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# Fine Scale Monitoring of Motupipi Estuary

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# Fine Scale Monitoring of Motupipi Estuary

Prepared by

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for

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## GLOSSARY

| | |
|---|---|
| AMBI | AZTI Marine Biotic Index |
| ANZECC | Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000). |
| ANZG | Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) |
| aRPD | Apparent Redox Potential Discontinuity |
| As | Arsenic |
| Cd | Cadmium |
| Cr | Chromium |
| Cu | Copper |
| DGV | Default Guideline Value |
| ETI | Estuarine Trophic Index |
| Hg | Mercury |
| NEMP | National Estuary Monitoring Protocol |
| Ni | Nickel |
| Pb | Lead |
| SACFOR | Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare |
| SOE | State of Environment (monitoring) |
| TDC | Tasman District Council |
| TN | Total nitrogen |
| TOC | Total Organic Carbon |
| TP | Total phosphorus |
| Zn | Zinc |

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# EXECUTIVE SUMMARY

## BACKGROUND

Tasman District Council (TDC) has in place a long-term State of Environment (SOE) monitoring programme for estuaries in the district. This report describes the findings of four surveys conducted at two sites in the Motupipi Estuary (Site A western arm; Site B eastern arm), largely following the fine scale survey methods described in New Zealand's National Estuary Monitoring Protocol (NEMP). Simultaneously, the report summarises the results of sedimentation monitoring (conducted every 1-2 years since 2007) using the sediment plate method, as well as intermittent synoptic assessments of water quality.

## KEY FINDINGS

There has been a steady increase in sediment accumulation at each site since 2007, with the most pronounced increase at Site B (~40mm since 2007) likely related to inputs following a significant flood in December 2011. The increase at Site B equates to ~3mm/yr of sediment accretion, which exceeds the 2mm/yr guideline proposed for New Zealand estuaries. A lesser increase at Site A (~15mm since 2007) likely reflects its proximity to the Motupipi River and stronger currents than in the eastern arm, which would be expected to reduce the deposition and accumulation of fine sediments. This expectation is supported by the results of sediment grain size analyses, which showed that the mud content of sediments at Site A was less than half that described for Site B over the four surveys.

In 2020, as in previous surveys, there have been no excessive intertidal biological growths (e.g. sea lettuce, microalgal mats) or other obvious symptoms that might indicate enriched or otherwise degraded conditions. This finding is consistent with sediment enrichment indicator results from laboratory samples, showing low levels of total organic carbon, nitrogen and phosphorus at both sites across all survey years. Similarly, field indicators of sediment enrichment provided no evidence of eutrophication.

There appear to be no significant ongoing sources of sediment contaminants to the estuary. Nickel was the only trace metal whose concentration (at Site A in all years except 2020) exceeded the ANZG (2018) default guideline value for 'possible' ecological effects. This result, together with slightly elevated concentrations of other metals (e.g. chromium), is consistent with studies of coastal sediments elsewhere in Tasman and Nelson and likely reflects catchment mineralogy.

Surface-dwelling animals and seaweeds were relatively uncommon over all surveys, although mud snails (*Amphibola crenata*) are conspicuous at Site B. Sediment-dwelling macrofauna communities had a different composition between the two sites. The number of species was greater at Site A, and was dominated by organisms that are relatively sensitive to environmental disturbance. Site B was characterised by a more hardy species suite. That site is probably stressed by the elevated deposition of mud and its location higher in the intertidal zone than Site A, which will expose the sediments to a greater period of stress (e.g. air exposure, desiccation, temperature variation) during low tide. In terms of differences among surveys, 2018 was anomalous in having a relatively low richness and abundance of species, for possible reasons discussed in the report.

Water quality remains an issue in the deeper areas of the lower Motupipi River that are subject to tidal seawater stratification and blooms of phytoplankton. The area affected is relatively extensive (1-2ha of the upper west arm of the estuary), and degraded water quality has been consistently recorded over the past three summer surveys. Seagrass (*Zostera*) beds mapped in the upper west arm in both 2008 and 2015 are now no longer present, which may be water quality related, for reasons discussed in the report.

Various suggestions are made in the report for enhancing the sediment and water quality sampling, and for optimising the macrofaunal component of the monitoring programme. These suggestions are reflected in the recommendations made below.

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## RECOMMENDATIONS

The results of the 2020 fine scale survey and synthesis of longer-term data generally show the estuary to be in good ecological condition, except for the areas of degraded water quality in the lower Motupipi River. On this basis the following is recommended:

1. **Fine scale monitoring frequency:** Conduct fine scale ecological and sediment quality surveys every five years, and sediment plate monitoring annually or at least biennially. This suggested frequency is typical for both of these methods, and adequate for the purposes of keeping a track of estuarine health in the long term.

2. **Fine scale sites:** The current sites appear appropriate for monitoring purposes. Although the sites are physically and biologically different, they have a sufficient range of taxa to enable any ecologically significant environmental changes to be detected.

3. **Fine scale sediment monitoring methods:** It is suggested that measurement of vertical ORP (oxidation reduction potential) profiles is discontinued. The method has too many limitations in the context of the Motupipi Estuary sites. Visual assessment of aRPD (apparent redox potential discontinuity), while itself imperfect, provides a suitable ancillary indicator of gross change in trophic status.

4. **Fine scale macrofauna sampling:** To achieve consistency among surveys, it would be of value to develop a macrofaunal reference collection for Motupipi Estuary, part of which would involve inter-provider comparison of voucher specimens. In terms of sampling effort, collection of 9 core samples in future surveys is considered more than adequate to describe the macrofaunal assemblage and ensure comparability among surveys, and has the added benefit of providing a balanced design for field sampling.

5. **Water quality:** Consider further investigation of the degraded water quality in the lower Motupipi River. Initially, this investigation could be limited to further field-based measurement of salinity, dissolved oxygen and chl-*a*. Depending on findings, a more comprehensive assessment may then be desirable; for example, to consider ecological implications (e.g. for estuarine macrofauna and fish), causes of degradation, and mitigation options.

# 1. INTRODUCTION

Monitoring the ecological condition of estuarine habitats is critical to their management. Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a,b,c). The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective, easy to use, nationally-applied standard protocol with which they can assess and monitor the ecological status of estuaries in their region. The results provide a valuable basis for establishing a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale monitoring to map estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring (at selected sites) of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

One of the key additional methods that has been put in place subsequent to the NEMP being developed is 'sediment plate' monitoring. This component involves an annual assessment of patterns of sediment accretion and erosion in estuaries, based on changes in sediment depth over buried concrete pavers. Sediment plate monitoring stations are often established at NEMP fine scale sites, or nearby.

Tasman District Council (TDC) has in place a long-term SOE monitoring programme for estuaries. The programme is designed to detect and understand changes in key estuaries over time and determine catchment influences, especially those due to the input of nutrients and muddy sediments. The TDC programme includes regular monitoring in five estuaries: Ruataniwha, Motupipi and Waimea, as well as Moutere Inlet and the Motueka River delta. Monitoring at each of these locations has been undertaken periodically for the last 10-20 years.

This report describes the methods and results of a fine scale monitoring survey undertaken at Motupipi Estuary (Fig. 1) in January 2020, along with a synthesis of the results of surveys from earlier years. A focus of the report is understanding changes in estuary health since the first fine scale survey that was undertaken in 2008 (Robertson & Stevens 2008a). Also included in the report is synopsis of a water quality monitoring that has been periodically conducted (including in January 2020) in the lower Motupipi River, primarily due to concerns regarding nutrient inputs and eutrophication.
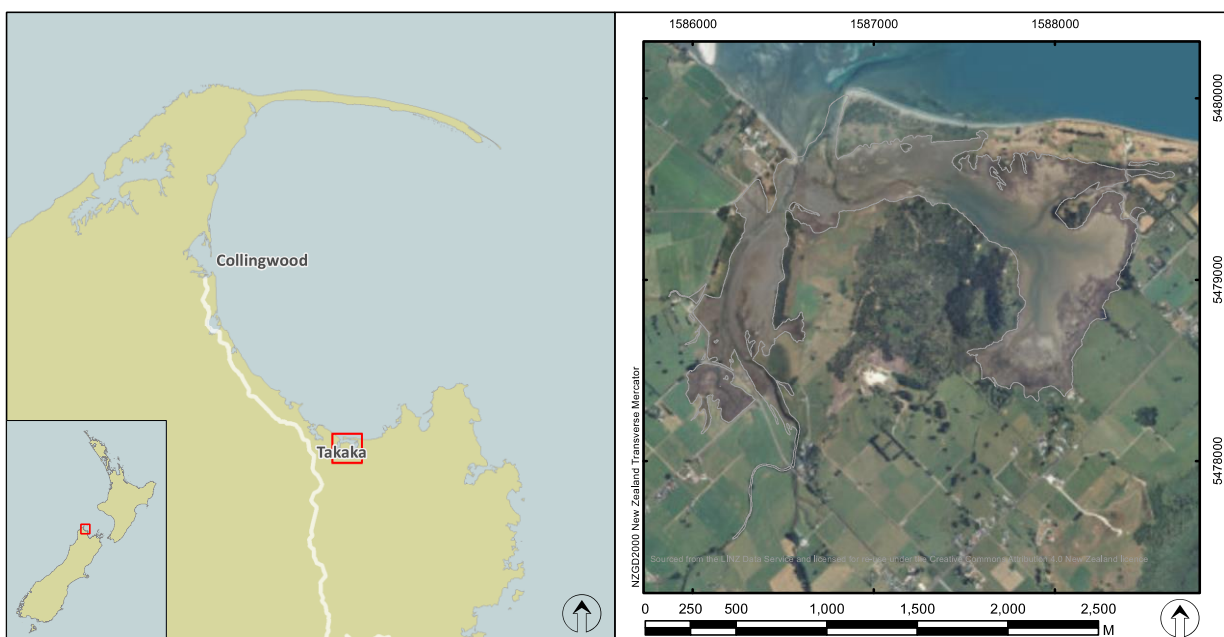


**Fig. 1. Location of Motupipi Estuary.**

## 2. BACKGROUND TO MOTUPIPI ESTUARY

An Ecological Vulnerability Assessment for Motupipi Estuary that was conducted in 2008 (Robertson & Stevens 2008b) set the foundation for the subsequent ecological monitoring that has been undertaken. Simultaneous with the NEMP fine scale survey in 2008, a broad scale survey was also undertaken (Stevens & Robertson 2008). The broad scale survey was repeated in 2015 (Stevens & Robertson 2015), with a repeat fine scale survey in

January 2018 (Robertson & Robertson 2018). A small amount of further fine scale sampling was conducted in October 2018 to clarify discrepancies evident in the results of the January survey. These previous reports have summarised background information on Motupipi Estuary, which is paraphrased (and expanded in places) below.

Motupipi Estuary is moderate in size (169ha), and classified as a shallow, intertidal-dominated estuary (SIDE). It has one tidal opening, and two main basins (Fig. 2). The latter are referred to hereafter as the western and eastern arms. The Motupipi River flows
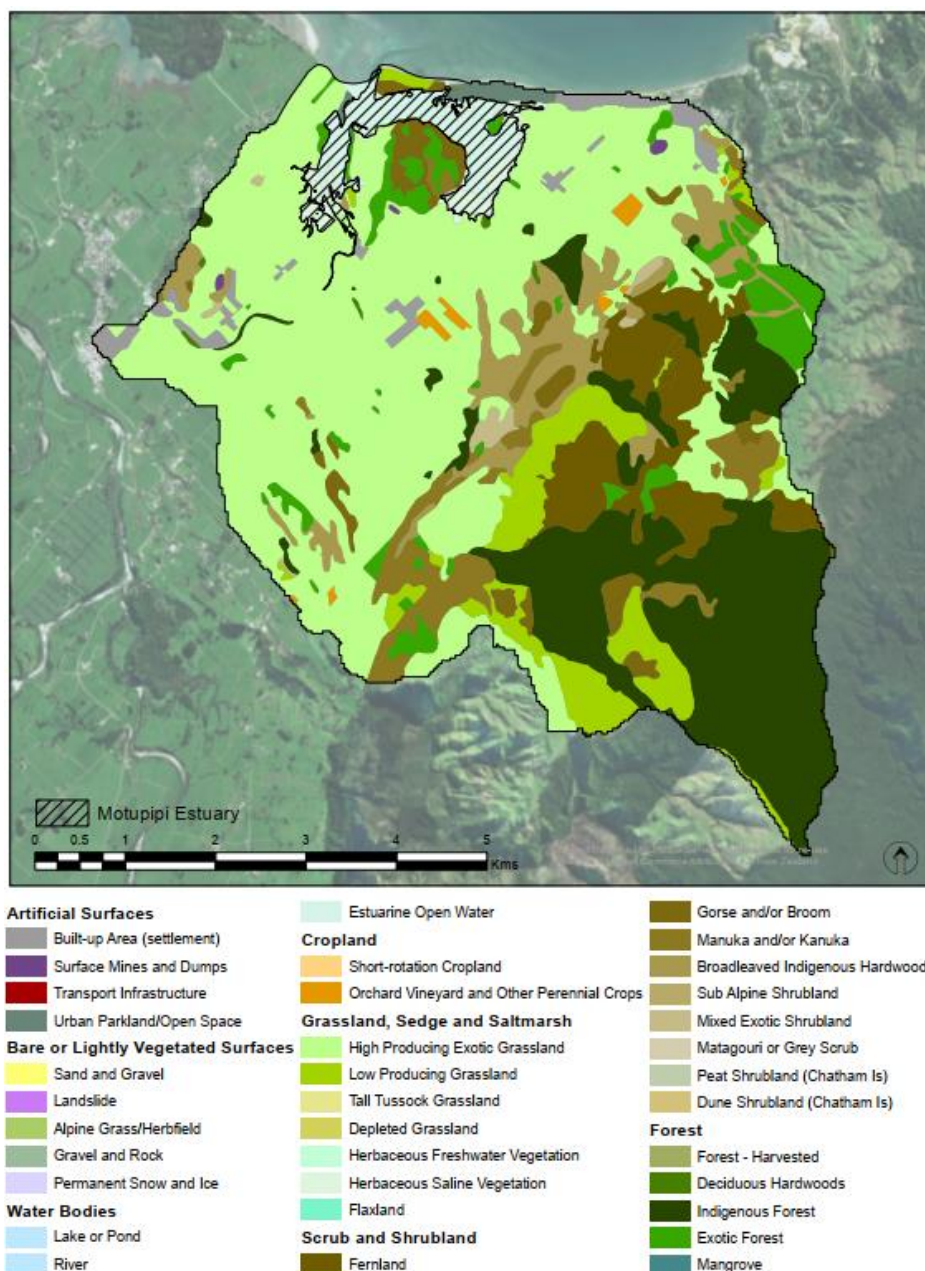


**Fig. 2. Main areas of Motupipi Estuary (hatched) and surrounding catchment land use classifications from LCDB5 database.**

relatively directly through the western arm to the entrance. As such, this part of the estuary responds more like a tidal river system than the seawater-dominated eastern arm. The eastern arm is relatively elevated and, as such, remains exposed to air 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 dominant source of flow in the Motupipi River is from springs, meaning there is very little flow variation and limited erosion. This is a key point of difference to all other estuaries sampled as part of the estuary monitoring programme in Tasman.

The Motupipi catchment (41km$^2$) is dominated by high producing pasture (45%), native forest and scrub (37%) and exotic forestry (8%). Much of the immediate estuary margin directly bordered by developed pasture and rural land, roads, and seawalls (see Fig. 2). Causeways (particularly Rototai Road and Boyle Street) separate small sections of saltmarsh from the main estuary. In the western arm, the upper estuary experiences salinity stratification during stable baseflows. The resulting high salinity bottom layer is generally more stable (less well-flushed) and therefore experiences nuisance phytoplankton blooms and depletion in dissolved oxygen when nutrient inputs are elevated (Robertson & Stevens 2008b).

Mud samples from the estuarine margin of the Rototai landfill, located on the western arm, and from the nearby fine scale Site A, show consistently low trace metal concentrations (used as indicators of potential toxicants), with non-significant concentrations of semi-volatile organic compounds (e.g. pesticides) found at Site A in 2018 (Robertson & Stevens 2008a; Robertson & Robertson 2018). Ecologically, habitat diversity is moderate to high, including 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 (see Fig. 1). Since 1943 there has been a loss of 28ha of saltmarsh through drainage and reclamation. However, significant saltmarsh modification is also likely to have occurred prior to this.

