coastalmanagement

Havelock Estuary

Fine Scale Monitoring 2014

Prepared for

Marlborough District Council

July 2014

Cover Photo: Havelock Estuary

Havelock Estuary looking towards Havelock township

Havelock Estuary

Fine Scale Monitoring 2013/14

Prepared for
Marlborough District Council

by

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HAVELOCK ESTUARY - EXECUTIVE SUMMARY

Havelock Estuary is an ~800ha, tidal river plus delta estuary located near Havelock in the Marlborough District. It is part of Marlborough District Council's coastal State of the Environment (SOE) monitoring programme. This report summarises the results of two years of the fine scale monitoring (2001 and 2014) at two sites within the estuary. The monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations are summarised below.

FINE SCALE RESULTS

- The sediment mud content in 2014 was relatively high at 14-29% mud, and had increased at Site A since 2001.
- Sediment oxygenation (aRPD depth) in both 2001 and 2014 was "moderate" (1-<3cm).
- Organic matter and nutrients were in the "low" or "moderate" risk categories in both 2014 and 2001.
- 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.
- Sediment toxicity was also monitored at a site adjacent to Havelock township ~500m west of the marina entrance. The results showed exceedance of the ANZECC ISQG low trigger for mercury, tributyl tin, Cu and Ni, but no exceedance of the ISQG high trigger. Results indicated localised sediment toxicity, with potential adverse impacts to aquatic life.
- Macroinvertebrates consisted of a mixed assemblage of species, with significant differences in community structure at each site between 2001 and 2014, particularly reduced abundances of species highly sensitive to mud/organic enrichment. In comparison to a reference estuary (Freshwater Estuary, Stewart Island), the community in Havelock Estuary was significantly different, which was attributed to Havelock's elevated mud and organic matter concentrations and poor sediment oxygenation compared to the sandy, well oxygenated, seagrass covered sediments of Freshwater Estaury.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

	Site A 2001	Site A 2014	Site B 2001	Site B 2014	Key Differences 2001-2014
Sediment Mud Content	High	Very High	High	High	Increasing Site A
Sediment Oxygenation (aRPD)	Moderate	Moderate	Moderate	Moderate	No differences
TOC (Total Organic Carbon)	Low	Low	Very Low	Very Low	No differences
TN (Total Nitrogen)	Low	Low	Low	Low	No differences
TP (Total Phosphorus)	Moderate	Moderate	Low	Low	Decreasing Site B
Toxicants	Very low-low risk across all sites and years				No differences
Invertebrate Mud/Org. Enrichment	Low	Low	Low	Low	Decline in mud sensitive species

ESTUARY CONDITION AND ISSUES

Overall, these 2001 and 2014 results indicate that Havelock Estuary is muddy, has got progressively muddier since 2001, and has low levels of organic matter, nutrients, and toxicants. It has a typical mud-tolerant macroinvertebrate community that has changed in structure since 2001 and includes very few mud intolerant species (e.g. pipi). The dominance of mud habitat, and associated low water clarity, is expected to have a negative effect on turbidity-sensitive species e.g. snapper, gulls and terns, seagrass, juvenile fish, and shellfish.

RECOMMENDED MONITORING AND MANAGEMENT

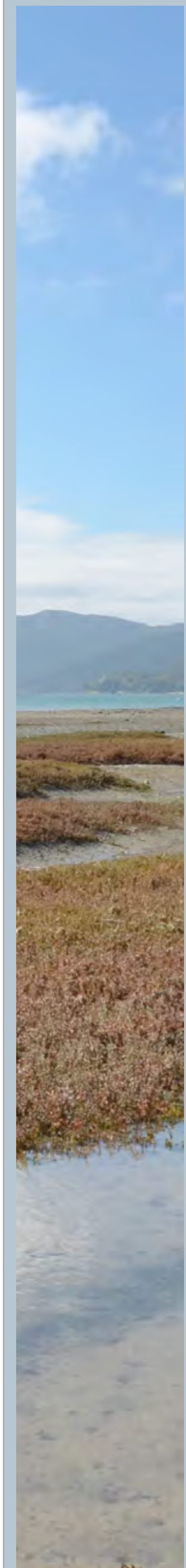
Given the magnitude of the muddiness changes between 2001 and 2014, and to establish whether the deteriorating results observed in 2014 are truly representative of current conditions, monitoring is recommended as follows: Sites A and B continue to be monitored, but two new sites be established in the dominant intertidal habitat type (very soft muds) and all 4 sites be monitored (data collection only) in February 2015, 2017 and 2019 to establish both a multi-year baseline, and relationships between soft mud and very soft mud habitats, so that the value of previous monitoring is not lost. A full report of all data should then be undertaken at the next scheduled 5 yearly monitoring interval (2019). This change is supported by the 2014 broad scale mapping results of dominant substrate types, nuisance macroalgae and seagrass beds in the estuary (Stevens and Robertson 2014). In addition, sedimentation rate should be monitored at annual intervals (with additional plates established in soft mud habitat), and broad scale habitat mapping be undertaken every 5 years (next scheduled in 2019).

Fine sediment has been identified as a major issue in Havelock Estuary (this report and Stevens and Robertson 2014) and therefore likely to be in need of a fine sediment reduction plan. However, prior to the instigation of such management, identification of the appropriate target condition for this estuary is required, particularly given the relatively high sensitivity of Havelock to mud inputs. This would involve development of sediment load/landuse response relationships, supported by dating of sediment cores to determine the timing and rate of past sediment inputs to the estuary.

Overall, if the approach is followed, and the estuary and its surroundings are managed to ensure that the assimilative capacity for muds is not breached, then the estuary will flourish and provide sustainable human use and ecological values in the long term. If not, the estuary will continue to get muddier, with consequent detrimental effects on seagrass, shellfish and fish stocks.

1. INTRODUCTION

OVERVIEW



Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. These objectives, along with understanding change in condition/trends, are key objectives of Marlborough District Council's State of the Environment Estuary monitoring programme. Recently, Marlborough District Council (MDC) prepared a coastal monitoring strategy which established priorities for a long-term coastal and estuarine monitoring programme (Tiernan 2012). The assessment identified Havelock Estuary as a priority for monitoring.

The estuary monitoring process consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) as follows:

1. **Ecological Vulnerability Assessment** (EVA) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. To date, neither estuary specific nor region-wide EVAs have been undertaken for the Marlborough region and therefore the vulnerability of Havelock to issues has not yet been fully assessed. However, in 2009 a preliminary vulnerability assessment was undertaken of the Havelock Estuary for NZ Landcare Trust (Robertson and Stevens 2009), and a recent report has documented selected ecologically significant marine sites in Marlborough (Davidson et al. 2011).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. Broad scale mapping of Havelock Estuary was undertaken in 2001 (Robertson et al. 2002) and was repeated in 2014 (Stevens and Robertson 2014).
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 Havelock Estuary, was undertaken once, in 2001 (Robertson et al. 2002). Because the NEMP requires 3-4 consecutive years of data for establishing a defensible baseline, the single year of data that exists for the Havelock Estuary is insufficient for use in trend analysis (i.e. trends in change between 2001 and 2014 data).

In 2014, MDC commissioned Wriggle Coastal Management to undertake a repeat of the fine scale monitoring of Havelock Estuary previously undertaken in 2001. The current report describes the 2014 results and compares them to the previous findings.

Havelock Estuary is a relatively large-sized (~800ha, Robertson et al. 2002), macrotidal (2.17m spring tidal range), poorly-flushed, delta estuary situated at the head of Pelorus Sound. It has one opening, one main basin, and several tidal arms. The catchment (1,149km^2) is partially developed and dominated by native forest (72%), exotic forestry (14%), dairying (4%), other pasture (8%) and scrub (2%). Part of the estuary margin is directly bordered by developed urban and rural land, roads, and seawalls.

The estuary is formed by the sediment output from the Kaituna and Pelorus Rivers (mean flows 3.7 and 45 m^3.s^{-1} respectively). Although the catchment is dominated by native forest and hard sedimentary rock types which don't erode very easily, the terrain is often steep, and therefore erosion can be elevated from developed areas. This erosion is exacerbated by the frequent and high rainfall in the catchments, which in a typical year has several rainfall events that deliver between 50-200mm of rain in one day. As a consequence, freshwater inputs to Havelock Estuary tend to be as intermittent pulses that carry elevated loads of suspended sediments, nutrients and faecal bacteria. The bulk of the sediment and nutrient loads settle in the estuary, resulting in a muddy estuary, with low clarity water. The cloudy waters and muddy bed result in the loss of high value seagrass from intertidal and subtidal areas, and reduced phytoplankton production, seabed life and fish communities. However, due to the relatively large area of upper intertidal shallows, the estuary has extensive beds of high value saltmarsh (predominantly jointed wire rush and sea rush), that provide valuable habitat for birdlife, macroinvertebrates and, at high water, fish.

The highly elevated mud content of the estuary has also provided ideal habitat for the invasion of opportunists (both plant and animal) such as the cordgrass *Spartina townsendii* and the Pacific oyster (*Crassostrea gigas*), both acting as stabilisers of the mud. Both species occupied primarily new habitat within the estuary and therefore did little damage to native species. Currently Pacific oyster growth is expanding in the estuary but *Spartina* has been eradicated, which has led to a large release of muds to the water column for redistribution within the estuary.

The estuary has high use and is valued for its aesthetic appeal, biodiversity, shellfish collection, bathing, waste assimilation, whitebaiting, fishing, boating, walking, and scientific appeal. The inlet is recognised as a valuable nursery area for marine and freshwater fish, an extensive shellfish resource, and is very important for birdlife. A small port and marina is located at Havelock near the Kaituna River mouth.

A 2009 synoptic catchment impact assessment (Robertson and Stevens 2009) identified excessive muddiness, localised eutrophication, and moderate disease risk as the most significant catchment-related issues in the estuary.

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

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

1. Sedimentation

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (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" that assign a relative level of risk (e.g. very low, low, moderate, high, very high) of specific indicators adversely affecting intertidal estuary condition have been proposed (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 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 for the Havelock Estuary 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.

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)	0-1.2 Intolerant of enriched conditions	>1.2-3.3 Tolerant of slight enrichment	>3.3-5.0 Tolerant of moderate enrichment	>5.0-6.0 Tolerant of high enrichment	>6.0 Azoic (devoid of invertebrate life)
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 ISQGLo	0.2 x ISQGLo to 0.5 x ISQGLo	>0.5 x ISQGLo to ISQGLo	ISQGLo to ISQGHi	>ISQGHi mg/kg

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) for Havelock.
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: these are measured in certain estuaries where a risk has been identified.

For Havelock Estuary, two fine scale sampling sites (Figure 3) were previously selected in unvegetated, mid-low water tidal flats (Robertson et al. 2002). At both sites, 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 (precise locations are in Appendix 1), 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. For semi-volatile organic contaminants (SVOCs), a composite sample was collected from each of the 4 sites (by subsampling each of the 10 replicates).
- 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, and semi-volatile organic compounds (SVOCs). 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 within the 60m x 30m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species were identified and allocated a SACFOR abundance category based on percentage cover (Appendix 1, Table A), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Appendix 1, Table B). Species size determined both the quadrat size and SACFOR density rating applied, while photographs were taken and archived. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal/microalgal cover.

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).

