coastalmanagement

Porirua Harbour

Fine Scale Monitoring 2014/15

Prepared
for

Greater
Wellington
Regional
Council

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Cover Photo: Porirua Harbour (Pauatahanui Arm)

Porirua Harbour (Onepoto Arm) sampling at the Railway site

Porirua Estuary

Fine Scale Monitoring 2014/15

Prepared for
Greater Wellington Regional Council

by

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PORIRUA HARBOUR - EXECUTIVE SUMMARY

Porirua Harbour is an ~807ha, tidal lagoon estuary located near Porirua in the Greater Wellington region. It is part of Greater Wellington Regional Council's coastal State of the Environment (SOE) monitoring programme. This report summarises the results of the fourth year of the fine scale monitoring (2015) at four sites within the estuary. The monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations are summarised below.

FINE SCALE MONITORING RESULTS

- Sand dominated the sediments, and mud content was low-moderate.
- Sediment Oxygenation: Redox Potential Discontinuity was 1cm deep indicating moderate-poor oxygenation.
- The benthic invertebrate community mud and organic enrichment rating indicated a low risk of eutrophication and mud impacts.
- The indicator of organic enrichment (Total Organic Carbon) was at low concentrations.
- Nutrient enrichment indicators (total nitrogen and phosphorus) were at low-moderate concentrations in all years.
- Heavy metals and arsenic were well below the ANZECC (2000) ISQG-Low trigger values (i.e. low toxicity).
- Macroalgal cover was elevated at most sites.
- Comparison of the macroinvertebrate results with environmental factors indicated that, although analyses of the faunal results showed differences between the baseline 2008-2010 and the post baseline 2015 years at each of the four sites, the environmental variables provided only a partial explanation for these differences, particularly at site Por A. Mud and heavy metal concentrations were identified as moderately to highly correlated with the macrobenthic faunal assemblages at sites Por B and Pau A, and to a lesser extent at Pau B.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

▦	Low	🟨	Moderate	🟥	Very High
░	Very Low	🟧	High	⬜	Not measured

	Porirua (Onepoto) Arm								Pauatahanui Arm							
	Site Por A Railway				Site Por B Polytech				Site Pau A Boatshed				Site Pau B Upper			
	2008	2009	2010	2015	2008	2009	2010	2015	2008	2009	2010	2015	2008	2009	2010	2015
Sediment Mud Content	🟨	🟨	🟨	🟨	🟨	🟨	🟨	▦	🟨	🟨	🟨	🟨	▦	▦	🟨	▦
aRPD (Sediment Oxygenation)	🟨	🟨	🟨	🟧	▦	🟨	🟧	🟧	▦	🟨	🟧	🟧	▦	▦	🟧	🟧
TOC (Total Organic Carbon)	▦	░	░	▦	░	░	░	░	▦	░	░	▦	░	░	░	░
Total Nitrogen	▦	▦	▦	▦	▦	▦	▦	▦	▦	▦	▦	▦	▦	▦	▦	▦
Total Phosphorus	🟨	🟨	🟨	🟨	░	░	░	▦	🟨	🟨	🟨	🟨	░	░	░	░
Invertebrate Mud/Org Enrichment	▦	▦	▦	▦	▦	░	░	░	▦	▦	▦	▦	▦	▦	▦	▦
Metals (Cd, Cu, Cr, Hg, Ni, Pb, Zn) & As	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░

ESTUARY CONDITION AND ISSUES

Overall, the first four years of fine scale monitoring show the dominant intertidal habitat (i.e. unvegetated tidal-flats) in the Porirua Harbour is generally in "good" to "moderate" condition. In 2015, as in the 2008-2010 baseline years, the fine scale intertidal sediments had low mud concentrations, low to moderate levels of organic enrichment, moderate sediment oxygenation, low levels of toxicity and a typical mixed tolerance macroinvertebrate community.

In terms of changes since 2010, the results showed the following;

- mud, nutrient and organic carbon concentrations were relatively stable
- heavy metals showed small increases at some sites and decreases at others
- significant small changes in the structure of the macroinvertebrate community

In terms of the condition of the harbour in relation to the key estuary ecological issues of sedimentation, eutrophication, toxicity and habitat modification, the findings of this report need to be viewed in conjunction with other relevant monitoring reports.

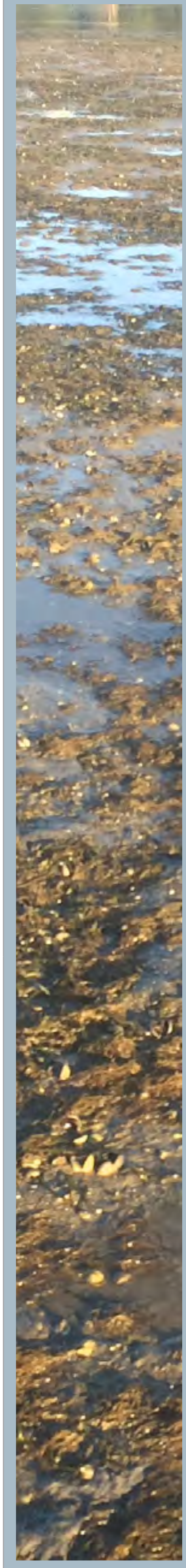
RECOMMENDED MONITORING AND MANAGEMENT

Because Porirua Harbour is large, has high ecological and human use values, and is very vulnerable to excessive sedimentation, eutrophication and disease risk, this estuary has been identified by GWRC as a priority for monitoring. Baseline fine scale intertidal conditions were established from 2008-2010, and one year of post baseline sampling has been completed (2015). It is recommended that the next fine scale monitoring of intertidal sites be undertaken at the scheduled 5 yearly monitoring interval (i.e. 2020).

Fine scale monitoring, in conjunction with sedimentation and broad scale monitoring, provides valuable information on current estuary condition and trends over time, particularly in relation to the widely acknowledged sedimentation issue in the estuary, and the potential for eutrophication and toxicity. Currently, the joint Wellington Councils have adopted long term sediment reduction targets for the Harbour and GWRC is currently undertaking a range of investigations in the Harbour catchment focussing on sediment mitigation and potential nutrient sources.

1. INTRODUCTION

OVERVIEW



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 in late 2007 began the monitoring programme in a staged manner. The estuaries currently included in the programme are; Porirua Harbour [Onepoto (Porirua) and Pauatahanui Arms], Whareama Estuary, Lake Onoke, Hutt Estuary and Waikanae Estuary. Risk assessments have been undertaken for a number of other estuaries in order to establish priorities for their management.

Monitoring of Porirua Harbour began in 2004, with the first year of fine scale baseline monitoring undertaken in January 2008. The estuary monitoring process consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) as follows:

1. **Ecological Vulnerability Assessment (EVA)** of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has been completed for Porirua Harbour and is reported on in Robertson and Stevens (2007).
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. Broad scale intertidal mapping of Porirua Harbour was undertaken in 2008 and 2013 (Stevens and Robertson 2008, 2013) and subtidal mapping in 2014 (Stevens and Robertson 2014). Since 2008, annual mapping of macroalgal cover has also been undertaken (see Stevens and Robertson 2015).
3. **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Porirua Harbour, was undertaken in 2008, 2009 and 2010 to establish a baseline (Robertson and Stevens, 2008, 2009 and 2010). The first year of impact monitoring was undertaken in January 2015 and is the subject of this report. Sedimentation rates in the estuary have been monitored annually in the Harbour since 2008 (see Stevens and Robertson 2015, Figure 1).

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of condition ratings have also been developed and are described in Section 2. The current report describes the 2015 fine scale results and compares them to the previous findings.

Porirua Harbour, is a large (807ha), well flushed “tidal lagoon” type estuary fed by a number of small streams. It comprises two arms, each a relatively simple shape, Onepoto (283ha) and Pauatahanui (524ha). The arms are connected by a narrow channel at Paremata, and the estuary discharges to the sea via a narrow entrance west of Plimmerton. Residence time in the estuary is less than 3 days, however, compared to the majority of NZ’s tidal lagoon estuaries which tend to drain almost completely at low tide, the harbour has a large subtidal component (65%).

The estuary is relatively shallow (mean depth ~1m), and the large intertidal area (287ha, 35% of the estuary) supports extensive areas (59ha) of seagrass growing in firm mud/sand and shellfish. The estuary has high ecological values and high human use, and provides a natural focal point for the thousands of people that live near or visit its shores.

The harbour has been extensively modified over the years (see following page), particularly the Onepoto Arm where almost all of the historical shoreline and saltmarsh have been reclaimed and most of the arm is now lined with steep straight rockwalls flanked by road and rail corridors. The Pauatahanui Arm is less modified (although most of the arm’s margins are also encircled by roads), with extensive areas of saltmarsh remaining in the north and east, a large percentage of which have been improved through local community efforts.

Catchment land use in the Onepoto Arm is dominated by urban (residential and commercial) cover. In the steeper Pauatahanui Arm catchment, grazing dominates although urban (residential) development is significant in some areas. A recent report (Gibb and Cox 2009) identifies sedimentation as a major problem in the estuary and indicates that both estuary arms are highly likely to rapidly infill and change from tidal estuaries to brackish swamps within 145-195 years. The dominant sources contributing to increasing sedimentation rates in the estuary were identified as discharges of both bedload and suspended load from the various input streams. Elevated nutrient inputs are also causing moderate eutrophication symptoms (i.e. poor sediment oxygenation and moderate nuisance macroalgal cover) in the estuary.

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

1. Sedimentation

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). 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 2007, 2010, 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	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 Potenial Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
	Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
	Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity, and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high, very high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data. However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

The indicators and interim risk ratings used for the Porirua Harbour fine scale monitoring programme are summarised in Table 2, and detailed background notes explaining the use and justifications for each indicator are presented in Appendix 4. 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 tidal lagoon estuaries throughout NZ. Work to refine and document these relationships is ongoing.

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

INDICATOR	**RISK RATING**				
	Very Low	Low	Moderate	High	Very High
Apparent Redox Potential Discontinuity (aRPD)	>10cm depth below surface	3-10cm depth below sediment surface	1-<3cm depth below sediment surface	0-<1cm depth below sediment surface	Anoxic conditions at surface
Sediment Mud Content (%mud)	<2%	2-5%	>5-15%	>15-25%	>25%
Macroinvertebrate Enrichment Index (WEBI)	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-<3.5%	>3.5%
Total Nitrogen (TN)	<250mg/kg	250-1000mg/kg	>1000-2000mg/kg	>2000-4000mg/kg	>4000mg/kg
Total Phosphorus (TP)	<100mg/kg	100-300mg/kg	>300-500mg/kg	>500-1000mg/kg	>1000mg/kg
Metals	<0.2 x ISQG Low	0.2 x ISQG Low to 0.5 x ISQG Low	>0.5 x ISQG Low to ISQG Low	>ISQG Low to ISQG High	>ISQG High

3. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary, but varies with estuary size) are selected and samples collected and analysed for the following variables.

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

For the Porirua Harbour, four fine scale sampling sites (Figure 1), were selected in unvegetated, mid-low water habitat of the dominant substrate type (avoiding areas of significant vegetation and channels). At each site, a 60m x 30m area in the lower intertidal was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and the following sampling undertaken:

Physical and chemical analyses.

- Within each plot, one random core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average apparent Redox Potential Discontinuity depth recorded.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. All samples were kept in a chilly bin in the field.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details of lab methods and detection limits in Appendix 1):
    - Grain size/Particle size distribution (% mud, sand, gravel).
    - Nutrients - total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC).
    - Trace metals (Cd, Cr, Cu, Ni, Pb, Zn, Hg), arsenic. Analyses were based on whole sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Epifauna (surface-dwelling animals).

Visually conspicuous epifauna were assessed from one random 0.25m^2 quadrat within each of ten plots. All animals observed on the sediment surface were identified and counted, and any visible microalgal mat development or macroalgal growth noted. The species, abundance and related descriptive information were recorded on specifically designed waterproof field sheets containing a checklist of expected species.

Infauna (animals within sediments).

- One randomly placed sediment core (130mm diameter (area = 0.0133m^2) PVC tube) was taken from each of ten plots.
- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled plastic bag.
- Once all replicates had been collected at a site, the plastic bags were transported to a nearby source of seawater and the contents of the core were washed through a 0.5mm nylon mesh bag. 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 then transported to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).

2. Methods (Continued)

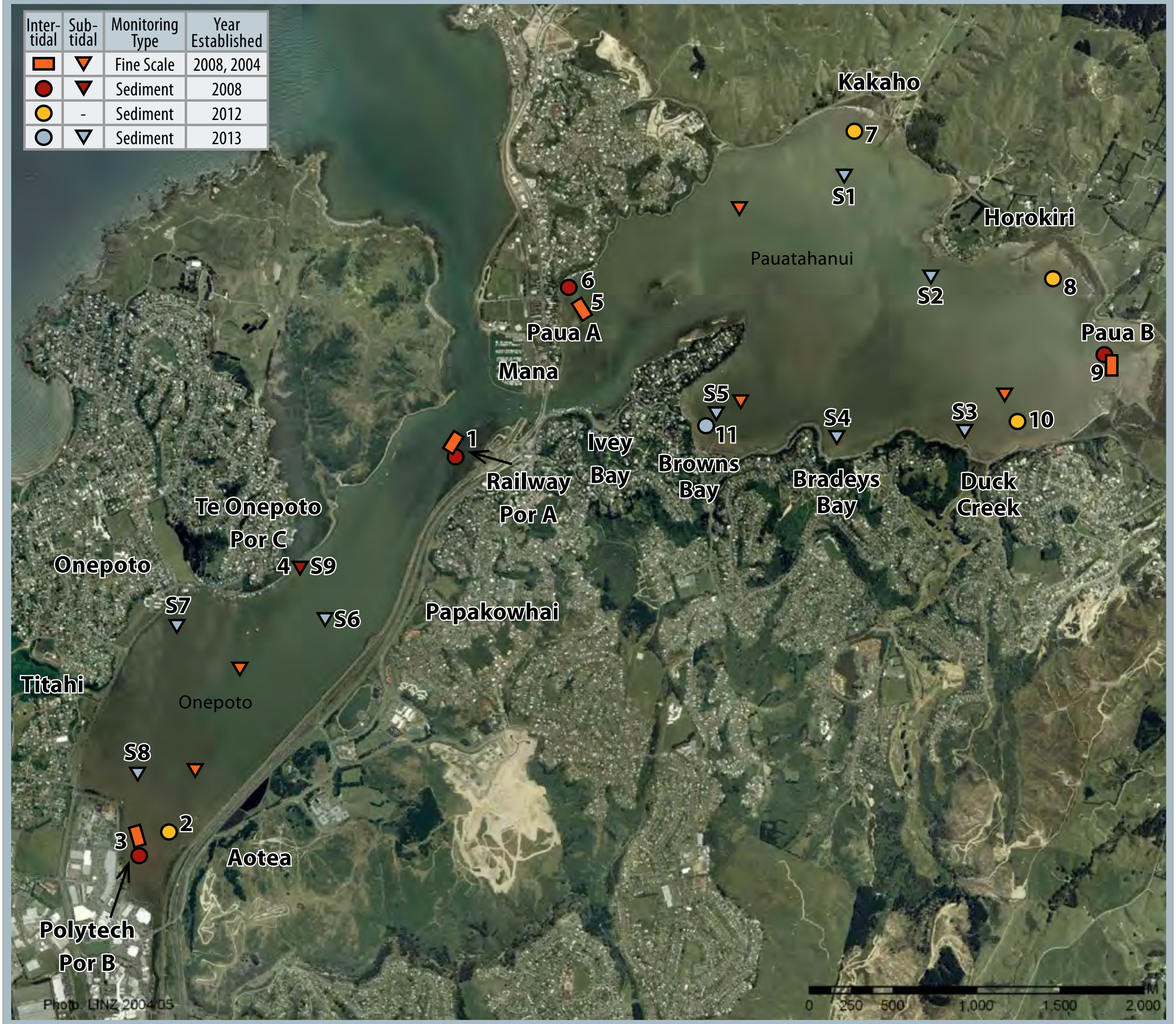


Figure 1. Porirua Harbour showing the location of fine scale sites and buried sediment plates established in 2007/8, 2012, and 2013.

Pauatahanui Inlet - View across Mana intertidal flats to Ivey Bay.

4. RESULTS AND DISCUSSION

A summary of the results of the 20-21 January 2015 fine scale intertidal monitoring of Porirua Harbour, together with the 2008-10 results, is presented in Table 3, with detailed results in Appendices 2 and 3. Analysis and discussion of the results is presented as two main steps; firstly, exploring the primary environmental variables that are most likely to be driving the ecological response in relation to the key issues of sedimentation, eutrophication, and toxicity, and secondly, investigating the biological response using the macroinvertebrate community.

Table 3. Summary of physical, chemical[a] and macrofauna results (means) for 4 fine scale sites (2008-10 and 2015) in Porirua Harbour.

	Site	Reps	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. of Species
			cm	ppt	%				mg/kg								No./m^2	No./core
2008	Por A	3	2-3	30	1.33	9.96	88.13	1.90	0.028	11.3	5.1	6.1	8.4	39.4	685	442	9833	20.5
	Por B	3	5	27	0.60	4.03	94.42	1.57	0.041	5.1	3.6	9.5	3.6	59.9	504	158	10410	17.7
	Pau A	3	4	30	1.32	12.23	81.60	6.20	0.029	10.7	4.9	6.5	8.8	36.7	823	447	8175	18.8
	Pau B	3	3	30	0.58	4.50	90.17	5.33	0.020	4.7	2.3	4.7	3.9	23.0	546	150	9405	21.6
2009	Por A	3	2-3	30	0.39	9.23	89.30	1.47	0.034	12.3	5.0	8.5	6.7	41.0	643	397	10103	22.1
	Por B	3	2	28	0.21	5.73	85.80	8.43	0.046	5.6	3.9	3.7	8.9	57.7	<500	147	7455	13.3
	Pau A	3	2	30	0.38	9.93	81.47	8.57	0.025	11.0	4.6	7.7	6.1	35.0	700	437	7388	20.7
	Pau B	3	4	30	0.23	4.43	87.43	8.17	0.019	4.5	2.0	3.4	4.5	21.0	<553	137	9788	17.8
2010	Por A	3	1.5	31	0.26	9.97	88.10	1.93	0.029	10.6	3.8	7.1	5.3	35.7	<500	393	10650	21.8
	Por B	3	1	30	0.19	9.40	88.97	1.67	0.044	5.2	3.4	3.4	9.1	62.3	555	163	10853	15.1
	Pau A	3	1	31	0.35	15.13	80.37	4.50	0.025	10.7	4.8	7.4	6.8	37.3	673	470	10605	24.7
	Pau B	3	1	31	0.23	7.53	88.97	3.53	0.019	4.1	1.8	3.0	4.2	19.3	597	120	11873	23.8
	2010 DDT results (single composite sample from each of the four sites) were below detection limits.																	
2015	Por A	3	1	31.5	0.79	9.2	82.4	8.3	0.022	11.0	4.8	8.1	6.6	37.3	600	450	6399	16.7
	Por B	3	1	31	0.32	3.3	91.0	5.7	0.021	4.1	2.0	3.3	4.1	20.2	<500	118	7015	17.2
	Pau A	3	1	31	0.58	8.3	89.4	2.3	0.023	10.8	4.2	8.0	5.7	38.0	<500	397	8113	20.3
	Pau B	3	1	31	0.29	4.3	93.4	2.3	0.046	5.6	3.9	4.0	9.9	77.7	<500	196	6760	14.9

[a] Data for arsenic and mercury are presented in Appendix 3.

