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coastalmanagement

Waikouaiti Estuary

Fine Scale Monitoring 2016/17

Prepared
for

**Otago
Regional
Council**

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Cover Photo: Waikouaiti Estuary middle reaches


Waikouaiti Estuary blooms of green macroalgae in middle reaches near channel

Waikouaiti Estuary

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Prepared for
Otago Regional Council

by

Barry Robertson, Ben Robertson and Leigh Stevens

Wriggle Limited, PO Box 1622, Nelson 7040, Ph 03 540 3060, 0275 417 935; 03 545 6315, 021 417 936, www.wriggle.co.nz

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WAIKOUAITI ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the first year of fine scale baseline monitoring (2016) of three benthic intertidal sites and three water column sites within Waikouaiti Estuary, a shallow, intertidal dominated (SIDE) estuary on the Otago coast. It is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. The following table summarises the fine scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring recommendations.

FINE SCALE BENTHIC MONITORING RESULTS

Benthic Intertidal Results

- Very dense growths of primarily green macroalgae were present at lower estuary Site A, moderate growth at mid estuary Site B and low growth at upper estuary Site C. Seagrass cover was absent at all sites. Note: in 2013, Site C had an extensive cover of high biomass sediment-entrained red macroalgae that was not present in 2016.
- Sediment mud content was low-moderate (8-12% mud) at the lower-mid estuary Sites A and B, but high at the upper Site C (31% mud).
- Sediment oxygenation was good-moderate at Sites A and B but poor at Site C (redox potential < -150mV below 0.5cm depth).
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations.
- The estuary macroinvertebrate community index (NZ HybAMBI) indicated an unbalanced community affected by high mud concentrations and poor oxygenation at Site C, but relatively balanced communities at Sites A and B.

Water Column Results

- The salinity results for the surface and bottom waters of the three sites did not detect any poorly flushed stratified areas containing isolated bottom water where nutrient concentrations can build-up.
- Total nitrogen concentrations in the water column were less than the accepted threshold level for the appearance of eutrophication symptoms in shallow estuaries.
- Chlorophyll *a* concentrations, the primary indicator of water column eutrophication, were all less than the NZ ETI eutrophication threshold level.
- Dissolved oxygen concentrations, the main supporting indicator of water column eutrophication, did not breach the threshold for eutrophic conditions.

BENTHIC RISK INDICATOR RATINGS

(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

🟦	Low	🟨	Moderate
⬜	Very Low	🟧	High

Waikouaiti Estuary	Site Wati A (lower)				Site Wati B (mid)				Site Wati B (upper)			
	2016	Yr 2	Yr 3	Yr 4	2016	Yr 2	Yr 3	Yr 4	2016	Yr 2	Yr 3	Yr 4
Sediment Mud Content	🟦				🟦				🟧			
Redox Potential (Oxygenation)	🟦				🟦				🟧			
TOC (Total Organic Carbon)	⬜				⬜				⬜			
Total Nitrogen	🟦				🟦				🟦			
Invertebrate Mud/Org Enrichment	🟦				🟦				🟧			
Metals (Cd, Cu, Cr, Hg, Ni, Pb, Zn As)	⬜				⬜				⬜			

ESTUARY CONDITION AND ISSUES

Benthic Habitat

The fine scale monitoring of representative upper estuary intertidal sediments showed the presence of muddy, poorly oxygenated sediments with an 'impoverished' type macroinvertebrate community, and in some years excessive growths of opportunistic, highly entrained, red macroalgae.

Waikouaiti Estuary - Executive Summary (continued)

In the mid-lower estuary, the sediments were sandier, with improved oxygenation and a balanced macroinvertebrate community, despite persistent and abundant growths of opportunistic green macroalgae particularly in the mid estuary.

Water Column Habitat

There was no evidence of stratification within the estuary on 8 December 2016, and total nitrogen and chlorophyll *a* were both less than the eutrophication threshold level. Such findings indicate a low susceptibility to water column phytoplankton blooms in the Waikouaiti Estuary at the time of sampling. However, given only one comprehensive sampling event and the possibility of stratification occurring later in the growing season, there is a possibility that stratified bottom water eutrophication could occur in parts of the estuary later in summer (e.g. upper estuary channel or in the main estuary channel if the flow at the estuary mouth is becomes constricted).

Overall, the findings indicate that muddiness, upper estuary red macroalgal blooms, main channel green macroalgal blooms and potentially upper estuary bottom-water phytoplankton blooms are issues that require further attention.

RECOMMENDED MONITORING

Waikouaiti Estuary has been identified by ORC as a priority for monitoring because it is a moderate-large estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2016). To complete the fine scale baseline in Waikouaiti Estuary, it is recommended that 3 consecutive years of annual summer (i.e. Dec-Feb) fine scale monitoring of intertidal sites (including sedimentation rate measures), and water column monitoring, be undertaken in 2017, 2018 and 2019.

Estuary mouth

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. The Otago Regional Council's "Regional Policy Statement and Regional Plan: Water" demonstrates the Council's determination to maintain estuaries in good condition. In the period 2005-2008 Otago Regional Council (ORC) undertook preliminary (one-off) monitoring of the condition of seven Otago estuaries in its region. In 2016, ORC began a more comprehensive long-term estuary monitoring programme designed to particularly address the key NZ estuary issues of eutrophication and sedimentation within their estuaries, as well as identifying any toxicity and habitat change issues. The estuaries currently included in the programme are; Shag Estuary, Waikouaiti Estuary and Catlins Estuary.

Monitoring of the Waikouaiti Estuary began with preliminary broad and fine scale monitoring undertaken in November 2006 and the first year of comprehensive baseline monitoring undertaken in December 2016.

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

1. **Ecological Vulnerability Assessment (EVA**) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has not yet been undertaken on a regional scale for Otago and hence relative vulnerabilities of their estuaries to the key issues have not been formally identified.
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Broad scale intertidal mapping of Waikouaiti Estuary was first undertaken in November 2006 (Stewart 2007) and was repeated in December 2016 (Stevens and Robertson 2017).
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 Waikouaiti Estuary, was undertaken in a partial form in November 2006 (Stewart 2007), with the first year of baseline monitoring undertaken on 8 December 2016. This latter monitoring is the subject of this report.

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of risk indicator ratings are presented and described in Section 2. The current report describes the 2016 fine scale results and compares them to the previous findings.

Waikouaiti Estuary

Waikouaiti Estuary is a 229ha shallow, intertidal dominated (SIDE) estuary (Figure 1) that discharges via one permanent open (but restricted) tidal mouth to the Pacific Ocean via a broad embayment at Karitane, Otago. Near the sea, a large barrier spit to the north, and the township of Karitane to the south, borders the estuary. Further inland it is bordered by farmland, some of which is intensive dairying. Situated at the mouth of the Waikouaiti River (mean flow ~3.5m^3.s^{-1}), the estuary drains a 421km^2, agricultural dominated catchment with high producing exotic pastures that support primarily sheep and beef farming occupying 74% of catchment. Some dairy production (total of 750 milking cows) is occurring in the lower catchment bordering the estuary and is aided by irrigation from the main stem of the river (main dairy farm is 513ha, other on Church Rd is 17.8ha). Because the estuary is fed by a relatively small river, the main channel of the upper-mid estuary is poorly flushed during baseflows. As a consequence, this section can become stratified with a surface layer of lighter, low salinity freshwater flowing over a layer of dense saline water at times.

Ecologically, habitat diversity is moderate to high with extensive shellfish beds, large areas of saltmarsh (35% of estuary), unvegetated tidal flats and some seagrass (<1% of estuary). However, the estuary is excessively muddy (22% soft mud), eutrophic in some areas, and the natural vegetated margin has been lost and developed for urban use and grazing. Also, since approximately the 1940's there has been a loss of extensive areas of saltmarsh through drainage and reclamation.

The Waikouaiti Estuary is a high use estuary that is valued for its cultural, spiritual, scientific and aesthetic appeal, its rich biodiversity, shellfish collection, bathing, whitebaiting, fishing, boating, surfing, and walking. The estuary includes a small wharf and moorings for fishing boats. In the "Otago Regional Plan: Water", the Waikouaiti Estuary is listed as a coastal protection area with Kai Tahu cultural and spiritual values. It is also important for coastal birds such as the eastern bar-tailed godwit and oystercatchers.

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

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 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/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll *a* concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

2. ESTUARY RISK INDICATOR RATINGS

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

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

- The importance of considering other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ and overseas data and presented in the NZ Estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    - * Statistical measures be used to refine indicator ratings where information is lacking.
    - * Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    - * The outputs stimulate discussion regarding what the acceptable level of risk is, and managing it.
    - * The indicators and condition ratings used for the Waikouaiti monitoring programme are summarised in Table 2, with detailed background notes explaining the use and justifications for each indicator presented in the NZ ETI (Robertson et al. 2016a and 2016b). The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of NZ estuaries. Work to refine and document these relationships is ongoing.

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

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
INDICATOR	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
Apparent Redox Potential Discontinuity (aRPD)**	Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (mV) upper 3cm***	>+100	-50 to +100	-50 to -150	<-150
Sediment Mud Content (%mud)*	<5%	5-10%	>10-25%	>25%
Macroinvertebrate Enrichment Index (NZ AMBI) ****	0-1.0 None to minor stress on benthic fauna	>1.0-2.5 Minor to moderate stress on fauna	>2.5-4.0 Moderate to high stress on fauna	>4.0 Persistent, high stress on benthic fauna
Total Organic Carbon (TOC)*	<0.5%	0.5-<1%	1-<2%	>2%
Total Nitrogen (TN)*	<250mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg
Metals	<0.2 x ISQG Low	0.2 - 0.5 x ISQG Low	0.5 x to ISQG Low	>ISQG Low

* NZ ETI (Robertson et al. 2016b), ** and *** Hargrave et al. (2008), ***Robertson (in prep.), Keeley et al. (2012), **** Robertson et al. (2016).

3. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002), and subsequent extensions (e.g. Robertson et al. 2016b) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). In addition, because some SIDE estuaries also include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted), synoptic water quality samples from surface and bottom waters, and subtidal sediment are commonly collected to support intertidal assessments.

Using the outputs of the broad scale habitat mapping, representative intertidal sampling sites (usually two per estuary, but varies with estuary size) are selected and samples collected and analysed for the following variables.

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

For the Waikouaiti Estuary, three fine scale sampling sites each 30m x 15m (Figure 1) were selected in unvegetated, mid-low water habitat. Sites A and B were located in the dominant habitat of the main channel in similar locations to those used in the preliminary monitoring undertaken in 2006. Site C was selected as a new site to ensure adequate representation of the main estuary deposition zone.

Each site was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and sampling undertaken as described in the following sections:

Physical and chemical analyses

- At each site, average apparent Redox Potential Discontinuity (aRPD) depth was recorded within three representative plots, and in one plot, redox potential (RP mV) was directly measured with an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10cm depths below the surface.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core for chemical analysis. All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

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

From each of 10 plots, 1 randomly placed sediment core (130mm diameter (area = 0.0133m^2) tube) was taken.

- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled 0.5mm nylon mesh bag. Once all replicates had been collected at a site, the bags were transported to a nearby source of seawater and fine sediments were washed from the core. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.

3. Methods (continued)

Figure 1. Location of water quality (orange) and fine scale monitoring (yellow) sites in Waikouaiti Estuary.

- The samples were sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).
- Where present, macroalgae and seagrass vegetation (including roots), was collected within each of three representative 0.0625m^2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured.
- Conspicuous epifauna visible on the sediment surface within the 15m x 30m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species are identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix 1), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Table B, Appendix 1). Species size determines both the quadrat size and SACFOR density rating applied, while photographs are taken and archived for future reference. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal and microalgal cover.

Water quality and subtidal sediment

Three representative sites were selected in deep main channel sections in the lower, mid and upper estuary where there was a potential for estuary water to become stratified (Sites X, Y and Z respectively, see Figure 1).

3. Methods (continued)

At each site at high tide, a YSI-Sonde (6000 series) hand held field meter was deployed from a kayak to directly measure and log depth, chlorophyll *a*, salinity, temperature, pH, and dissolved oxygen in upper and lower 0.5m of the water column. At the same locations water samples were also collected with a van dorn water sampler for laboratory nutrient analyses (total N, nitrate-N, ammonia-N, dissolved reactive P and total P concentrations).

