B 1-4	0.10	0.062	14.0	11.4	12.7	18.5	70	4.0	0.081
2017	Hutt B 5-8	0.12	0.034	14.1	10.7	12.2	15.8	71	5.9	0.090
2017	Hutt B 9-10	0.08	0.042	13.9	11.2	12.7	15.9	68	4.0	0.075
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		<0.4	<0.3	<16	<13	<4.2	<10	<40	<4	<0.03
[a] Band B Low Risk		0.4 - 1.0	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		1.0 - 2.0	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		>2.0	>1.5	>80	>65	>21	>50	>200	>20	>0.15
[a] ISQG-Low		2.0	1.5	80	65	21	50	200	20	0.15
[a] ISQG-High		25	10	370	270	52	220	410	70	1

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

4.1.4 Benthic Macroinvertebrate Community

Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong primary linkage to sediments and secondary linkage to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987, Robertson et al. 2016).

4. Results and Discussion (continued)

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 Hutt Estuary has been examined in four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (v.6) package was 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).

Macroinvertebrate Community Ordination

Principle Coordinates Analysis (PCO), based on species abundance data for both Sites A and B (2010-12 and 2017), showed that the invertebrate community in the baseline years was significantly different from the post baseline year 2017 (i.e. PERMANOVA P<0.0001, Figure 8).

Vector overlays of environmental variables (based on Pearson correlations) are also presented in order to provide information in relation to the potential influence of environmental factors at the site over years. The results identify differences in mud and sand content, nutrients, TOC and aRPD as likely partial explanations for the differences in invertebrate community structure between years. Comparison of the faunal results with abiotic factors using the BIOENV procedure (correlates rank values of faunal similarities between sites with rank Euclidean distances based on environmental factors between sites) indicated that at Site A the combination of TOC, mud and Cu correlated well with the faunal results (Spearman correlation coefficient r=0.952), but at Site B, the correlations were less significant (r=0.57) with sand, and aRPD providing the most significant combination.

Species Richness, Abundance and Diversity

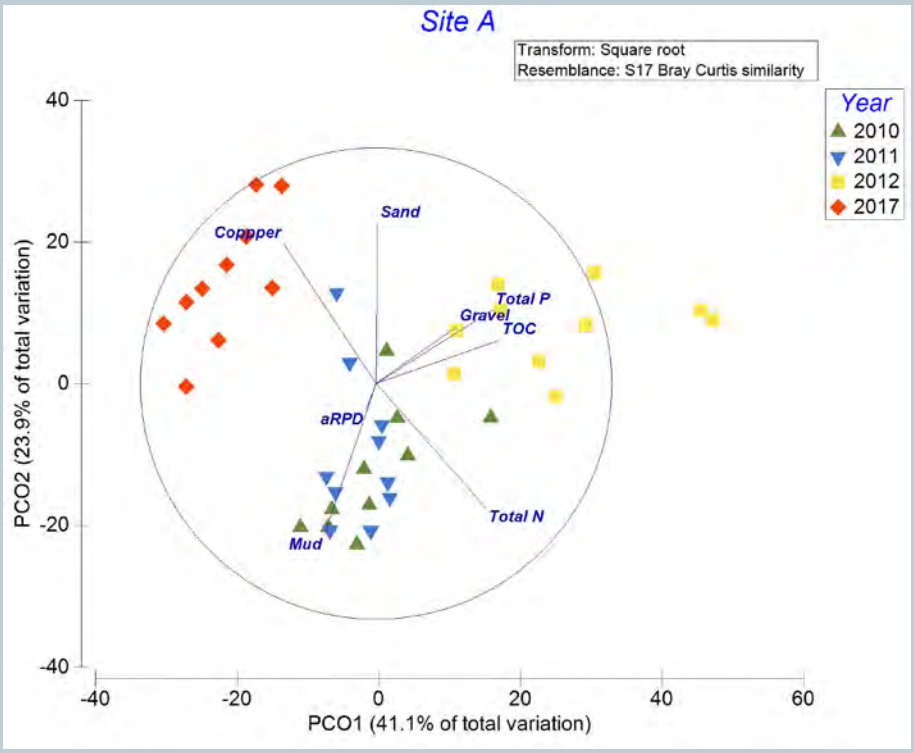
The next step was to assess whether simple univariate whole community indices, i.e. species richness, abundance and diversity at each site (Figure 9), could explain the differences between years indicated by the PCO analysis.

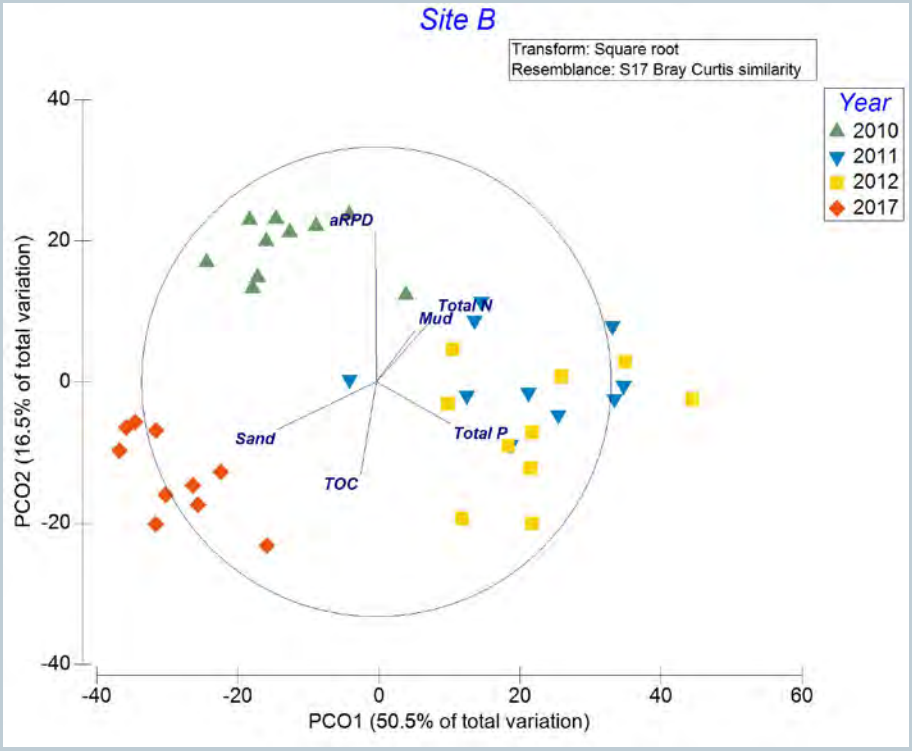
The data for all years (i.e. 2010-12 and 2017) at Sites A and B showed that species richness, abundance and Shannon diversity differed between at least two years (Table 6 ANOVA results). The Tukey post-hoc test (p=0.05) for Site A found there was a significant difference between the post baseline 2017 data and all of the 2010-2012 baseline data for species richness, but not for abundance or Shannon diversity. For Site B, there was a significant difference between the post baseline 2017 data and all of the 2010-2012 baseline data for species richness and Shannon diversity, but not for abundance. Overall, the data clearly supports a decrease in the number of species at both sites in 2017 as a major difference between baseline and post baseline results.