PRIMARY ENVIRONMENTAL VARIABLES

The primary environmental variables are related to sediment **muddiness** - in particular sediment mud content (often the primary controlling factor) and sedimentation rate; and **eutrophication**, commonly assessed by sediment aRPD depth (a qualitative measure of both available oxygen and the presence of eutrophication related toxicants such as ammonia and sulphide), organic matter (measured as TOC), and nutrients (Dauer et al. 2000, Magni et al. 2009, Robertson 2013). 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 Porirua Harbour has been examined in two steps:

- One way ANOVA (p=0.05) was used to assess if there was a significant difference between means for any two years at each site, for each environmental factor.
- The ANOVA analysis was followed by a Tukey post hoc test to determine if there was a significant difference between 2015 data (i.e. “post baseline” data) and all of the baseline years 2008-10 and, if there was a significant difference between all of the years, whether the 2015 data was outside of the baseline data range. If the latter was true, then it was concluded that there had been a significant change between the baseline years and the post baseline year for that particular variable.

The results of these analyses are summarised in Table 4.

4. Results and Discussion (Continued)

Table 4. Summary of one way ANOVA (p=0.05) and Tukey post hoc tests for physical and chemical data for 4 fine scale sites (2008-10 and 2015) in Porirua Harbour.

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 there a significant difference between 2015 data and all of the baseline years 2008-2010? Also is 2015 data outside of the baseline data range?
Por A	**TOC**	F = 111.5, P < 0.001. Significant	Significant, but still within the range of baseline data.
	Mud	F = 3.75, P = 0.019. Significant	Not Significant
	Cadmium	F =7.25, P = 0.001. Significant	Not Significant
	Chromium	F =5.42, P = 0.004. Significant	Not Significant
	Copper	F =76.98, P < 0.001. Significant	Significant, but still within the range of baseline data.
	Nickel	F =75.337, P < 0.001. Significant	Significant, but still within the range of baseline data.
	Lead	F =10.34, P < 0.001. Significant	Not Significant
	Zinc	F =37.96, P < 0.001. Significant	Significant, but still within the range of baseline data.
	RPD	F = 63.85, P < 0.001. Significant	Significant.
	TN	F =1 3.77, P < 0.001. Significant	Not Significant
	TP	F = 13.50, P < 0.001. Significant	Not Significant
Por B	**TOC**	F = 88.79, P < 0.001. Significant	Not Significant
	Mud	F = 22.02, P < 0.001. Significant	Not Significant
	Cadmium	F = 147.96, P < 0.001. Significant	Not Significant
	Chromium	F =3 0.94, P < 0.001. Significant	Significant (small increase)
	Copper	F = 119.09, P < 0.001. Significant	Not Significant
	Nickel	F = 28.56, P < 0.001. Significant	Significant (small increase)
	Lead	F = 79.73, P < 0.001. Significant	Not Significant
	Zinc	F = 1018.58, P < 0.001. Significant	Significant (small increase)
	RPD	F = 193.89, P < 0.001. Significant	Not Significant
	TN	F =10.42, P < 0.001. Significant	Not Significant
	TP	F = 63.51, P < 0.001. Significant	Significant (small increase)
Pau A	**TOC**	F = 978.53, P < 0.001. Significant	Significant, but still within the range of baseline data.
	Mud	F = 29.10, P < 0.001. Significant	Not Significant
	Cadmium	F =86.86, P < 0.001. Significant	Significant (small decrease)
	Chromium	F = 35.84, P < 0.001. Significant	Not Significant
	Copper	F = 4.14, P = 0.013. Significant	Not Significant
	Nickel	F = 48.01, P < 0.001. Significant	Significant, but still within the range of baseline data.
	Lead	F = 0.613, P = 0.611. Not Significant	Not Significant
	Zinc	F = 26.58, P < 0.001. Significant	Not Significant
	RPD	F = 154.8, P < 0.001. Significant	Not Significant
	TN	F =35.13, P < 0.001. Significant	Not Significant
	TP	F = 35.90, P < 0.001. Significant	Not Significant
Pau B	**TOC**	F = 35.33, P < 0.001. Significant	Not Significant
	Mud	F = 42.32, P < 0.001. Significant	Not Significant
	Cadmium	F = 184.11, P < 0.001. Significant	Not Significant
	Chromium	F = 88.05, P < 0.001. Significant	Not Significant
	Copper	F = 25.47, P < 0.001. Significant	Not Significant
	Nickel	F = 65.32, P < 0.001. Significant	Significant, but still within the range of baseline data.
	Lead	F = 474.95, P < 0.001. Significant	Not Significant
	Zinc	F = 753.69, P < 0.001. Significant	Not Significant
	RPD	F = 106.8, P < 0.001. Significant	Not Significant
	TN	F = 13.82, P < 0.001. Significant	Not Significant
	TP	F = 14.85, P < 0.001. Significant	Not Significant

4. Results and Discussion (Continued)

SEDIMENT INDICATORS

Sediment Mud Content

Sediment mud content (i.e. % grain size <63µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments, unless naturally erosion-prone with few wetland filters, are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island). 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% mud).

The 2015 monitoring results for sediment mud content (Table 3, Figure 2) were at relatively low levels (3.3 to 9.2% mud). The data for all years (i.e. 2008-10 and 2015) showed that mean mud content differed between at least two years at all sites (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the "post baseline" 2015 data and all of the "baseline" 2008-10 data. These results indicate no significantly increased muddiness at the fine scale sites and, as such, adverse impacts to benthic macroinvertebrates from increased muddiness are unlikely.

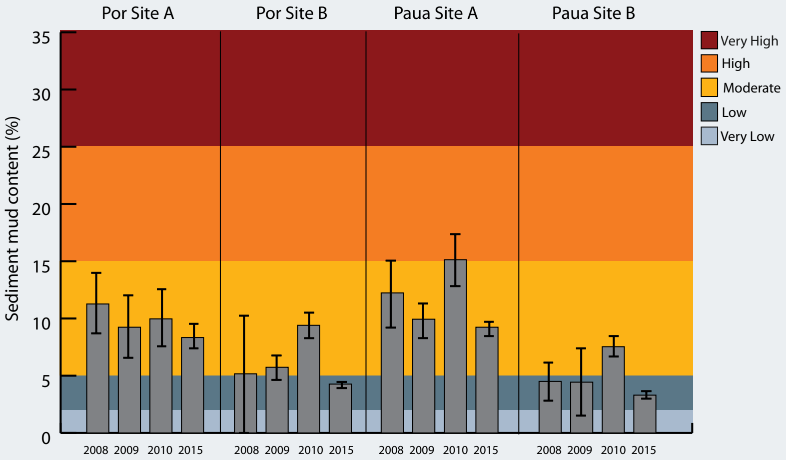


Figure 2. Mean sediment mud content (±SE, n=3), Porirua Harbour, 2008, 2009, 2010 and 2015.

EUTROPHICATION INDICATORS

The primary variables indicating eutrophication impacts are sediment mud content, aRPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal cover. The former are discussed below, with macroalgal cover assessed previously in the broad scale report (see Stevens and Robertson 2014).

Sediment Grain Size (% Mud)

This indicator has been discussed in the sediment section above and is not repeated here. However, in relation to eutrophication, the low mud contents at all sites indicate sediment oxygenation is likely to be relatively good.

Apparent Redox Potential Discontinuity (aRPD)

The depth of the aRPD boundary indicates the extent of oxygenation within sediments. Figure 3 shows the aRPD depths for the four Porirua sampling sites. In 2015, the aRPD depth was shallow (1cm) at all sites, indicating a "high" risk of ecological impacts. The data for all years (i.e. 2008-10 and 2015) showed that aRPD differed between at least two years for all sites (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the "post baseline" 2015 data and all of the "baseline" 2008-2010 data, except for site Por A. However, these results must be considered as very preliminary in nature given the semi-quantitative nature of the method. In future, it is envisaged that more quantitative assessments of sediment oxygenation in relation to ecological change will be undertaken using more robust indicators (e.g. redox potential, presence of sulphides and bacterial status). Currently, this data is being collected, and assessed for use in estuary long term monitoring programmes, as part of a GWRC and Wriggle funded PhD at Otago University.

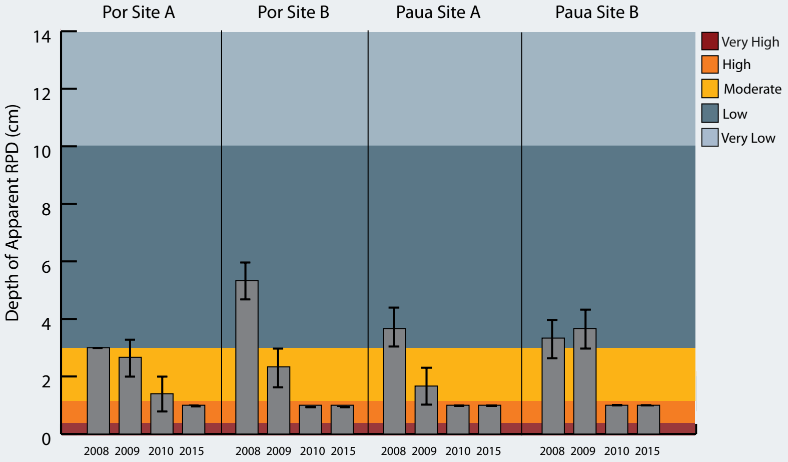


Figure 3. Mean apparent Redox Potential Discontinuity (aRPD) depth, (±SE, n=3), Porirua Harbour, 2008, 2009, 2010 and 2015.

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 WEBI biotic coefficient (see the following macroinvertebrate condition section), then TN, TP and TOC concentrations provide a good indication that loadings are exceeding the assimilative capacity of the estuary. However, a low TOC, TN, or TP concentration does not in itself indicate an absence of eutrophication symptoms. It may be that the estuary, or part of an estuary, may have reached a eutrophic condition and simply exhausted the available nutrient supply. Obviously, the latter case is likely to better respond to input load reduction than the former.

The 2008-2015 results showed TOC (<0.9%) and TN (<900mg/kg) were in the "low" risk indicator rating, while TP was rated "moderate" for Por A and Paua A and "very low" for Por B and Paua B (Figures 4, 5, and 6). The "low" TOC, TN and "low-moderate" TP concentrations reflect the likely moderate load of organic matter and nutrients, sourced primarily from the catchment.

The data for all years (i.e. 2008-10 and 2015) showed that TOC, TN and TP differed between at least two years for all sites (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the "post baseline" 2015 data and all of the "baseline" 2008-10 data, except for TP at site Por B where there was a significant small increase.

Overall, the results for the sediment and eutrophication environmental variables indicate that the sediment conditions at the four sites over the period 2008-10 and 2015 have been variable, but there has been little change between baseline and post baseline years. In general, the conditions can be described as:

- low-moderate muddiness
- moderate sediment oxygenation
- relatively low organic carbon and nutrient concentrations.

TOXICITY INDICATORS

In 2008-2010 and 2015, the heavy metals Cd, Cr, Cu, Pb, Ni, and Zn, used as an indicator of potential toxicants, were present at "very low" to "low" concentrations with all non-normalised values below the ANZECC (2000) ISQG-Low trigger values (Figures 7 and 8), with little evidence of any increasing trend. The data for all years (i.e. 2008-10 and 2015) showed that metals differed between at least two years for all sites (Table 4 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the "post baseline" 2015 data and all of the "baseline" 2008-2010 data, except for a small increase in Cr, Ni and Zn at site Por B in 2015 and a small decrease in Cd at Pau A. The 2015 results also showed that concentrations of the heavy metal mercury and the metalloid arsenic were also well below the ANZECC (2000) ISQG Low limit (Appendix 2) and therefore, like all of the metal results, posed no toxicity threat to aquatic life.

4. Results and Discussion (Continued)

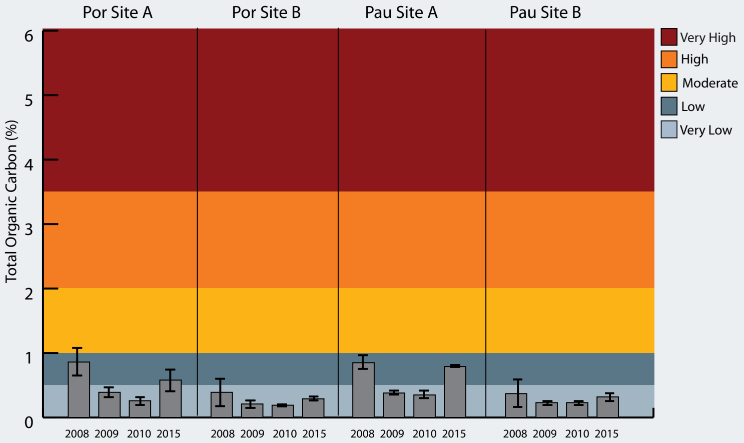


Figure 4. Mean total organic carbon (±SE, n=3), Porirua Harbour, 2008, 2009, 2010 and 2015.

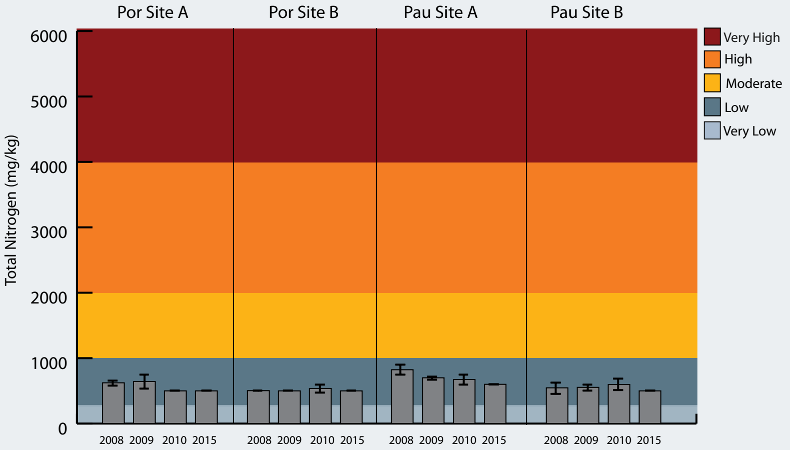


Figure 5. Mean total nitrogen (±SE, n=3), Porirua Harbour, 2008, 2009, 2010 and 2015.

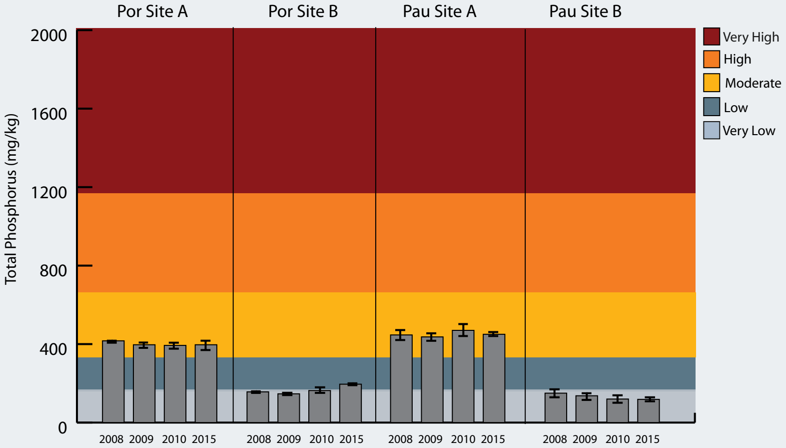


Figure 6. Mean total phosphorus (±SE, n=3), Porirua Harbour, 2008, 2009, 2010 and 2015.

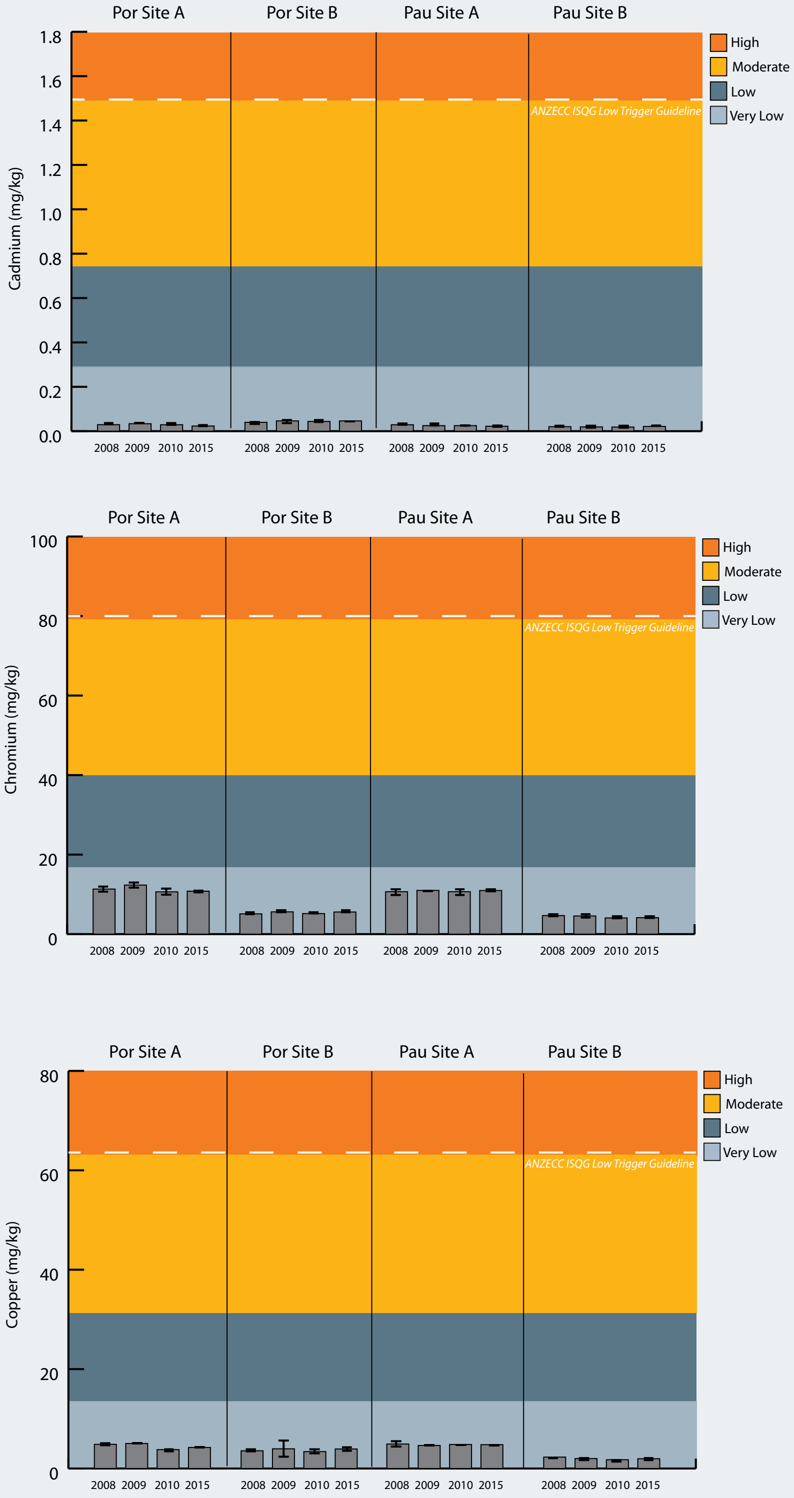


Figure 7. Mean sediment cadmium, chromium and copper concentrations (±SE, n=3), Porirua Harbour, 2008, 2009, 2010 and 2015.