In addition, at each site secchi disc clarity was measured and one benthic sediment sample was collected using either a remotely triggered van veen grab sampler or a custom built sediment sampling hoe with telescopic handle). Once at the surface the sediment aRPD depth was measured, and a subsample collected for subsequent chemical analysis for TOC, grain size, TN and TP.

- All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.

Collecting water samples

Sediment accumulation

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

Two sites, each with four plates (20cm square concrete paving stones) were established in December 2016 in Waikouaiti Estuary at fine scale Sites B and C (Figure 1), with Site C representing the main deposition zone and Site B the main estuary basin. Plates were buried deeply in the sediments where stable substrate was located and positioned 2m apart in a linear configuration along the baseline of each fine scale site. Steel reinforcing rod was also placed horizontally next to each buried plate to enable relocation with a metal detector.

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

4. RESULTS AND DISCUSSION

A summary of the results of the 10 December 2016 fine scale benthic and water quality monitoring of the Waikouaiti Estuary is presented in Tables 3 and 4, with detailed results in Appendices 2 and 3. Also included are the summary results of the preliminary fine scale sediment monitoring undertaken in 2006 (Stewart (2007).

Table 3. Mean fine scale sediment physical, chemical, plant growth (n=3) and macrofauna (n=10) results, Waikouaiti Estuary, November 2006 and 8 December 2016.

Year Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2016 A	3	34	0.50	11.9	74.6	13.5	0.0257	6.4	5.0	6.9	4.4	26.7	7.9	0.0125	700	487
2016 B	5	28	0.20	8.0	79.0	13.0	<0.010	3.9	3.4	4.5	2.8	18.0	4.0	<0.010	<500	683
2016 C	0	25	0.41	30.9	68.9	0.3	0.0487	5.3	3.3	3.9	3.5	22.0	4.1	0.011	633	463
2006 D/S	3	NA	NA	10.7	75.5	13.7	0.02	6.4	4.6	6.0	4.21	26.3	6.2	NA	700	466
2006 U/S	5	NA	NA	8.7	73.4	17.9	0.01	5.1	4.8	5.9	4.28	26.3	6.7	NA	600	417

Year Site	Seagrass Biomass and Cover	Macroalgal Biomass and Cover	Macrofauna Abundance	Macrofauna Richness
	$g.m^{-2}$ wet weight (%)	$g.m^{-2}$ wet weight (%)	Individuals/m^2	Species/core
2016 A	0 (0%)	2125 (90%)	2306	7
2016 B	0 (0%)	300 (30%)	1115	4
2016 C	0 (0%)	20 (<5%)	2577	4
2006 D/S	NA	NA	2675	7
2006 U/S	NA	NA	4875	8

NA = Not Assessed

Table 4. Summary of fine scale water quality results (surface water, bottom water and bottom sediment), Waikouaiti Estuary, December 2016.

Parameter	Units	Waikouaiti Lower Site X (surface)	Waikouaiti Lower Site X (bottom)	Waikouaiti Mid Site Y (surface)	Waikouaiti Mid Site Y (bottom)	Waikouaiti Upstream Site Z (surface)	Waikouaiti Upstream Site Z (bottom)
Depth	m	0.1	2.7	0.1	1.6	0.1	3.0
Temperature	degrees C	15.6	15.6	17.0	16.4	15.2	15.4
Salinity	ppt	34.2	34.2	24.7	26.8	0.25	1.1
Dissolved Oxygen	mg/l	8.8	8.8	8.30	8.38	7.59	8.14
pH		8.4	8.4	8.3	8.4	7.6	8.1
Chlorophyll *a*	mg/m^3	0.1	0.1	0.05	0.1	0.7	0.5
Total Nitrogen	g/m^3	<0.3	<0.3	<0.3	<0.3	0.3	0.2
Total Ammoniacal-N	g/m^3	<0.010	<0.010	0.031	0.029	0.025	0.017
Nitrate-N	g/m^3	0.002	< 0.002	0.002	0.007	0.024	0.027
Dissolved Reactive P	g/m^3	0.006	0.005	0.009	0.008	0.006	0.006
Total Phosphorus	g/m^3	0.01	0.013	0.025	0.013	0.009	0.008

Site	aRPD (cm)	TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TP (mg/kg)	TN (mg/kg)
Waikouaiti Bottom Sediment Site X	>10	<0.05	1.6	93.2	5.2	340	<500
Waikouaiti Bottom Sediment Site Y	1	0.39	6.9	50.7	42.4	450	<500
Waikouaiti Bottom Sediment Site Z	3	1.32	25.7	64	10.3	780	1300

4. Results and Discussion (continued)

Analysis and discussion of the 2016 results are presented as two main steps; firstly, the intertidal benthic habitat condition and secondly, the water column condition. The assessment is undertaken with a focus on the key SIDE estuary issues of muddiness (or sedimentation), eutrophication, and toxicity.

4.1 Benthic Habitat Condition

4.1.1 Muddiness (or Sedimentation)

The primary environmental variables that are most likely to be driving the ecological response in relation to estuary muddiness are sediment mud content (often the primary controlling factor) and sedimentation rate. Sediment mud content data are presented and assessed below, however, preliminary sedimentation rate data will not be available until December 2017.

Sediment Mud Content

Sediment mud content (i.e. % grain size <63µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island), unless naturally erosion-prone with few wetland filters (e.g. Whareama Estuary, Wairarapa). In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >25% mud) in the primary sediment settlement areas e.g. where salinity driven flocculation occurs, or in areas that experience low energy tidal currents and waves (i.e. upper estuary intertidal margins and deeper subtidal basins). Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

Results showed the Waikouaiti Estuary fine scale sites had a mix of sediment mud contents (5-32% mud) (Table 3, Figure 2) with muddier sediments in the estuary's main deposition zone (Site C in the Merton arm - mean 31% mud) and sandier sediments in the two main channel sites in the lower to mid estuary (mean 12% and 8% mud content for Sites A and B respectively).

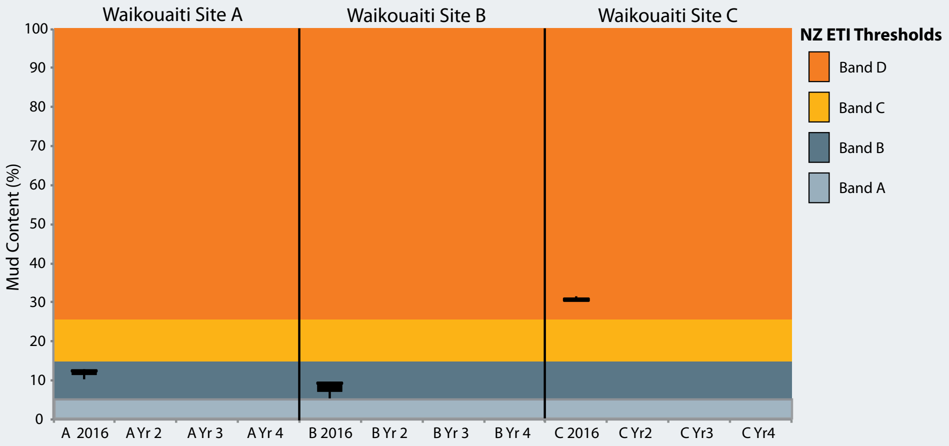


Figure 2. Mean mud content (median, interquartile range, total range, n=3), December 2016.

The low mud contents for Sites A and B fit the Band B rating, and indicates the following ecological conditions are likely (Robertson et al. 2016b): *a minor stress on sensitive organisms caused by the indicator.* The high mud content for Site C fits the Band D rating, and indicates the following ecological conditions are likely (Robertson et al. 2016b):

- *Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels and a likelihood of local extinctions of keystone species and loss of ecological integrity.*

4. Results and Discussion (continued)

Waikouaiti Estuary: Photographs taken December 2016

Upper estuary, above SH1 bridge

Mid-estuary main channel

Lower estuary intertidal flats near main channel

Waikouaiti Estuary Site A - dense sea lettuce (*Ulva intestinalis*) algal bloom on gravel sands

Waikouaiti Estuary Site B - sparse sea lettuce (*Ulva intestinalis*) on gravel sands

Waikouaiti Estuary Site C - soft muds

4.1.2 Eutrophication

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

Macroalgae and Seagrass

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

Results showed no seagrass was present at the fine scale sites, but there was a variable cover and biomass of opportunistic macroalgae, with very dense growths dominated by green macroalgae (*Ulva intestinalis*) at Site A (i.e. >90% cover and mean biomass of 2125gm^{-2} wet wgt.), moderate growth at Site B (30% cover and mean biomass of 300gm^{-2} wet wgt.), but low growth at Site C (<5% cover and mean biomass of 20gm^{-2} wet wgt.) (Figure 3). Despite the excessive cover at Sites A and B, macroalgae was not entrained in sediments and sediments were not anoxic (see RPD section on following page).

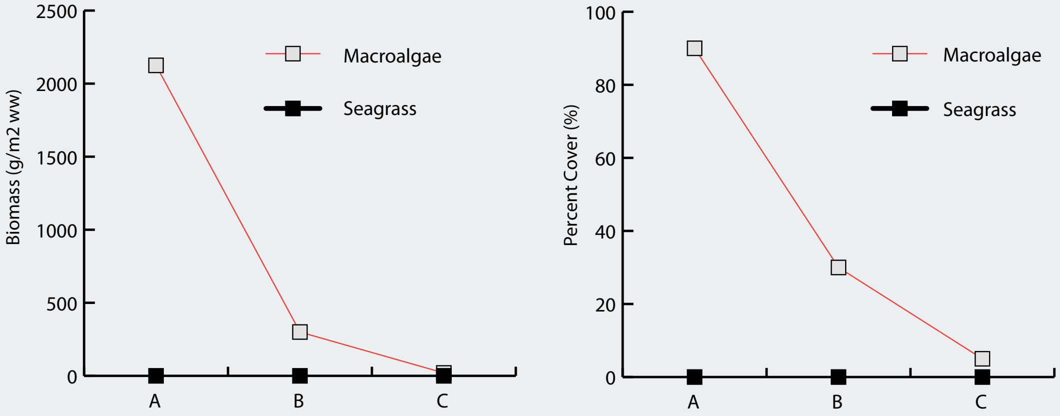
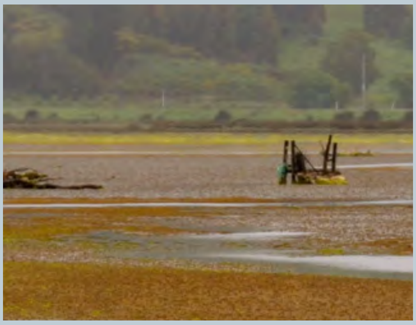


Figure 3. Biomass and percent cover of opportunistic macroalgae and seagrass, Waikouaiti Estuary, December 2016.

The estuary has previously shown excessive macroalgal growth. Data collected by the author from the same approximate locations in 2013 shows similar densities of *Ulva intestinalis* at Sites A and B (i.e. mean biomass of 2500 and 500gm^{-2} wet wgt. respectively). In addition, the estuary also experiences nuisance red algal blooms in some years. Site C in 2013 was covered by a dense bloom of the red opportunistic macroalgae *Gracilaria chilensis*, with a subdominant cover of *Ulva intestinalis* (>95% cover and mean biomass of 3500gm^{-2} wet wgt.), with "gross eutrophic zone" conditions present e.g. anoxic sediments, soft muds and high nuisance macroalgal cover.



High density macroalgal beds (*Gracilaria* and *Ulva* sp.) at Site C, Merton Arm, late November 2013

Very low macroalgal density at Site C, Merton Arm, Dec 2016

Sediment Mud Content

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, the low mud content at Sites A and B indicates potentially good sediment oxygenation, but the high mud content at Site C indicates a potential for relatively poor oxygenation.

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the extent of oxygenation within sediments. Currently, the condition rating for redox potential is under development (Robertson et al. 2016b) pending the results of a PhD study in which aRPD and redox potential (RP) measured with an ORP electrode and meter are being assessed for a gradient of eutrophication symptoms. Initial findings indicate that the recommended NZ estuary aRPD and RP thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Table 2 and Figure 3).

