coastalmanagement

Ruataniwha Estuary

Fine Scale Monitoring 2016/17

Prepared for

Tasman District Council

May 2017

Cover Photo: Ruataniwha Estuary, mid estuary zone (Site A).


Ruataniwha Estuary upper estuary deposition zone (Site D)

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Prepared for
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by

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RUATANIWHA ESTUARY - EXECUTIVE SUMMARY

This report summarises fine scale monitoring undertaken at two benthic intertidal sites in Ruataniwha Estuary, a shallow, intertidal dominated (SIDE) estuary on the Golden Bay coast. Site A was established in 2001 in dominant firm mud sand habitat (representative of 43% of the intertidal area), and Site D was established in 2017 in soft mud habitat (representative of 18% of the intertidal area). It is one of the key estuaries in Tasman District Council's (TDC's) long-term coastal monitoring programme. Monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations are presented below.

FINE SCALE MONITORING RESULTS

- No macroalgae or seagrass was growing at fine scale Sites A or D in 2017, and was also absent at Site A in 2001. Macroalgae was relatively uncommon in the estuary as a whole, with seagrass beds confined to the lower estuary away from fine scale sites A and D (Stevens and Robertson 2015).
- Sediment mud content at Site A was low-moderate (10% mud) in 2001, but had increased to 45% mud in 2017. Site D was not measured in 2001, but in 2017 mud content was very high (86% mud).
- Sediment oxygenation was good-moderate at Site A in 2001 (aRPD 3cm depth), but both Sites A and D had poor oxygenation in 2017 (aRPD 0.5cm and RP <-150mV below 0.5cm depth).
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations in both 2001 and 2017.
- The estuary macroinvertebrate community index (NZ HybAMBI) indicated a "slightly unbalanced" to "transitional" type community affected by high mud concentrations and poor oxygenation at both Sites A and D in 2017. In 2001, Site A results indicated a "low" ecological risk rating category (i.e. a "slightly unbalanced" community indicative of low-moderate mud and organic enrichment).
- In terms of the individual taxa causing these differences, the results showed that Site A in 2001 had a more diverse community with more abundant cockles and wedge shells, and relatively low numbers of taxa highly tolerant of muddy conditions (e.g. the amphipod *P. excavatum*) than at the same site in 2017. The results also showed that although the highly muddy Site D in 2017 had a similar spread of taxa to Site A in 2017, the dominant taxa (i.e. the amphipods *P. excavatum* and Phoxocephalidae sp.) were more abundant at the less muddy Site A.

BENTHIC RISK INDICATOR RATINGS

(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

	Low		Moderate
	Very Low		High

Ruataniwha Estuary	Site Rua A (Central)				Site Rua D (Upper)		
	2001	2017	Yr 2	Yr 3	2017	Yr2	Yr 3
Sediment Mud Content							
Redox Potential (Oxygenation)							
TOC (Total Organic Carbon)							
Total Nitrogen							
Invertebrate Mud/Org Enrichment		Low-Mod			Low-Mod		
Metals (Cd, Cu, Cr, Pb, Zn)							
Metal (Ni)							
Metal (As)							
Metal (Hg)							

ESTUARY CONDITION AND ISSUES

In terms of mud and organic enrichment, the various physical and chemical indicators, NZ Hybrid AMBI scores, and macroinvertebrate taxa analyses, all indicated a muddiness issue in the upper estuary, accompanied with poor sediment oxygenation. Increased muddiness at Site A since 2001, with a consequent shift towards a more mud tolerant community, indicates that estuary condition has deteriorated since it was last monitored in 2001, and is currently in a moderate ecological condition.

Ruataniwha Estuary - Executive Summary (continued)

RECOMMENDED MONITORING AND MANAGEMENT

Robertson and Stevens (2012) assessed Ruataniwha Estuary to be vulnerable to pathogen inputs (predominantly from the 10% high-producing pasture within the catchment), but to be only moderately vulnerable to excessive sedimentation and eutrophication because most of the catchment (80%) has a native forest and scrub cover. However, because it is a moderate-large estuary with high ecological and human use values, it is one of the key estuaries in Tasman District Council's (TDC's) long-term coastal monitoring programme.

The common practice amongst NZ Regional Councils to assess ongoing long-term trends in the condition of estuaries is 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. In some situations, where estuary condition is good and issues are at a low level, fine scale monitoring is often reduced to every 5 years with baselines only implemented once issues are identified. Ruataniwha Estuary was previously regarded as being in the latter category, however recent broad scale monitoring (Stevens and Robertson 2015) identified excessive muddiness as an issue in the estuary, and the current fine scale results, particularly the changes at Site A since 2001, highlight a significant increase in estuary muddiness.

Based on these results, the recommendations for ongoing fine scale and broad scale monitoring for the Ruataniwha Estuary are as follows:

Fine Scale Monitoring

Due to the deterioration (significantly increased muddiness) identified at Site A since it was last monitored in 2001, it is recommended that a fine scale baseline be established in Ruataniwha Estuary by completing two further consecutive years of annual summer (i.e. Dec-Feb) fine scale monitoring at Sites A and D in 2018 and 2019, and then undertaking impact monitoring at 5 yearly intervals. This will establish a robust ecological baseline of monitoring data which can be used as a reference for assessing any change in the estuary over time.

To characterise the potential for excessive sedimentation, it is recommended that sedimentation rate be assessed annually by measuring established sediment plates in conjunction with the fine scale sampling.

Broad Scale Habitat Mapping

It is recommended that the spatial extent of muddy sediments be mapped at 5 yearly intervals (next proposed for 2020), with more detailed habitat mapping (e.g. saltmarsh, seagrass, macroalgae), undertaken at 10 yearly intervals (next proposed for 2025), unless obvious changes are observed in the interim.

Catchment sources

It is recommended that the potential source of sediments entering the estuary be assessed (e.g. directly assessing or modelling land use changes over the past decade, or using source tracking methods of fine sediments deposited in the estuary).

Recommended Management

The initial monitoring has identified specific issues in the estuary that will require ongoing monitoring of changes from the baseline in order to appropriately characterise them for management purposes. In the interim it is recommended that the estuary be managed in a way that does not exacerbate current conditions (i.e. no increase in current sediment loads, and no loss of estuary high value habitat). In the future, as more monitoring data become available, the full extent of the identified muddiness issue can be more accurately identified and defensible management decisions developed to help ensure that the assimilative capacity of the estuary is not exceeded and that the estuary can flourish and provide sustainable human use and ecological values in the long term.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of these ecosystems and the catchments that discharge into them. These objectives, along with understanding change in condition/trends, are key objectives of Tasman District Council's State of the Environment Estuary monitoring programme. Recently, Tasman District Council (TDC) undertook a vulnerability assessment of the region's coastlines to establish priorities for a long-term monitoring programme (Robertson and Stevens 2012). The assessment identified the Waimea, Moutere, Motueka Delta, Motupipi, Ruataniwha and Whanganui estuaries as priorities for monitoring.

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 the estuary to major issues (see Table 1) and appropriate monitoring design. A region-wide EVA has been undertaken (Robertson and Stevens 2012) providing specific recommendations for Ruataniwha Estuary.
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. Broad scale mapping of Ruataniwha Estuary was first undertaken in 2000 during development of the NEMP (Robertson et al. 2002), and again in 2015 (Stevens and Robertson 2015). In addition, historical vegetation cover was assessed from 1950 and 1972 aerial photographs (Tuckey and Robertson 2003).
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 Ruataniwha Estuary, was first undertaken in 2001 during development of the NEMP (Robertson et al. 2002), and again in January 2017 which is the subject of this report.

In 2016, TDC commissioned Wriggle Coastal Management to undertake fine scale monitoring at two sites in Ruataniwha Estuary, the first fine scale assessment since inaugural monitoring of the estuary in 2001 during development of the NEMP. The current report presents the January 2017 fine scale monitoring results. It is proposed that when a full baseline of data has been collected e.g. (3 consecutive years of annual data), the combined data set will be fully analysed and compared with estuary risk indicator ratings in order to assess the overall estuary condition, identify any issues, and recommend ongoing monitoring and management.

Ruataniwha Estuary

Ruataniwha Inlet is a moderately large-sized (~850ha), macrotidal (3.66m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary (Figure 1, Table 2, Robertson et al. 2002). It has a single wide tidal opening (1.6km), one large basin, and several narrow upper estuary tidal arms (largely confined within river banks), several small causeways, and extensive areas of shoreline armouring.

The catchment (767km^2) is dominated by native forest and scrub (80%) and high-producing pasture (10%), with much of the immediate estuary margin directly bordered by developed pasture /rural land, roads, causeways and seawalls.

The estuary has a relatively simple shape, but contains a wide variety of intertidal habitats due, in part, to the strong influence of the Aorere River which enters the estuary in the south west and where extensive cobble, gravel, sand, and biogenic (cockle, mussel, tubeworm) habitats are located in the well flushed lower reaches of the estuary.

Previous broad scale mapping (Robertson et al 2002) has shown the estuary is dominated by intertidal sand and mudflats (firm mud sands (204ha), firm sands (214ha),soft muds (90ha)), as well as saltmarsh (133ha), seagrass (12ha), and cobble and gravel fields (86ha).

Historical loss of high value saltmarsh habitat through conversion to pasture is likely to have been very high. Tuckey and Robertson (2003) showed no appreciable differences in saltmarsh cover in 1950, 1972 and 2000 (based on mapping dominant habitat features using the aerial photographs of the estuary). However, most saltmarsh modification is likely to have occurred prior to 1950. The loss of saltmarsh habitat will primarily have been due to reclamation and drainage around margin areas, with resulting shoreline modification (e.g. seawalls, bunds, roads) now greatly limiting natural saltmarsh expansion and restricting its capacity to migrate inland in response to predicted sea level rise. Thus under predicted scenarios of increasing sea level, saltmarsh is expected to become progressively displaced in the future.