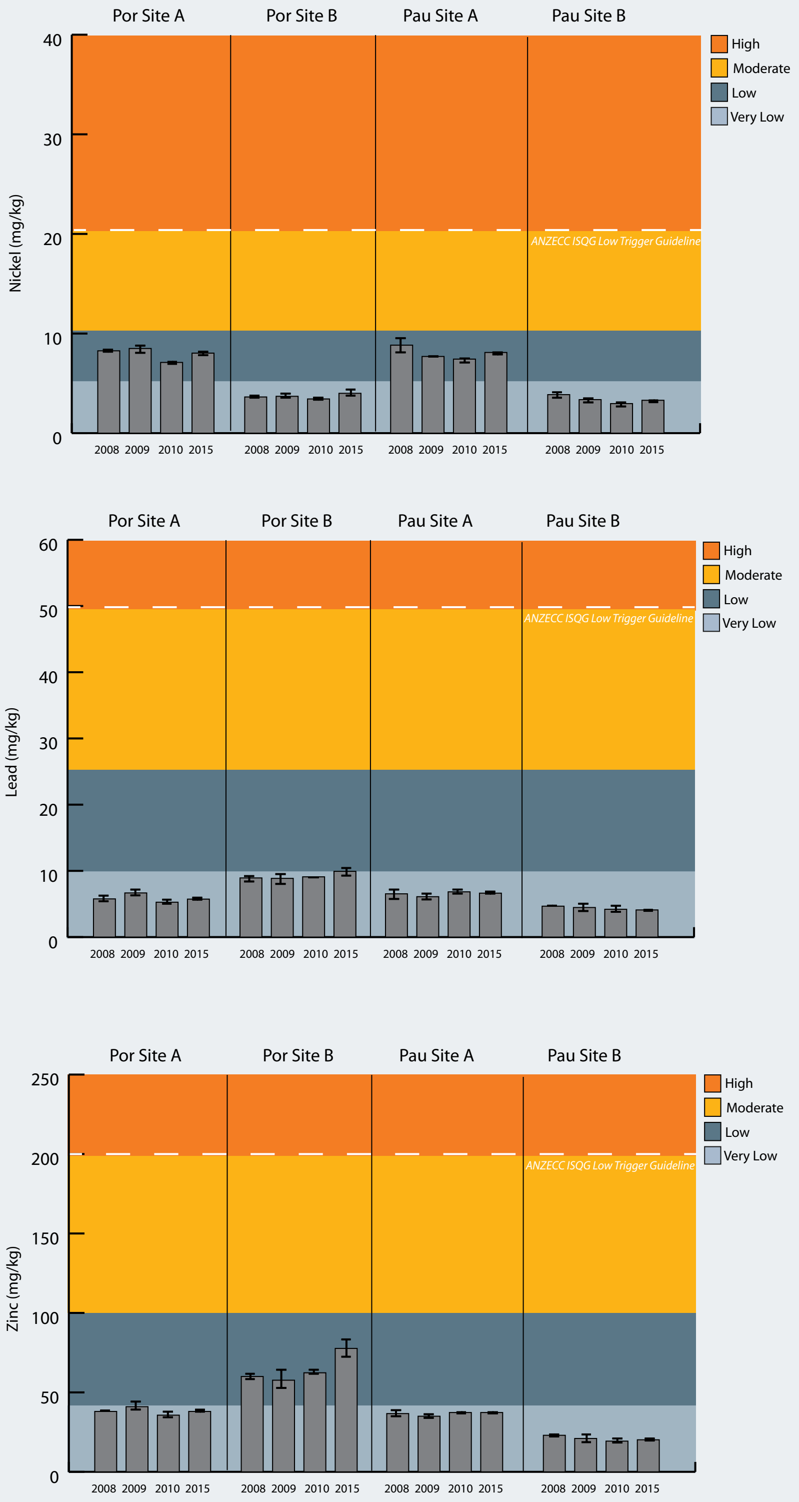


Figure 8. Mean sediment nickel, lead and zinc concentrations (±SE, n=3), Porirua Harbour, 2008, 2009, 2010 and 2015.

4. Results and Discussion (Continued)

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. 2015 in press). Because they integrate recent pollution history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macroinvertebrates to stressors in Porirua Harbour 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 fine scale sites sampled in 2008, 2009, 2010 and 2015.
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 sampled in 2008, 2009, 2010 and 2015, based on identified tolerance thresholds for NZ taxa (Robertson 2013, Robertson et al. 2015 in press).

Macroinvertebrate Community Ordination

Principle Coordinates Analysis (PCO), based on between-year species abundance data collected in 2008-10 and 2015, showed that the invertebrate community at the four sites (Por A, Por B, Pau A and Pau B) in 2015 were significantly different from 2008, 2009 and 2010 (i.e. PERMANOVA P<0.0002 for all sites, for between-year comparisons, Figure 9), indicating significant structural changes to the community over this period. Vector overlays of environmental variables (based on Pearson correlations) are also presented in order to provide preliminary exploratory information in relation to the potential influence of environmental factors at each of the four sites (a more robust analysis is presented below).

Influence of Environmental Factors

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, although analyses of the faunal results showed differences between years at each of the four sites (Figure 9), the environmental variables provided only a partial explanation for these differences.

- At Por A, no one or combination of the environmental factors measured was well correlated with the faunal results (r=0.35) (Table 5).
- At Por B, TOC and heavy metals (Cd, Cu, Cr, Ni, Pb and Zn) were identified as being moderately correlated with the macrobenthic faunal assemblages of the study area at different range of rank correlations (r<0.467-0.514) (Table 5).
- At Pau A, TOC, mud, and heavy metals (Cd, Cu, Cr, Ni, Pb and Zn) were identified as being moderately to highly correlated with the macrobenthic faunal assemblages of the study area at different range of rank correlations (r<0.544-0.724) (Table 5).
- At Pau B, mud and heavy metals (Cr, Ni, Pb and Zn) were identified as being low to moderately correlated with the macrobenthic faunal assemblages of the study area at different range of rank correlations (r<0.353-0.422) (Table 5).

Species Richness, Abundance, Diversity and Infauna Groups

The next step was to assess whether simple univariate whole community indices, i.e. species richness, abundance and diversity at each site (Figure 10), could explain the differences between years indicated by the PCO analysis. The data for all years (i.e. 2008-10 and 2015) showed that species richness, abundance and Shannon diversity differed between at least two years for all sites (Table 6 ANOVA results), except for diversity at Por A. However, the Tukey post-hoc test (p=0.05) indicated no significant difference between the "post baseline" 2015 data and all of the "baseline" 2008-10 data, except for the following:

- There was a significant small decline in both species number and abundance at Por A, but not diversity.
- There was a significant small increase in species abundance at Por B, but not species number or diversity.

Figure 11 shows that although the community at all sites in 2008, 2009, 2010 and 2015 was dominated by polychaetes, crustacea, bivalves and gastropods, there were obvious differences between years within most taxa groups.

4. Results and Discussion (Continued)

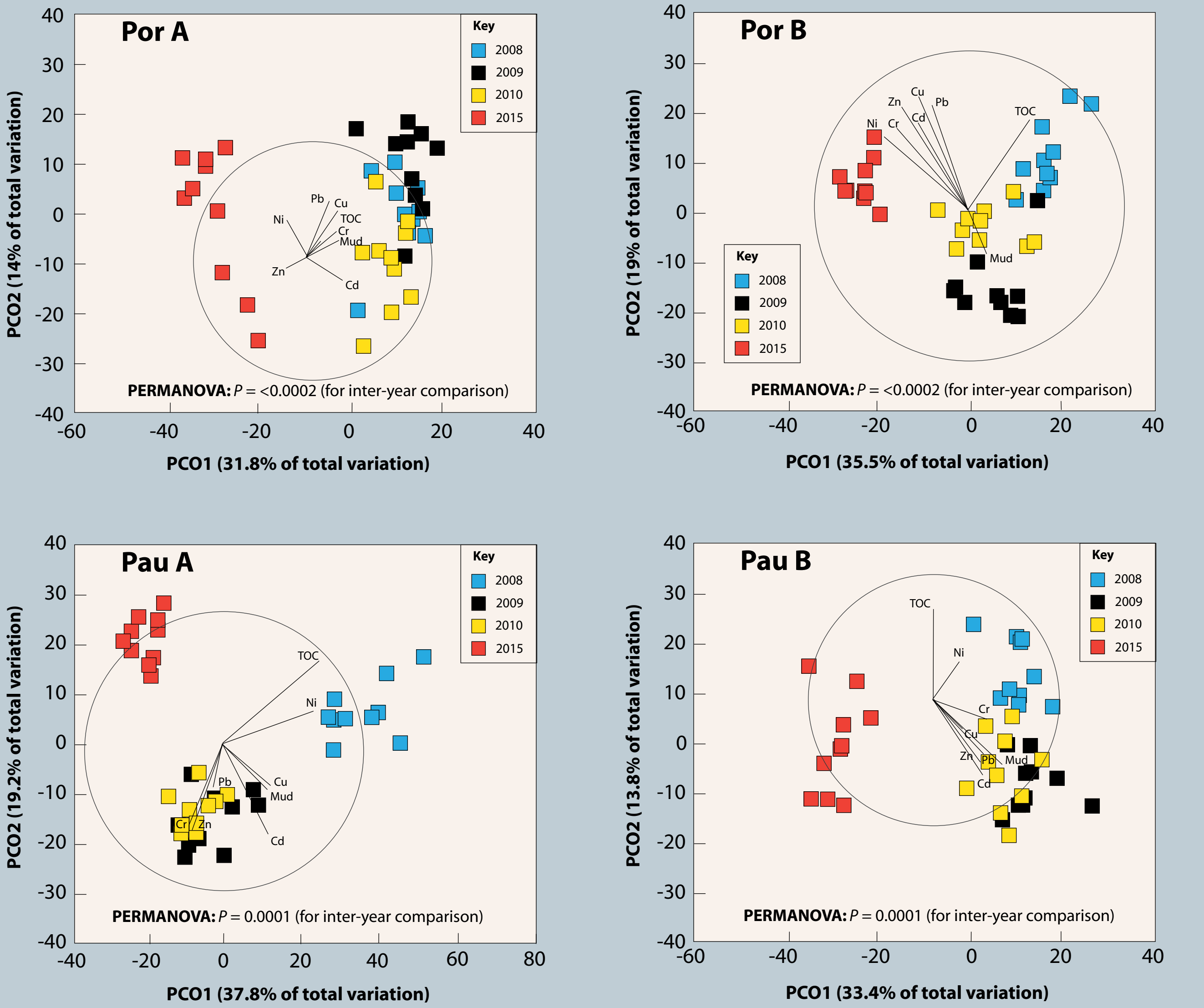


Figure 9. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at each site, Porirua Harbour, 2008, 2009, 2010 and 2015, and the environmental variables that possibly reflect the observed differences.

Figure 9 shows the relationship among samples in terms of similarity in macroinvertebrate community composition at Sites Por A, Por B, Pau A and Pau B, for the sampling period 2008, 2009, 2010 and 2015. The plot shows the 10 replicate samples for each site, 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(s) 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 >47-57% for all sites, indicating a relatively good representation of the abundance matrix.

PERMANOVA, testing for statistical significant differences in the invertebrate communities among samples, reflected highly significant (*P*>0.0002) structural changes over the sampling period 2008, 2009, 2010 and 2015.

The environmental vector overlays, based on Pearson correlations, show preliminary exploratory information on the strength of environmental relationships with their length in relation to the circle boundary indicating the magnitude of the strength. In this case, the results indicate that the 2015 communities were likely separated from the 2008-2010 at each of the sites by the following: Por A by factors other than those measured; Por B partially by increased metal concentrations; Pau B partially by decreased metal, TOC and mud concentrations and Pau B partially by decreased metal and mud concentrations.

4. Results and Discussion (Continued)

Table 5. Combinations of factors with highest Spearman correlation coefficients between mean faunal and sediment similarity matrices (Primer's BIOENV routine) for each of four Porirua harbour sites (2008-10 and 2015).

Site	Variables	Best Combination	2nd Combination	3rd Combination	4th Combination	5th Combination
Por A	1	Cr 0.313	Cd 0.144	Cu 0.130		
	2	Cr, Zn 0.118	Cu, Ni 0.113	Cd, Pb 0.109	Cr, Cu 0.108	Cd, Cr 0.101
Por B	2	TOC, Ni 0.480	TOC, Zn 0.475			
	3	TOC, Ni, Zn 0.514	TOC, Cu, Ni 0.499	TOC, Cd, Ni 0.472	TOC, Ni, Pb 0.467	
	4	TOC, Cu, Ni, Zn 0.484	TOC, Cr, Ni, Zn 0.477	TOC, Cu, Ni, Pb 0.467		
Pau A	1	TOC 0.724				
	2	TOC, Cu 0.649	TOC, Pb 0.608	TOC, Ni 0.550	TOC, Cd 0.544	
	3	TOC, Cu, Pb 0.613	TOC Cu, Ni 0.547			
	4	TOC, Cu, Ni, Pb 0.559	TOC, Mud, Cu, Pb 0.548			
Pau B	1	Mud 0.422				
	2	Mud, Cr 0.398	Mud, Pb 0.386	Mud, Zn 0.374	Mud, Ni 0.349	
	3	Mud, Cr, Pb 0.371	Mud, Cr, Zn 0.358	Mud, Cr, Ni 0.353		
	4	Mud, Cr, Ni, Pb 0.344				

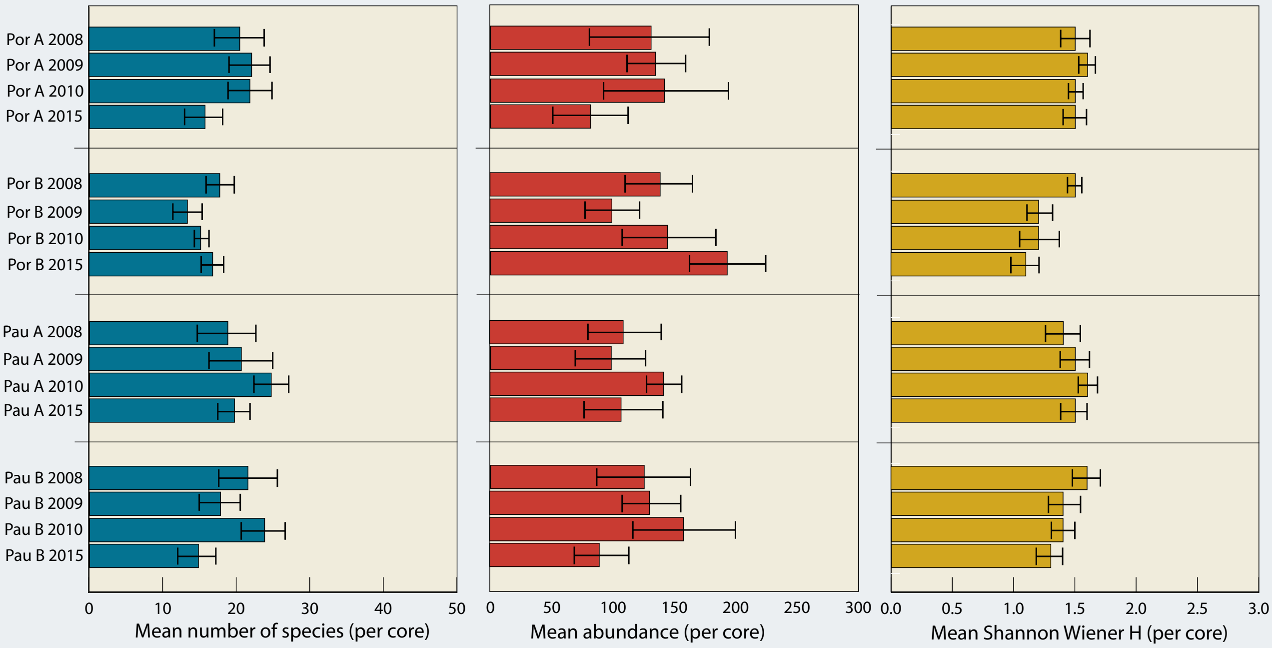


Figure 10. Mean number of species, abundance per core, and Shannon diversity index (±SE, n=10), Porirua Harbour, 2008, 2009, 2010 and 2015.

Table 6. Summary of one way ANOVA (p=0.05) and Tukey post hoc tests for macroinvertebrate data for 4 fine scale sites (2008-10 and 2015) in Porirua Harbour.

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 there a significant difference between 2015 data and all of the baseline years 2008-2010? Also is 2015 data outside of the baseline data range?
Por A	Mean No Species	F = 9.28, P < 0.001. Significant	Significant, decline in species number
	Mean Abundance	F = 4.61, P = 0.008. Significant	Significant, decline in species abundance
	Shannon Wiener (H)	F = 1.02, P = 0.394. Not Significant	Not Significant
Por B	Mean No Species	F = 11.85, P < 0.001. Significant	Not Significant
	Mean Abundance	F = 15.99, P < 0.001. Significant	Significant, increase in species abundance
	Shannon Wiener (H)	F = 16.27, P < 0.001. Significant	Not Significant
Pau A	Mean No Species	F = 5.56, P = 0.003. Significant	Not Significant
	Mean Abundance	F = 4.63, P = 0.008. Significant	Not Significant
	Shannon Wiener (H)	F = 4.62, P = 0.007. Significant	Not Significant
Pau B	Mean No Species	F = 14.46, P < 0.001. Significant	Not Significant
	Mean Abundance	F = 7.5, P = 0.001. Significant	Not Significant
	Shannon Wiener (H)	F = 10.71, P < 0.001. Significant	Not Significant

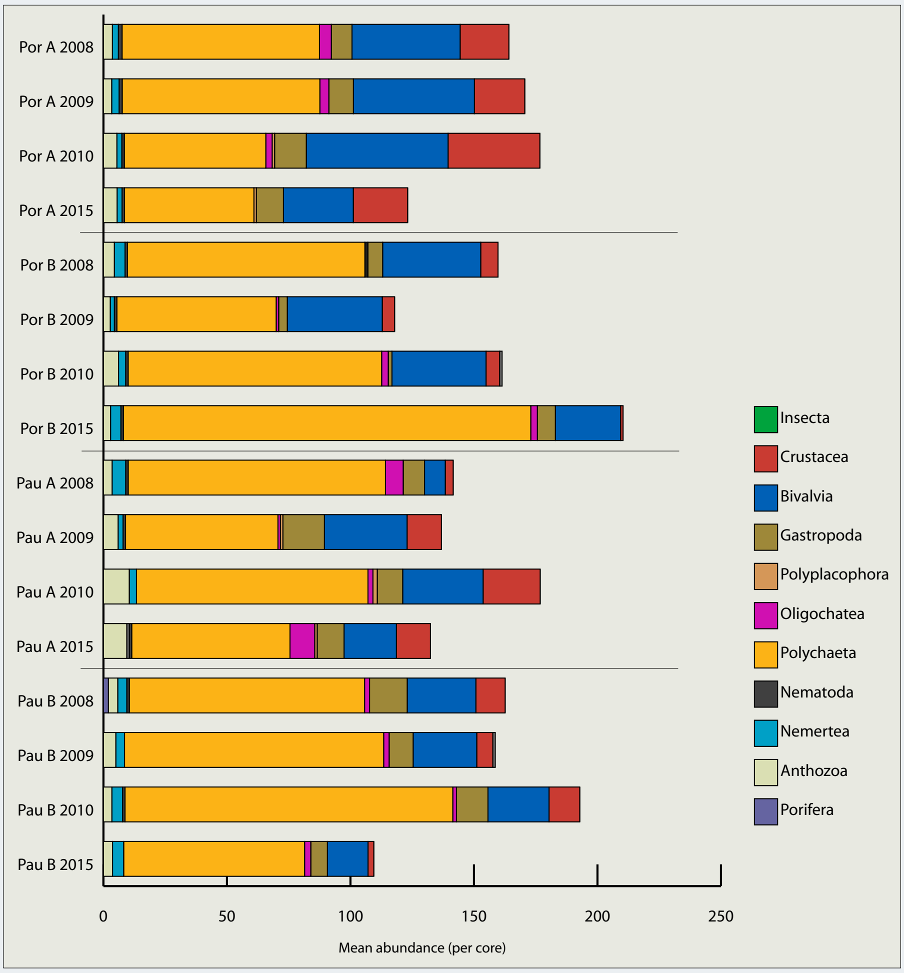


Figure 11. Mean abundance of major infauna groups (n=10), Porirua Harbour, 2008, 2009, 2010 and 2015.