Figure 4 shows the aRPD depths from the surface, and redox potentials (5 depths at each site, mean of triplicate measures plotted) for the three Waikouaiti Estuary sampling sites for December 2016.

The results show that the aRPD depth was 3cm at Site A, 5cm at Site B and 0cm at Site C. The redox potential for the sites (Figure 4) identified good oxygenation conditions throughout most of the sediment profile at Site A (i.e. >-50mV up to ~7cm deep), at least half the sediment profile at Site B (i.e. >-50mV up to ~5cm deep), but poor oxygenation conditions at Site C (i.e. <-150mV within 1cm of the surface). These results indicate that conditions at Site A, and to a slightly lesser extent Site B, are sufficiently well oxygenated to support a range of sensitive taxa. However, the very low redox levels throughout the sediment profile at Site C (Band D) indicate sediment oxygenation is likely to support predominantly tolerant opportunistic species. Such findings are likely to be reflected as a change in the abundance of mud and organic enrichment sensitive taxa between sites (see Section 4.1.4).

Total Organic Carbon and Nutrients

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

Results for the three sites showed TOC (<0.5%) and TN (<700mg/kg) were in the “very low” or “low” risk indicator ratings, while TP (rating not yet developed) was relatively low at 463-683mg/kg (Figures 5, 6 and 7). Of particular note, is the fact that the most impacted site in terms of mud and redox potential (i.e. Site C), did not have elevated TOC, TN and TP concentrations. However, given that the survey was undertaken in a year in which macroalgal biomass was very low at the site (<50gm^{-2} wet wgt.), such low concentrations are not unexpected. If instead, the survey had been undertaken in December 2013, when macroalgal biomass at Site C was 3000-5000gm^{-2} wet wgt., nutrient and organic carbon concentrations would likely have been much greater (i.e. Band C or D based on data from other estuaries with a similar biomass).

Synoptic fine scale monitoring results collected from two sites in November 2006 (Stewart 2007) are presented alongside the current results in Table 3 and show 2006 results were similar to those from nearby Sites A and B in 2016, indicating those parts of the estuary are unlikely to have significantly changed over in the past decade. However, the 2006 synoptic survey has not been comprehensively assessed in the current report as it did not meet the requirements of a full baseline survey [e.g. involved one-off sampling outside of the recommended December-March summer period, used limited replication (a single composite chemistry sample and 3 macroinvertebrate replicates instead of the recommended 10), did not assess the high susceptibility upper estuary arm, and did not monitor for water column eutrophication].

4. Results and Discussion (continued)

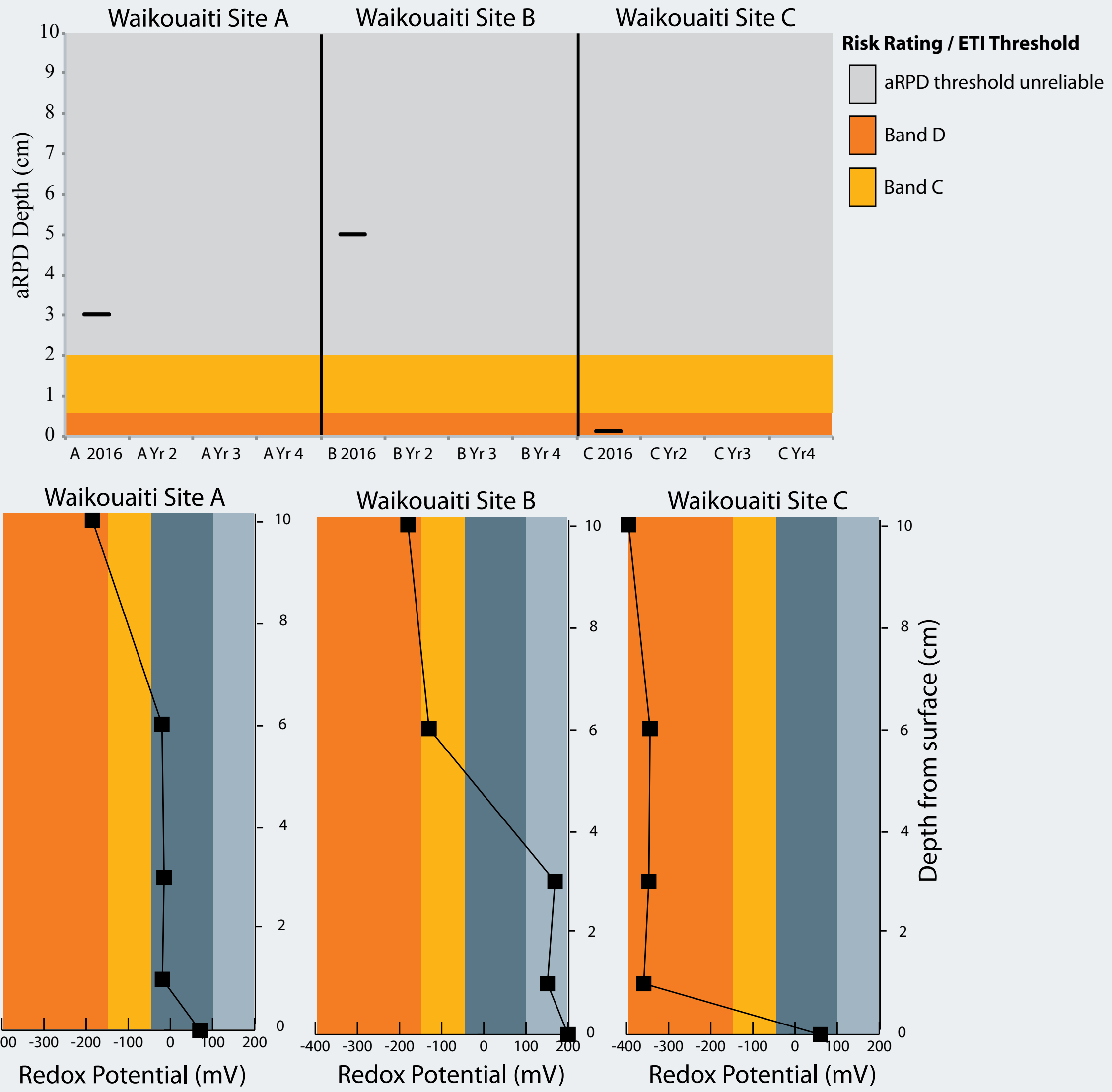


Figure 4. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3), and redox potential (mV) at 5 depths in December 2016.

Very soft muddy sediments at Site C, Merton arm, December 2016

Sandy sediments Site B, December 2016

4. Results and Discussion (continued)

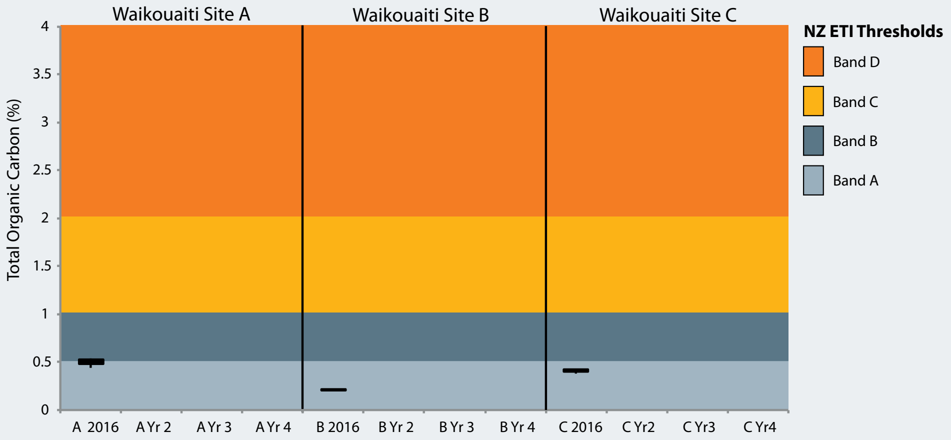


Figure 5. Mean total organic carbon (median, interquartile range, total range, n=3), December 2016.

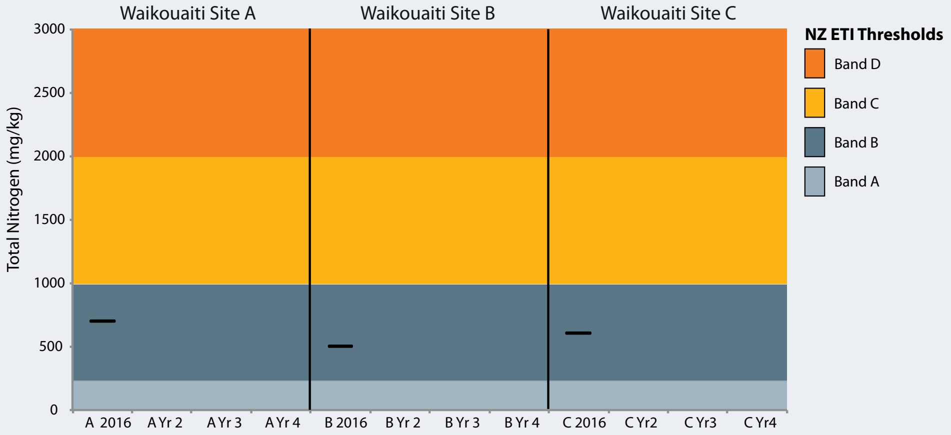


Figure 6. Mean total nitrogen (median, interquartile range, total range, n=3), December 2016.

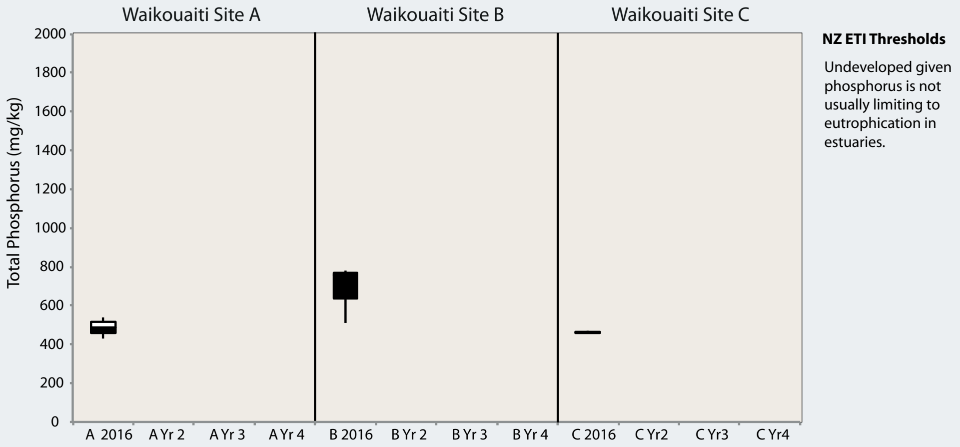


Figure 7. Mean total phosphorus (median, interquartile range, total range, n=3), December 2016.

4.1.3 Toxicity

The influence of non-eutrophication related toxicity is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs generally only assessed where inputs are likely, or metal concentrations are found to be elevated.

Results for heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn and arsenic, used as indicators of potential toxicants, were present at "very low" to "low" concentrations at all sites, with all non-normalised values below the ANZECC (2000) ISQG-Low trigger values (Table 5), and therefore posed no toxicity threat to aquatic life.

Table 5. Indicator toxicant results for Waikouaiti Estuary (Sites A, B and C), December 2016.