The inlet is regarded as a valuable nursery area for marine and freshwater fish, has an extensive shellfish resource, and is very important for birdlife. The estuary has high use and is valued for its aesthetic appeal, rich biodiversity, shellfish collection, swimming, waste assimilation, whitebaiting, fishing, boating, walking, and scientific interest. Vulnerability assessments (e.g. Robertson & Stevens 2008b) have identified excessive muddiness and nutrient inputs as important ecological stressors, as well as habitat loss, and shifts in biota as a result of climate change.

# 3. FINE SCALE METHODS

## 3.1 OVERVIEW OF NEMP APPROACH

The broad scale survey methodology provides a basis for selection of sites for fine scale monitoring. Broad scale surveys involve describing and mapping estuaries according to the dominant habitat features (substrate and vegetation) present. This procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position, size, or type of dominant habitats can be monitored by repeating the mapping exercise. Extensions to the NEMP methodology that support the fine scale approach include the development of various metrics for assessing ecological condition according to prescribed criteria.

Once an estuary has been classified according to its main habitats and their condition ratings, representative habitats can be selected and targeted for fine scale monitoring. The NEMP advocates monitoring soft sediment (sand/mud) habitat in the mid to low tidal range of priority estuaries, although seagrass habitats or areas with high enrichment conditions are sometimes included. The environmental characteristics assessed in fine scale surveys incorporate a suite of common benthic indicators, including biological attributes (e.g. macrofauna) and physico-chemical characteristics (e.g. sediment mud content, trace metals, nutrients).

As noted above, sediment plate monitoring is a more recent extension to the NEMP. Where significant issues are identified using the sediment plate approach, more comprehensive assessment methods are commonly used, e.g. bathymetric studies or transect-based cross-sectional survey approaches.

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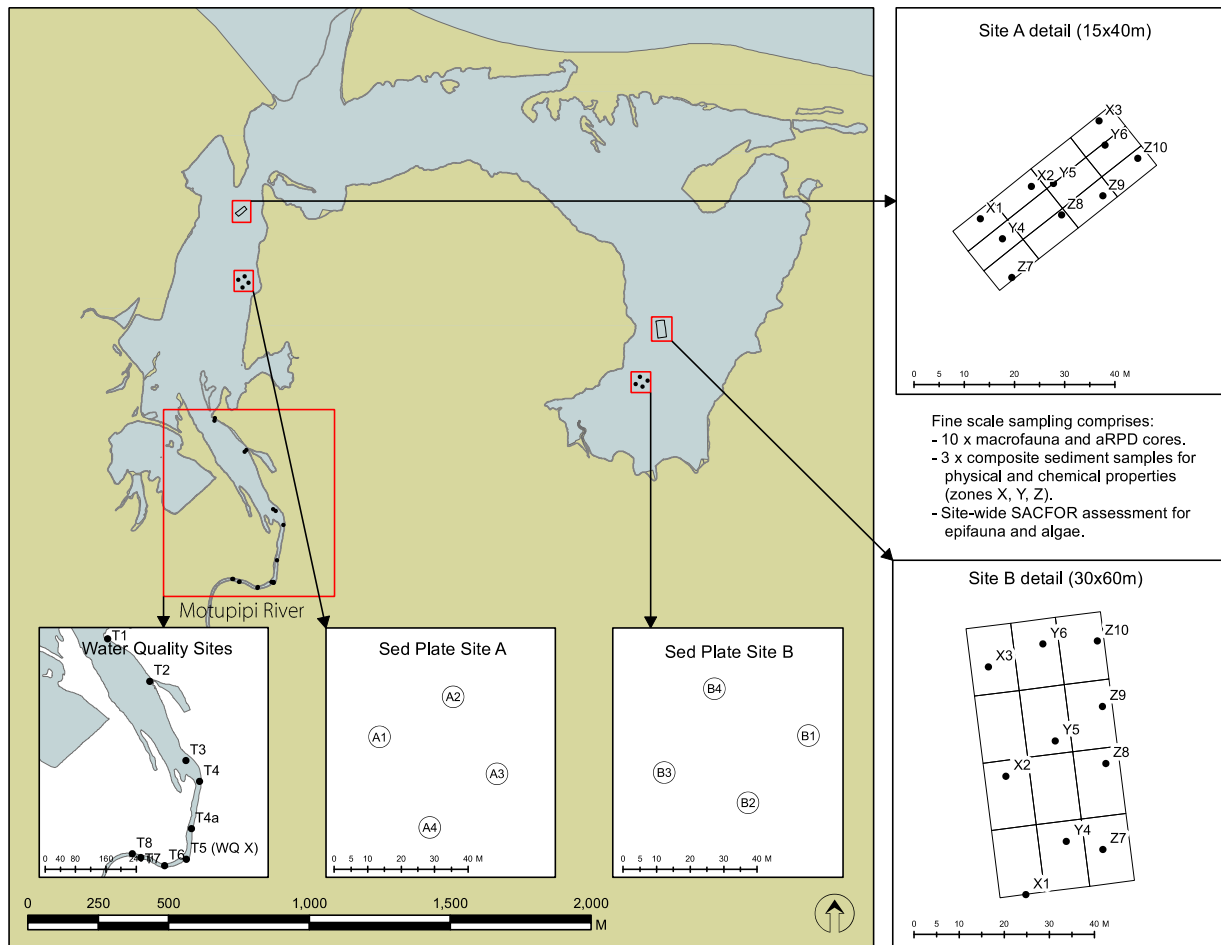
**Fig. 3. Location and schematic of fine scale, sediment plate and water quality monitoring sites in Motupipi Estuary.**

## 3.2 MOTUPIPI FINE SCALE AND SEDIMENT PLATE SITES

The Motupipi fine scale survey involves sampling two unvegetated sites (A & B), in the western and eastern arms of the estuary, respectively. Whereas Site A borders the Motupipi River channel, Site B is in the upper portion of the eastern arm (Fig. 3). The sites are located in habitats classified as 'firm muddy sand'. Fine scale site boundaries are marked with pegs, with coordinates provided in Appendix 1. Note that Site B has the same 30 x 60m dimensions recommended in the NEMP for fine scale sites, whereas Site A is constrained to dimensions of 15 x 40m to minimise the influence of cross-channel slope and sediment changes in the vicinity of Motupipi River.

Each of the fine scale sites has a sediment plate site nearby (see Fig. 3). In addition to providing information on patterns of sediment accretion and erosion, sediment plate monitoring aids interpretation of physical and biological changes at fine scale sites. Motupipi sediment plate sites are marked with wooden pegs, with coordinates of plates and pegs provided in Appendix 1.

A schematic of the layout and sampling approach for fine scale and sediment plate monitoring is provided in Fig. 3, with methods detailed below. For the 2020 survey, all field sampling was undertaken on 5 January.

## 3.3    SEDIMENT PLATES AND SAMPLING

Concrete pavers (20 x 20cm) were installed at Motupipi Estuary sediment plate sites on 27 September 2007. At that time, each plate was positioned in stable sediment, levelled (using a spirit level) before being reburied, and baseline depth measurements were then made.

Subsequent to establishing the baseline, sediment depth had been measured six times between 2010 and 2018. To measure sediment depth in 2020, a 2.5m straight edge was placed over each plate position to average out any small-scale irregularities in surface topography. The depth to each buried plate was then measured by vertically inserting a measuring probe into the sediment until the plate was located. Depth was measured with a ruler to the nearest mm. At least three measurements per plate were made, and a greater number if there was high plate-scale variability.
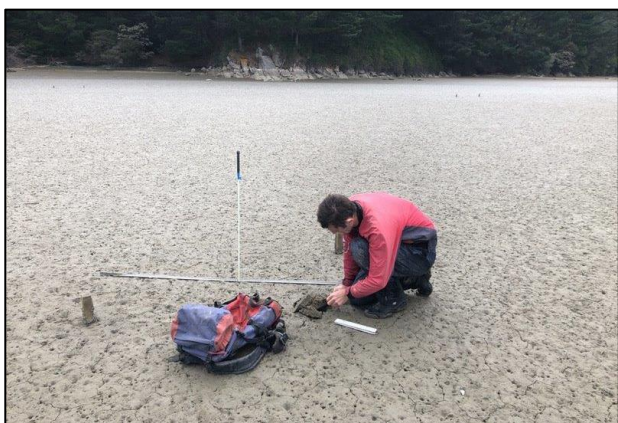


Sediment plate monitoring at Site A, involving measuring sediment depth over buried concrete pavers

## 3.4    Fine scale sampling and benthic indicators

Each of the two fine scale sites was divided into a 3 x 4 grid of 12 plots (see Fig. 3). Fine scale sampling for sediment indicators was conducted in 10 of these plots, with Fig. 3 showing the standard designation of zones X, Y, Z (for compositing sediment samples; see below) and the numbering sequence for replicates used at both sites.

A summary of the benthic indicators, the rationale for their inclusion, and the field sampling methods, is provided in Table 1. Although the general sampling approach closely follows the NEMP, a recent review undertaken for Marlborough District Council (Forrest & Stevens 2019a) highlighted that alterations and

additions to early NEMP methods have been introduced in most surveys conducted over the last 10 or more years. For present purposes we have adopted these modifications as indicated in Table 1.

Three composite sediment samples (each ~250g) were collected from sub-samples (to 20mm depth) pooled across each of plots 1-3, 4-6 and 7-10, which were designated as zones X, Y and Z, respectively. Samples were stored on ice and sent to a RJ Hill Laboratories for analysis of: particle grain size in three categories (% mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP); and trace metals or metalloids (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; nickel, Ni; zinc, Zn). Details of laboratory methods and detection limits are provided in Appendix 2.

The apparent redox potential discontinuity (aRPD) layer (Table 1) is a subjective measure of the enrichment state of sediments according to the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). In the 2020 survey, the aRPD depth was measured (to the nearest mm) after extracting a large sediment core (130mm diameter, 150mm deep) from each of the 10 subplots, placing it on a tray, and splitting it vertically. Representative split cores (1, 4 and 7) were also photographed.



Measurement of Oxidation Reduction Potential at Site B

Although not part of the NEMP, the measurement of oxidation reduction potential (ORP) (see Table 1) is increasingly being evaluated for use in council monitoring programmes. To provide sufficient data to enable comparison against results from the visual

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**Table 1. Summary of NEMP fine scale benthic indicators, rationale for their use, field sampling method, and any differences with NEMP implemented in Motupipi Estuary surveys.**

| NEMP benthic indicators | General rationale | Sampling method and changes from NEMP where relevant |
|---|---|---|
| **Physical and chemical** | | |
| Sediment grain size | Indicates the relative proportion of fine-grained sediments that have accumulated | 1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across the 10 plots |
| Nutrients (nitrogen and phosphorus) and organic matter | Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment | 1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across the 10 plots |
| Trace metals (copper, chromium, cadmium, lead, nickel, zinc) | Common toxic contaminants generally associated with human activities | 1 x surface scrape to 20mm sediment depth for each of 10 plots. Arsenic and mercury also added in this study |
| Depth of apparent redox potential discontinuity layer (aRPD) | Subjective time-integrated measure of the enrichment state of sediments according to the visual transition between oxygenated surface sediments and deeper deoxygenated black sediments. The aRPD can occur closer to the sediment surface as organic matter loading increases. | 1 x 130mm diameter sediment core (150mm deep) for each of 10 plots, split vertically, with depth of aRPD recorded in the field where visible |
| Oxidation redox potential (ORP) profiles | Quantitative instantaneous measure of redox state over a core depth profile, as a complement to aRPD. In theory, ORP values should sharply decline at a depth in the sediment that corresponds to the aRPD. | Not part of NEMP. 1 x 120mm diameter sediment core (150mm deep) for each of 3 plots, with ORP measured across core depth profile using field meter. |
| **Biological** | | |
| Macrofauna | The abundance, composition and diversity of macrofauna, especially the infauna living with the sediment, are commonly-used indicators of estuarine health | 1 x 130mm diameter sediment core (150mm deep) for each of 10 plots, sieved to 0.5mm to retain macrofauna |
| Epibiota | Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health | Abundance score based on ordinal SACFOR scale in favour of NEMP quadrat sampling. Quadrat sampling subject to considerable within-site variation for epibiota with clumped or patchy distributions. |
| Macroalgae | The composition and prevalence of macroalgae are indicators of nutrient enrichment | Percent cover score based on ordinal SACFOR scale in favour of NEMP quadrat sampling (see above comments for epibiota) |
| Microalgae | The composition and prevalence of microalgae are indicators of nutrient enrichment. The utility of microalgae as a robust or useful routine indicator is yet to be demonstrated. | Visual assessment of conspicuous growths as part of SACFOR. Composition requires specialist taxonomic expertise and is not typically undertaken in NEMP studies. |

assessment of the aRPD depth, in each of three plots (1, 4 and 7), a sediment core (120mm diameter, 150mm deep) was taken using a Perspex corer, and ORP was measured at up to five sediment depths (10, 30, 50, 70 and 100mm). ORP measurements were made using a YSI Pro10 ORP meter and YSI 1002 ORP (redox) sensor. The sensor probe was inserted horizontally into holes pre-drilled at the designated depth in the Perspex corer and, after allowing the probe to stabilise at each depth for a consistent 1-minute interval, ORP (mV) was measured.

Each of the large sediment cores used for assessment of aRPD was placed in a separate 0.5mm sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a 75% isopropyl alcohol and 25% seawater mixture for later sorting by Salt Ecology staff and taxonomic identification by Gary Stephenson, Coastal Marine Ecology Consultants (CMEC). The types of animals present in each sample (commonly referred to as 'macrofauna'), as well as the range of different species (i.e. richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments. As a QA/QC cross-check on the macrofaunal identifications made in 2020, a single additional large core was collected from sampling plot Y5 (see Fig. 3) at each site, and extracted macrofauna were sent to NIWA for taxonomic identification.

In addition to macrofaunal core sampling, conspicuous epibiota (macroalgae, and surface-dwelling animals nominally >5mm body size) visible on the sediment surface at each site were semi-quantitatively categorised using the 'SACFOR' abundance (animals) or percentage cover (macroalgae) ratings shown in Table 2.

These ratings represent a scoring scheme simplified from established monitoring methods that have been implemented by the United Kingdom's Joint Nature Conservation Committee since 1990 (MNCR 1990; Blyth-Skyrme et al. 2008).

The SACFOR method is ideally suited to characterise intertidal epibiota with patchy or clumped distributions. It was conducted in 2018 and 2020 as an alternative to the quantitative quadrat sampling specified in NEMP, which is known to poorly characterise scarce or clumped species (e.g. Forrest & Stevens 2019b). Note that our epibiota assessment did not include infaunal species that may be visible on the sediment surface, but whose abundance

cannot be reliably determined from surface observation (e.g. cockles).

**Table 2. SACFOR ratings for site-scale abundance, and percent cover of epibiota and macroalgae, respectively.**

| SACFOR category | Code | Density per m$^2$ | Percent cover |
|---|---|---|---|
| Super abundant | S | > 1000 | > 50 |
| Abundant | A | 100 - 999 | 20 - 50 |
| Common | C | 10 - 99 | 10 - 19 |
| Frequent | F | 2 - 9 | 5 - 9 |
| Occasional | O | 0.1 - 1 | 1 - 4 |
| Rare | R | < 0.1 | < 1 |

*The SACFOR method is intended to characterise the most conspicuous epibiota that are readily apparent to the naked eye (typically organisms exceeding 5mm in size). Our assessment did not include infaunal species that may be visible on the sediment surface, but whose abundance cannot be reliably determine from surface observation (e.g. cockles).*

### 3.5 MOTUPIPI RIVER SAMPLING

Although not part of the NEMP, limited sampling of water quality and sediment quality was undertaken in the lower Motupipi River in 2020, focusing on areas that were influenced by tidal seawater intrusion. In addition, depth gauging across river cross-sections was undertaken to evaluate the presence of deep areas where seawater could be trapped beneath less dense overlying river water. Such areas can be vulnerable to the development of phytoplankton blooms, especially where influenced by catchment nutrient inputs.