3. Methods (Continued)

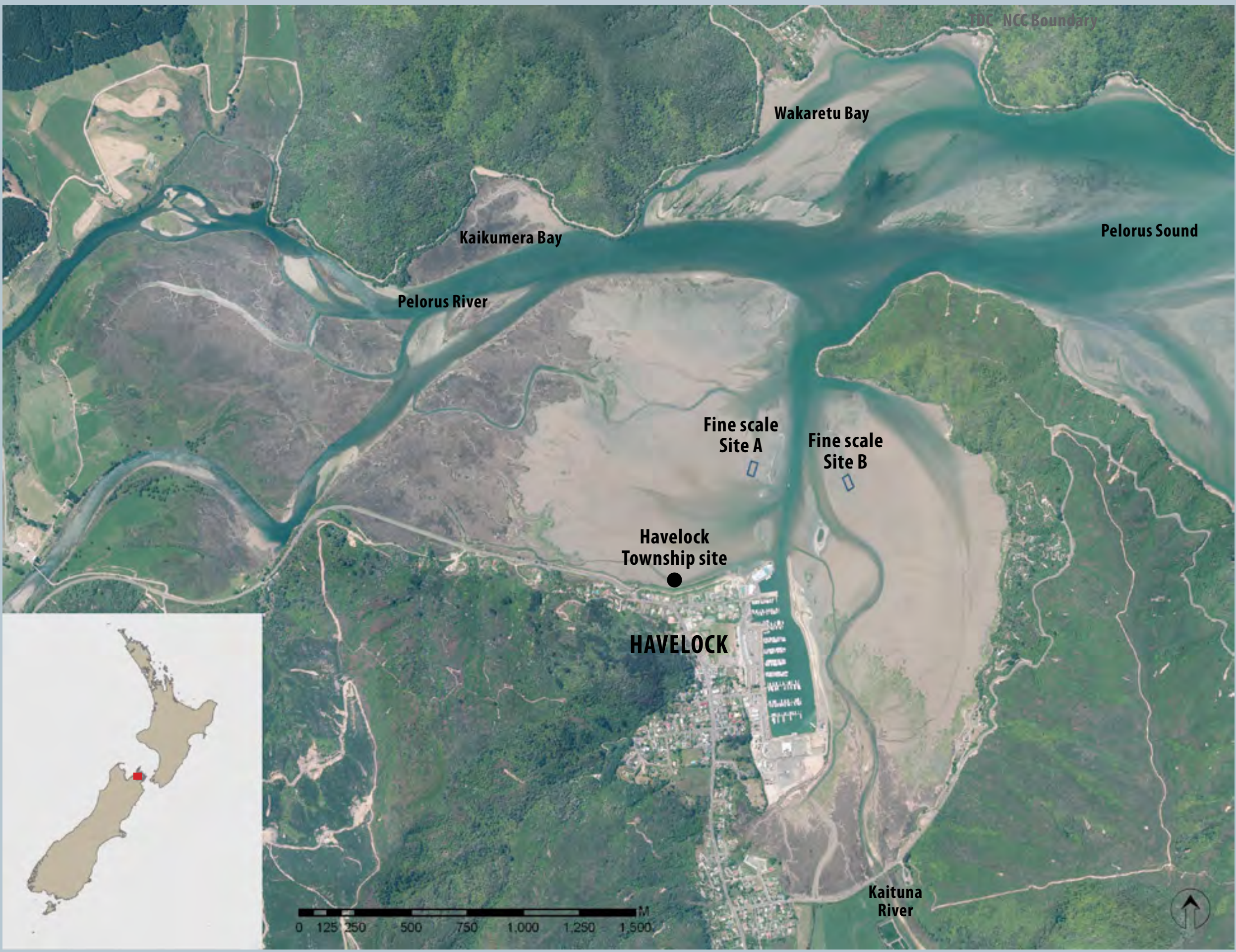


Figure 1. Havelock Estuary - location of fine scale monitoring sites.

Installing sediment plates at Site B

Sedimentation Plate Deployment (28 March 2014)

Determining the future sedimentation rate involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried and levelled, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance.

Two sites, each with four plates (20cm square concrete paving stones) have been established in Havelock Estuary at fine scale Sites A and B. Plates were buried deeply in the sediments where stable substrate was located and positioned 2m apart in a liner configuration along the baseline of each fine scale site. Both fine scale sites are located in firm mud sand where sediment from input rivers is likely to deposit.

The GPS positions of each plate were logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded (Appendix 1). In the future, these depths will be measured annually and, over the long term, will provide a measure of the rate of sedimentation in the estuary.

4. RESULTS AND DISCUSSION

A summary of the results of the 28 March 2014 fine scale monitoring of Havelock Estuary, together with the 2001 fine scale 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 two fine scale sites (2001 and 2014) in Havelock Estuary.

Site	aRPD	Salinity	TOC AFDW [b]	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Species Abundance	Species Richness
	cm	ppt	%				mg/kg								No./core	No./core
2001 A	1	30	0.67	20.4	73.6	6.0	0.40	70.1	11.2	38.1	5.6	51.1	608	394	27.3	11.5
2001 B	1	30	0.51	17.8	80.6	1.6	0.41	27.4	10.1	14.8	5.7	34.8	700	266	18.7	6.3
2014 A	1	30	0.65	27.2	70.9	1.9	0.04	50.7	11.6	39.3	5.8	41.7	650	380	24.1	9.2
2014 B	1	30	0.49	16.9	82.0	1.2	0.02	24.0	7.9	18.8	4.0	26.3	<500	223	13.9	7.1

[a] Data for arsenic, mercury and semi-volatile organic compounds are presented in Appendix 3.
[b] 2001 TOC values estimated from AFDW as follows: 1g AFDW as equivalent to 0.2 g TOC (± 100%) based on a preliminary analysis of NZ estuary data.

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 assessed where inputs are likely, or metal concentrations are found to be elevated.

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 2014 monitoring results for sediment mud content (Table 3, Figure 2) showed Site A had a mud content of >25% and therefore a “very high” risk indicator rating, whereas Site B was less muddy (17% mud) and rated in the “high” risk category (Figure 2).

Statistical analyses (Figure 2) showed a significant increase in mud content at Site A between 2001 and 2014 (i.e. $P<0.005$; Figure 2), but no difference at Site B (i.e. $P=0.46$; Figure 2). However, due to the absence of 3-4 years of consecutive baseline data (as required by the NEMP - Robertson et al. 2002), this change cannot be reliably categorised as outside of natural variation, although this is seen as likely. Since 2001, the mean mud content of sediments reflected an overall increase of 28% at Site A, and a 5% reduction at Site B.

These results show there has been a clear decline in sediment condition at Site A, and the shift to a “very high” risk indicator rating in 2014 highlights that a likely consequence is adverse impacts to benthic macroinvertebrates (investigated further on pages 10-12).

Buried plates (4 per site) installed at each fine scale site in 2014 will be measured annually and will, over time, enable the sedimentation rate at these sites to be determined. Additional plates installed in soft mud deposition zones will help to derive overall sedimentation rates for the estuary.

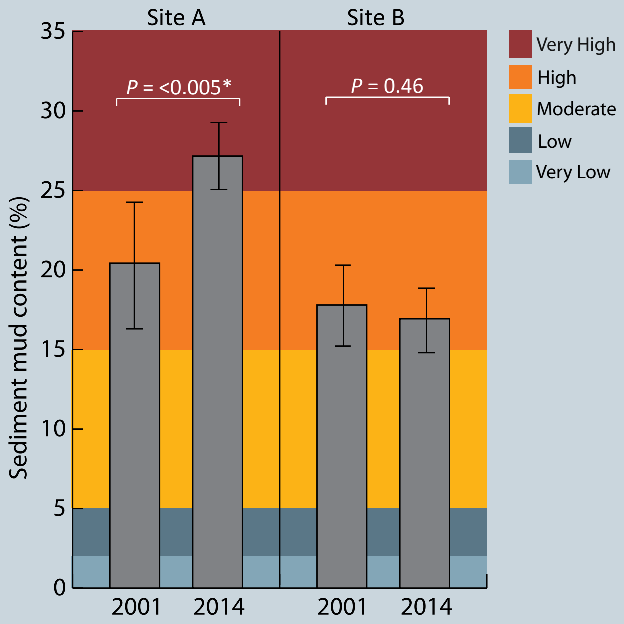


Figure 2. Mean sediment mud content (±SE, n=3), Havelock Estuary, 2001 and 2014.
*** denotes a significant change in mud content between 2001 and 2014.**

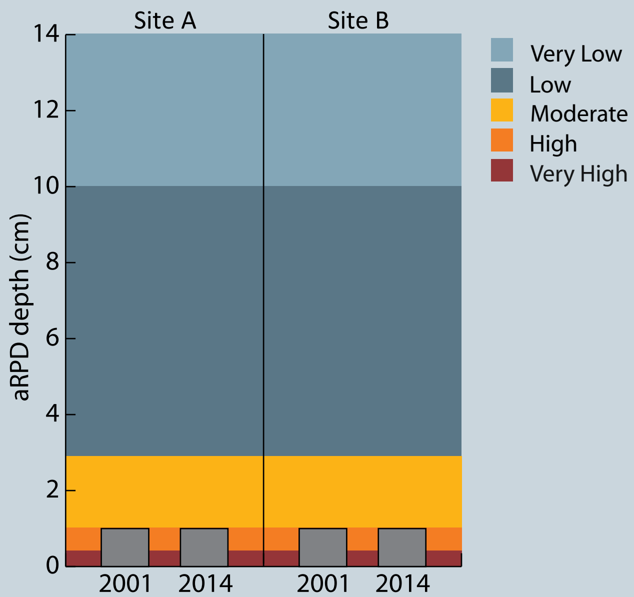


Figure 3. Mean apparent Redox Potential Discontinuity (aRPD) depth, Havelock Estuary, 2001 and 2014.

The reason for the increase in mud content at Site A is currently unclear but may possibly reflect an increase in the mud proportion of sediment inputs to the estuary since 2001 (e.g. increased land development, changing climate patterns), the release and transport of mud from old *Spartina* beds, and/or the ongoing erosion of estuary margins.

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 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 high mud contents at Sites A and B indicate upper sediment oxygenation is likely to be reduced, and depending on catchment sources, sediment bound organic matter, nutrients and metals may be elevated.

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 two Havelock sampling sites. In both 2001 and 2014, the aRPD depth was shallow (1cm) at both Sites A and B indicating a "moderate-high" risk of reduced sediment oxygenation and detrimental effects to sediment dwelling invertebrates. However, because the sediment coloration was only slightly grey below the aRPD depth, it is likely that redox levels were not strongly reducing. Consequently, an overall moderate aRPD rating for 2014 results is indicated, which suggests that the benthic invertebrate community was likely to be in a "transitional" state.

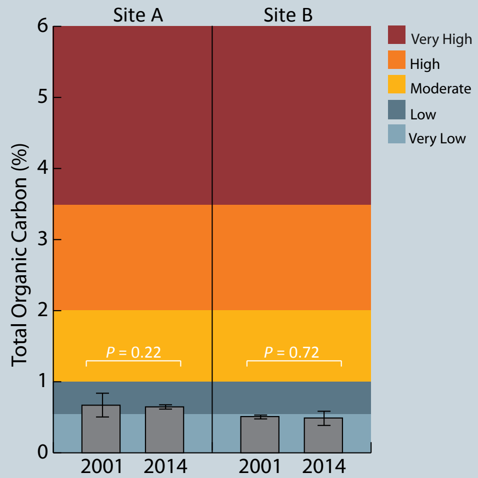


Figure 4. Mean total organic carbon (±SE, n=3), Havelock Estuary, 2001 and 2014.

Note: 2001 data was measured as ash-free dry weight (AFDW) and converted to TOC using the following equation (TOC = AFDW x 0.38) (Lindquist et al. 2008).

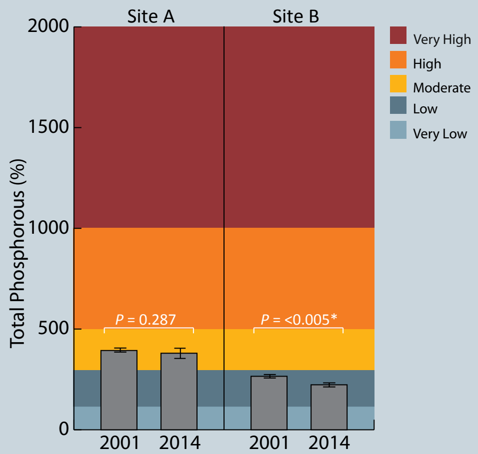


Figure 5. Mean total phosphorus (±SE, n=3), Havelock Estuary, 2001 and 2014. *denotes a significant change in TP content between 2001 and 2014.

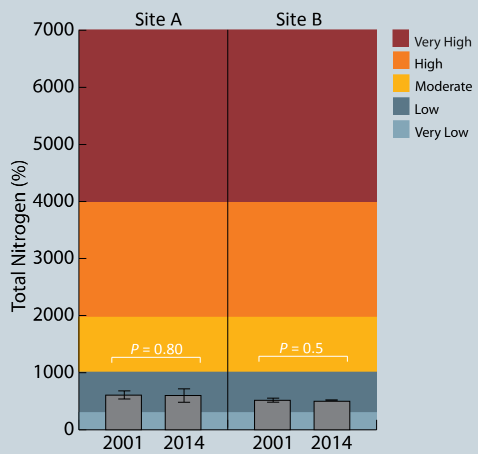


Figure 6. Mean total nitrogen (±SE, n=3), Havelock Estuary, 2001 and 2014.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and to a limited extent, 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 2014 results showed TOC (<0.7%) and TN (<600mg/kg) were in the "low" risk indicator rating, while TP was rated "moderate" for Site A and "low" for Site B (Figures 4, 5, and 6). The "low" TOC, TN and "low-moderate" TP concentration reflects the likely moderate load of organic matter and nutrients, sourced primarily from the catchment. Statistical analyses showed no significant difference in TOC and TN content at both sites, and TP at Site A, between 2001 and 2014 (i.e. $P>0.05$; Figures 4, 5 and 6). However, there was a significant reduction in TP at Site B between 2001 and 2014 (i.e. $P=<0.005$).