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
2016 A 1-4 [b]	0.02	6.1	5	7	4.3	27	7.8	<0.010
2016 A-4-8 [b]	0.03	6.2	4.8	6.6	4.3	26	7.9	0.014
2016 A-9-10 [b]	0.027	6.9	5.3	7.1	4.6	27	8	0.011
2016 B-1-4 [b]	<0.010	4	3.6	4.5	2.8	17.8	3.9	<0.010
2016 B-4-8 [b]	< .010	4.3	3.4	4.9	3	19.4	3.8	<0.010
2016 B-9-10 [b]	<0.010	3.5	3.2	4.1	2.5	16.9	4.3	<0.010
2016 C-1-4 [b]	0.05	5.1	3.1	3.7	3.4	21	3.9	0.011
2016 C-4-8 [b]	0.046	5.4	3.4	4.1	3.6	23	4.2	0.011
2016 C-9-10 [b]	0.05	5.5	3.3	3.8	3.5	22	4.2	0.011
Condition Thresholds (ANZECC 2000 criteria, Very Low, <0.2 x ISQG Low; Low, 0.2 - 0.5 x ISQG Low; Moderate, 0.5 x to ISQG Low; High, >ISQG Low)								
[a] Band A Very Low Risk	<0.3	<16	<13	<4.2	<10	<40	<4	<0.03
[a] Band B Low Risk	0.3 - 0.75	16 - 40	13 - 32.5	4.2 - 10.5	10 - 25	40 - 100	4 - 10	0.03 - 0.075
[a] Band C Moderate Risk	0.75 - 1.5	40 - 80	32.5 - 65	10.5 - 21	25 - 50	100 - 200	10 - 20	0.075 - 0.15
[a] Band D High Risk	>1.5	>80	>65	>21	>50	>200	>20	>0.15
[a] ISQG-Low	1.5	80	65	21	50	200	20	0.15
[a] ISQG-High	10	370	270	52	220	410	70	1

[a] ANZECC 2000, *composite samples

4.1.4 Benthic Macroinvertebrate Community

Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong primary linkage to sediments and secondary linkage to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987, Robertson et al. 2016). Because they integrate recent disturbance history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macroinvertebrates to stressors in Waikouaiti Estuary will be analysed in detail once sufficient baseline monitoring data is available. This analysis will include four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (v.6) package will be used to evaluate and compare the relative importance of different environmental factors and their influence on the identified macrobenthic communities.
3. Assessment of species richness, abundance, diversity and major infauna groups.
4. Assessment of the response of the macroinvertebrate community to increasing mud and organic matter among fine scale sites over time, based on identified tolerance thresholds for NZ taxa (NZ AMBI, Robertson et al. 2015, Robertson et al. 2016).

At this stage, with only one year of monitoring data, this section of the report will present and interpret data in relation to steps 3 and 4 only.

Species Richness, Abundance, Diversity and Infauna Groups

In this step, simple univariate whole community indices, i.e. species richness, abundance and diversity are presented for each site (Figure 8), and in the future when more data are available, will be used to help explain any differences between years indicated by other analyses.

The data showed relatively low species richness (1-11 per core), abundance (2-48 per core) and Shannon diversity (0.3-1.3 per core), similar to the fine scale sites in Waimea Inlet [i.e. species richness (6-13 per core), abundance (8-83 per core) and Shannon diversity (1.4-2.4 per core) - Robertson and Stevens 2014)], but a lot lower than Porirua Harbour [i.e. species richness (10-25 per core), abundance (50-220 per core) and Shannon diversity (1.1-1.6 per core) - Robertson and Stevens 2015)].

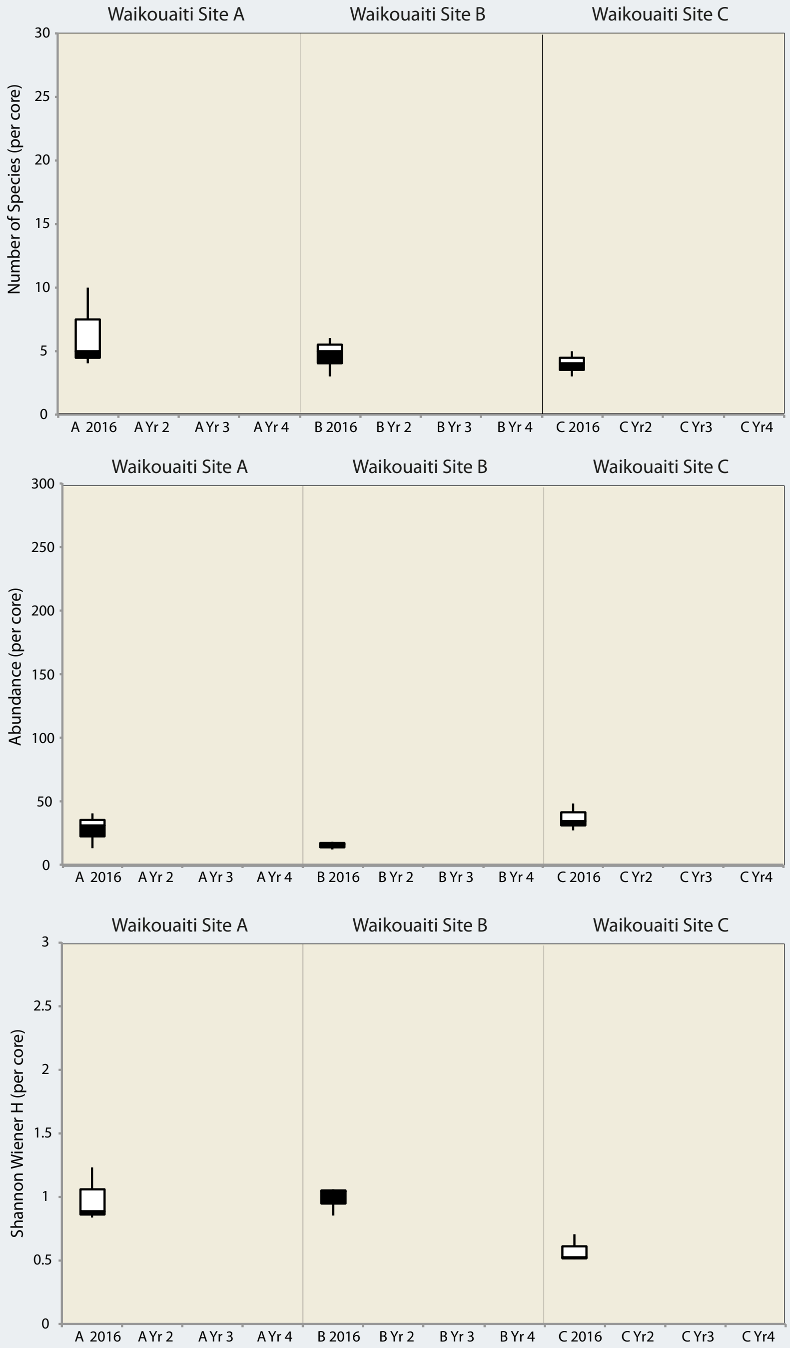


Figure 8. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Waikouaiti Estuary, December 2016.

4. Results and Discussion (continued)

Figure 9 shows that the macroinvertebrate community at all three sites was dominated by polychaetes, and to a lesser extent bivalves, gastropods and crustacea, with obvious differences in abundance between sites, particularly in relation to polychaetes and bivalves. These differences are discussed in more detail in the following sections.

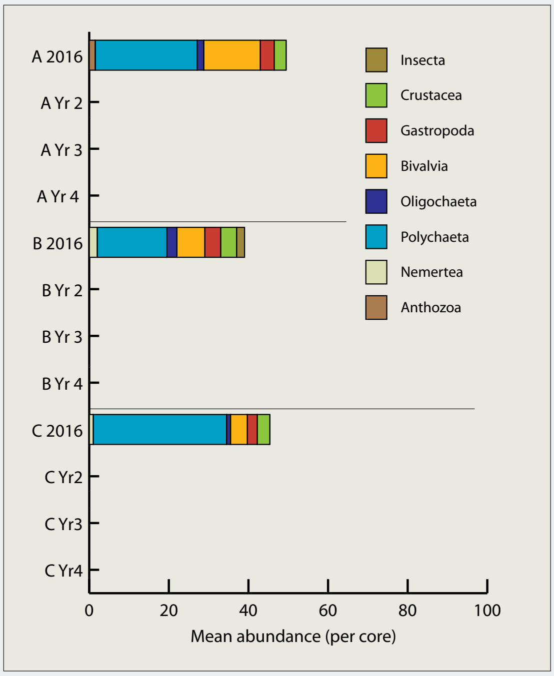


Figure 9. Mean abundance of major infauna groups (n=10), Waikouaiti Estuary, December 2016.

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

1. Mud and Organic Enrichment Index (NZ AMBI)

This step is undertaken using the NZ AMBI (Robertson et al. 2016), a benthic macroinvertebrate index based on the international AMBI approach (Borja et al. 2000) which includes several modifications to strengthen its response to anthropogenic stressors, particularly mud and organic enrichment as follows:

- integration of previously established, quantitative ecological group classifications (Robertson et al. 2015),
- addition of a meaningful macrofaunal component (taxa richness), and
- derivation of classification-based and breakpoint-based thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents). The latter was used to evaluate the applicability of existing AMBI condition bands, which were shown to accurately reflect benthic condition for the >100 intertidal NZ estuarine sites surveyed: 2% to ~30% mud reflected a “normal” to “impoverished” macrofauna community, or “high” to “good” status; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an “unbalanced” to “transitional to pollution” macrofauna community, or “good” to “moderate” status; and >3% to 4% TOC reflected a “transitional to pollution” to “polluted” macrofauna community, or “moderate” to “poor” status.

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

4. Results and Discussion (continued)

For the three fine scale sites in Waikouaiti Estuary, the median NZ Hybrid AMBI biotic coefficients ranged from 1.35 at Site A, 2.0 at Site B and 4.5 at Site C (Figure 10). The coefficients for the more marine dominated, mid to lower estuary sites A and B were predominantly in the “good” ecological condition category (i.e. a “normal” to “slightly unbalanced” type community indicative of low levels of organic enrichment and, in this case, high mud concentrations) whereas, for the upper estuary deposition zone site C, the coefficients were in the “poor” category (i.e. an impoverished type community indicative of high mud concentrations, possibly accompanied by organic enrichment).

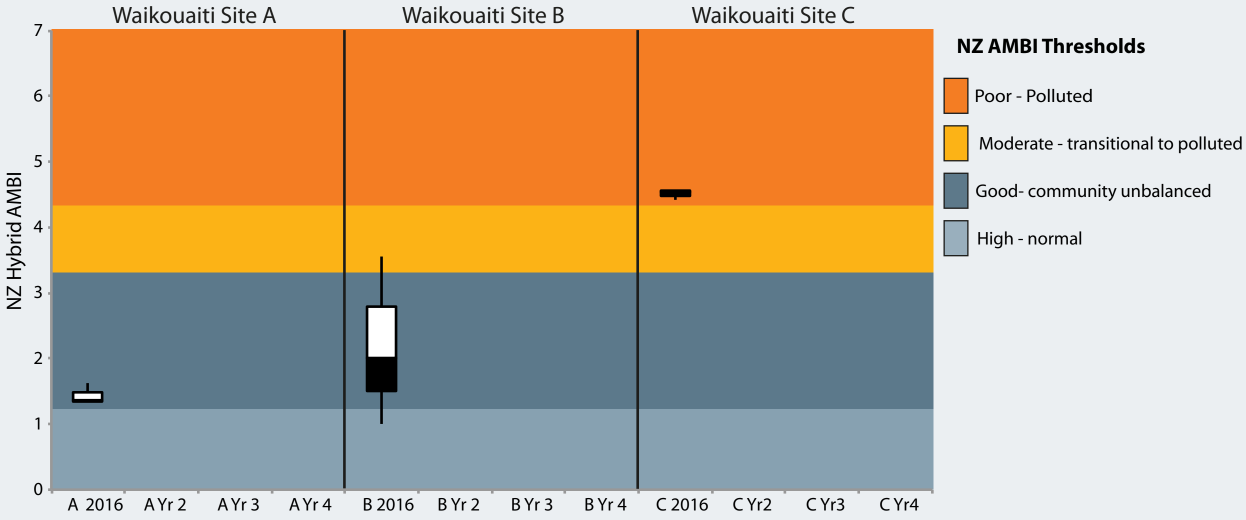


Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Waikouaiti Estuary, December 2016.

2. Individual Species

To further explore the macroinvertebrate community in relation to taxa sensitivities to mud and organic enrichment, a comparison was made of the mean abundances of individual taxa within the 5 major mud/enrichment tolerance groupings (i.e. *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*) (Figures 11a and b).

The results indicate that the majority of taxa and individuals at the sandy Sites A and B were distributed in the Group 1, 2 and 3 categories (i.e. from highly sensitive to widely tolerant of mud and organic enrichment). Taxa that prefer muddy sediments were poorly represented at these sites, with the lower Site A having only 2 species and middle Site B having 4 species.

At Site A, the small, highly sensitive, surface-deposit-feeding spionid polychatete *Aonides trifida* and the long, slender, burrowing, deposit-feeding orbiniid polychaete *Scoloplos cylindrifer*, were the dominant Group 1 species, and the suspension-feeding cockle *Austrovenus stutchburyi*, was dominant in Group 2.