The estuary has high use and is valued for its aesthetic appeal, rich biodiversity, shellfish collection, bathing, waste assimilation, whitebaiting, fishing, boating, walking, and scientific appeal. The inlet is a valuable nursery area for marine and freshwater fish, an extensive shellfish resource, and is very important for birdlife. A small wharf is located at Collingwood near the south eastern entrance.

Recent broad scale mapping (Stevens and Robertson 2015) identified the main issues in the estuary as excessive muddiness (18.5% of the estuary), as well as significant habitat modification, primarily through the displacement and reclamation of saltmarsh, ingress of terrestrial weeds (e.g. gorse, blackberry, tall fescue), and the conversion of much of the densely vegetated terrestrial margin to pasture. Eutrophication, expressed through indicators of macroalgal growth and the presence of gross eutrophic conditions, was not a significant issue. More recently, trials have commenced to assess the sustainability of harvesting of juvenile cockles from the estuary for translocation to nearby commercial beds.

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

1. Sediment Changes

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

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

Recommended Key Indicators:

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

2. Eutrophication

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

Recommended Key Indicators:

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

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

2. ESTUARY RISK INDICATOR RATINGS

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

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

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

The indicators and condition ratings used for the Ruataniwha 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) with 1-2 sites per estuary (although this varies depending on estuary size or complexity). The recently developed NZ ETI (Robertson et al. 2016b) also requires assessment of sediment condition in the primary mud deposition zone of estuaries where eutrophic conditions are most likely to be first expressed.

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

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

Synoptic water samples from estuary surface and bottom waters and subtidal sediment samples also provide very useful information to support intertidal assessments where estuaries include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted). This was not an identified issue in Ruataniwha.

For the Ruataniwha Estuary, two fine scale sampling sites each 30m x 60m (Figure 1), were selected in unvegetated, mid-low water habitat. Site A was located in the sand dominated flats representative of much of the upper main basin (this was the same Site A established in 2001). Site D was established in an upper estuary deposition zone dominated by fine muds and has not been monitored previously. Two other sites that were monitored in 2001 (Sites B and C) were not monitored in 2017 because of the need to optimise monitoring to two sites, and because neither site was located in the mud deposition zone of the estuary, as required by the ETI. 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.

Figure 1. Location of fine scale sampling sites, Ruataniwha Inlet, Golden Bay.

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

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

- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled 0.5mm nylon mesh bag. Once all replicates had been collected at a site, the bags were transported to a nearby source of seawater and fine sediments were washed from the core. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.
- The samples were sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).
- Where present, macroalgae and seagrass vegetation (including roots) was collected within each of three representative 0.0625m2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured.

3. Methods (continued)

- 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 were identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix 1), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Table B, Appendix 1). Species size determines both the quadrat size and SACFOR density rating applied, while photographs are taken and archived for future reference. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal and microalgal cover.

Sediment accumulation

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

Two sites, each with four plates (20cm square concrete paving stones) were established in Ruataniwha Estuary (15 December 2015) in the deposition area in the north of the estuary (Site D) and at the more central fine scale Site A (Figure 1). Plates were buried within sediments where stable substrate was located and positioned 2m apart in a linear configuration. Wooden pegs were used to mark either end and the midpoint of the plate configuration. To ensure plate stability, steel waratahs (0.8m long) were driven into the sediments until firm substrate was encountered beneath the plates, and the plates placed on these. 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. The first of the annual monitoring results are presented in Appendix 2.

Installing sediment plates 2015.

4. RESULTS AND DISCUSSION

A summary of the results of the 9 January 2017 and 14 March 2001 fine scale intertidal monitoring of Ruataniwha Estuary is presented in Table 3, with detailed results in Appendices 2 and 3. Analysis and discussion of the results are presented as two main steps; firstly, exploring the primary environmental variables that are most likely to be driving the ecological response in relation to the key issues of sedimentation, eutrophication and toxicity, and secondly, investigating the biological response using the macroinvertebrate community.

Table 3. Summary of fine scale physical, chemical, vegetation, and macrofauna results (means), Ruataniwha Estuary, January 2017 and March 2001.

Year Site	aRPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2017 A	0.5	30	0.42	44.6	55.0	1.0	0.050	21.7	11.3	17.4	5.0	40.3	4.7	<0.01	<500	580
2017 D	0.5	30	0.79	85.6	14.3	0.1	0.056	27.0	14.4	21.3	7.4	47.7	5.2	0.016	567	730
2001 A	3	NA	NA	10.2	89.5	0.4	0.1	27.1	8.7	15.5	7.6	40.8	NA	NA	250	542

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
2017 A	0	0	1726	7.2
2017 D	0	0	874	5.4
2001 A	0	0	867	6.2

NA = Not Assessed

Primary Environmental Variables

The primary environmental variables that are most likely to be driving the ecological response in relation to the key potential issues of sedimentation, eutrophication and toxicity are as follows:

- For sedimentation or sediment muddiness, the variables are sediment mud content (often the primary controlling factor) and sedimentation rate.
- For eutrophication, the variables are organic matter (measured as TOC and macroalgal biomass), nutrients, sediment oxygenation [either directly measured as redox potential, or by measuring the redox potential discontinuity depth (aRPD), a qualitative measure of both available oxygen and the presence of eutrophication related toxicants such as ammonia and sulphide)] (Dauer et al. 2000, Magni et al. 2009).

The influence of non-eutrophication related toxicity is primarily indicated by concentrations of heavy metals. Where metal concentrations are found to be elevated or direct inputs are likely, a second screen for pesticides, polycyclic aromatic hydrocarbons, and semi-volatile organic compoundss is usually undertaken. This second screen was not undertaken because metal concentrations were found to be low.

Fine scale Site A in soft muddy sand sediments

Fine scale Site D in very muddy sediments

SEDIMENT INDICATORS

4.1.1 Sediment Mud Content

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

Results showed that the two Ruataniwha Estuary sites had contrasting sediment mud contents (Table 3, Figure 2). The upper estuary deposition zone Site D (representative of 18% of the intertidal area) had the highest mud concentrations (mean 86% mud), while the more centrally located and better flushed Site A (representative of 43% of the intertidal area) had lower mud concentrations (mean 45%). The high mud content for both sites 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*. Sedimentation rates have been measured over buried plates for only one year, so are very preliminary in terms of trends, but showed high mean annual average deposition at both Site A (6.8mm) and Site D (5mm) from 2016 to 2017 (data in Appendix 2).

Figure 2 also shows a large change in mean mud content at Site A, from 10% mud in 2001 to 45% mud in 2017, an increase of over 400%. The reason for this change is almost certainly the result of fine sediment inputs from the estuary catchment.

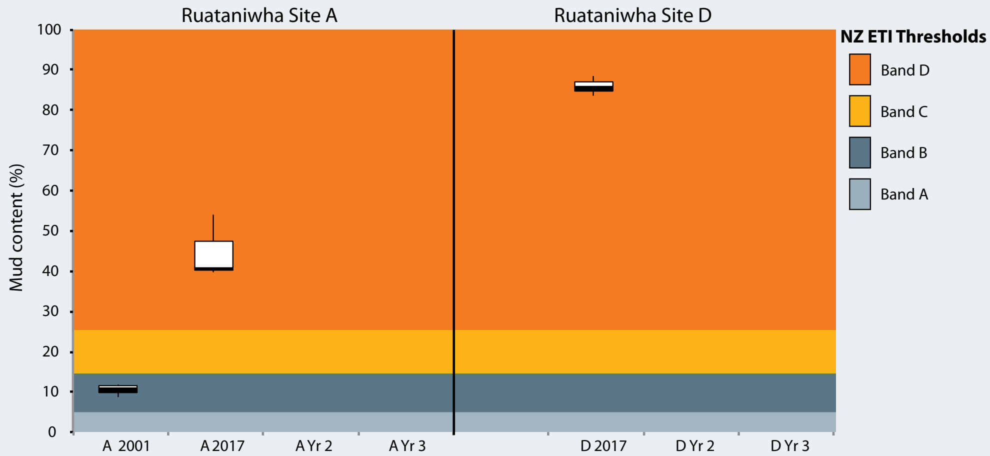


Figure 2. Mean mud content (median, interquartile range, total range, n=3), Ruataniwha Estuary 2001 and 2017.

4.1.2 Eutrophication

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

Macroalgae and Seagrass

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

4. Results and Discussion (continued)

Results for 2017 at both Sites A and D showed <5% cover of opportunistic macroalgae and the absence of seagrass (Figure 3). Such findings indicate low levels of eutrophication at the sites and unsuitable conditions for seagrass growth. In 2001, conditions at Site A were similar to 2017.

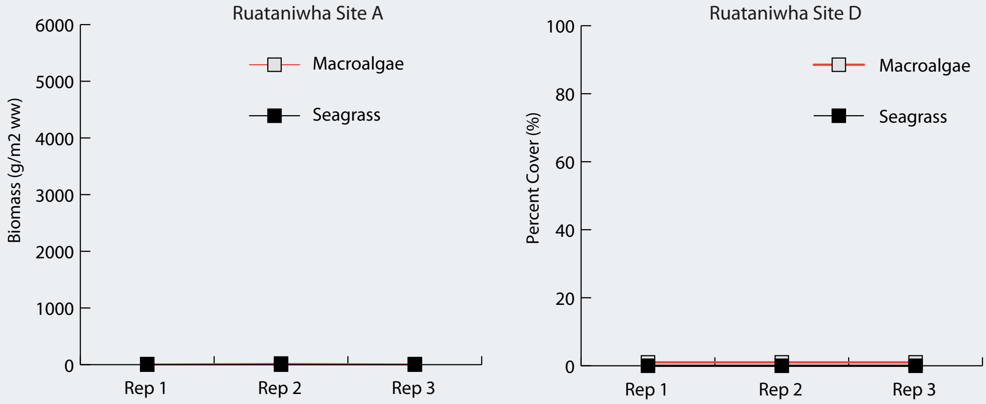


Figure 3. Biomass and percent cover of opportunistic macroalgae and seagrass, Ruataniwha Estuary 2017.