### 3.5.1 Water and sediment quality

To provide a comparison with previous surveys, in 2020 a surface (0.2m deep) and bottom water (0.2m above the river bed) grab sample was collected at a single site (Site X, T5) beneath the Abel Tasman Drive bridge (see Fig. 3). Care was taken not to disturb bottom sediments before sampling. The two samples were stored on ice and sent to RJ Hill Laboratories for analysis of nutrients as follows: Total nitrogen (N), total ammoniacal-N, nitrite-N, nitrate-N, total Kjeldahl N (TKN), and total phosphorus. Details of laboratory methods and detection limits are provided in Appendix 2. In addition, a single composite riverbed sediment sample (20mm deep, ~250g) was also

collected from water quality Site X and analysed for the same parameters as described above for the fine scale sites.

To more broadly characterise water quality in 2020, field-based measurements were made at 10 transect stations along the Motupipi River between the upper western arm of the estuary to a point ~150m upstream of the Abel Tasman Drive bridge (Fig. 3). At each station, measurements were made in situ using a YSI Pro10 multimeter (pH, dissolved oxygen, temperature, salinity) and a Delrin Cyclops-7F fluorometer with chlorophyll optics. Measurements were taken at each station of surface and bottom water as above. The thermocline and halocline depths, represented by abrupt changes in temperature and salinity, respectively, were recorded if present. A modified Secchi method was used to obtain a field estimate of water clarity.

### 3.5.2    River cross sections
Gauging of water depth along river cross sections was undertaken at transect stations T1 to T8 (see Fig. 3). Depth gauging was made by wading, or from a kayak, using a graduated survey staff, with measurements rounded to the nearest centimetre. Depths were benchmarked to Mean Low Water Spring tide level.

### 3.6    DATA RECORDING, QA/QC AND ANALYSIS

In 2020, all sediment and macrofaunal samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. Field measurements from the fine scale and sediment plate surveys were recorded electronically in templates that were custom-built using software available at www.fulcrumapp.com. Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position for that record (e.g. a sediment core). Field data were exported to Excel, together with data from the sediment and macrofaunal analyses.

To assess changes over surveys, and minimise the risk of data manipulation errors, Excel sheets for the different data types and years (Table 3) were imported into the software R 3.5.3 (R Core Team 2019) and merged by common sample identification codes. All summaries of univariate responses were produced in R, including tabulated or graphical

representations of data from sediment plates, laboratory sediment/water quality analyses, and macrofauna (e.g. total, mean ± 1 standard error). Where results for sediment quality parameters were below analytical detection limits, averages were calculated using half the detection limit value, according to convention.

Before macrofaunal analyses, the data were screened to remove species that were not regarded as a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g. terrestrial beetles). In addition, to enable comparisons across surveys, cross-checks were made to ensure consistent naming of species and higher taxa across years (e.g. name changes for some genera have occurred in recent years).

Macrofaunal response variables included richness and abundance by species and higher taxonomic groupings. In addition, scores for the biotic health index AMBI (Borja et al. 2000) were derived. AMBI scores reflect the proportion of taxa falling into one of five eco-groups that reflect sensitivity to pollution (in particular eutrophication), ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

To meet the criteria for AMBI calculation, macrofauna data were reduced to a subset that included only adult infauna (those organisms living within the sediment matrix), which involved removing surface dwelling epibiota and any juvenile organisms. AMBI scores were calculated based on standard international eco-group classifications (http://ambi.azti.es) where possible. However, to reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand described by Berthelsen et al. (2018), which drew on prior New Zealand studies (Keeley et al. 2012; Robertson et al. 2015).

We also drew on recent work that assigned specific eco-groups sensitivities to amphipods of known genus (Robertson et al. 2016c; Robertson 2018), but defaulted to the eco-group designation used in the Berthelsen et al. (2018) study for unknown genera (e.g. Amphipod sp. 1). Note that AMBI scores were not calculated for macrofaunal cores that did not meet operational limits defined by Borja et al. (2012), in terms of the percentage of unassigned taxa (>20%), or low sample richness (<3 taxa) or abundances (<6 individuals).

**Table 3. Summary of fine scale and Motupipi River sampling, which began in 2008. Sediment plate sampling has been more frequent (see Section 3.3).**

| Year | Macrofauna cores | Fine scale sediments | Water/sediment quality (Site X) |
|------|------------------|----------------------|----------------------------------|
| 2008 | x | x | |
| 2018 | x | x | x |
| 2018(v) | x | | |
| 2019 | x | x | x |
| 2020 | x | x | x |

*Surveys undertaken in summer following full fine scale approach except for 2018(v), for which macrofaunal cores were collected in Oct 2018 from only a subset of stations (n=3) for verification purposes. In all main surveys, an extra sediment sample was collected from water quality sampling Site X, and in 2018 composite sediment samples were collected for a scan of semi-volatile organic compounds such as pesticides.*

Multivariate representation of the macrofaunal community data used the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in similarity as a function of macrofauna composition and abundance were assessed using a non-metric multidimensional scaling (nMDS) ordination biplot, based on pairwise Bray-Curtis similarity index scores among samples aggregated within each of zones X, Y and Z. The purpose of aggregation was to smooth over the 'noise' associated with a core level analysis and enable the relationship to patterns in sediment quality variables to be determined (i.e. as the sediment samples were composites for each corresponding zone).

Following the nMDS, the similarity percentages procedure (SIMPER) was used to explore the main species or higher taxa that characterised the ordination cluster groups or discriminated groups from each other. Overlay vectors were used to visualise relationships between multivariate biological patterns and sediment quality variables. Additionally, the Primer procedure Bio-Env was used to evaluate the suite of variables that best explained the biological ordination pattern. For all nMDS analyses, abundance data were square-root transformed to down-weight the influence on the ordination of the most dominant species or taxa, and sediment quality data were normalised to a standard scale.

In addition to macrofauna analysis on the 10 cores from each fine scale site, macrofaunal richness, abundance and composition for the 2020 survey data were assessed against the taxonomic identifications for the additional cores sent to NIWA (see Section 3.4), and the adequacy of the current level of replication for macrofaunal sampling was reviewed.

## 3.7    ASSESSMENT OF ESTUARY CONDITION

To supplement our analysis and interpretation of the data, fine scale survey results across all years were assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas. These metrics assign different indicators to one of four 'health status' bands, colour-coded as shown in Table 4. Most of the condition ratings in Table 4 were derived from those described in a New Zealand Estuarine Trophic Index (Robertson et al. 2016a, b), which includes purpose-developed criteria for eutrophication, and also draws on wider national and international environmental quality guidelines. Key elements of this approach are as follows:

- *New Zealand Estuarine Trophic Index (ETI):* The ETI provides screening guidance for assessing where an estuary is positioned on a eutrophication gradient. While many of the constituent metrics are intended to be applied to the estuary as a whole (i.e. in a broad scale context), site-specific thresholds for %mud, TOC, TN, aRPD and AMBI are described by Robertson et al. (2016b). We adopted those thresholds for present purposes, except: (i) for %mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016c); and (ii) for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012). Note that we did not use the ORP thresholds in the ETI as they are provisional and have been recognised as requiring further development.

- *ANZG (2018)* sediment quality guidelines: The condition rating categories for trace metals and metalloids are benchmarked to ANZG (2018) sediment quality guidelines as described in Table 4. The Default Guideline Value (DGV) and Guideline Value-High (GV-high) specified in ANZG are thresholds that can be interpreted as reflecting the potential for 'possible' or 'probable' ecological effects, respectively. Until recently,

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these thresholds were referred to as ANZECC (2000) Interim Sediment Quality Guideline low (ISQG-low) and Interim Sediment Quality Guideline high (ISQG-high) values, respectively.

In addition, for assessing and managing sediment effects, two guidelines are available at a national level. Townsend and Lohrer (2015) propose a Default Guideline Value (DGV) of 2mm of sediment accumulation per year above the natural (native forest) sedimentation rate. If the latter is unknown, the default assumption is that it is zero. They emphasise that the DGV should be refined by further development of relationships between annual sedimentation rate and the health/condition of estuaries. The ETI recommends using the ratio of estimated current to natural (pre-human) sedimentation rates, with increasing values considered to be associated with increasing ecological stress (Robertson et al. 2016b).

Note that the scoring categories in Table 4 should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the health categories that are of most interest, rather than their subjective condition descriptors; i.e. descriptors such as 'poor' health status should be regarded more as a relative rather than absolute rating. For present purposes, our assessment of the multi-year data against the rating thresholds is based on site-level mean values for the different parameters.

**Table 4. Condition ratings used to characterise estuarine health for key fine scale indicators. See text for explanation of the origin or derivation of the different metrics.**

| Indicator | Unit | Very good | Good | Fair | Poor |
|---|---|---|---|---|---|
| **General indicators[1]** | | | | | |
| Mud content | % | < 5 | 5 to < 10 | 10 to < 25 | ≥ 25 |
| aRPD depth | mm | ≥ 50 | 20 to < 50 | 10 to < 20 | < 10 |
| TN | mg/kg | < 250 | 250 to < 1000 | 1000 to < 2000 | ≥ 2000 |
| TOC | % | < 0.5 | 0.5 to < 1 | 1 to < 2 | ≥ 2 |
| AMBI | na | 0 to 1.2 | > 1.2 to 3.3 | > 3.3 to 4.3 | ≥ 4.3 |
| **Trace elements[2]** | | | | | |
| As | mg/kg | < 10 | 10 to < 20 | 20 to < 70 | ≥ 70 |
| Cd | mg/kg | < 0.75 | 0.75 to <1.5 | 1.5 to < 10 | ≥ 10 |
| Cr | mg/kg | < 40 | 40 to <80 | 80 to < 370 | ≥ 370 |
| Cu | mg/kg | < 32.5 | 32.5 to <65 | 65 to < 270 | ≥ 270 |
| Hg | mg/kg | < 0.075 | 0.075 to <0.15 | 0.15 to < 1 | ≥ 1 |
| Ni | mg/kg | < 10.5 | 10.5 to <21 | 21 to < 52 | ≥ 52 |
| Pb | mg/kg | < 25 | 25 to <50 | 50 to < 220 | ≥ 220 |
| Zn | mg/kg | < 100 | 100 to <200 | 200 to < 410 | ≥ 410 |

1. General indicator thresholds derived from a New Zealand Estuarine Tropic Index, with adjustments for mud and aRPD as described in the main text.

2. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good = < 0.5 x DGV; Good = 0.5 x DGV to < DGV; Fair = DGV to < GV-high; Poor = > GV-high. DGV = Default Guideline Value, GV-high = Guideline Value-high. These were formerly the ANZECC (2000) sediment quality guidelines whose exceedance roughly equates to the occurrence of 'possible' and 'probable' ecological effects, respectively.

# 4. KEY FINDINGS

## 4.1 GENERAL FEATURES OF FINE SCALE SITES

Both of the fine scale sites are relatively barren in terms of their surface features, consisting of firm muddy sand sediments. The sediments contain little shell material, although there is more at Site A than Site B. In January 2020 there were no excessive intertidal biological growths (e.g. sea lettuce, microalgal mats) or other obvious symptoms that might indicate enriched or otherwise degraded conditions in estuarine sediments. As was the case in previous years, no seagrass was recorded within the fine scale sites.



Fine scale sites consisted of relatively featureless firm muddy sands with limited shell

## 4.2 SEDIMENT PLATES

Sediment plate raw data are in Appendix 3. Fig. 4 reveals an overall trend for steady sediment accumulation at both sites over the most recent 10-year period from 2010 to 2020, with abrupt increases in some years. The cumulative change is ~15mm at Site A and ~40mm at Site B. The smaller change at Site A likely reflects the proximity of this site to the Motupipi River, and the relatively confined tidal channel of the western arm. Both factors are likely to result in stronger currents than in the eastern arm, which would be expected to reduce the deposition and accumulation of fine sediments.

The more pronounced increase at Site B, and in particular an abrupt increase in sediment depth between the 2010 and 2012 sampling, is likely related to inputs following a significant flood in December 2011. This flood was reported as the second highest rainfall event in a populated area in New Zealand (Stevens & Robertson 2015). The increase at Site B equates to ~3mm/yr of sediment accretion, which exceeds the 2mm/yr DGV proposed for New Zealand estuaries by Townsend and Lohrer (2015).

## 4.3 SEDIMENT CHARACTERISTICS

Composite sediment sample raw data are tabulated in Appendix 4.
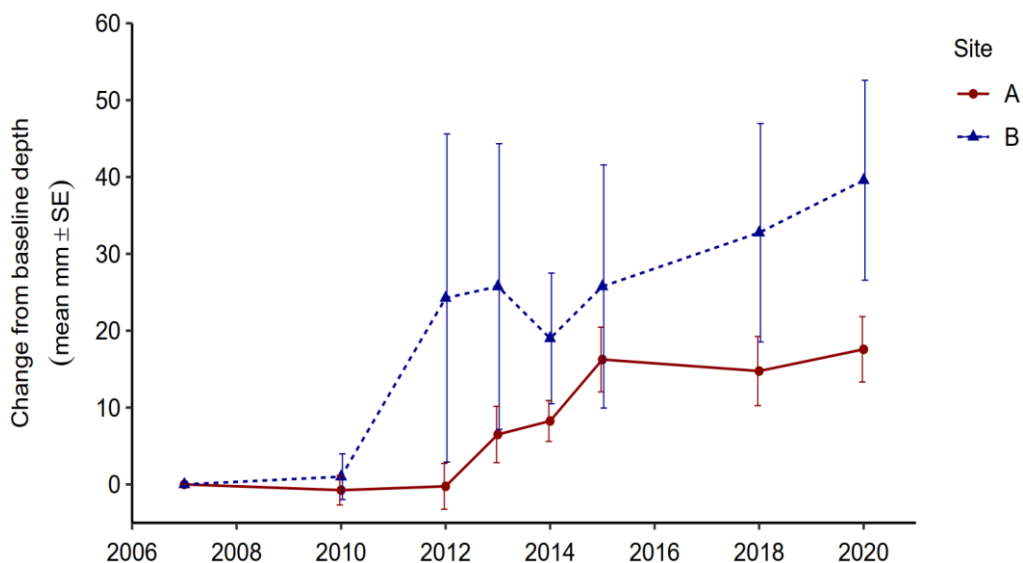


**Fig. 4. Mean cumulative change (± SE) in sediment depth (mm) over buried plates at each of the two fine scale sites. Data for each year are expressed relative to baseline established in 2007.**

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### 4.3.1 Sediment grain size composition

The sand fraction was dominant at both sites in 2020, with the mud content similar to (or slightly less than) previous years ( Fig. 5). The mean mud content at Site A (10-20%) is lower than Site B (~27-39%), consistent with a less depositional environment due to a stronger water flow as suggested above.

To provide a visual impression of sediment quality relative to condition ratings, Fig. 6 shows the mean percentage mud from composite samples against the Table 4 rating criteria. Due to mud content exceeding 25% at Site B in all years, the condition rating there was 'poor'. The Site A rating ranged from 'good' to 'fair'.

### 4.3.2 TOC and nutrients

Mean values of total organic carbon (TOC) and total nitrogen (TN) in composite samples are also compared against rating criteria in Fig. 6 Concentrations were generally low across all years, although TN shows a marked temporal variability. In all cases values fall with condition rating bands of 'good' or 'very good'. Although total phosphorus (TP) does not have a rating criterion, values were also low across all years and similar at both sites (Appendix 4).

### 4.3.3 Redox status

No signs of excessive sediment enrichment were evident in 2020, which is consistent with the sites being sandy, and relatively well-flushed in the case of Site A.

The aRPD transition between brown oxic surface sediments and deeper grey/black sediments (indicating reduced oxygenation) occurred at ~10-30mm at Site A and ~20-100mm at Site B (Fig. 7, Fig. 8).

Most of the aRPD values were rated as 'good', although in 2018 the sediments at Site A were rated on the boundary of 'fair' and 'poor'. Note that in 2008 the aRPD was recorded as >100mm for Site B, not the fixed value represented in Fig. 7.