At Site B, *Scoloplos cylindrifer* was the dominant Group 1 species and *Austrovenus stutchburyi* the dominant Group 2 species.

At the muddy Site C, the results indicate that the majority of taxa and individuals were distributed in Groups 3, 4 and 5 categories (i.e. high preference for, to widely tolerant of, mud and organic enrichment). Taxa that prefer sandy sediments were poorly represented at this site, only 1 species present in each of the Group 1 and 2 categories. By far the most dominant taxa at Site C was the surface deposit feeding spionid polychaete *Scolecolepides benhami*. This spionid is very tolerant of mud, fluctuating salinities, organic enrichment and toxicants (e.g. heavy metals). It 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 the low water mark.

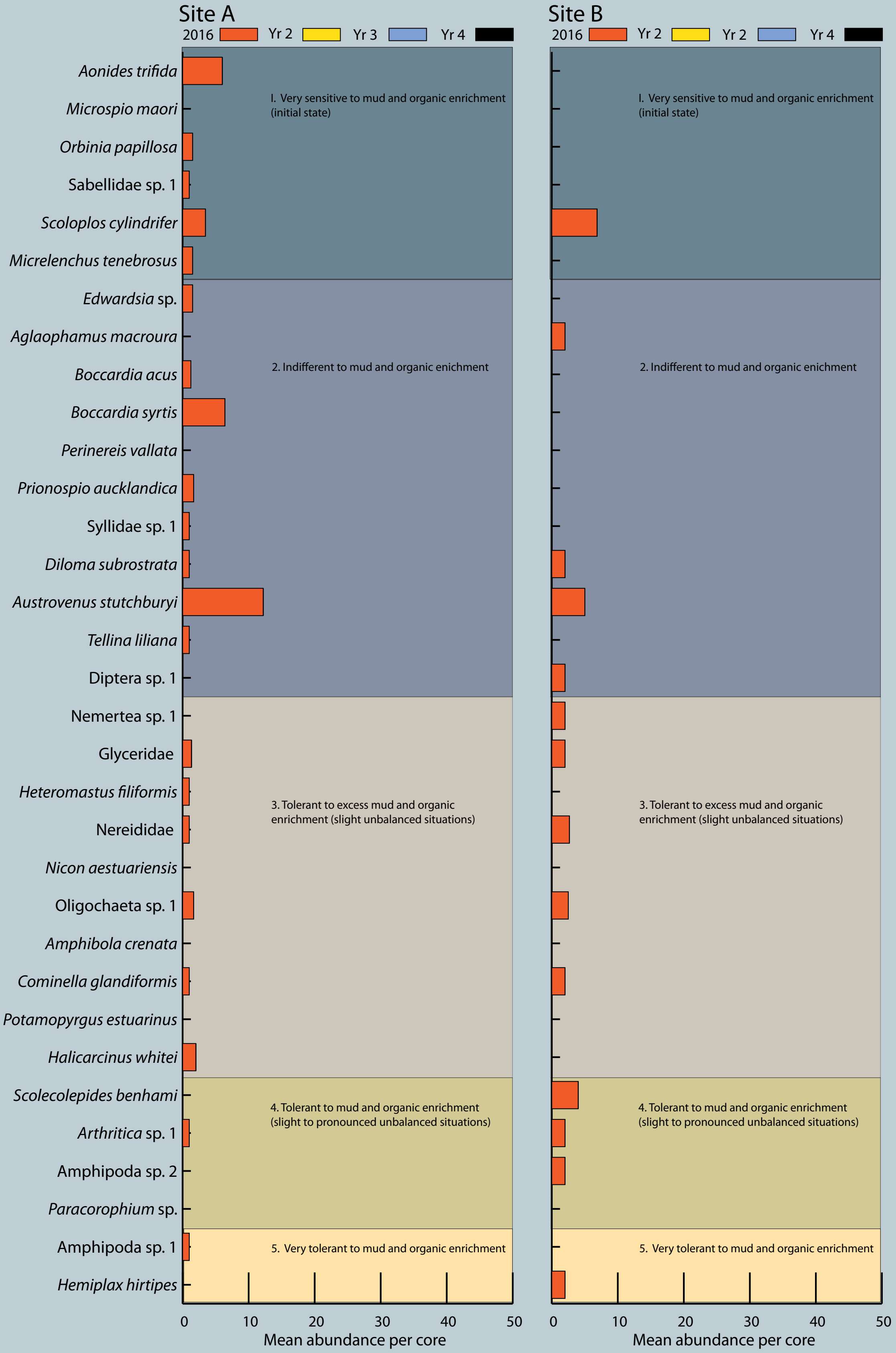


Figure 11a. Mud and organic enrichment sensitivity of macroinvertebrates, Waikouaiti Estuary Sites A and B, December 2016 (see Appendix 3 for sensitivity details).

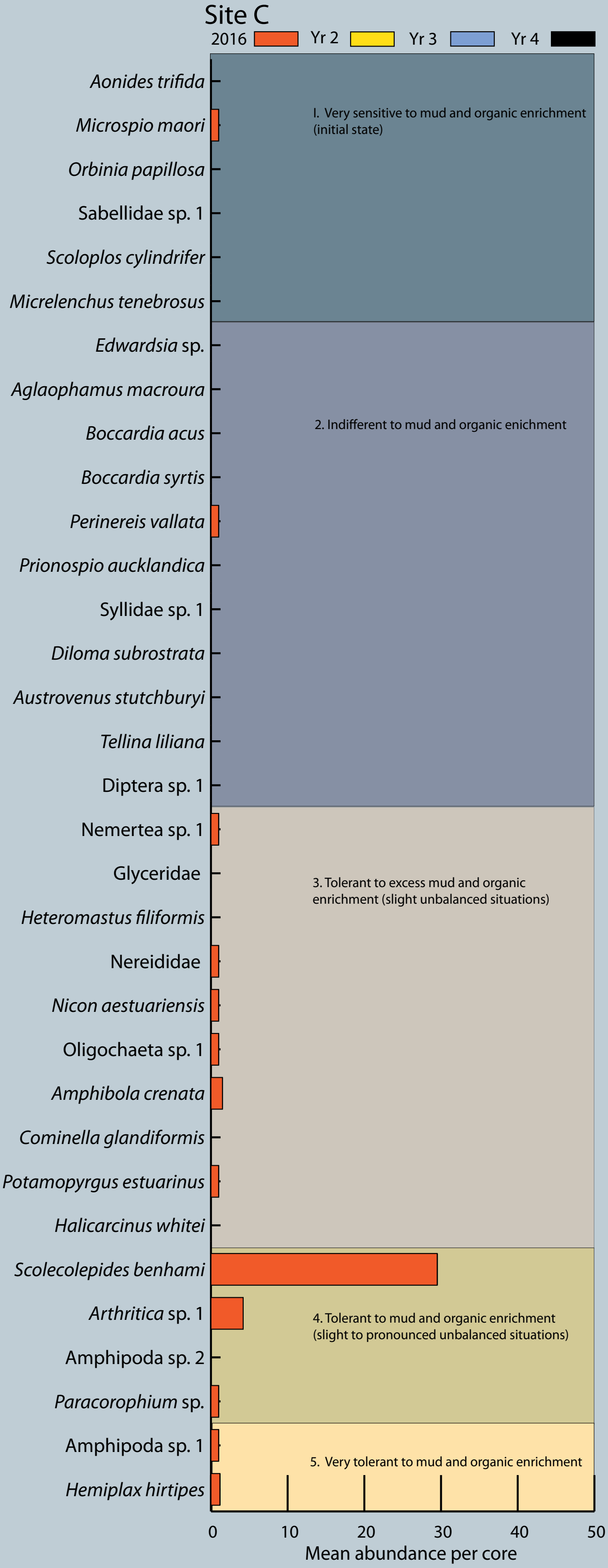


Figure 11b. Mud and organic enrichment sensitivity of macroinvertebrates, Waikouaiti Estuary Site C, December 2016 (see Appendix 3 for sensitivity details).

4.2 Water Column Condition

Background

In NZ SIDEs the rapid flushing time (<3 days for these estuaries) means water column phytoplankton cannot reach high concentrations before they are flushed to the sea. As a consequence, water column eutrophication is minimal, except for some estuaries where parts of the upper estuary water column can be more poorly flushed. This occurs in low flow-baseflow periods when inflowing freshwater flows over more saline tidal water and results in a dense isolated layer of saline bottom water that neither freshwater or tidal inflow currents are strong enough to flush out. Such isolated (or stratified) bottom water (often situated in the 1-2m depth range) is susceptible to phytoplankton blooms, low dissolved oxygen, elevated nutrient concentrations and accumulation of fine sediment.

In estuaries where stratification occurs, the preferred target for eutrophication management is nitrogen which has been identified as the element most limiting to algal production in most estuaries in the temperate zone (Howarth and Marino 2006). Since nitrogen is continually cycling between all of the major nitrogen forms, an assessment of total nitrogen (TN) is needed in order to gauge the level of nitrogen within an embayment and therefore its potential nutrient related health. Reliance on a nitrogen fraction, e.g. inorganic nitrogen, results in inaccurate assessments, since even in a large algal bloom inorganic concentrations may be low due to the uptake by the plants (Howes et al. 2003). Based on the following literature, a TN threshold concentration of approximately 400ugTN.l-^{1} (0.4mgNl^{-1}) for the appearance of eutrophic conditions in poorly flushed sections of SIDE estuaries can be identified (see inset).

Literature Supporting TN Threshold

- In Horsen's Estuary, Denmark, research indicates a mean growing season threshold value of 0.398mgTN l^{-1} to meet good ecological status (Hinsby et al. 2012). This research also identified a threshold for inorganic nutrients as 0.021mgDIN l^{-1} and 0.007mgDIP l^{-1}.
- Similarly, ECan Avon-Heathcote Estuary data from 2010-2014 suggests the appearance of eutrophic conditions may be unlikely below a TN concentration around 0.4mgTN/l (John Zeldis pers. comm. 2016).
- In the US, EPA Region 1 has considered total N threshold concentrations for estuaries and coastal waters of 0.45mgTN l^{-1} as protective of DO standards and 0.34mgTN l^{-1} as protective for eelgrass (Latimer and Rego 2010, State of New Hampshire 2009, Benson et al. 2009).
- As concentrations at inner Massachusetts estuaries rose to levels above 0.40gTN l^{-1}, with the entry of a wastewater nitrogen plume, eelgrass beds began declining and localized macro-algal accumulations were reported (Howes et al. 2003).

Results

The water quality results for the surface and bottom waters at three sites in the Waikouaiti Estuary (lower, mid and upper estuary sites, Sites X, Y and Z respectively) are presented in Table 4 (see Figure 1 for site locations). The main findings were as follows:

Stratification

There was minimal difference between surface and bottom water temperature, salinity (Figure 12), or chlorophyll *a* or dissolved oxygen (Figure 15) indicating stratification was not occurring at the three sites in the upper, mid and lower estuary on the day of sampling (8/12/16). However, in the past, stratification has been found at Site Z (Robertson 1978) and Site Y (ORC SOE Report 2010) in summer low flow periods, and therefore it is possible that at other times stratification does occur, particularly in periods of prolonged low flows. Consequently there remains a potential for poorly flushed bottom water, with a high potential for eutrophication, to be intermittently present in the estuary.

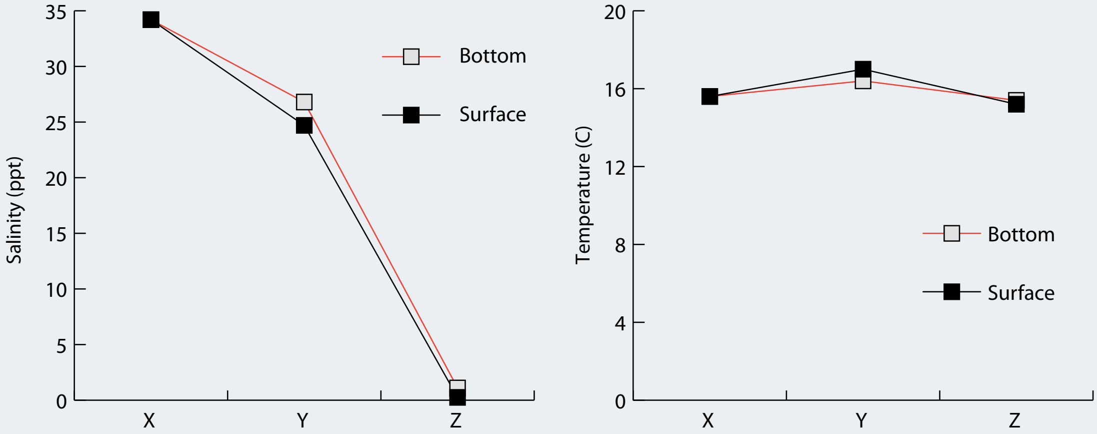


Figure 12. Salinity and temperature in surface and bottom water, Waikouaiti Estuary, 8 December 2016.

