Wriggle coastalmanagement

Motupipi Estuary

Fine Scale Monitoring 2017/18

Prepared for

Tasman District Council

May 2018

Cover Photo: Motupipi Estuary eastern arm facing southwest

Motupipi Estuary main channel flowing through the upper western arm

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by

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RECOMMENDED CITATION:

Robertson, B.P. and Robertson, B.M. 2018. Motupipi Estuary: Fine Scale Monitoring 2018. Report prepared by Wriggle Coastal Management for Tasman District Council. 40p.

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MOTUPIPI ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the second year of fine scale baseline monitoring (2017/18) of two benthic intertidal sites and one upper estuary subtidal channel site within Motupipi Estuary, a moderate sized, shallow, intertidal dominated (SIDE) estuary on the Golden Bay coast. It is one of the key estuaries in Tasman District Council's (TDC's) long-term coastal monitoring programme. The fine scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring recommendations are summarised below.

FINE SCALE MONITORING RESULTS

Benthic Intertidal Habitat Results

- Both seagrass and opportunistic macroalgae, the latter a primary indicator of eutrophication, were absent from fine scale sites, and had not changed since 2008.
- Sediment mud content was "low" (13.8 % mud) at Site A and "high" (averaging 27.1 % mud) at Site B, and had reduced by 34 % at Site A and 31 % at Site B from 2008.
- Based on sediment plate data, the rate of sediment infilling was in the "very low" (western arm Site A) to "moderate" (eastern arm Site B) category in 2007-2018.
- Sediment oxygenation depth in 2018 was good in the eastern arm (redox potential >-150 mV to 5 cm depth, Site B), and poor in western arm sediments (redox potential <-150 mV below 1 cm depth, Site A), and had reduced (worsened) since 2008 (2-5 cm).
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations across both fine scale sites.
- Trace metal concentrations were at concentrations that were unlikely to cause toxicity to macroinvertebrates.
- The estuary macroinvertebrate community index (NZ AMBI) indicated relatively low stress on benthic macrofauna across sites, with communities generally dominated by taxa tolerant of slight organic enrichment and moderate mud content. There was a reduction in both abundance and richness from 2008.

BENTHIC RISK INDICATOR RATINGS

(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

	Low		Moderate
	Very Low		High

Motupipi Estuary	Site A (Western Arm)				Site B (Eastern Arm)			
	2008	2018	Yr 3	Yr 4	2008	2018	Yr 3	Yr 4
Sediment Mud Content								
Redox Potential (Oxygenation)								
TOC (Total Organic Carbon)								
Total Nitrogen								
Macroinvert condition (NZ AMBI)								
Metals (Cd, Cu, Cr, Hg, Ni, Pb, Zn As)								

Upper Estuary Subtidal Habitat Results

- The salinity results for the surface and bottom waters of the subtidal site indicated that the main upper estuary channel (50 m stretch at the very least) was stratified with saline bottom water overlain by a freshwater-influenced, less dense, saline layer. The presence of isolated (stratified) bottom water where nutrient concentrations can build-up indicates a high potential for eutrophication symptoms to develop.
- Total nitrogen (TN), dissolved inorganic nitrogen (DIN) and total phosphorus (TP) concentrations greatly exceeded the eutrophication thresholds of 0.4 mg TN l^{-1}, 0.096 mg DIN l^{-1} and 0.025 mg TP l^{-1} in both the surface and bottom waters.
- Chlorophyll *a* concentrations, the primary indicator of water column eutrophication, also greatly exceeded the NZ ETI eutrophication threshold level of 16 ug l^{-1}. Bottom water had a high concentration (44.9 ug l^{-1}), whereas surface waters had low concentrations (9.4 ug l^{-1}).

Motupipi Estuary - Executive Summary (continued)

ESTUARY CONDITION AND ISSUES

Benthic Intertidal Habitat

The fine scale monitoring of representative intertidal sediments showed that the trophic state of the estuary was good (i.e. minimal macroalgal growth coupled with low levels of organic enrichment in sediments). However, despite reductions in sediment mud content from 2008, the estuary did exhibit a sedimentation issue which manifested in 2018 as elevated muds, particularly in the eastern arm where average sedimentation rates (3 mm yr^{-1} between 2007-2018) were 'moderate'. The presence of this issue was supported by the 2015 broad scale monitoring findings, which indicated a large extent (32.2ha, 36 %) of estuary substrate was dominated by muds. Although the sites have not shown any broad trends of change in the macroinvertebrate community since 2008, losses in a range of organisms (both sensitive to and tolerant of increasing mud/organic enrichment and representative of a range of taxomonic and functional groupings) have occurred since that time, possibly as a consequence of past disturbance events (e.g. December 2011 floods - the second highest rainfall event in a populated area in NZ).

Upper Estuary Subtidal Habitat

Taken as a whole, the January 2018 data showed that the bottom water in the poorly flushed upper estuary channel was stratified and eutrophic, as indicated by very high chlorophyll *a* and the presence of TN, DIN and TP exceeding eutrophication threshold concentrations. However, given only one comprehensive sampling event, questions remain around likely duration, magnitude and frequency of such eutrophication symptoms. Upper estuary bottom water stratification is a natural event in many shallow NZ estuaries. Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nitrogen inputs would need to be less than 0.4 mg N l^{-1} in order to minimise eutrophication symptoms in this sensitive zone of the estuary.

Overall, these 2008-2018 findings indicate that muddiness (primarily in the eastern arm of the estuary), and upper estuary eutrophication (i.e. bottom-water phytoplankton blooms), are issues that require further attention. The NZ Estuary Trophic Index (ETI) score has been calculated using available broad scale and fine scale indicators. The ETI score for Motupipi Estuary was 0.39, Band B, reflecting a low degree of eutrophic symptoms.

Estuary Trophic and Sedimentation Condition and Catchment Loads

In order to assess the potential of the estuary for eutrophication and sedimentation issues, the current estimated (via CLUES model) and measured (TDC water quality data collected at Reilly Bridge between 2015 and 2018) nitrogen loads and estimated (via CLUES model) sediment loads to the estuary were compared with existing thresholds for expression of associated problems. The results showed that estimated and measured inputs to the estuary were most likely below the threshold of 100 mg N m^{-2} d^{-1} (Robertson 2018; Robertson & Savage *under review*) for the expression of primary eutrophic conditions (i.e. excessive macroalgal growth) in the main body of this shallow estuary. However, because quantitative sediment load versus sedimentation thresholds have yet to be developed for NZ estuaries, the issue of ongoing sedimentation in the estuary is more difficult to predict.

RECOMMENDED MONITORING

Given the statistical limitations associated to a single-year baseline data set (i.e. trend analysis invalid), it is recommended that for the next two years (2019 and 2020) TDC collect data only, from both sites (excluding heavy metals, SVOCs, mercury and arsenic) to establish a multi-year baseline, and undertake a full report of all data at the next scheduled 5 yearly monitoring interval (2024/25).

To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a summer, prolonged low flow period in 2018/19.

Broad scale sedimentation rate monitoring should continue at annual intervals and broad scale mapping every 5 years (next due in 2020).

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. The Tasman District Council's 'Tasman Resource Management Plan (TRMP)' demonstrates the Council's determination to maintain estuaries in good condition. In 2006, Tasman District Council (TDC) began a more comprehensive long-term estuary monitoring programme designed to specifically address the key NZ estuary issues of eutrophication and sedimentation within their estuaries, as well as identifying any toxicity and habitat change issues. The estuaries currently included in the programme are; Ruataniwha, Motupipi, Waimea and Moutere Inlets and the Motueka Estuary.

Monitoring of the Motupipi Estuary began with broad and fine scale monitoring undertaken in 2007/08, and the second year of comprehensive fine scale monitoring undertaken in January 2018.

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

1. **Ecological Vulnerability Assessment (EVA**): of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has been completed and is reported on in Robertson & Stevens (2008b).
2. **Broad Scale Habitat Mapping (NEMP approach):** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Broad scale intertidal mapping of Motupipi Estuary was first undertaken in September 2007 (Stevens & Robertson 2007), and repeated in March 2015 (Stevens & Robertson 2015).
3. **Fine Scale Monitoring (NEMP approach):** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Motupipi Estuary, was first undertaken in January 2008 (Robertson and Stevens 2008a), and repeated in January 2018. This latter monitoring is the subject of this report.

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of risk indicator ratings are presented and described in Section 2. The current report describes the 2018 fine scale results and compares them to the 2008 findings.

Motupipi Estuary

Motupipi Estuary is a moderate-sized (169 ha), shallow, intertidal-dominated estuary (SIDE) with one tidal opening, and two main basins. Because the Motupipi River flows relatively directly through the western arm to the entrance, this part of the estuary responds more like a tidal river system than the seawater-dominated eastern basin, which is relatively elevated, drying rapidly and remaining exposed for much of the tidal cycle. There is an extensive coastal intertidal delta seaward of the mouth, and a barrier sandspit extends to the west of the entrance.

The catchment (41 km^2) is dominated by high producing pasture (45 %), native forest and scrub (37 %) and exotic forestry (8 %), with much of the immediate estuary margin directly bordered by developed pasture/rural land, roads, and seawalls. Causeways separate small sections of saltmarsh from the main estuary.

Ecologically, habitat diversity is moderate to high with much of its intertidal vegetation intact, extensive shellfish beds, large areas of saltmarsh (38 % of estuary), and some seagrass (1.6 % of estuary). However, the estuary is excessively muddy (36 % soft and very soft mud in 2015), and much of the natural vegetated margin has been lost and developed for grazing. Since 1943 there has been a loss of 28 ha of saltmarsh through drainage and reclamation, However, significant saltmarsh modification is likely to have occurred prior to this.

The upper estuary experiences salinity stratification during stable baseflows (i.e. salt wedge effect). The resulting high salinity bottom layer is generally more stable (less well-flushed) and therefore experiences nuisance phytoplankton blooms when nutrient inputs are elevated (Robertson and Stevens 2008b). Historically, the Takaka landfill was sited on the margin, but heavy metals, used as an indicator of potential toxicants, were very low at fine scale monitoring sites (Robertson and Stevens 2008a).

Recent vulnerability assessments (Robertson and Stevens 2008, 2012), and subsequent broad scale assessments (Stevens and Robertson 2015) identified excessive muddiness and disease risk as the major estuary stressors, with habitat loss, and changes in biota as a result of climate change, rated as moderate issues in the estuary. Localised eutrophication is present in poorly flushed upper estuary arms at times, while toxicity was not considered significant, although there are localised areas with elevated mud contents which are likely to concentrate sediment bound nutrients and heavy metals.

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

1. Sediment Changes

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

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

Recommended Key Indicators:

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

2. Eutrophication

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

Recommended Key Indicators:

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

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

2. 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. 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 (refer to Appendix 1 for detailed background). This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). In addition, because some estuaries, including SIDEs, also include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted), synoptic water quality samples from surface and bottom waters, and subtidal sediment are commonly collected to support intertidal assessments.

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

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

For the Motupipi Estuary, two previously established fine scale sampling sites (Figure 1), were sampled in unvegetated, mid-low water habitat. Sites A (Western Arm) and B (Eastern Arm) comprised a 15 m x 40 m and 30 m x 60 m area, respectively, with each site 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 Redox Potential Discontinuity (RPD expressed in mV) depth was recorded within three representative plots using an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10 cm 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 20 mm of sediment (each approx. 250 g) 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 2):
- 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.

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

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

Figure 1. Location of subtidal channel quality (orange), benthic intertidal quality (yellow) and sediment plate (black) monitoring sites in Motupipi Estuary (Photo: Google).

- The core tube was manually driven 150 mm into the sediments, removed with the core intact and inverted into a labelled 0.5 mm 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 2).
- Where present, macroalgae and seagrass vegetation (including roots), was collected within each of three representative 0.0625 m^2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured.
- Conspicuous epifauna visible on the sediment surface within each fine scale site were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species are identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix 2), or by counting individual organisms >5 mm in size within quadrats placed in representative areas (Table B, Appendix 2). 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.

2. Methods (continued)

Upper Estuary Subtidal Water and Sediment Quality

One representative site was selected in the deep main channel section in the upper estuary where there was a potential for the estuary water to become stratified (Site X, see Figure 1). At the site at high tide, a YSI-Sonde (6000 series) hand-held field meter was used to directly measure and log depth, chlorophyll *a*, salinity, temperature, pH, and dissolved oxygen in the upper and lower 0.5 m of the water column. At the same location water samples were also collected with a Van Dorn water sampler for laboratory nutrient analyses (total N, nitrate-N, ammoniacal-N, dissolved reactive P and total P concentrations).

In addition, at the site secchi disc clarity was measured and one benthic sediment sample was collected using either a remotely triggered Van Veen grab sampler or a custom built sediment sampling hoe with telescopic handle). Once at the surface the sediment apparent Redox Potential Discontinuity (aRPD) depth was measured, and a sub-sample collected for subsequent chemical analysis for TOC, grain size, TN and TP.

- All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 2).
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.

Fieldwork for this component was undertaken in Motupipi Estuary on 14 January 2018 coincident with prolonged low freshwater inflow conditions.

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 (Eastern Arm and Western Arm) were established in Motupipi Estuary on 25-27 September 2007 (Figure 1). The sites were located in mud/sand habitat in areas of each estuary arm where sedimentation rates are likely to be elevated. At each site, four plates (20 cm square concrete block pavers) were buried (to approximately 200 mm depth or where stable substrate is located), approximately 30 m apart in a square configuration. The position of each plate was marked with wooden stakes driven into the sediment, their GPS positions logged, and the depth from the undisturbed mud surface to the top of the sediment plate and the top of the wooden stakes was recorded (Appendix 3). It should be noted that because the current plate configurations in Motupipi no longer align with standardised configuration guidelines adhered to by other NZ Regional Councils (e.g. Environment Southland), it is recommended that any future plates be installed in accordance with these guidelines.

Since deployment in 2007, sediment plate depths have been measured in 2010, 2012, 2013, 2014, 2015 and 2018. The rate of sedimentation in the estuary over this 11-year period is discussed in the present report.

3. RESULTS AND DISCUSSION

A summary of the results of the 2018 fine scale benthic intertidal and upper estuary subtidal monitoring of the Motupipi Estuary is presented in Tables 2 and 3, with detailed results in Appendices 2 and 3. Also included are the summary results of the preliminary fine scale sediment monitoring undertaken in 2008 (Robertson & Stevens 2008a).

Table 2. Mean fine scale sediment physical, chemical, plant growth (*n* = 3) and macrofauna (*n* = 10) results, Motupipi Estuary, January 2008 and 14 January 2018. NA = not assessed.