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

Site	Variable	ANOVA F and P value Is there a significant difference between at least two of the years means? (p=0.05)		Post hoc test (Tukey P=0.05) Is the difference between 2017 and all baseline years (2010-2012) significant? Is 2017 data outside of the baseline data range?
Hutt A	Mean No. Species	F = 12.54, P <0.001	Significant	Significant, decline in number of species
Hutt A	Mean Abundance	F = 10.63, P <0.001	Significant	Not Significant
Hutt A	Shannon Wiener (H)	F = 26.01, P <0.001	Significant	Not Significant
Hutt B	Mean No. Species	F = 9.98, P <0.001	Significant	Significant, decline in number of species
Hutt B	Mean Abundance	F = 24.5, P <0.001	Significant	Not Significant
Hutt B	Shannon Wiener (H)	F = 53.4, P <0.001	Significant	Significant, decline in Shannon diversity

4. Results and Discussion (continued)





Explanatory Notes For Figure 8

Figure 8 shows the relationship among samples in terms of similarity in macroinvertebrate community composition at Site A, for the sampling period 2010-2012 and 2017. The plot shows the 10 replicate samples for Sites A and B in each year, and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves an unconstrained multivariate data analysis method, in this case principle coordinates analysis (PCO) using PERMANOVA version 1.0.5 (PRIMER-e v6.1.15). The analysis plots the site and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities (i.e. how much of the variation in the data matrix is explained by the first two PCO axes). For the present plots, the cumulative variation explained was >60%, indicating a good representation of the abundance matrix.

PERMANOVA, testing for statistical significant differences in the invertebrate communities among samples, reflected significant (P<0.05) structural differences between years for all Site A and B data.

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

Figure 8. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at Sites A and B, 2010-12 and 2017, and key environmental variables(e.g. mud, sand, aRPD, TOC).