Susceptibility To Eutrophication Based on TN Concentrations

Total nitrogen (TN) concentrations in the water column at all sites (<0.3mgNl^{-1}) were all lower than the identified eutrophication threshold level of mean 0.4mgNl^{-1} (Figure 13). Although some previous water quality data exists for the estuary, it was restricted to surface waters at one site only and was measured prior to 2010 (ORC SOE Report 2010) so was not considered for inclusion.

The results indicate that the susceptibility to water column eutrophication, based on TN concentrations alone (i.e. not considering flushing), was low throughout the estuary. However, in this case, where data for only one discrete event was collected, the results can only be used as an early indicator of likely growing season susceptibility. To assess the susceptibility to eutrophication over the whole growing season (November-April), monthly TN concentrations should be used.

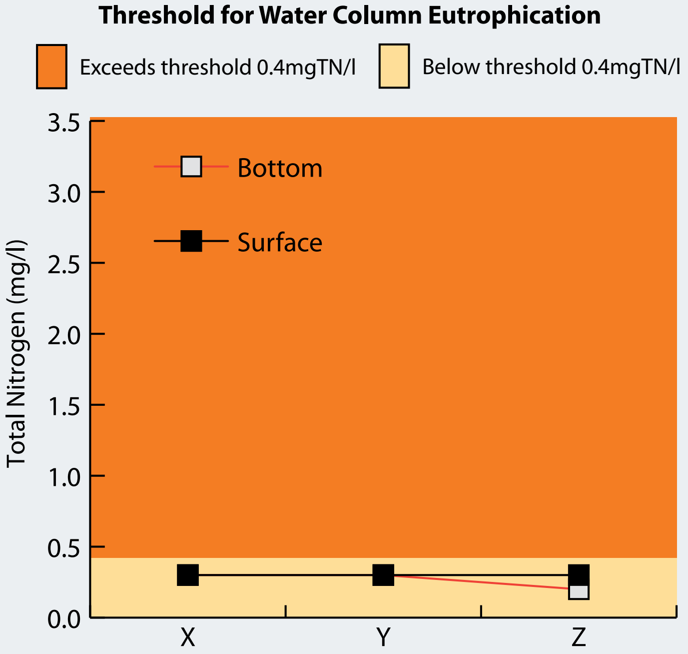


Figure 13. Total nitrogen concentration in surface and bottom water, Waikouaiti Estuary, 8 December 2016.

Other measurements supporting the low levels of plant nutrients in the water column were nitrate-N <0.025mgl^{-1}, ammoniacal N <0.031mgl^{-1}, TP <0.025mgl^{-1} and DRP <0.009mgl^{-1} (Table 4, Figure 14).

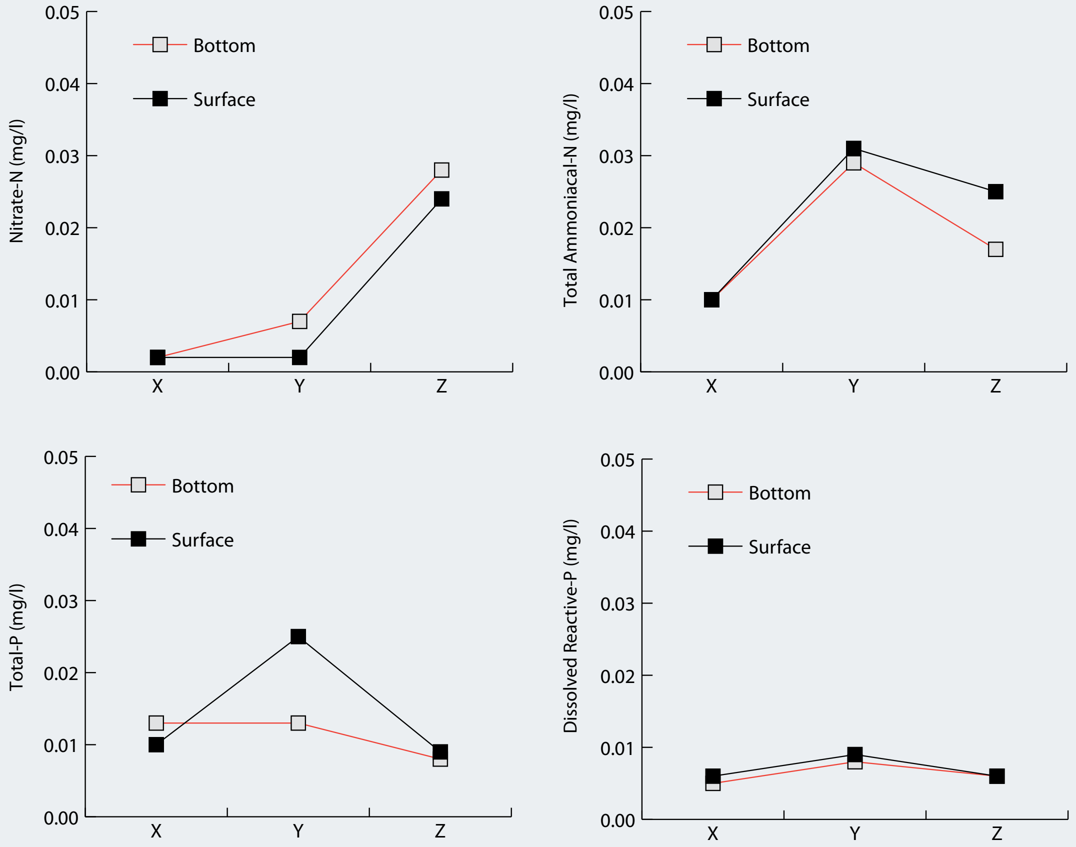


Figure 14. Nitrate N, Ammoniacal N, TP, and DRP concentrations in surface and bottom water, Waikouaiti Estuary, 8 December 2016.

Eutrophic Status Based on Chlorophyll *a* and Dissolved Oxygen

The NZ ETI threshold for chlorophyll *a* (the primary indicator of water column eutrophication) is expressed as the 90th percentile of monthly measures collected during the growing season, and for dissolved oxygen (the main eutrophication supporting indicator), a 7 day mean. Consequently the one-off measures collected on 8 December 2016 can only be used as an indication of current condition.

On that date, chlorophyll *a* concentrations at all sites were very low (<1ugl^{-1}, Figure 15), well below the NZ ETI eutrophication Band D ("Poor") threshold level of 16ugl^{-1} (Robertson et al. 2016b). Dissolved oxygen concentrations were all above the eutrophication Band D ("Poor") threshold (6mgl^{-1}, Figure 15). Both these indicate that there were no signs of eutrophication issues in the estuary water column.

Water Quality Overview

Taken as a whole, the available N concentration and stratification data indicate that susceptibility to water column phytoplankton blooms in the Waikouaiti Estuary in December 2016 was low. However, given only one comprehensive sampling event and the possibility of stratification occurring later in the growing season, there is a possibility that stratified bottom water eutrophication could occur in parts of the estuary later in summer (e.g. upper estuary channel or in the main estuary channel if the flow at the estuary mouth becomes constricted).

4. Results and Discussion (continued)

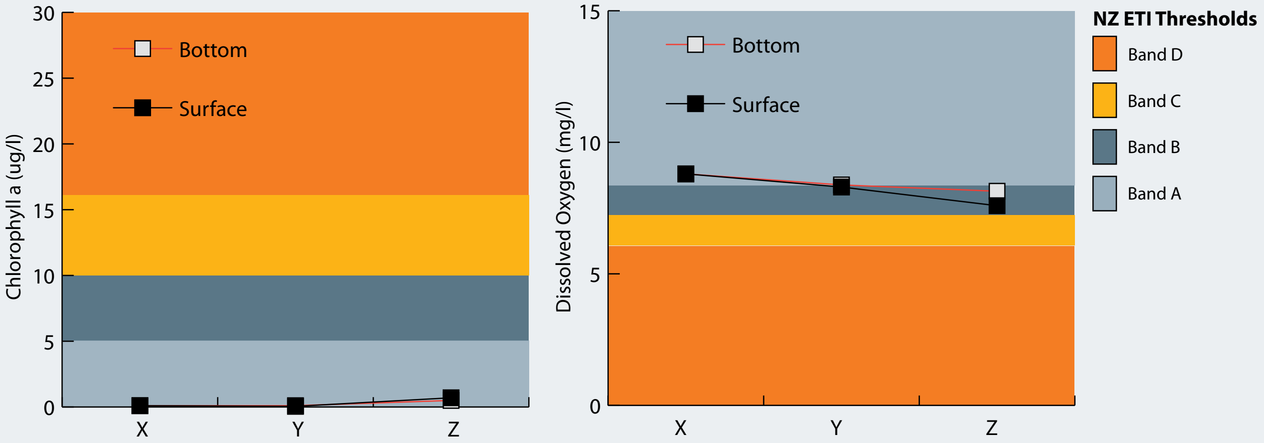


Figure 15. Chlorophyll *a* and dissolved oxygen concentrations in surface and bottom water, Waikouaiti Estuary, 8 December 2016.

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for three long term intertidal monitoring sites established within Waikouaiti Estuary in December 2016 showed the following findings in relation to the key estuary issues of eutrophication, muddiness and toxicity:

BENTHIC HABITAT

Muddiness

The intertidal sites, chosen to represent the main benthic habitats in the estuary, showed a mix of sediment mud contents (5-32% mud), with muddier sediments in the estuary's main upper estuary deposition zone (Site C- Merton arm, mean 31% mud) and sandier sediments in the two main channel sites in the lower to mid estuary (mean 11.9% and 8% mud content for Sites A and B respectively). In terms of potential for ecological effects, the low mud contents for Sites A and B indicate good conditions likely to place *a minor stress on sensitive organisms*, however, the high mud content for Site C indicates a potential for an unbalanced community with conditions likely to place *significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels and a likelihood of local extinctions of keystone species and loss of ecological integrity* (Robertson et al. 2016b).

Eutrophication

The macroalgal results show that in December 2016, the estuary had a problem with excessive growths of green opportunistic macroalgae in the mid-lower estuary (i.e. >90% cover and mean biomass of 2125gm^{-2} wet wgt. at Site A), but not in the upper estuary at Site C where the muddy sediments had a very low cover. However, data collected from the same sites in 2013 by the author in association with the NZ ETI study, indicates that in some years "gross eutrophic zones" (i.e. sediment-entrained, high biomass, red algal blooms growing on soft anoxic muds) can occur at Site C, in addition to the mid-lower estuary blooms of green algae.

Despite the differences in macroalgal cover and mud content in 2016, all three sites had low organic carbon and nutrient contents in the underlying sediments. However, such findings do not themselves indicate an absence of eutrophication symptoms. It may be that the estuary, or part of the estuary, has reached a eutrophic condition (e.g. in the previous growing season) and subsequently has simply exhausted the available nutrient supply.

This conclusion was supported by the fact that sediment oxygenation, as measured by redox potential, identified good oxygenation conditions throughout most of the sediment profile at Site A (i.e. >-50mV up to ~7cm deep), at least half the sediment profile at Site B (i.e. >-50mV up to ~5cm deep), but poor oxygenation conditions at Site C (i.e. <-150mV within 1cm of the surface).

These results indicate that conditions at Site A, and to a slightly lesser extent Site B, are sufficiently well oxygenated to support a range of sensitive taxa. However, the very low redox levels throughout the sediment profile at Site C (Band D) indicate sediment oxygenation is likely to support predominantly tolerant opportunistic species.