Overall, the sediment and eutrophication results indicate that the sediment conditions at Sites A and B were:

- moderately muddy
- moderately oxygenated
- had relatively low organic carbon and nutrient concentrations.

4. Results and Discussion (Continued)

TOXICITY INDICATORS

In 2001 and 2014, the heavy metals Cd, Cr, Cu, Pb, Zn at both sites, and Ni at Site B, used as an indicator of potential toxicants, were present at "very low" to "moderate" concentrations with all non-normalised values below the ANZECC (2000) ISQG-Low trigger values (Figure 7). The 2014 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 most of the metal results, posed no toxicity threat to aquatic life. However, nickel was present at Site A at concentrations exceeding the ISQG low limits in both 2001 and 2014. This was likely attributable to elevated inputs in run-off from the geologically nickel and chromium enriched catchment (Rattenbury et al. 1998), and the high affinity of heavy metals for muds acting to transport and sequester them into estuarine sediments (Whitehouse et al. 1999). In such cases as this, where the ISQG low limit is exceeded and the likely cause is natural, the ANZECC (2000) guidelines recommend no further action.

Organic compounds (polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs)) and tributyl tin were also analysed to screen for key pollutants at both sites (Appendix 2). All analytes were found to be less than the analytical detection limits and were therefore unlikely to cause toxicity to benthic macrofauna. Sediment toxicity was also monitored at a site adjacent to Havelock township ~500m west of the marina entrance (Figure 1). The results (Appendix 2) showed exceedance of the ANZECC ISQG low trigger for mercury, tributyl tin, Cu and Ni, but no exceedance of the ISQG high trigger. Such results indicate localised sediment toxicity in this area, with potential adverse impacts to aquatic life. In such cases, ANZECC (2000) guidelines indicate further investigation is required to assess the extent of this toxicity.

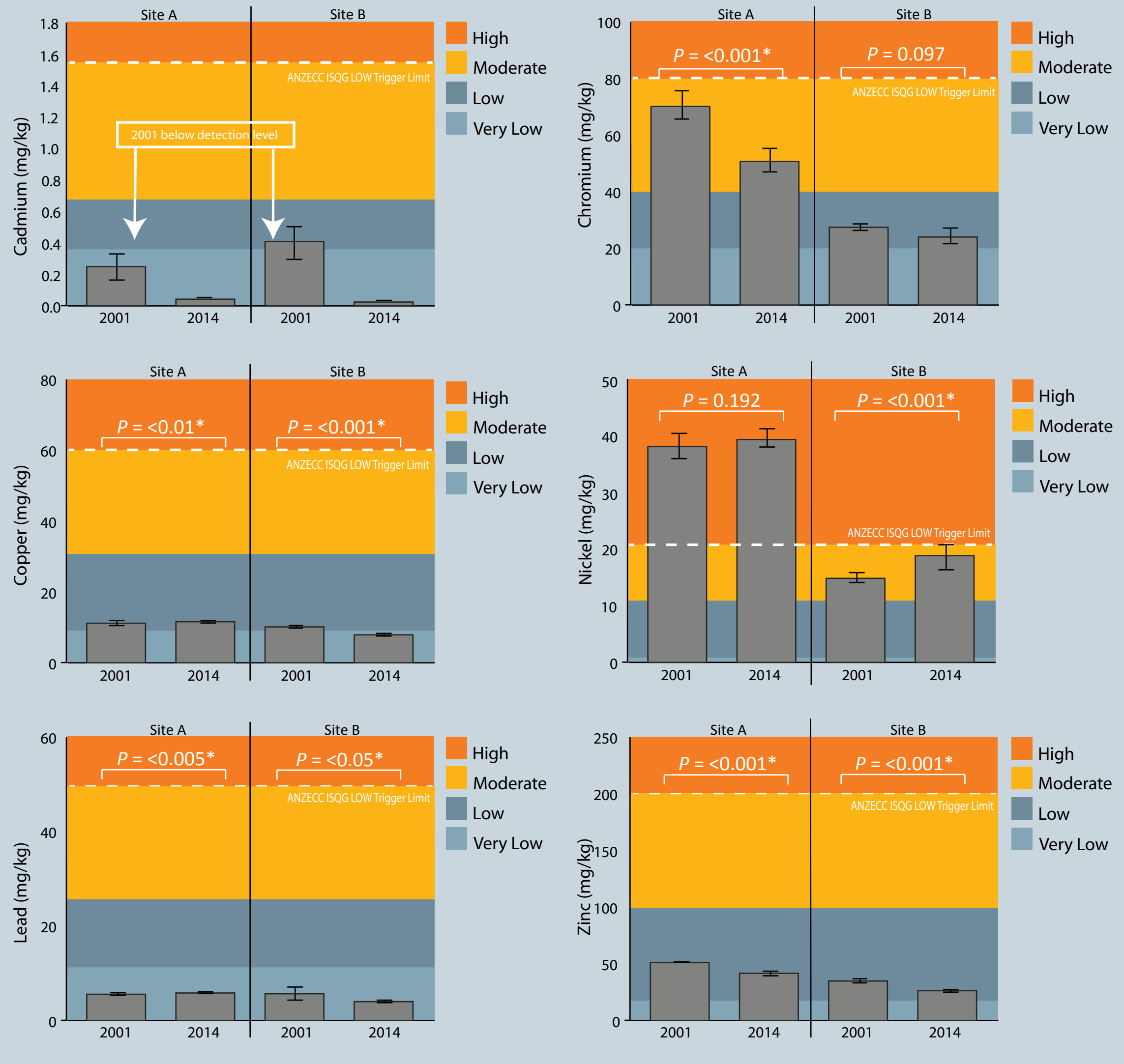


Figure 7. Sediment metal concentrations (±SE, n=3), Havelock Estuary, 2001 and 2014.

4. Results and Discussion (Continued)

BENTHIC MACROINVERTEBRATE COMMUNITY

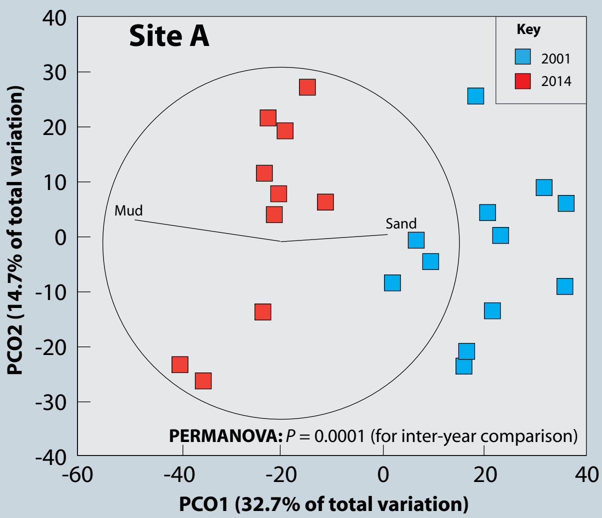
Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong linkage to sediments and, secondarily, to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987). Because they integrate recent pollution history 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 Havelock Estuary has been examined in four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among fine scale sites sampled in 2001 and 2014.
2. Assessment of species richness, abundance, diversity and major infauna groups.
3. Assessment of the response of the macroinvertebrate community to increasing mud and organic matter between 2001 and 2014 based on identified tolerance thresholds for NZ taxa (Robertson 2013).
4. Comparisons with a "reference" estuary of the same type and size as Havelock (Freshwater Estuary, Stewart Island).

Macroinvertebrate Community Ordination

Principle Coordinates Analysis (PCO), based on between-year species abundance data collected in 2001 and 2014, showed that the invertebrate community at Sites A and B were significantly different from one another (i.e. PERMANOVA P<0.0001 for both sites, for between-year comparisons, Figure 8), indicating significant structural changes to the community over this period. Vector overlays (based on Pearson correlations) indicate that at Site A, the 2001 communities were likely separated from those in 2014 by their lower mud content, and at Site B by increased zinc, copper and lead, and reduced nickel concentrations (Figure 8). However, given the fact that the metals concentrations were below levels likely to cause biological stress (Figure 7) and that a 3-4 year baseline has not yet been undertaken for Havelock Estuary, such conclusions can only be regarded as tentative. As a consequence, attributing the community differences at Site B to natural population fluctuations cannot be ruled out.



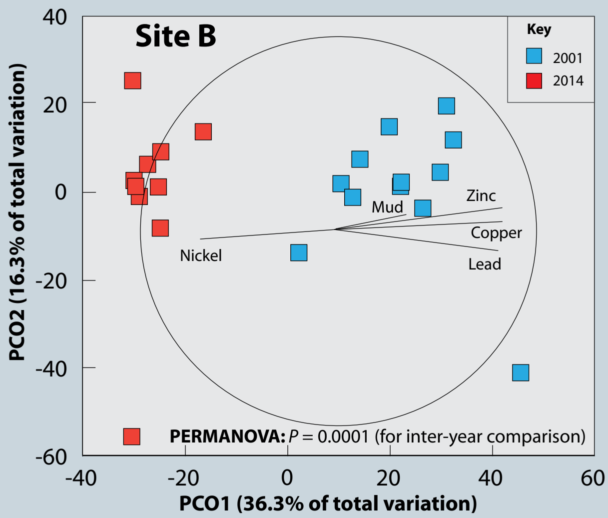


Figure 8. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at each site, Havelock Estuary, 2001 and 2014, and the environmental variables likely responsible for the observed differences.

Figure 8 shows the relationship among samples in terms of similarity in macroinvertebrate community composition at Sites A and B, for the sampling period 2001 and 2014. The plot shows the replicate samples for each site (12 rep for Sites A and B in 2001 and 10 replicates in 2014) 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% for both 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*>0.0001) structural changes over the sampling period 2001-2014. The environmental vector overlays, based on Pearson correlations, show the strength of environmental relationships with their length in relation to the circle boundary indicating the magnitude of the strength. In this case, the Site A results indicate that the 2001 communities were likely separated from the 2014 by their lower mud content and at Site B by increased zinc, copper and lead concentrations and reduced nickel.

4. Results and Discussion (Continued)

Species Richness, Abundance, Diversity and Infauna Groups

The next step was to assess whether simple univariate whole community indices, i.e. species richness, abundance and diversity at each site, could explain the differences between years indicated by the PCO analysis. Statistical analyses showed no significant difference in either species richness, abundance or Shannon diversity at both sites between 2001 and 2014 (i.e. $P>0.05$; Figure 9). Such findings therefore indicate that the between year differences were likely the result of changes at the species, rather than the whole community, level. Analysis of the mean abundance of the major infauna groups provides early support for such a conclusion. Figure 10 shows that although the community at both sites in 2001 and 2014 was dominated by polychaetes, crustacea, bivalves and gastropods, there were obvious differences between years, especially to bivalves.