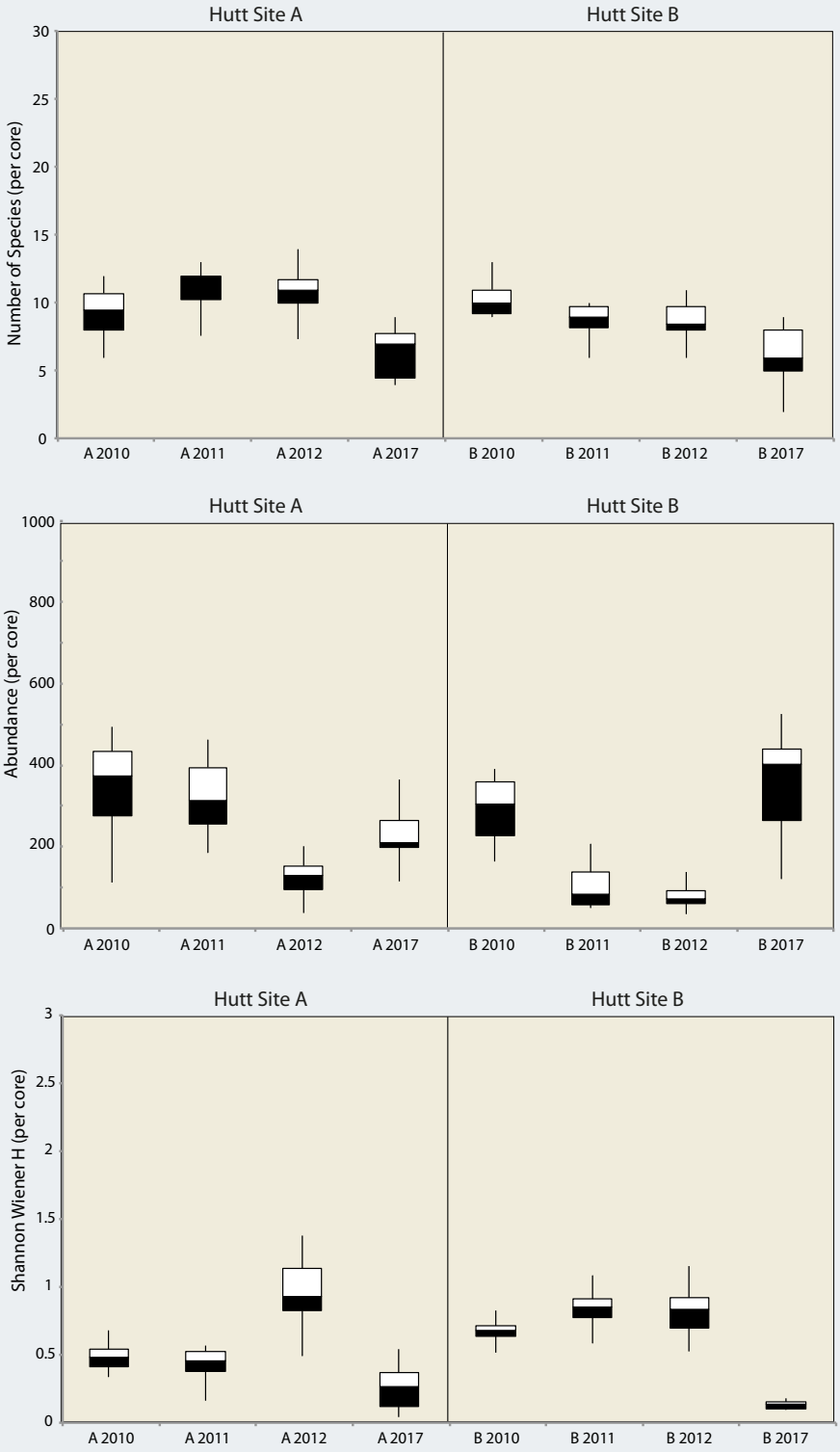


Figure 9. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Hutt Estuary, 2010-12 and 2017.

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

A. Mud and Organic Enrichment Index (NZ AMBI)

This step is undertaken by using the NZ AMBI 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" macrofauna community, or "high" to "good" status; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an "unbalanced" to "transitional to polluted" macrofauna community, or "good" to "moderate" status; and >3% to 4% TOC reflected a "transitional to polluted" to "polluted" macrofauna community, or "moderate" to "poor" status.

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

The median NZ Hybrid AMBI biotic coefficients for Hutt Estuary for 2010, 2011, 2012 and 2017 were; Site A 4.4, 4.4, 3.8 and 4.3; Site B 4.0, 3.9, 3.7 and 4.4.

The results identified both Sites A and B to be in the "moderate" to "poor" ecological condition category (i.e. a "transitional to impoverished" type macroinvertebrate community). Tukey post-hoc testing found no significant difference between the NZ Hybrid AMBI post baseline 2017 and all of the 2010-2012 baseline scores for Site A, but did indicate a significant small increase in the score (degradation) at Site B in 2017 (Table 7).

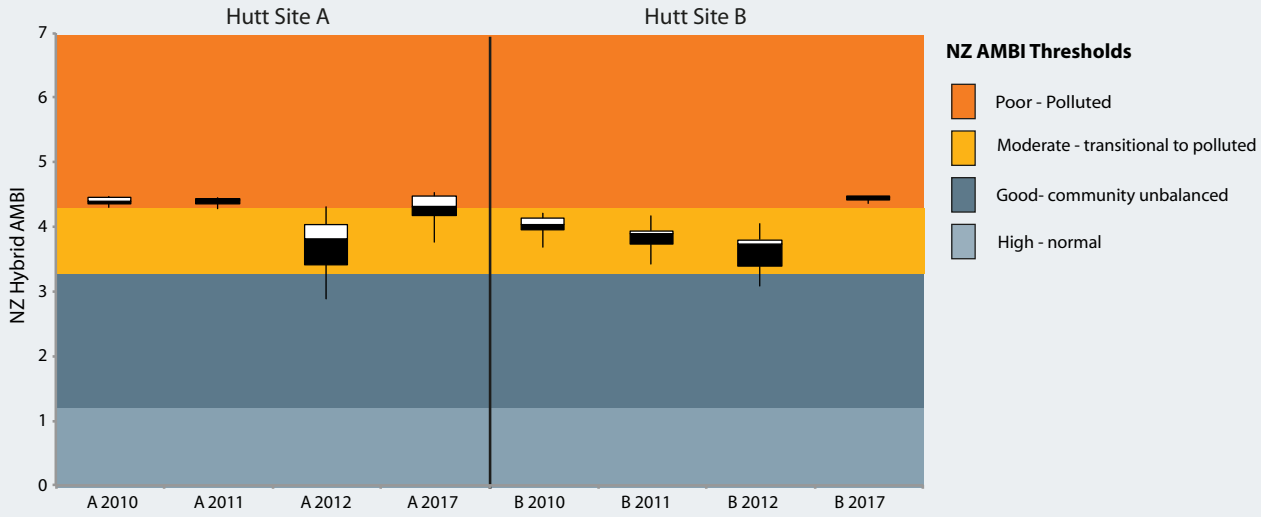


Figure 10. Benthic invertebrate NZ Hybrid AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Hutt Estuary, 2010-12 and 2017.

Table 7. Summary of One-Way ANOVA (p=0.05) and Tukey post hoc tests for NZ Hybrid AMBI for 2010-12 and 2017.

Site	Variable	ANOVA F and P value. Is there a significant difference between at least two of the years means? (p=0.05)		Post hoc test (Tukey P=0.05). Is the difference between 2017 and all baseline years (2010-2012) significant? Is 2017 data outside of the baseline data range?
Hutt A	NZ Hybrid AMBI	F = 13.5, P <0.001	Significant	Not Significant
Hutt B	NZ Hybrid AMBI	F = 20.5, P <0.001	Significant	Significant, increase in NZ Hybrid AMBI score

B. Taxonomic Groups and Individual Species

This step compares the structure of the macrofaunal community within each of the sites, firstly in terms of their general taxonomic grouping and secondly in terms of individual taxa. The aim of this final step is to identify the taxa that are responsible for the observed macrofaunal differences between the sites (i.e. results of PCO ordinations, univariate and NZ Hybrid AMBI analyses) and to hypothesize on potential reasons based on their individual sensitivity to stressors.

1. Taxonomic Groups

Table 8 shows that the community was dominated by crustaceans and polychaete worms in all years at both sites. Other taxa groups present at the sites included nematode and nemertean worms, bivalves, gastropods, oligochaete worms and insects. Such findings provide a preliminary insight into the taxonomic differences between the years at Sites A and B.