Year Site	aRPD	RP (mV)	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TP	TN
	cm	cm	ppt	%				mg kg^{-1}									
2018 A	1	1	27	0.5	13.8	85.6	0.6	0.04	42.0	9.8	21.7	6.4	40.3	6.2	<0.02	666	<600
2008 A	3.0	NA	27	0.8*	20.9	78.4	0.8	0.04	43.7	9.6	28.3	6.3	44.0	NA	NA	573	730
2018 B	>5	3	30	0.4	27.1	72.8	0.2	0.02	29.7	5.9	15.0	4.4	29.3	6.3	<0.02	610	<500
2008 B	>10	NA	30	0.8*	39.0	61.0	0.1	0.01	26.3	5.7	16.3	3.9	27.3	NA	NA	556	756

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

Year Site	Seagrass Biomass and Cover	Macroalgal Biomass and Cover	Macrofauna Abundance	Macrofauna Richness
	g m^{-2} wet weight / (% cover)	g m^{-2} wet weight / (% cover)	Individuals per m^2	Species per core (0.013 m^2)
2018 A	0 (0 %)	0 (0 %)	505	4
2008 A	0 (0 %)	10 (< 5 %)	3526	12.4
2018 B	0 (0 %)	0 (0 %)	452	2.9
2008 B	0 (0 %)	0 (0 %)	1800	6.4

Table 3. Summary of upper estuary channel quality results (upper water column, bottom water column and bottom sediment, Motupipi Estuary, 14 January 2018.

Parameter	Site X	
	Surface	Bottom
Depth (m)	0.2	1.3
Temperature (degrees C)	21.6	23.1
Salinity (ppt)	5.9	30.7
Dissolved Oxygen (mg l^{-1})	6.5	7.0
Chlorophyll *a* (ug l^{-1})	9.4	44.9
Total N (g m^{-3})	2.9	2.8
Total Ammoniacal-N (g m^{-3})	0.05	0.05
Nitrate-N (g m^{-3})	2.2	2.2
Dissolved Reactive P (g m^{-3})	0.03	0.03
Total P (g m^{-3})	0.04	0.04

Bottom Sediment Site	aRPD (cm)	TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TN (mg/kg)	TP (mg/kg)
Motupipi Site X	1*	1.52	23.3	76.5	0.2	1100	1210

* measured visually, compared with 2018 benthic intertidal results which were measured using ORP meter.

3. Results and Discussion (continued)

Analysis and discussion of the 2008 and 2018 results are presented as two main steps; firstly, the intertidal benthic habitat condition and secondly, the upper estuary water column condition. The assessment is undertaken with a focus on the key estuarine issues of muddiness (or sedimentation), eutrophication, and toxicity.

3.1 Benthic Habitat Condition

3.1.1 Sedimentation

The primary environmental variables that are most likely to be driving the ecological response in relation to estuary muddiness are sediment mud content (often the primary controlling factor) and sedimentation rate. Sediment mud content data are presented and assessed alongside the long term sedimentation rate monitoring (2007-2018) results below.

Sediment Mud Content

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

Results showed the Motupipi Estuary fine scale sites in 2018 had moderate (mean 13.8 % mud at Site A and 27.1 % mud at Site B) sediment mud contents (Table 2, Figure 2), and indicated a slight reduction in mud content at both fine scale sites since 2008. This latter finding reflects the overall reduction in mud area from both arms of the estuary between 2007 and 2015 (Stevens and Robertson 2015).

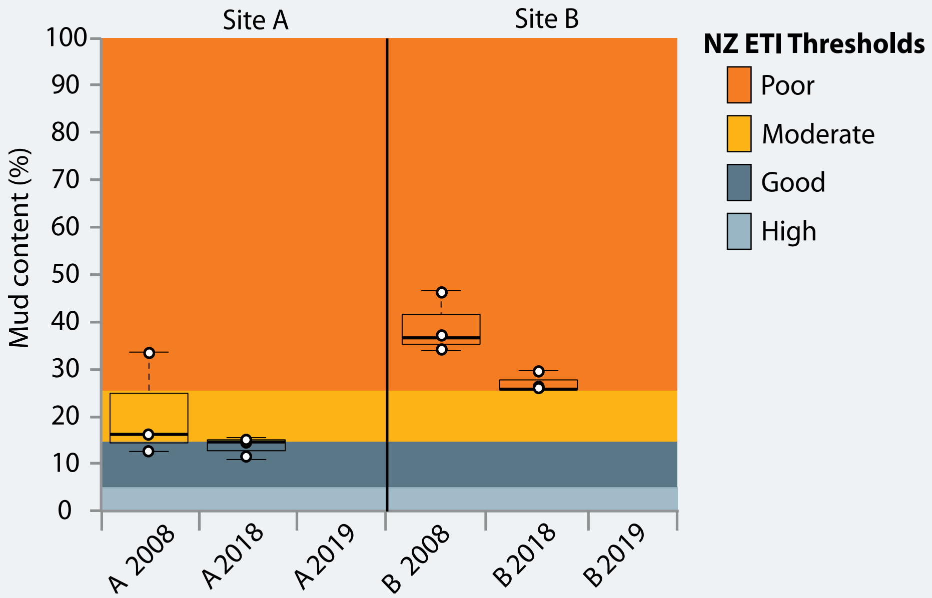

Figure 2. Mean sediment mud content (raw values, median, interquartile range, total range), Motupipi Estuary, January 2008 and 2018.

In 2018, Site A (Western Arm) showed the sandiest sediments, primarily because of the site's proximity to the main river channel and ocean-derived sands which intermittently mix with catchment derived muds. Site B showed the highest mud content (mean 27.1 % mud) reflecting each site's physical position in the estuary as a natural deposition zone for fine sediments. The overall moderate mud content

Muddy, moderately oxygenated sediment profile at Site B (Eastern Arm) in 2018.

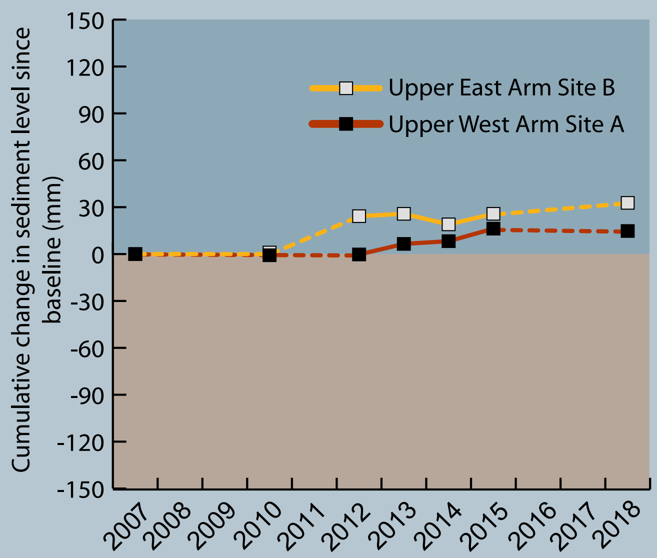

Figure 3. Cumulative change in sediment levels over buried plates in Motupipi Estuary, 2007 to 2018. Dashed lines indicate interpolated trends.

fits the band C rating, and indicates the following ecological conditions are likely (Robertson et al. 2016b):

- *Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost, especially if nutrient loads are elevated.*

Sedimentation Rate

Table 4 presents the January 2018 sedimentation rate monitoring results for the plates buried in the upper Western (Motu A) and Eastern (Motu B) Arms, Motupipi Estuary (refer to Figure 1 for locations), with cumulative changes in sediment height over time (2007-2018) presented in Figure 3.

From Sept 2007 to Jan 2018, both sites showed a cumulative increase in sediment height. Rates of increase were greatest in the upper Eastern Arm of the estuary (overall mean increase of 3 mm yr^{-1} at Motu B) and was rated in the "moderate" category, whereas Motu B, in the upper basin of the Western Arm, showed no substantial change and was rated "very low", reflecting slight deposition (overall mean increase of 1.3 mm yr^{-1}) of sediments across the site.

Also notable was the apparent erosion of soft muds from the upper Eastern Arm (Motu B) subsequent to the Dec 2011 floods - the second highest rainfall event in a populated area in NZ - which delivered a large (23 mm average) deposit of soft mud to the site.

The contribution to sedimentation in the estuary from current sediment loading from the catchment is investigated in more detail in Section 3.3 of this report.

Table 4. Sedimentation rate results showing cumulative change from baseline and average change (mm yr^{-1}) at two sites in Motupipi Estuary, September 2007-January 2018.

		Cumulative Change Since Baseline (mm)						Site Mean (mm yr^{-1})						Overall Rate (mm yr^{-1})	SEDIMENTATION RATE CONDITION RATING
SITE	PLATE	2007-2010	2010-2012	2012-2013	2013-2014	2014-2015	2015-2018	2007-2010	2010-2012	2012-2013	2013-2014	2014-2015	2015-2018	2007-2018	
Motu A Upper Western Arm	1	-5	1	-1	4	7	16	-0.3	-0.1	1.1	1.2	2.0	1.3	1.3	VERY LOW
	2	-3	3	3	6	12	2								
	3	2	4	16	16	26	23								
	4	3	-9	8	7	20	18								
Motu B Upper Eastern Arm	1	6	12	19	16	21	48	0.3	4.9	4.3	2.7	3.2	3.0	3.0	MODERATE
	2	-7	-15	-12	1	-10	-5								
	3	5	15	19	17	25	28								
	4	0	85	77	42	67	60								

3. Results and Discussion (continued)

3.1.2 Eutrophication

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

Macroalgae and Seagrass

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

Results showed a complete absence of seagrass and macroalgae at benthic fine scale Sites A and B (Figure 4). Such findings indicate low levels of eutrophication, and that conditions at both sampling sites are unsuitable for high value seagrass habitat.

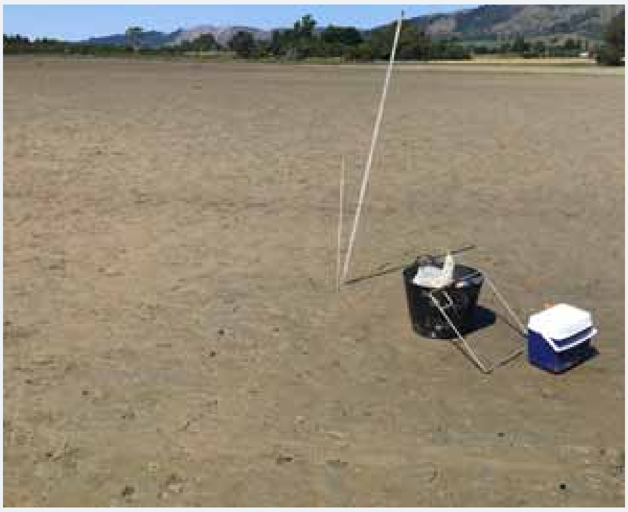

Figure 4. An absence of opportunistic macroalgae and seagrass at representative intertidal sites in the Western Site A (left) and Eastern Arm Site B (right), Motupipi Estuary, 14 January 2018.

Sediment Mud Content

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, given that elevated sediment mud content limits oxygen transfer across the water-sediment interface, the overall moderate mud contents in Motupipi indicate sediment oxygenation is likely to be relatively moderate-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 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 redox potential thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Appendix 1).

Figure 5 shows the redox potentials (5 depths at each site, mean of triplicate measures plotted) for the two Motupipi Estuary sampling sites for January 2018. Note that 2008 RPD depths were measured visually and therefore cannot be compared with the 2018 profiles which were measured using an ORP meter.

The redox potential for Site B indicates that the upper ~3 cm sediments are sufficiently well oxygenated to support a range of sensitive benthic macroinvertebrate taxa (i.e. relatively positive redox ranging between -50 and +100 mV, Band B). By contrast, Western Arm Site A had poorly oxygenated conditions throughout the entire 10 cm sediment profile (i.e. low redox <-150 mV, Band D). Such poorly oxygenated sediments are likely to only support low diversity macroinvertebrate communities dominated by tolerant taxa (see Section 3.1.4).

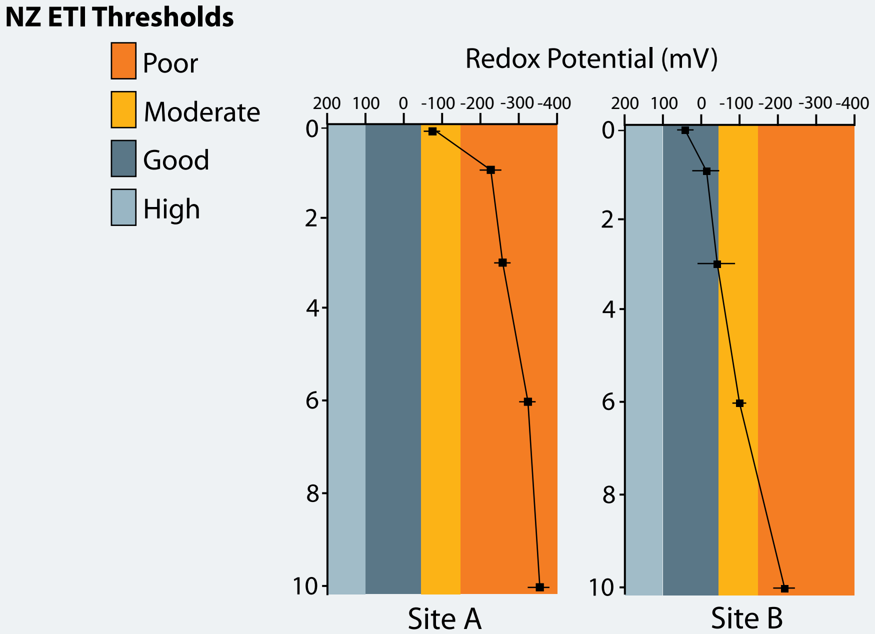

Figure 5. Mean down-core sediment Redox Potential (mV) measured at 0, 1, 3, 6 and 10 cm depths (*n* = 3, ±SD), Motupipi Estuary, 14 January 2018.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated and eutrophication symptoms are present [i.e. shallow RPD, 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 their respective loadings are exceeding the assimilative capacity of the estuary.

The 2018 results for the two benthic fine scale sites showed TOC (0.4-0.5 %) and TN (<600 mg kg^{-1}) were in the “very low” to “low” risk indicator ratings, with TP (rating not yet developed) also relatively low at both sites (340 mg kg^{-1}) (Figures 6, 7 and 8).