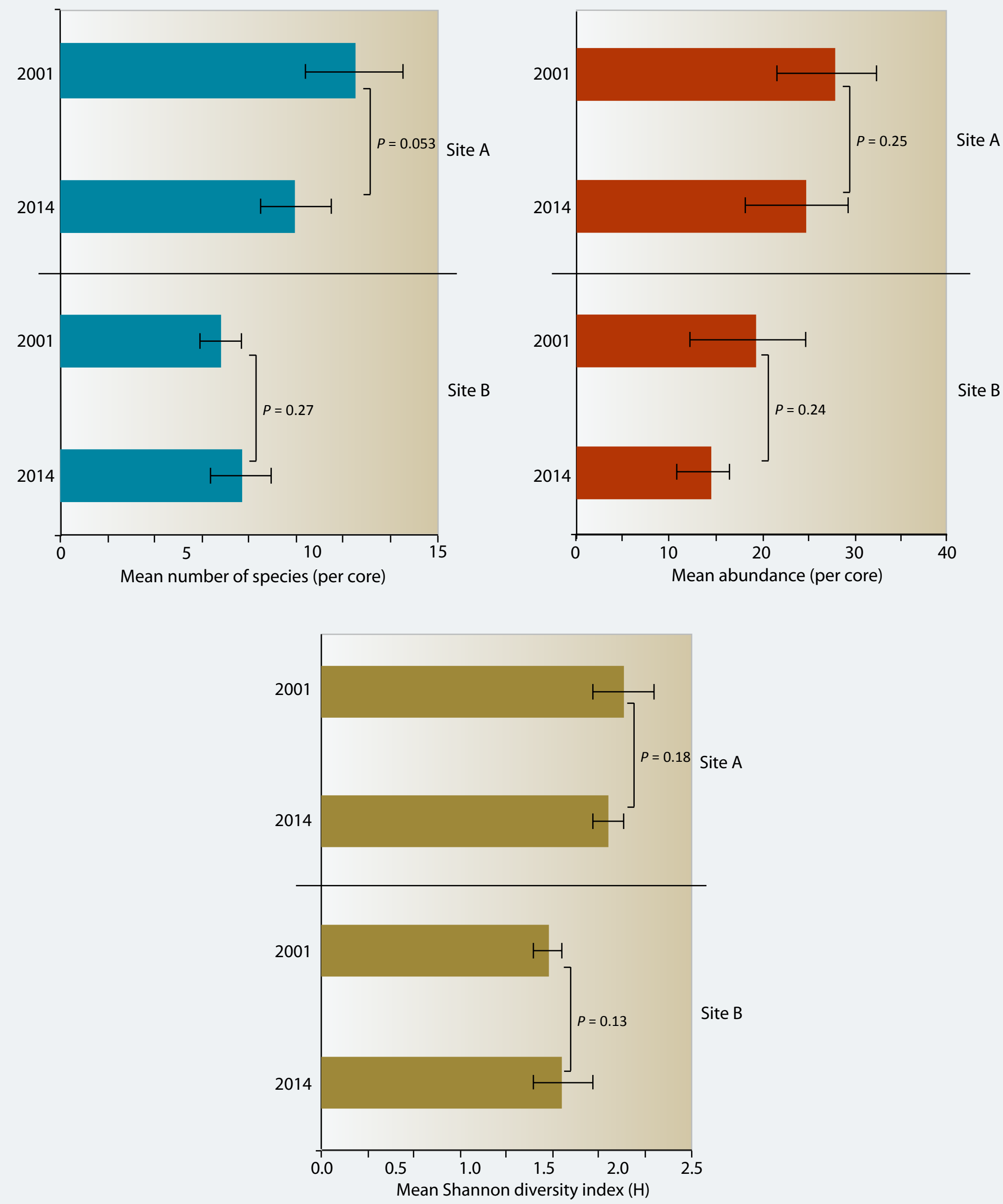
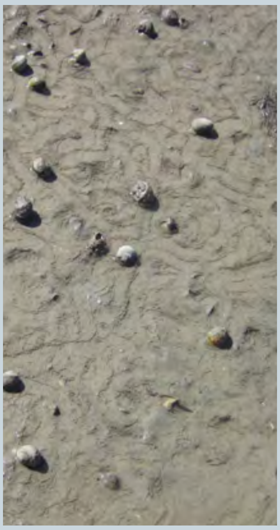


Figure 9. Mean number of species, abundance per core, and Shannon diversity index (±SE, n=10), Havelock Estuary, 2001 and 2014.

Note: Overlaid t Test, $P>0.05$ for all sites, indicate no significant differences in either species richness, abundance or Shannon diversity index between 2001 and 2014.

Typical muddy sediments Havelock Estuary



Amphibola crenata (mudflat snail)

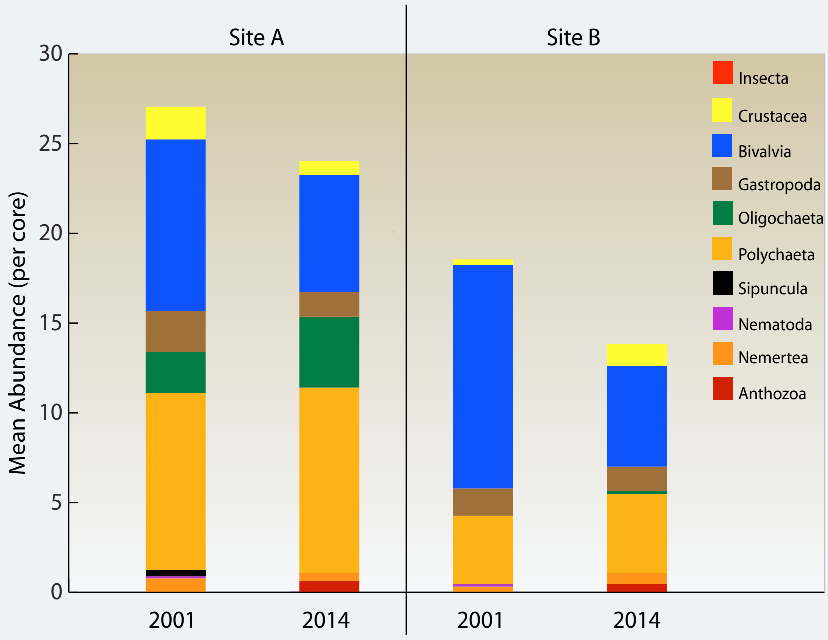


Figure 10. Mean abundance of major infauna groups (n=10), Havelock Estuary, 2001 and 2014.

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 that there were no clear trends in the change in species abundance, richness or diversity, aRPD, mud and TOC concentrations between 2001 and 2014, despite obvious 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). 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.

WEBI biotic coefficients, and mud and organic enrichment tolerance ratings, for the Havelock fine scale sites are presented in Figure 11. Coefficients ranged from 1.5-3, and were all in the "low" risk indicator category (i.e. a transitional type community indicative of low levels of organic enrichment and moderate mud concentrations). The WEBI values showed a significant (p=0.005) difference between 2001 and 2014 at Site B, but not at Site A. The WEBI findings were therefore consistent with results showing significant change in the macroinvertebrate community between 2001 and 2014 (PCO/PERMANOVA, P<0.05) for Site B, but not for Site A. The likely reason for this is, as alluded to above, the failure of the AMBI equation to account for all aspects of community structural change, in particular changes in species richness and diversity.

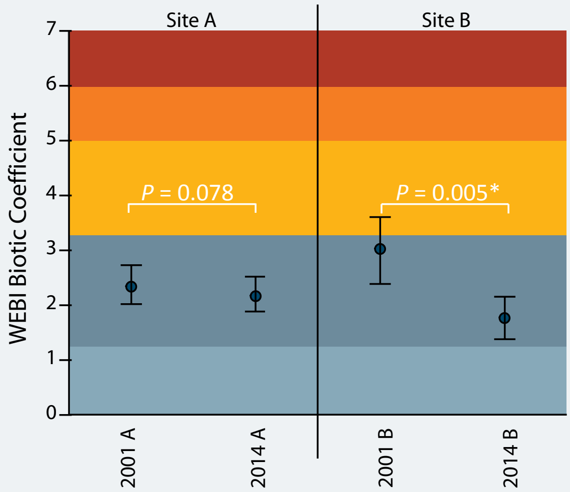


Figure 11. Benthic invertebrate mud/organic enrichment tolerance rating (±SE, n=10), 2001 and 2014.

For example, six Group 1 (highly mud sensitive) species with an abundance of 4 individuals each, rates the same as a single Group 1 species with an abundance of 24, effectively stating that one sensitive species is as good as six; (refer to Appendix 3 for details on species tolerance groupings); or, in another example, a change at one site from 4 taxa in Group 1 with abundance of 20, to 4 taxa (with different names) and an abundance of 20, is not picked up in the final rating, despite the significance of such a community shift. 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.

2. Individual Species Changes

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

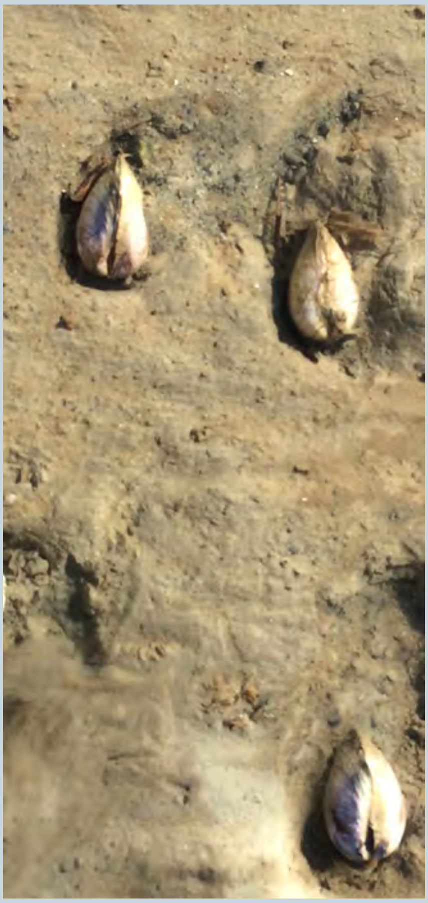
- Univariate SIMPER (PRIMER-e) analysis (Table 4).
- Comparing direct plots of mean abundances of the 5 major mud/enrichment tolerance groupings (i.e. "very sensitive to organic enrichment" group through to "1st-order opportunistic species" group) (Figure 12).

The results of the SIMPER analysis (Table 4) shows major changes in the abundance of certain species at each site between 2001 and 2014. At Site A (Table 4) the major changes occurred to the following species:

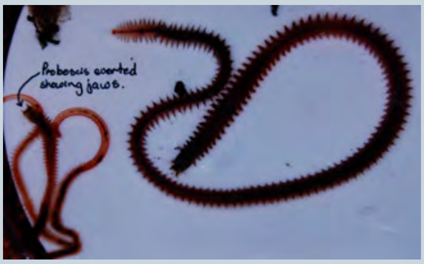
Table 4. Mean abundance of the species causing the greatest contribution to the difference between macroinvertebrate community structure between 2001 and 2014 at Sites A and B.

SITE A. Species	2001 Mean Abundance	2014 Mean Abundance	Contribution to Community Difference %
Austrovenus stutchburyi	8.7	5.7	15.1
Oligochaeta	2.3	4.0	12.2
Paraonidae sp. 1	-	3.4	10.4
Heteromastus filiformis	2.8	2.6	7.6
Prionospio sp.	1.67	-	5.0
SITE B. Species	**2001 Mean Abundance**	**2014 Mean Abundance**	**Contribution to Community Difference %**
Arthritica bifurca	8.0	0.1	29.6
Austrovenus stutchburyi	4.5	5.2	15.2
Nicon aestuariensis	1.5	0.1	6.7
Notoacmea helmsi	0.25	1.3	5.8

4. Results and Discussion (Continued)



Small cockles on surface of very soft muds near Site B



Nicon aesturiensis (ragwom)

Paphies australis (pipi)

- *Austrovenus stutchburyi* (cockle) - a reduction from 8.7 to 5.7 individuals per core for 2001 and 2014 respectively. *Austrovenus* is a common suspension feeding bivalve that lives a few cm from the sediment surface at mid-low water situations and has an important role in improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). Although cockles are often found in mud concentrations greater than 10%, the evidence suggests that they struggle. Small cockles are an important part of the diet of some wading bird species including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. The decrease in cockles at Site A in 2014 was likely related to the increased mud content (from 20% mud in 2001 to 27% in 2014).
- Oligochaeta (worms) - an increase from 2.3 to 4 individuals per core for 2001 and 2014 respectively. Oligochaetes are segmented worms that are deposit feeders. Many are very pollution and mud tolerant (e.g. tubificid worms) although there are some less tolerant species. The increase in oligochaetes in 2014 was also likely related to the increased mud content at Site A.
- Paraonidae (polychaetes) - an increase from 0 to 3.4 individuals per core for 2001 and 2014 respectively. Paraonidae are slender burrowing polychaete worms that feed on grain-sized organisms such as diatoms and protozoans and prefer moderate mud concentrations. The increase in Paraonidae in 2014 was also likely related to the increased mud content at Site A, but could also be attributed to natural population fluctuations.

At Site B (Table 4) the major changes occurred to the following species:

- *Arthritica bifurca* - a decrease from 8 to 0.1 individuals per core for 2001 and 2014 respectively. *Arthritica* is a small sedentary deposit feeding bivalve that lives greater than 2cm deep in the muds. *Arthritica* tolerates a sediment mud content of up to 75% with an optimum range of 20-60%. Its abundance fluctuates considerably (Halliday and Cummings 2012) with peaks generally in January. The reason for the reduction in *Arthritica* in 2014 and the high numbers in 2001, is likely related to the naturally fluctuating population structure of this species.
- *Austrovenus stutchburyi* (cockle) - an increase from 4.5 to 5.2 individuals per core for 2001 and 2014 respectively. The reason for the slight increase is likely related to natural variation.
- *Nicon aestuariensis* (ragworm) - a decrease from 1.5 to 0.1 individuals per core for 2001 and 2014 respectively. *Nicon* is a surface deposit feeding nereid that is tolerant of freshwater that prefers to live in moderate mud content sediments. The reason for the slight increase is likely related to natural variation.

These results, which show significant changes in species abundances between years at each site at the species level, are illustrated in Figure 12. This graph shows a comparison of the mean abundances 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).