It is important to recognise that the aRPD is not always well-defined. In free-draining sandy sediments, such as at these estuary monitoring sites, the aRPD may be indistinct, or absent. Furthermore, factors such as bioturbation (e.g. by cockles, crabs) can lead to the mixing of oxic surface sediments with deeper oxygen-reduced sediments, as illustrated by the photograph below (next page).
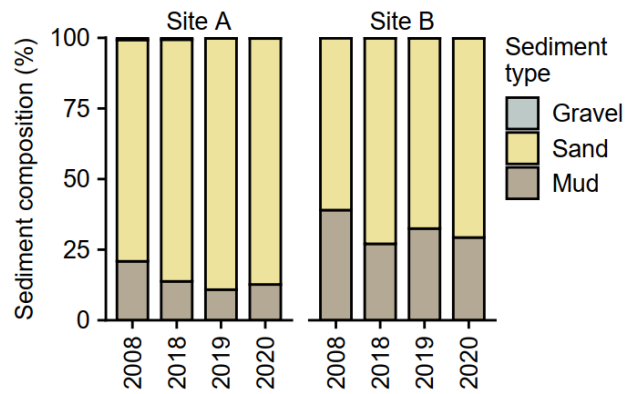


**Fig. 5. Sediment particle grain size analysis, showing site-averaged percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm).**
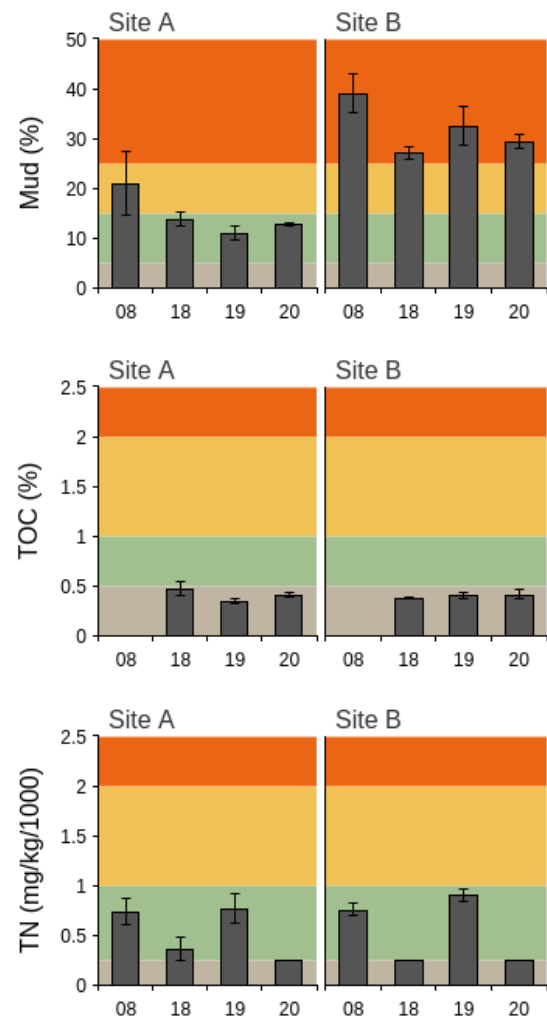


**Fig. 6. Sediment mud, TOC and TN levels relative to condition ratings. Note: TOC not measured in 2008.**

*Condition rating key:*

| Very Good | Good | Fair | Poor |
|-----------|------|------|------|
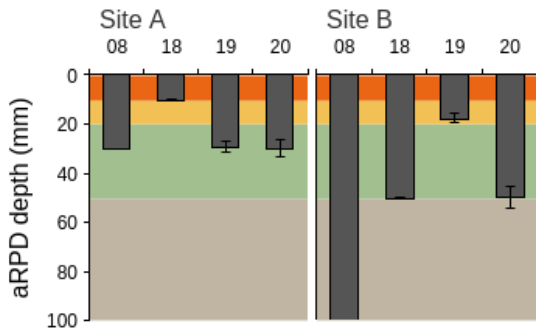
**Fig. 7. Condition ratings for aRPD. Note, the values for Site B in 2008 were reported as >100mm. Condition rating key as per Fig. 6.**
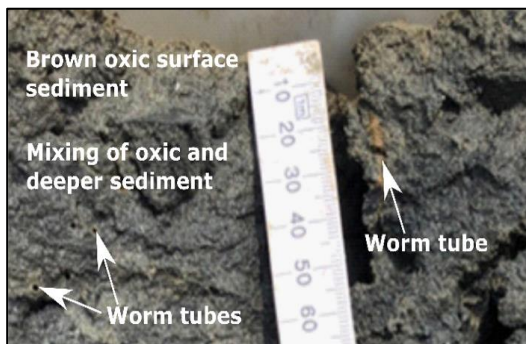


Close up of core showing mixing of sediments that confounds redox assessment

In these situations, there is inherent subjectivity in the determination of aRPD depth, hence the apparent variability across surveys will to some extent reflect provider or assessor differences in interpretation, rather than a true reflection of redox status. Despite such limitations, of most importance is that none of the surveys provide evidence of the aRPD occurring at, or close to (i.e. within a few mm of), the sediment surface, as would occur under highly depositional and/or enriched conditions.

Vertical ORP profiles in the sediment are shown for the 2020 survey in Fig. 9. Of most interest is not the absolute ORP values, as these can change according to sediment mineralogy and other factors, but the occurrence of a rapid change in ORP from relatively positive to negative values across a small change in sediment depth. This point reflects the transition from oxic to reduced sediments and should correspond with the visual transition in the aRPD.

Fig. 9 reveals that no strong or meaningful patterns in the ORP profiles in 2020 are evident. At site B the profiles are counter-intuitive in that ORP values increase (become more positive) rather than decrease with depth in the sediment. Even at Site A only two of the core profiles show a gradual decline in ORP with depth.

**Site A**
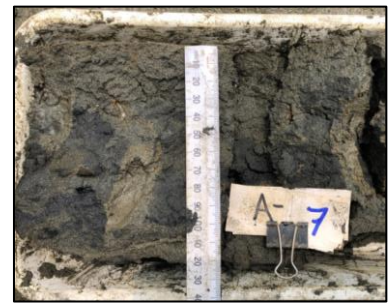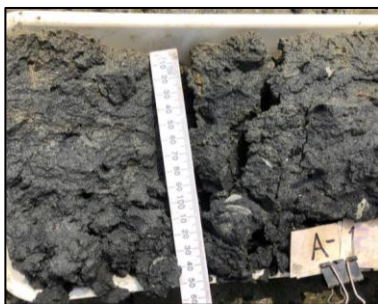


**Site B**



**Fig. 8. Example sediment cores from each of the two fine scale sites in 2020.**

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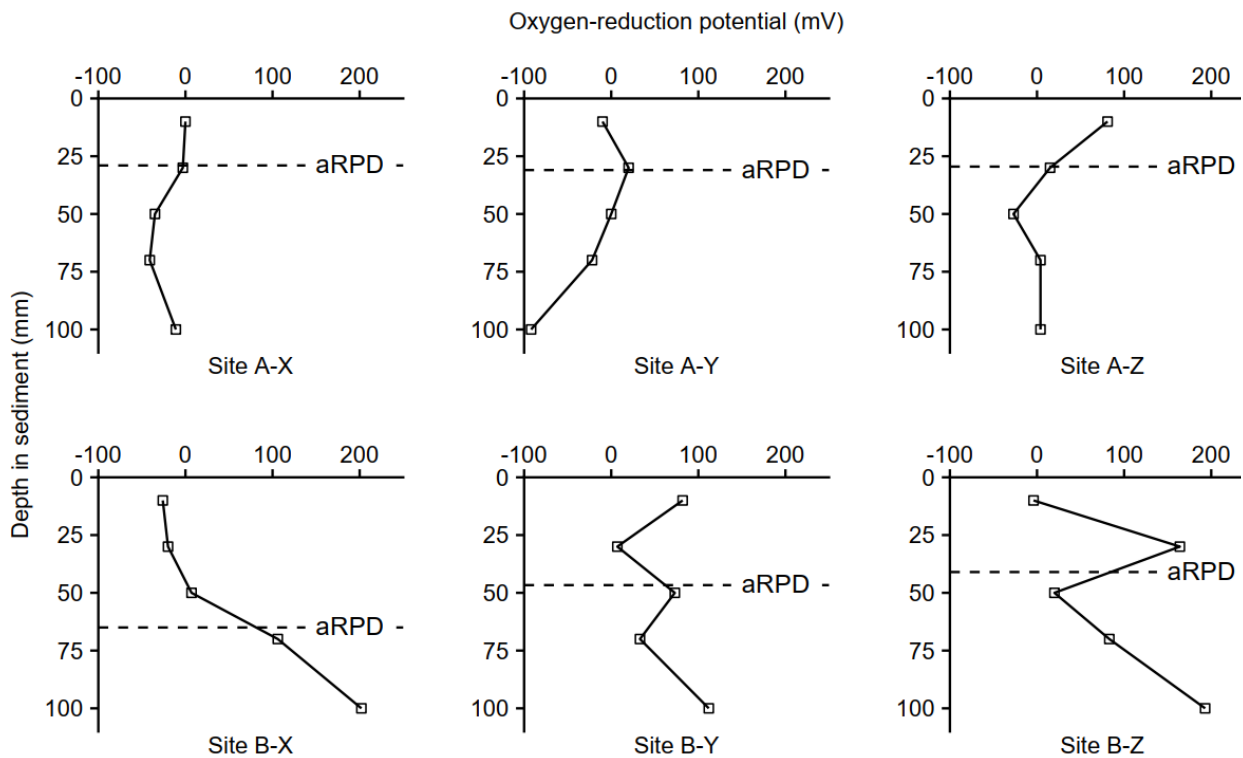
**Fig. 9. Oxidation-reduction potential (ORP) profiles for three cores (X, Y, Z) taken from each of Sites A and B in 2020, showing associated aRPD depth for that core.**

Marked core-to-core variability and inconsistency between aRPD and ORP has been described in other studies that have compared these methods (Forrest & Creese 2006; Gerwing et al. 2013). To some extent these results likely reflect the occurrence of oxic zones throughout the core profile, such as caused by the mixing of surface and deeper sediments by bioturbation as noted above and visible in the photograph. It is a matter of chance whether the ORP probe encounters these areas when it is inserted into the sediment core.

However, there are also other difficulties in measuring ORP that arise in sandy sediments. For example, as the sediments drain relatively freely at low tide, they can be too dry to obtain a reliable ORP reading; this issue was illustrated by Site B in the 2020 Motupipi survey.

### 4.3.4 Trace contaminants

Plots of trace metal contaminants in relation to condition ratings and ANZG (2018) sediment quality guidelines are provided in Fig. 10 (see also Appendix 4). The main impression from Fig. 10 is that trace metal concentrations are very low and generally rated as 'very good', except for nickel (Ni). The concentration of Ni slightly exceeded the DGV for 'possible' ecological effects at Site A in the three surveys prior to 2020, thereby scoring 'fair' on the condition rating scale. However, none of the values exceeded the DGV-high level for 'probable' ecological effects. These elevated Ni levels likely reflect catchment inputs, for reasons discussed in Section 5.1.

As well as the comparison against rating criteria, there are more subtle trends in metal concentrations that are not evident in Fig. 10 due to scaling against the criteria values, but which are apparent from the raw data (Appendix 4). For example, except for arsenic (As) and mercury (Hg), mean trace metal concentrations were consistently higher at Site A than at Site B. Also, it is of interest at Site A that five metals (Cd, Cr, Ni, Pb, Zn) showed a steady decline in mean concentrations over the four survey years (2008-2020). Further discussion and potential explanations for these patterns are provided in Section 5.1.
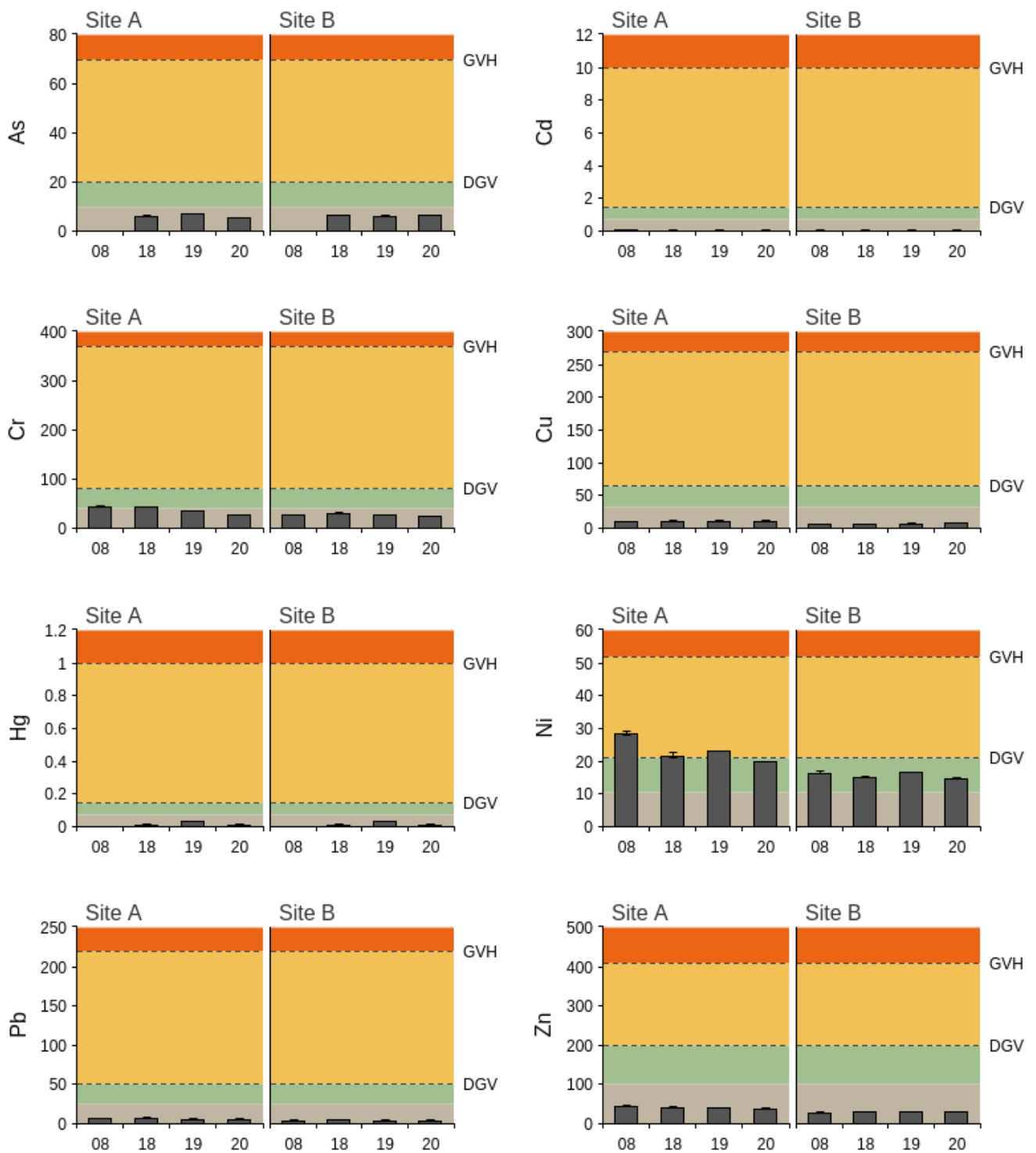
**Fig. 10. Condition rating plots for trace metals (site means ± SE). ANZG (2018) sediment quality guideline thresholds are indicated as Default Guideline Value (DVG) and Guideline Value-high (GVH). Note that concentrations of certain analytes are barely visible on the rating scale.**

*Condition rating key:*

| Very Good | Good | Fair | Poor |
|-----------|------|------|------|

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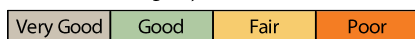
## 4.4 MACROFAUNA

### 4.4.1 Conspicuous surface epibiota

Results from the site-level visual assessment of surface-dwelling epibiota in 2020 are compared with previous surveys in Table 5.

The presence and abundance of epibiota appears quite variable across sites and years. The most conspicuous species is the mud snail, *Amphibola crenata*, which has been consistently present at Site B. By contrast, Site A has three smaller species of mudflat snail that have not been recorded at Site B. The only seaweed recorded is the red alga *Gracilaria chilensis*, but its cover is sparse when it occurs. Numerous crab holes were typically also present, but these were not counted.