Comparison with 2008 benthic physicochemical results

Fine scale monitoring results collected from Sites A and B in January 2008 (Robertson and Stevens 2008) are presented alongside the current results in Table 3 and relevant sections above. Comparisons show that 2008 benthic physicochemical results were similar to those from Sites A and B in 2018, indicating those parts of the estuary are unlikely to have significantly changed in terms of sediment mud, TOC, TN and TP concentrations in the past decade. However, the 2008 survey results have not been comprehensively assessed in the current report as they did not meet the requirements of a full baseline survey (i.e. involved a one-off sampling event rather than a sampling over 3-4 consecutive years).

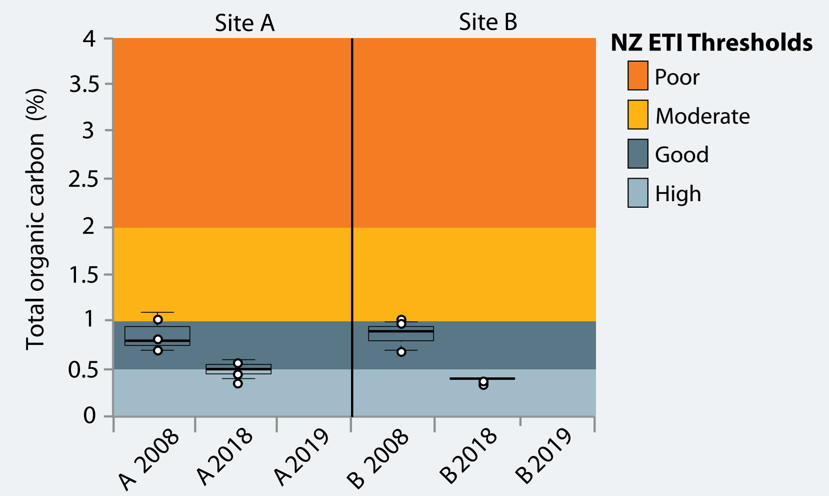

Figure 6. Sediment total organic carbon (%) (raw values, median, interquartile range, total range), January 2008 and 2018. Note 2008 data was measured as ash-free dry weight (AFDW) and converted to TOC using the following equation (TOC = AFDW x 0.38) (Lindquist et al. 2008).

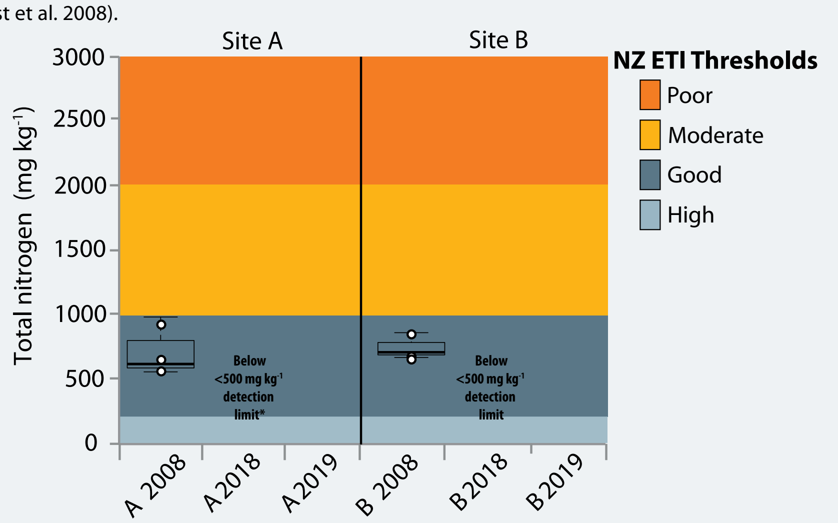

Figure 7. Sediment total nitrogen (mg kg^{-1}) (raw values, median, interquartile range, total range), January 2008 and 2018. *1 of 3 replicate samples had a concentration of 600 mg kg^{-1}.

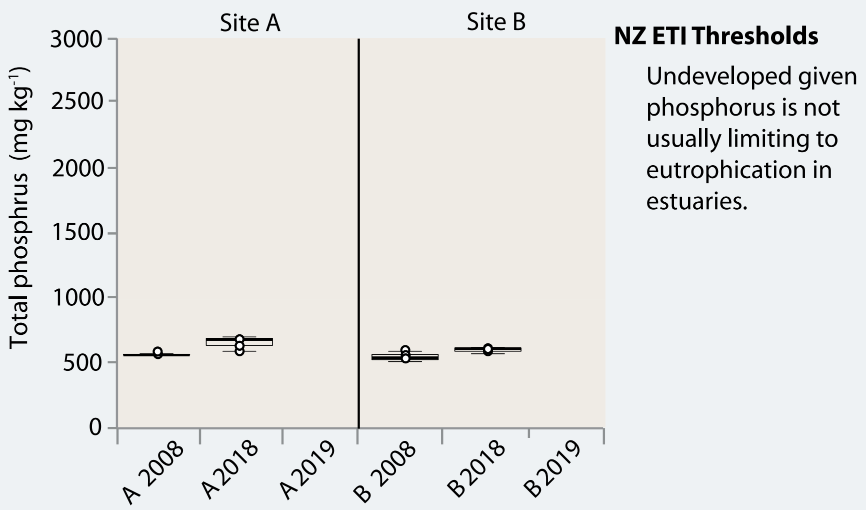

Figure 8. Sediment total phosphorus (mg kg^{-1}) (raw values, median, interquartile range, total range), January 2008 and 2018.

3.1.3 Toxicity

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

2008 and 2018 results (Table 5) for heavy metals Cd, Cu, Hg, Pb, Zn and As, used as indicators of potential toxicants, were rated with a “very low” to “low” risk. However, nickel at both sites and chromium at Site A, were present at concentrations exceeding the ISQG Low limits. This exceedance was likely attributable to elevated inputs in run-off from the geologically nickel and chromium enriched catchment (Robinson et al. 1996, Rattenbury et al. 1998), and the high affinity of heavy metals for muds acting to transport and sequester them into estuarine sediments (Whitehouse et al. 1999). Such findings are typical of other estuaries in the Tasman Bay region. In such cases as this, where the ISQG Low limit is exceeded, but not the ISQG High limit, and the likely cause is natural, the ANZECC (2000) guidelines recommend no further investigation.

Table 5. Indicator toxicant results for Motupipi Estuary (Sites A and B), January 2008 and 2018. NA = not assessed.

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
2018 A 1-4 [b]	0.04	41	9.9	21	6.9	40	5.8	<0.02
2018 A-4-8 [b]	0.04	43	10.4	23	6.7	43	6.7	<0.02
2018 A-9-10 [b]	0.04	42	9	21	5.7	38	6.0	<0.02
2008 A 1-4 [b]	0.05	44	10	29	6.3	46	NA	NA
2008 A-4-8 [b]	0.04	43	9.1	27	6	42	NA	NA
2008 A-9-10 [b]	0.04	44	9.8	29	6.5	44	NA	NA
2018 B-1-4 [b]	0.02	31	6.2	15.3	4.6	30	6.1	<0.02
2018 B-4-8 [b]	0.02	31	5.7	14.9	4.4	29	6.1	<0.02
2018 B-9-10 [b]	0.02	27	5.8	14.7	4.3	29	6.6	<0.02
2008 B-1-4 [b]	0.02	27	6.3	17	4.2	29	NA	NA
2008 B-4-8 [b]	0.01	26	5.8	16	3.9	28	NA	NA
2008 B-9-10 [b]	0.01	26	5	16	3.6	25	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, [b] composite samples

Semi-volatile organic compounds (SVOCs) were also analysed to screen for key pollutants of organochlorine and organonitro/phosphate pesticides (OCPs and ONPPs) (Appendix 2 describes the analytical methods and Appendix 3 presents the results in full). All analytes were found to be less than the analytical detection limits and the ANZECC (2000) ISQG Low or High trigger values, and therefore unlikely to cause toxicity to benthic macrofauna.

In addition, the Rototai Landfill is located immediately adjacent to the Motupipi Estuary, to the east of Rototai Road and south of the intersection with Nees Rd. The site is approximately 500m long (north to south) and 80-150m wide. It operated for around 40 years before being closed around 1994. The underlying geology is predominantly free-draining marine sediments. The landfill was used to dispose of predominaintly domestic and light industrial waste. The southern end of the site was cleared, levelled and capped to an acceptable level and rock protection installed between 2001-03, with subsequent remedial works to the northern end undertaken in 2010.

The 2015 inspection report found no settlement or sinking of the cap, any protruding objects, stressed or dying vegetation, landfill gas, or leachate seeps. Therefore, any threat posed by the landfill to the ecological condition of the estuary is likely to be minimal. However, the 2015 report did recommend removal of gorse and other tree weeds that could compromise the ongoing integrity of the landfill cap.

3.1.4 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 the Motupipi Estuary will be analysed in detail once sufficient baseline monitoring data is available. This analysis will include four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (version 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, in the absence of 3-4 year baseline monitoring data, this section of the report will present and interpret data in relation to steps 3 and 4 only, with 2008 macroinvertebrate results included wherever appropriate.

Species Richness, Abundance, Diversity and Infaunal Groups

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 are available, will be used to help explain any differences between years indicated by other analyses.

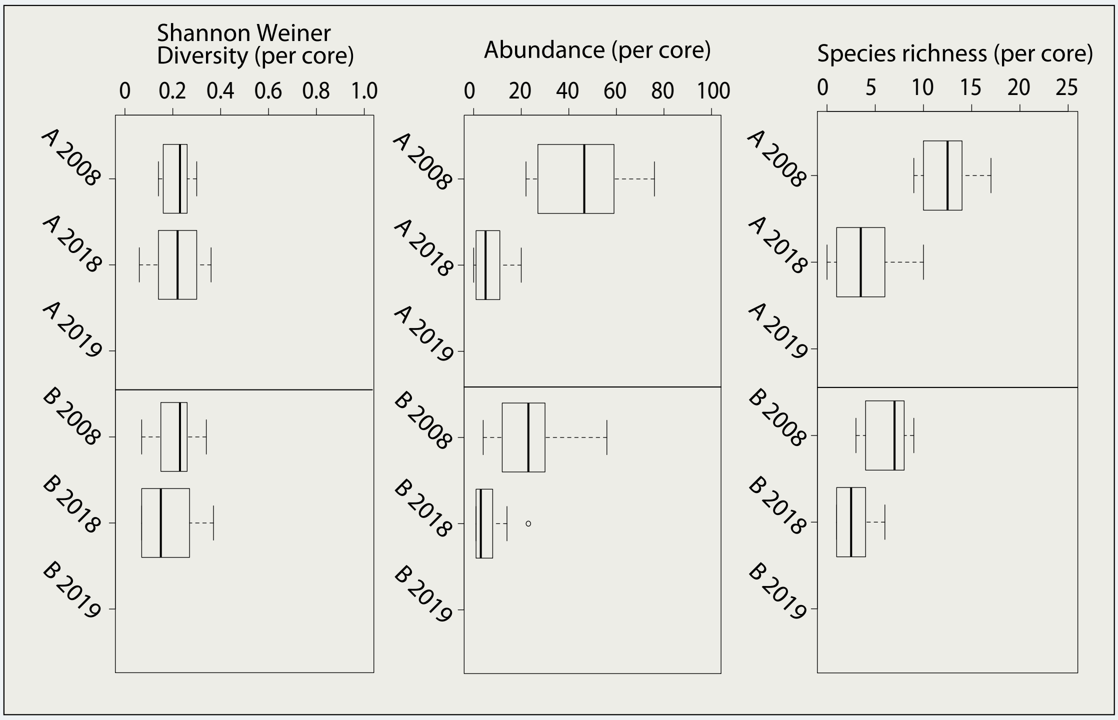

Figure 9. Boxplot showing species richness, abundance, and Shannon Diversity index per core (median, interquartile range, total range, outliers, *n* = 10) at fine-scale Sites A and B, Motupipi Estuary, January 2008 and 2018.

3. Results and Discussion (continued)

Figure 9 shows that in 2018 at monitoring sites representing the middle estuary intertidal flats in each main arm of Motupipi Estuary (Sites A and B), there was relatively low mean species richness (3-4 per core), abundance (6-7 per core) and Shannon diversity (0.17-0.18 per core). Comparisons with the 2008 results [i.e. mean species richness (6-13 per core), abundance (24-47 per core) and Shannon diversity (0.21-0.22 per core)] indicate that, while species richness and abundance decreased, Shannon diversity remained similar, at each of the fine scale sites. Since 2008, overall species richness has declined from 31 to 18 (42 % decline) at Site A and 16 to 13 (19 % decline) at Site B.

In terms of taxonomic groups present at each fine scale site in 2018, Figure 10 indicates that the macroinvertebrate community at Site A (Western Arm) and Site B (Eastern Arm) comprised a mix of anthozoa, polychaeta, bivalvia and crustacea, and to a lesser extent, gastropoda and oligochaeta, with only small differences in abundance between sites. Similar groups were represented in 2008, but generally at higher abundances, particularly in terms of polychaeta, bivalvia, and crustacea.

At a relevant functional level (i.e. functional groups may be defined as a group of taxa that share common biogeochemical and interspecific attributes, e.g. feeding strategy; Alexandridis et al. 2017), macrofauna represented a wide range of feeding types at both sites in 2018 (Figure 11). Similar feeding groups were present in 2008, but with generally higher abundances of filter/deposit feeders, infaunal deposit feeders and surface deposit feeders at Site A (Western Arm) and infaunal deposit feeders at Site B (Eastern Arm).

A robust explanation for the overall decline in both the number and abundance of macrofaunal taxa (representing a wide range of taxonomic and functional groups) in the estuary between 2008 and 2018 is difficult to pinpoint without comprehensive baseline data, but may be linked to past disturbance events (e.g. December 2011 floods) and/or other factors (e.g. natural variability) not measured in this study.

These temporal differences are discussed in more detail (at the individual taxon level) in the following sections.