4. Results and Discussion (Continued)

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

Organic matter and mud are major determinants of the structure of the benthic invertebrate community. The previous section has already established the following:

- For the two Pauatahanui Arm sites (Pau A and Pau B) there were no clear trends in the change in species abundance, richness or diversity between the baseline years (2008-10) and post baseline 2015, despite obvious differences between whole communities over this time.
- For the lower Porirua Arm site (Por A) there was a significant small decline in species richness and abundance (but no significant change in species diversity) between the baseline years (2008-10) and post baseline 2015, which may partially explain differences between whole communities over this time.
- For the upper Porirua Arm site (Por B) there was a significant small increase in species abundance (but no significant change in species richness or diversity) between the baseline years (2008-10) and post baseline 2015, which may partially explain differences between whole communities over this time.

The following analyses explore the macrofaunal results in greater detail using two steps as follows:

1. Modified AMBI Mud and Organic Enrichment Index (WEBI)

The first approach is undertaken by using the WEBI mud/organic enrichment rating (Appendix 4), which is basically the international AMBI approach (Borja at al. 2000) modified by using mud (and because of its co-variation with mud, TOC) sensitivity ratings for NZ macrofauna (Robertson 2013, Robertson et al. 2015 in press). The WEBI is clearly an improvement on the AMBI approach for NZ estuary macrofauna, but because it still relies on the AMBI formula, which does not directly account for species richness and diversity (i.e. conditioned on abundance only), its results must be considered alongside a range of other relevant indicators to ensure a reliable conclusion is reached. Currently, PhD research is being undertaken by Ben Robertson at University of Otago to develop a more robust NZ biotic index for addressing the primary issues of estuary sedimentation and eutrophication, thereby improving robustness and cost effectiveness of long term estuary monitoring programmes.

WEBI biotic coefficients, and mud and organic enrichment tolerance ratings, for the Porirua intertidal fine scale sites are presented in Figure 12. Coefficients ranged from 0.8-2.4, and were all in the “low” to “low-moderate” risk indicator category (i.e. a transitional type community indicative of low levels of organic enrichment and low-moderate mud concentrations). The data for all years (i.e. 2008-10 and 2015) showed that the WEBI coefficient significantly differed between at least two years for all sites (Table 7 ANOVA results), but the Tukey post-hoc test (p=0.05) indicated no significant difference between the “post baseline” 2015 data and all of the “baseline” 2008-10 data. These results indicate that the difference between the macroinvertebrate community at each site in 2015, compared with the baseline years, was unlikely to be a result of changes in mud content or organic enrichment.

The WEBI findings were therefore consistent with results showing significant differences in the macroinvertebrate community between post baseline and baseline years (PCO/PERMANOVA, P<0.05) for all sites, but no significant differences between mud and TOC concentrations for these years.

Table 7. Summary of one way ANOVA (p=0.05) and Tukey post hoc tests for macroinvertebrate WEBI data for 4 fine scale sites (2008-10 and 2015) in Porirua Harbour.

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 there a significant difference between 2015 data and all of the baseline years 2008-2010? Also is 2015 data outside of the baseline data range?
Por A	WEBI	F = 3.89, P = 0.017. Significant	Not Significant
Por B	WEBI	F = 23.60, P < 0.001. Significant	Not Significant
Pau A	WEBI	F = 11.05, P < 0.001. Significant	Not Significant
Pau B	WEBI	F = 42.53, P < 0.001. Significant	Significant, but still within the range of baseline data.

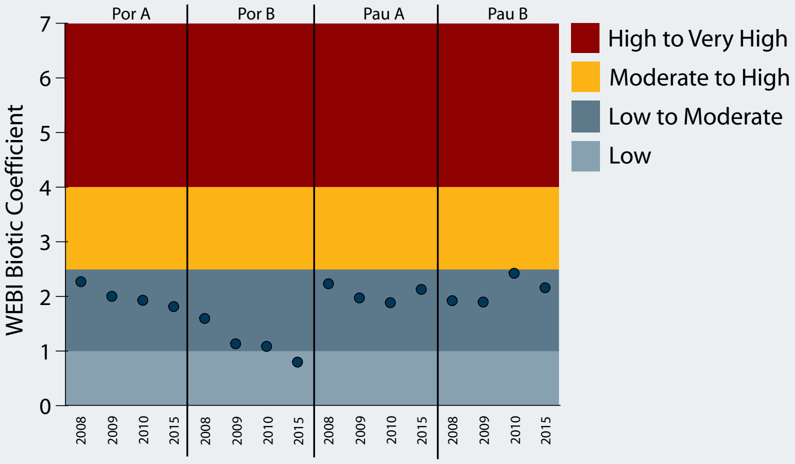


Figure 12. Benthic invertebrate WEBI mud/organic enrichment tolerance rating (±SE, n=10), Porirua Harbour, 2008-10 and 2015.

2. Individual Species Changes

To further explore possible reasons for why the community analysis shows differences at each site between the baseline and post baseline years, it is appropriate to look at changes in abundance of individual species over time using:

- Univariate SIMPER (PRIMER-e) analysis (Table 8 and details in Appendix 2).
- Comparing direct plots of mean abundances of the 5 major mud/enrichment tolerance groupings (i.e. "very sensitive to organic enrichment" group through to "1st-order opportunistic species" group) (Figures 13 and 14).

The SIMPER analysis (summarised in Table 8) shows what taxa are causing the greatest contribution (including the magnitude of each taxon - see Appendix 2 for details) to the difference between macroinvertebrate community structure between baseline years 2008-10 and post baseline 2015 changes. The results indicate that a range of taxa was responsible for the greatest differences, but perhaps the most significant point is that these changes were generally relatively small (i.e. <30%, except for *Aonides trifida* at Por B where there was an approximate 50% increase in this taxa in 2015 compared to baseline years).

Table 8. Species causing the greatest contribution to the difference between macroinvertebrate community structure between baseline years 2008-10 and post baseline 2015 at Porirua Harbour sites (SIMPER Analysis, details see Appendix 5).

Por A	**Por B**	**Pau A**	**Pau B**
Heteromastus filiformis	*Aonides trifida*	Paraonidae	*Heteromastus filiformis*
Linucula hartvigiana	*Axiothella serrata*	*Heteromastus filiformis*	*Boccardia* sp.
Boccardia sp.	*Austrovenus stutchburyi*	*Linucula hartvigiana*	*Axiothella serrata*
Phoxocephalidae sp. 1	*Heteromastus filiformis*	*Boccardia syrtis*	*Boccardia acus*
Arthritica bifurca	*Orbinia papillosa*	Oligochaeta	*Tellina liliana*
Ostracod sp. 1	*Capitella capitata*	*Edwardsia* sp.	*Austrovenus stutchburyi*
Paraonidae	*Boccardia* sp.		*Prionospio aucklandica*
	Edwardsia sp.		

These results, which show significant but relatively small changes in species abundances between years at each site at the species level, are illustrated in Figures 13 and 14. This graph 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 in press).

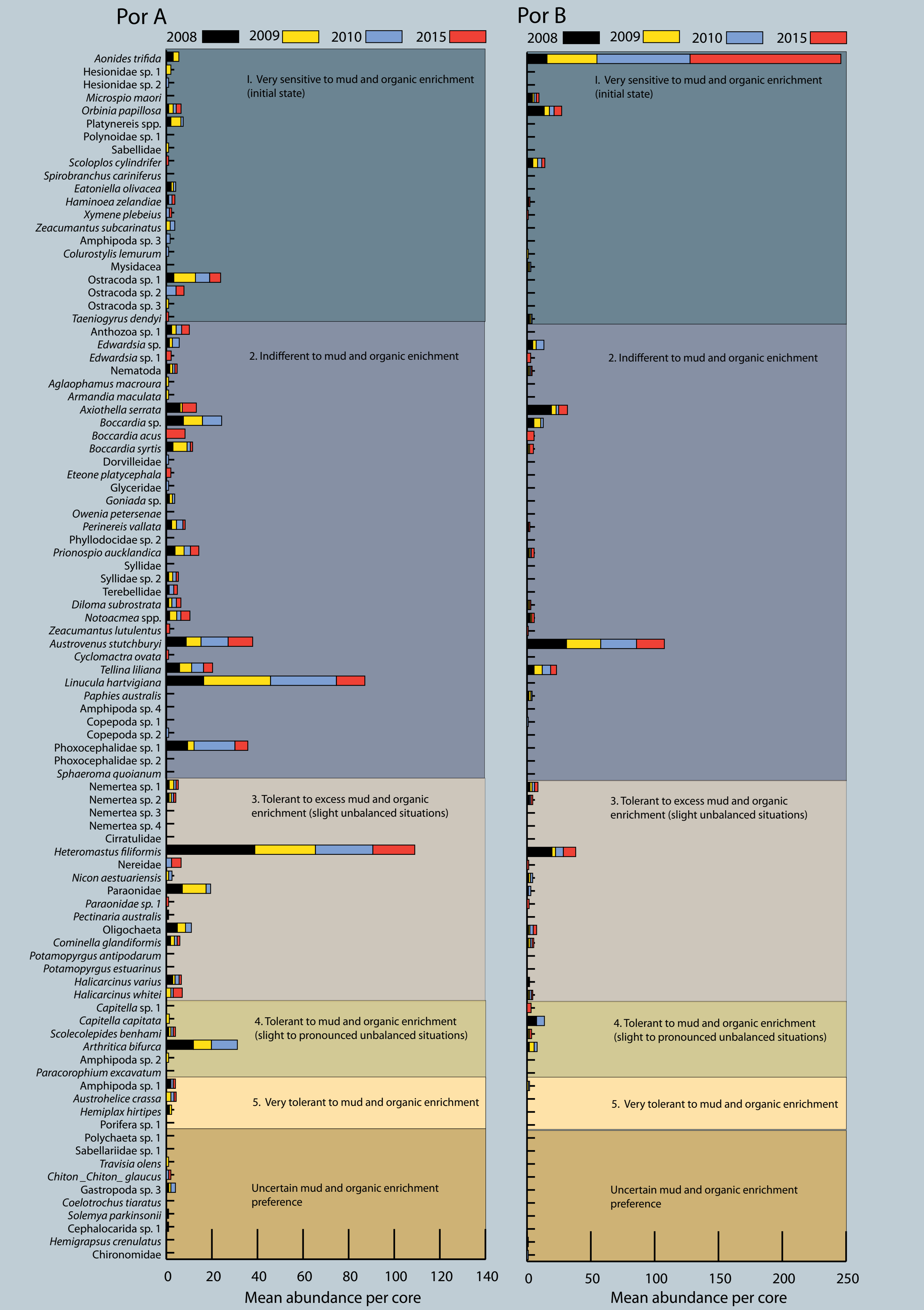


Figure 13. Mud and organic enrichment sensitivity of macroinvertebrates, Porirua Harbour (Onepoto Arm), 2008, 2009, 2010 and 2015 (see Appendix 4 for sensitivity details).

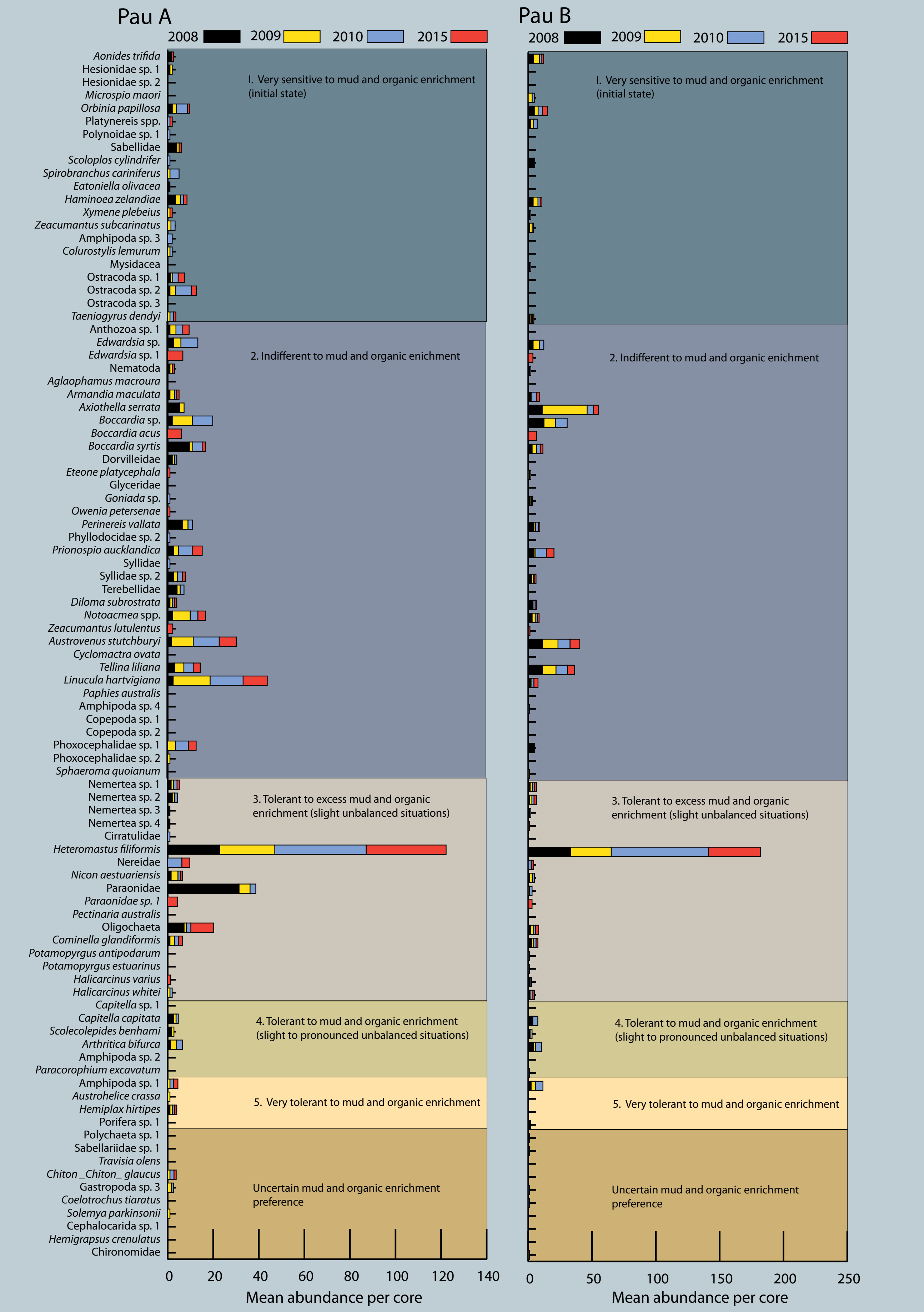


Figure 14. Mud and organic enrichment sensitivity of macroinvertebrates, Porirua Harbour (Pauatahanui Arm), 2008, 2009, 2010 and 2015 (see Appendix 4 for sensitivity details).

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for four long term intertidal monitoring sites within Porirua Harbour in 2015, and supported by the baseline 2008, 2009 and 2010 results, showed the following key findings:

Physical and Chemical Condition

- Sediment mud content in 2015 was at relatively low levels (3.3 to 9.2% mud). The data for all years (i.e. 2008-10 and 2015) indicated no significant difference between the “post baseline” 2015 data and all of the “baseline” 2008-10 data. These results indicate that adverse impacts to benthic macroinvertebrates at these sites through increased muddiness was unlikely.
- Sediment oxygenation (aRPD) in 2015 was shallow (1cm) at all sites. The data for all years (i.e. 2008-10 and 2015) indicated no significant difference between the “post baseline” and “baseline” years, except for site Por A. In the future it is recommended that the semi-quantitative visual RPD measures be collected in tandem with the more quantitative ORP meter redox potential measures in order to more accurately assess the ecological significance of RPD measures in Porirua Harbour.
- The 2015 results showed TOC (<0.8%) and TN (<600mg/kg) were in the “low” risk indicator rating and there was no significant difference between the “post baseline” 2015 data and all of the “baseline” 2008-10 data.
- Sediment toxicants (heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn)), and arsenic were at concentrations that were not expected to pose toxicity threats to aquatic life. The data indicated no significant difference between the “post baseline” 2015 data and all of the “baseline” 2008-10 data, except for a small increase in Cr, Ni and Zn at site Por B in 2015 and a small decrease in Cd at Pau A.

Biological Condition

- Macroinvertebrates consisted of a mixed assemblage of species, dominated by polychaetes, crustacea, bivalves and gastropods, spread across all sites between 2008-10 and 2015.
- Statistical analysis of the results showed significant, but relatively small, differences in the communities at each site between the “post baseline” 2015 data and all of the “baseline” 2008-10 data. Comparison of the faunal results with abiotic factors indicated that, although analyses of the faunal results showed differences between years at each of the four sites, the environmental variables provided only a partial explanation for these differences, particularly at site Por A.

In summary, the results showed that the current fine scale sites in Porirua Harbour were located in unvegetated mud/sand habitat near low water. In 2015, as in the baseline years 2008-10, the fine scale intertidal sediments had low mud concentrations, low to moderate levels of organic enrichment, moderate sediment oxygenation, low levels of toxicity and a typical mixed tolerance macroinvertebrate community.

In terms of changes since 2010 the results showed the following:

- mud, nutrient and organic carbon concentrations were relatively stable
- heavy metals showed small increases at some sites and decreases at others
- significant small changes in the structure of the macroinvertebrate community

In terms of the condition of the wider harbour (i.e. outside the fine scale sites) in relation to the key estuary ecological issues of sedimentation, eutrophication, toxicity and habitat modification, the findings of this report need to be viewed in conjunction with other reports that document the condition of other susceptible habitats in the Harbour, particularly reports related to broad scale habitat mapping and monitoring (both subtidal and intertidal - see Stevens and Robertson 2008 and 2013, Stevens and Robertson 2014), fine scale subtidal monitoring (Milne et al. 2008, Oliver and Conwell 2014), annual macroalgal mapping (e.g. Stevens and Robertson 2014), and fine scale stormwater discharge monitoring.

6. MONITORING AND MANAGEMENT

MONITORING

Because Porirua Harbour is large, has high ecological and human use values, and is very vulnerable to excessive sedimentation, eutrophication and disease risk, this estuary has been identified by GWRC as a priority for monitoring. As a consequence, it is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout the Wellington region. This monitoring programme consists of a wide range of intertidal, subtidal and catchment components, including long term fine scale and broad scale elements as well as short term intensive investigations. The present report addresses the fine scale intertidal component of the long term programme. The recommendation for ongoing monitoring for this component is as follows.

Fine Scale Monitoring

Fine scale intertidal sampling of sites Por A, Por B, Pau A and Pau B in Porirua Harbour has now been undertaken for three baseline years (2008-10) and one post baseline year (2015). It is recommended that the next fine scale monitoring of intertidal sites be undertaken at the next scheduled 5 yearly monitoring interval (2020).