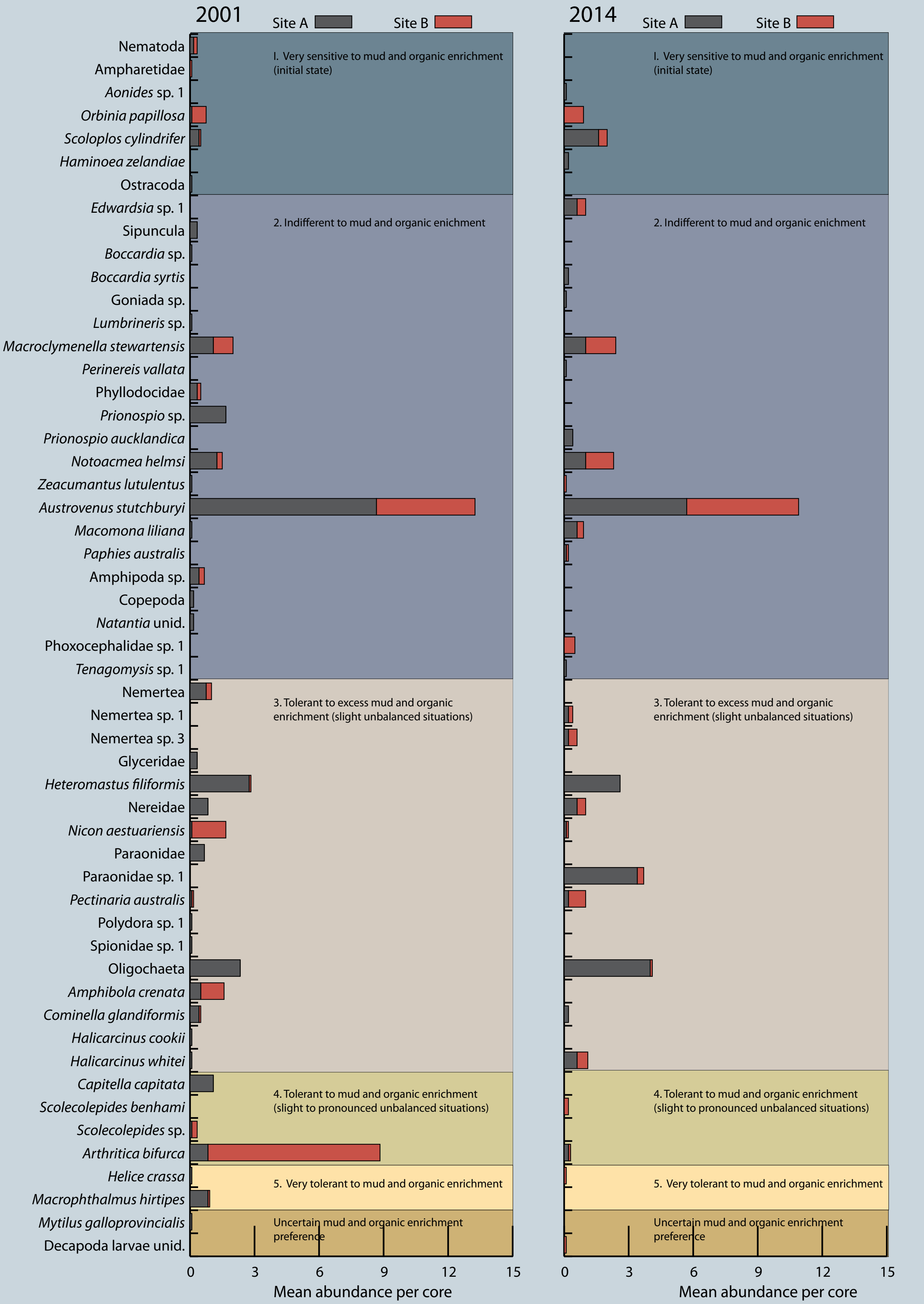


Figure 12. Mud and organic enrichment sensitivity of macroinvertebrates, Havelock Estuary, 2001 and 2014 (see Appendix 4 for sensitivity details).

4. Results and Discussion (Continued)

Comparison with Stewart Island Reference Estuary

Freshwater Estuary (Stewart Island) is a relatively large (812ha), primarily intertidal, "pristine" delta estuary at the mouth of a tidal river, and located inside a sheltered embayment similar to Havelock. A key aspect of its high ecological value is the abundance of seagrass (60% of intertidal) and the very low sediment mud (<1%) and TOC (0.2%) contents (Robertson and Stevens 2013). Its pristine condition is attributed to the native forest and wetland catchment and the consequent very low sediment and nutrient load. Because of its unmodified nature, it is frequently used as a "reference" estuary for comparison of estuary condition with other NZ estuaries. In the future, a Marlborough estuary is planned to be used as a reference once data is available.

Principle Coordinates Analysis (PCO) showed that compared with Havelock, the macroinvertebrate community was significantly different (p=0.0002) from Freshwater Estuary with the major differences being changes at the species level (Figure 12 and Table 5). For example, the mud intolerant endemic bivalve *Paphies australis* (pipi) was very scarce in Havelock but relatively abundant in Freshwater, whereas the mud tolerant bivalve, *Arthritica bifurca* was abundant in Havelock but scarce in Freshwater. Vector overlays (based on Pearson correlations) indicate that Havelock communities were likely separated from Freshwater by their elevated mud and TOC concentrations, shallow aRPD and reduced sand contents (Figure 13).

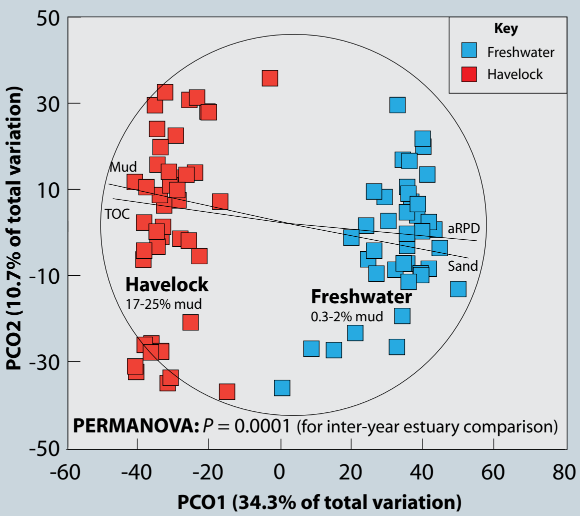


Figure 13. Vector overlays on the PCO ordination plots reflecting structural differences in the macroinvertebrate community at sites in Havelock and Freshwater Estuaries, and the likely environmental variables responsible for differences.

Figure 13 shows the relationship among samples in terms of similarity in macroinvertebrate community composition at fine scale sites in Havelock, and the reference estuary, Freshwater. The plot shows the replicate samples for two sites in each estuary and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves a PCO analysis (see details of method in Figure 8). For the present plot, the cumulative variation explained was 45% for both sites, indicating a good representation of the abundance matrix. PERMANOVA, testing for statistical significant differences in the invertebrate communities among estuaries, reflected highly significant (P>0.0001) structural changes between Freshwater and Havelock Estuaries. The environmental vector overlays are based on Pearson correlations and their length in relation to the circle boundary indicates the strength of the relationships. In this case, the results indicate that Havelock communities were likely separated from Freshwater by their elevated mud and TOC concentrations and reduced sand.

Table 5. Mean abundance of the species causing the greatest contribution to the difference between macroinvertebrate community structure between Freshwater and Havelock Estuaries.

Species	WEBI Rating	Freshwater Mean Abundance	Havelock Mean Abundance	Contribution to Community Difference %
Prionospio aucklandica	2	8.1	1.5	11.0
Aonides sp. 1	1	7.0	-	10.9
Austrovenus stutchburyi	2	0.6	6.4	9.9
Amphipoda sp. 4	2	6.2	-	8.9
Paphies australis	2	6.9	0.03	8.6
Perrierina turneri	1	4.0	-	5.9
Heteromastus filiformis	3	0.5	3.6	5.3
Amphipoda sp. 1	2	3.7	-	5.1
Arthritica bifurca	4	0.2	2.3	4.0

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for two long term monitoring sites within Havelock Estuary in 2014, and supported by 2001 results, showed the following key findings:

Physical and Chemical Condition

- The sediment mud content in 2014 was relatively high at 14-29% mud. Since 2001, the mean mud content of sediments reflected an overall increase of 28% at Site A, and a 5% reduction at Site B.
- Sediment oxygenation (aRPD) in both 2001 and 2014 was "moderate" (1-<3cm).
- Sediment organic matter (TOC), and nutrients (TN and TP) were in the "low" or "moderate" risk categories in both 2014 and 2001.
- 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.
- Sediment toxicity was also monitored at a site adjacent to Havelock township ~500m west of the marina entrance. The results showed exceedance of the ANZECC ISQG low trigger for mercury, tributyl tin, Cu and Ni, but no exceedance of the ISQG high trigger. Such results indicate localised sediment toxicity in this area, with potential adverse impacts to aquatic life. In such cases, ANZECC (2000) guidelines indicate further investigation is required to assess the extent of this toxicity.

Biological Condition

- Macroinvertebrates consisted of a mixed assemblage of species, dominated by polychaetes, crustacea, bivalves and gastropods, spread across all sites between 2001 and 2014.
- Statistical analysis of the results showed significant differences in the communities at each site between 2001 and 2014. In particular, there were reduced abundances of species highly sensitive to mud/organic enrichment from 2001 to 2014.
- In comparison to the reference estuary (Freshwater Estuary, Stewart Island), the community in Havelock Estuary was significantly different, which was attributed to Havelock's elevated mud and organic matter concentrations and poor sediment oxygenation compared to the sandy, well oxygenated, seagrass covered sediments of Freshwater Estuary.

In summary, the results showed that the current fine scale sites in Havelock Estuary were located in unvegetated soft mud/sand habitat near low water. In 2014, the sediments had high mud concentrations, low to moderate levels of organic enrichment, moderate sediment oxygenation, low levels of toxicity and a typical mud-tolerant macroinvertebrate community that included very few mud intolerant species (e.g. pipi). These results also showed significant changes in the structure of the macroinvertebrate community between 2001 and 2014, a likely consequence of increasing mud concentrations.

Such a dominance of muddy habitat has significant ecological consequences, in particular its negative effect on water clarity and the types of flora and fauna that require clear waters. For example, lower water clarity can result in the following:

- Reduced ability of visual predators (such as snapper, gulls and terns) to hunt, and therefore their reduced abundance in turbid estuaries.
- Reduced light to seagrass (*Zostera muelleri*). Seagrass, particularly subtidal beds, provide important food and habitat to support high abundances of juvenile snapper, trevally, flatfish and spotties. Poor water clarity suppresses seagrass growth and displaces it from deeper water.
- Increased energy required by shellfish (such as cockles and pipi) to filter food from the water column. Many fish species (e.g. snapper and flounder) feed on shellfish.

Havelock Estuary - western tidal flats looking towards Pelorus Sound

5. Summary And Conclusions (Continued)

The monitoring results also raise two very fundamental monitoring design issues that require resolution:

1. Because the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) requires 3-4 consecutive years of data for establishing a defensible baseline, the two single years of data that exist for the Havelock Estuary are insufficient for use in trend analysis (i.e. trends in change between 2001 and 2014 data). Therefore it is recommended that this be rectified by repeat monitoring over the next 3 years.
2. Another very relevant aspect of the Havelock monitoring was the extent to which the two fine scale sites represented the bulk of the intertidal habitat in Havelock Estuary. The choice for the site locations was made back in 2001, when they were chosen as experimental test sites for the development of the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002). However, based on the final NEMP criteria for site selection (i.e. sites should be located in the dominant mid-low water habitat, which in the case of Havelock would be very soft mud rather than the firm mud sand/soft mud habitat that they are currently located in) additional sites need to be established in the dominant very soft mud habitat in Havelock Estuary, or the existing two sites in Havelock be shifted to this habitat.

6. MONITORING AND MANAGEMENT

Installing sediment plates at Site B

Havelock Estuary has been identified by MDC as a priority for monitoring, and is a key part of MDC's coastal monitoring programme being undertaken in a staged manner throughout the Marlborough region. Based on the 2014 monitoring results and risk indicator ratings, it is recommended that monitoring continue as follows:

Fine Scale Monitoring
Given the magnitude of the muddiness changes between 2001 and 2014, and to establish whether the deteriorating results observed in 2014 are truly representative of current conditions, monitoring is recommended as follows: Sites A and B continue to be monitored, but two new sites be established in the dominant intertidal habitat type (very soft muds) and all 4 sites be monitored (data collection only) in February 2015, 2017 and 2019 to establish both a multi-year baseline and relationships between soft mud and very soft mud habitats so that the value of previous monitoring is not lost. A full report of all data should then be undertaken at the next scheduled 5 yearly monitoring interval (2019). This change is supported by the 2014 broad scale mapping results of dominant substrate types, opportunistic macroalgae, and seagrass beds in the estuary (Stevens and Robertson 2014).