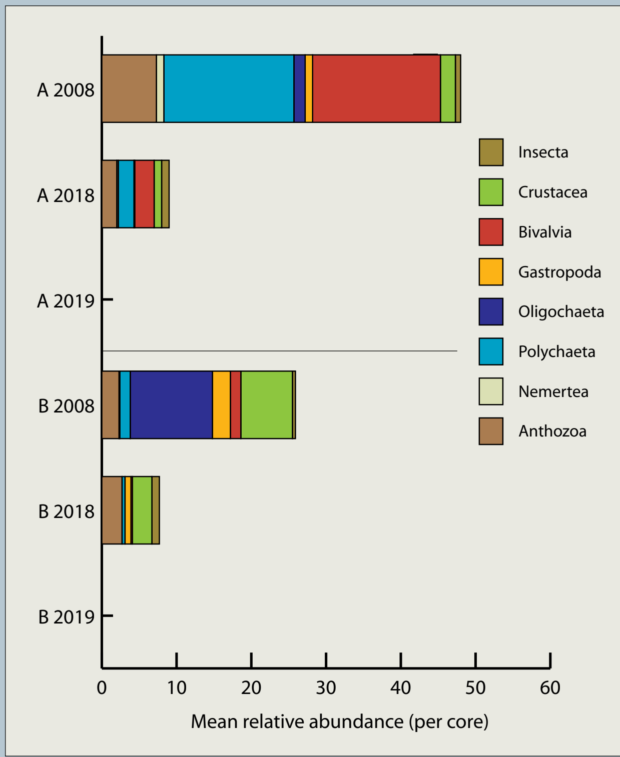

Figure 10. Mean relative abundance of major benthic macroinvertebrate groups (n = 10), Motupipi Estuary, January 2008 and 2018.

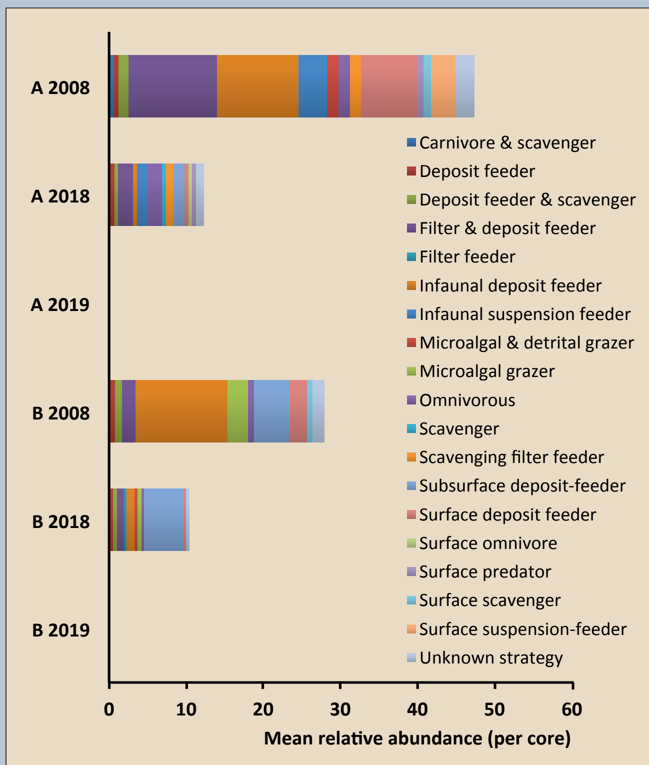

Figure 11. Mean relative abundance of feeding groups (n = 10), Motupipi Estuary, January 2008 and 2018.

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

1. 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 response to anthropogenic stressors, particularly mud and organic enrichment as follows:

- Integration of previously established, quantitative ecological group classifications (Robertson et al. 2015);
- Addition of a meaningful macrofaunal component (taxa richness), which means the index now accounts for diversity rather than abundance only;
- Derivation of thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents);
- The AMBI was successfully validated (R^2 values >0.5 for mud, and >0.4 for total organic carbon) for use in shallow estuaries New Zealand-wide.
- Also note the NZ AMBI index has recently undergone further optimisation to more accurately diagnose benthic health in relation to nutrient enrichment of shallow estuaries (e.g. Motupipi Estuary) (B.P. Robertson, PhD thesis). The updated index is expected to be available from September 2018 following journal publication.

NZ AMBI coefficients for the Motupipi fine scale sites are presented in Figure 12. Mean coefficients (2.5 at Site A and 2.4 at Site B) were in the "good" condition category (i.e. a transitional type community indicative of low levels of organic enrichment and moderate mud concentrations), except for coefficients at Site B in 2008, where the condition was rated as "moderate". The observed shift from "moderate" to "good" at Site B between 2008 and 2018 most likely reflects the observed reductions in sediment mud, TOC and TN contents over that period (Figure 4, 5 and 6). It should be noted that the robustness of the NZ AMBI could be reduced when only a very low number of taxa (1–3) and/or individuals (<3 per replicate) are found in a sample (Borja and Muxika 2005). However, because these criteria were met for the majority (70 % at Site A and 60 % at Site B) of macrofaunal samples collected in 2018, the resulting NZ AMBI scores are likely to be reliable.

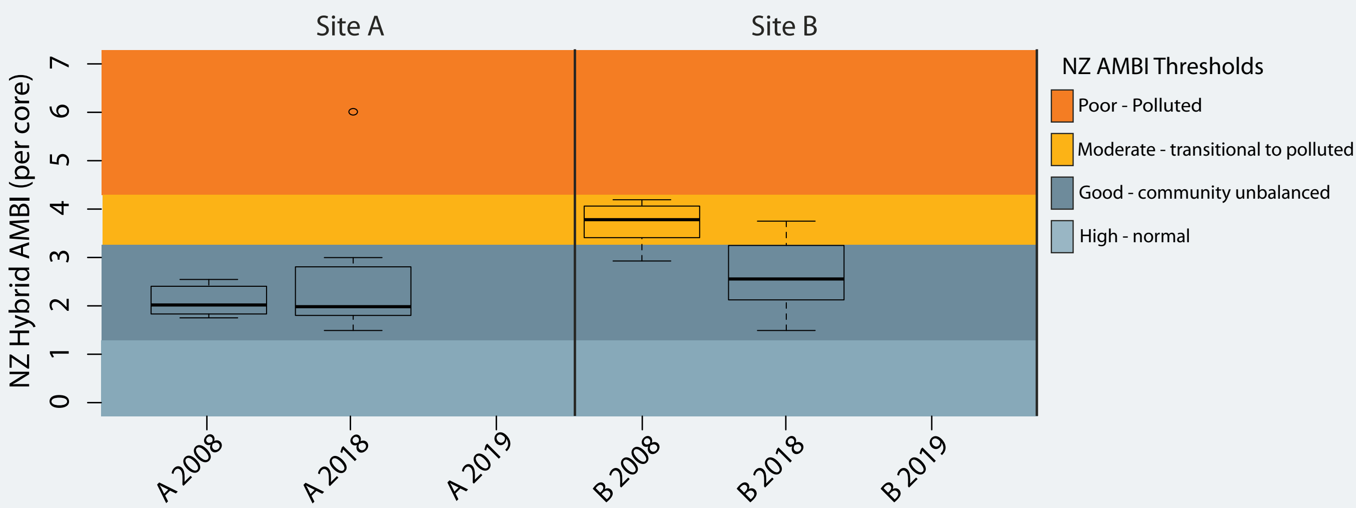

Figure 12. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, outliers, *n* = 10), Motupipi Estuary, January 2008 and 2018.

2. Individual Species

To further explore the macroinvertebrate community in terms of taxa sensitivities to the key benthic stressors, sediment muddiness and organic enrichment, a comparison was made of the mean abundances of individual taxa within the 5 major mud/enrichment tolerance groupings (i.e. *1 = highly sensitive to (intolerant of) mud and organic enrichment; 2 = sensitive to mud and organic enrichment; 3 = widely tolerant of mud and organic enrichment; 4 = prefers muddy, organic enriched sediments; 5 = very strong preference for muddy, organic enriched sediments*) (Figure 13).

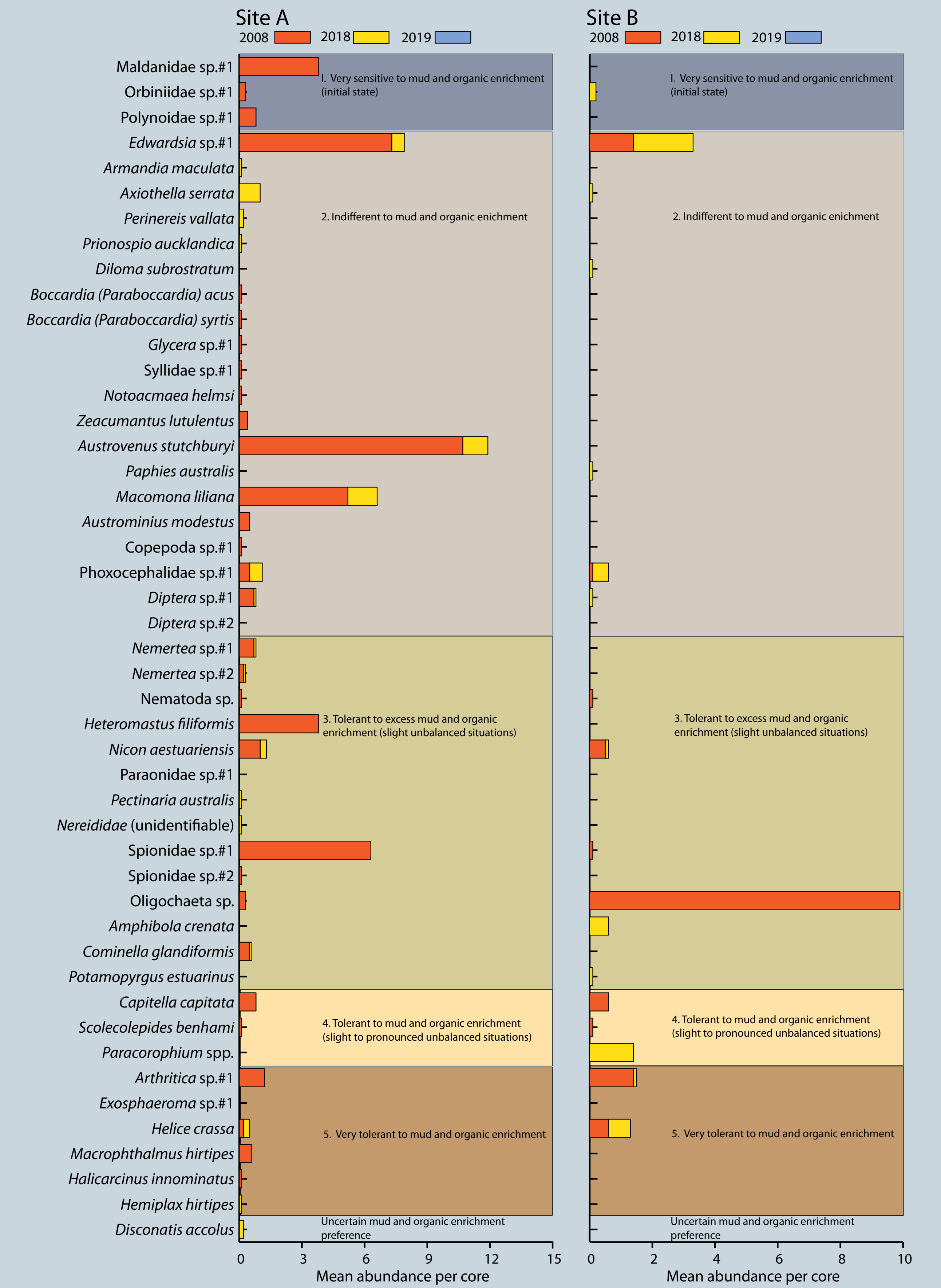

Figure 13. Mud and organic enrichment sensitivity of macroinvertebrates, Motupipi Estuary Sites A and B, January 2008 and 2018 (see Appendix 4 for sensitivity details).

While Figure 12 provides support for mud/organic enrichment as a key determinant of macroinvertebrate community condition in Motupipi Estuary, Figure 13 and Table 6 highlight some important changes at the individual taxon level. Table 6 shows a widespread decline in the number of taxa representing all 5 major mud/enrichment tolerance groupings at Site A (Western Arm) between 2008 and 2018, including the complete loss of Group 1 (highly senstive taxa) and Group 4 (Prefers muddy, organically enriched sediments) organisms. Meanwhile, group differences in the Eastern Arm (Site B) were more variable, with a greater number taxa representing Groups 1 (100 % increase, from 0 in 2008, to 1 in 2018), 2 (66 % increase, from 2 in 2008, to 6 in 2018) and 5 (33.3 % increase, from 2 in 2008, to 3 in 2018) organisms, while those in Groups 3 and 4 both reduced by 50 %.

Table 6. Percent change in total taxa numbers in each NZ AMBI group between 2008 and 2018, Motupipi Estuary.

NZ AMBI (Mud/Organic Enrichment Tolerance) Group	Site A			Site B		
	No. of taxa in 2008	No. of taxa in 2018	% Change in no. of taxa between 2008 and 2018	No. of taxa in 2008	No. of taxa in 2018	% Change in no. of taxa between 2008 and 2018
1. Highly sensitive to (intolerant of) mud and organic enrichment	3	0	100 % reduction	0	1	100 % increase
2. Sensitive to mud and organic enrichment	13	9	30.7 % reduction	2	6	66.6 % increase
3. Widely tolerant of mud and organic enrichment	9	6	33 % reduction	4	2	50 % reduction
4. Prefers muddy, organically enriched sediments	2	0	100 % reduction	2	1	50 % reduction
5. Very strong preference for muddy, organically enriched sediments	4	2	50 % reduction	2	3	33.3 % increase

The identity of the individual species that have been lost from Site A between 2008 and 2018 can be assessed from Figure 13 and supported by a more detailed examination of the macroinvertebrate data using univariate SIMPER (PRIMER-e) analysis. They show for example, the following losses of highly sensitive/ sensitive taxa:

- *Austrominius modestus,* a suspension feeding barnacle that attaches to a wide variety of substrata including rocks, stones, shells, other crustaceans (e.g. cockles) and artificial structures. It is tolerant of turbidity and reduced salinity and is found in estuaries as well as on open coasts where the wave exposure is not high. The mean abundance of *A. modestus* declined from 0.5 at Site A in 2008 to zero in 2018, but was absent from Site B in both sampling years.
- *Maldanidae* sp., a large, blunt-ended, cylindrical polychaete worm that live below the surface in flimsy sediment tubes and feed as bulk consumers of sediment using a balloon-like proboscis. They process copious amounts of sediment and deposit it in earthworm-like surface casts. The mean abundance of *Maldanidae* declined from 3.8 at Site A in 2008 to zero in 2018, but was absent from Site B in both years.
- *Polynoidae* sp., a long, slender, sand-dwelling unselective deposit feeding polychaete worm that are found only in fine and very fine sands. They are intolerant of eutrophic or muddy conditions. The mean abundance of *Polyonidae* declined from 0.8 at Site A in 2008 to zero in 2018, while it was absent from Site B in 2008 and 2018.