These expectations were reflected in the abundance of mud and organic enrichment sensitive taxa between sites, with the median NZ Hybrid AMBI biotic coefficients ranging from 1.35 at Site A, 2.0 at Site B and 4.5 at Site C. The coefficients for the more marine dominated, mid to lower estuary sites A and B were predominantly in the "good" ecological condition category (i.e. a "normal" to "slightly unbalanced" type community indicative of low levels of organic enrichment and, in this case, high mud concentrations) whereas, for the upper estuary, deposition zone site C, the coefficients were in the "poor" category (i.e. an "impoverished" type community indicative of high mud concentrations, possibly accompanied by organic enrichment).

Toxicity

Indicators of sediment toxicants [heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, Zn and As)] were at concentrations that were not expected to pose toxicity threats to aquatic life.

WATER COLUMN HABITAT

Eutrophication

The December 2016 water quality results for the surface and bottom waters at three upper, mid and lower estuary sites, indicate little evidence of eutrophication symptoms as follows:

- An absence of poorly flushed stratified areas containing isolated bottom water where nutrient concentrations can build-up.
- Total nitrogen concentrations in the water column were less than the accepted threshold level for the appearance of eutrophication symptoms in shallow estuaries.
- Chlorophyll *a* concentrations, the primary indicator of water column eutrophication, were all less than the NZ ETI eutrophication threshold level.
- Dissolved oxygen concentrations, the main supporting indicator of water column eutrophication, did not breach the threshold for eutrophic conditions.

Taken as a whole, the available data indicates that susceptibility to algal blooms in non-stratified surface waters to be low.

However, given only one comprehensive sampling event, there is a possibility that stratified bottom water eutrophication events could occur in parts of the estuary later in the growing season. Based on expert opinion, the events would likely manifest as cycles of bottom water stratification and accompanying eutrophication, that gradually increases towards the end of the cycle, with the cycles being broken by intermittent high flow events that disrupt the stratification and flushes phytoplankton and nutrients into the main body of the estuary and out to sea. The magnitude of the blooms will likely depend on the duration between flood events, with nuisance conditions increasing as time between floods increases.

Although upper estuary bottom water stratification is a natural event in many shallow NZ estuaries, it can be exacerbated by reductions in natural river inflows (e.g. from upstream water abstraction and damming). Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nitrogen inputs would need to be much less than $0.4 mgNl^{-1}$ in order to minimise eutrophication symptoms in this sensitive zone of an estuary.

In terms of risk to estuarine ecology from this cyclical degradation of the upper-mid estuary bottom water layer, the likely main threats would be to benthic macroinvertebrates and fish through loss of important habitat.

Overview

In overview, the benthic habitat results indicate the estuary expresses symptoms of both muddiness and eutrophication (elevated mud content and dense macroalgal cover in parts of the estuary), with "gross eutrophic zones (GEZ)" present in some years. Over-enrichment with nutrients, and fine sediments in the GEZ case, are the most likely cause of these conditions.

5. Summary and Conclusions (continued)

The relatively good sediment chemical and biological conditions underlying abundant green macroalgal cover in 2016, represent moderate symptoms of eutrophication, possibly driven by a combination of the presence of available attachment sites and moderate levels of nutrient inputs (both from the underlying sediments and the water column).

The water column results indicate no stratification at the time of sampling and a low risk of eutrophication under such conditions. However, should the estuary stratify, current nutrient concentrations appear sufficiently high to result in eutrophication conditions establishing.

The "Overview Report" which accompanies the current fine and broad scale reports identifies appropriate nutrient load versus estuary eutrophication response thresholds that can be used to manage these issues, as well as providing more details on the issues.

6. MONITORING

Waikouaiti Estuary has been identified by ORC as a priority for monitoring because it is a moderate-large estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of ORC's coastal monitoring programme being undertaken throughout the Otago region. Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2016).

In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

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

Fine Scale Monitoring

To complete the fine scale baseline in Waikouaiti Estuary it is recommended that the remaining 3 consecutive years of annual summer (i.e. December-February) fine scale monitoring of intertidal sites (including sedimentation rate measures), be undertaken in 2017, 2018 and 2019 (preferably during a summer low flow period).

To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a prolonged summer, low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 5-6 sites, between the Railway Bridge and 1km below Orbells Crossing.

To fully characterise the observed variation in opportunistic macroalgal growth (both green and red blooms) between years, it is recommended that a strong baseline be established through undertaking an annual macroalgal survey (January/February) over the next three years in conjunction with fine scale sampling.

To characterise the potential for excessive sedimentation, it is recommended that sedimentation rate be assessed annually, using appropriately placed sediment plates, and the areal extent of muddy sediments be assessed at 5-10 yearly intervals (the latter assessed in broad scale monitoring).

Broad Scale Habitat Mapping

To characterise any issues of change in habitat (e.g. saltmarsh or seagrass area, soft mud extent), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2026) unless obvious changes are observed in the interim.

7. ACKNOWLEDGEMENTS

Many thanks to Rachel Ozanne (Otago Regional Council) for her support, feedback and review of this report.

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

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

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

Water Quality Indicator	Laboratory	Method	Detection Limit
Filtration, Unpreserved	R.J Hill	Sample filtration through 0.45µm membrane filter.	-
Total Kjeldahl Digestion	R.J Hill	Sulphuric acid digestion with copper sulphate catalyst.	-
Total Phosphorus Digestion	R.J Hill	Acid persulphate digestion.	-
Total Nitrogen	R.J Hill	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: Default Detection Limit of 0.05 g/m3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m3.	0.05 g/m^3
Total Ammoniacal-N	R.J Hill	Saline, filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500- NH3 F (modified from manual analysis) 22nd ed. 2012.	0.010 g/m^3
Nitrite-N	R.J Hill	Saline sample. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g/m^3
Nitrate-N	R.J Hill	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3
Nitrate-N + Nitrite-N	R.J Hill	Saline sample. Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g/m^3
Total Kjeldahl Nitrogen (TKN)	R.J Hill	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-Norg D. (modified) 4500 NH3 F (modified) 22nd ed. 2012.	0.10 g/m^3
Dissolved Reactive Phosphorus	R.J Hill	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd ed. 2012.	0.004 g/m^3
Total Phosphorus	R.J Hill	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NWASCA, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g/m^3

Appendix 1. Details on Analytical Methods (continued)

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

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

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

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

B. DENSITY SCALES

SACFOR size class				Density				
i	ii	iii	iv	0.25m^2	1.0m^2	10m^2	100m^2	1,000m^2
<1cm	1-3cm	3-15cm	>15cm	(50x50cm)	(100x100cm)	(3.16x3.16m)	(10x10m)	(31.6x31.6m)
S	-	-	-	>2500	>10,000			
A	S	-	-	250-2500	1000-9999	>10,000		
C	A	S	-	25-249	100-999	1000-9999	>10,000	
F	C	A	S	3-24	10-99	100-999	1000-9999	>10,000
O	F	C	A	1-2	1-9	10-99	100-999	1000-9999
R	O	F	C			1-9	10-99	100-999
-	R	O	F				1-9	10-99
-	-	R	O					1-9
-	-	-	R					<1

APPENDIX 2. 2016/17 DETAILED RESULTS

Waikouaiti Estuary fine scale site boundaries

Waikouaiti Site A	1	2	3	4	**Waikouaiti Site B**	1	2	3	4
NZTM EAST	1417283	1417296	1417311	1417298	NZTM EAST	1416853	1416866	1416878	1416864
NZTM NORTH	4943823	4943831	4943805	4943797	NZTM NORTH	4944928	4944934	4944906	4944901
Waikouaiti Site C	1	2	3	4					
NZTM EAST	1415752	1415776	1415785	1415760					
NZTM NORTH	4945365	4945383	4945371	4945353					

Fine scale station locations, Waikouaiti Estuary, 8 December 2016

Waikouaiti Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1417288	1417291	1417295	1417300	1417304	1417300	1417295	1417291	1417295	1417299
NZTM NORTH	4943823	4943815	4943808	4943801	4943804	4943811	4943819	4943825	4943827	4943822
Waikouaiti Site B	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1416856	1416860	1416862	1416866	1416871	1416867	1416865	1416862	1416865	1416869
NZTM NORTH	4944927	4944920	4944913	4944905	4944906	4944914	4944920	4944927	4944929	4944924
Waikouaiti Site BC	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1415756	1415764	1415770	1415777	1415778	1415771	1415764	1415759	1415762	1415767
NZTM NORTH	4945364	4945369	4945376	4945377	4945373	4945368	4945364	4945360	4945356	4945360

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

Site B Sed Plates (Firm Muddy Sand)	NZTM East	NZTM North	Height/Depth (mm) Dec 2016	**Site C Sed Plates** (Soft Mud)	NZTM East	NZTM North	Height/Depth (mm) 8 Dec 2016
Peg 1 (0m)	1416853	4944928		Peg 1 (0m)	1415752	4945365	
Plate 1 (2m)	1416855	4944929	-62	Plate 1 (2m)	1415753	4945363	-115
Plate 2 (4m)	1416856	4944930	-114	Plate 2 (4m)	1415754	4945362	-116
Peg 2 (5m)	1416857	4944930		Peg 2 (5m)	1415755	4945361	
Plate 3 (6m)	1416858	4944930	-104	Plate 3 (6m)	1415756	4945360	-105
Plate 4 (8m)	1416860	4944931	-123	Plate 4 (8m)	1415757	4945358	-103
Peg 3 (10m)	1416862	4944932		Peg 3 (10m)	1415758	4945357	

Water quality and subtidal sediment site locations, Waikouaiti Estuary, 8 December 2016

Waikouaiti	**Site X (lower)**	**Site Y (mid)**	**Site Z (upper)**
NZTM EAST	1417799	1416532	1416297
NZTM NORTH	4943176	4945341	4947434

Sediment quality results for Sites X, Y and Z, Waikouaiti Estuary, 8 December 2016

Year/Site	**TOC**	**Mud**	**Sand**	**Gravel**	**TN**	**TP**
	%				**mg/kg**	
Waikouaiti SED X 2016	<0.05	1.6	93.2	5.2	340	<500
Waikouaiti SED Y 2016	0.39	6.9	50.7	42.4	450	<500
Waikouaiti SED Z 2016	1.32	25.7	64	10.3	780	1300

Redox Potential (mV) at fine scale sites 8 December, Waikouaiti Estuary, 8 December 2016

Year/Site	**Redox Potential (mV)**				
	0cm	**1 cm**	**3cm**	**6cm**	**10cm**
2016 A	70	-19	-15	-20	-185
2016 B	200	151	169	-130	-180
2016 C	60	-359	-347	-344	-395

Appendix 2. 2016/17 Detailed Results (continued)

Physical and chemical results for fine scale Sites A, B and C, Waikouaiti Estuary, 8 December 2016

Year/Site/Rep	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2016 A 1-4 [b]	3	34	0.44	10.3	79.6	10.1	0.02	6.1	5	7	4.3	27	7.8	<0.010	700	490
2016 A-4-8 [b]	3	34	0.52	12.9	72.6	14.5	0.03	6.2	4.8	6.6	4.3	26	7.9	0.014	700	430
2016 A-9-10 [b]	3	34	0.54	12.4	71.7	15.9	0.027	6.9	5.3	7.1	4.6	27	8	0.011	700	540
2016 B-1-4 [b]	5	28	0.2	9.6	78.3	12	0.010	4	3.6	4.5	2.8	17.8	3.9	<0.010	<500	760
2016 B-4-8 [b]	5	28	0.21	9.1	68.3	22.6	< 0.010	4.3	3.4	4.9	3	19.4	3.8	<0.010	<500	780
2016 B-9-10 [b]	5	28	0.2	5.4	90.3	4.4	<0.010	3.5	3.2	4.1	2.5	16.9	4.3	<0.010	<500	510
2016 C-1-4 [b]	0	25	0.38	30.5	69.3	0.2	0.05	5.1	3.1	3.7	3.4	21	3.9	0.011	600	460
2016 C-4-8 [b]	0	25	0.42	30.5	69.4	0.2	0.046	5.4	3.4	4.1	3.6	23	4.2	0.011	600	470
2016 C-9-10 [b]	0	25	0.42	31.6	67.9	0.5	0.05	5.5	3.3	3.8	3.5	22	4.2	0.011	700	460
ISQG-Low[b]	-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High[b]	-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-

[a] ANZECC 2000. [b] composite samples.