Sediment Mud Content

This indicator has been discussed in the Section 4.1.1 and is not repeated here. However, in relation to eutrophication, the high mud contents at both sites indicate sediment oxygenation is likely to be relatively poor.

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 4).

Figure 4 shows the aRPD depths from the surface in 2017 and 2001, and redox potentials (5 depths at each site, mean of triplicate measures plotted) for the two Ruataniwha Estuary sampling sites in 2017.

The results show that the aRPD depth was relatively shallow at 0.5cm at both Sites A and D in 2017. In 2001 at Site A the aRPD depth was deeper at 3cm. The RP for the sites in 2017 (Figure 4) identified poor oxygenation conditions (i.e. low redox <-150mV, Band D) beginning at ~0.5cm depth at both sites. These results indicate that sediment oxygenation was likely to support predominantly tolerant opportunistic species.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and nutrients (TN and TP) in estuarine mud 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 two sites in 2017 showed TOC (<0.8%) and TN (<600mg/kg) were in the "very low" or "low" risk indicator ratings, while TP (rating not yet developed) was relatively low at 580-730mg/kg (Figures 5, 6 and 7). Whilst TOC was not measured in 2001, TN and TP were at similar low concentrations to those measured in 2017.

Of particular note, was the fact that the most impacted site in terms of mud and redox potential (i.e. Site D), did not have elevated TOC, TN and TP concentrations, a fact which probably contributes to the low level of macroalgae at the site.

The combined expression of the above results are likely to be reflected as a change in the abundance of mud and organic enrichment sensitive taxa between sites (see discussion later in this Section).

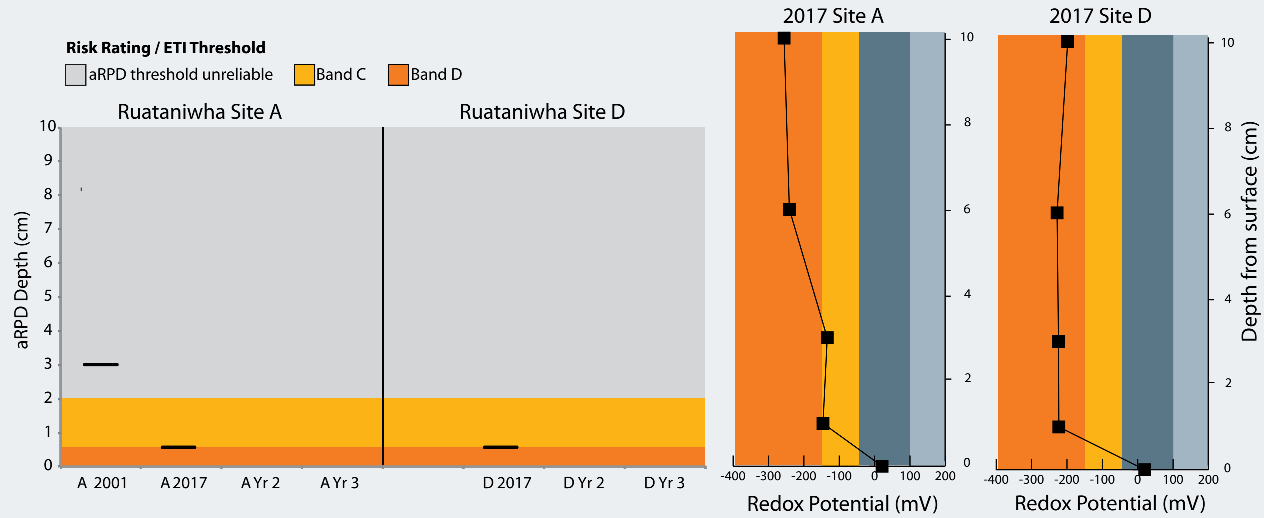


Figure 4. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3) in 2001 and 2017, and Redox Potential (RPmV) at 5 depths in 2017.

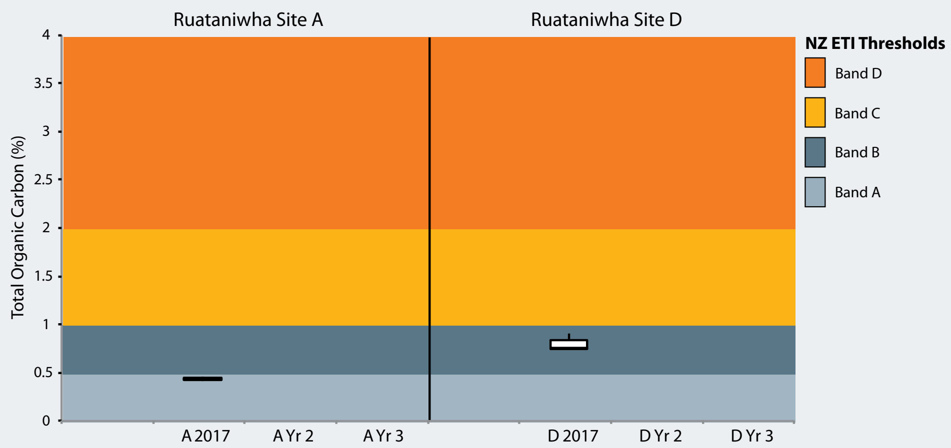


Figure 5. Mean total organic carbon (median, interquartile range, total range, n=3), 2017.

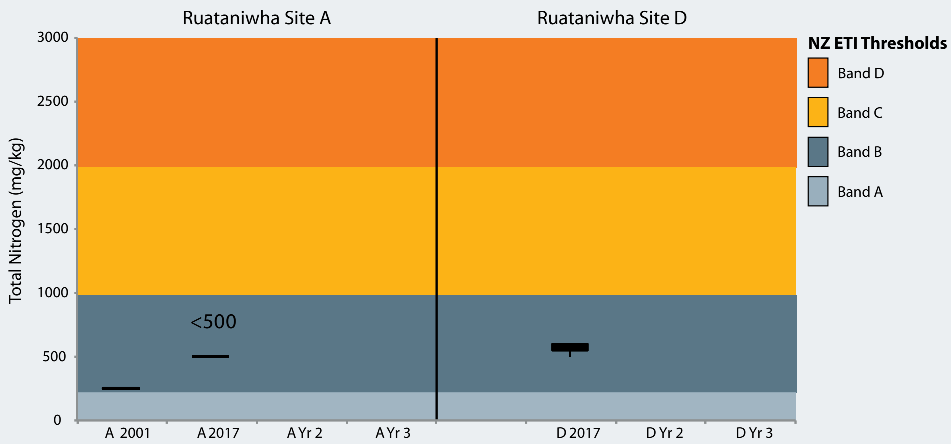


Figure 6. Mean total nitrogen (median, interquartile range, total range, n=3), 2001 (A) and 2017 (A and D).

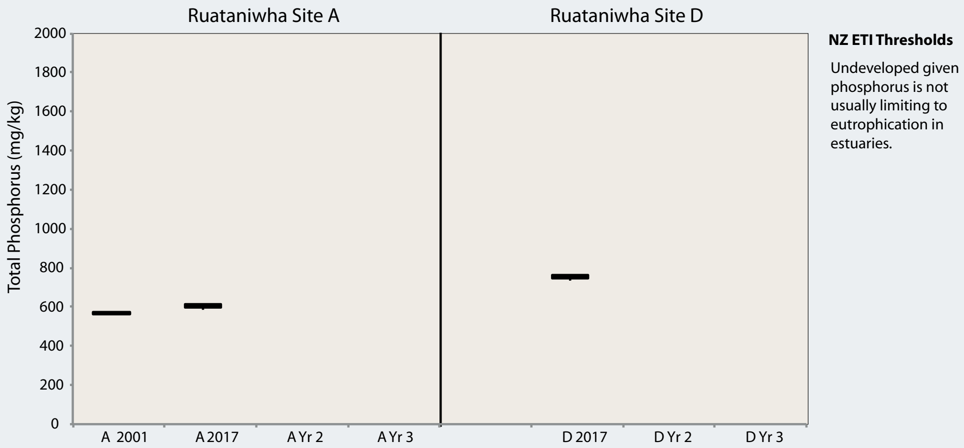


Figure 7. Mean total phosphorus (median, interquartile range, total range, n=3), 2001 (A) and 2017 (A and D).

4.1.3 Toxicity

The 2017 results for heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn and arsenic, used as indicators of potential toxicants, were present at all sites at "very low" to "low" concentrations, or "moderate" in the case of arsenic.

In 2001, Site A had "very low" to "low" concentrations for Cd, Cr, Cu, Pb, and Zn, and "moderate" concentrations for nickel.

All non-normalised values were below the ANZECC (2000) ISQG-Low trigger values (Table 4), and therefore posed no toxicity threat to aquatic life.

Table 4. Indicator toxicant results for Ruataniwha Estuary, Site A (2001) and Sites A and D (2017).