In terms of the influence of the observed macrofaunal decline (Table 6) on NZ AMBI scores, reductions in sensitive taxa (i.e. Groups 1 and 2 organisms e.g. *Austrominius modestus*) were clearly offset by concurrent changes in tolerant taxa (i.e. Groups 4 and 5 organisms e.g. *Capitella capitata*), resulting in negligible changes to NZ AMBI scores at this mid-estuary monitoring site over the sampling period (Figure 12). This suggests that factors other than sediment muddiness and organic enrichment were responsible for the macrofaunal losses, which were particularly pronounced in the Western Arm (Site A) but did include losses from Site B (e.g. *Oligochaeta* sp.), between 2008 and 2018. As mentioned above, reasons for these changes are difficult to ascertain without comprehensive baseline data, but possibly include the influence of past disturbance events (e.g. December 2011 floods) and/or other factors (e.g. natural variability) not measured in this study.

3. Results and Discussion (continued)

Also notable was an increase in the number of Groups 1 and 2 organisms present at Site B (2 taxa in 2008, to 7 in 2018), which included *Paphies australis* (pipi), an endemic bivalve that is intolerant of mud, and *Axiothella serrata,* a polycheate worm commonly found on the sand flats of sheltered coasts and in enclosed inlets and estuaries, from about mid-tide level down to the shallow subtidal, burrowing in substrates from soft mud to coarse sand and often associated with seagrass beds. The mean abundance of *Paphies* and *Axiothella* increased from a total of zero across all sites in 2008, to 1 in 2018. This increase in Groups 1 and 2 organisms underpinned the above change in NZ AMBI scores at Site B from "moderate" in 2008, to "good" in 2018. Although, the magnitude of this shift was limited by the mud/organic enrichment tolerant, corophioid amphipod *Paracorophium* spp. (Group 4, prefers muddy, organically enriched sediments), which increased from a mean abundance of zero in 2008 to 1.4 in 2018.

In summary, notwithstanding the potential ecological consequences of such a biological decline (i.e. a potential loss of the ecosystem functionality that particular macroinvertebrate taxa provide, particularly at Site A), overall, taxa that prefer sandy, low organic content sediments remained relatively well represented across the estuary in 2018, but with generally fewer taxa present at Site B, as was the case in 2008.

3.2 Upper Estuary Subtidal Channel Condition

Background

In SIDEs the rapid flushing time (<3 days for these estuaries) means water column phytoplankton cannot reach high concentrations before they are flushed to the sea. However, the Motupipi can experience elevated concentrations in parts of the upper estuary during low flow-baseflow periods when inflowing freshwater flows over more saline tidal water and results in a dense isolated layer of saline bottom water that neither freshwater or tidal inflow currents are strong enough to flush out. Such isolated (or stratified) bottom water (often situated in the 1-2 m depth range) is susceptible to phytoplankton blooms, low dissolved oxygen, elevated nutrient concentrations and accumulation of fine sediment. In these situations, which vary between marine and close to freshwater salinities, a co-limiting situation between nitrogen (N) and phosphorus (P) is expected, and as a consequence any assessment of nutrient impacts should include both N and P.

Since both N and P are continually cycling between all of their major nutrient forms, an assessment of total N (TN), dissolved inorganic N (DIN) and total P (TP) is needed in order to gauge the level of N and P within an estuary and therefore its potential nutrient related health. Reliance on a single N or P fraction, e.g. inorganic N, results in inaccurate assessments, since even in a large algal bloom inorganic concentrations may be low due to the uptake by the plants (Howes et al. 2003). Based on the following literature, a TN, DIN and TP threshold concentration of approximately 0.4 mg TN l^{-1}, 0.096 mg DIN l^{-1} and 0.025 mg TP l^{-1} for the appearance of eutrophic conditions can be identified (see inset).

Literature supporting water column TN, DIN and TP thresholds

- In Horsen's Estuary, Denmark, research indicates a mean growing season threshold value of 0.398 mg TN l^{-1} to meet good ecological status (Hinsby et al. 2012). This research also identified a threshold for inorganic nutrients as 0.021 mg DIN l^{-1} and 0.007 mg DIP l^{-1}.
- Similarly, ECan Avon-Heathcote Estuary data from 2010-2014 suggests the appearance of eutrophic conditions may be unlikely below a TN concentration around 0.4 mg TN l^{-1} (John Zeldis pers. comm. 2016).
- In the US, EPA Region 1 has considered total N threshold concentrations for estuaries and coastal waters of 0.45 mg TN l^{-1} as protective of DO standards and 0.34 mg TN l^{-1} as protective for eelgrass (Latimer and Rego 2010, State of New Hampshire 2009, Benson et al. 2009).
- As concentrations at inner Massachusetts estuaries rose to levels above 0.4 mg TN l^{-1}, with the entry of a wastewater nitrogen plume, eelgrass beds began declining and localized macro-algal accumulations were reported (Howes et al. 2003).
- In Waituna Lagoon, a coastal lagoon in Southland, thresholds of 0.33 mg N l^{-1} and 0.02 mg P l^{-1} have been identified to maintain a healthy rooted aquatic plant community (particularly key species like *Ruppia* spp.) (Robertson et al. 2013; Burns et al. 2000; Schallenburg et al. 2017).
- In Kakanui Estuary, a coastal lagoon in Otago, DIN thresholds of 0.07 mg DIN l^{-1} when the mouth is closed and 0.096 mg DIN l^{-1} when open have been proposed to limit nuisance level production of the opportunistic macroalga *Ulva* sp. (Plew and Barr 2015).

Results

The water quality results for the surface and bottom waters at the upper estuary site in the Motupipi Estuary (Site X) where susceptibility to nutrients was greatest, are presented in Table 3 (see Figure 1 for the site location). The main findings were as follows:

Water column stratification

There was minimal difference between surface and bottom water temperature, but salinity (Figure 14), chlorophyll *a* and dissolved oxygen (Figure 15) indicated stratification was occurring at upper estuary Site X when sampled on 14 January 2018. The presence of water column stratification, and the consequent likelihood of poorly flushed bottom water, means there is a high potential for intermittent eutrophication of the upper estuary water column as discussed on the following pages.

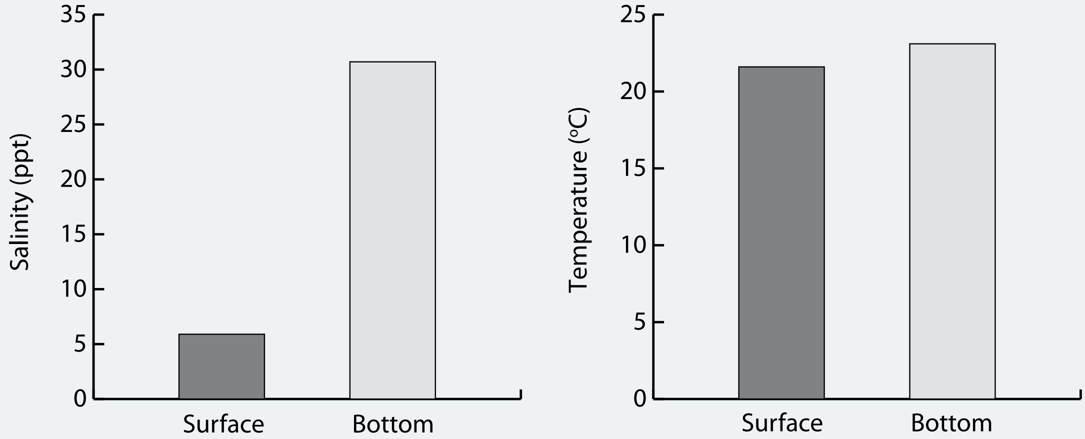

Figure 14. Salinity and temperature in surface and bottom water (n = 1) at upper estuary channel Site X, Motupipi Estuary, 14 January 2018.

Developed pasture and riparian strip to upper estuary river channel margins (top panel) and poorly flushed, nutrient/phytoplankton rich bottom waters at upper estuary channel Site X where sampling was undertaken (bottom panel), Motupipi Estuary.

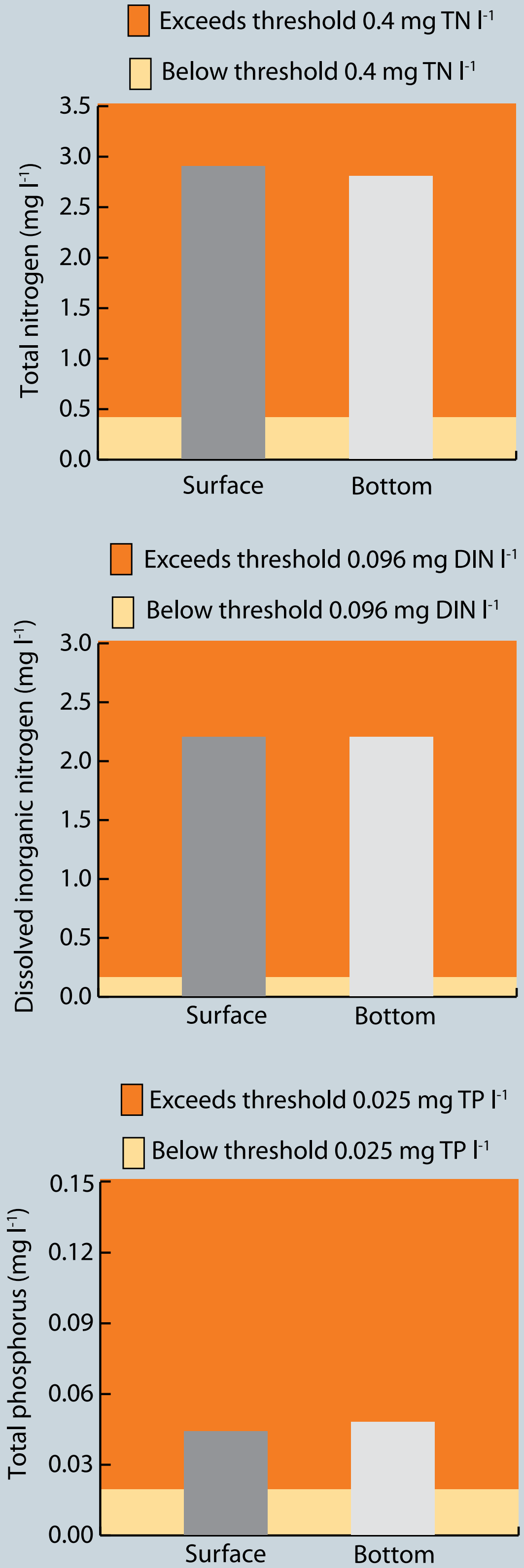

Figure 15. Total nitrogen, dissolved inorganic nitrogen and total phosphorus concentrations (*n* = 1) in surface and bottom water at upper estuary channel Site X, Motupipi Estuary, 14 January 2018.

Susceptibility to eutrophication based on water column TN, DIN and TP concentrations

Total nitrogen (TN), dissolved inorganic nitrogen (DIN) and total phosphorus (TP) concentrations in both the surface and bottom waters at upper estuary Site X exceeded the eutrophication threshold levels of 0.4 mg TN l^{-1}, 0.096 mg DIN l^{-1} and 0.025 mg P l^{-1} (Figure 15). These plots show that TN, DIN and TP concentrations were similar in surface and bottom waters. In addition, TDC stream monitoring data (collected upstream of the Site X at Reilly Bridge) suggests that concentrations of TN entering the estuary are likely to be consistently in breach of threshold levels, based on a mean baseflow concentration of 1.8±0.7 mg TN l^{-1} (i.e. for the 2015-18 period).

Taken together, these results indicate a relatively high likelihood of eutrophication symptoms (e.g. high chlorophyll *a* concentrations) being present in the bottom and surface waters of the upper estuary, and possibly also in the middle estuary or in the main estuary channel, particularly if the flow at the estuary mouth becomes constricted. However, in the case of the 2018 results, where data for only one discrete event were collected, the results can only be used as an early indicator of likely growing season susceptibility. To assess the susceptibility to eutrophication over the whole growing season (November-April), monthly TN, DIN and TP concentrations and appropriate biological indicator (e.g. chlorophyll *a*) data should be used.

Eutrophic status based on water column chlorophyll *a* and dissolved oxygen concentrations

The NZ ETI threshold for chlorophyll *a* (the primary indicator of water column eutrophication) is expressed as the 90th percentile of monthly measures collected during the growing season, and for dissolved oxygen (the main eutrophication supporting indicator), a 7 day mean. Consequently the one-off measures collected on 14 January 2018 can only be used as an indication of current condition.

Chlorophyll *a* concentrations were low (<10 µg l^{-1}) in surface waters at upper estuary Site X (Figure 16). However, concentrations in denser saline bottom water exceeded the NZ ETI threshold level of 16 µg l^{-1} (Robertson et al. 2016b). The same sites had depressed dissolved oxygen concentrations in both surface and bottom water during daylight (6.5 and 7.0 mg DO l^{-1} respectively), indicating a potential for further depression to lower levels during the night. Both these indicators highlight potential eutrophication issues in the upper estuary channel.

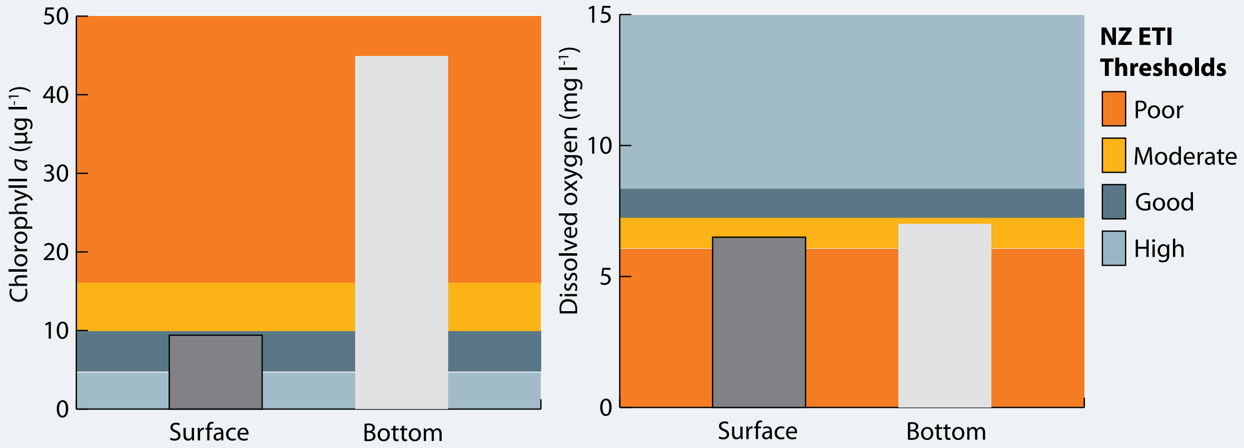

Figure 16. Chlorophyll *a* and dissolved oxygen concentrations (*n* = 1) in surface and bottom water at upper estuary channel Site X, Motupipi Estuary, 14 January 2018.