Table 8. Summary of major taxa groupings data for Hutt Estuary Sites A and B (2010-12 and 2017).

Site	Hutt A				Hutt B			
Major Taxa Group	2010	2011	2012	2017	2010	2011	2012	2017
	Mean abundance per core							
Nematoda (round worms)	1.0	-	1.3	2.6	1.0	2.0	-	-
Nemertea (ribbon worms)	2.0	1.0	1.6	3.2	2.9	1.8	-	1.3
Polychaeta (bristle worms)	43.8	29.4	37.8	25.9	20.7	21.1	10.1	7.0
Oligochaeta (worms)	3.7	7.8	3.8	7.3	4.3	7.8	-	-
Gastropoda (snails)	1.3	20.0	4.8	5.0	1.5	2.4	2.0	1.0
Bivalvia (e.g. cockle, pipi)	7.8	31.8	9.4	13.1	11.1	16.5	31.3	6.7
Crustacea (e.g. amphipod)	298.7	219.5	285.7	61.0	98.5	49.1	225.2	354.4
Insecta (insects)	-	-	-	2.0	-	-	1.0	1.0

2. Dominant Taxa

Changes in species abundances between years at the species level are illustrated in Figures 11 and 12. These graphs shows a comparison of the mean abundances of each of the 5 major mud/enrichment tolerance groupings between years (i.e. "very sensitive to organic enrichment" group through to "1st-order opportunistic species" group, 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. Group 4), with only a few species (at low abundances) in the highly-moderately sensitive Groups 1, 2 and 3 or the highly tolerant Group 5.

4. Results and Discussion (continued)

The dominant taxa for each year at both Sites A and B was the tube-dwelling corophioid amphipod *Paracorophium excavatum,* which is often present in muddy upper estuary areas with regular low salinity conditions. Other taxa that were present in moderate numbers were the capitellid polychaete *Capitella* sp., pipi (*Paphies australis*), and the small estuarine snail *Potamopyrgus estuarinus* (limited to brackish upper estuary conditions) (Table 9).

The Similarity Percentages procedure (SIMPER) (PRIMER-e) (Clarke 1993) was also applied to indicate which taxa contributed most to the difference in macroinvertebrate community structure between baseline years 2010-12 and post baseline 2017 (Table 10). As expected, the results clearly indicate that *Paracorophium excavatum* was responsible for the greatest differences between each of the baseline years and 2017 at both sites. At Site A, the abundance of *P. excavatum* was highest in 2010 and 2011, relatively low in 2012, and moderately high in 2017. At Site B, it was highest in 2017, moderately high in 2010 and relatively low in 2011 and 2012.

Also noteworthy in relation to the taxa causing the differences between baseline and post baseline years, was the capitellid polychaete *Capitella* sp. which was present at relatively low numbers in 2017 at both sites, and the sensitive pipi (*Paphies australis*) which in 2017 was relatively abundant at Site A, but was relatively scarce at Site B.

Table 9. Dominant macroinvertebrate taxa in Hutt Estuary.

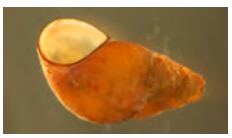
Paracorophium excavatum	A tube-dwelling corophioid amphipod that lives in the top 2cm - endemic to NZ. It is a suspension feeder that uses the long setae to trap suspended organic matter. Found mainly in NZ east coast habitats and is sensitive to metals. Also very strong mud preference. Often present in muddy upper estuaries with regular low salinity conditions.	
Capitella sp.	Small sized capitellid polychaete worm. A sub-surface deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate.	
Paphies australis	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.	
Potamopyrgus estuarinus	Small estuarine snail, requiring brackish conditions for survival. Endemic to NZ. Common in upper estuary tidal flats adjacent to freshwater inflows. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.	
Prionospio sp.	Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment.	
Austrovenus stutchburyi	The cockle is a suspension feeding bivalve with a short siphon - lives in upper few cm at mid-low water situations. More abundant near estuary mouth. Best growth at less than 10% mud. Important part of the diet of wading bird species and fish. It is a strong bioturbator whose presence enhances nutrient and oxygen fluxes and influences the types of other macroinvertebrate species present.	

Table 10. Species causing the greatest contribution to the difference between macroinvertebrate community structure between years at Site A and Site B (SIMPER Analysis - cutoff for low contributions 90%).

	Species	NZH AMBI	2010 Av.Abund	2011 Av.Abund	Contribution %
SITE A	*Paracorophium excavatum*	4	294.1	272.8	73.75
	Capitella sp. 1	4	30.8	28.9	12.48
	Paphies australis	2	1.5	3.1	1.94
	Species	**NZH AMBI**	**2010 Av.Abund**	**2012 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	294.1	86.4	76.78
	Capitella sp. 1	4	30.8	5.6	10.36
	Prionospio sp.	2	0.3	6.1	2.51
	Species	**NZH AMBI**	**2011 Av.Abund**	**2012 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	272.8	86.4	75.41
	Capitella sp. 1	4	28.9	5.6	9.52
	Prionospio sp.v	2	0.4	6.1	2.52
	Species	**NZH AMBI**	**2010 Av.Abund**	**2017 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	294.1	212	65.54
	Capitella sp. 1	4	30.8	0	14.81
	Paphies australis	2	1.5	18.4	8.38
	Species	**NZH AMBI**	**2011 Av.Abund**	**2017 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	272.8	212	59.85
	Capitella sp. 1	4	28.9	0	15.83
	Paphies australis	2	3.1	18.4	9.69
	Species	**NZH AMBI**	**2012 Av.Abund**	**2017 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	86.4	212	66.53
	Paphies australis	2	0.8	18.4	9.21
	Austrovenus stutchburyi	2	8.8	3	3.96