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
Feb 2017 A 1-4 *	0.013	8.5	3.3	5.6	4.5	27	10.3	0.011
Feb 2017 A 4-8 *	0.015	8.7	3.4	5.9	4.7	27	11.5	0.016
Feb 2017 A 9-10 *	0.018	8.9	3.3	5.8	4.7	27	11.1	0.017
Feb 2017 D 1-4 *	0.025	9.8	5.3	8.2	5.9	37	15.6	0.033
Feb 2017 D 4-8 *	0.026	9.4	5.4	8.3	5.9	36	16.7	0.032
Feb 2017 D 9-10 *	0.021	9.5	5.2	8	5.7	35	16.9	0.03
March 2001 A 1-4 **	0.020	27.0	8.8	15.8	6.6	42.0	NA	NA
March 2001 A 4-8 **	0.020	28.0	8.9	15.5	8.1	40.3	NA	NA
March 2001 A 9-10 **	0.020	24.0	8.0	13.5	7.8	37.5	NA	NA
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, mean of 4 samples

4.1.4 Benthic Macroinvertebrate Community

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

The response of macroinvertebrates to stressors in Ruataniwha Estuary will be analysed in detail once sufficient baseline monitoring data (i.e. 3-4 consecutive years) is available. This analysis will include four steps:

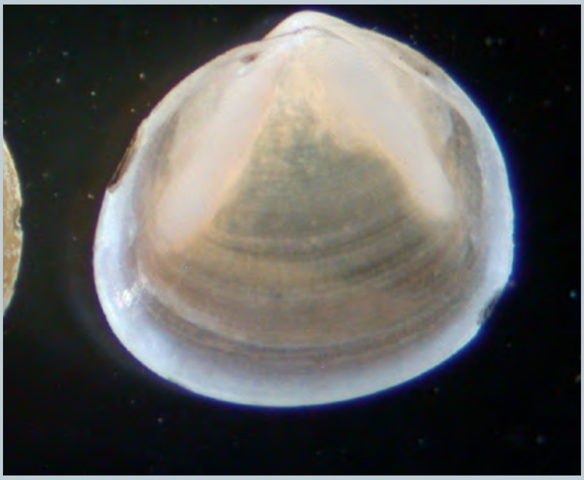
1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (v.6) package will be used to evaluate and compare the relative importance of 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 baseline monitoring data for both sites, this section of the report will present and interpret data in relation to steps 1, 3 and 4 only.

Macroinvertebrate Community Ordination

Principle Coordinates Analysis (PCO), based on species abundance data for Site A (2001 and 2017) and Site D (2017), showed that the invertebrate community at Site A in 2001 and in 2017 was significantly different (i.e. PERMANOVA $P<0.0001$, Figure 8). In addition it showed that the invertebrate community at Site A in 2017 was significantly different from Site D in 2017 (i.e. PERMANOVA $P<0.0001$, Figure 8).

Vector overlays of environmental variables (based on Pearson correlations) are also presented in order to provide information in relation to the potential influence of environmental factors at each of the sites (a more robust analysis will be undertaken once a full set of baseline data has been collected). The results clearly identify differences in mud content and redox potential discontinuity depth (aRPD) as a likely explanation of the differences in invertebrate community structure between the 2001 and 2017 Site A data as well as between the 2017 data for Sites A and D.



Arthritica bifurca (nut clam) dominant at Site D 2017

Paracorophium sp. (amphipod) dominant at Sites A and D 2017 (Photo Landcare Research)

4. Results and Discussion (continued)

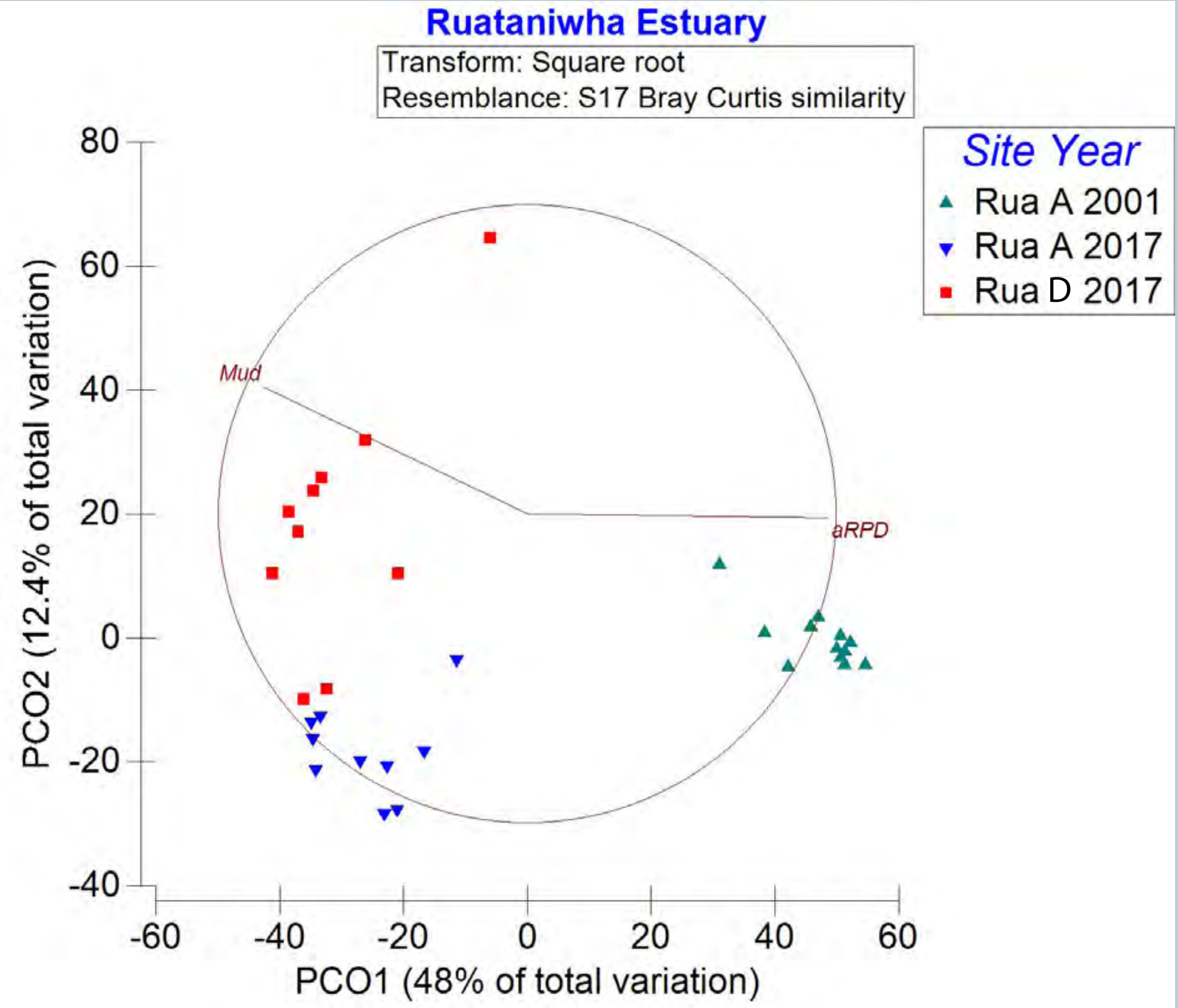


Figure 8. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at each site, Ruataniwha Estuary, 2001 and 2017 and the environmental variables mud and redox potential discontinuity depth (aRPD) that closely reflect the observed differences.

Figure 8 shows the relationship among samples in terms of similarity in macroinvertebrate community composition at Sites A and D, for the sampling period 2001 and 2017. The plot shows the 10 replicate samples for Sites A and D in 2017 and 12 replicates for Site A in 2001, and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves an unconstrained multivariate data analysis method, in this case principle coordinates analysis (PCO) using PERMANOVA version 1.0.5 (PRIMER-e v6.1.15). The analysis plots the site and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities (i.e. how much of the variation in the data matrix is explained by the first two PCO axes). For the present plots, the cumulative variation explained was >60% for all sites, indicating a good representation of the abundance matrix.

PERMANOVA, testing for statistical significant differences in the invertebrate communities among samples, reflected highly significant (*P*>0.0001) structural changes between both Site A 2001 and Site A 2017, as well as between Site A 2017 and Site D 2017.

The environmental vector overlays, based on Pearson correlations, show preliminary exploratory information on the strength of environmental relationships with their length in relation to the circle boundary indicating the magnitude of the strength. In this case, the results indicate that the 2001 communities were likely separated from the 2017 by mud concentrations and sediment oxygenation (i.e. aRPD).

4. Results and Discussion (continued)

Species Richness, Abundance and Diversity

In this step, simple univariate whole community indices, i.e. species richness, abundance and diversity are presented for each site (Figure 9), and in the future when more data is available, will be used to help explain any differences between years indicated by other analyses.

The data showed relatively low species richness (2-13 per core), abundance (4-61 per core) and Shannon diversity (0.6-2.3 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 (1.2-2.8 per core) - Robertson and Stevens 2015)].