3.3 Estuary Trophic and Sedimentation Condition versus Catchment Loads

To provide screening-level guidance on whether managing contaminant loading to the Motupipi Estuary from the surrounding catchment would shift the estuary towards a different ecological state (e.g. to improve its condition), the results for the most pertinent condition indicators [based on the combined fine scale (this report) and most recent broad scale (Stevens and Robertson 2015) monitoring results and NZ ETI criteria (Robertson et al. 2016a,b)] are summarised in relation to estimated nitrogen (N) load[1] thresholds and sediment loads[1] in Figure 17 overleaf. Appendix 5 presents detailed background information on the indicator values and criteria used to derive an overall NZ ETI score.

In relation to catchment contaminant loads, while the NZ ETI rates the physical and nitrogen susceptibility of Motupipi Estuary as "MODERATE", its susceptibility to suspended sediment loads is more difficult to predict, which is supported by the following:

- In terms of the mean annual N load to the estuary, estimated inputs using three approaches were as follows:
    i. 72.1 mg N m^{-2} d^{-1}, obtained from NIWA's CLUES (v 10.5) modelling system which includes estimates for all river flow regimes). It is noted however, that CLUES is known to misrepresent actual catchment loading rates for both N and SS (refer to Robertson 2018 for detailed limitations associated to CLUES).
    ii. 58.9 mg N m^{-2} d^{-1}, obtained using TDC "baseflow only" monitoring data collected at Reilly's Bridge, 2015-18 (i.e. annual N load (26 t N yr^{-1}) = mean baseflow concentration (1.8±0.7 mg TN l^{-1}) x the mean annual water input load (14,500,000 m^3 yr^{-1}) to the estuary). Because this measured N load estimate did not include the often dominant flood-flow contribution, it is almost certain that the result is an underestimation. For example, for the Ngongotahā Stream, Rotorua, in 2011 (BOP 2013), baseflow TN catchment yields have been found to be up to 60 % of the total nitrogen catchment yield.
    iii. 138.2 mg N m^{-2} d^{-1}, obtained from Fenemor et al. (2008) who used a relatively crude modelling approach involving landuse data (primarily from other NZ catchments) to estimate N losses from the Motupipi catchment. Broadly speaking, this approach is likely to be less reliable than the more comprehensive modelling undertaken in CLUES.

Taking into account the limitations of each of the three estimates, it is reasonable to conclude that the annual N load to the estuary is close to breaching the critical eutrophication threshold (100 mg N m^{-2} d^{-1}; Robertson 2018; Robertson & Savage *under review*). Further support that the theshold is not actually being breached is provided by the "low" expression of measured primary eutrophication symptoms (NZ ETI score of 0.39, Band B) in the estuary (i.e. absence of extensive intertidal habitat characterised by dense opportunistic macroalgae underlain by poorly oxygenated sediments). In addition, it is noted that all three estimates exceeded natural state N loads estimated by assuming a native forest land cover (28 mg N m^{-2} d^{-1} - note this excludes any further attenuation by associated wetlands). To provide more robust load estimates, it is recommended that future stream N load sampling be undertaken during representative lowflow, baseflow and floodflow periods. This would in turn allow for local calibration of the CLUES model thereby providing necessary confidence in its use for associated management initiatives.

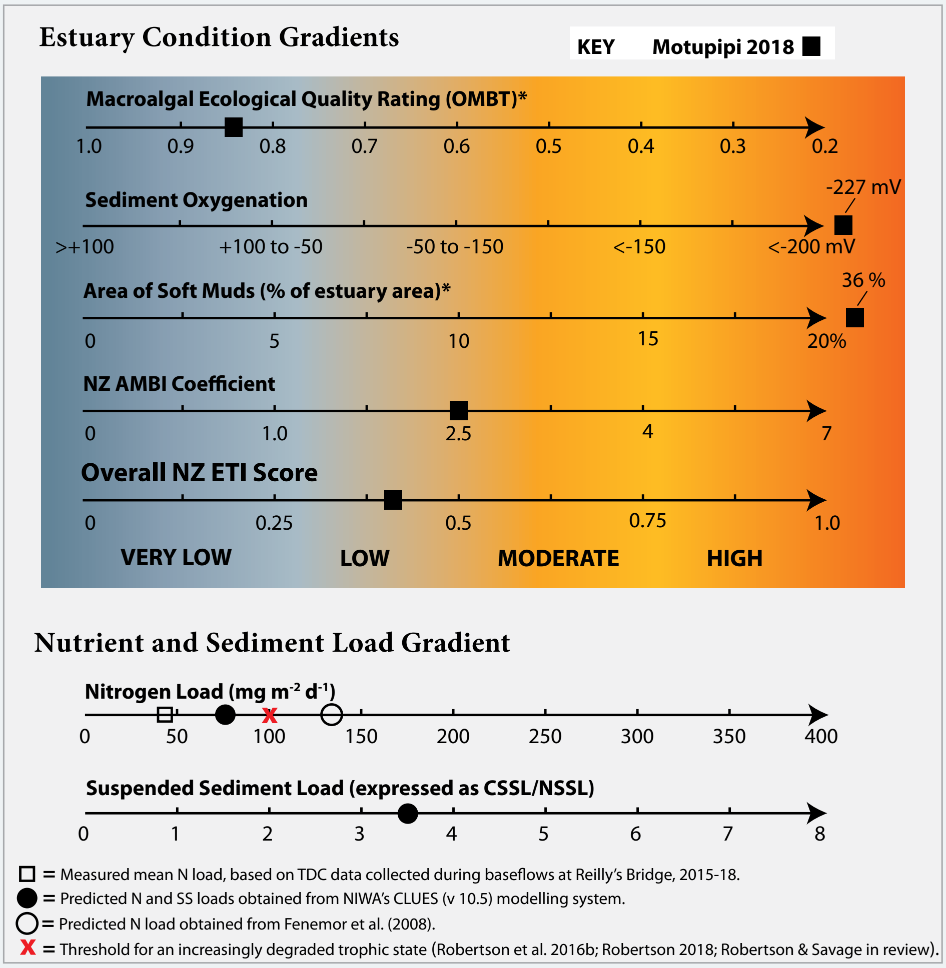

Figure 17. Pertinent indicator and NZ ETI scores, and matching catchment nitrogen and suspended sediment loading rates, Motupipi Estuary, 2018. 'Sediment Oxygenation' expressed as mean redox potential (mV) at 1 cm depth in most impacted sediments and representing at least 10 % of estuary area. 'NZ AMBI' expressed as mean NZ AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10% of estuary area. *based on 2015 broad scale survey findings (Stevens and Robertson 2015).

[1] Estimates of the total nitrogen load and total current state/natural state sediment load (i.e. CSSL/NSSL) for Motupipi Estuary catchment were derived from NIWA's Catchment Land Use for Environmental Sustainability model – CLUES 10.5. CLUES is a modelling system for assessing the effects of land use change and mitigation practices on water quality (TN, TP, sediment and *E. coli*) and socio-economic factors for catchments (~10 km^2 and above). The basic spatial unit within CLUES is the River Environments Classification (REC2) (Snelder et al. 2010) river reach and surrounding subcatchment. CLUES couples a number of existing models within a GIS-platform, and incorporates the Landcare Research Land Cover Data Base (LCDB3) as a default land cover layer for deriving loads. Of most importance to this application of CLUES is the SPARROW component which predicts annual average stream loads of total nitrogen, total phosphorus, sediment and *E. coli*. It includes extensive provisions for stream routing and loss processes (storage and attenuation). This modelling procedure was originally developed by the United States Geological Survey (Smith et al. 1997) and has since been applied and modified in the New Zealand context with extensive liaison with the developers. SPARROW has been applied to nitrogen and phosphorus in Waikato (Alexander et al. 2002) and subsequently to the whole New Zealand landscape (Elliott et al. 2005). Further details on the CLUES modelling framework can be found in Semadeni-Davies et al. (2011, 2015), Woods et al. (2006), and more recently in Plew et al. (2018).

[2] Natural state sediment loads (NSSL) were estimated with all landuse set at native forest cover and corrected for wetland attenuation. Final NSSL = NFL x NSWA where NFL is Native forest load (kt.yr^{-1}) and NSWA is the estimated natural state wetland attenuation for suspended sediment. In this case, NSWA is estimated as 0.5, indicating a mean wetland removal efficiency of ~50 %. This assumption is based on the following study results:

- A wetland complex, draining suburban catchments in Wisconsin USA, attenuated ~71 %, 21 %, and 13 % of the annual loads of SS, TP and TN respectively over a four year period (Schubauer-Berigan et al. 2008).
- Previous studies in New Zealand (McKergow et al. 2007; Tanner et al. 2010) and around the world (Kadlec & Wallace 2009; Mitsch & Grosslink 2007) have identified the need for wetland areas of 1-5 % of the contributing catchment to provide reasonable levels of nutrient attenuation in humid-climate agricultural landscapes. Depending on the specific attributes of suspended solids, smaller wetland areas in the range of 0.1-1 % of contributing catchment can often achieve satisfactory suspended sediment removal.
- The average stormwater suspended sediment removal efficiency for a large number of both NZ and international wetlands showed a mean of 58 % (International BMP Database 2007, as presented in Semadeni-Davies 2009).

- With regard to sediment loading, the combination of current (10.3 kT SS yr^{-1}) and historic (unknown) suspended sediment loads to the estuary is predicted to cause stress to aquatic organisms (Robertson et al. 2016b), based on observed sedimentation issues (i.e. >30 % intertidal area in soft or very soft mud in 2015). However, at this stage, and without an established sediment load/estuary response threshold, it is difficult to determine the magnitude of likely ongoing sedimentation. In order to provide a tentative desktop estimate of the potential for ongoing sedimentation, the magnitude of modelled estimates of the Current State Sediment load (CSSL) can be compared with estimates of the historic Natural State Sediment Load (NSSL)[2]. The NSSL can be estimated by assuming a native forest land cover and the presence of sufficient catchment wetlands to retain 50 % of the load. In effect, such a ratio of CSSL/NSSL indicates whether appropriate soil conservation practices are currently undertaken in the catchment (e.g. a high ratio indicating further effort is required). For the Motupipi, the CSSL/NSSL ratio was estimated to be 3.3 (i.e. 10.3 kT yr^{-1}/3.1 kT yr^{-1}), which indicates that the current sedimentation rate is likely to exceed the natural state sedimentation rate by a similar amount.

4. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for benthic intertidal and upper estuary channel monitoring sites within Motupipi Estuary in January 2018, and supported by 2008 results, showed the following findings in relation to the key issues of sedimentation, eutrophication and toxicity:

Benthic habitat

Muddiness: The two intertidal sites, chosen to represent the main middle estuary benthic habitat, showed low-moderate mud contents (mean 13.8-27.1 % mud), with muddier sediments in the Eastern Arm (Sites B) and sandier sediments in Western Arm (Site A). Ecologically, the overall moderate mud content fits the Band C rating, and indicates a '*moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some taxa and a risk of sensitive macroinvertebrate taxa being lost, especially if nutrient loads are excessive*' (Robertson et al. 2016b).

Eutrophication: The results show that in January 2018 there was an absence of both seagrass and opportunistic macroalgal cover at the two fine scale sites. Underlying sediments had low organic carbon and nutrient contents and were well oxygenated, except for those in the Western Arm (Site A) which were characterised by poor oxygenation conditions (i.e. low redox <-150 mV, Band D) in shallow surface sediments beginning below 1 cm depth.

The combination of moderate mud content and moderate-poor oxygenation indicates that the macroinvertebrate community would likely include mud and/or enrichment tolerant taxa. Such a biological response was reflected in the NZ estuary macroinvertebrate community index (the NZ AMBI) results, mean 2.5 at Site A and 2.4 at Site B. These coefficients indicate a good-moderate ecological condition category (i.e. minor to moderate stress on benthic macrofauna - community tolerant of slight organic enrichment and moderate muds).

Toxicity: Indicators of sediment toxicants [heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, Zn and As)] were at concentrations that were not expected to pose toxicity threats to aquatic life. Nickel, while likely from a natural source, was elevated at Site A but did not exceed the ISQG high toxicity limit (ANZECC 2000) and therefore does not require further investigation of factors controlling bioavailability.

Comparison with 2008 results

A comparison of the 2008 (Robertson and Stevens 2008) and 2018 results show that 2008 benthic physicochemical results were similar to those from Sites A and B in 2018, indicating those parts of the estuary are unlikely to have significantly changed in terms of sediment mud, TOC, TN and TP concentrations in the past decade. Based on NZ AMBI scores, macroinvertebrate communities, which consisted of a broad range of taxomonic and functional groupings, were in "good" condition in 2018, but with generally fewer taxa present at lower abundances across fine scale sites compared to 2008, indicating a potential loss of the ecosystem functionality that macroinvertebrates provide during that period. However, in the absence of a full baseline dataset (i.e. the 2008 fine scale survey data represented only a single-year sampling event rather than sampling over a recommended 3-4 consecutive year period), these temporal trends should be considered with caution.

4. Summary and Conclusions (continued)

Upper estuary subtidal habitat

Eutrophication: Taken as a whole, the January 2018 upper estuary subtidal channel data showed that a localised 50 m stretch (at the very least) of bottom water and underlying sediment was eutrophic at the time of sampling, as indicated by TN, DIN, TP and chlorophyll *a* exceeding the eutrophication threshold concentrations and anoxic, nutrient rich underlying sediments at Site X. However, given only one comprehensive (single site) sampling event, questions remain around the likely extent, duration, magnitude and frequency of such eutrophication symptoms.

Based on expert opinion, the bottom water stratification and accompanying eutrophication likely manifest as cycles that gradually increase in intensity towards the end of the cycle, with the cycles being broken by intermittent high flow events that disrupt the stratification and flush phytoplankton and nutrients into the main body of the estuary and out to sea. The magnitude of the blooms will likely depend on the duration between flood events, with nuisance conditions increasing as time between floods increases. Although upper estuary bottom water stratification is a natural event in many shallow NZ estuaries, it can be exacerbated by reductions in natural river inflows (e.g. from upstream water abstraction and damming). Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nutrient inputs would need to be much less than 0.4 mg TN l^{-1}, 0.096 mg DIN l^{-1} and 0.025 mg TP l^{-1} in order to minimise eutrophication symptoms in the sensitive upper channel of the estuary.