In general, considerable variability in distribution and abundance makes epibiota of limited utility as a quantitative fine scale indicator (e.g. by quadrat sampling as per NEMP). However, the SACFOR approach is suitable for the purposes of broadly characterising these types of macrofauna.

### 4.4.2 Macrofauna cores

#### Richness, abundance and AMBI

Raw macrofaunal data are given in Appendix 5, with Appendix 6 containing QA/QC data and an assessment of the adequacy of current sampling effort. A total of 103 taxa were recorded across the four surveys. Background information on the most common of these is given in Table 6. The single QA/QC cores taken at each site and assessed by NIWA in 2020 were comparable in species richness, abundance and composition, with reasons for any differences outlined in Appendix 6.

For the main dataset (i.e. excluding QA/QC cores), mean species richness per core across all years was greatest at Site A, ranging from 4-13 compared with 3-8 at Site B (Fig. 11a). Similarly, mean macrofaunal abundances were greater at Site A than Site B (Fig. 11b). There was a marked within-site difference in richness and abundance among surveys, with the macrofauna being relatively impoverished in January

**Table 5. SACFOR scores for epibiota over all surveys, based on the scale in Table 2.**

| Species | | 2008 A | 2008 B | 2018 A | 2018 B | 2019 A | 2019 B | 2020 A | 2020 B |
|---|---|---|---|---|---|---|---|---|---|
| **Animals (density per m$^2$)** | | | | | | | | | |
| *Amphibola crenata* | Mud snail | C | F | R | C | | C | | F |
| *Cominella glandiformis* | Mudflat whelk | O | | R | | | | O | |
| *Diloma subrostrata* | Mudflat topshell | O | | O | | | | O | |
| *Zeacumantus lutulentus* | Horn snail | F | | R | | C | | F | |
| **Macroalgae (% cover)** | | | | | | | | | |
| *Gracilaria chilensis* | Red seaweed | R | | | | | | R | |

*SACFOR scores for 2008 estimated from quadrat data presented in Robertson and Stevens (2008a).*



Epibiota were present but not conspicuous, except for mud snails at Site B

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**Table 6. Description and abundance per core (pooled across years) of the sediment-dwelling species that were the most common at Site A and/or B. Images are illustrative and do not necessary show the exact species, but an example from the general group.**

| Taxa | A | B | Description | Image |
|---|---|---|---|---|
| Amphipoda (*Paracorophium excavatum*) | 5 | 563 | Amphipods are shrimp-like crustaceans. Corophioid amphipods are opportunistic tube-dwelling species that can occur in high densities in mud and sand habitats, often in estuaries subjected to disturbance and low salinity water. |  |
| Amphipoda (Phoxocephalidae sp. 1) | 106 | 42 | A family of gammarid amphipods. |  |
| Anthozoa (*Edwardsia* sp. 1) | 83 | 70 | A small elongate anemone adapted for burrowing. Fairly common throughout New Zealand. Associated with sandy sediments with low-moderate mud, and appears intolerant of anoxic conditions. |  |
| Bivalvia (*Arthritica* sp. 1) | 13 | 97 | A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment. |  |
| Bivalvia (*Austrovenus stutchburyi*) | 161 | 12 | Cockles are suspension feeding bivalves, living near sediment surface at mid-low tide. Can improve sediment oxygenation, increasing nutrient fluxes and influencing the type of macrofauna present. Sensitive to organic enrichment. Small cockles important in diet of some wading birds. |  |
| Bivalvia (*Macomona liliana*) | 195 | 1 | 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. |  |
| Oligochaeta (Oligochaeta sp. 1) | 3 | 100 | Segmented worms. Deposit feeders that are generally considered very pollution tolerant. |  |
| Polychaeta (*Axiothella serrata*) | 143 | 6 | A maldanid polychaete worm that is a common infaunal species on the sheltered flats of central NZ estuaries. Occupies a fragile J-shaped vertical tube. It has a 3-4 yr life span. |  |
| Polychaeta (*Heteromastus filiformis*) | 76 | 0 | Small capitellid polychaete worm. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and is typically associated with muddy-sand substrate. Thrives under conditions of moderate organic enrichment. |  |
| Polychaeta (*Prionospio aucklandica*) | 173 | 1 | Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid associated mainly with muddy sands, but is sensitive to changes in the level of silt/clay in the sediment. |  |

2018 and to some extent in 2019. The assemblage was particularly species-poor in January 2018; e.g. mean organism richness and abundance at that time was 3 to 5-times lower than in other surveys.

AMBI values (based on a reduced macrofaunal dataset; see methods section) were relatively similar within each site across years, but suggested that conditions at Site B were relatively degraded. At that site, mean AMBI values were relatively high (Fig. 12), resulting in a 'fair' or 'poor' ecological condition rating.

Although the taxa present at both sites spanned all eco-groups (EG; see Section 3.6), Site B was characterised by a relatively low prevalence of sensitive species (EG I and II) in favour of more resilient EG IV and V species (Fig. 13). These hardy species included the tube-dwelling amphipod *Paracorophium excavatum* and the small bivalve *Arthritica* sp. 1 (both EG IV).

By contrast, prevalent at Site A were EG II sensitive species, which included cockles (*Austrovenus stutchburyi*) and wedge shells (*Macomona liliana*), bamboo worms (*Axiothella serrata*), spionid worms (*Prionospio aucklandica*), and certain species of amphipod (Phoxocephalidae sp. 1). Site A also included highly sensitive species, especially the spionid worm *Aonides trifida* (see Appendix 5).
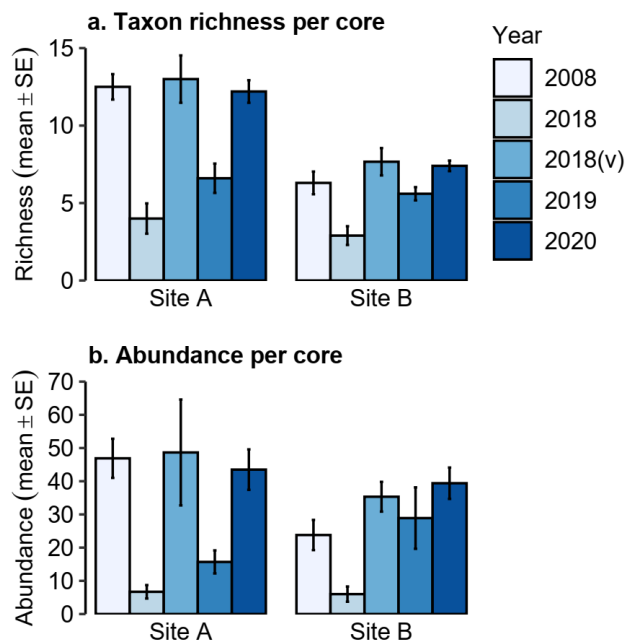


**Fig. 12. Patterns (mean ± SE) in AMBI scores. The AMBI for Site B in 2018 is for site aggregated data**

## Main taxonomic groups

General patterns in the composition of the main taxonomic groups across sites are shown in Fig. 14. In total the species present spanned 12 higher taxonomic groups (Fig. 14). Polychaete worms were by far the most represented group in terms of species richness, especially at Site A (Fig. 14a).

In terms of abundances among the main groups, amphipods were the most dominant and bivalves were also reasonably prevalent (Fig. 14b). Polychaete worms were well-represented at Site A but less so at Site B. Note that the abundances illustrated in Fig. 14b are square-root transformed so that the less common groups display (i.e. these numbers need to be squared to obtain the raw value).

## Multivariate patterns and association with sediment quality variables

In order to further explore the differences and similarities among sites and surveys in terms of macrofaunal assemblage composition, the nMDS ordination in Fig. 15 places zone-aggregated samples of similar composition close to each other in a 2-dimensional biplot, with less similar samples being further apart.

The cluster pattern reveals the key differences in the two sites that were described above, illustrated by the separate grouping of blue (Site A) and red (Site B) samples. The species or higher taxa that characterise each sample grouping are shown on Fig. 15a, generally highlighting that the temporal differences within each site often reflected shifts in the dominance of one species over another.



**Fig. 11. Patterns (mean ± SE) in: a) Taxon richness (taxa per core) and b) Abundance (individuals per core). The verification sampling in 2018 is denoted 2018(v).**
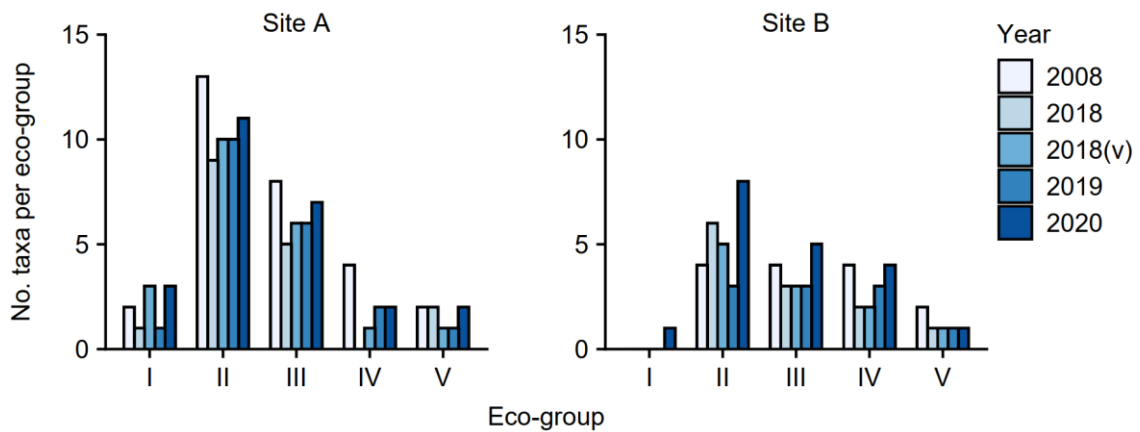
**Fig. 13. Site-level data showing number of taxa within each of five eco-groups ranging from relatively sensitive (EG-I) to relatively resilient (EG-V) taxa for sites A and B, 2008-2020.**
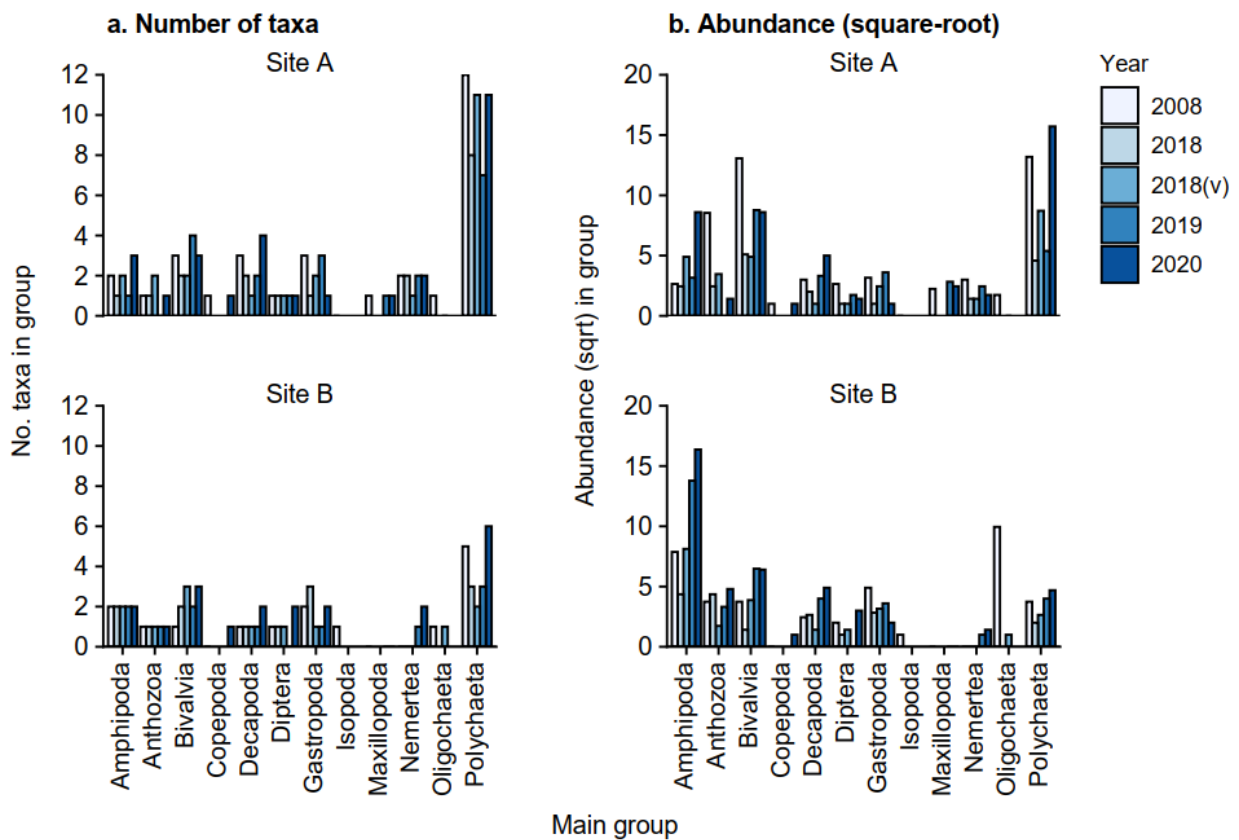


**Fig. 14. Site-level data showing the contribution of main taxonomic groups to richness and abundance values for sites A and B, 2008-2020.**

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### a. Species overlay
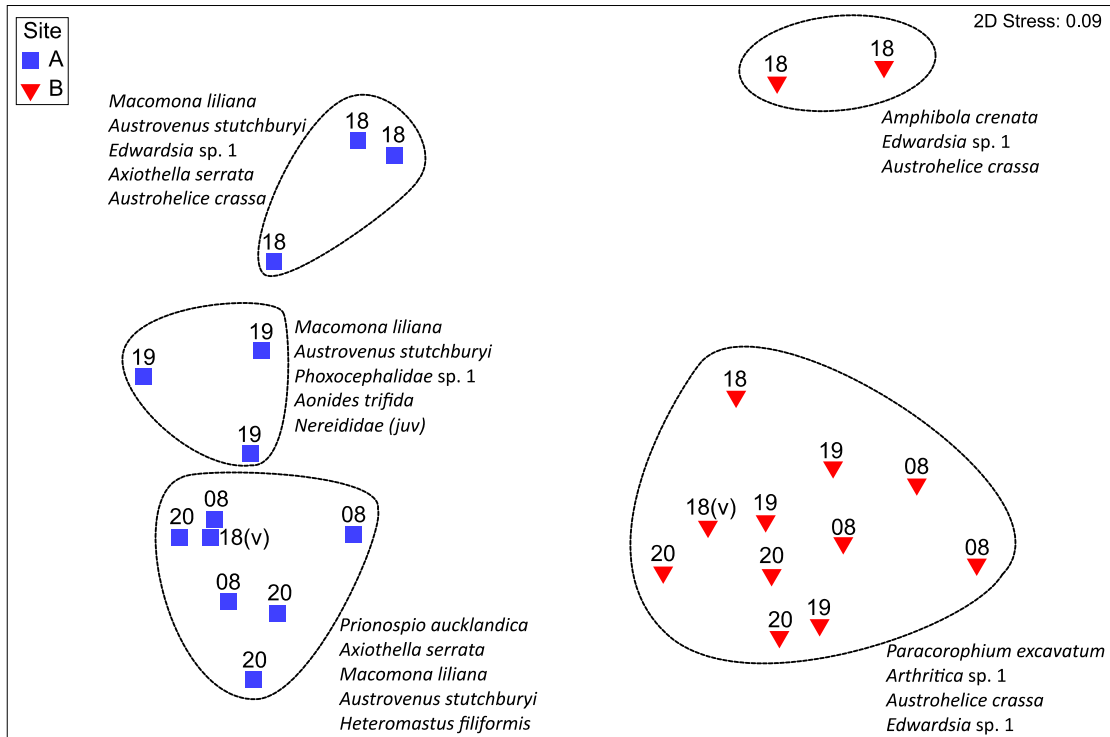