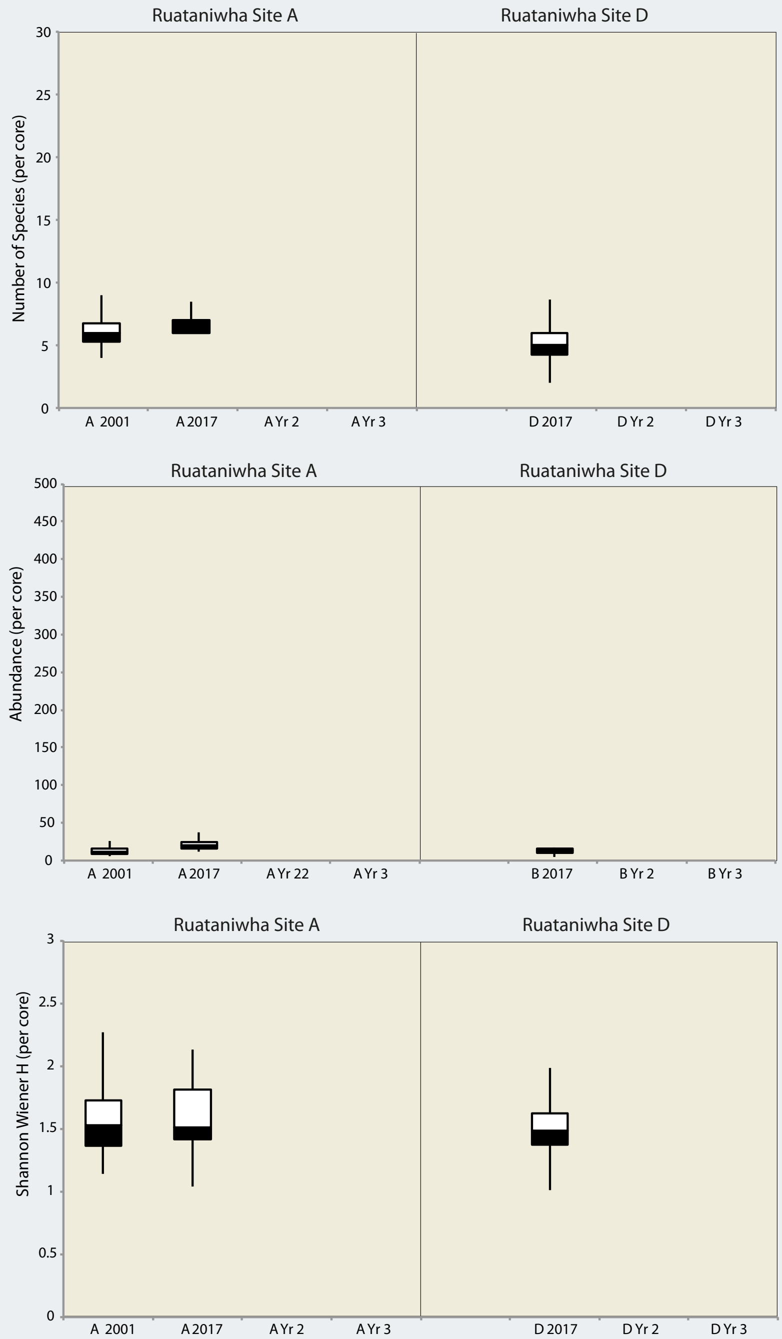


Figure 9. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Ruataniwha Estuary, March 2001 and January 2017.

4. Results and Discussion (continued)

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

A. Mud and Organic Enrichment Index (NZ AMBI)

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

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

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

For the two fine scale sites in Ruataniwha Estuary, the median NZ AMBI biotic coefficients were; for Site A, 2.0 in 2001 and 2.9 in 2017; and for Site D 3.0 in 2017. The results identified both Sites A and D in 2017 to be in the “good” to “moderate” ecological condition category (i.e. a “slightly unbalanced” to “transitional” type community indicative of low levels of organic enrichment and moderate to high mud concentrations) (Figure 10). In 2001, the Site A results indicated a “good” ecological condition category (i.e. a “slightly unbalanced” community indicative of low levels of mud and organic enrichment) (Figure 10). As expected, the muddier Site D, as well as Site A in 2017, had consistently higher NZ AMBI biotic coefficients than the more sand dominated main basin Site A in 2001.

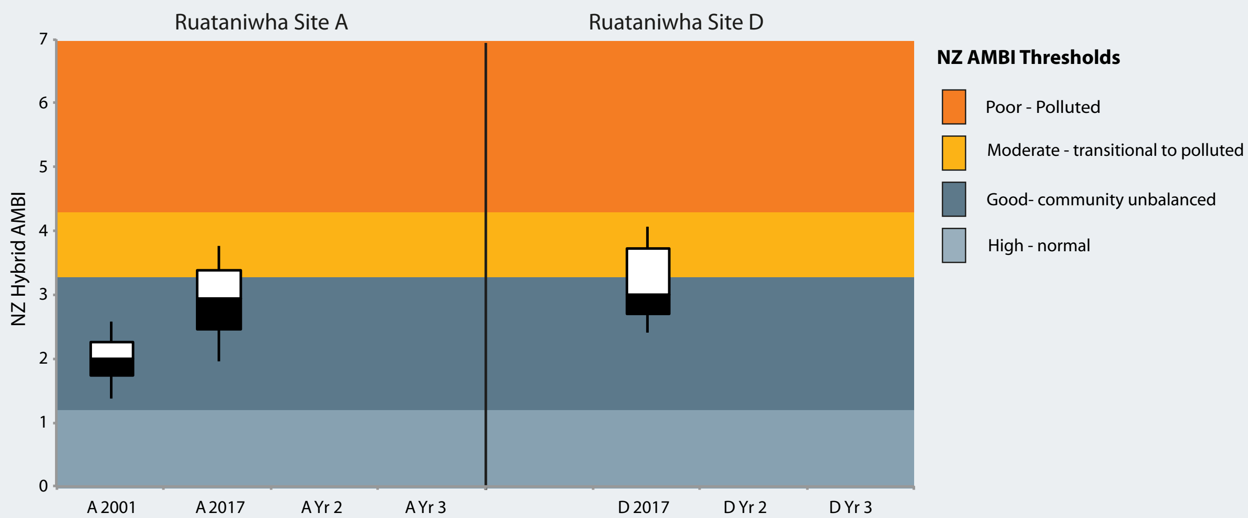


Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Ruataniwha Estuary, 2001 and 2017.

B. Taxonomic Groups and Individual Species

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

1. Taxonomic Groups

Table 5 shows that in 2001 the Site A community was the most diverse in terms of major taxa groups (i.e. 8) and was dominated by polychaetes and bivalves, and to a lesser extent crustaceans. However, in 2017, the Site A community had lower diversity (i.e. 6 major taxa groups) and was dominated by crustaceans, and to a lesser extent, anemones and polychaetes. Table 5 also shows that in 2017 Sites A and D had similar taxa diversity (i.e. both had 6 taxa groups) but differing abundances for the dominant groups. Such findings provide a preliminary insight into the taxonomic differences between the sites and years.

Table 5. Summary of major taxa groupings data for Ruataniwha Estuary sites in 2001 and 2017.

Major Taxa Group	Site A 2001	Site A 2017	Site D 2017
	Mean abundance per core		
Anthozoa (sea anemones)	0.00	1.90	0.30
Nemertea (ribbon worms)	0.42	0.60	0.10
Sipuncula (peanut worms)	0.33	0.00	0.00
Polychaeta (bristle worms)	3.67	1.60	1.90
Oligochaeta (worms)	0.17	0.00	0.10
Gastropoda (snails)	0.25	0.00	0.00
Bivalvia (e.g. cockle)	4.50	0.80	2.20
Crustacea (e.g. amphipod)	1.58	17.90	7.00
Insecta	0.58	0.10	0.00

2. Dominant Taxa

Table 6 shows the dominant taxa at each site with the most significant points as follows:

- **Site A 2001**. The dominant taxa were the suspension feeding cockle *A. stutchburyi*, the capitellid polychaete *H. filiformis*, the bamboo worm *M. stewartensis,* an amphipod, and the deposit feeding wedge shell *T. liliana.*
- **Site A 2017**. The dominant taxa were very different from 2001 and included the tube-dwelling corophioid amphipod *P. excavatum,* a gammarid amphipod Phoxocephalidae, the burrowing anemone *Edwardsia* sp., and the burrowing mud crab *A. crassa*.
- **Site D 2017**. The dominant taxa were a gammarid amphipod Phoxocephalidae, the tube-dwelling corophioid amphipod *P. excavatum,* the small deposit feeding bivalve *Arthritica sp.,* and two polychaetes *N. aesturiensis* and *B. syrtis.*

3. Dominant Taxa Differences Between Sites and Years

The Similarity Percentages procedure (SIMPER) (PRIMER-e) (Clarke 1993) was applied to indicate which macrofauna taxa contributed most to the difference in macroinvertebrate community structure between sites and years (Table 7). The dominant species in each site and a brief overview (including photograph) of their characteristics are presented in Table 8.

Table 6. Most abundant species at each site in 2001 and 2017.