MANAGEMENT

Fine scale monitoring, in conjunction with sedimentation and broad scale monitoring, provides valuable information on current estuary condition and trends over time, particularly in relation to the widely acknowledged sedimentation issue in the estuary, and the potential for eutrophication and toxicity. The sediment indicators monitored in 2015 reinforce the 2008-10 fine scale monitoring results about the need to manage fine sediment inputs to the estuary. In particular, limiting catchment sediment inputs to more natural levels that will not cause excessive estuary infilling and will improve harbour water clarity. To achieve this, interim and long term targets have been prepared and approved by the joint councils (Porirua City Council, Wellington City Council and Greater Wellington Regional Council), Te Runanga Toa Rangatira and other key agencies with interests in Porirua Harbour and catchment, as follows:

- Interim – Reduce sediment inputs from tributary streams by 50% by 2121
- Long-term – Reduce sediment accumulation rate in the harbour to 1mm per year by 2031 (averaged over whole harbour)

Greater Wellington's ongoing catchment and sediment transport modelling will help determine the catchment suspended sediment load inputs and the target reductions required to reduce in-estuary sedimentation rates. GWRC and PCC have also undertaken desktop assessments to determine the likely sediment input loads from different landuses, including the Transmission Gully motorway development, and modelled the zones of deposition within the estuary. Strategies to determine the best options for managing sediment within the catchment are currently being developed.

In addition, because macroalgae is on the cusp of causing nuisance conditions in several areas, and there is scheduled catchment development (urban growth, exotic forest harvesting and motorway construction) that may contribute to increased nutrient loads entering the estuary, it is also recommended that nutrient guideline criteria be developed for the Harbour, and that the extent to which catchment loads meet these guidelines be assessed.

Overall, the approach presented above is intended to help ensure that the assimilative capacity of the estuary is not exceeded so that the estuary can flourish and provide sustainable human use and ecological values in the long term.

7. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g/100g dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg/kg dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt
Dry Matter (Env)	R.J. Hill	Dried at 103°C (removes 3-5% more water than air dry)	

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

Station Locations

Porirua A	PorA-01	PorA-02	PorA-03	PorA-04	PorA-05	PorA-06	PorA-07	PorA-08	PorA-09	PorA-10
NZTM EAST	1756495	1756492	1756484	1756479	1756467	1756468	1756474	1756480	1756472	1756465
NZTM NORTH	5447818	5447807	5447789	5447772	5447774	5447788	5447805	5447818	5447819	5447807

Porirua B	PorB-01	PorB-02	PorB-03	PorB-04	PorB-05	PorB-06	PorB-07	PorB-08	PorB-09	PorB-10
NZTM EAST	1754565	1754559	1754551	1754544	1754554	1754559	1754565	1754576	1754586	1754595
NZTM NORTH	5445474	5445483	5445499	5445510	5445518	5445503	5445493	5445482	5445486	5445502

Pauatahanui A	PauA-01	PauA-02	PauA-03	PauA-04	PauA-05	PauA-06	PauA-07	PauA-08	PauA-09	PauA-10
NZTM EAST	1757247	1757254	1757256	1757265	1757270	1757265	1757258	1757256	1757261	1757267
NZTM NORTH	5448650	5448639	5448630	5448621	5448631	5448638	5448645	5448651	5448655	5448646

Pauatahanui B	PauB-01	PauB-02	PauB-03	PauB-04	PauB-05	PauB-06	PauB-07	PauB-08	PauB-09	PauB-10
NZTM EAST	1760357	1760358	1760362	1760361	1760372	1760369	1760367	1760366	1760378	1760379
NZTM NORTH	5448354	5448335	5448319	5448302	5448302	5448318	5448355	5448348	5448346	5448335

APPENDIX 2. 2015 DETAILED RESULTS

Seagrass and Macroalgal cover (%) at fine scale sites 2008, 2009, 2010 and 2015.

Site	Por A	Por B	Pau A	Pau B	Por A	Por B	Pau A	Pau B	Por A	Por B	Pau A	Pau B	Por A	Por B	Pau A	Pau B
Year	2008	2008	2008	2008	2009	2009	2009	2009	2010	2010	2010	2010	2015	2015	2015	2015
Ulva spp.	1	1	0	1	0	14	1.5	16	5	23	2	3	0	4	0	2
Gracilaria chilensis	5	1	1	5	0	3	3	11	3	4	3	25	2	3	5	30
Zostera muelleri	31	0	0	0	53	0	0	0	44	0	0	0	48	0	0	0
Total Vegetative Cover (%)	37	2	1	6	53	17	4.5	27	52	27	5	28	50	7	5	32

APPENDIX 2. 2015 DETAILED RESULTS (CONTINUED)

Physical and chemical results for Porirua Harbour, 20-21 January 2015.

Year/Site/Rep c	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2015 Por A-01	1	31.5	0.42	7.3	90.4	2.3	0.024	10.6	4.2	7.9	5.7	37	6.1	0.024	<500	380
2015 Por A-02	1	31.5	0.62	8.6	88.1	3.3	0.026	10.7	4.2	8	5.6	38	6.3	0.023	<500	390
2015 Por A-03	1	31.5	0.71	9.1	89.7	1.2	0.02	11.1	4.3	8.2	5.9	39	6.3	0.02	<500	420
2015 Por B-01	1	31	0.28	4	92.9	3.1	0.047	5.3	3.6	3.8	9.5	73	3.1	0.023	<500	189
2015 Por B-02	1	31	0.27	4.2	93.1	2.7	0.046	5.5	4.1	3.9	9.8	77	3.2	0.021	<500	198
2015 Por B-03	1	31	0.32	4.6	94.2	1.2	0.046	5.9	4.1	4.3	10.5	83	3.4	0.021	<500	200
2015 Pau A-01	1	31	0.8	9.9	81	9	0.025	11.1	4.8	8.1	6.7	38	7.5	0.025	600	450
2015 Pau A-02	1	31	0.8	8.8	82.9	8.3	0.019	10.7	4.7	8	6.5	37	7.5	0.033	600	440
2015 Pau A-03	1	31	0.76	9	83.4	7.6	0.023	11.1	4.9	8.2	6.7	37	7.6	0.029	600	460
2015 Pau B-01	1	31	0.37	3.4	90.2	6.4	0.021	4.3	2.1	3.4	4.2	21	2.1	0.022	<500	111
2015 Pau B-02	1	31	0.26	3.5	92.2	4.3	0.022	4	1.9	3.3	4	19.8	1.9	0.022	<500	132
2015 Pau B-03	1	31	0.32	3	90.6	6.4	0.021	4.1	1.9	3.2	4.1	19.7	2	0.021	<500	112
ISQG-Low a	-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High a	-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-

a ANZECC 2000.

Epifauna (numbers per 0.25m² quadrat) - 20-21 January 2015

Porirua A

Scientific name	Common name	PorA-01	PorA-02	PorA-03	PorA-04	PorA-05	PorA-06	PorA-07	PorA-08	PorA-09	PorA-10
Austrovenus stutchburyi	Cockle	3	4		3	0	0	4	1		1
Cominella glandiformis	Mudflat whelk	4	1		2	2	4	7	1	3	3
Diloma subrostrata	Mudflat topshell	10	2	1		1					
Zeacumantus lutulentus	Spire shell	2	8	5				10		8	2

Porirua B

Scientific name	Common name	PorB-01	PorB-02	PorB-03	PorB-04	PorB-05	PorB-06	PorB-07	PorB-08	PorB-09	PorB-10
Austrovenus stutchburyi	Cockle		2	3		5	2	3			
Cominella glandiformis	Mudflat whelk		1	1		1					3
Diloma subrostrata	Mudflat topshell		1	2				5			
Haminoea zelandiae	Bubble shell			2							
Zeacumantus lutulentus	Spire shell	1		6	2	1	1	1	1	2	

Pauatahanui A

Scientific name	Common name	PauA-01	PauA-02	PauA-03	PauA-04	PauA-05	PauA-06	PauA-07	PauA-08	PauA-09	PauA-10
Austrovenus stutchburyi	Cockle	4	2	2	3	6	2	2	7	6	3
Cominella glandiformis	Mudflat whelk	1	1			2	2	11	1		1
Diloma subrostrata	Mudflat topshell			2					1		
Zeacumantus lutulentus	Spire shell	3		2			1	2	2		1

Pauatahanui B

Scientific name	Common name	PauB-01	PauB-02	PauB-03	PauB-04	PauB-05	PauB-06	PauB-07	PauB-08	PauB-09	PauB-10
Austrovenus stutchburyi	Cockle				1	1		3		1	1
Cominella glandiformis	Mudflat whelk	1	4	4	3	1	3	8	4	1	1
Diloma subrostrata	Mudflat topshell			1	2	2	2	3	4	4	
Notoacmea helmsi	Estuarine limpet						1				
Zeacumantus lutulentus	Spire shell	5	5	8	12	6	8	3	6	6	4

APPENDIX 2. 2015 DETAILED RESULTS (CONTINUED)

Porirua Arm Sites (Por A and Por B) 2015. Infauna (numbers per 0.01327m² core) (Note NA = Not Assigned)

Group	Species	WEBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
Anthozoa	Anthozoa sp.#1	2	12	4	1	4		1	1	3		1										
	Edwardsia sp.#1	2	4	3	1	1			1		2	3	3		1	4	1	1		3	4	6
Nemertea	Nemertea sp.#1	3		1	1				1				1	1	2	7	1	1		2	2	7
	Nemertea sp.#2	3		1														2		1		
	Nemertea sp.#4	3																				
Nematoda	Nematoda	2								1						1						
Polychaeta	*Aonides trifida*	1											176	126	129	126	94	121	75	101	101	133
	Armandia maculata	2																				
	Axiothella serrata	2	9	18	4			1	4	1			4	9	9	14	9	3	4	6	6	5
	Boccardia (Paraboccardia) acus	2	6	13	7		1	8	11	6	13	9	4	4	4	9	14	2	7	5	1	5
	Boccardia (Paraboccardia) syrtis	2		1	1												3					
	Capitella sp.#1	4											3	2	2	4	9	1	3	4	1	
	Dorvilleidae sp.#1	2																				
	Eteone platycephala	2		2																		
	Glycera lamelliformis	2			1																	
	Goniada sp.#1	2					1		1			1										
	Heteromastus filiformis	3	28	14	24	14	13	18	19	10	10	34	8	9	6	22	17	5	5	10	8	7
	Microspio maori	1											1		1	1	1			7	2	
	Nereidae (unidentified juveniles)	3	6	8	10	3	3	3	6	1	1	1			1	2						1
	Nicon aestuariensis	3																				
	Orbinia papillosa	1	6	3			1	1	2	1	1		8	3	3	6	7	9	9	3	6	6
	Owenia petersenae	2																				
	Paraonidae sp.#1	3	1						1				3	1	1							
	Perinereis vallata	2				1			1		1								1			1
	Platynereis spp.	1																				
	Prionospio aucklandica	2	8	4	1	2		3	5	3	2	5	1	3	5			1	1	4	2	1
	Sabellidae sp.#1	1																				
	Scolecolepides benhami	4	1						1	1			1		2	2				1	2	
	Scoloplos (Scoloplos) cylindrifer	1	1									1	1	3	1	2	1	1	6	5	2	2
	Syllidae sp.#2	2					1															
	Terebellidae sp.#1	2			4		1	1	1			1										
	Travisia olens	NA					1					2										
Oligochatea	Oligochaeta	3													2	2	1	1	9	1		
Polyplacophora	*Acanthochitona zelandica*	NA	1																			
	Chiton (Chiton) glaucus	NA				1																
Gastropoda	*Cominella glandiformis*	3	1	1	1	2					1		1			1	1		2	1	1	2
	Diloma subrostrata	2	2		2									1			1	1	1			
	Haminoea zelandiae	1		1			1	1				2				1						
	Notoacmaea spp.	2	11		1		2			2				5				1		1	1	
	Xymene plebeius	1							1												1	1
	Zeacumantus lutulentus	2	2			1											1	1			1	
Bivalvia	*Amphipoda sp.#1*	5								1												
	Arthritica sp.#1	4	12	8	1	1				2		2		8		24			9	22	1	
	Austrohelice crassa	5						1														
	Austrovenus stutchburyi	2	10	14	12		2	14	13	8	11	13	28	27	18	25	23	10	23	20	16	28
	Cyclomactra ovata	2								1												
	Halicarcinus varius	3						1		1												
	Halicarcinus whitei	3										4	1					1		1		1
	Hemiplax hirtipes	5																				
	Linucula hartvigiana	2	25	18	12	10	7	11	11	13	10	8										
	Ostracoda sp.#1	1	12	1		4	5	4		3												
	Ostracoda sp.#2	1				2	5															
	Ostracoda sp.#4	1																				
	Phoxocephalidae sp.#1	2				3	9	5														
	Taeniogyrus dendyi	1	1							1												
	Tellina liliana	2	5	4	2	2	5	4	5	4	5	4	2	5	3	8	7	3	4	4	6	4
Total species in sample			**22**	**19**	**18**	**14**	**16**	**16**	**17**	**19**	**10**	**16**	**17**	**15**	**17**	**19**	**17**	**18**	**15**	**20**	**19**	**15**
Total individuals in sample			**164**	**119**	**86**	**51**	**58**	**77**	**85**	**63**	**57**	**91**	**246**	**207**	**190**	**261**	**191**	**165**	**159**	**202**	**164**	**210**

APPENDIX 2. 2015 DETAILED RESULTS (CONTINUED)

Pauatahanui Arm Sites (Pau A and Pau B) 2015. Infauna (numbers per 0.01327m² core) (Note NA = Not Assigned)

Group	Species	WEBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
Anthozoa	Anthozoa sp.#1	2	1		3	2	5	2	1	5	3	3										
	Edwardsia sp.#1	2		3	6	13	8	7	1	13	5	4	4	4	1	5	9		4	3	2	1
Nemertea	Nemertea sp.#1	3				1	1	1	1	1		1		1	2	2	2			1	1	
	Nemertea sp.#2	3													3							1
	Nemertea sp.#4	3															1					
Nematoda	Nematoda	2	1		1				1		1											
Polychaeta	*Aonides trifida*	1			1											2				1		
	Armandia maculata	2					1								2							
	Axiothella serrata	2												3	5	3	4	1	7	5	4	1
	Boccardia (Paraboccardia) acus	2	9	6	13	4	4	7	5	2		4	8	2	17	8	2	2	6	1	8	11
	Boccardia (Paraboccardia) syrtis	2	1				2	1			2			1		2	1		1	5	3	2
	Capitella sp.#1	4																				
	Dorvilleidae sp.#1	2			1			1														
	Eteone platycephala	2								1												
	Glycera lamelliformis	2																				
	Goniada sp.#1	2	1				3															
	Heteromastus filiformis	3	48	23	22	60	28	50	29	24	27	40	30	38	44	22	39	43	49	49	46	47
	Microspio maori	1																				
	Nereidae (unidentified juveniles)	3	7	5	6	3	3	1	3	3	3	1		2	4	1	1		2	2	2	1
	Nicon aestuariensis	3										1										
	Orbinia papillosa	1	1	1		1	1	1				1			10	1	3	5	5	2	3	2
	Owenia petersenae	2							1													
	Paraonidae sp.#1	3	7	1	1	3	1	1	20	4	1				4	1	6	1				
	Perinereis vallata	2																			1	
	Platynereis spp.	1								1												
	Prionospio aucklandica	2	8	2	1	3	3	3	9	4	6	5	3	3	5	6	9	5	10	6	5	8
	Sabellidae sp.#1	1						1				1										
	Scolecolepides benhami	4																				
	Scoloplos (Scoloplos) cylindrifer	1																				
	Syllidae sp.#2	2	2	1	1							1						1				
	Terebellidae sp.#1	2																				
	Travisia olens	NA																				
Oligochatea	Oligochaeta	3	2	3	1	1	1		75	3	2	2			7			1	1			1
Polyplacophora	*Acanthochitona zelandica*	NA									1											
	Chiton (Chiton) glaucus	NA			1					1												
Gastropoda	*Cominella glandiformis*	3			1			3		3	1	1		1	2							
	Diloma subrostrata	2	1		1				1		1			1						1		
	Haminoea zelandiae	1	2	3	1	2	1		1		1	1	2		1			1			2	1
	Notoacmaea spp.	2	8		2	2			3	3	2		1		2	2			1			
	Xymene plebeius	1			1					1												
	Zeacumantus lutulentus	2		3	3	1			2						2		1					1
Bivalvia	*Amphipoda sp.#1*	5			3	1																
	Arthritica sp.#1	4							1			1									3	1
	Austrohelice crassa	5																				
	Austrovenus stutchburyi	2	11	4	12	4	7	7	10	6	5	9	11	5	14	8	7	4	8	3	5	12
	Cyclomactra ovata	2																				
	Halicarcinus varius	3			2				1			1										
	Halicarcinus whitei	3												1	1			1	2	2		1
	Hemiplax hirtipes	5									1											
	Linucula hartvigiana	2	9	7	14	15	6	9	13	12	10	11	2	4	6			2	2	3	3	4
	Ostracoda sp.#1	1	1	1			5	3	3	3	2	5										
	Ostracoda sp.#2	1				1	3		2	1	1	5										
	Ostracoda sp.#4	1						1														
	Phoxocephalidae sp.#1	2	1			2				10	3	1										
	Taeniogyrus dendyi	1				1	1	1				1		1				1	1		1	1
	Tellina liliana	2	3	4	2	3	5	3	2	3	3	3	3	6	7	2	2	8	5	7	6	9
Total species in sample			**20**	**15**	**24**	**20**	**20**	**19**	**22**	**20**	**21**	**22**	**9**	**15**	**20**	**14**	**14**	**14**	**15**	**15**	**15**	**18**
Total individuals in sample			**124**	**67**	**100**	**123**	**89**	**103**	**185**	**104**	**81**	**103**	**64**	**73**	**139**	**65**	**87**	**76**	**104**	**91**	**95**	**105**

APPENDIX 2. 2015 DETAILED RESULTS (CONTINUED) SIMPER ANALYSIS

Mean abundance of the species causing the greatest contribution to the difference between macroinvertebrate community structure between years at Porirua Harbour sites (SIMPER Analysis).