### b. Sediment quality overlay (not including verification survey)
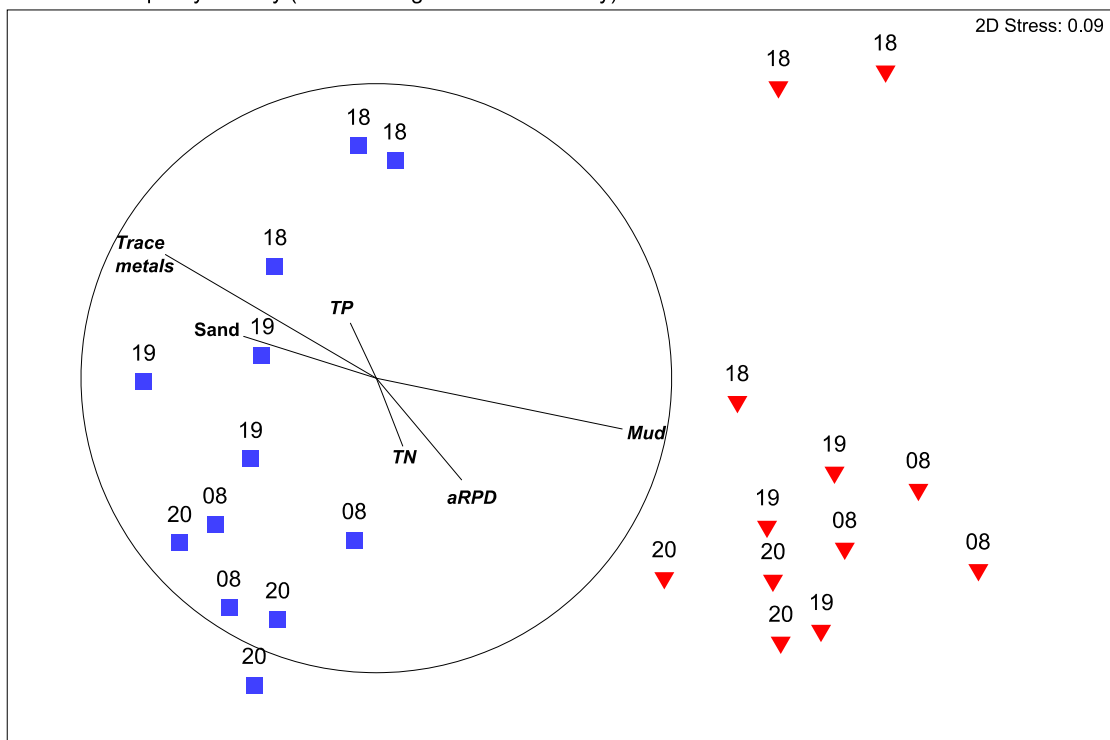


**Fig. 15. Non-metric MDS ordination of macrofaunal core samples aggregated with each of zones X, Y and Z (see Fig. 3), resulting in triplicate representation of each site-year combination.**

*The two panels are as follows:*

*a) dotted ellipses enclose macrofaunal groups clustering at ≥60% Bray-Curtis similarity, with the main taxa identified that discriminate the groups from each other. Verification samples collected in October 2018 labelled 18(v);*

*b) vector overlays indicate the direction and strength of association (length of line) between macrofaunal patterns and key sediment quality variables (full data years only). Trace metals are represented by the vector for zinc, which was used as a proxy for other trace metals with which it was highly correlated (Pearson r² = 0.87 to 0.96).*

Two of the aggregated samples for the 2018 survey cluster as being highly distinct from the other samples and survey years, reflecting the notably impoverished macrofauna reported in Jan 2018 that was described above. In particular, the small disturbance-tolerant species that were typical of Site B were not recorded in 2018 or were in greatly reduced abundance.

Of the sediment quality variables measured, the general differences between the main site groups were most closely correlated with sediment grain size, with increasing mud content strongly associated with the left-right separation of each site-zone in Fig. 15. The association between trace metals and macrofaunal patterns was also strongly associated with the left-right separation in the nMDS, reflecting that metal concentrations at Site A were consistently greater than at Site B. Interestingly, there was little association between trophic state indicators (aRPD, TN, TP) and macrofaunal patterns, which is consistent with the absence of any symptoms of excessive sediment enrichment. Further discussion of these results is provided in Section 5.1, with details of the analysis in Appendix 7.

## 4.5    MOTUPIPI RIVER WATER AND SEDIMENT QUALITY

Water and sediment quality at Motupipi River Site X (T5) (see Fig. 3 map) is provided in Table 7 covering the last three summer surveys. Stratification of the water column is evident in this location in all years, with denser saline water trapped beneath overlying river water. Associated with this effect, phytoplankton production, as indicated by chl-*a*, is typically elevated in bottom waters, and dissolved oxygen can be depleted. The increased phytoplankton production is clearly visible in the water column to the naked eye (see photo below). Despite this situation, a measurable difference in nutrient concentrations between surface and bottom waters is not evident.

Sediment grain size at Site X has been highly variable over the years, with sediments sampled in 2020 being quite coarse relative to the high mud content in 2019. At the time of the latter survey, sediment organic matter (TOC) and nutrient concentrations were also very high. These variable results conceivably reflect change due to periods of erosional river scouring or depositional events during lower flows.

The data from the broader water quality transect survey are largely consistent with the Site X data, showing widespread water column stratification in 2019, and a stratification effect in 2020 that was more confined to the transects near Site X (Table 8). River-bed cross-sectional profiles in Appendix 8 illustrate this stratification effect, showing the deeper area around Site X (Transect 5) that leads to saline water entrapment.



Phytoplankton blooms are regularly visible in the water column as a green/brown plume

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**Table 7.** Summary of water and sediment quality data for Site X in the lower Motupipi River. Water quality data were collected from the surface and bottom.

| Analyte | Units | 2018 | | 2019 | | 2020 | |
|---|---|---|---|---|---|---|---|
| **Water** | | **Surface** | **Bottom** | **Surface** | **Bottom** | **Surface** | **Bottom** |
| Temperature | °C | 21.6 | 23.1 | 19.1 | 19.9 | 16.7 (0.78) | 22.1 (1.99) |
| Salinity (psu) | psu | 5.9 | 30.7 | 3 | 33 | 2.3 (2.13) | 22.2 (7.88) |
| DO conc (g/m3) | g/m$^3$ | 6.5 | 7.0 | 11.1 | 4.5 | 9.4 (2.37) | 3.4 (0.88) |
| DO sat (%) | % | - | - | 123.1 | 63 | 98 (18.22) | 46.6 (10.82) |
| ph | pH units | - | - | 8.8 | 8.2 | 7.9 (0.18) | 7.1 (0.47) |
| Chl-a (mg/m3) | mg/m$^3$ | 9.4 | 44.9 | 5.4 | 7.5 | 1.5 (0.4) | 5.5 (3.52) |
| Dissolved Reactive Phosphorus | g/m$^3$ | 0.034 | 0.033 | 0.0031 | 0.0072 | 0.0067 | 0.0051 |
| Nitrate-N | g/m$^3$ | 2.20 | 2.20 | 1.27 | 0.10 | 2.40 | 0.50 |
| Nitrate-N + Nitrite-N | g/m$^3$ | 2.20 | 2.20 | 1.27 | 0.10 | 2.40 | 0.51 |
| Nitrite-N | g/m$^3$ | 0.0108 | 0.0107 | 0.0057 | 0.004 | 0.005 | 0.0089 |
| Total Ammoniacal-N | g/m$^3$ | 0.054 | 0.055 | 0.016 | 0.28 | < 0.005 | 0.21 |
| Total Kjeldahl Nitrogen (TKN) | g/m$^3$ | 0.70 | 0.60 | 0.30 | 0.60 | 0.12 | 0.33 |
| Total Nitrogen | g/m$^3$ | 2.90 | 2.80 | 1.60 | 0.70 | 2.50 | 0.85 |
| Total Phosphorus | g/m$^3$ | 0.044 | 0.048 | 0.017 | 0.067 | 0.014 | 0.022 |
| | | | | | | | |
| **Sediment** | | **2018** | | **2019** | | **2020** | |
| Gravel | % | 0.2 | | 5.2 | | 17.8 | |
| Sand | % | 76.5 | | 13.8 | | 77.9 | |
| Mud | % | 23.3 | | 81.0 | | 4.4 | |
| TOC | % | 1.52 | | 4.30 | | 0.46 | |
| TN | mg/kg | 1100 | | 4000 | | < 500 | |
| TP | mg/kg | 1210 | | 1090 | | 820 | |

**Table 8.** Summary of field-based water quality data from lower Motupipi River transects in 2019 and 2020. Measurements were made of surface (S) and bottom (B) water at each station.

| Station | Channel width (m) | Max depth (m) | Halocline depth (m) | Secchi depth (m) | Temp (°C) S | Temp (°C) B | Salinity (psu) S | Salinity (psu) B | DO conc (g/m³) S | DO conc (g/m³) B | DO sat (%) S | DO sat (%) B | pH S | pH B | Chl-a (mg/m³) S | Chl-a (mg/m³) B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2019** | | | | | | | | | | | | | | | | |
| T1 | 14 | 0.73 | 0.4 | 0.5 | 20.9 | 21.8 | 17.2 | 30 | 14.1 | 12.8 | 174 | 179.2 | 8.7 | 8.6 | 45.5 | 49.9 |
| T2 | 14 | 0.97 | 0.3 | 0.5 | 20.3 | 22 | 12.6 | 33.2 | 12.2 | 8.9 | 145.5 | 123.2 | 8.7 | 8.5 | 42.5 | 30 |
| T3 | 13 | 0.93 | 0.3 | 0.6 | 20.1 | 21.6 | 11.3 | 32.4 | 11.7 | 8.6 | 139.5 | 119 | 8.7 | 8.5 | 25.5 | 33.5 |
| T4 | 14 | 0.85 | 0.3 | 0.55 | 21.7 | 21.9 | 28.9 | 33.4 | 15.8 | 8.4 | 215 | 129 | 8.7 | 8.6 | 53 | 148 |
| T5 | 15 | 2.3 | 0.3 | 0.75 | 19.1 | 19.9 | 3 | 33 | 11.1 | 4.5 | 123.1 | 63 | 8.8 | 8.2 | 5.4 | 7.5 |
| T6 | 12 | 0.91 | 0.3 | 0.7 | 18.8 | 20.6 | 3 | 29.3 | 10.4 | 5.8 | 113.6 | 77.5 | 8.8 | 7.9 | 6.7 | 17.5 |
| T7 | 9 | 0.37 | na | > 0.37 | 18.3 | | 1.5 | | 10.7 | | 114.7 | | 8.7 | | 5.4 | |
| T8 | 8 | 0.76 | 0.4 | > 0.76 | 18.3 | 19.1 | 1.4 | 18.5 | 10.6 | 10.2 | 122 | 120.7 | 8.4 | 7.5 | 7.5 | 46 |
| **2020** | | | | | | | | | | | | | | | | |
| T1 | 10 | 0.4 | na | > 0.40 | 15.7 | - | 0.7 | - | 10.4 | - | 105.3 | - | 7.4 | - | 0.7 | - |
| T2 | 12 | 0.8 | na | > 0.80 | 15.8 | - | 0.4 | - | 11.3 | - | 112.6 | - | 7.4 | - | 1.5 | - |
| T3 | 10 | 0.8 | na | > 0.80 | 15.9 | - | 0.3 | - | 11.3 | - | 113.6 | - | 8.2 | - | 0.7 | - |
| T4a | 15 | 1.6 | 1 | > 1.60 | 15.7 | 22.9 | 0.1 | 15.2 | 12.1 | 3.8 | 121.8 | 47.7 | 7.6 | 6.6 | 1.3 | 1.3 |
| T5 | 22 | 2.2 | 0.5 | 2 | 15.7 | 23.6 | 0.1 | 31.8 | 12 | 3.7 | 120.2 | 52.2 | 7.6 | 6.7 | 1.1 | 12.5 |
| T5a | 12 | 1.2 | 0.8 | > 1.20 | 18.2 | 18.2 | 6.6 | 6.6 | 4.7 | 4.7 | 61.9 | 61.9 | 8 | 8 | 2.3 | 2.3 |
| T5b | 10 | 1.7 | 0.9 | > 1.70 | 16.1 | 24.6 | 0.3 | 28.3 | 11.6 | 1.7 | 112 | 25.7 | 8.2 | 6.5 | 1.1 | 1.6 |
| T6 | 15 | 1.5 | na | > 1.50 | 15.7 | - | 0.1 | - | 11.9 | - | 121.6 | - | 7.8 | - | 1.3 | - |
| T7 | 6 | 0.4 | na | > 0.40 | 15.6 | - | 0.1 | - | 12 | - | 119.5 | - | 7.5 | - | 1.5 | - |
| T8 | 6 | 0.4 | na | > 0.40 | 15.7 | - | 0.1 | - | 11.7 | - | 118.4 | - | 7.4 | - | 1.7 | - |

# 5. SYNTHESIS AND RECOMMENDATIONS

## 5.1    SYNTHESIS OF KEY FINDINGS

This report has described the findings of four surveys conducted at two sites in the Motupipi Estuary, largely following the fine scale survey methods described in New Zealand's National Estuary Monitoring Protocol (NEMP). Both sites consist of unvegetated firm muddy sand habitats, with Site A bordering the Motupipi River channel and Site B situated in the upper portion of the eastern arm of the estuary. A summary of estuary health against established and provisional condition ratings (see Table 4) is provided in Table 9.

There has been a small but steady increase in sediment accumulation at each site since 2007. The most pronounced increase at Site B (~40mm since 2007) equates to ~3mm/yr of sediment accretion, with floods in December 2011 likely to have contributed to abrupt increases around that time. The 3mm/yr increase exceeds the 2mm/yr Default Guideline Value (DGV) proposed by Townsend and Lohrer (2015) and is rated as 'fair' against Estuarine Trophic Index criteria (current to natural sediment ratio of 2.8). The results indicate that adverse ecological effects are likely to have occurred as a result of excessive fine sediment deposition at this site. The lesser increase at Site A likely reflects its proximity to the Motupipi River, and the confined tidal channel of the western arm. Both factors are likely to result in stronger currents than in the eastern arm, which would be expected to reduce the deposition and accumulation of fine sediments. This expectation is supported by the results of sediment grain size analyses; the mud content of sediments at Site A was less than half that described for Site B over the four surveys, with Site B rated as 'poor' due to the mud content exceeding 25% (Table 9).

In 2020, there were no excessive intertidal biological growths (e.g. sea lettuce, microalgal mats) or other obvious symptoms that might indicate enriched or otherwise degraded conditions at the monitoring sites. This finding is consistent with sediment quality monitoring results, which show low levels of total organic carbon, nitrogen and phosphorus at both sites across all survey years. Similarly, based on field indicators of sediment enrichment (apparent redox potential discontinuity, aRPD; Oxidation Reduction Potential, ORP) there was no evidence of sediment eutrophication. However, the ORP data were poorly representative of redox status due to various methodological limitations discussed in the main

**Table 9. Summary of condition scores of ecological health for each site, based on mean values of key indicators, and criteria and ratings in Table 4. Note, rating criteria not established for TP.**

| Site | Year | Mud % | TOC % | TN mg/kg | TP mg/kg | aRPD mm | As mg/kg | Cd mg/kg | Cr mg/kg | Cu mg/kg | Hg mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg | AMBI na |
|------|------|-------|-------|----------|----------|---------|----------|----------|----------|----------|----------|----------|----------|----------|---------|
| A | 2008 | 20.9 | - | 730 | 573 | 30 | - | 0.041 | 43.7 | 9.6 | - | 28.3 | 6.3 | 44.0 | 2.0 |
| A | 2018 | 13.8 | 0.47 | 367* | 667 | 10 | 6.2 | 0.038 | 42.0 | 9.8 | < 0.02 | 21.7 | 6.4 | 40.3 | 2.8 |
| A | 2019 | 10.8 | 0.34 | 767 | 633 | 29 | 6.9 | 0.032 | 35.0 | 10.5 | 0.03 | 23.0 | 5.7 | 40.0 | 2.0 |
| A | 2020 | 12.7 | 0.41 | < 500 | 640 | 30 | 5.2 | 0.031 | 27.0 | 10.2 | < 0.02 | 19.7 | 5.4 | 38.0 | 1.8 |
| B | 2008 | 39.0 | - | 757 | 557 | 999 | - | 0.014 | 26.3 | 5.7 | - | 16.3 | 3.9 | 27.3 | 3.8 |
| B | 2018 | 27.1 | 0.38 | < 500 | 610 | 30 | 6.3 | 0.018 | 29.7 | 5.9 | < 0.02 | 15.0 | 4.4 | 29.3 | 4.1 |
| B | 2019 | 32.5 | 0.40 | 900 | 597 | 18 | 6.2 | 0.019 | 27.0 | 6.2 | 0.03 | 16.6 | 4.1 | 30.0 | 4.6 |
| B | 2020 | 29.3 | 0.41 | < 500 | 620 | 50 | 6.4 | 0.018 | 23.0 | 7.5 | < 0.02 | 14.7 | 4.0 | 30.0 | 4.3 |

*Sample mean includes values below lab detection limits*

*< All values below lab detection limit*

*Condition rating key:*

| Very Good | Good | Fair | Poor |
|-----------|------|------|------|

text. As such, it is suggested for Motupipi Estuary that measurement of ORP is not particularly worthwhile, especially given that undertaking such measurements greatly adds to field time and cost (Forrest & Stevens 2019a). Although aRPD is far from perfect as an indicator, it at least provides a simple and rapid means of assessing any gross-level increase in eutrophication status.