Broad Scale Habitat Mapping, Including Macroalgae
Continue with the programme of 5 yearly broad scale habitat mapping. Next monitoring due in February/March 2019. Undertake a rapid visual assessment of macroalgal growth annually, and initiate broad scale macroalgal mapping if growth appears significant, or if conditions appear to be worsening over the 5 years before broad scale mapping is repeated.

Sedimentation Rate Monitoring
Because sedimentation is a priority issue in the estuary it is recommended that sediment plate depths be measured annually, and new plates be deployed in the dominant very soft mud locations where sediment appears to be rapidly accumulating.

6. MONITORING AND MANAGEMENT

Management

The combined results from the 2014 fine scale and broad scale reports (Stevens and Robertson 2014) identify fine sediment as a major issue in Havelock Estuary, and is therefore likely to be in need of a sediment reduction plan. However, prior to the instigation of such management, it is recommended that a comprehensive Coastal Vulnerability Assessment (CVA) be undertaken to identify monitoring and management priorities throughout the Marlborough region. If the excessive muddiness of Havelock Estuary is identified as a regional priority in the CVA, then a sediment reduction plan for Havelock is recommended as follows (in order of priority):

The first step would be to identify the appropriate target condition for this estuary, particularly given the relatively high sensitivity of Havelock to mud inputs. This sensitivity arises from both its poorly flushed nature (i.e. at the head of a Sound, which means most of its mud load settles in the estuary and upper sound), and the large, steep catchments that drain into it (meaning it has a large potential for elevated sediment supply).

Establishing its target condition would require a combination of the following:

- **Establishment of Landuse/Sediment Load Relationships using Modelling Approaches.** Landuse modelling of sediment input loads under natural state conditions (i.e. native cover and extensive freshwater and upper estuarine wetlands), moderate state (i.e. minimal development, with no steep slope plantation forestry), and current state conditions would be undertaken to establish a meaningful range of landuse/sediment load relationships and associated estuary sedimentation rates.
- **Identifying Estuary Response to Landuse using Historical Coring.** Historical sediment cores would be taken from representative sites to identify the sedimentation rate (i.e. rate and timing of infilling) over the last few hundred years, and determine when the surface substrate was predominantly sandy. Such an approach would allow determination of when the major period of infilling occurred and if it is currently excessive compared to the natural state. It would also identify periods where the sediments were sandier, which would then be linked, using historical landuse data, to identifying less erosive landuse patterns.

Once these preliminary investigations have been undertaken and a target estuary condition identified and assessed by the wider community, then a more detailed assessment may be required to more accurately determine: sediment sources, transport/deposition patterns of sediment within the estuary and losses to the greater Pelorus Sound, input load guideline criteria, options for reducing existing areas of fine sediment within the estuary, particularly options to reduce resuspension (e.g. saltmarsh) and replace muddy areas with high ecological value habitat, and landuse management and monitoring options to meet the target condition.

Related Notes:

- The recent MDC "State of the Environment Surface Water Quality Monitoring Report, 2013" provides some useful data that could be used to help identify sources of sediment to the catchment, but because it was not designed to measure suspended sediment "loads" from multi-catchments (i.e. it does not aim to measure SS concentrations under the full range of river flows), its value for such a purpose is limited.
- The recent MDC report "Some Observations of Erosion as a Result of the 28 December 2010 Storm Event" (Technical publication No 11-024) also provides very valuable anecdotal information of likely sources of sediment during heavy rain events, particularly from exotic forestry on steep slopes. It will be particularly useful in the design of an appropriate monitoring programme for sediment (and related nutrient) load tracking.
- Although this report does not specifically address disease risk issues, it is appropriate to note that currently, MDC are aware that there are periodic sewage overflows to the estuary from Havelock, and discharges from industrial premises that exceed Enteroccoci levels on the estuary (pers. comm. Steve Urlich). For example, the 2014 "Muddy Buddy" fun run was postponed due to a raw sewage overflow into the estuary.

7. ACKNOWLEDGEMENTS

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Sampling at Site B

Havelock Estuary - northern tidal flats

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
Organochlorine Pesticides	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Organonitro/phosphorus Pesticides	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Dry Matter (Env)	R.J. Hill	Dried at 103°C (removes 3-5% more water than air dry)	

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

Epifauna (surface-dwelling animals).
SACFOR Percentage Cover and Density Scales (after Marine Nature Conservation Review - MNCR).

A. PERCENTAGE COVER	Growth Form	
	i. Crust/Meadow	ii. Massive/Turf
>80	S	-
40-79	A	S
20-39	C	A
10-19	F	C
5-9	O	F
1-4	R	O
<1	-	R

SACFOR Category
S = Super Abundant
A = Abundant
C = Common
F = Frequent
O = Occasional
R = Rare

- Whenever percentage cover can be estimated for an attached species, it should be used in preference to the density scale.
- The massive/turf percentage cover scale should be used for all species except those classified under crust/meadow.
- Where two or more layers exist, for instance foliose algae overgrowing crustose algae, total percentage cover can be over 100%.

B. DENSITY SCALES

SACFOR size class				Density				
i	ii	iii	iv	$0.25m^2$	$1.0m^2$	$10m^2$	$100m^2$	$1,000m^2$
<1cm	1-3cm	3-15cm	>15cm	(50x50cm)	(100x100cm)	(3.16x3.16m)	(10x10m)	(31.6x31.6m)
S	-	-	-	>2500	>10,000			
A	S	-	-	250-2500	1000-9999	>10,000		
C	A	S	-	25-249	100-999	1000-9999	>10,000	
F	C	A	S	1-9	10-99	100-999	1000-9999	>10,000
O	F	C	A		1-9	10-99	100-999	1000-9999
R	O	F	C			1-9	10-99	100-999
-	R	O	F				1-9	10-99
-	-	R	O					1-9
-	-	-	R					<1

APPENDIX 1. DETAILS ON ANALYTICAL METHODS (CONTINUED)

Station Locations

Havelock Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1664419.22	1664424.10	1664427.73	1664434.08	1664424.67	1664420.36	1664414.91	1664410.15	1664403.91	1664409.24
NZTM NORTH	5430917.19	5430927.73	5430943.84	5430956.31	5430968.56	5430949.85	5430937.14	5430919.34	5430928.19	5430944.63
Havelock Site B	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1664820.51	1664830.79	1664840.50	1664845.76	1664854.06	1664848.10	1664839.56	1664835.47	1664842.84	1664849.15
NZTM NORTH	5430899.04	5430884.43	5430867.24	5430856.13	5430863.27	5430873.91	5430891.44	5430908.16	5430912.37	5430897.05
Havelock Township	1	Sediment	A1	A2	A3	A4	B1	B2	B3	B4
NZTM EAST	1664063.31	Plate Site	1664438	1664436	1664434	1664431	1664844	1664845	1664846	1664849
NZTM NORTH	5430437.56	Locations	5430967	5430967	5430968	5430969	5430850	5430852	5430853	5430855
		Depth (mm)	186	142	131	143	138	154	166	149

APPENDIX 2. 2014 DETAILED RESULTS

Physical and Chemical Results for Havelock Estuary (Sites A and B), 2001 and 2014.

Year/Site/Rep [c]	RPD	Salinity	TOC [d] AFDW	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2001 A-01	1		1.2	19.5	76	4.5	<0.2	74	11	41	5.6	51			500	385
2001 A-02	1		1.9	15.6	75.9	8.5	<0.2	70	11	39	6.2	52			500	413
2001 A-03	1		2	17.6	73.1	9.3	<0.2	67	11	41	5.4	52			600	433
2001 A-04	1		1.2	17.9	76.7	5.4	<0.2	68	10	39	5	50			500	376
2001 A-05	1		2.2	16.7	76.2	7.1	<0.2	71	11	40	5.6	51			900	365
2001 A-06	1		2	18.7	73.8	7.5	<0.2	63	11	41	5.7	52			600	411
2001 A-07	1		2.1	20.9	73.6	5.5	<0.2	57	11	36	5	51			600	385
2001 A-08	1		2.1	20.8	74.7	4.5	<0.2	73	11	36	5.5	52			500	388
2001 A-09	1		1.7	25.4	70.9	3.7	<0.2	82	12	36	4.8	52			700	380
2001 A-10	1		2.3	21.5	74.5	4.1	0.4	72	11	36	4.2	51			600	389
2001 A-11	1		1	26.1	68.3	5.6	0.4	73	12	35	5.3	53			700	387
2001 A-12	1		1.3	24.5	69.6	5.8	0.4	71	12	37	8.5	46			600	410
2001 B-01	1		1.3	25.8	72.8	1.5	0.3	29	11	16	3.5	39			700	284
2001 B-02	1		1.1	18.4	80.4	1.2	0.3	28	11	17	3.1	39			<500	284
2001 B-03	1		1.8	17.2	81.1	1.7	0.3	23	10	15	3.4	36			<500	274
2001 B-04	1		1	19.9	79.5	0.5	0.3	25	10	14	6.8	31			<500	255
2001 B-05	1		1.2	13.5	85	1.5	0.4	25	9.1	14	5.9	31			<500	257
2001 B-06	1		0.7	16.4	82.4	1.2	0.4	26	9.2	13	5.7	33			<500	241
2001 B-07	1		1.8	17.3	81.4	1.3	0.4	27	10	16	6.5	35			<500	273
2001 B-08	1		1.7	20.7	76.9	2.4	0.5	32	11	17	6.7	36			<500	295
2001 B-09	1		0.8	20.2	76.3	3.5	0.5	37	12	17	7.6	40			<500	284
2001 B-10	1		1.4	13.4	84.8	1.8	0.5	25	9.2	13	6.3	32			<500	248
2001 B-11	1		2.3	16.4	82.6	1	0.5	27	10	13	6.5	33			<500	248
2001 B-12	1		1	14.4	83.6	2	0.5	25	9.2	13	6	33			<500	243
2014 A 1-4 [b]	1	30	0.64	27.4	71	1.6	0.043	49	11.4	39	5.9	42	4.7	0.047	<500	410
2014 A-4-8 [b]	1	30	0.68	28.9	69.5	1.6	0.044	55	12.1	41	6	43	4.5	0.039	700	370
2014 A-9-10 [b]	1	30	0.62	25.2	72.3	2.5	0.041	48	11.3	38	5.6	40	4.1	0.038	600	360
2014 B-1-4 [b]	1	30	0.46	17	82	1	0.026	26	8.2	20	4.1	27	2.1	0.012	<500	230
2014 B-4-8 [b]	1	30	0.59	18.7	80	1.4	0.028	25	8.1	20	4.1	27	2.1	0.015	<500	230
2014 B-9-10 [b]	1	30	0.42	15.1	83.9	1.1	0.02	21	7.4	16.5	3.8	25	2	0.012	<500	210
Marina [b]	1	30	NA	64.6	33.1	2.4	0.075	62	66	47	15.5	88	6.1	0.23	NA	NA
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. [b] composite samples. [c] 2001 results from Robertson et al. 2002.
[d] 2001-2011 TOC values estimated from AFDW as follows: 1g AFDW as equivalent to 0.2 g TOC (± 100%) based on a preliminary analysis of NZ estuary data.

APPENDIX 2. 2014 DETAILED RESULTS (CONTINUED)

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

Havelock Estuary Sites A and B, 28 March 2014

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	*Edwardsia* sp. 1	2		3			1		1			1		1		1	1	1				
NEMERTEA	Nemertea sp. 1	3			1	1							1			1						
	Nemertea sp. 3	3	1								1					1	1	1				1
POLYCHAETA	*Aonides* sp. 1	1							1													
	Boccardia syrtis	2			1						1											
	Disconatis accolus	1	1	1						1										1		1
	Goniadidae	2		1																		
	Heteromastus filiformis	3	3	3	7	1	6		1	1	4											
	Macroclymenella stewartensis	2	2	1	1		2		1	1	1	1	2	2	1	1	3		1	2	1	1
	Nereidae	3		2			2		1	1			1								1	2
	Nicon aestuariensis	3			1									1								
	Orbinia papillosa	1													2	2		2		1	1	1
	Paraonidae sp. 1	3	8	3	1	1	7	3	4	3	3	1				1	2					
	Pectinaria australis	3	1					1					4		1		2				1	
	Perinereis vallata	2										1										
	Prionospio aucklandica	2			1	1			1		1											
	Scolecolepides benhami	4													1	1						
	Scoloplos cylindrifer	1	4	3	2			2	2	3					1		2	1				
OLIGOCHAETA	Oligochaeta	3		2	13	2	1	12	8	1		1				1						
GASTROPODA	*Cominella glandiformis*	3		2																		
	Haminoea zelandiae	1			2																	
	Notoacmaea helmsi	2		2		5		1		1	1					1			1	2	9	
	Zeacumantus lutulentus	1												1								
BIVALVIA	*Arthritica bifurca*	4			2												1					
	Austrovenus stutchburyi	2	8	15	5	1	4	3	9	4	3	5	0	6	10	4	4	8	5	2	8	5
	Macomona liliana	2			1	2	2	1						1				2				
	Paphies australis	2		1														1				
CRUSTACEA	*Austrohelice crassa*	5																		1		
	Decapoda larvae unid.	NA																			1	
	Halicarcinus whitei	3			1	2		2			1			1	1		1	1			1	
	Phoxocephalidae sp. 1	2															1	1	1	1		1
	Tenagomysis sp. 1	2		1																		
Total individuals in sample			28	40	39	16	25	25	29	16	16	10	8	13	17	14	18	18	8	10	23	12
Total species in sample			8	14	14	9	8	8	10	9	9	6	5	7	7	10	10	9	4	7	8	7

Epifauna and macroalgal cover (0.25m² quadrats, Havelock Estuary Sites A and B, 2014).