	Species	NZH AMBI	2010 Av.Abund	2011 Av.Abund	Contribution %
SITE B	*Paracorophium excavatum*	4	204.9	59	63.38
	Potamopyrgus estuarinus	3	18.2	0	7.36
	Paphies australis	2	26.5	10.7	7.33
	Species	**NZH AMBI**	**2010 Av.Abund**	**2012 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	204.9	43.8	64.6
	Paphies australis	2	26.5	8.4	7.74
	Potamopyrgus estuarinus	3	18.2	0	6.98
	Species	**NZH AMBI**	**2011 Av.Abund**	**2012 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	59	43.8	44.31
	Capitella sp. 1	4	16.3	14.1	15.33
	Oligochaeta	3	7.3	7	8.62
	Species	**NZH AMBI**	**2010 Av.Abund**	**2017 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	204.9	346.9	65.28
	Paphies australis	2	26.5	2.9	9.9
	Potamopyrgus estuarinus	3	18.2	0	7.18
	Species	**NZH AMBI**	**2011 Av.Abund**	**2017 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	59	346.9	84.04
	Capitella sp. 1	4	16.3	0.2	5.14
	Paphies australis	2	10.7	2.9	2.93
	Species	**NZH AMBI**	**2012 Av.Abund**	**2017 Av.Abund**	**Contribution %**
	Paracorophium excavatum	4	43.8	346.9	86.15
	Capitella sp. 1	4	14.1	0.2	4.34

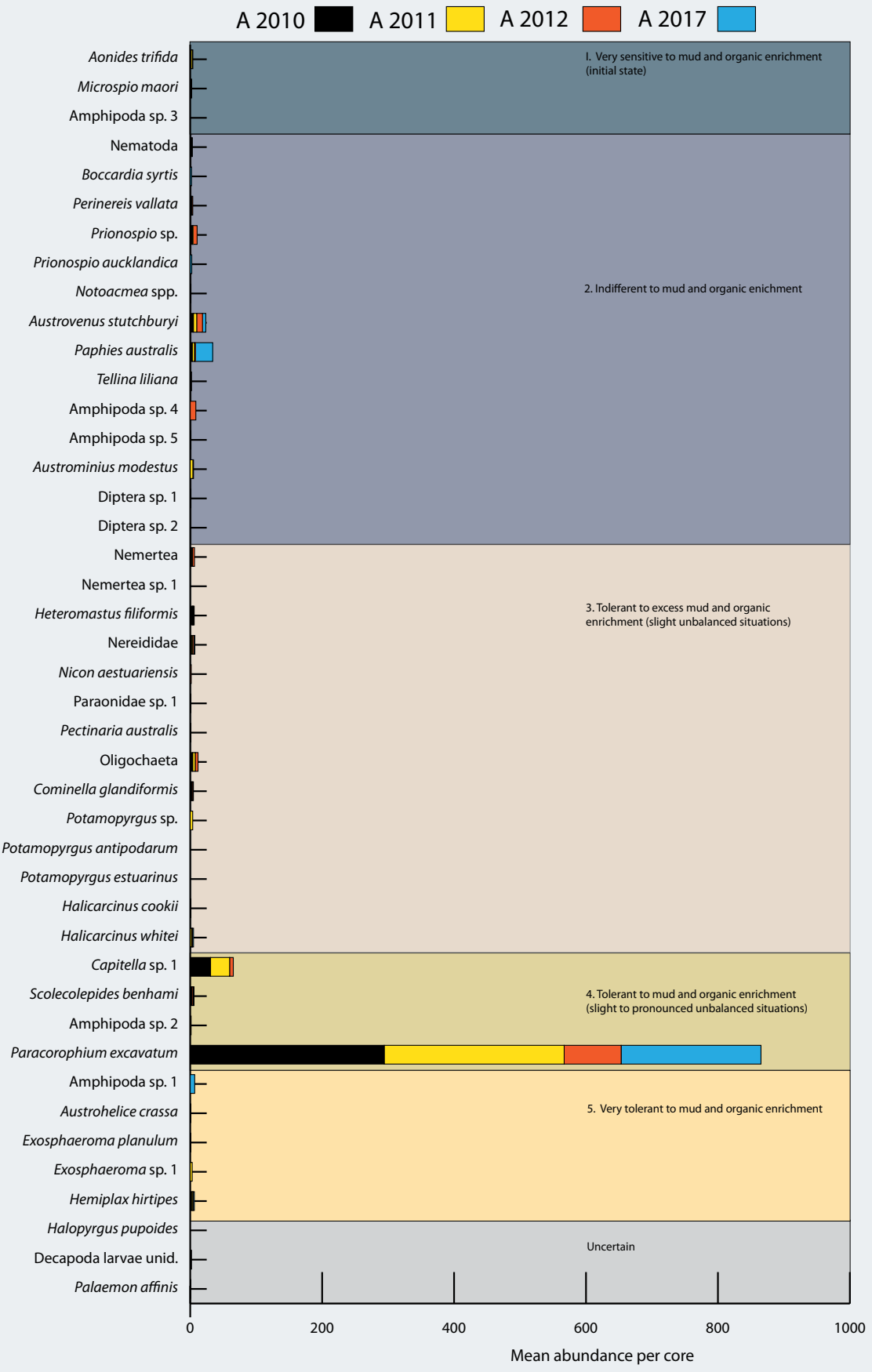


Figure 11. Mud and organic enrichment sensitivity of macroinvertebrates, Hutt Estuary, Site A 2010-12 and 2017 (see Appendix 3 for sensitivity details).