Site A 2001			
Group	**Taxa**	**NZ H AMBI**	**Nos/Core**
Bivalvia	*Austrovenus stutchburyi*	2	3.8
Polychaeta	*Heteromastus filiformis*	3	1.8
Polychaeta	*Macroclymenella stewartensis*	2	1.1
Crustacea	Amphipoda sp.	2	0.9
Bivalvia	*Tellina liliana*	2	0.7
Insecta	Diptera sp. 2	2	0.6
Nemertea	Nemertea	0	0.4
Crustacea	*Austrohelice crassa*	5	0.4
Sipuncula	Sipuncula	2	0.3
Polychaeta	*Capitella capitata*	4	0.3

The cockle, *Austrovenus stutchburyi*, was dominant at Site A in 2001 but was less abundant at the same site in 2017

Site A 2017			
Group	**Taxa**	**NZ H AMBI**	**Nos/Core**
Crustacea	*Paracorophium* sp.	4	8.3
Crustacea	Phoxocephalidae sp. 1	2	6.8
Anthozoa	*Edwardsia* sp. 1	2	1.9
Crustacea	*Austrohelice crassa*	5	1.3
Crustacea	Decapoda larvae unid.	0	1.2
Nemertea	Nemertea sp. 1	0	0.6
Bivalvia	*Austrovenus stutchburyi*	2	0.5
Polychaeta	Maldanidae	1	0.4
Polychaeta	Nereididae	3	0.4
Bivalvia	*Tellina liliana*	2	0.3

Site D 2017			
Group	**Taxa**	**NZ H AMBI**	**Nos/Core**
Crustacea	Phoxocephalidae sp. 1	2	3.2
Crustacea	*Paracorophium* sp.	4	3.0
Bivalvia	*Arthritica* sp. 1	4	1.9
Polychaeta	*Nicon aestuariensis*	3	1.0
Polychaeta	*Boccardia syrtis*	2	0.4
Polychaeta	Nereididae	3	0.4
Crustacea	*Austrohelice crassa*	5	0.4
Anthozoa	*Edwardsia* sp. 1	2	0.3
Bivalvia	*Cyclomactra ovata*	2	0.2
Crustacea	Decapoda larvae unid.	0	0.2

Table 7. Species causing the greatest contribution to the difference between macroinvertebrate community structure between Site A 2001 and 2017 (left table) and Site A 2017 and Site D 2017 (right table) (SIMPER Analysis - cutoff for low contributions 90%).

Site A 2001 and 2017				
Species	**NZH AMBI**	**2001 Av.Abund**	**2017 Av.Abund**	**Contrib %**
Paracorophium sp.	4	0	8.3	21.38
Phoxocephalidae sp. 1	2	0	6.8	19.38
Austrovenus stutchburyi	2	4.3	0.5	12.29
Edwardsia sp. 1	2	0	1.9	6.59
Heteromastus filiformis	3	1.6	0.2	4.69
Austrohelice crassa	5	0.3	1.3	4.27
Decapoda larvae unid.	NA	0	1.2	4.12
Amphipoda sp.	2	1	0	3.1
Macroclymenella stewartensis	2	1.1	0	2.89
Tellina liliana	2	0.8	0.3	2.59
Diptera sp. 2	2	0.6	0	2.09
Nemertea sp. 1	3	0	0.6	2.05
Nemertea	3	0.5	0	1.7
Nereididae	3	0.1	0.4	1.59
Maldanidae	1	0	0.4	1.4

Site A 2017 and Site D 2017				
Species	**NZH AMBI**	**Site A Av.Abund**	**Site D Av.Abund**	**Contrib %**
Paracorophium sp.	4	8.3	3	26.03
Phoxocephalidae sp. 1	2	6.8	3.2	17.09
Arthritica sp. 1	4	0	1.9	9.19
Edwardsia sp. 1	2	1.9	0.3	8.87
Austrohelice crassa	5	1.3	0.4	6.34
Decapoda larvae unid.	NA	1.2	0.2	5.47
Nicon aestuariensis	3	0.1	1	4.77
Nereididae	3	0.4	0.4	3.08
Nemertea sp. 1	3	0.6	0.1	2.93
Austrovenus stutchburyi	2	0.5	0.1	2.59
Boccardia syrtis	2	0.2	0.4	2.37
Maldanidae	1	0.4	0	2.07

4. Results and Discussion (continued)

Table 8. Dominant species causing the greatest contribution to the difference between macroinvertebrate community structure between sites and years (2001 and 2017) in Ruataniwha Estuary.

Paracorophium excavatum	A tube-dwelling corophioid amphipod that lives in the top 2cm - endemic to NZ. It is a suspension feeder that uses the long setae on their gnathopods to trap suspended organic matter. Found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Optimum range 0-50% mud, but can be abundant at 80-90% mud. Often present in muddy upper estuaries with regular low salinity conditions.	
Phoxocephalidae	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.	
Austrovenus stutchburyi	The cockle is a suspension feeding bivalve with a short siphon - lives in the upper few cm at mid-low water situations. More abundant near estuary mouth. Best growth at less than 10% mud. Important part of the diet of wading bird species and fish. It is a strong bioturbator whose presence enhances nutrient and oxygen fluxes and influences the types of other macroinvertebrate species present.	
Edwardia sp.	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 NZ. Prefers mud-sand sediments with mud content 7-33% but can tolerate high mud contents.	
Heteromastus filiformis	Small sized capitellid polychaete. A sub-surface deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Despite being a capitellid, *Heteromastus* is not opportunistic and does not show a preference for areas of high 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.	
Arthritica bifurca	*Arthritica bifurca* is a small sedentary, deposit feeding bivalve (<6mm shell length). Lives greater than 2cm deep in the mud-sand, intertidal and subtidal. Prefers moderately muddy habitats (>25% mud). Where estuarine sediments change from a sandy to muddier type habitat the abundance of *Arthritica bifurca* is expected to increase.	
Austrohelice crassa	Endemic, burrowing mud crab. *Helice crassa* is concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.	
Tellina (Macomona) liliana	A deposit feeding wedge shell, living at 5–10cm depth with a long siphon, that is also capable of suspension feeding (Olafsson 1986). Juveniles live in top 2cm. Optimum mud range 1-38%, but thrive best in <10% mud. It is a strong bioturbator whose presence enhances nutrient and oxygen fluxes and influences the types of other macroinvertebrate species present (Thrush et al. 2006).	
Macroclymenella stewartensis	Bamboo worms. A sub-surface, deposit-feeder that is usually found in tubes of fine sand or mud. This species is found throughout the sediment to depths of 15cm and potentially has a key role in the re-working and turn-over of sediment. Common at low water in estuaries. Intolerant of anoxic conditions.	

4. Results and Discussion (continued)

Differences Between Site A 2001 and Site A 2017

SIMPER analysis (Table 7) showed that the species that contributed most to the dissimilarity between Site A 2001 and Site A 2017 were the amphipods *P. excavatum* and Phoxocephalidae sp., which were both absent from Site A in 2001 but abundant at Site A in 2017 (8.3 and 6.8 per core respectively), and the cockle *A. stutchburyi*, which was relatively abundant at Site A 2001 (3.8 per core) compared to Site A 2017 (0.5 per core).

Interestingly, the two species that contributed most to the dissimilarity between Site A 2017 and Site D 2017 were the same as between Site A in 2001 and 2017, i.e. the amphipods *P. excavatum* and Phoxocephalidae sp. However, this dissimilarity was expressed differently in that these taxa were present at both sites, but the abundances of both taxa were greater at Site A 2017.

Also of interest is the declining abundance of the two larger shellfish, i.e. the cockle *A. stutchburyi*, and the wedge shell *T. liliana,* between Site A 2001 (4.3 and 0.8 per core respectively), Site A 2017 (0.5 and 0.3 per core respectively), and Site D 2017 (0.1 and 0 per core respectively).

The reasons for these dissimilarities are more clearly portrayed in Figure 11, which shows the mean dominant taxa abundances for these three physico-chemically different habitats, but also includes their mud and organic enrichment sensitivity groupings (Robertson et al. 2015). It is apparent from the plot that the majority of Site A 2001 taxa and abundances fit in the moderate sensitivity groups i.e. Group 2 (sensitive to mud and organic enrichment) and Group 3 (widely tolerant of mud and organic enrichment). On the other hand, the majority of Site A 2017 taxa and abundances, as well as fitting Groups 2 and 3, also extend into Groups 4 (prefers muddy, organic enriched sediments) and 5 (very strong preference for muddy, organic enriched sediments). Site A in both years also showed the presence of some taxa in Group 1 (highly sensitive to mud and organic enrichment).

However, the highly muddy Site D in 2017 had no taxa in the highly sensitive Group 1, and a spread of taxa in each of the other sensitivity groups. Such findings provide further information to support the earlier PCO ordination, and NZH AMBI-RI results, that mud content is a likely major driver of the macroafaunal community.

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for the two long term intertidal monitoring sites within Ruataniwha Estuary in 2017, and for one Site in 2001, showed the following key findings:

Physical and Chemical Condition

- Macroalgae were absent from the fine scale sites, and relatively uncommon in the estuary generally (Stevens and Robertson 2015), indicating low levels of eutrophication.
- Sediment mud content showed a large change at Site A, from 10% mud in 2001 to 45% mud in 2017, an increase of over 400% indicating a muddiness issue in the upper estuary. In 2017 the mud content at the main deposition Site D was very high at 86% mud. The high mud content for both sites in 2017 fits the Band D rating, and indicates the following ecological conditions are likely: *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.*
- Sediment oxygenation (aRPD) was 0.5cm at Sites A and D in 2017 indicating of “high risk of ecological impacts”. This conclusion was supported by the fact that sediment oxygenation, as measured by redox potential, identified poor oxygenation conditions at both sites in 2017 (i.e. <-150mV within 1cm of the surface). In contrast, Site A in 2001 had an aRPD of 3cm indicating a “low risk of ecological impacts”.

Figure 11. Mud and organic enrichment sensitivity of macroinvertebrates, Ruataniwha Estuary, 2001 and 2017 (see Appendix 3 for sensitivity details).

5. Summary and Conclusions (continued)

- Sediment organic matter and nutrient concentrations for the two sites in 2017 were low (TOC <0.8% and TN <600mg/kg) i.e. "very low" or "low" risk indicator ratings, while TP was unrated but relatively low at 580-730mg/kg. Whilst TOC was not measured in 2001, TN and TP were at similar low concentrations to those measured in 2017. Of particular note, is the fact that the most impacted site in terms of mud and redox potential (i.e. Site D), did not have elevated TOC, TN and TP concentrations, a fact which is probably related to the low level of macroalgae at the site.
- Sediment toxicants, heavy metals (Cd, Cu, Pb, Hg, Zn and arsenic), at Sites A and D in 2017 and Site A in 2001, were at concentrations that were not expected to pose toxicity threats to aquatic life.