Group	Family	Species	Common name	Scale	Class	A	B
Topshells	Amphibolidae	*Amphibola crenata*	Mudflat snail	#	ii	A	A
	Buccinidae	*Cominella glandiformis*	Mudflat whelk	#	ii	O	-
	Haminoeidae	*Haminoea zelandiae*	White bubble shell	#	ii	O	-
	Batillariidae	*Zeacumantus lutulentus*	Spire shell	#	ii	O	-
Limpets	Lottiidae	*Notoacmaea helmsi*	Estuarine limpet	#	i	F	F
Red algae	Gracilariaceae	*Gracilaria sp. ?secundata*	Gracilaria weed	%	ii	R	R

APPENDIX 2. 2014 DETAILED RESULTS (CONTINUED)

Non-normalised semi volatile organic compounds (SVOCs), Havelock Estuary, 28 March 2014. Note: results are for a single composite sample for each site, with no analysed compound present at detectable levels (all reported as mg/kg d.w.).

GROUP	Organic Chemical	Havelock Township	Havelock A	Havelock B
Polycyclic Aromatic Hydrocarbons Screening in Soil	*Acenaphthene*	< 0.05	< 0.03	< 0.04
	Acenaphthylene	< 0.05	< 0.03	< 0.04
	Anthracene	< 0.05	< 0.03	< 0.04
	Benzo[a]anthracene	< 0.05	< 0.03	< 0.04
	Benzo[a]pyrene (BAP)	< 0.05	< 0.03	< 0.04
	Benzo[b]fluoranthene + Benzo[j]fluoranthene	< 0.05	< 0.03	< 0.04
	Benzo[g,h,i]perylene	< 0.05	< 0.03	< 0.04
	Benzo[k]fluoranthene	< 0.05	< 0.03	< 0.04
	Chrysene	< 0.05	< 0.03	< 0.04
	Dibenzo[a,h]anthracene	< 0.05	< 0.03	< 0.04
	Fluoranthene	< 0.05	< 0.03	< 0.04
	Fluorene	< 0.05	< 0.03	< 0.04
	Indeno(1,2,3-c,d)pyrene	< 0.05	< 0.03	< 0.04
	Naphthalene	< 0.3	< 0.15	< 0.16
	Phenanthrene	< 0.05	< 0.03	< 0.04
	Pyrene	< 0.05	< 0.03	< 0.04
Polychlorinated Biphenyls Screening in Soil	*PCB-18*	< 0.010	< 0.010	< 0.010
	PCB-28	< 0.010	< 0.010	< 0.010
	PCB-31	< 0.010	< 0.010	< 0.010
	PCB-44	< 0.010	< 0.010	< 0.010
	PCB-49	< 0.010	< 0.010	< 0.010
	PCB-52	< 0.010	< 0.010	< 0.010
	PCB-60	< 0.010	< 0.010	< 0.010
	PCB-77	< 0.010	< 0.010	< 0.010
	PCB-81	< 0.010	< 0.010	< 0.010
	PCB-86	< 0.010	< 0.010	< 0.010
	PCB-101	< 0.010	< 0.010	< 0.010
	PCB-105	< 0.010	< 0.010	< 0.010
	PCB-110	< 0.010	< 0.010	< 0.010
	PCB-114	< 0.010	< 0.010	< 0.010
	PCB-118	< 0.010	< 0.010	< 0.010
	PCB-121	< 0.010	< 0.010	< 0.010
	PCB-123	< 0.010	< 0.010	< 0.010
	PCB-126	< 0.010	< 0.010	< 0.010
	PCB-128	< 0.010	< 0.010	< 0.010
	PCB-138	< 0.010	< 0.010	< 0.010
	PCB-141	< 0.010	< 0.010	< 0.010
	PCB-149	< 0.010	< 0.010	< 0.010
	PCB-151	< 0.010	< 0.010	< 0.010
	PCB-153	< 0.010	< 0.010	< 0.010
	PCB-156	< 0.010	< 0.010	< 0.010
	PCB-157	< 0.010	< 0.010	< 0.010
	PCB-159	< 0.010	< 0.010	< 0.010
	PCB-167	< 0.010	< 0.010	< 0.010
	PCB-169	< 0.010	< 0.010	< 0.010
	PCB-170	< 0.010	< 0.010	< 0.010
	PCB-180	< 0.010	< 0.010	< 0.010
	PCB-189	< 0.010	< 0.010	< 0.010
	PCB-194	< 0.010	< 0.010	< 0.010
	PCB-206	< 0.010	< 0.010	< 0.010
	PCB-209	< 0.010	< 0.010	< 0.010
Tributyl Tin Trace in Soil samples by GCMS	*Dibutyltin (as Sn)*	0.011	< 0.005	< 0.005
	Monobutyltin (as Sn)	< 0.007	< 0.007	< 0.007
	Tributyltin (as Sn)	0.028	< 0.004	< 0.004
	Triphenyltin (as Sn)	< 0.003	< 0.003	< 0.003

APPENDIX 3. INFAUNA CHARACTERISTICS

	Group and Species	WEBI Group *	Details
Anthozoa	*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	Ampharetidae	1	Ampharetidae are a family of terebellid "bristle worm". Some inhabit brackish or freshwater. Most are smallish deposit feeders which frequently live in small tubes they build from mud or similar substrate, or burrow in the sand.
	Aonides sp.#1	1	Small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. *Aonides* is free-living, not very mobile and strongly prefers to live in fine sands; also very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds.
	Boccardia 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.
	Boccardia syrtis	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Some species very sensitive to organic enrichment and usually present under unenriched conditions.
	Capitella capitata	4	A blood red capitellid polychaete which is very pollution tolerant. Common in suphide rich anoxic sediments.
	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.
	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.
	Lumbrineris sp.	2	Muscular, elongate, cylindrical worms with reduced parapodia, and belonging to the Lumrineriidae Family of polychaetes.
	Macroclymenella stewartensis	2	A sub-surface, deposit-feeder that is usually found in tubes of fine sand or mud. This species is found throughout the sediment to depths of 15cm and potentially has a key role in the reworking and turn-over of sediment. This worm may modify the sediment conditions, making it more suitable for other species (Thrush et al. 1988). Common at low water in estuaries. Intolerant of anoxic conditions.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

	Group and Species	WEBI Group *	Details
Polychaete	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.
	Paraonidae sp.#1	3	Slender burrowing worms, 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 to a depth of 15cm. 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 sandy, muddy 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. They are common intertidally and in shallow waters.
	Polydora sp.#1	3	A spionid, relatively uncommon.
	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).
	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.
	Spionidae sp.#1	3	A spionid. Small burrowers or surface tube-dwellers or crevice- and algal turf-dwellers, or shell-borers with one pair of deciduous feeding palps, and multiple pairs of segmental gills. Spionids occur across the shore from the upper intertidal, and also subtidally to the deep sea. Spionids are very common polychaetes in all sandy substrata, and rather infrequent on rocky shores. Spionids selectively deposit-feed on the substratum surface by exploring it with a pair of feeding palps, which in this family are long ciliated filaments, usually with a ciliated groove for transporting particles to the mouth. *Prionospio aucklandica* is common at low water mark in harbours and estuaries. *Microspio maori* is occasionally abundant in the intertidal of harbours and sheltered shores. *Scolelepis* spp. populations tend to occur in small localised dense patches on medium-grained open beaches. *Scolecolepides benhami* is rarely absent in sandy mud estuaries.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group	Species	WEBI Group *	Details
Oligochaeta	Oligochaeta	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. tubificid worms) although there are some less tolerant species.
Gastropoda	*Amphibola crenata*	3	A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria. They are useful as an indicator species being sensitive to heavy metal pollution. The mudflat snail breathes air and survives underwater between tides by taking in a bubble of air before closing its operculum. They are most active when the tide is out. At high tide the snails lie buried and motionless in the sediments to avoid being eaten by fish. Mudflat snails reach maturity at 2 years and can live for 12 or more years. These snails are effective "gardeners", sifting and ploughing twice their own body weight of sediment hourly (approx 58kg annually per snail!). A characteristic long, thin meandering faecal string is left behind once the nutrients have been extracted from the organic matter in the mud.
	Cominella glandiformis	3	Cominella glandiformis, or the mud whelk or mud-flat whelk is a species of predatory sea snail, a marine gastropod mollusc in the family Buccinidae, the true whelks. Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds. Strong Sand Preference.
	Haminoea zelandiae	1	The white bubble shell, is a species of medium-sized sea snail or bubble snail, a marine opistho-branch 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. Mud Tolerance; prefers 0-20% mud.
	Notoacmea helmsi	2	Endemic to NZ, a small grazing limpet attached to stones and shells in intertidal zone. Intoler-ant of anoxic surface muds and sensitive to pollution.
	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.
Bivalvia	*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 estuar-ies, 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	*Macomona 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.
	Mytilis galloprovinciallis	NA	Mytilus galloprovincialis (blue mussel) is an invasive species and is now common throughout NZ. It is dark blue or brown to almost black. Common in estuaries, often on rocks but also can be found on sands. It is known that *M. galloprovincialis* is able to outcompete and displace native mussels and become the dominant mussel species in certain localities. This is because it may grow faster than native mussels, be more tolerant to air exposure and have a reproductive output of between 20% and 200% greater than that of indigenous species. Prefers sandy environments with substrate for attachment.
	Paphies australis	2	The pipi is endemic to New Zealand. 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. Populations of *Austrovenus stutchburyi* and *Paphies australis* inhabiting river deltas near the outflow of the power station in inner Doubtful Sound were more than an order of magnitude smaller in abundance than populations in neighbouring Bradshaw Sound where the salinity regime is unaltered. In addition, there was a lack of small size classes of both species in inner Doubtful Sound, suggesting that these populations are unsustainable over the long term (10–20 years). Laboratory experiments demonstrated that sustained exposure (>30 days) to low salinity (<10) significantly decreased bivalve survivorship; however, both species survived periods of exposure to freshwater up to at least 20 days in duration if followed by a period of return to normal seawater salinity. Examination of the extant salinity regime in light of these results indicates the current salinity environment in Doubtful Sound restricts bivalves to deeper waters (5–6 m depth). The observed discrepancy in the total biomass of these active suspension feeders between altered and control sites has potential implications for the flux of organic matter in the food webs of Fiordland's shallow soft sediment communities (McLeod and Wing 2008).
Crustacea	*Amphipoda* sp. 1	2	An unidentified amphipod species.
	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.
	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 cookii	3	Pillbox crab. NZ hymenosomatids are generally sub-littoral, although *H. cookii, H. varius, H. pubescens* and *H. innominatus* can inhabit shores as high as the lower mid-littoral zone depending on algal cover. *H. cookii* is endemic to New Zealand. It is an opportunistic carnivore and scavenger, with a diet consisting of molluscs, polychaetes and especially amphipods.
	Halicarcinus whitei	3	Another species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Helice 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.
	Macrophthalmus 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.

APPENDIX 3. INFAUNA CHARACTERISTICS (CONTINUED)

Group and Species		WEBI Group *	Details
Crustacea	*Natantia* sp.	2	True shrimps are small, swimming, decapod crustaceans usually classified in the suborder Natantia, found widely around the world in both fresh and salt water.
	Ostracoda	1	Ostracoda is a class of the Crustacea, sometimes known as the seed shrimp because of their appearance. They are typically around 1 millimetre. The body of an ostracod is encased by two valves, superficially resembling the shell of a clam.
	Phoxocephalidae	2	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Tenagomysis sp.#1	2	*Tenagomysis* is a genus of mysid shrimps in the family Mysidae. At least nine of the fifteen species known are from New Zealand.

* 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 macroalgal 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).