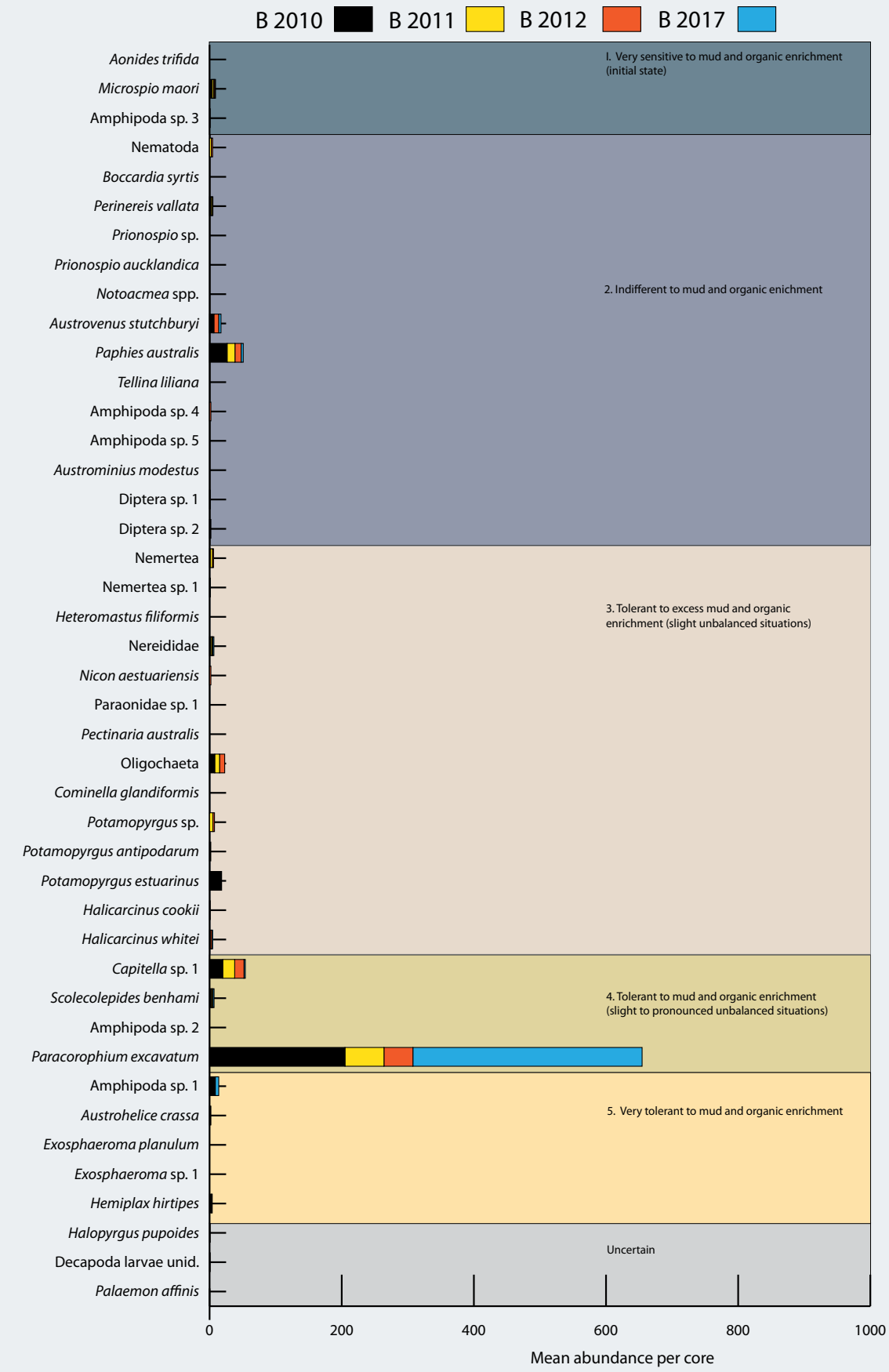


Figure 12. Mud and organic enrichment sensitivity of macroinvertebrates, Hutt Estuary, Site B 2010-12 and 2017 (see Appendix 3 for sensitivity details).

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for the long term intertidal monitoring at Sites A and B within Hutt Estuary in 2017, and in the baseline years 2010-2012, showed the following key findings:

Overall, the results for the sediment and eutrophication environmental variables indicate that the sediment conditions at Site A and B over the period 2010-2012 and 2017 have been variable, but there was no significant change between baseline and post baseline years for environmental variables, except for a slight reduction in TN, and a slight increase in Cu, at Site A in 2017. The absence of a significant change in most environmental variables was reflected in the macroinvertebrate community index (NZH AMBI) which showed no significant change at Site A, and a but slight degradation at Site B, between baseline and post baseline years. In general, the conditions can be described as:

- Moderate-high muddiness (23-51% mud).
- Moderate sediment oxygenation (1-3.5cm aRPD).
- Low-moderate organic carbon and nutrient concentrations.
- Elevated macroalgal growth in some years, indicating the presence of intermittent eutrophication symptoms.
- Relatively low toxicity with heavy metals (Sb, 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 identified both Sites A and B to have a "transitional to impoverished" type macroinvertebrate community. The community at both sites was dominated by species tolerant of mud and organic enrichment, in particular the tube-dwelling corophioid amphipod *Paracorophium excavatum,* that is often present in muddy upper estuary areas with regular low salinity conditions. Other taxa that were present in moderate numbers were the capitellid polychaete *Capitella* sp., pipi (*Paphies australis*), and the small estuarine snail *Potamopyrgus estuarinus* (limited to brackish upper estuary conditions).

6. MONITORING AND MANAGEMENT

Hutt River has been identified by GWRC as a priority for monitoring, and is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout the Wellington region. Based on the 2017 monitoring results and risk indicator ratings, as well as previous broad scale monitoring reports, the following monitoring recommendations are proposed by Wriggle for consideration by GWRC:

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

Broad Scale Habitat Mapping.
Continue broad scale habitat mapping at 10 yearly intervals, unless obvious changes are observed in the interim. Next monitoring recommended for Jan-Mar 2026.

Macroalgal Mapping.
Continue broad scale macroalgal monitoring at five yearly intervals, unless obvious changes are observed in the interim. Next monitoring recommended for Jan-Mar 2022.