These results indicate that conditions at Site A in 2001, had a sufficiently low level of mud to support a wide range of sensitive taxa. However, the high to very high mud content and very low redox levels throughout the sediment profile at Sites A and D in 2017 indicate conditions are unlikely to support well-balanced communities.

Biological Condition

These findings of a potential muddiness and sediment oxygenation issue in the estuary, based on the physical and chemical data analysis, were supported by the macroinvertebrate data. In particular, it was reflected in the abundance of mud and organic enrichment sensitive taxa between sites and years as portrayed by the NZ Hybrid AMBI biotic coefficients (i.e. a decline at Site A, where it was 2.0 in 2001 and 2.9 in 2017; to Site D where it was 3.0 in 2017. The results identified both Sites A and D in 2017 to be in the "good" to "moderate" ecological condition category (i.e. a "slightly unbalanced" to "transitional" type community indicative of low levels of organic enrichment and moderate to high mud concentrations). In 2001, the Site A results indicated a "good" ecological condition category (i.e. a "slightly unbalanced" community indicative of low levels of mud and organic enrichment).

In terms of the individual taxa causing these differences, the results showed that, compared with Site A in 2017, much lower mud content Site A in 2001 had a more diverse community with more abundant cockles and wedge shells, and relatively low numbers of taxa highly tolerant of muddy conditions (e.g. the amphipod *P. excavatum*). The results also showed that, although the highly muddy Site D in 2017 had a similar spread of taxa to Site A 2017, the abundances of the dominant taxa in each site (i.e. *P. excavatum* and Phoxocephalidae sp.) were greater at the latter. Interestingly, Site D 2017 also had the lowest abundances of the high value shellfish species i.e. cockles and wedge shells.

In terms of mud and organic enrichment, the various physical and chemical indicators, the NZ Hybrid AMBI scores and other macroinvertebrate taxa analyses, indicated that the estuary has an upper estuary muddiness (and accompanying poor sediment oxygenation) issue that has likely deteriorated since 2001. As a consequence, there has been a shift towards a more mud tolerant community and an overall moderate ecological condition.

Given the existence of both steep bush-dominated land and intensively farmed flats, the cause of the muddiness in the estuary is currently uncertain. As such, any monitoring focus should be on both determining the dominant source (e.g. through source tracking methods) and developing a solid ecological baseline of monitoring data which can be used as a reference for assessing changes in the estuary over time.

6. RECOMMENDED MONITORING

Robertson and Stevens (2012) assessed Ruataniwha Estuary to be vulnerable to pathogen inputs (predominantly from the 10% high-producing pasture within the catchment), but only moderately vulnerable to excessive sedimentation and eutrophication because most of the catchment (80%) has a native forest and scrub cover. However, because it is a moderate-large estuary with high ecological and human use values, it is one of the key estuaries in Tasman District Council's (TDC's) long-term coastal monitoring programme.

The common practice amongst NZ Regional Councils to assess ongoing long-term trends in the condition of estuaries is 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. In some situations, where estuary condition is good and issues are at a low level, fine scale monitoring is often reduced to every 5 years with baselines only implemented once issues are identified. Ruataniwha Estuary was previously regarded as being in the latter category, however recent broad scale monitoring (Stevens and Robertson 2015) identified excessive muddiness as an issue in the estuary and the current fine scale results, particularly the changes at Site A since 2001, highlight a significant increase in estuary muddiness.

Based on these results, the recommendations for ongoing fine scale and broad scale monitoring for the Ruataniwha Estuary are as follows:

Fine Scale Monitoring
Due to the deterioration (significantly increased muddiness) identified at Site A since it was last monitored in 2001, it is recommended that a fine scale baseline be established in Ruataniwha Estuary by completing two further consecutive years of annual summer (i.e. Dec-Feb) fine scale monitoring at Sites A and D sites in 2018 and 2019, and then undertaking impact monitoring at 5 yearly intervals. This will establish a robust ecological baseline of monitoring data which can be used as a reference for assessing any change in the estuary over time.

To characterise the potential for excessive sedimentation, it is recommended that sedimentation rate be assessed annually by measuring established sediment plates in conjunction with the fine scale sampling.

Broad Scale Habitat Mapping
It is recommended that the spatial extent of muddy sediments be mapped at 5 yearly intervals (next proposed for 2020), with more detailed habitat mapping (e.g. saltmarsh, seagrass, macroalgae), undertaken at 10 yearly intervals (next proposed for 2025), unless obvious changes are observed in the interim.

Catchment sources
It is recommended that the potential source of sediments entering the estuary should be assessed (e.g. directly assessing or modelling land use changes over the past decade, or using source tracking methods of fine sediments deposited in the estuary).

7. RECOMMENDED MANAGEMENT

The initial monitoring has identified specific issues in the estuary that will require ongoing monitoring of changes from the baseline in order to appropriately characterise them for management purposes. In the interim it is recommended that the estuary be managed in a way that does not exacerbate current conditions (i.e. no increase in current sediment loads, and no loss of estuary high value habitat). In the future, as more monitoring data become available, the full extent of the identified muddiness issue can be more accurately identified and defensible management decisions developed to help ensure that the assimilative capacity of the estuary is not exceeded and that the estuary can flourish and provide sustainable human use and ecological values in the long term.

8. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

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

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

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

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

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

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

B. DENSITY SCALES

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

Appendix 1. Details on Analytical Methods (Continued)

Macroinvertebrate sampling, sorting, identification and enumeration follows the general principles laid out in the protocol for processing, identification and quality assurance of New Zealand marine benthic invertebrate samples proposed by Hewitt et al. (2014). However, because the draft protocol does not address many important aspects for ensuring taxonomic consistency or required resolution, and provides limited explanation or support for many recommended procedures, Wriggle have instead adopted the following approach:

1. All sample processing follows the standard protocol guidance, and uses experienced sample sorters to cross check 10% of each others samples to ensure >95% of animals are being collected.
2. Species identification is conducted by a highly competent and experienced estuary taxonomist (Gary Stephenson, Coastal Marine Ecological Consultants - CMEC) who has a demonstrated ability to reliably and consistently identify all of the NZ species for which there are sensitivity data, and which are used in determining biological indices e.g. AMBI-NZ.
3. Where any identifications are uncertain, they are evaluated against a comprehensive in-house reference collection of specimens from throughout NZ that have been compiled specifically by CMEC for this purpose.
4. Where this does not resolve uncertainty, specific taxonomic expertise is sought from either NIWA or Te Papa to further resolve uncertainty.
5. In addition, species lists published by other providers from comparable locations are also assessed to highlight any potential differences in identifications or naming, or where regionally specific animals may potentially be mis-classified. Any discrepancies are noted in the reports provided.
6. Consistency in nomenclature is provided by reference to the most up to date online publications.
7. Taxa from NZ groups that are relatively poorly understood, or for which identification keys are limited (e.g. amphipods), are identified to the lowest readily identifiable groupings (i.e. Family or Genus) and consistently labelled and held in the in-house CMEC reference collection. Until species sensitivity information and taxonomic capacity are further developed for such groups, there is little defensible support for the further enumeration of such groups for the current SOE monitoring purposes.
8. The suggested requirement of Hewitt et al. (2014) that 10% of all samples be assessed for independent QAQC by another taxonomist is not supported in the absence of a list of taxa (relevant for SOE monitoring purposes) that taxonomic providers are expected to be able to readily identify to defined levels, combined with a minimum defined standard of competence for taxonomists to undertake QAQC assessments, and a defined process for resolving potential disagreements between taxonomic experts.

For the current work, no key specimens were collected that could not be reliably identified and, consequently, no additional taxonomic expertise was sought from either NIWA or Te Papa. The following table summarise the QAQC for Ruataniwha Estuary samples (January 2017).

Evaluation Criterion	Staff	Assessor	Outcome
>95% picking efficiency (10% of samples randomly assessed)	Reuben McKay (Wriggle)	Leigh Stevens (Wriggle)	PASS
Enumeration of individuals (<10% difference in repeat counts)	Gary Stephenson (CMEC)	Gary Stephenson (CMEC)	PASS
Enumeration of common taxa (<10% difference in repeat counts)	Gary Stephenson (CMEC)	Gary Stephenson (CMEC)	PASS
Taxonomic identification possible with current expertise	Gary Stephenson (CMEC)	Gary Stephenson (CMEC)	PASS
Identification consistent with in-house reference collection	Gary Stephenson (CMEC)	Gary Stephenson (CMEC)	PASS
External validation to resolve any identification uncertainty	Gary Stephenson (CMEC)	Gary Stephenson (CMEC)	NOT REQUIRED
Comparison of site data with published data from other providers	Barry Robertson (Wriggle)	Barry Robertson (Wriggle))	PASS
Nomenclature checked against latest online publications	Gary Stephenson (CMEC)	Gary Stephenson (CMEC)	PASS

Hewitt, J.E., Hailes, S.F. and Greenfield, B.L. 2014. Protocol for processing, identification and quality assurance of New Zealand marine benthic invertebrate samples. Prepared for Northland Regional Council by NIWA. NIWA Client Report No: HAM2014-105.

APPENDIX 2. 2016/17 DETAILED RESULTS

Fine Scale Site Boundaries - Sites A, B and C established 2001, Site D established 2017.