		Species	Av.Abund	Av.Abund	Contrib%				Species	Av.Abund	Av.Abund	Contrib%
Por A	2008 vs 2015	*Heteromastus filiformis*	38.8	18.4	18.23		Pau A	2008 vs 2015	Paraonidae	31.3	0	20.64
		Linucula hartvigiana	16.4	12.5	7.73				*Heteromastus filiformis*	22.9	35.1	11.45
		Boccardia sp.	7.5	0	6.85				*Linucula hartvigiana*	1.2	10.6	6.35
		Phoxocephalidae sp.#1	9.3	1.7	6.72				*Boccardia syrtis*	9.5	0.6	5.9
		Arthritica bifurca	9.5	0	6.7				Oligochaeta	4.3	9	5.84
		Boccardia acus	0	7.4	6.34				*Perinereis vallata*	6.4	0	4.28
		Paraonidae	6.3	0	5.08				*Austrovenus stutchburyi*	1.2	7.5	4.26
		Austrovenus stutchburyi	8.7	9.7	4.35				*Edwardsia* sp.#1	0	6	4.15
		Oligochaeta	4.8	0	3.97				*Boccardia acus*	0	5.4	3.65
		Nereidae	0	4.2	3.51				*Axiothella serrata*	5.2	0	3.25
	2009 vs 2015	*Linucula hartvigiana*	29.3	12.5	13.97			2009 vs 2015	*Heteromastus filiformis*	24.1	35.1	15.51
		Heteromastus filiformis	26.6	18.4	9.33				*Boccardia* sp.	7.9	0	7.13
		Ostracoda sp.#1	7.6	2.9	6.03				*Linucula hartvigiana*	16.2	10.6	7.04
		Boccardia acus	0	7.4	5.89				Oligochaeta	0.3	9	6.38
		Boccardia sp.	7.5	0	5.82				*Edwardsia* sp.#1	0	6	5.83
		Paraonidae	7.3	0	5.81				*Boccardia acus*	0	5.4	5.13
		Arthritica bifurca	7.1	0	5.76				*Austrovenus stutchburyi*	9.5	7.5	4.51
		Austrovenus stutchburyi	6.5	9.7	4.93				*Notoacmea* spp.	4.6	2	4.03
		Boccardia syrtis	6.2	0.2	4.79				Nereidae	0	3.5	3.37
		Platynereis spp.	4.4	0	3.6				*Edwardsia* sp.	3.3	0	3.16
	2010 vs 2015	*Linucula hartvigiana*	28.9	12.5	14.03			2010 vs 2015	*Heteromastus filiformis*	40.1	35.1	11.81
		Phoxocephalidae sp.#1	17.9	1.7	12.96				*Boccardia* sp.	9	0	7.68
		Heteromastus filiformis	25.2	18.4	10.33				Oligochaeta	0.4	9	6
		Arthritica bifurca	11.4	0	8.23				*Edwardsia* sp.	6.7	0	5.74
		Boccardia acus	0	7.4	6.07				*Edwardsia* sp.#1	0	6	5.19
		Boccardia sp.	7.6	0	5.85				*Linucula hartvigiana*	14.5	10.6	4.96
		Austrovenus stutchburyi	11.9	9.7	4.65				*Austrovenus stutchburyi*	11.4	7.5	4.79
		Ostracoda sp.#1	6.2	2.9	4.21				Ostracoda sp.#2	6.3	1.3	4.72
		Axiothella serrata	0	3.7	2.7				*Boccardia acus*	0	5.4	4.58
		Nereidae	1.6	4.2	2.69				*Phoxocephalidae* sp.#1	5.6	1.7	4.16
Por B	2008 vs 2015	*Aonides trifida*	15.6	118.2	51.7		Pau B	2008 vs 2015	*Heteromastus filiformis*	33.2	40.7	16.99
		Axiothella serrata	19.1	6.9	6.49				*Boccardia* sp.	12.3	0	11.53
		Austrovenus stutchburyi	30.9	21.8	5.81				*Axiothella serrata*	9.8	3.3	6.53
		Heteromastus filiformis	19.5	9.7	5.56				*Boccardia acus*	0	6.5	5.98
		Orbinia papillosa	13.5	6	3.98				*Tellina liliana*	11	5.5	5.47
		Capitella capitata	6.7	0	3.34				*Austrovenus stutchburyi*	11	7.7	4.53
		Boccardia acus	0	5.5	2.79				*Phoxocephalidae* sp.#1	4.3	0	4
		Boccardia sp.	5.4	0	2.69				*Prionospio aucklandica*	4.6	6	3.49
		Edwardsia sp.	4.4	0	2.19				*Edwardsia* sp.#1	0	3.3	3.24
		Capitella sp.#1	0	2.9	1.48				*Haminoea zelandiae*	3.8	0.7	3.21
	2009 vs 2015	*Aonides trifida*	39.2	118.2	56.06			2009 vs 2015	*Axiothella serrata*	35.2	3.3	26.95
		Heteromastus filiformis	1.7	9.7	5.57				*Heteromastus filiformis*	31.8	40.7	12.43
		Austrovenus stutchburyi	26.8	21.8	5.5				*Boccardia* sp.	9.1	0	7.51
		Boccardia acus	0	5.5	3.89				*Boccardia acus*	0	6.5	5.36
		Boccardia sp.	4.8	0	3.38				*Austrovenus stutchburyi*	12.3	7.7	5.16
		Axiothella serrata	3.3	6.9	3.08				*Tellina liliana*	10.7	5.5	4.52
		Orbinia papillosa	4	6	2.23				*Prionospio aucklandica*	0.8	6	4.4
		Capitella sp.#1	0	2.9	2.06				*Edwardsia* sp.	5	0	4.26
		Tellina liliana	6.4	4.6	1.85				*Edwardsia* sp.#1	0	3.3	2.9
		Edwardsia sp.#1	0	2.3	1.59				*Aonides trifida*	3.4	0.3	2.89
	2010 vs 2015	*Aonides trifida*	72.9	118.2	43.29			2010 vs 2015	*Heteromastus filiformis*	76.2	40.7	29.52
		Austrovenus stutchburyi	28.1	21.8	7.53				*Boccardia* sp.	9.1	0	8.05
		Edwardsia sp.	6.1	0	5.14				*Boccardia acus*	0	6.5	5.62
		Capitella capitata	6.2	0	5.06				*Prionospio aucklandica*	7.4	6	4.82
		Boccardia acus	0	5.5	4.5				*Tellina liliana*	9.1	5.5	3.57
		Heteromastus filiformis	5.5	9.7	4.49				*Arthritica bifurca*	3.7	0	3.35
		Axiothella serrata	1.8	6.9	4.11				*Austrovenus stutchburyi*	9.4	7.7	3.32
		Orbinia papillosa	3.3	6	2.85				*Armandia maculata*	3.9	0.2	3.11
		Tellina liliana	6.6	4.6	2.42				*Axiothella serrata*	4.6	3.3	3.09
		Capitella sp.#1	0	2.9	2.38				*Edwardsia* sp.#1	0	3.3	3.02

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		WEBI Group *	Details
Porifera	Porifera sp.	NA	Unidentified sponge
Anthozoa	Anthozoa sp.#1	2	Unidentified anemone. An upright, stout, pale cream-coloured species.
	Edwardsia sp.#1	2	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
Nemertea	Nemertea sp.	3	Ribbon or proboscis worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda	1	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.
Sipuncula	Sipuncula	1	Peanut worms, or sipunculids, are a phylum containing 144-320 species (estimates vary) of bilaterally symmetrical, unsegmented marine worms. Relatively uncommon in NZ estuaries.
Polychaeta	*Aglaophamous macroura*	1	A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate (Beesley et al. 2000). Feeding type is carnivorous. Significant avoidance behaviour by other species. Feeds on *Heteromastus filiformis, Orbinia papillosa* and *Scoloplos cylindrifer* etc.
	Aonides trifida	1	Small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. *Aonides* is free-living, not very mobile and strongly prefers to live in fine sands; also very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds.
	Armandia maculata	2	Common subsurface deposit-feeding/herbivore. Belongs to Family Dpheliidae. Found intertidally as well as subtidal in bays and sheltered beaches. Prefers fine sand to sandy mud at low water. Does not live in a tube. Depth range: 0-1000m. A good coloniser and explorer. Pollution and mud intolerant.
	Boccardia sp.	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.	4	A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments. Commonly *Capitella capitata*.
	Cirratulidae sp.	3	Small subsurface deposit feeder, prefers sands, tolerant of slight to unbalanced situations.
	Dorvilleidae sp.	2	Active surface-dwelling omnivores with chitinous jaw elements consisting of four longitudinal rows of minute, toothed, black plates, and with two pairs of appendages on the rounded prostomium. Not generally common. Sensitive to mud and organic enrichment.
	Eteone platycephala	2	A phyllodocid polychaete. The phyllodocids are a colourful family of long, slender, and very active carnivorous worms characteristically possessing enlarged dorsal and ventral cirri which are often flattened and leaf-like (paddleworms). Common intertidally and in shallow waters.
	Glyceridae	3	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions and low salinity.
	Goniada sp.	2	Slender burrowing predators (of other smaller polychaetes) with proboscis tip with two ornamented fangs. The goniadids are often smaller, more slender worms than the glycerids. The small goniadid *Glycinde dorsalis* occurs low on the shore in fine sand in estuaries.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		WEBI Group *	Details
Polychaeta	Hesionidae	1	Fragile active surface-dwelling predators somewhat intermediate in appearance between nereidids and syllids. The NZ species are little known.
	Heteromastus filiformis	3	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate organic enrichment as other members of this polychaete group do. 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.
	Nereidae	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.
	Orbinia papillosa	1	Endemic orbiniid. Long, slender, sand-dwelling unselective deposit feeders which are without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant.
	Owenia petersenae	2	Family Owenidae. Relatively uncommon. Endemic. Oweniids are permanent tube-dwellers but have minimal head structure. Owenia petersenae occurs in sands of sheltered shores and is common in seagrass beds. It inhabits the lower shore and shallow subtidal. It is both a suspension and surface deposit feeder. Is readily recognised by the overlapping pine-cone-like sets of tiles of shell and sand built into a tightly adhering flexible tube. Mud Tolerance; low mud content.
	Paraonidae	3	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans. *Aricidea* sp., a common estuarine paraonid, is a small sub-surface, deposit-feeding worm found in muddy-sands. These occur throughout the sediment down to a depth of 15cm and appear to be sensitive to changes in the mud content of the sediment. Some species of *Aricidea* are associated with sediments with high organic content
	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. 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.
	Phyllodocidae	2	The phyllodocids are a colourful family of long, slender, and very active carnivorous worms characteristically possessing enlarged dorsal and ventral cirri which are often flattened and leaf-like (paddleworms). They are common intertidally and in shallow waters.
	Platynereis sp.	1	An intertidal soft shore nereid (which are common and very active, omnivorous worms). Prefers mud/sand sediments.
	Polynoidae	1	The polynoid scale worms are dorsoventrally flattened predators. Lower intertidal and subtidal to deep sea throughout NZ. Conspicuous, but never abundant.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		**WEBI Group ***	**Details**
Polychaeta	*Prionospio* sp.	2	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was renamed to *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001).
	Sabellariidae	NA	Sabellariids live in thick-walled sand and shell-fragment tubes cemented to rock or to any durable surface. As such they often modify the habitat. Some colonial species form conspicuous hummocks and substantial reefs. Sabellariids are filter feeders and detritus feeders. Pollution and mud intolerant.
	Sabellidae	1	Sabellids are not usually present in intertidal sands, though some minute forms do occur low on the shore. They are referred to as fan or feather-duster worms and are so-called from the appearance of the feeding appendages, which comprise a crown of two semicircular fans of stiff filaments projected from their tube.
	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.
	Scoloplos cylindrifer	1	Originally, Haploscoloplos cylindrifer. Belongs to Family Orbiniidae which are thread-like burrowers without head appendages. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. Pollution and mud intolerant.
	Spirobranchus cariniferus	1	Better known as *Pomatoceros caeruleus* this conspicuous serpulid was the first NZ polychaete to be given a name, and was described as a new species (with different names) at least 6 times! Currently in genus Spirobranchus but further study may place it back in *Pomatoceros*. *Spirobranchus cariniferus* is the common colonial serpulid of NZ shores. It is found mostly on the lower shore on shaded rock faces, becoming more prominent in the cooler south, where tube layers up to 30cm thick may occur. On soft shores small groups occur on top of any suitable hard object such as small stones and dead shell.
	Syllidae	2	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers mud/sand sediments.
	Terebellidae	2	Large tube or crevice dwellers with a confusion of constantly active head tentacles and a few pairs of anterior gills.
	Travisia olens	NA	Belong to the Opheliids. Short-bodied, cigar-shaped, muscular sand burrowers. Opheliids are deposit feeders, but probably selective in their intake of particulate material. The large, fat, bad smelling, grey-white coloured scalibregmatid *Travisia olens* is found on open to semi-protected sand beaches.
Oligochaeta	Oligochaetes	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Polyplacophora	*Acanthochitona zelandica*	NA	is a species of chiton in the family Acanthochitonidae. Common in reef areas within estuaries and very tolerant of silt.
	Chiton (chiton) glaucus	NA	*Chiton glaucus*, or the green chiton, is a species of chiton, a marine polyplacophoran mollusk in the family Chitonidae, the typical chitons. It is the most common chiton species in New Zealand. The shell consists of eight valves surrounded by a girdle, is fairly large, up to 55 mm in length.
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.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		WEBI Group *	Details
Gastropoda	*Diloma subrostrata*	2	The mudflat top shell, lives on sandflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ and feeds on the film of microscopic algae on top of the sand. Has a strong sand preference.
	Eatoniella olivacea		A small smooth conical gastropod, 2mm long and dark brown to black. It lives by scraping the detritus or diatomaceous film from the surfaces of algae.
	Haminoea zelandiae	1	The white bubble shell, is a species of medium-sized sea snail or bubble snail, a marine opisthobranch gastropod mollusc in the family Haminoeidae, the bubble snails. This bubble snail is common on intertidal mudflats in sheltered situations associated with eel grass. This species is endemic to New Zealand. It is found around the North Island and the northern part of the South Island.
	Notoacmea spp.	2	Endemic to NZ, a small grazing limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds and sensitive to pollution.
	Potamopyrgus antipodarum	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	3	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
	Coelotrochus tiaratus	NA	A small top snail from the family Trochidae and is endemic to NZ.
	Xymene plebeius	1	Endemic to NZ. Small limpet attached to stones and shells in intertidal zone. Intolerant of anoxic surface muds.
	Zeacumantus lutulentus	2	Belongs to the Family Muricidae, or murex snails, which are a large and varied taxonomic family of small to large predatory sea snails.
	Zeacumantus subcarinatus	1	Belongs to the Family Muricidae, or murex snails, which are a large and varied taxonomic family of small to large predatory sea snails
	Arthritica bifurca	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
	Austrovenus stutchburyi	2	Family Veneridae which is a family of bivalves which are very sensitive to organic enrichment. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects. Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community who are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). Prefers sand with some mud.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		WEBI Group *	Details
Bivalvia	*Cyclomactra ovata*	2	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water.
	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.
	Linucula hartvigiana	2	Small deposit feeder. Nut clam of the family Nuculidae (<5mm), is endemic to NZ. Often abundant in top few cm. It is found intertidally and in shallow water, especially in *Zostera* eel grass flats. It is often found together with the NZ cockle, *Austrovenus stutchburyi*, but is not as abundant. Like *Arthritica* this species feeds on organic particles within the sediment. Has a plug-like foot, which it uses for motion in mud deposits. Intolerant of organic enrichment. High abundance in Porirua Harbour near sea (Railway and Boatshed sites). None in Freshwater Estuary.
	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.
	Solemya parkinsoni	NA	The razor mussel. The elongate cylindrical shell valves have the brown, smooth shining epidermis extending beyond the margin forming a characteristic and distinctive fringe; interior of the shell a dull grey-white; grows up to 5cm in length. A common species on sand banks at depths up to 25cm.
Crustacea	Amphipoda	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.
	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.
	Cephalocaridae	NA	Cephalocarida (horseshoe shrimps) is a class of only about nine shrimp-like benthic species. Discovered in 1955. Found from the intertidal zone down to a depth of 1500m, in all kinds of sediments. They feed on marine detritus.
	Colurostylis lemurum	1	A cumacean and a semi-pelagic detritus feeder. Cumacea is an order of small marine crustaceans, occasionally called hooded shrimps. Some species can survive in water with a lower salinity rate, like in brackish water (e.g. estuaries). Most species live only one year or less, and reproduce twice in their lifetime. Cumaceans feed mainly on microorganisms and organic material from the sediment. Species that live in the mud filter their food, while species that live in sand browse individual grains of sand.
	Copepoda	2	Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat and they constitute the biggest source of protein in the oceans. Usually having six pairs of limbs on the thorax. The benthic group of copepods (Harpactacoida) have worm-shaped bodies.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		WEBI Group *	Details
Crustacea	Decapoda larvae unid.	NA	The decapods or Decapoda (literally means "ten footed") are an order of crustaceans within the class Malacostraca, including many familiar groups, such as crayfish, crabs, lobsters, prawns and shrimp. Most decapods are scavengers. It is estimated that the order contains nearly 15,000 species in around 2,700 genera, with approximately 3,300 fossil species. Nearly half of these species are crabs, with the shrimps (~3000 species) and Anomura (including hermit crabs, porcelain crabs, squat lobsters: ~2500 species), making up the bulk of the remainder.
	Halicarninus varius	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	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Hemigraspus crenulatus	NA	The hairy-handed crab is commonly found on mud flats and sand flats, but it may also occur under boulders on the intertidal rocky shore. Is a very effective scavenger and tolerates brackish conditions.
	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*.
	Mysidacea spp.	1	Mysidacea is a group of small, shrimp-like creatures. They are sometimes referred to as opossum shrimps. Wherever mysids occur, whether in salt or fresh water, they are often very abundant and form an important part of the normal diet of many fishes.
	Ostracoda sp	1	Ostracods or seed shrimps, have a body which is encased by two valves.
	Paracorophium spp.	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites like Whareama A and B (30-70% mud) we get very few.
	Phoxocephalidae sp.	2	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Sphaeroma quoyanum	2	A marine boring isopod found in the estuarine waters of NZ, Australia and California. Forms burrows in a variety of substrates. Well known as an invader that forms burrows along marsh edges which encourages erosion.
Holothuroidea	*Trochodota dendyi*	1	A sea cucumber, that is soft bodied and worm-like in appearance and burrows up to 20cm into sand - a deposit feeder and sediment disturber.
Insecta	Chironomidae	NA	A member of this non-biting midge family.

* Wriggle Estuary Biotic Index (WEBI).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.

APPENDIX 4.

ESTUARY CONDITION RISK RATINGS FOR KEY INDICATORS

DEVELOPED BY WRIGGLE COASTAL MANAGEMENT

JUNE 2014

GUIDELINES FOR USE

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), 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 process, "risk indicator ratings" have been proposed that assign a relative level of risk of adversely affecting estuarine conditions (e.g. very low, low, moderate, high, very high) to each indicator. Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within a 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 estuary data. However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

The indicators and risk ratings used in the Havelock Estuary fine scale monitoring programme, and their justifications, are summarised in the following sections.

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

1. SEDIMENT PERCENT MUD CONTENT

In their natural state, most NZ estuaries would have been dominated by sandy or shelly substrates, while most NZ beaches are dominated by sandy substrates due to their relatively high wave exposure. In estuaries or beaches not naturally prone to muddy conditions, a significant shift towards elevated concentrations of mud (grain size <63um) is likely to result in detrimental and difficult to reverse changes in biotic community composition, and adverse impacts to human uses and values (e.g. through reduced water clarity and increased muddiness). Consequently, mud content can indicate where changes in land management may be needed.

Subsequent to the development of NEMP (Robertson et al. 2002) which uses sediment grain size as one indicator of sediment condition, the relationships between sediment mud content, the benthic macrofaunal community, sediment cohesiveness or stickiness, and organic carbon concentration have been further defined (see supporting evidence below). This included a widespread Wriggle funded study of NZ estuarine habitats (Robertson 2013) which found estuarine sediments with low to intermediate mud concentrations (i.e. 2-25% mud) were more likely to have a diverse and abundant macroinvertebrate assemblage and low organic enrichment (<1% TOC) than muddier sediments. Based on this, and other supporting work, the associated characteristics of the sediment % mud content indicator can be summarised as follows:

"% Mud Content" Characteristics

- Sediments are relatively incohesive at mud contents below 20-30% (i.e. are not sticky and are relatively firm to walk on), but become cohesive and "sticky" at higher mud contents (i.e. you begin to sink into the muds).
- There is a marked shift in the macroinvertebrate assemblage when mud content exceeds 25-30% to one dominated by mud tolerant and/or species of intermediate tolerance. This shift is most apparent when elevated mud content is contiguous with high total organic carbon (TOC) concentrations.
- As % mud content increases, the concentrations of organic carbon and nutrients (total organic carbon and total nitrogen) also generally increase, particularly for estuaries with highly developed catchments. As a consequence, such sediments are often poorly oxygenated and, when present in intertidal flats of tidal lagoon estuaries (particularly in poorly flushed areas), are often overlain with dense nuisance macroalgal blooms.
- In typical NZ shallow tidal lagoon estuaries, muddy sediments (>40% mud) and elevated nitrogen loadings (100mgN.m^{-2}.d^{-1}), commonly coincide with dense macroalagal cover (>80% cover) and gross eutrophic conditions (TOC >3%, RPD at surface). Similar gross eutrophic conditions occur in shallow coastal lagoons or ICOLLs where conditions are not too turbid, but the minimum mud content at which they occur is expected to be much less than for tidal lagoon estuaries. In narrow tidal river estuaries, which are well flushed and lack large settling basins, such gross eutrophic conditions are rare.