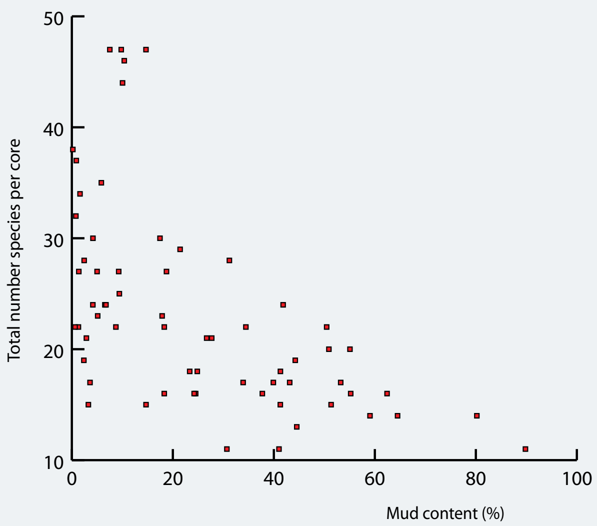


Figure 1. Sediment mud content and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).

1. SEDIMENT PERCENT MUD CONTENT (CONTINUED)

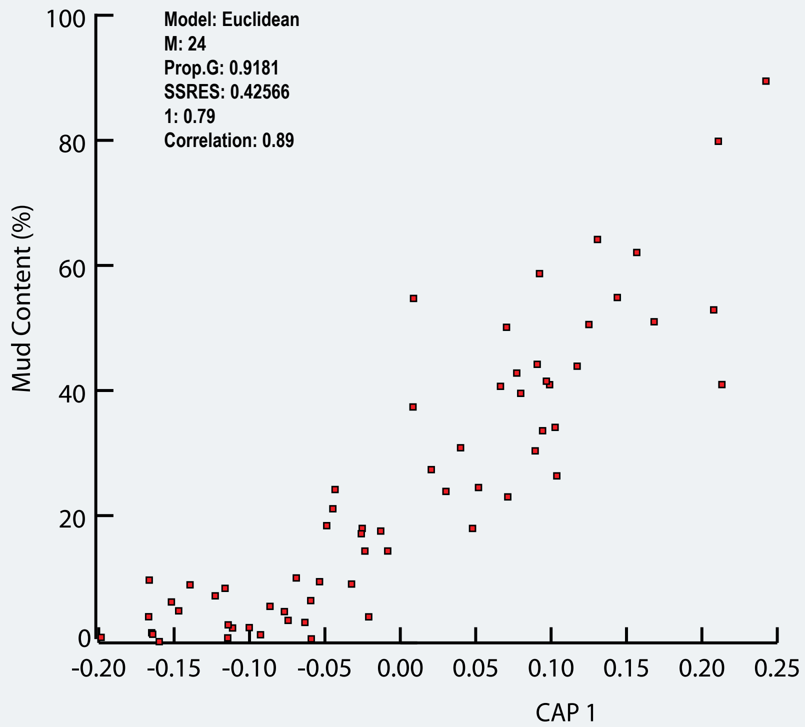


Figure. 2. Canonical analysis of the principal coordinates (CAP) for the effect of sediment mud content (exclusively) on the macroinvertebrate assemblages from 25 typical NZ estuaries (i.e. CAP1) among sites. Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total 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)

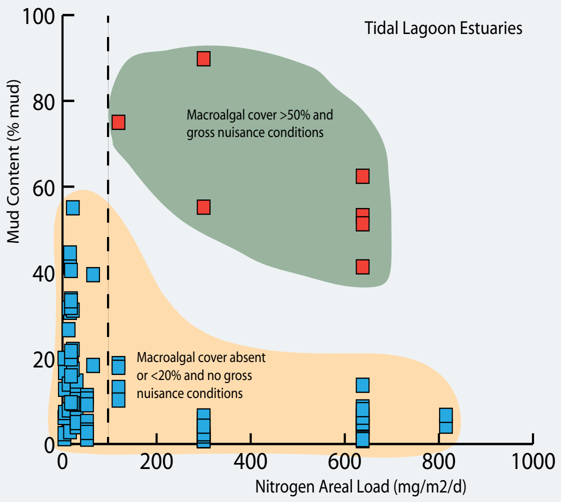


Figure 3. Mud content of sediment and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 15 typical NZ tidal lagoon estuaries (shallow, residence time <3d, >50% of estuary intertidal) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013, Robertson et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

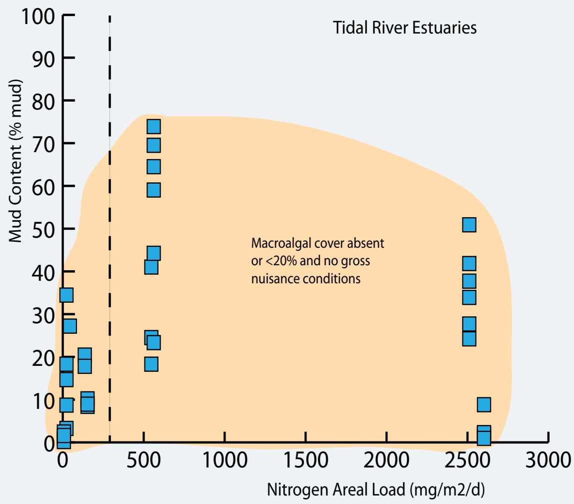


Figure 4. Mud content of sediment and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 5 typical NZ tidal river estuaries (data sourced from Wriggle Coastal Management monitoring reports 2006-2013).

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.

References

Houwing, E.J. 2000. Sediment dynamics in the pioneer zone in the land reclamation area of the Wadden Sea, Groningen, The Netherlands. PhD thesis, University of Utrecht, Utrecht.

Robertson, B.M. Gillespie, P.A. Asher, R.A. Frisk, S. Keeley, N.B. Hopkins, G.A. Thompson S.J. and Tuckey, B.J. 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

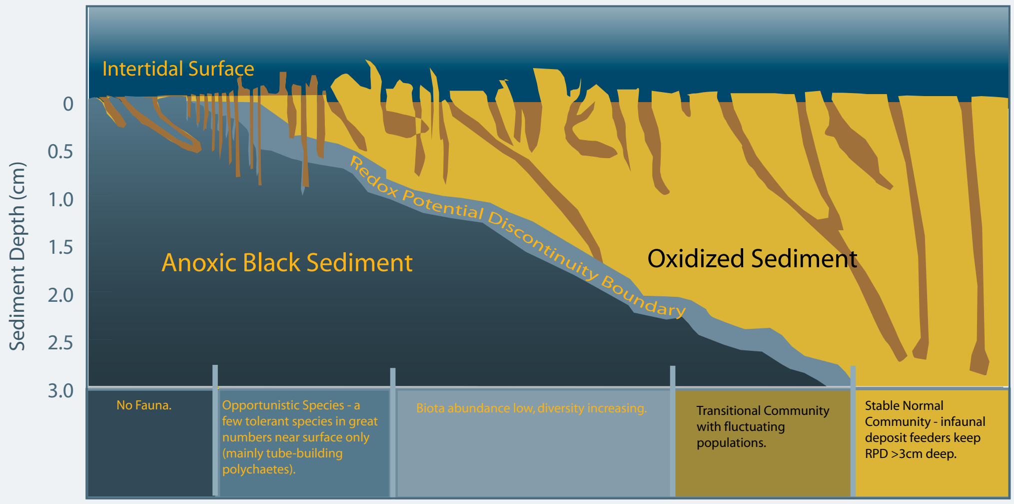
Robertson, B.P. 2013. Determining the sensitivity of macroinvertebrates to fine sediments in representative New Zealand estuaries. Honours dissertation, Victoria University of Wellington - Note: In preparation for journal publication.

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.

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

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).

References

Birchenough S., Parker N., McManus E. and Barry J. 2012. Combining bioturbation and redox metrics: potential tools for assessing seabed function. Ecological Indicators 12:8–16.

Diaz R.J. and Trefry J.H. 2006. Comparison of sediment profile image data with profiles of oxygen and Eh from sediment cores J. Mar Syst 62: 164-172.

Gerwing T. G., Gerwing A.M., Drolet D., Hamilton D.J. and Barbeau M.A. 2013. Two methods of measuring the depth of potential discontinuity in intertidal mudflat sediments. Marine Ecology Progress Series, 487: 7-13.

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

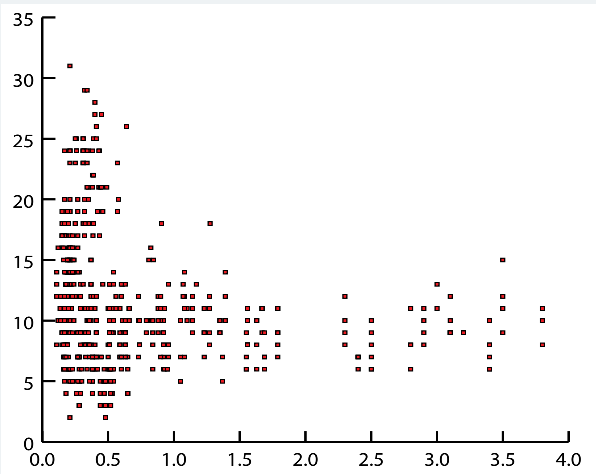


Figure 1. Sediment TOC concentrations and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).

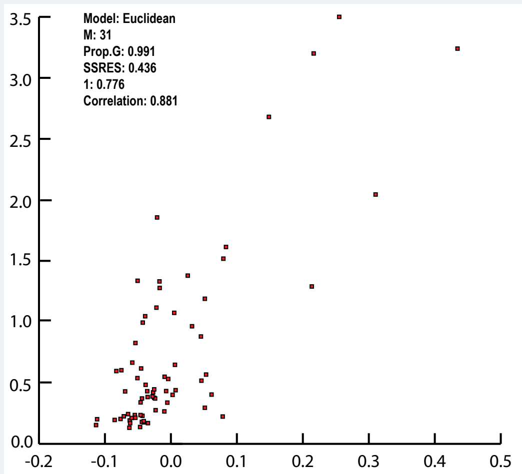


Figure 2. Canonical analysis of the principal coordinates (CAP) for the effect of total organic carbon content, on the macroinvertebrate assemblages from 12 typical NZ estuaries (i.e. CAP1) among sites.

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).

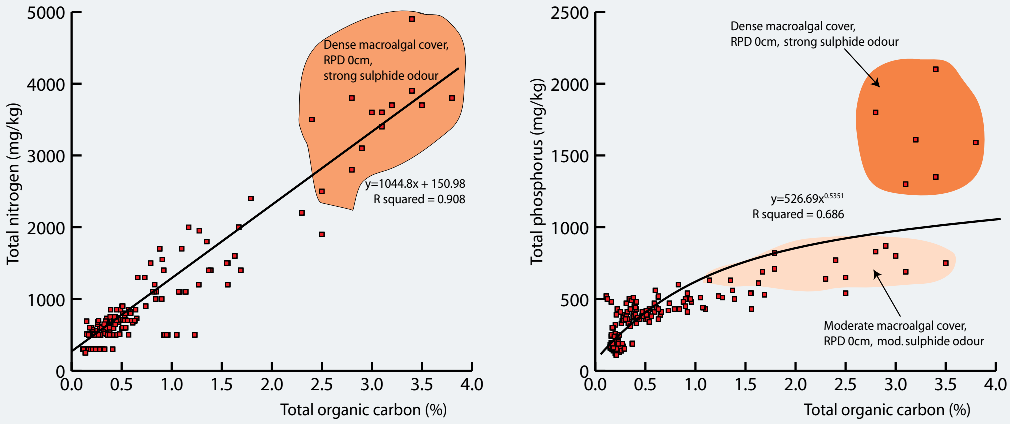


Figure 2. Sediment TOC and TN, and sediment TOC and TP concentrations from 12 estuaries scattered throughout NZ, and representing most NZ estuary types (Wriggle Coastal Management database 2009-2013).

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

Hyland, J.L., Balthis, L., Karakassis, I., Magni, P., Petrov, A.N., Shine, J.P., Vestergaard, O. and Warwick, R.M. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Mar Ecol. Prog. Ser., 295, 91-103.

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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).

APPENDIX 4. ESTUARY CONDITION RISK RATINGS (CONTINUED)

5. MACROINVERTEBRATE COMMUNITY (CONTINUED)

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 - the "Wriggle Estuary Benthic Index" (WEBI) for available NZ data.

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 datasets (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)

5. MACROINVERTEBRATE COMMUNITY (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.

Estuary Condition Risk Indicator Rating: WEBI Mud and Organic Enrichment

Risk Rating	Very Low	Low	Moderate	High	Very High
Macroinvertebrate Enrichment Index (WEBI)	0-1.2 Intolerant of enriched conditions	>1.2-3.3 Tolerant of slight enrichment	>3.3-5.0 Tolerant of moderate enrichment	>5.0-6.0 Tolerant of high enrichment	>6.0 Azoic (devoid of invertebrate 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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