There appear to be no significant ongoing sources of contaminant inputs to the estuary. Nickel was the only trace metal whose concentration (at Site A in all years except 2020) exceeded the ANZG (2018) DGV for 'possible' ecological effects. However, none of the Ni values exceeded DGV-high levels. Nonetheless, the trace metal analyses provided some counter-intuitive results. Concentrations were consistently higher at Site A than in the muddier sediments at Site B. This result is opposite to the typical trend for metal levels to increase in proportion to sediment mud content.

The reason for the site differences is unknown, but it is also of interest that concentrations of five trace metals at Site A have shown a steady decline over the four surveys. Leachate from the historic Rototai landfill (closed in 1994) upstream of Site A is in theory a potential source. However, previous monitoring of target leachate contaminants at the fine scale sites and in estuarine sediments next to the landfill site, has not revealed elevated concentrations (e.g. Robertson & Robertson 2018). Even if a declining landfill source explained the temporal change, and the disparity between Site A and B, any ongoing effect is clearly negligible and not important ecologically. The elevated metal levels likely reflect natural inputs due to catchment mineralogy (ultramafic rock), with high metal concentrations described in estuarine and coastal sediments in other locations in Tasman and Nelson. For example, a study by Forrest et al. (2007) revealed elevated nickel, chromium and copper concentrations in Motueka River plume sediments, with nickel exceeding the DGV-high threshold of 52mg/kg.

Epibiota (surface-dwelling animals and seaweeds) were relatively uncommon, except for the mud snail *Amphibola crenata* being conspicuous at Site B. Due to the high variability in epibiota occurrences over time, and across spatial scales of metres to tens of metres within sites, the semi-quantitative SACFOR approach (used in 2018 and present survey) is considered more appropriate for the characterisation of epibiota than the quantitative quadrat sampling approach specified in the NEMP.

In terms of the assemblage of organisms sampled in macrofaunal cores, each site was characterised by a different suite of species. Site A was dominated by species relatively sensitive to environmental disturbance, whereas Site B was characterised by more hardy species. The compositional differences observed were most closely correlated with sediment grain size. The macrofaunal assemblage at Site B was associated with an increased mud content, while at Site A the relatively low mud (i.e. high sand) and elevated trace metal content of sediment samples were the most important explanatory variables. It is plausible that sediment grain size is a causal factor in the macrofaunal differences. However, any causal association between macrofauna and metals is unlikely given: (i) the generally low metal concentrations relative to ANZG (2018) guidelines; (ii) regional data from subtidal locations that suggest an absence of measurable effects at the concentrations in Motupipi Estuary (Forrest et al. 2007); and (iii) the presence or dominance of relatively sensitive species at Site A where metal concentrations were greatest.

As well as the likely importance of sediment grain size, it can be expected that the composition and temporal change in the macrofauna at both sites is influenced by a range of other factors. For example, Site A is likely to be influenced by the Motupipi River inflow to the western arm of the estuary. By contrast Site B, with its hardier species suite, may be naturally stressed by being higher in the intertidal zone than Site A, which will expose the sediments to a greater period of air exposure during low tide. On hot summer days the muddier sediments in this arm can become relatively dry and hard.

The macrofaunal data show a reasonable consistency among surveys, except for January 2018 when the richness and abundance of species were notably low, but still within the range reported for other estuaries in the top of the South Island (Fig. 16). There was no gradient in the measured sediment quality variables that explained the anomalous results in that year. Furthermore, sampling to verify these low values in October 2018 revealed a macrofaunal composition comparable to 2008 and 2020. Hence, the January 2018 results suggest unmeasured environmental factors may be driving the temporal changes. It is also possible that a provider difference explains the discrepancy, as a different provider undertook the

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field survey in 2018 (although the same taxonomist was used). For example, the dominant species at Site B (the most dissimilar) in January 2018 were large and relatively conspicuous organisms; namely, mud snails (*Amphibola crenata*), anemones (*Edwardsia* sp. 1), and mud crabs (*Austrohelice crassa*). It is possible that the typically abundant disturbance-tolerant species evident in other surveys were present in 2018, but not detected during sample processing due to their very small size. Monitoring in future years will help to determine whether January 2018 was a sampling anomaly or a reflection of the range of natural temporal variability.

An additional component to the 2020 survey was a comparison of the laboratory providers undertaking macrofauna taxonomy. The results were not detailed in the main report, but an assessment of the outcomes is included in Appendix 6. It is reassuring from the assessment that the taxonomic providers (CMEC for the fine scale surveys, NIWA for QA/QC) described assemblages that were similar in richness and abundance, with any apparent discrepancies in composition most likely explained by sample size or taxonomic resolution. In order to have complete confidence in the consistency of the taxonomic providers, it would be necessary for voucher specimens to be compared. This depth of assessment was beyond the present scope but would be a useful subsequent step towards developing a reference collection for Motupipi Estuary. Such a collection would provide a valuable resource for future surveys, as inter-provider differences are likely to be a significant source of survey data mismatch.
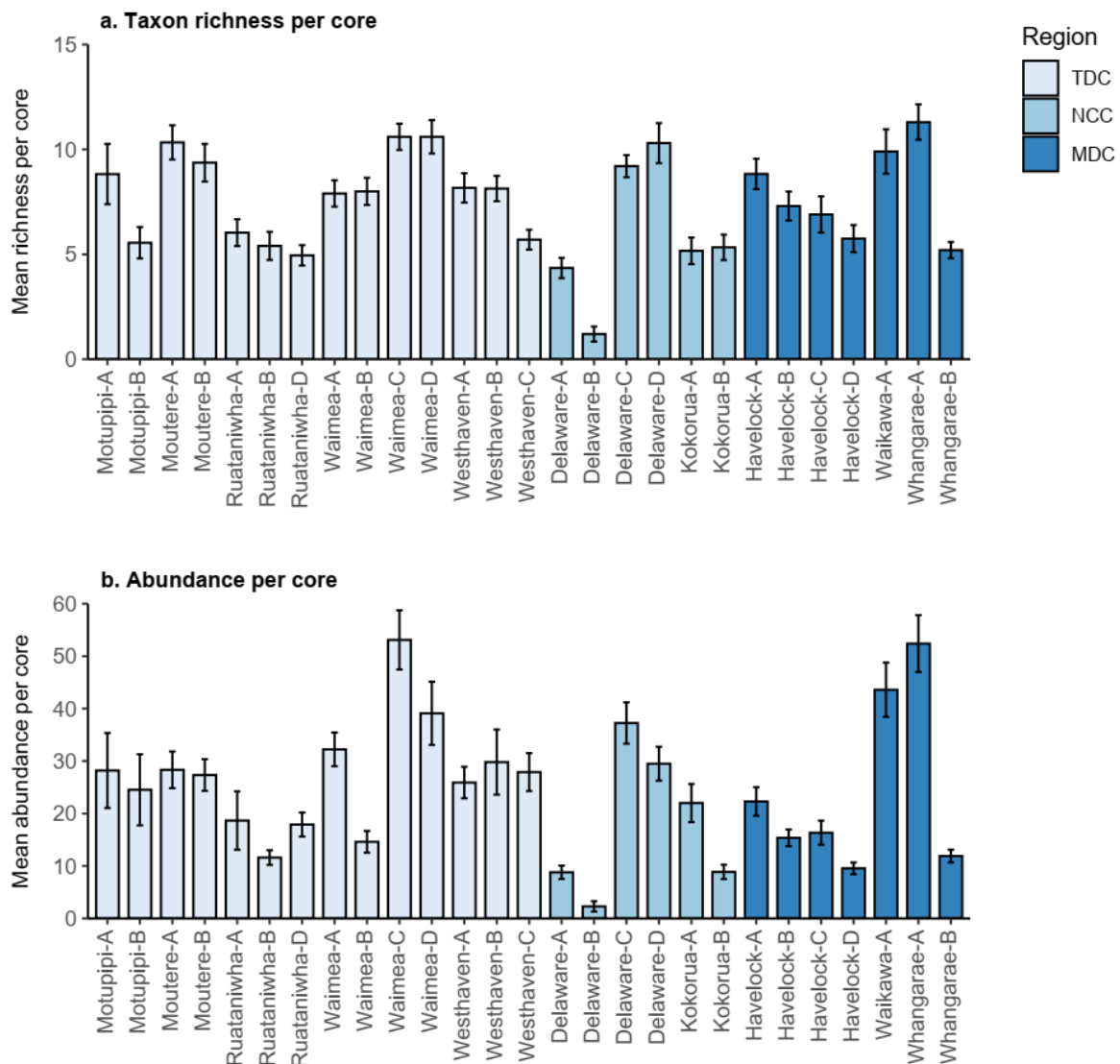


Fig. 16. Macrofauna richness and abundance summary (mean ±SE) for estuaries in the top of the South Island (grouped by council region). For illustrative purposes, site-level data are average across multiple survey years in each location.

As part of a separate undertaking, an assessment of macrofaunal sampling adequacy was also undertaken based on an analysis of species richness and dominance in relation to the current 10 cores per site sampling effort. Results, detailed in Appendix 6, revealed that characterisation of dominant site macrofauna can often be achieved with far fewer cores, but that at least nine cores may be needed in some years. As such, nine cores are considered a minimum that should be collected in future surveys. Reducing sampling effort to this level will maintain comparability with existing Motupipi data, and with other estuaries in the NEMP programme, and would have the benefits of providing a balanced sampling design (consisting of a 3 x 3 sampling plot) and reduced costs for future surveys.

As in previous surveys, water quality is an issue in the deeper areas of the lower Motupipi River that are subject to tidal seawater stratification and blooms of phytoplankton. The area affected is relatively extensive (1-2ha of the upper estuary), and degraded water quality has been consistently monitored over the past three summer surveys. However, it has been observed that the flushing effect of flood overflows from Takaka River can mitigate this effect.

While not the focus of the current work, it was noted that seagrass (*Zostera*) beds mapped in the upper west arm in both 2008 and 2015 are now no longer present. Stevens and Robertson (2015) suggested the reduction in seagrass density between 2008 and 2015 may have been the result of substrate changes; however, it is also possible that reduced water clarity from phytoplankton blooms, and elevated nutrient concentrations resulting in epiphytic algal smothering of seagrass, contributed to the losses. Support for the latter is provided by NIWA's CLUES model outputs (Appendix 9), which estimate the current nutrient (nitrogen) load to be ~179mg/m$^2$/d to the west arm, and ~30mg/m$^2$/d to the east arm. Loads to the west arm are well above the 20-50mg/m$^2$/d recommended to avoid impacts to seagrass (Robertson 2018).

## 5.2    RECOMMENDATIONS

The results of the 2020 fine scale survey and synthesis of longer-term data generally show the estuary to be in good ecological condition, except for the areas of degraded water quality in the upper west arm (lower Motupipi River). On this basis the following recommendations are made:

1. **Fine scale monitoring frequency:** Conduct fine scale ecological and sediment quality surveys every five years, and sediment plate monitoring annually or at least biennially. This suggested frequency is typical for both of these methods, and adequate for the purposes of keeping a track of estuarine health in the long term.

2. **Fine scale sites:** The current sites appear appropriate for monitoring purposes. Although the sites are physically and biologically different, they have a sufficient range of taxa to enable any ecologically significant environmental changes to be detected.

3. **Fine scale sediment monitoring methods:** Discontinue measurement of vertical ORP profiles as a health indicator. The method has too many limitations in the context of the Motupipi Estuary sites. Visual assessment of aRPD, while itself imperfect, provides a suitable ancillary indicator of gross change in trophic status.

4. **Fine scale macrofauna sampling:** To achieve consistency among surveys and taxonomic providers, it would be of value to develop a macrofaunal reference collection for Motupipi Estuary, part of which would involve inter-provider comparison of voucher specimens. In terms of sampling effort, collection of 9 core samples in future surveys is considered adequate for describing the macrofauna. Reducing sampling from ten to nine cores will still ensure comparability with future results and existing data (including other estuaries in the SOE programme) and has the added benefits of providing a balanced design for field sampling and reducing cost.

5. **Water quality:** Consider further investigation of the degraded water quality in the lower Motupipi River. Initially, this investigation could be limited to further field-based measurement of salinity, dissolved oxygen and chlorophyll-*a*. For example, it could be as simple as using a field meter to measure vertical profiles from the Abel Tasman Drive bridge, every 1-2 months over a year. Depending on findings, a more comprehensive assessment may then be desirable; for example, to consider ecological implications (e.g. for estuarine macrofauna and fish), causes of degradation, and mitigation options.

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# APPENDICES

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# Appendix 1. GPS coordinates of fine scale sites (corners) and sediment plates

| Site | Location | NZTM_North | NZTM_East |
|---|---|---|---|
| **Fine scale site corners** | | | |
| West arm | A1 | 5479280 | 1586416 |
| | A2 | 5479305 | 1586447 |
| | A3 | 5479293 | 1586457 |
| | A4 | 5479269 | 1586425 |
| East arm | B1 | 5478837 | 1587916 |
| | B2 | 5478897 | 1587908 |
| | B3 | 5478900 | 1587938 |
| | B4 | 5478841 | 1587945 |
| **Sediment plate locations** | | | |
| West arm | Plate A-1 | 5479044 | 1586427 |
| | Plate A-2 | 5479056 | 1586448 |
| | Plate A-3 | 5479033 | 1586461 |
| | Plate A-4 | 5479017 | 1586441 |
| East arm | Plate B-1 | 5478685 | 1587879 |
| | Plate B-2 | 5478665 | 1587861 |
| | Plate B-3 | 5478674 | 1587836 |
| | Plate B-4 | 5478699 | 1587851 |
| **Transect sampling stations** | | | |
| Motupipi River | T1 | 5478552 | 1586342 |
| | T2 | 5478440 | 1586454 |
| | T3 | 5478229 | 1586550 |
| | T4 | 5478174 | 1586585 |
| | T4a | 5478048 | 1586564 |
| | T5 (WQ X) | 5477968 | 1586551 |
| | T6 | 5477951 | 1586494 |
| | T7 | 5477973 | 1586430 |
| | T8 | 5477982 | 1586408 |

# Appendix 2. RJ Hill analytical methods and results for sediments

## Hill Laboratories
### TRIED, TESTED AND TRUSTED

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| Certificate of Analysis | Page 1 of 3 |
|---|---|

| | | |
|---|---|---|
| **Client:** | Salt Ecology Limited | |
| **Contact:** | Leigh Stevens | **Lab No:** 2300784  SPv1 |
| | C/- Salt Ecology Limited | **Date Received:** 07-Jan-2020 |
| | 21 Mount Vernon Place | **Date Reported:** 31-Jan-2020 |
| | Washington Valley | **Quote No:** 96724 |
| | Nelson 7010 | **Order No:** |
| | | **Client Reference:** Motupipi Estuary, TDC |
| | | **Submitted By:** Leigh Stevens |