These characteristics indicate that NZ estuary sediments with a widespread mud content of greater than 20-30% are likely to have a degraded macroinvertebrate community, and sediments that are non-cohesive (soft and muddy). Such impacts are most significant if such conditions are occurring in estuaries with a naturally low mud content. Of particular importance are the typical NZ shallow, tidal lagoon and ICOLL estuaries.

SUPPORTING EVIDENCE

1. Mud Content - Relationship to Macroinvertebrate Community

A review of monitoring data from 25 typical NZ estuaries (shallow, short residence time estuaries) (Wriggle database 2009-2014) confirmed a "high" risk of reduced macrobenthic species richness for NZ estuaries when mud values were >25-30% mud and a "very high" risk at >55% (this last value is more tentative given the low number of data-points beyond this mud content) (Figure 1). This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of mud content) by the increasing dissimilarity in the macrobenthic community as mud contents increase above 25-30% mud (Figure 2).

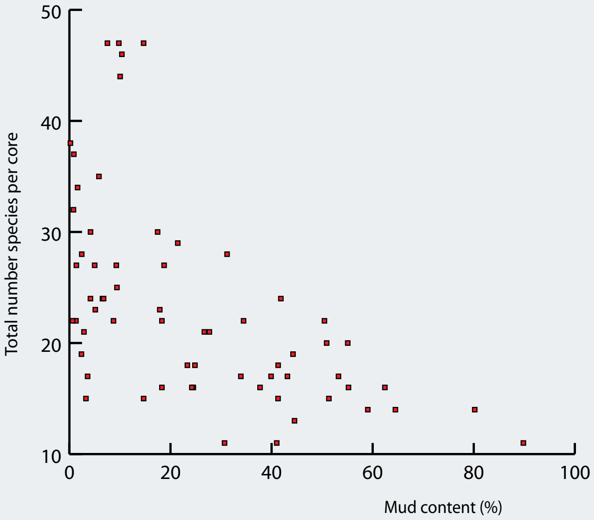

Figure 1. Sediment mud content and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

1. SEDIMENT PERCENT MUD CONTENT (CONTINUED)

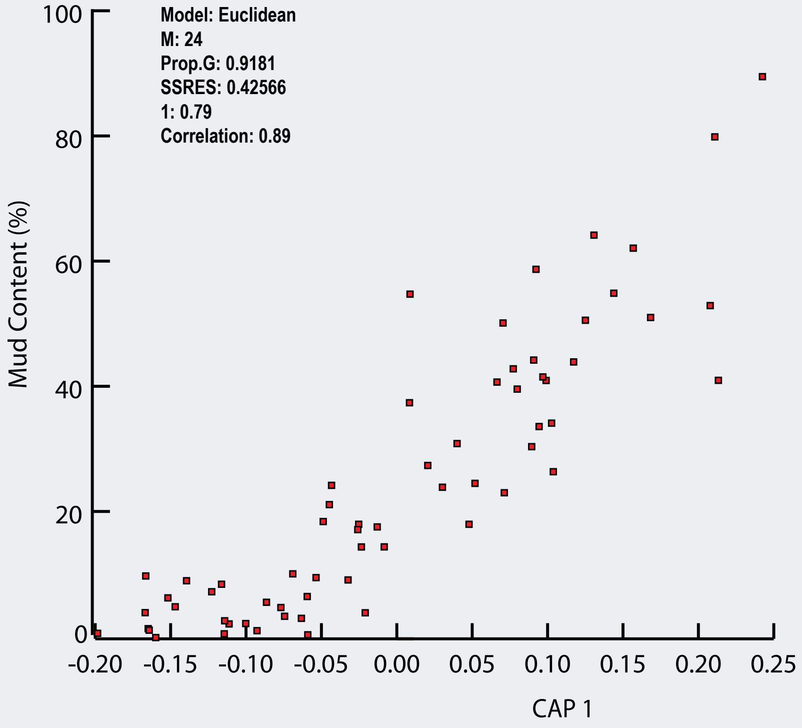

Figure. 2. Canonical analysis of the principal coordinates (CAP) for the effect of sediment mud content (exclusively) on the macroinvertebrate assemblages from 25 typical NZ estuaries (i.e. CAP1) among sites. Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.

2. Mud Content - Relationship to Sediment Cohesiveness

Studies show that sediments become “cohesive” or sticky once the % mud content increases above approximately 20-30% mud depending on such factors as the clay content (Houwing 2000).

3. Mud Content- Relationship to Gross Nuisance Conditions

The trophic response to muddy sediments under elevated nitrogen loadings, in this case macroalgal cover, has been explored for 15 shallow tidal lagoon estuaries in NZ (tidal lagoon type with flushing potentials <0.1 days, mean depth 0.5-2m, intertidal flats >50% estuary area). The results (Figure 3) showed that where mud content was greater than 40% and the nitrogen load to the estuary was greater than 100mgN.m^{-2}.d^{-1}, macroalgal cover was greater than 80% and was accompanied by gross eutrophic conditions (mud content >30%, TOC >3%, RPD at surface).

Similar gross eutrophic conditions have been found to occur in shallow coastal lagoons or ICOLLs where conditions are not too turbid (e.g. Hoopers Inlet, Waituna Lagoon), but the minimum mud content at which they occur is expected to be much less than for tidal lagoon estuaries. Further work is however required to confirm this.

The trophic response to muddy sediments under elevated nitrogen loadings, in this case macroalgal cover, has been explored for 5 shallow tidal river estuaries in NZ (tidal river type with flushing potentials <0.1 days, mean depth 0.5-2m, intertidal flats <5% estuary area). In these narrow, well flushed, tidal river estuaries, where intertidal area is small and therefore the opportunity for nuisance macroalgal growth limited, such gross eutrophic conditions were rare (Figure 4).

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

1. SEDIMENT PERCENT MUD CONTENT (CONTINUED)

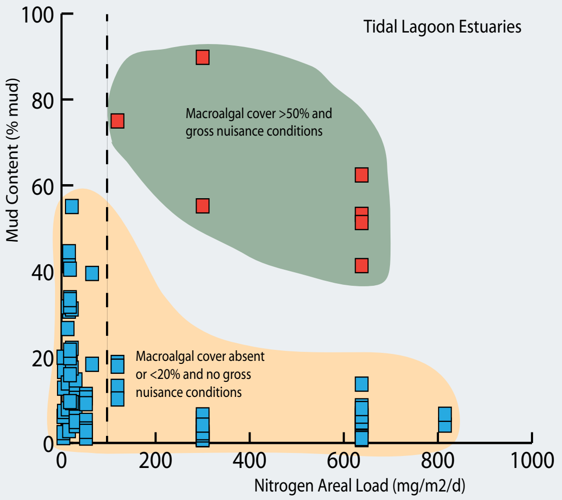

Figure 3. Mud content of sediment and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 15 typical NZ tidal lagoon estuaries (shallow, residence time <3d, >50% of estuary intertidal) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013, Robertson et al. 2002).

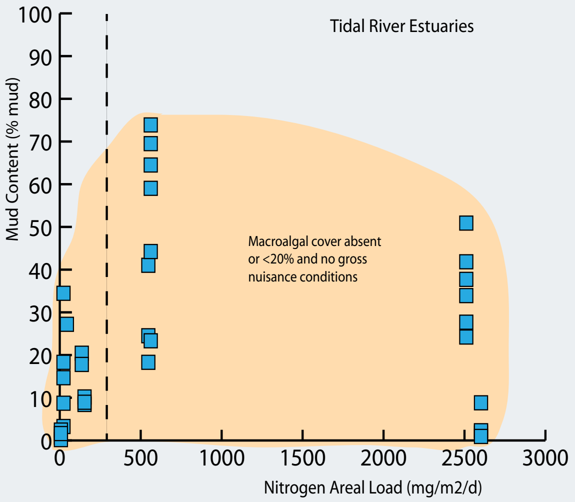

Figure 4. Mud content of sediment and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 5 typical NZ tidal river estuaries (data sourced from Wriggle Coastal Management monitoring reports 2006-2013).

RECOMMENDED SEDIMENT MUD CONTENT RISK RATING (INTERIM)

It is recommended that the estuary sediment-macroinvertebrate-mud thresholds (primarily adapted from Robertson 2013) be used to provide an interim indicator of estuary risk based on the magnitude of likely impact on sediment biota from measured % mud content as follows:

Estuary Condition Risk Rating (Interim): Sediment Mud Content					
Risk Rating	Very Low	Low	Moderate	High	Very High
Sediment Mud Content (% mud)	<2%	2-5%	>5-15%	>15-25%	>25%

Clearly, this rating is intended for the determination of site-specific conditions at monitoring sites, not for whole estuary assessments (unless representative sites have been monitored over the whole estuary).

RECOMMENDED RESEARCH

Undertake extensive grain size validation monitoring of the following habitat types: firm muddy sand, soft mud, and very soft mud to confirm and refine the measured range of % mud found in each these broad scale monitoring categories from estuaries throughout NZ.
Undertake further studies in typical NZ estuaries on % mud and the incidence of:

- gross eutrophic conditions,
- adverse impacts macroinvertebrates, seagrass, saltmarsh, fish, and/or birds.

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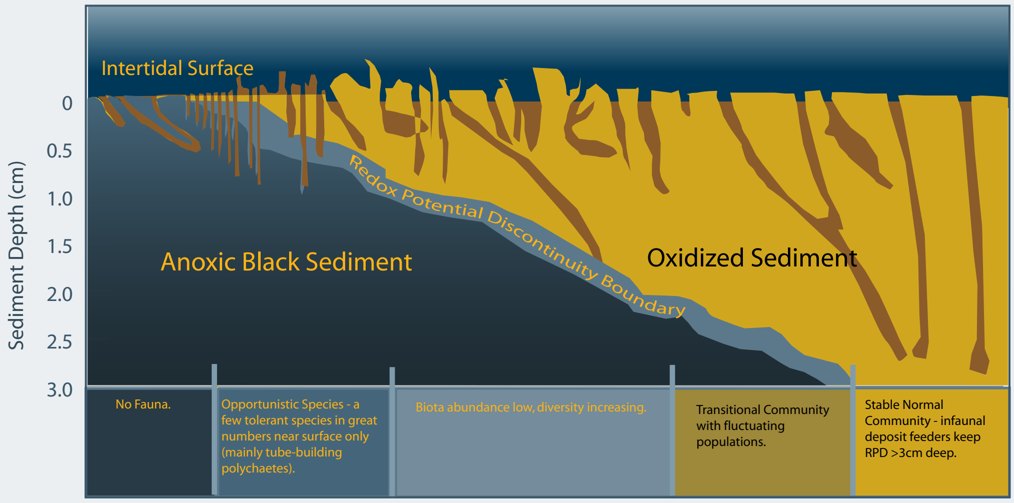
APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

2. REDOX POTENTIAL DISCONTINUITY (RPD) DEPTH

Redox Potential Discontinuity (RPD) depth measures the transition between oxygenated sediments near the surface and deeper anoxic sediments. It is a primary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Anoxic sediments contain toxic sulphides, which support very little aquatic life, and as the RPD layer gets close to the surface, a "tipping point" is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and worsen sediment conditions. In sandy porous sediments, the RPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

The RPD layer is an effective ecological barrier for most, but not all, sediment-dwelling species. A rising RPD will force most macrofauna towards the sediment surface to where oxygen is available. Pearson and Rosenberg (1978) developed a useful organic enrichment tool that indicates the likely benthic macrofauna community that is supported at a particular site based on the measured RPD depth (see Figure below for summary). This tool has been used extensively to date to help interpret intertidal monitoring data in New Zealand and its relationship to organic enrichment. However, it is important to note that this tool was based primarily on studies conducted in stable subtidal sediments of coastal estuaries and embayments rather than the more unstable intertidal sediments of beach habitat or shallow, well-flushed estuaries commonly found in NZ.



An indication of the likely benthic community supported at measured RPD depths **(adapted from Pearson and Rosenberg 1978).**

In addition, a recent study (Gerwing et al. 2013) describes two common methods for measuring RPD as follows:

- **Visual assessment** (often by digital imaging e.g. Munari et al. 2003) based on the assumption that in the absence of oxygen, ferrous sulphides produced by microbial sulphate reduction precipitate as Fe-sulphides, which produce a grey or black coloration of the sediment, which signifies the RPD depth (Valdemarsen et al. 2009). When redox measurements (Eh) are not considered simultaneously, the RPD is termed the apparent RPD (aRPD) (Birchenough et al. 2012).
- **Redox potential (Eh) measurements** represent a bulk measurement that reflects the occurrence of multiple redox equilibria at the surface of an electrode and reflects a system's tendency to receive or donate electrons. Electrodes are inserted either vertically or horizontally at different depths (Rosenberg et al. 2001, Diaz & Trefry 2006) into the sediment. The depth of the RPD is identified as the zone where conditions change from oxidizing to reducing or the transition from positive to negative mV readings (Birchenough et al. 2012).

Gerwing et al. (2013) compared the methods and found similar results for stable subtidal (Rosenberg et al. 2001) and deep sea sediments (Diaz & Trefry 2006), but different results for relatively dynamic intertidal sediments.

Such findings, indicate two important points:

1. The use of the Pearson-Rosenberg (1978) approach for assessing macrobenthic response to organic enrichment in dynamic, shallow intertidal sediments (i.e. the dominant habitats in most NZ estuaries and beaches) has yet to be proven, and
2. The appropriate RPD method for use in such intertidal sediments and its relationship with biotic indicators needs to be identified.

2. REDOX POTENTIAL DISCONTINUITY (RPD) DEPTH (CONTINUED)

RECOMMENDED RPD RISK RATING (INTERIM)

In the interim period prior to the results of proposed Otago University research being available (see recommended research section below), it is recommended that the RPD risk rating be based on aRPD results and predicted ecological response bands similar to those proposed by Pearson-Rosenberg (1978) as presented in the Table below. In addition, it is recommended that other indicators are used to further assess sediment oxygenation if the aRPD indicates a high/very high risk of ecological impacts. The measurement of redox potential and/or various sulphur fractions are the most common approaches.

Estuary and Beach Condition Risk Indicator Rating (Interim): Apparent RPD Depth

Risk Rating	Very Low	Low	Moderate	High	Very High
aRPD depth (cm)	>10cm	3-10cm	1-<3cm	0-<1cm	Anoxic at surface

RECOMMENDED RESEARCH

Clearly, there is an urgent requirement for a direct comparison between both RPD methods (visual and redox) for intertidal and subtidal estuary and beach habitats in NZ, and particularly the relationship between the RPD depth measured by each, and other indicators, especially biotic factors such as macroinvertebrates and macroalgal cover, and environmental factors such as sulphur species. This is to be included as part of Wriggle sponsored PhD research being undertaken by Ben Robertson (commenced in June 2014).

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Jorgenson N. and Revsbach N.P. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. Limnology and Oceanography 30:111-112.

Munari C., Modugno S., Ghion F., Casteldelli G., Fano E.A., Rossi R. and Mistri M. 2003. Recovery of the macrobenthic community in the Valli di Comacchio, Northern Adriatic Sea, Italy. Oceanol Acta 26:67-75.

Pearson T. H. and Rosenberg R. 1978. Macrobenthic succession in relation to organic enrichment and pollution in the marine environment. Oceanography and Marine Biology: an Annual Review, 16: 229-311.

Rosenberg R., Nilsson H.C. and Diaz R.J. 2001. Response of benthic fauna and changing sediment redox profiles over a hypoxic gradient. Estuarine Coast Shelf Sci 53: 343-350.

Veldemarsen T., Kristensen E. and Holmer M. 2009. Metabolic threshold and sulfide-buffering in diffusion controlled marine sediments impacted by continuous organic enrichment. Biogeochemistry 95: 335-353.

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

3. TOTAL ORGANIC CARBON (TOC) AND RELATED NUTRIENTS

Estuaries with a high sediment organic content can result in anoxic sediments and bottom water, which contribute to the release of excessive nutrients and have adverse impacts on biota - key symptoms of eutrophication. Elevated sediment organic content (measured as total organic carbon, TOC) is generally caused by excessive plant growth within an estuary, or from catchment inputs (including point sources). In NZ's shallow, short residence time estuaries (SSRTEs), decaying macroalgae, seagrass and saltmarsh vegetation are the major sources of sediment TOC. In deep, long residence time estuaries (DLRTEs), the major source is phytoplankton.

Hyland et al. (2005) recently expanded upon the Pearson and Rosenberg (1978) model (which describes benthic community response along an organic enrichment gradient) by using it as a conceptual basis for defining lower and upper thresholds in TOC concentrations corresponding to low versus high levels of benthic species richness in samples from seven coastal regions of the world. Specifically, it was shown that risks of reduced macrobenthic species richness from organic loading and other associated stressors in sediments should, in general, be relatively low where TOC values were <1%, and relatively high where values were >3.5%.

While not a direct measure of causality (i.e. it does not imply that the observed bioeffect was caused by TOC itself), it was anticipated that these TOC thresholds may serve as a general screening-level indicator, or symptom, of ecological stress in the benthos from related factors. Such factors may include high levels of ammonia and sulphide, or low levels of dissolved oxygen associated with the decomposition of organic matter, or the presence of chemical contaminants co-varying with TOC in relation to a common controlling factor such as sediment particle size. Subsequently, the TOC threshold values have been confirmed by several sources:

- Analysis of TOC sediment data collected in EMAP-Virginian Province Study indicated that TOC values in the 1 to 3% range were associated with impacted benthic communities, while values less than 1% were not (Paul et al. 1999).
- Magni et al. (2009) confirmed a high risk of reduced macrobenthic species richness for Mediterranean coastal lagoons when TOC values were >2.8%.
- A review of monitoring data from 25 typical NZ estuaries (SSRTEs) (Wriggle database 2009-2014) confirmed a "high" risk of reduced macro-benthic species richness when TOC values were >2% and a "very high" risk at >3.5% (this last value is more tentative given the low number of data-points beyond this TOC concentration) (Figure 1). This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of TOC content, Figure 2) by the increasing dissimilarity in the macrobenthic community as TOC concentrations increase above 2%.

SUPPORTING EVIDENCE

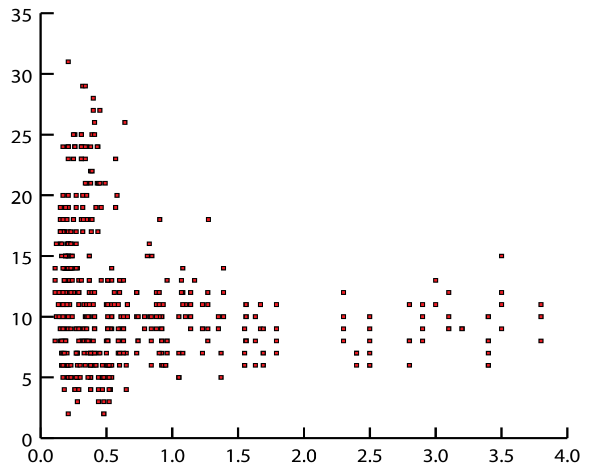

Figure 1. Sediment TOC concentrations and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).