Water quality results for Sites X, Y and Z, Waikouaiti Estuary, 8 December 2016

Parameter	Units	Lower Site X (surface)	Lower Site X (bottom)	Mid Site Y (surface)	Mid Site Y (bottom)	Upstream Site Z (surface)	Upstream Site Z (bottom)
Depth	m	0.1	2.7	0.1	1.6	0.1	3.0
Temperature	degrees C	15.6	15.6	17.0	16.4	15.2	15.4
Salinity	ppt	34.2	34.2	24.7	26.8	0.25	1.1
Dissolved Oxygen	mg/l	8.8	8.8	8.30	8.38	7.59	8.14
pH		8.35	8.35	8.30	8.38	7.59	8.14
Chlorophyll a	mg/m^3	0.1	0.1	0.05	0.1	0.7	0.5
Total Nitrogen	g/m^3	<0.3	<0.3	<0.3	<0.3	0.3	0.2
Total Ammoniacal-N	g/m^3	<0.010	< 0.010	0.031	0.029	0.025	0.017
Nitrite-N	g/m^3	<0.002	<0.002	<0.002	0.002	<0.002	<0.002
Nitrate-N	g/m^3	0.002	<0.002	0.002	0.007	0.024	0.027
Nitrate-N + Nitrite-N	g/m^3	0.002	<0.002	0.002	0.007	0.025	0.028
Total Kjeldahl Nitrogen (TKN)	g/m^3	<0.2	<0.2	<0.2	<0.2	0.3	<0.2
Dissolved Reactive Phosphorus	g/m^3	0.006	0.005	0.009	0.008	0.006	0.006
Total Phosphorus	g/m^3	0.01	0.013	0.025	0.013	0.009	0.008

Epifauna abundance and macroalgal cover at fine scale sites, Waikouaiti Estuary, 8 December 2016

Group	Family	Species	Common name	Scale	Class	A	B	C
Topshell	Amphibolidae	*Amphibola crenata*	Estuary mud snail	#	ii	C	A	C
Topshells	Trochidae	*Diloma subrostratum*	Grooved topshell	#	ii	R	F	R
Red algae	Gracilariaceae	*Gracilaria* sp.	*Gracilaria* weed	%	ii	R	R	R
Green algae	Ulvaceae	*Ulva intestinalis*	Sea lettuce	%	ii	C	S	R

Seagrass (*Zostera muelleri*) and macroalgal cover and biomass at fine scale sites, Waikouaiti Estuary, 8 December 2016

Year/Site	Seagrass Biomass and Cover ($g.m^{-2}$ wet weight (%)	Macroalgal Biomass and Cover $g.m^{-2}$ wet weight (%)
2016 A	0 (0%)	2125 (90%)
2016 B	0 (0%)	300 (30%)
2016 C	0 (0%)	20 (<5%)

Appendix 2. 2016/17 Detailed Results (continued)

Infauna results for fine scale Sites A and B, Waikouaiti Estuary, 8 December 2016

Infauna (numbers per 0.01327m² core)

Group	Species	NZ Hyb AMBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
ANTHOZOA	*Edwardsia* sp.	2					1	2														
NEMERTEA	*Nemertea* sp.#1	3												2						2		
POLYCHAETA	*Aonides trifida*	1			2	3	4	4	19		1	9										
	Microspio maori	1																				
	Orbinia papillosa	1					1					2										
	Sabellidae sp.#1	1	1							1	1											
	Scoloplos cylindrifer	1	7		1	8	3	4	4	1	2	1		2	6	10	6			2	8	14
	Aglaophamus macroura	2																2				2
	Boccardia acus	2	1				1		1			2										
	Boccardia syrtis	2	6	2	6	4	13	4	5	8	8	8										
	Perinereis vallata	2																				
	Prionospio aucklandica	2	2	2			1	3			1	1										
	Syllidae sp.#1	2	1																			
	Glyceridae	3	2					1			1				2							
	Heteromastus filiformis	3					1				1											
	Nereididae	3									1		2	4		2						
	Nicon aestuariensis	3																				
	Scolecolepides benhami	4											6			2	6			2		
OLIGOCHAETA	Oligochaeta sp.#1	3	2	1			2						2				2			2	4	
GASTROPODA	*Micrelenchus tenebrosus*	1						1		2												
	Diloma subrostrata	2			1								2									
	Amphibola crenata	3																				
	Cominella glandiformis	3					1							2								
	Potamopyrgus estuarinus	3																				
BIVALVIA	*Austrovenus stutchburyi*	2	17	8	21	4	17	14	11	13	7	10	2	8	4	4			4	6	8	4
	Tellina liliana	2	1																			
	Arthritica sp.#1	4						1												2		
CRUSTACEA	*Halicarcinus whitei*	3							2													
	Amphipoda sp.#2	4														2						
	Paracorophium sp.	4																				
	Amphipoda sp.#1	5									1											
	Hemiplax hirtipes	5											2									
INSECTA	Diptera sp.#1	2															2			2	2	
Total individuals in sample			**40**	**13**	**31**	**19**	**45**	**34**	**42**	**25**	**24**	**33**	**16**	**18**	**12**	**20**	**16**	**2**	**4**	**18**	**22**	**20**
Total number of species in sample			**10**	**4**	**5**	**4**	**11**	**9**	**6**	**5**	**10**	**7**	**6**	**5**	**3**	**5**	**4**	**1**	**1**	**7**	**4**	**3**

Appendix 2. 2016/17 Detailed Results (continued)

Infauna results for fine scale Site C, Waikouaiti Estuary, 8 December 2016

Infauna (numbers per 0.01327m² core)

Group	Species	NZ Hyb AMBI	C-01	C-02	C-03	C-04	C-05	C-06	C-07	C-08	C-09	C-10
ANTHOZOA	*Edwardsia* sp.	2										
NEMERTEA	*Nemertea* sp.#1	3									1	
POLYCHAETA	*Aonides trifida*	1										
	Microspio maori	1										1
	Orbinia papillosa	1										
	Sabellidae sp.#1	1										
	Scoloplos cylindrifer	1										
	Aglaophamus macroura	2										
	Boccardia acus	2										
	Boccardia syrtis	2										
	Perinereis vallata	2				1						1
	Prionospio aucklandica	2										
	Syllidae sp.#1	2										
	Glyceridae	3										
	Heteromastus filiformis	3										
	Nereididae	3							1			
	Nicon aestuariensis	3	1									
	Scolecolepides benhami	4	34	24	31	27	33	32	28	25	26	35
OLIGOCHAETA	Oligochaeta sp.#1	3						1			1	1
GASTROPODA	*Micrelenchus tenebrosus*	1										
	Diloma subrostrata	2										
	Amphibola crenata	3			2	1						
	Cominella glandiformis	3										
	Potamopyrgus estuarinus	3		1					1			
BIVALVIA	*Austrovenus stutchburyi*	2										
	Tellina liliana	2										
	Arthritica sp.#1	4	10		1	2					4	4
CRUSTACEA	*Halicarcinus whitei*	3										
	Amphipoda sp.#2	4										
	Paracorophium sp.	4	1									1
	Amphipoda sp.#1	5		1			1		1			
	Hemiplax hirtipes	5	2	1		1		1		1		1
INSECTA	Diptera sp.#1	2										
Total individuals in sample			**48**	**27**	**34**	**32**	**34**	**34**	**31**	**26**	**32**	**44**
Total number of species in sample			**5**	**4**	**3**	**5**	**2**	**3**	**4**	**2**	**4**	**7**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		NZ Hyb AMBI Gp*	Details
Anthozoa	*Edwardsia* sp.	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. 1	3	Ribbon or Proboscis worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Polychaeta	*Aglaophamus macroura*	2	A large, long-lived (5yrs or more) intertidal and subtidal nephtyid that prefers a sandier, rather than muddier substrate (Beesley et al. 2000). Feeding type is carnivorous. Significant avoidance behaviour by other species. Feeds on *Heteromastus filiformis, Orbinia papillosa* and *Scoloplos cylindrifer* etc.
	Aonides trifida	1	Small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. *Aonides* is free-living, not very mobile and strongly prefers to live in fine sands; also very sensitive to changes in the silt/clay content of the sediment. In general, polychaetes are important prey items for fish and birds.
	Boccardia acus	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
	Boccardia syrtis	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
	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.
	Heteromastus filiformis	3	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	Microspio maori	1	A small, common, intertidal spionid. Can handle moderately enriched situations. Prey items for fish and birds.
	Nereididae	3	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of elevated sulphide concentrations.
	Nicon aestuariensis	3	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate mud content sediments.
	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.
	Perinereis vallata	2	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Polychaeta	*Prionospio aucklandica*	2	Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001).
	Sabellidae sp. 1	1	Sabellids are not usually present in intertidal sands, though some minute forms do occur low on the shore. They are referred to as fan or feather-duster worms and are so-called from the appearance of the feeding appendages, which comprise a crown of two semicircular fans of stiff filaments projected from their tube.
	Scolecolepides benhami	4	A spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. A close relative, the larger Scolecolepides freemani occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary.
	Scoloplos cylindrifer	1	Originally, *Haploscoloplos cylindrifer.* Belongs to Family Orbiniidae which are thread-like burrowers without head appendages. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. Pollution and mud intolerant.
	Syllidae sp. 1	2	Belongs to Family Syllidae which are delicate and colourful predators. Very common, often hidden amongst epifauna. Small size and delicate in appearance. Prefers mud/sand sediments.
Oligochaeta	Oligochaeta sp. 1	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Bivalvia	Arthritica sp. 1	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
	Austrovenus stutchburyi	2	Family Veneridae bivalves are very sensitive to organic enrichment. Cockles are suspension feeders with a short siphon - live a few cm deep at mid-low water situations. Responds positively to relatively high levels of suspended sediment for short period; long term exposure has adverse effects. Small cockles are important in diet of wading bird species; including SI and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, they struggle. Cockles improve sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).
	Tellina liliana	2	A deposit feeding wedge shell. This species lives at depths of 5–10cm in the sediment and uses a long inhalant siphon to feed on surface deposits and/or particles in the water column. Rarely found beneath the RPD layer. Adversely affected at elevated suspended sediment concentrations.
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.
	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.
	Diloma subrostratum	2	The mudflat top shell, lives on sandflats, but prefers a more solid substrate such as shells, stones etc. Endemic to NZ and feeds on the film of microscopic algae on top of the sand. Has a strong sand preference.

Appendix 3. Infauna Characteristics (continued)

Group and Species		**NZ Hyb AMBI Gp***	**Details**
Gastropoda	*Micrelenchus tenebrosus*	1	A species of small sea snail found in New Zealand, which has a shell with a pearly interior. It is a marine gastropod mollusc in the family Trochidae, the top snails or top shells. Previously divided into two species (*M. huttoni* and *M. tenebrosus*) between them occupying a range of habitats from open water situations to more sheltered situations. The former *M. huttoni* is now recognised as an 'ecotype' (a subset of individuals within a species with a characteristic appearance) or variant of *M. tenebrosus*. Generally associated with seaweeds (e.g. *Ulva, Gracillaria*) and seagrass in the sheltered waters of tidal mudflats.
	Potamopyrgus estuarinus	3	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
Crustacea	Amphipoda sp. 1	5	An unidentified amphipod species.
	Amphipoda sp. 2	4	Amphipoda is an order of malacostracan crustaceans with no carapace and generally with laterally compressed bodies. The name amphipoda means "different-footed", and refers to the different forms of appendages, unlike isopods, where all the legs are alike. Of the 7,000 species, 5,500 are classified into one suborder, Gammaridea. The remainder are divided into two or three further suborders. Amphipods range in size from 1 to 340 millimetres (0.039 to 13 in) and are mostly detritivores or scavengers. They live in almost all aquatic environments. Amphipods are difficult to identify, due to their small size, and the fact that they must be dissected. As a result, ecological studies and environmental surveys often lump all amphipods together. Species sensitivities to muds and organic enrichment differs.
	Halicarcinus whitei	3	A species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Hemiplax hirtipes	5	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. Previously *Macrophthalmus hirtipes*.
	Paracorophium sp.	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi*, both endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference.
Insecta	Diptera sp. 1	2	Fly or midge larvae - species unknown.

* NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al. (2015).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.

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