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

Overview

In overview, the results for the two habitat types assessed, i.e. the intertidal benthic habitat throughout the estuary and the upper estuary water column, were as follows:

- The benthic intertidal results indicated that the trophic state of representative habitat within Motupipi Estuary in January 2018 was good (i.e. minimal macroalgal growth). Macroinvertebrate communities, although reduced in both abundance and richness compared to 2008, remained in relatively good condition in relation to the key issues of sediment muddiness and organic enrichment.
- The upper estuary subtidal channel results showed the upper estuary bottom water to be expressing eutrophic symptoms (i.e. TN, DIN, TP and chlorophyll *a* levels all exceeded established eutrophication thresholds).

Finally, in order to assess the potential of the estuary for eutrophication and sedimentation issues, the current estimated nitrogen and sediment loads to the estuary were compared with existing thresholds for expression of problems. The results showed that nitrogen inputs to the estuary were likely below the threshold for the expression of eutrophic conditions, based on the "LOW" NZ ETI score in the main body of this shallow estuary. To improve sediment anoxia and potentially the health of associated macroinvertebrates, as well as possibly allow for expansion of seagrass habitat in the future, areal nitrogen loading rates should be managed below critical thresholds of 100 mg N m^{-2} d^{-1} (Robertson 2018; Robertson & Savage *under review*). Also, based on the elevated area of soft mud habitat in the estuary, it is apparent that the combination of current and historic suspended sediment loads to the estuary is predicted to cause moderate stress to aquatic organisms. However, because quantitative sediment load versus sedimentation thresholds have yet to be developed for NZ estuaries, the issue of ongoing sedimentation rates in the estuary is more difficult to predict.

5. MONITORING

Monitoring

Motupipi Estuary has been identified by TDC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of TDC's coastal monitoring programme being undertaken throughout the Tasman region. Based on the 2018 monitoring results and risk indicator ratings, it is recommended that monitoring continue as follows:

- **Fine scale benthic monitoring**: Sampling of fine scale Sites A and B have now been completed for 2008 and 2018. Given the statistical limitations associated to a single-year baseline data set (i.e. trend analysis invalid), it is recommended that for the next two years (2019 and 2020) TDC collect data only, from both sites (excluding heavy metals, SVOCs, mercury and arsenic) to establish a multi-year baseline, and undertake a full report of all data at the next scheduled 5 yearly monitoring interval (2024/25).
- **Fine scale upper estuary channel monitoring:** To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column and sediment monitoring of the upper-middle estuary channel habitat be undertaken during a summer, prolonged low flow period in 2018/19. It is envisaged that this should include sampling of surface and bottom water at 5-6 sites (with replication) in the main channel of the estuary.
- **Broad scale habitat mapping, including macroalgae:** Continue with the programme of 5 yearly broad scale habitat mapping. Next monitoring due in February/March 2020. Undertake a rapid visual assessment of macroalgal growth annually, and initiate broad scale macroalgal mapping if conditions appear to be worsening over the 5 years before broad scale mapping is repeated.
- **Sedimentation rate monitoring**: Because fine sediment is the priority issue in the estuary it is recommended that established sediment plates continue to be measured annually by TDC, new plates be deployed in locations where sediment accumulation is likely (e.g. eastern corner of the Eastern Arm), and sediment also be analysed for grain size at these sites to establish a baseline and determine if sediments are getting muddier.

6. ACKNOWLEDGEMENTS

Many thanks to Trevor James and Rob Smith (Tasman District Council) for their support, and feedback and review of this report.

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APPENDIX 1. 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 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:
    i. Statistical measures be used to refine indicator ratings where information is lacking.
    ii. 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.
    iii. The outputs stimulate discussion regarding what the acceptable level of risk is, and managing it.
    iv. The indicators and condition ratings used for the Motupipi 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.

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 - 2 cm	<0.5 cm
Redox Potential (mV) upper 3cm***	>+100	-50 to +100	-50 to -150	<-150
Sediment Mud Content (%mud)*	<5 %	5-15 %	>15-25 %	>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)*	<250 mg kg^{-1}	250-1000 mg kg^{-1}	>1000-2000 mg kg^{-1}	>2000 mg kg^{-1}
Trace 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).

APPENDIX 2. 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 100^{-9} dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g 100^{-9} dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg kg^{-1} dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg kg^{-1} dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg kg^{-1} dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg kg^{-1} dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg kg^{-1} dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg kg^{-1} dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg kg^{-1} dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg kg^{-1} dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg kg^{-1} dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg kg^{-1} dry wgt
Organochlorine Pesticides	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Organonitro/phosphorus Pesticides	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Dry Matter (Env)	R.J. Hill	Dried at 103 °C (removes 3-5 % more water than air dry)	

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

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

Appendix 2. Details on Analytical Methods (continued)

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

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

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

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

B. DENSITY SCALES

SACFOR size class				Density				
i	ii	iii	iv	0.25 m^2	1.0 m^2	10 m^2	100 m^2	1,000 m^2
<1 cm	1-3 cm	3-15 cm	>15 cm	(50x50 cm)	(100x100 cm)	(3.16x3.16 m)	(10x10 m)	(31.6x31.6 m)
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 3. 2017/18 DETAILED RESULTS

Fine scale station locations, Motupipi Estuary, 14 January 2018

Motupipi Site A	1	2	3	4	5	6	7	8	9	10
NZMG260 E	2496430	2496426	2496418	2496414	2496413	2496422	2496430	2496439	2496438	2496434
NZMG260 N	6041020	6041018	6041007	6041008	6041001	6041005	6041012	6041021	6041013	6041013
Motupipi Site B	1	2	3	4	5	6	7	8	9	10
NZMG260 E	2497944	2497897	2497891	2497895	2497900	2497906	2497910	2497906	2497920	2497921
NZMG260 N	6040515	6040601	6040580	6040572	6040566	6040585	6040601	6040613	6040614	6040598

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

		Plate Location		Mean Sediment Depth (mm)						
Site	Plate	NZMG260 E	NZMG260 N	26 Sept 2007	15 Feb 2010	1 May 2012	9 July 2013	19 Sept 2014	21 Oct 2015	14 Jan 2018
Motu A Upper Western Arm	1	2496407	6040764	248	243	249	247	252	255	264
	2	2496429	6040776	215	212	218	218	221	227	217
	3	2496442	6040753	190	192	194	206	206	216	213
	4	2496422	6040737	210	213	201	218	217	230	228
Motu B Upper Eastern Arm	1	2497860	6040405	205	211	217	224	221	226	253
	2	2497842	6040385	205	198	190	193	206	195	200
	3	2497817	6040394	200	205	215	219	217	225	228
	4	2497832	6040419	210	210	295	287	252	277	270

Upper estuary water quality and subtidal sediment site location, Motupipi Estuary, 14 January 2018

Motupipi	Site X
NZMG260 E	2496517
NZMG260 N	6039689

Sediment Redox Potential (mV) profiles at fine scale sites, Motupipi Estuary, 14 January 2018

Year/Site	Redox Potential (mV) / Depth														
	0 cm			-1 cm			-3 cm			-6 cm			-10 cm		
2018 A	-78	-67	-81	-236	-227	-218	-259	-262	-254	-320	-335	-316	-355	-370	-341
2018 B	-84	42	31	-45	50	-47	63	-87	-101	-89	-116	-96	-190	-194	-269

Physical and chemical results for fine scale Sites A and B, Motupipi Estuary, 14 January 2018

Year/Site/Rep	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TP	TN
	cm	ppt	%				mg/kg									
2018 A 1-4 [b]	1	27	0.60	15.6	83.9	0.5	0.04	41.00	9.90	21.00	6.90	40.00	5.80	<0.02	690	<500
2018 A-4-8 [b]	1	27	0.45	14.7	85	0.3	0.04	43.00	10.40	23.00	6.70	43.00	6.70	<0.02	710	600
2018 A-9-10 [b]	1	27	0.35	11	87.9	1.1	0.04	42.00	9.00	21.00	5.70	38.00	6.00	<0.02	600	<500
2018 B-1-4 [b]	>5	30	0.38	25.8	74.1	0.2	0.02	31.00	6.20	15.30	4.60	30.00	6.10	<0.02	630	<500
2018 B-4-8 [b]	>5	30	0.36	29.7	70.1	0.2	0.02	31.00	5.70	14.90	4.40	29.00	6.10	<0.02	580	<500
2018 B-9-10 [b]	>5	30	0.39	25.7	74.3	<0.1	0.02	27.00	5.80	14.70	4.30	29.00	6.60	<0.02	620	<500
ISQG-Low [a]	-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High [a]	-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-

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

Appendix 3. 2017/18 Detailed Results (continued)

Water quality results (*n* = 1) for upper estuary Site X, Motupipi Estuary, 14 January 2018

Parameter	Units	Motupipi Site X (surface)	Motupipi Site X (bottom)
Depth	m	0.2	1.3
Temperature	degrees C	21.6	23.1
Salinity	ppt	5.9	30.7
Dissolved Oxygen	mg l^{-1}	6.5	7.0
Chlorophyll *a*	µg l^{-1}	9.4	44.9
Total Nitrogen	g m^{-3}	2.9	2.8
Total Ammoniacal-N	g m^{-3}	0.05	0.06
Nitrite-N	g m^{-3}	0.01	0.01
Nitrate-N	g m^{-3}	2.20	2.20
Nitrate-N + Nitrite-N	g m^{-3}	2.21	2.21
Total Kjeldahl Nitrogen (TKN)	g m^{-3}	0.70	0.60
Dissolved Reactive Phosphorus	g m^{-3}	0.03	0.03
Total Phosphorus	g m^{-3}	0.04	0.05

Sediment quality results (*n* = 1) for subtidal Site X, Motupipi Estuary, 14 January 2018

Year/Site	TOC	Mud	Sand	Gravel	TN	TP
	%				mg kg^{-1}	
Motupipi SED X 2018	1.52	23.3	76.5	0.2	1100	1210

Appendix 3. 2017/18 Detailed Results (continued)

Non-normalised semi volatile organic compounds (SVOCs) in Motupipi Estuary, 2018. Note: results are for a single composite sample for each site, with no analysed compound present at detectable levels (all reported as mg kg^{-1} dry weight).

GROUP	Organic Chemical	Site A 2018	Site B 2018
Organochlorine Pesticides	*Aldrin*	< 0.0010	< 0.0010
	alpha-BHC	< 0.0010	< 0.0010
	beta-BHC	< 0.0010	< 0.0010
	delta-BHC	< 0.0010	< 0.0010
	gamma-BHC (Lindane)	< 0.0010	< 0.0010
	cis-Chlordane	< 0.0010	< 0.0010
	trans-Chlordane	< 0.0010	< 0.0010
	2,4'-DDD	< 0.0010	< 0.0010
	4,4'-DDD	< 0.0010	< 0.0010
	2,4'-DDE	< 0.0010	< 0.0010
	4,4'-DDE	< 0.0010	< 0.0010
	2,4'-DDT	< 0.0010	< 0.0010
	4,4'-DDT	< 0.0010	< 0.0010
	Dieldrin	< 0.0010	< 0.0010
	Endosulfan I	< 0.0010	< 0.0010
	Endosulfan II	< 0.0010	< 0.0010
	Endosulfan sulphate	< 0.0010	< 0.0010
	Endrin	< 0.0010	< 0.0010
	Endrin aldehyde	< 0.0010	< 0.0010
	Endrin ketone	< 0.0010	< 0.0010
	Heptachlor	< 0.0010	< 0.0010
	Heptachlor epoxide	< 0.0010	< 0.0010
	Hexachlorobenzene	< 0.0010	< 0.0010
	Methoxychlor	< 0.0010	< 0.0010
	*Total Chlordane [(cis+trans)*100/42]*	< 0.002	< 0.002
Organonitro & phosphorus Pesticides	*Acetochlor*	< 0.009	< 0.009
	Alachlor	< 0.006	< 0.006
	Atrazine	< 0.009	< 0.009
	Atrazine-desethyl	< 0.009	< 0.009
	Atrazine-desisopropyl	< 0.018	< 0.018
	Azaconazole	< 0.005	< 0.005
	Azinphos-methyl	< 0.018	< 0.018
	Benalaxyl	< 0.005	< 0.005
	Bitertanol	< 0.018	< 0.018
	Bromacil	< 0.009	< 0.009
	Bromopropylate	< 0.009	< 0.009
	Butachlor	< 0.009	< 0.009
	Captan	< 0.018	< 0.018
	Carbaryl	< 0.009	< 0.009
	Carbofuran	< 0.009	< 0.009
	Chlorfluazuron	< 0.009	< 0.009
	Chlorothalonil	< 0.009	< 0.009
	Chlorpyrifos	< 0.009	< 0.009
	Chlorpyrifos-methyl	< 0.009	< 0.009
	Chlortoluron	< 0.018	< 0.018
	Cyanazine	< 0.009	< 0.009
	Cyfluthrin	< 0.009	< 0.009
	Cyhalothrin	< 0.009	< 0.009
	Cypermethrin	< 0.018	< 0.018
	Deltamethrin (including Tralomethrin)	< 0.009	< 0.009
	Diazinon	< 0.005	< 0.005
	Dichlofluanid	< 0.009	< 0.009
	Dichloran	< 0.03	< 0.03
	Dichlorvos	< 0.010	< 0.010
	Difenoconazole	< 0.013	< 0.013
	Dimethoate	< 0.018	< 0.018
	Diphenylamine	< 0.018	< 0.018

Appendix 3. 2017/18 Detailed Results (continued)