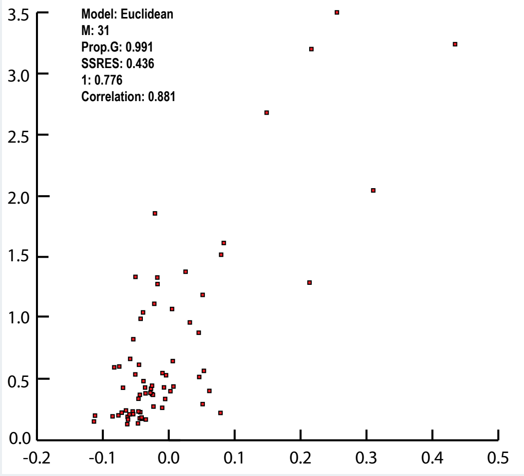

Figure 2. Canonical analysis of the principal coordinates (CAP) for the effect of total organic carbon content, on the macroinvertebrate assemblages from 12 typical NZ estuaries (i.e. CAP1) among sites.

Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

3. TOTAL ORGANIC CARBON (TOC) AND RELATED NUTRIENTS (CONTINUED)

Data from 12 estuaries scattered throughout NZ, and representing most NZ estuary types were reviewed in relation to TOC and nutrients (Figure 3). Total nitrogen was found to be very strongly correlated with TOC (r^2 =0.90). Total phosphorus was less strongly correlated (r^2 =0.68), but preliminary analysis of the data suggests a likely explanation for the variability at elevated P concentrations. Surface P concentrations can become elevated if P that is released from intense sulphate reduction process at depth in sediment, is trapped by iron oxyhydroxides in the surface oxygenated layer. This process is likely to be expressed in a variable way, being most intense in situations with dense macroalgal cover, and less intense where macroalgal cover is moderate (Figure 3).

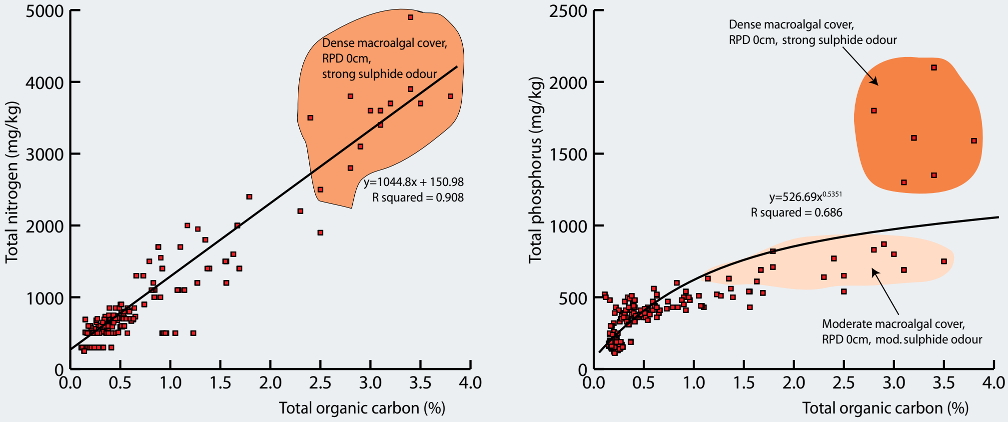

Figure 2. Sediment TOC and TN, and sediment TOC and TP concentrations from 12 estuaries scattered throughout NZ, and representing most NZ estuary types (Wriggle Coastal Management database 2009-2013).

RECOMMENDED TOC AND RELATED NUTRIENTS RISK RATING (INTERIM)

In order to assess the likely risk of estuary ecological condition being affected by the sediment TOC concentration it is recommended that the following thresholds be used.

Estuary Condition Risk Indicator Rating: TOC and Related Nutrients (TN and TP)

Indicator	Risk Rating	Very Low	Low	Moderate	High	Very High
Primary	Total Organic Carbon	<0.5%	0.5-1%	1-2%	2-3.5%	>3.5%
Secondary	Total Nitrogen	<250mg/kg	250-1000mg/kg	1000-2000mg/kg	2000-4000mg/kg	>4000mg/kg
	Total Phosphorus	<100mg/kg	100-300mg/kg	300-500mg/kg	500-1000mg/kg	>1000mg/kg

However, it is emphasised that in order to assess the condition of NZ estuaries using TOC, a multi-criteria approach (physical, chemical and biotic indicators) is recommended, so that TOC concentration measurements are supported by related indicators, in particular mud content, RPD, macroinvertebrates, macroalgal cover, and the secondary indicators TP and TN.

RECOMMENDED RESEARCH

- Undertake studies to further expand the sediment macroinvertebrate/TOC relationships for NZ estuaries into highly eutrophic habitats, particularly those with >3.5% TOC concentrations.
- Develop a list of macrobenthic species sensitivities to TOC concentrations under varying mud, redox, and heavy metal concentrations.

References

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APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

4. TOXICANTS (HEAVY METALS ETC)

Many urban estuaries have sediments contaminated with toxicants, both heavy metals and hydrophobic organic compounds (ANZECC 2000). Heavy metals provide a low-cost preliminary assessment of toxic contamination, and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for other major contaminant classes: pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

The ANZECC (2000) sediment criteria (Interim Sediment Quality Guidelines - ISQG) have been developed on the basis that "guideline numbers are trigger values that, if exceeded, prompt further action as defined by the decision tree". The first-level screening compares the trigger value with the measured value for the total contaminant concentration in the sediment. If the trigger value (ISQGLow) is exceeded, then this triggers either management/remedial action, or further investigation to consider natural background levels and the fraction of the contaminant that is bioavailable (or can be transformed and mobilised in a bioavailable form).

If the natural background concentration is less than the ISQG High trigger then it is considered a low risk and no action is recommended. If the natural background concentration is greater than ISQG High trigger then it is considered a risk and further investigation is recommended.

RECOMMENDED TOXICANT RISK RATING

In order to assess the likely risk of estuary ecological condition being affected by the sediment toxicant concentration it is recommended that the following thresholds be used (broadly based on the ANZECC (2000) sediment quality guidelines).

Estuary Condition Risk Indicator Rating: Toxicants

Risk Rating	Very Low	Low	Moderate	High	Very High
Toxicant (e.g. heavy metals)	<0.2 x ISQGLow	0.2 x ISQGLow to 0.5 x ISQGLow	>0.5 x ISQGLow to ISQGLow	ISQGLow to ISQGHigh	>ISQGHigh
Actions	No action	No action	Monitor trends	Further investigate if not due to high natural background levels	Further investigation recommended

RECOMMENDED RESEARCH

- Undertake studies to further expand the sediment macroinvertebrate/toxicant relationships for NZ estuaries.
- Develop a list of macrobenthic species sensitivities to various toxicant concentrations under varying mud, redox, and TOC concentrations.

References

ANZECC. 2000. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

5. MACROINVERTEBRATE COMMUNITY

Because of their proven ability to indicate and integrate complex environmental conditions, soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). Such a classification is particularly useful given the fact that most estuaries are dominated by soft sediments. However, assessing estuarine condition by macroinvertebrates is difficult due to the high variability of natural conditions in estuaries and their often modified nature. Importantly, the use of this approach must include an awareness of it's advantages and disadvantages (Table 1).

Table 1. Advantages and disadvantages of using macroinvertebrates to assess ecological quality.

Advantages (Dauvin 2007)	**Disadvantages** (Rakocinski and Zapfe 2005)
• Sedentary nature and therefore inability to avoid water/sediment quality conditions. • Relatively long life spans. • High species diversity with different tolerances to stress. • Important in water/sediment biogeochemical cycling.	• Static expression of an ecological condition. • Not directly linked to changes in ecological function. • May not be specific with respect to different kinds of stressors. • Subject to underlying taxonomic changes across estuarine gradients. • Labour intensive. • Not applied consistently across biogeographic provinces.

As a by-product of the development of macroinvertebrate/estuary condition indicator relationships, a large number of macroinvertebrate biotic indices (sometimes associated with other environmental or biological variables) have been developed and used to assess estuary condition. These range from simple univariate indices, such as species richness (number of species), and diversity indices (e.g. Shannon diversity index, H'), to more complex functional indices, multimetric indices (e.g. BQI: Biological Quality Index) and multivariate approaches (e.g. M-AMBI: Multivariate-AMBI) (see list in Borja et al. 2012).

These indices, result in a single number which summarises the complex estuary condition and is statistically supported by a wide range of physical, chemical and biological measures. The development of these indices reflects the facts that biological communities are a product of their environment, and organisms can be grouped according to different habitat preferences and pollution tolerance. Most of the estuarine biotic indices are only used in a limited way at present, but AMBI and multivariate AMBI (M-AMBI), BQI (and its various adaptations), B-IBI, and Infaunal Trophic Index (ITI) are currently widely used throughout the world (Borja et al. 2012). However, a recent review (Borja et al. 2012) concluded that no single biotic index can correctly assess the estuary condition, and that a multi-criteria approach is favoured.

Within NZ, there have been several approaches to the development of macroinvertebrate/estuary condition relationships based on the response of NZ species to estuarine variables. The most common environmental variables for which taxa responses have been identified are: mud content (Norkko et al. 2002, Robertson 2013), heavy metals (Rodil et al. 2013), and redox and organic matter (Robertson 2013). A summary of the approaches and results, in order of their development, are presented below.

- **Mud Sensitivity Ratings** - based on the environmental condition indicator of % mud. From a limited dataset of 14 upper North Island estuaries, as well as short-term laboratory experiments, a macroinvertebrate-mud sensitivity rating (based on % mud) was estimated for 38 taxa, of which 13 were able to be statistically modelled, and 25 assessed through visual interpretation of the raw macroinvertebrate abundance data (Norkko et al. 2002, Thrush et al. 2003). These species ratings have been subsequently used to assess benthic macroinvertebrate community condition in relation to muddiness in estuaries throughout NZ (e.g. see Gibbs and Hewitt 2004, Hailes and Hewitt 2012). However, in a national context, such ratings potentially lack strong regional transferability and are limited in terms of the number of taxa with assigned ratings. As such, their use in assessing estuary condition at any particular site needs to be supported by information that indicates that: i. the estuary in question fits within the upper North Island estuary type classification used to produce the ratings, ii. that due regard is given to taxa that have not yet been rated for sensitivity and, iii. that the ratings are only used to assess sensitivity to sediment mud content. Use of a multi-metric approach is required to gain a true indication of the factors driving a particular macroinvertebrate assemblage, particularly the inclusion of indicators of eutrophication and toxicity.

- **Local Trophic Biotic Index (TBI)** - based on the environmental condition indicators of % mud and metal concentrations. Rodil et al. (2013) developed the local traits based index (TBI) primarily to predict the response of the macrofauna community to metal gradients. They assigned macroinvertebrate species from 84 intertidal soft-sediment sites from three Auckland harbour estuaries (Mahurangi, Waitemata, and Manukau), into one of 29 functional groupings. Correlation strengths between the number of taxa and individuals in each of the 29 functional groups were evaluated and related to sediment mud content (using the Mahurangi data) and metal content (using the Waitemata/Manukau data). Based on these correlations, seven functional groups were retained for use in the TBI, due to their observed responsiveness to both mud and metals in two independent data sets. The utility of the TBI was then verified using independent data from >100 additional Auckland estuary sites and results from these upper North Island estuaries showed the TBI responded to changes in sediment mud percentage and heavy metal contaminant concentration gradients at levels below international toxicity thresholds, and therefore successfully tracked the most relevant local stressors. The rating results were also compared with results from two other indices; the AMBI, which is designed to respond to mud and organic enrichment, and the B-IBI which evaluates the ecological condition of a sample by comparing values of benthic community attributes to reference values expected under non-degraded conditions in similar habitat types (Weisberg et al. 1997).

The results from the AMBI showed that this indicator performed well for the job it was designed to do (i.e. predict response to organic enrichment). The AMBI coefficients were in the low range (1-4, indicating undegraded states), which was expected given that all the sites experienced low levels of organic enrichment (expert opinion rather than measured). They also predictably showed that the increased AMBI scores (indicative of degrading health) were associated with declines in the abundances of sensitive species and declines in species diversity.

The results from the B-IBI, which was calculated using well known metrics of species abundance, diversity and the abundance of sensitive species, carnivores and deposit feeders, were correlated with gradients of increasing muddiness, although B-IBI was unsuccessful at distinguishing reference sites from known degraded sites. It calculated 58% of the sites correctly as uncontaminated, and it was not closely related to the mud gradient. Concordance between the two indices was also relatively poor.

Although a promising tool, before the TBI can be applied nationally, it needs to be tested for other estuaries outside of the upper North Island, and also for other environmental factors known to influence macrofauna in NZ estuaries, particularly organic enrichment indicators (e.g. TOC, TN, macroalgal cover, RPD). Therefore, although this rating is likely to be useful in the Auckland region where metal toxicity and muddiness are key stressors, its wider use in other NZ estuaries where organic enrichment, muddiness and low metal concentrations are more evident, is currently unproven.

- **Mud and Organic Carbon Sensitivity Ratings.** Robertson (2013) used organic enrichment, grain size and macroinvertebrate data from 135 sites in 25 estuaries scattered throughout NZ, and representing most NZ estuary types, to produce mud and organic sensitivity ratings for NZ estuarine macroinvertebrates. The results confirmed sediment mud content and TOC as co-varying ($R^2 = 0.706$; $P = 0.001$) key drivers of the macroinvertebrate community (noting that all sites had metals concentrations below ANZECC ISQG toxicity thresholds). Mud/organic enrichment sensitivity ratings (5 sensitivity groupings) were subsequently established through statistical modelling for a total of 42 species, with a further 56 species assessed through visual interpretation of the raw data. These results were then used as inputs to the AMBI biotic coefficient equation to produce an integrated mud and organic enrichment rating ["Wriggle Estuary Benthic Index" (WEBI)] for NZ estuaries, with the rating thresholds divided into 4 Bands of ecological condition (see following table), determined from available NZ estuary data (Robertson and Stevens 2015).

RECOMMENDATIONS FOR MACROINVERTEBRATE INDICATORS FOR NZ ESTUARIES

It is strongly recommended that only NZ macroinvertebrate/physico-chemical variable relationships be used to assess estuary condition in NZ. This is because the physical conditions of most NZ estuaries (dominated by largely intertidal, well-flushed, shallow, short residence time estuary types and absence of midwater saltmarsh), differ greatly from the majority of the overseas estuaries types and the associated data-sets (dominated by marine/estuarine subtidal data) which have been used to derive international biotic indices. Further, in order to assess the ecological condition of NZ estuaries using macroinvertebrates, particularly in relation to three of the major estuary stressors, i.e. muddiness, eutrophication and toxicity, a multi-criteria approach using physical, chemical and biotic indicators is recommended. This approach is recommended because the response of NZ estuary macroinvertebrate taxa to these issues has not yet been reflected in any one integrated biotic indice. This recommended approach should include the following:

1. Measure key physical and chemical indicators of NZ estuary condition (e.g. TOC, TN, redox/RPD, grain size, heavy metals) and compare the monitoring data with established physico-chemical/macroinvertebrate response relationships for representative NZ estuaries. For example:
   - TOC concentration versus species richness (see preceding TOC Rating section)
   - TOC concentration versus macroinvertebrate community similarity (see preceding TOC Rating section, i.e. CAP Plot)
   - Mud content versus species richness (see preceding Mud Content Rating section)
   - Mud content versus macroinvertebrate community similarity (see preceding Mud Content Rating section, i.e. CAP Plot)
   - Toxic contaminant (e.g. heavy metals) concentration versus macroinvertebrate community similarity (these relationships will be developed once sufficient monitoring data from a range of NZ estuaries has been collected - the current data set held by Wriggle does not include high toxicity sites) - in the meantime it may be appropriate to use the TBI approach mentioned above.
2. Use the mud/organic enrichment sensitivity ratings (5 sensitivity groupings, Gp1-Gp5) established by Robertson (2013) for NZ estuary taxa, as inputs to the AMBI biotic coefficient equation (until a more appropriate local equation has been derived). This so called "Wriggle Estuary Benthic Index" (WEBI) calculates an integrated mud and organic enrichment rating for a site using the following AMBI equation and the ratings indicated in the table below:

   Biotic Coefficient (BC) = {(0 x %Rating Gp1) + (1.5 x %Rating Gp2) + (3 x %Rating Gp3) + (4.5 x %Rating Gp4) + (6 x %Rating Gp5)}/100. Verify the WEBI score in relation to the measured physical and chemical results and thresholds for TOC and mud content.

   At sites where toxicity is present, the use of the TBI mentioned above is recommended, particularly as a screening tool.
3. Finally, assess changes in abundance of individual species, preferably in relation to their sensitivity to relevant stressors, e.g. the 5 major mud/enrichment tolerance groupings (i.e. "very sensitive to organic enrichment" group through to "1st-order opportunistic species" group) (Robertson 2013). This final analysis is vital, given the tendency for community indices and statistical approaches to mask potentially important changes at a species level.

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

RECOMMENDED MACROINVERTEBRATE RISK RATING

In order to assess the likely risk of estuary ecological condition being affected by excessive muddiness or organic enrichment, it is recommended that the following thresholds be used.

WEBI Mud and Organic Enrichment Ratings

Risk Rating Band	A	B	C	D
Macroinvertebrate Mud and Organic Enrichment Index (WEBI)	0-1.0 None to minor stress on benthic fauna. Community intolerant of organically enriched conditions and elevated muds	>1.0-2.5 Minor to moderate stress on benthic fauna. Community tolerant of slight organic enrichment and moderate muds	>2.5-4.0 Moderate to high stress on benthic fauna. Community tolerant of moderate organic enrichment and elevated muds	>4.0 Persistent, high stress on benthic fauna. Community tolerant of high and very enrichment and elevated muds or community is devoid of life.

The characteristics of the ecological groups (G1, G2, G3, G4 and G5) are summarised as follows:

- Group 1. Species very sensitive to mud and organic enrichment and present under unpolluted conditions (initial state).
- Group 2. Species indifferent to mud and organic enrichment.
- Group 3. Species tolerant to excess mud and organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalanced situations).
- Group 4. Species tolerant of mud and organic enrichment (slight to pronounced unbalanced situations).
- Group 5. Species tolerant of mud and organic enrichment (pronounced unbalanced situations).

If the toxicity levels (apart from toxicity related to eutrophic conditions, i.e. elevated sulphide or ammonia) exceed levels that cause biotic stress, it is recommended that the TBI be used and the scores be verified in relation to the measured results and thresholds for toxic contaminants and mud content.

RECOMMENDED RESEARCH

- Because opportunistic macroalgae are the predominant source of elevated organic matter (and therefore eutrophication symptoms) in NZ shallow, intertidally dominated estuaries, with very short residence times (SSRTEs) (i.e. NZ's dominant estuary type), it is recommended that further studies be undertaken to establish the relationship between macroalgal cover and the macroinvertebrate community. Such a study should aim to provide a predictive tool for macroinvertebrate response to macroalgal cover.
- Because NZ estuarine ecology is susceptible to the influence of fine sediments and nutrients, research is required to investigate the combined influence of fine sediment and nutrient loads on macroinvertebrates in NZ shallow estuaries. Such a study should aim to provide a predictive tool for macroinvertebrate response to nutrient and fine sediment input loads to key estuary types and estuary habitats (particularly SSRTEs).
- Development of macrobenthic biotic indices for each of the major estuary issues of muddiness, organic enrichment and toxicity. Research is required to tease apart the covariance between these issues so that macrobenthic response relationships can be derived for mud content alone, TOC/redox at varying mud contents, then TOC/redox, toxicants at varying mud contents. Careful site selection to minimise the influence of other variables (e.g. tide height, freshwater influence, resuspension, etc) is recommended in the design.

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