Sedimentation Rate Monitoring.
Although fine sediment has not been identified as a priority issue in the estuary, it is recommended that sediment plates established in the estuary in 2010 be measured annually if other monitoring is being undertaken in the vicinity of the estuary, and a single composite sediment sample be analysed for grain size.

Intensive Investigations.
In addition to the above routine SOE monitoring of long term fine scale and broad scale elements, to defensibly address the likely cause of macroalgal growths and subtidal habitat degradation, it is recommended that the following intensive investigations be considered:

6. Monitoring and Management (continued)

1. Identify catchment sediment and nutrient sources (e.g. catchment wide nutrient inputs or localised sources), and derive a guideline limit for nutrient inputs (likely to be nitrogen) as the first step, followed by identification of major sources and their subsequent reduction to meet the guideline. The key steps in such an approach are as follows:
   - Assign catchment nutrient load guideline criteria to the estuary based on available catchment load/estuary response information from other relevant estuaries.
   - Estimate catchment nutrient loads to the estuary using available catchment models and stream monitoring data.
   - Determine the extent to which the estuary meets guideline catchment load criteria.
   - Assess the potential for requiring more detailed assessments of priority catchments (e.g. estuary response modelling, stream and tributary monitoring, catchment load modelling).
   - Develop plans for targeted management or restoration of priority catchments.

   GWRC is currently investigating the sources of nutrients in the Hutt River catchment with a focus on nitrogen. Preliminary results from work by GWRC and GNS indicate that in addition to catchment sources, groundwater is a significant source of nitrogen to the river. Although these investigations are currently centred around the occurrence of cyanobacteria blooms in the Hutt River, the information will also be relevant to macroalgal blooms in the estuary.
2. Design and implement a subtidal mapping and monitoring programme to define the spatial extent of degraded subtidal habitat, and the extent of any biological impacts that may be occurring. Particular focus should be given to the impact of dredging in the lower estuary on the accumulation and settlement of organic material and fine muds.

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Hutt Estuary 2015 showing very high macroalgal growth

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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 antimony	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg 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.

Station Locations (NZGD2000 NZTM)

HUTT A	HuttAPeg1	HuttA 1	HuttA 2	HuttA 3	HuttA 4	HuttA 5	HuttA 6	HuttA 7	HuttA 8	HuttA 9	HuttA 10	HuttAPeg2
NZTM East	1759174.1	1759175.8	1759175.8	1759175.8	1759175.7	1759175.7	1759175.7	1759175.7	1759175.6	1759175.5	1759175.5	1759174.4
NZTM North	5433638.0	5433637.0	5433635.3	5433633.3	5433631.3	5433629.3	5433627.3	5433625.3	5433623.2	5433621.2	5433619.2	5433618.1
HUTT B	HuttBPeg1	HuttB 1	HuttB 2	HuttB 3	HuttB 4	HuttB 5	HuttB 6	HuttB 7	HuttB 8	HuttB 9	HuttB 10	HuttBPeg2
NZTM East	1759369.4	1759367.2	1759367.2	1759367.2	1759367.3	1759367.3	1759367.3	1759367.3	1759367.4	1759367.5	1759367.5	1759369.0
NZTM North	5434135.8	5434117.5	5434119.5	5434121.4	5434123.6	5434125.5	5434127.5	5434129.6	5434131.5	5434133.5	5434135.3	5434116.9

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 Hutt 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

Physical and chemical results for Hutt Estuary, 27 January 2017.

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Sb	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
		cm	ppt	%				mg/kg										
HuttA	1-4	3	NA	0.76	26.9	70.6	2.5	0.09	0.043	13.6	10.4	12.4	15.5	67	4.7	0.063	600	440
HuttA	5-8	1	NA	0.83	28.0	59.6	12.4	0.29	0.054	16.6	14.3	16.1	16.3	68	5.5	0.076	700	440
HuttA	9-10	2	NA	1.53	48.9	49.9	1.2	0.12	0.061	14.9	12.6	13.0	20.0	75	5.0	0.08	1100	470
HuttB	1-4	1	NA	1.01	32.7	66.0	1.3	0.10	0.062	14.0	11.4	12.7	18.5	70	4.0	0.081	800	430
HuttB	5-8	1	NA	1.21	23.5	76.1	0.5	0.12	0.034	14.1	10.7	12.2	15.8	71	5.9	0.090	900	450
HuttB	9-10	1	NA	0.92	23.6	76.2	0.2	0.08	0.042	13.9	11.2	12.7	15.9	68	4.0	0.075	700	430
ISQG-Low [a]			-	-	-	-	-	2.0	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High [a]			-	-	-	-	-	25	10	370	270	52	220	410	70	1	-	-

[a] ANZECC 2000. *composite samples (2-4).

Appendix 2. 2016/17 Detailed Results (continued)