Ruataniwha Site A	1	2	3	4	Ruataniwha Site B	1	2	3	4
NZTM EAST	1571574	1571604	1571597	1571570	NZTM EAST	1572744	1572778	1572718	1572751
NZTM NORTH	5500155	5500156	5500096	5500096	NZTM NORTH	5499553	5499503	5499539	5499490
Ruataniwha Site C	1	2	3	4	**Ruataniwha Site D**	1	2	3	4
NZTM EAST	1571863	1571902	1571842	1571881	NZTM EAST	1571626	1571666	1571645	1571064
NZTM NORTH	5500070	5500025	5500048	5500003	NZTM NORTH	5500833	5500877	5500898	5500854

Fine Scale Station Locations Monitored in 2017

Ruataniwha Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1571577	1571576	1571576	1571577	1571587	1571587	1571588	1571589	1571599	1571599
NZTM NORTH	5500149	5500132	5500117	5500100	5500100	5500117	5500131	5500149	5500149	5500132
Ruataniwha Site D	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1571626	1571638	1571650	1571659	1571651	1571640	1571632	1571619	1571613	1571624
NZTM NORTH	5500843	5500857	5500868	5500878	5500887	5500873	5500862	5500850	5500856	5500868

Sediment plate locations, peg height and plate depth (mm).

Sed FS Site A	NZTM EAST	NZTM NORTH	Distance from start peg	17/12/2015	9/1/2017
Peg 1	1571571	5500154	0m	+100mm	
Plate 1	1571573	5500154	2m	-73mm	-85mm
Plate 2	1571575	5500153	4m	-73mm	-72mm
Peg 2	1571576	5500153	5m	+100mm	
Plate 3	1571577	5500153	6m	-76mm	-80mm
Plate 4	1571579	5500153	8m	-78mm	-90mm
Peg 3	1571581	5500153	10m	+100mm	
Sed North Site D	NZTM EAST	NZTM NORTH	Distance from start peg	17/12/2015	9/1/2017
Peg 1	1571617	5500840	0m	+100mm	
Plate 1	1571619	5500838	2m	-66mm	-70mm
Plate 2	1571621	5500837	4m	-98mm	-102mm
Peg 2	1571622	5500836	5m	+100mm	
Plate 3	1571623	5500837	6m	-91mm	-96mm
Plate 4	1571625	5500836	8m	-80mm	-87mm
Peg 3	1571626	5500833	10m	+100mm	

Epifauna abundance and macroalgal cover at fine scale sites, January 2017

Group	Family	Species	Common name	Scale	Class	A	D
Topshells	Amphibolidae	*Amphibola crenata*	Estuary mud snail	#	ii	F	A
Red algae	Gracilariaceae	*Gracilaria* sp.	Gracilaria weed	%	ii	-	-

Redox Potential (mV) at fine scale sites January 2017

Year/Site	Redox Potential (mV)				
	0cm	1 cm	3cm	6cm	10cm
2016 A	+21	-146	-134	-241	-256
2016 D	+20	-223	-224	-228	-198

Appendix 2. 2016/17 Detailed Results (Continued)

Physical and Chemical Results for Ruataniwha Estuary (Sites A and D), January 2017

Year/Site/Rep	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
Jan 2017 A 1-4 *	0.5	30	0.42	53.7	46.3	< 0.1	0.066	22	11.6	17.5	5.2	41	4.8	< 0.010	<500	590
Jan 2017 A 4-8 *	0.5	30	0.45	40.6	58.4	1	0.039	22	11.4	17.5	4.9	40	4.8	< 0.010	<500	590
Jan 2017 A 9-10 *	0.5	30	0.4	39.4	60.4	< 0.1	0.046	21	11	17.1	4.8	40	4.5	0.012	<500	560
Jan 2017 D 1-4 *	0.5	31	0.75	88.1	11.7	< 0.1	0.055	27	14.2	21	7.5	48	5.0	0.018	600	740
Jan 2017 D 4-8 *	0.5	30	0.9	85.5	14.5	< 0.1	0.059	27	14.7	22	7.5	48	5.0	< 0.010	600	710
Jan 2017 D 9-10 *	0.5	30	0.73	83.1	16.7	< 0.1	0.054	27	14.2	21	7.3	47	5.6	0.014	500	740
ISQG-Low [a]	-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High [a]	-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-

[a] ANZECC 2000. * composite samples.

Infauna (numbers per 0.01327m² core) Ruataniwha Estuary January 2017. (NA = Not Assigned)

Ruataniwha Estuary Sites A and D, January 2017

	Species	NZH AMBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	D-01	D-02	D-03	D-04	D-05	D-06	D-07	D-08	D-09	D-10
Anthozoa	*Edwardsia* sp. 1	2		5	3	1	2	2	1	2	3				1	1					1	
Nemertea	Nemertea sp. 1	NA	1		1		1		1	1		1			1							
Polychaeta	*Boccardia syrtis*	2	1		1										1		1			2		
	Disconatis accolus	1				1																
	Heteromastus filiformis	3	2																			
	Maldanidae	1			1	1		1				1										
	Microspio maori	1									1											
	Nereididae	3		1				1		2						1	2				1	
	Nicon aestuariensis	3				1								2	1	2		1	2	1	1	
	Scolecolepides benhami	4							1												1	
Oligochaeta	Oligochaeta sp. 1	3																		1		
Bivalvia	*Arthritica* sp. 1	4												3	2	3	2	1	6	1	1	
	Austrovenus stutchburyi	2		1		2					1	1									1	
	Cyclomactra ovata	2															1	1				
	Tellina liliana	2			1	2																
Crustacea	Amphipoda sp. 4	2	1		1																	
	Austrohelice crassa	5			5	1	2	2	2	1			2					1	1			
	Decapoda larvae unid.	NA	1	1	1		1	3		2	1	2		1							1	
	Hemiplax hirtipes	5					1															
	Paracorophium sp.	4	2	1	2	2	12	3	6	15	32	8	9	2	4	2			6	4	1	2
	Phoxocephalidae sp. 1	2	5	2	5	7	5	3	5	3	23	10	5	1	4	4	4		2	6	2	4
	Tenagomysis sp. 1	2											1								1	
Insecta	Diptera sp. 1	2			1																	
Total species in sample			**7**	**6**	**11**	**9**	**7**	**7**	**6**	**7**	**6**	**6**	**4**	**5**	**7**	**6**	**5**	**4**	**5**	**6**	**10**	**2**
Total individuals in sample			**13**	**11**	**22**	**18**	**24**	**15**	**16**	**26**	**61**	**23**	**17**	**9**	**14**	**13**	**10**	**4**	**17**	**15**	**11**	**6**

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	*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.
	Disconatis accolus	1	*Disconatis accolus* (previously *Lepidaesthenia accolus*) is sand-dwelling, sharing the tube of the common intertidal maldanid polychaete *Macroclymenella stewartensis* and also occasionally found in tubes of other polychaetes. It is a polynoid scale worm.
	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.
	Maldanidae	1	Bamboo worms are large, blunt-ended, cylindrical worms and feed as bulk consumers of sediment using a balloon-like proboscis. Most bamboo worms live below the surface in flimsy sediment tubes. They process copious amounts of sediment and deposit it in earthworm-like surface casts.
	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.
	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.
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.

Appendix 3. Infauna Characteristics (Continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Bivalvia	*Austrovenus stutchburyi*	2	Family Veneridae which is a family of bivalves which are very sensitive to organic enrichment. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Responds positively to relatively high levels of suspended sediment concentrations for short period; long term exposure has adverse effects. Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community who are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006). Prefers sand with some mud.
	Cyclomactra ovata	2	Trough shell of the family Mactridae, endemic to New Zealand. It is found intertidally and in shallow water, deeply buried in soft mud in estuaries and tidal flats. The shell is large, thin, roundly ovate and inflated, without a posterior ridge. The surface is almost smooth. It makes contact with the surface through its breathing tubes which are long and fused. It feeds on minute organisms and detritus floating in the water when the tide covers the shell's site. Often present in upper estuaries so tolerates brackish water.
	Tellina liliana	2	A deposit feeding wedge shell. This species lives at depths of 5–10cm in the sediment and uses a long inhalant siphon to feed on surface deposits and/or particles in the water column. Rarely found beneath the RPD layer. Adversely affected at elevated suspended sediment concentrations.
Crustacea	Amphipoda sp. 4	2	Amphipoda is an order of malacostracan crustaceans with no carapace and generally with laterally compressed bodies. The name amphipoda means "different-footed", and refers to the different forms of appendages, unlike isopods, where all the legs are alike. Of the 7,000 species, 5,500 are classified into one suborder, Gammaridea. The remainder are divided into two or three further suborders. Amphipods range in size from 1 to 340 millimetres (0.039 to 13 in) and are mostly detritivores or scavengers. They live in almost all aquatic environments. Amphipods are difficult to identify, due to their small size, and the fact that they must be dissected. As a result, ecological studies and environmental surveys often lump all amphipods together. Species sensitivities to muds and organic enrichment differs.
	Austrohelice crassa	5	Endemic, burrowing mud crab. *Austrohelice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
	Decapoda larvae unid	NA	The decapods or Decapoda (literally means "ten footed") are an order of crustaceans within the class Malacostraca, including many familiar groups, such as crayfish, crabs, lobsters, prawns and shrimp. Most decapods are scavengers. It is estimated that the order contains nearly 15,000 species in around 2,700 genera, with approximately 3,300 fossil species. Nearly half of these species are crabs, with the shrimps (~3000 species) and Anomura (including hermit crabs, porcelain crabs, squat lobsters: ~2500 species), making up the bulk of the remainder.
	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*.

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Crustacea	*Paracorophium* sp.	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites we get very few.
	Phoxocephalidae sp. 1	2	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Tenagomysis sp. 1	2	*Tenagomysis* is a genus of mysid shrimps in the family Mysidae. At least nine of the fifteen species known are from New Zealand.
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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