GROUP	Organic Chemical	Site A 2018	Site B 2018
Organonitro & phosphorus Pesticides (continued)	*Diuron*	< 0.009	< 0.009
	Fenpropimorph	< 0.009	< 0.009
	Fluazifop-butyl	< 0.009	< 0.009
	Fluometuron	< 0.009	< 0.009
	Flusilazole	< 0.009	< 0.009
	Fluvalinate	< 0.007	< 0.007
	Furalaxyl	< 0.005	< 0.005
	Haloxyfop-methyl	< 0.009	< 0.009
	Hexaconazole	< 0.009	< 0.009
	Hexazinone	< 0.005	< 0.005
	IPBC (3-Iodo-2-propynyl-n-butylcarbamate)	< 0.05	< 0.05
	Kresoxim-methyl	< 0.005	< 0.005
	Linuron	< 0.009	< 0.009
	Malathion	< 0.009	< 0.009
	Metalaxyl	< 0.009	< 0.009
	Methamidophos	< 0.05	< 0.05
	Metolachlor	< 0.006	< 0.006
	Metribuzin	< 0.009	< 0.009
	Molinate	< 0.018	< 0.018
	Myclobutanil	< 0.009	< 0.009
	Naled	< 0.05	< 0.05
	Norflurazon	< 0.018	< 0.018
	Oxadiazon	< 0.009	< 0.009
	Oxyfluorfen	< 0.005	< 0.005
	Paclobutrazol	< 0.009	< 0.009
	Parathion-ethyl	< 0.009	< 0.009
	Parathion-methyl	< 0.009	< 0.009
	Pendimethalin	< 0.009	< 0.009
	Permethrin	< 0.003	< 0.003
	Pirimicarb	< 0.009	< 0.009
	Pirimiphos-methyl	< 0.009	< 0.009
	Prochloraz	< 0.05	< 0.05
	Procymidone	< 0.009	< 0.009
	Prometryn	< 0.005	< 0.005
	Propachlor	< 0.009	< 0.009
	Propanil	< 0.03	< 0.03
	Propazine	< 0.005	< 0.005
	Propiconazole	< 0.007	< 0.007
	Pyriproxyfen	< 0.009	< 0.009
	Quizalofop-ethyl	< 0.009	< 0.009
	Simazine	< 0.009	< 0.009
	Simetryn	< 0.009	< 0.009
	Sulfentrazone	< 0.05	< 0.05
	TCMTB [2-(thiocyanomethylthio)benzothiazole,Busan]	< 0.018	< 0.018
	Tebuconazole	< 0.009	< 0.009
	Terbacil	< 0.009	< 0.009
	Terbumeton	< 0.009	< 0.009
	Terbuthylazine	< 0.005	< 0.005
	Terbuthylazine-desethyl	< 0.009	< 0.009
	Terbutryn	< 0.009	< 0.009
	Thiabendazole	< 0.05	< 0.05
	Thiobencarb	< 0.009	< 0.009
	Tolylfluanid	< 0.005	< 0.005
	Triazophos	< 0.009	< 0.009
	Trifluralin	< 0.009	< 0.009
	Vinclozolin	< 0.009	< 0.009

Appendix 3. 2017/18 Detailed Results (continued)

Epifauna abundance and macroalgal cover at fine scale sites, Motupipi Estuary, 14 January 2018

Group	Family	Taxon	Common name	Scale	Class	A	B
Gastropoda	Amphibolidae	*Amphibola crenata*	Mud-flat snail	#	ii	R	C
Bivalvia	Veneridae	*Austrovenus stutchburyi*	Cockle	#	ii	R	-
Gastropoda	Buccinidae	*Cominella glandiformis*	Mud-flat whelk	#	ii	R	-
Gastropoda	Trochidae	*Diloma subrostrata*	Mud-flat topshell	#	i	R	-
Gastropoda	Batillariidae	*Zeacumantus lutulentus*	Shire shell	#	ii	R	-

Seagrass (*Zostera muelleri*) and macroalgal cover and biomass at fine scale sites, Motupipi Estuary, 14 January 2018

Year/Site	Seagrass Biomass (g m^{-2} wet weight) and Cover (%)	Macroalgal Biomass (g m^{-2} wet weight) and Cover (%)
2018 A	0 (0%)	0 (0 %)
2018 B	0 (0%)	0 (0 %)

Infauna results for fine scale Sites A and B, Motupipi Estuary, 14 January 2018

Infauna (numbers per 0.01327 m² core)

Group	Species	NZ Hyb AMBI*	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
Anthozoa	*Edwardsia* sp.#1	2			1		3				2			8	4	2			1	2	1	1
Nemertea	*Nemertea* sp.#1	3										1										
	Nemertea sp.#2	3										1										
Polychaeta	*Armandia maculata*	2			1																	
	Axiothella serrata	2	3		4		1	1				1		1								
	Disconatis accolus	NA	1				1															
	Nereididae (unidentifiable)	3									1											
	Nicon aestuariensis	3			3														1			
	Orbiniidae (unidentifiable)	1															1		1			
	Pectinaria australis	3			1																	
	Perinereis vallata	2	1				1															
	Prionospio aucklandica	2			1																	
Gastropoa	*Amphibola crenata*	3											1			1		1	3			
	Cominella glandiformis	3			1																	
	Diloma subrostratum	2																	1			
	Potamopyrgus estuarinus	3																		1		
Bivalvia	*Arthritica* sp.#1	4											1									
	Austrovenus stutchburyi	2			2	1	3		2		2	2										
	Paphies australis	2													1							
	Macomona liliana	2	1		5		4		1			3										
Crustacea	*Austrohelice crassa*	5		1				1	1					2	2	1		1	1			
	Hemiplax hirtipes	5	1																			
	Paracorophium excavatum	4													14							
	Phoxocephalidae sp.#1	2	3		1			1			1			3	1			1				
Insecta	*Diptera* sp.#1	2	1												1							
Total individuals in sample			11	1	20	1	13	3	4	0	6	8	2	14	23	4	1	3	8	3	1	1
Total number of taxa in sample			7	1	10	1	6	3	3	0	4	5	2	4	6	3	1	3	6	2	1	1

*sourced from Robertson et al. 2015, 2016

APPENDIX 4. INFAUNA CHARACTERISTICS

Group	Species	NZ AMBI Gp*	Details
Anthozoa	*Edwardsia* sp.#1	2	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
Nemertea	*Nemertea* sp.#1	3	Distinctive species, widespread in shallow estuaries in NZ. Body moderately dorsoventrally flattened; anterior end broadly rounded; cervical groove present; no eyes; a pair of dark, longitudinal pigment bands on the dorsal surface and a single broad, longitudinal pigment band on the ventral surface.
Polychaeta	Nereidae	3	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of elevated sulphide concentrations.
	Nicon aestuariensis	3	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate mud content sediments.
	Prionospio sp.	2	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was renamed to *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001).
	Perinereis vallata	2	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
	Orbiniidae (unidentifiable)	1	Family Orbiniidae. Live in sandy or fine sand sediments. Do not have a burrow. A large non-selective deposit feeder. Endemic orbiniid. Without head appendages. Found only in fine and very fine sands, and can be common. Pollution and mud intolerant. Prefers 5-10 % mud but found from 0-50 % mud. Sensitive to changes in sedimentation rate. Low numbers in Bluff Harbour (2-20 % mud), New River Estuary (1-6 % mud).
	Pectinaria australis	3	Subsurface deposit-feeding/herbivore. Lives in a cemented sand grain cone-shaped tube. Feeds head down with tube tip near surface. Prefers fine sands to muddy sands. Mid tide to coastal shallows. Belongs to Family Pectinariidae. Often present in NZ estuaries. Density may increase around sources of organic pollution and eelgrass beds. Intolerant of anoxic conditions.
	Prionospio aucklandica	2	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is Prionospio aucklandica which was originally Aquilaspio aucklandica. Common at low water mark in harbours and estuaries. A suspension feeding spionid (also capable of detrital feeding) that prefers living in muddy sands (65-70 % mud) but does not like higher levels. But animals found in 0-95 % mud. Commonly an indicator of increase in mud content. Tolerant of organically enriched conditions. Common in Freshwater estuary (<1% mud). Present in Waikawa (10% mud), Jacobs River Estuary (5-10 % muds).
Gastropoda	*Amphibola crenata*	3	A pulmonate gastropod endemic to NZ. Common on a variety of intertidal muddy and sandy sediments. A detritus or deposit feeder, it extracts bacteria, diatoms and decomposing matter from the surface sand. It egests the sand and a slimy secretion that is a rich source of food for bacteria.

Appendix 4. Infauna Characteristics (Continued)

Group and Species		NZ AMBI Gp*	Details
Gastropoda	*Potamopyrgus* sp.	3	Endemic to NZ. Small snail that can live in freshwater as well as brackish conditions. In estuaries *P. antipodarum* can tolerate up to 17-24 % salinity. Shell varies in colour (gray, light to dark brown). Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds but can tolerate organically enriched conditions. Tolerant of muds. Populations in saline conditions produce fewer offspring, grow more slowly, and undergo longer gestation periods. *Potamopyrgus estuarinus* is a small estuarine snail, requiring brackish conditions for survival. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
	Cominella glandiformis	3	Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 m away, even when the tide is out. Intolerant of anoxic surface muds.
	Diloma subrostrata	2	Endemic, mudflat top shell, lives on mudflats, but prefers a more solid substrate such as shells, stones etc. Feeds on the film of microscopic algae on top of the sand.
Bivalvia	*Arthritica bifurca*	4	A small sedentary deposit feeding bivalve. Lives greater than 2 cm deep in the muds. Sensitive to changes in sediment composition.
	Austrovenus stutchburyi	2	Family Veneridae. 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.
	Macomona liliana	2	A deposit feeding wedge shell. This species lives at depths of 5–10 cm 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.
	Paphies australis	2	The pipi is endemic to New Zealand. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents.
Crustacea	*Austrohelice crassa*	5	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
	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 (<4 ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
	Phoxocephalidae	2	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
	Paracorophium excavatum	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ.
Insecta	*Diptera* sp. 1	2	An unknown dipteran or fly larvae.

* NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al. (2015) and nationally validated in Robertson et al. (2016).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.

APPENDIX 5. NZ ESTUARY TROPHIC INDEX

The NZ ETI (Robertson et al. 2016a,b) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness issues. An integrated online calculator is available [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/] to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary), as well as trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]. The more indicators included, the more robust the ETI score becomes. Where established ratings are not yet incorporated into the NIWA ETI online calculator they are included via spreadsheet calculator.

The indicators used to derive an ETI score and determine current trophic and sedimentation state for the Motupipi Estuary (as presented in Figure 16) are presented below using the most recent broad scale monitoring results (Stevens and Robertson 2015) and fine scale monitoring results (this report).

The input values used in the online calculator are presented on the following page.

ETI Tool 1 rates the physical and nutrient load susceptibility of Motupipi Estuary as "MODERATE".

ETI Tool 2 online calculator scores the estuary 0.39, Band B, a rating of "LOW" for eutrophic symptoms.

ETI SCORING SUMMARY FOR MOTUPIPI ESTUARY, JANUARY 2018.			NIWA online calculator	Spreadsheet calculator
PRIMARY SYMPTOM INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)			**Primary symptom value**	
Required	Opportunistic Macroalgae	Macroalgal Ecological Quality - Opportunistic Macroalgal Blooming Tool (OMBT) coefficient*	0.84	0.84
Required	Macroalgal Gross Nuisance Zone (GNA) %	% Gross Nuisance Area (GNA)/Estuary Area*	0	0
Required	Macroalgal GNA Ha	Ha Gross Nuisance Area (GNA)*	0	0
Optional	Phytoplankton biomass	Chl *a* (summer 90 pctl, mg m^{-3})	-	-
Optional	Cyanobacteria (if issue identified) - NOTE ETI rating not yet developed		-	-
SUPPORTING INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)			**Supporting Indicator Value**	
Required indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1 cm depth in most impacted sediments and representing at least 10 % of estuary area**	-227	-227
Required indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*		0
Required indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*		0
Required indicators	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2 cm depth in most impacted sediments and representing at least 10 % of estuary area**	0.5	0.5
Required indicators	Sediment Total Nitrogen	Mean TN (mg kg^{-1}) measured at 0-2 cm depth in most impacted sediments and representing at least 10 % of estuary area***	-	-
Required indicators	Macroinvertebrates	Mean AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10 % of estuary area**	2.5	2.5
Optional	Muddy sediment	% estuary area with soft mud (>25 % mud content)*	36.1	36.1
Optional	Sedimentation rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State Sediment Load (NSSL)		3.4
Optional	Dissolved Oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) (mg m^{-3})	-	-
	NZ ETI Score		**0.39**	**0.39**

* Based on 2015 broad scale findings (Stevens and Robertson 2015), ** Based on 2018 fine scale findings (this report), ***not included - below detection limit in 2018.

Appendix 5. NZ Estuary Trophic Index (Continued)

Input values used in the NZ ETI online calculator (May 2018). See the NIWA online tool metadata spreadsheets for full explanation of terms and abbreviations.

NZ ETI Tool 1 Input details	Calculator Headings	Unit	Input Value
Estuary Number	Est_no		1149
Estuary Name	Est_name		Motupipi River
Regional Council	Reg_Council		Tasman-Nelson
Island	Island		South Island
NZCHS geomorphic code	NZCHS_code		7A
NZCHS geomorphic class	NZCHS_class		Tidal lagoon (perm. open)
ETI Class	ETI_class		SIDE
Latitude	LAT	decimal degrees	-40.83270928
Longitude	LON	decimal degrees	172.8484131
Freshwater inflow	Qf	m3/s	0.46
Annual river total nitrogen loading	TNriver	T/yr	42.13
Annual river total phosphorus loading	TPriver	T/yr	4.25
Volume	V	m3	2988676.357
Tidal Prism	P	m3	2565293.911
Return flow fraction	b	unitless	NA
ACExR fitted exponent	A	unitless	-0.516802242
ACExR fitted constant	B	unitless	158.2926164
Ratio NO3	R_NO3	unitless	0.788754136
Ratio DRP	R_DRP	unitless	0.682195341
Ocean salinity	OceanSalinity_mean	ppt	34.63711142
Ocean nitrate concentration	NOcean	mg/m3	12.87077525
Ocean DRP concentration	POcean	mg/m3	7.236170997
Intertidal area	Intertidal	%	94
Typical closure length	Tl	days	NA
ICOE class	isICOE	one of: TRUE, FALSE	FALSE
Closure length	closure_length	one of: days, months	days
Estuary Area	est_area_m2	m2	1600000
Mean depth	mean_depth	m	2.47
Tidal height	tidal_height	m	3.6114
Low tide area	LOWTIDEest_area_m2	m2	1437000
Low tide mean depth	LOWTIDEmean_depth	m	0.75
Low tide volume	LOWTIDEvolume	m3	1077750

NZ ETI Tool 2 Input details			
Name of estuary	estuary_name		Motupipi River
Phytoplankton Biomass (Chlorophyll a)	CHLA	mg/m3	NA
Macroalgal GNA	macroalgae_GNA_ha	ha	0
Macroalgal GNA/Estuary Area	macroalgae_GNA_percent	%	0
Opportunistic Macroalgae	macroalgae_EQR	OMBT EQR	0.84
Dissolved Oxygen (DO)	DO	mg/m3	6.5
Sediment Redox Potential (RP)	REDOX	mV	-227
Total Organic Carbon (TOC)	TOC	%	0.5
Total Nitrogen (TN)	TN	mg/kg	NA
Macroinvertebrates	AMBI	NZ AMBI	2.5
Area of soft mud	soft_mud	Proportion	0.361
Estuary type	estuary_type		SIDE
ICOE status	isICOE	TRUE/FALSE	FALSE