Hutt Estuary (Site A and Site B) 2017. Infauna (numbers per 0.01327m² core) (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			1					2	1
	Nemertea sp. 2	3																				
Nematoda	Nematoda	2																				
Polychaeta	*Aonides trifida*	1																				
	Boccardia syrtis	2							2													
	Capitella sp. 1	4																		2		
	Heteromastus filiformis	3						1														
	Microspio maori	1	1														2				1	1
	Nereididae	3	3		1	1	1	3		1	3	1			2	1	2	1	1	2		4
	Nicon aestuariensis	3																				
	Paraonidae sp. 1	3																				
	Pectinaria australis	3								1												
	Perinereis vallata	2																				
	Prionospio aucklandica	2	3		3				1													
	Scolecolepides benhami	4			1	1	1				1		5				1	1	1		1	
Oligochaeta	Oligochaeta	3																				
Gastropoda	*Cominella glandiformis*	3										1										
	Halopyrgus pupoides	NA														1						
	Notoacmaea sp.	2									1											
	Potamopyrgus sp.	3																				
Bivalvia	*Austrovenus stutchburyi*	2	2	10		4			3	10		1	7	7	3	1	2	2	6	1	3	3
	Paphies australis	2	3	54	8	48			15	47	9		3		1	11	2	4	2	2	2	2
	Tellina liliana	2																				
Crustacea	Amphipoda sp. 1	5	10	19	2	1	3	3	3	15	5					4	5				4	8
	Amphipoda sp. 2	4																				
	Amphipoda sp. 3	1																				
	Amphipoda sp. 4	2																				
	Amphipoda sp. 5	2																				
	Austrohelice crassa	5																				
	Austrominius modestus	2		1																		
	Exosphaeroma sp. 1	5																				
	Halicarcinus whitei	3	1	1							3		1			2			1			1
	Hemiplax hirtipes	5		3	1				1	2											1	1
	Paracorophium sp.	4	392	134	100	183	193	192	174	342	252	158	508	114	219	389	378	414	247	276	498	426
	Palaemon affinis	NA		1																		
	Decapoda larvae unid	NA							1													
Insecta	Diptera sp. 1	2	1																			
	Diptera sp. 2	2														1	1					
Total species in sample			**9**	**8**	**7**	**6**	**4**	**4**	**8**	**7**	**7**	**4**	**6**	**2**	**4**	**9**	**8**	**5**	**6**	**5**	**8**	**9**
Total individuals in sample			**416**	**223**	**116**	**238**	**198**	**199**	**200**	**418**	**274**	**161**	**525**	**121**	**225**	**411**	**393**	**422**	**258**	**283**	**512**	**447**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		NZ Hyb AMBI Gp*	Details
Nemertea	Nemertea	3	Ribbon or Proboscis worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions
	Nemertea sp. 1	3	
Nematoda	Nematoda	2	Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5mm mesh sieve. Generally reside in the upper 2.5cm of sediment. Intolerant of anoxic conditions.
Polychaeta	*Aonides trifida*	1	Small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. *Aonides* is free-living, not very mobile and strongly prefers to live in fine sands; also very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds.
	Boccardia syrtis	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
	Capitella sp. 1	4	A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments. Commonly *Capitella capitata*.
	Heteromastus filiformis	3	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	Microspio maori	1	A small, common, intertidal spionid. Can handle moderately enriched situations. Prey items for fish and birds.
	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.
	Paraonidae sp. 1	3	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans.
	Pectinaria australis	3	Subsurface deposit-feeding/herbivore. Lives in a cemented sand grain cone-shaped tube. Feeds head down with tube tip near surface. Prefers fine sands to muddy sands (0-20% muds). Mid tide to coastal shallows. Belongs to Family Pectinariidae. Often present in NZ estuaries. Density may increase around sources of organic pollution and eelgrass beds. Intolerant of anoxic conditions.
	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.
	Prionospio aucklandica	2	Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001)
	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.

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Oligochaeta	Oligochaeta	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
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. Strong Sand Preference. Optimum mud range 5-10% mud.
	Halopyrgus pupoides	0	This species is widespread and can be abundant. Found in coastal waters, including estuaries, on fine muddy sediment.
	Notoacmea spp.	2	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Has a strong sand preference.
	Potamopyrgus sp.	3	Endemic to NZ. Small snail that can live in freshwater as well as brackish conditions. In estuaries *P. antipodarum* can tolerate up to 17-24% salinity. Shell varies in colour (gray, light to dark brown). Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds but can tolerate organically enriched conditions. Tolerant of muds. Populations in saline conditions produce fewer offspring, grow more slowly, and undergo longer gestation periods. *Potamopyrgus estuarinus* is a small estuarine snail, requiring brackish conditions for survival. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
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 e.g. SI 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.
	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.
	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.
Crustacea	Amphipoda sp.	Sp 1 = 5 Sp 2 = 4 Sp 3 = 1 Sp 4 = 2	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.

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Crustacea	*Austrohelice crassa*	5	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
	Austrominius modestus	2	Small acorn barnacle (also named *Elminius modestus*). Capable of rapid colonisation of any hard surface in intertidal areas including shells and stones. A filter feeder that prefers sandy substrate.
	Decapoda larvae unid.	0	The decapods or Decapoda (literally means "ten footed") are an order of crustaceans within the class Malacostraca, including many familiar groups, such as crayfish, crabs, lobsters, prawns and shrimp. Most decapods are scavengers. It is estimated that the order contains nearly 15,000 species in around 2,700 genera, with approximately 3,300 fossil species. Nearly half of these species are crabs, with the shrimps (c. 3000 species) and Anomura (including hermit crabs, porcelain crabs, squat lobsters: c. 2500 species), making up the bulk of the remainder.
	Exosphaeroma sp. 1	5	Small seaweed dwelling isopod. Isopods are an order of peracarid crustaceans, including familiar animals such as woodlice and pill bugs. The name Isopoda derives from the Greek iso meaning "same" and pod meaning "foot".
	Halicarcinus cookii	3	Pillbox crab. NZ hymenosomatids are generally sub-littoral, although *H. cookii, H. varius, H. pubescens* and *H. innominatus* can inhabit shores as high as the lower mid-littoral zone depending on algal cover. H. cookii is endemic to New Zealand. It is an opportunistic carnivore and scavenger, with a diet consisting of molluscs, polychaetes and especially amphipods.
	Halicarcinus whitei	3	A species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Hemiplax hirtipes	5	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. Previously *Macrophthalmus hirtipes*.
	Palaemon affinis	1	Common among rocks and under rocky overhangs. Large numbers can often be found in pockets of deep brackish water around estuaries. Ferocious predators and scavengers. They can tolerate a wide range of salinity and can be found near freshwater or in rock pools where water has evaporated leaving a very salty mix behind (salinity range 5-43g salt/L seawater).
	Paracorophium excavatum	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.
Insecta	Diptera sp. 1	2	Fly or midge larvae - species unknown.
	Diptera sp. 2	2	An unknown dipteran or fly larvae.

* 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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