### Sample Type: Saline

| Sample Name: | | MOPI-TASM WQX SUR 05-Jan-2020 | MOPI-TASM WQX BOT 05-Jan-2020 | | | |
|---|---|---|---|---|---|---|
| Lab Number: | | 2300784.8 | 2300784.9 | | | |
| Individual Tests | | | | | | |
| Total Nitrogen* | g/m³ | 2.5 | 0.85 | - | - | - |
| Total Ammoniacal-N | g/m³ | < 0.005 | 0.21 | - | - | - |
| Nitrite-N | g/m³ | 0.0050 | 0.0089 | - | - | - |
| Nitrate-N | g/m³ | 2.4 | 0.50 | - | - | - |
| Nitrate-N + Nitrite-N | g/m³ | 2.4 | 0.51 | - | - | - |
| Total Kjeldahl Nitrogen (TKN)* | g/m³ | 0.12 | 0.33 | - | - | - |
| Dissolved Reactive Phosphorus | g/m³ | 0.0067 | 0.0051 | - | - | - |
| Total Phosphorus* | g/m³ | 0.014 | 0.022 | - | - | - |

### Sample Type: Sediment

| Sample Name: | | MOPI-TASM A-X 05-Jan-2020 | MOPI-TASM A-Y 05-Jan-2020 | MOPI-TASM A-Z 05-Jan-2020 | MOPI-TASM B-X 05-Jan-2020 | MOPI-TASM B-Y 05-Jan-2020 |
|---|---|---|---|---|---|---|
| Lab Number: | | 2300784.1 | 2300784.2 | 2300784.3 | 2300784.4 | 2300784.5 |
| Individual Tests | | | | | | |
| Dry Matter of Sieved Sample* | g/100g as rcvd | 74 | 76 | 74 | 77 | 77 |
| Total Recoverable Phosphorus | mg/kg dry wt | 660 | 600 | 660 | 590 | 670 |
| Total Nitrogen* | g/100g dry wt | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 |
| Total Organic Carbon* | g/100g dry wt | 0.37 | 0.42 | 0.43 | 0.51 | 0.37 |
| Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg | | | | | | |
| Total Recoverable Arsenic | mg/kg dry wt | 5.2 | - | - | 6.4 | - |
| Total Recoverable Cadmium | mg/kg dry wt | 0.031 | - | - | 0.018 | - |
| Total Recoverable Chromium | mg/kg dry wt | 27 | - | - | 23 | - |
| Total Recoverable Copper | mg/kg dry wt | 10.2 | - | - | 7.5 | - |
| Total Recoverable Lead | mg/kg dry wt | 5.4 | - | - | 4.0 | - |
| Total Recoverable Mercury | mg/kg dry wt | < 0.02 | - | - | < 0.02 | - |
| Total Recoverable Nickel | mg/kg dry wt | 19.7 | - | - | 14.7 | - |
| Total Recoverable Zinc | mg/kg dry wt | 38 | - | - | 30 | - |
| 3 Grain Sizes Profile as received* | | | | | | |
| Fraction >/= 2 mm* | g/100g dry wt | 0.4 | 0.1 | < 0.1 | 0.1 | < 0.1 |
| Fraction < 2 mm, >/= 63 µm* | g/100g dry wt | 87.4 | 86.6 | 87.3 | 71.3 | 72.6 |
| Fraction < 63 µm* | g/100g dry wt | 12.2 | 13.2 | 12.6 | 28.5 | 27.3 |

| Sample Name: | | MOPI-TASM B-Z 05-Jan-2020 | MOPI-TASM WQX 05-Jan-2020 | | | |
|---|---|---|---|---|---|---|
| Lab Number: | | 2300784.6 | 2300784.7 | | | |

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

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## Sample Type: Sediment

| Sample Name: | MOPI-TASM B-Z 05-Jan-2020 | MOPI-TASM WQX 05-Jan-2020 | | | |
|---|---|---|---|---|---|
| **Lab Number:** | 2300784.6 | 2300784.7 | | | |
| **Individual Tests** | | | | | |
| Dry Matter of Sieved Sample*   g/100g as rcvd | 79 | 81 | - | - | - |
| Total Recoverable Phosphorus   mg/kg dry wt | 600 | 820 | - | - | - |
| Total Nitrogen*   g/100g dry wt | < 0.05 | < 0.05 | - | - | - |
| Total Organic Carbon*   g/100g dry wt | 0.36 | 0.46 | - | - | - |
| **3 Grain Sizes Profile as received*** | | | | | |
| Fraction >/= 2 mm*   g/100g dry wt | < 0.1 | 17.8 | - | - | - |
| Fraction < 2 mm, >/= 63 μm*   g/100g dry wt | 67.8 | 77.9 | - | - | - |
| Fraction < 63 μm*   g/100g dry wt | 32.1 | 4.4 | - | - | - |

## Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job.  The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.  A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

### Sample Type:  Saline

| Test | Method Description | Default Detection Limit | Sample No |
|---|---|---|---|
| **Individual Tests** | | | |
| Filtration, Unpreserved* | Sample filtration through 0.45μm membrane filter. | - | 8-9 |
| Total Kjeldahl Digestion - Trace level* | Sulphuric acid digestion with copper sulphate catalyst. | - | 8-9 |
| Total Nitrogen* | Calculation: TKN + Nitrate-N + Nitrite-N.  Please note: The 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 $g/m^3$ | 8-9 |
| Total Ammoniacal-N | Saline sample.  Phenol/hypochlorite colorimetry. Flow injection analyser.  (NH4-N = NH4+-N + NH3-N). APHA 4500-NH$_3$ H 23rd ed. 2017. | 0.005 $g/m^3$ | 8-9 |
| Nitrite-N | Saline sample.  Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO$_3^-$ I (modified) 23rd ed. 2017. | 0.0010 $g/m^3$ | 8-9 |
| Nitrate-N | Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House. | 0.0010 $g/m^3$ | 8-9 |
| Nitrate-N + Nitrite-N | Saline sample.  Total oxidised nitrogen.  Automated cadmium reduction, Flow injection analyser. APHA 4500-NO$_3^-$ I (modified) 23rd ed. 2017. | 0.0010 $g/m^3$ | 8-9 |
| Total Kjeldahl Nitrogen (TKN)* | Total Kjeldahl digestion, phenol/hypochlorite colorimetry (Discrete Analysis). Trace level. APHA 4500-N$_{org}$ D (modified) 4500 NH$_3$ F (modified) 23rd ed. 2017. | 0.05 $g/m^3$ | 8-9 |
| Dissolved Reactive Phosphorus | Saline sample.  Molybdenum blue colorimetry.  Flow injection analyser. APHA 4500-P G 23rd ed. 2017. | 0.0010 $g/m^3$ | 8-9 |
| Total Phosphorus* | Total phosphorus digestion, ascorbic acid colorimetry.  Discrete Analyser. APHA 4500-P B & E (modified from manual analysis and also modified to include a reductant to reduce interference from any arsenic present in the sample) 23rd ed. 2017. NWASCO, Water & soil Miscellaneous Publication No. 38, 1982. | 0.004 $g/m^3$ | 8-9 |

### Sample Type:  Sediment

| Test | Method Description | Default Detection Limit | Sample No |
|---|---|---|---|
| **Individual Tests** | | | |
| Environmental Solids Sample Drying* | Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%. | - | 1-7 |
| Environmental Solids Sample Preparation | Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%. | - | 1-7 |
| Dry Matter for Grainsize samples (sieved as received)* | Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis). | 0.10 g/100g as rcvd | 1-7 |
| Total Recoverable digestion | Nitric / hydrochloric acid digestion. US EPA 200.2. | - | 1-7 |
| Total Recoverable Phosphorus | Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion,  ICP-MS, screen level. US EPA 200.2. | 40 mg/kg dry wt | 1-7 |
| Total Nitrogen* | Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]. | 0.05 g/100g dry wt | 1-7 |

| Sample Type: Sediment | | | |
|---|---|---|---|
| **Test** | **Method Description** | **Default Detection Limit** | **Sample No** |
| Total Organic Carbon* | Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]. | 0.05 g/100g dry wt | 1-7 |
| Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg | Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level. | 0.010 - 0.4 mg/kg dry wt | 1, 4 |
| 3 Grain Sizes Profile as received | | | |
| Fraction >/= 2 mm* | Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry. | 0.1 g/100g dry wt | 1-7 |
| Fraction < 2 mm, >/= 63 µm* | Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference). | 0.1 g/100g dry wt | 1-7 |
| Fraction < 63 µm* | Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference). | 0.1 g/100g dry wt | 1-7 |

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Dates of testing are available on request. Please contact the laboratory for more information.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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Ara Heron BSc (Tech)
Client Services Manager - Environmental

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# Appendix 3. Sediment plate raw data

The baseline depth was measured on 27 September 2007 immediately after plate installation.

| Date | Year | Site | Plate | Depth (mm) | Baseline depth (mm) | Annualised change | Change from baseline |
|---|---|---|---|---|---|---|---|
| 27/09/2007 | 2007_09 | A | p1 | 248 | 248 | NA | 0 |
| 15/02/2010 | 2010_02 | A | p1 | 243 | 248 | -2.1 | -5 |
| 1/05/2012 | 2012_05 | A | p1 | 249 | 248 | 2.7 | 1 |
| 9/07/2013 | 2013_07 | A | p1 | 247 | 248 | -1.7 | -1 |
| 19/09/2014 | 2014_09 | A | p1 | 252 | 248 | 4.2 | 4 |
| 21/10/2015 | 2015_10 | A | p1 | 255 | 248 | 2.8 | 7 |
| 14/01/2018 | 2018_01 | A | p1 | 264 | 248 | 4 | 16 |
| 5/01/2020 | 2020_01 | A | p1 | 269 | 248 | 2.7 | 21.3 |
| 27/09/2007 | 2007_09 | A | p2 | 215 | 215 | NA | 0 |
| 15/02/2010 | 2010_02 | A | p2 | 212 | 215 | -1.3 | -3 |
| 1/05/2012 | 2012_05 | A | p2 | 218 | 215 | 2.7 | 3 |
| 9/07/2013 | 2013_07 | A | p2 | 218 | 215 | 0 | 3 |
| 19/09/2014 | 2014_09 | A | p2 | 221 | 215 | 2.5 | 6 |
| 21/10/2015 | 2015_10 | A | p2 | 227 | 215 | 5.5 | 12 |
| 14/01/2018 | 2018_01 | A | p2 | 217 | 215 | -4.5 | 2 |
| 5/01/2020 | 2020_01 | A | p2 | 220 | 215 | 1.7 | 5.3 |
| 27/09/2007 | 2007_09 | A | p3 | 190 | 190 | NA | 0 |
| 15/02/2010 | 2010_02 | A | p3 | 192 | 190 | 0.8 | 2 |
| 1/05/2012 | 2012_05 | A | p3 | 194 | 190 | 0.9 | 4 |
| 9/07/2013 | 2013_07 | A | p3 | 206 | 190 | 10.1 | 16 |
| 19/09/2014 | 2014_09 | A | p3 | 206 | 190 | 0 | 16 |
| 21/10/2015 | 2015_10 | A | p3 | 216 | 190 | 9.2 | 26 |
| 14/01/2018 | 2018_01 | A | p3 | 213 | 190 | -1.3 | 23 |
| 5/01/2020 | 2020_01 | A | p3 | 215 | 190 | 0.8 | 24.7 |
| 27/09/2007 | 2007_09 | A | p4 | 210 | 210 | NA | 0 |
| 15/02/2010 | 2010_02 | A | p4 | 213 | 210 | 1.3 | 3 |
| 1/05/2012 | 2012_05 | A | p4 | 201 | 210 | -5.4 | -9 |
| 9/07/2013 | 2013_07 | A | p4 | 218 | 210 | 14.3 | 8 |
| 19/09/2014 | 2014_09 | A | p4 | 217 | 210 | -0.8 | 7 |
| 21/10/2015 | 2015_10 | A | p4 | 230 | 210 | 12 | 20 |
| 14/01/2018 | 2018_01 | A | p4 | 228 | 210 | -0.9 | 18 |
| 5/01/2020 | 2020_01 | A | p4 | 229 | 210 | 0.5 | 19 |
| 26/09/2007 | 2007_09 | B | p1 | 205 | 205 | NA | 0 |
| 15/02/2010 | 2010_02 | B | p1 | 211 | 205 | 2.5 | 6 |
| 1/05/2012 | 2012_05 | B | p1 | 217 | 205 | 2.7 | 12 |
| 9/07/2013 | 2013_07 | B | p1 | 224 | 205 | 5.9 | 19 |
| 19/09/2014 | 2014_09 | B | p1 | 221 | 205 | -2.5 | 16 |
| 21/10/2015 | 2015_10 | B | p1 | 226 | 205 | 4.6 | 21 |
| 14/01/2018 | 2018_01 | B | p1 | 253 | 205 | 12.1 | 48 |

| 5/01/2020 | 2020_01 | B | p1 | 263 | 205 | 5.1 | 58 |
|---|---|---|---|---|---|---|---|
| 26/09/2007 | 2007_09 | B | p2 | 205 | 205 | NA | 0 |
| 15/02/2010 | 2010_02 | B | p2 | 198 | 205 | -2.9 | -7 |
| 1/05/2012 | 2012_05 | B | p2 | 190 | 205 | -3.6 | -15 |
| 9/07/2013 | 2013_07 | B | p2 | 193 | 205 | 2.5 | -12 |
| 19/09/2014 | 2014_09 | B | p2 | 206 | 205 | 10.9 | 1 |
| 21/10/2015 | 2015_10 | B | p2 | 195 | 205 | -10.1 | -10 |
| 14/01/2018 | 2018_01 | B | p2 | 200 | 205 | 2.2 | -5 |
| 5/01/2020 | 2020_01 | B | p2 | 209 | 205 | 4.7 | 4.3 |
| 26/09/2007 | 2007_09 | B | p3 | 200 | 200 | NA | 0 |
| 15/02/2010 | 2010_02 | B | p3 | 205 | 200 | 2.1 | 5 |
| 1/05/2012 | 2012_05 | B | p3 | 215 | 200 | 4.5 | 15 |
| 9/07/2013 | 2013_07 | B | p3 | 219 | 200 | 3.4 | 19 |
| 19/09/2014 | 2014_09 | B | p3 | 217 | 200 | -1.7 | 17 |
| 21/10/2015 | 2015_10 | B | p3 | 225 | 200 | 7.4 | 25 |
| 14/01/2018 | 2018_01 | B | p3 | 228 | 200 | 1.3 | 28 |
| 5/01/2020 | 2020_01 | B | p3 | 236 | 200 | 3.9 | 35.7 |
| 26/09/2007 | 2007_09 | B | p4 | 210 | 210 | NA | 0 |
| 15/02/2010 | 2010_02 | B | p4 | 210 | 210 | 0 | 0 |
| 1/05/2012 | 2012_05 | B | p4 | 295 | 210 | 38.5 | 85 |
| 9/07/2013 | 2013_07 | B | p4 | 287 | 210 | -6.7 | 77 |
| 19/09/2014 | 2014_09 | B | p4 | 252 | 210 | -29.2 | 42 |
| 21/10/2015 | 2015_10 | B | p4 | 277 | 210 | 23 | 67 |
| 14/01/2018 | 2018_01 | B | p4 | 270 | 210 | -3.1 | 60 |
| 5/01/2020 | 2020_01 | B | p4 | 270 | 210 | 0.2 | 60.3 |

# Appendix 4. Sediment core raw data for all years

For aRPD, the range in 2018 and 19 is based on 10 measurements made in the field. All other analytes results are from laboratory analysis of triplicate samples composited within each of the three zones (X-Z) at each site.

| Year | Site | Zone | Gravel % | Sand % | Mud % | TOC % | TN mg/kg | TP mg/kg | aRPD mm | ORP10 mV | ORP30 mV | ORP50 mV | ORP70 mV | ORP100 mV | As mg/kg | Cd mg/kg | Cr mg/kg | Cu mg/kg | Hg mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | A | X | 1.7 | 85.6 | 12.7 | - | 630 | 580 | 30 | - | - | - | - | - | - | 0.046 | 44.00 | 10.00 | - | 29.00 | 6.30 | 46 |
| | | Y | 0.1 | 83.6 | 16.3 | - | 570 | 570 | 30 | - | - | - | - | - | - | 0.036 | 43.00 | 9.10 | - | 27.00 | 6.00 | 42 |
| | | Z | 0.5 | 66.0 | 33.6 | - | 990 | 570 | 30 | - | - | - | - | - | - | 0.042 | 44.00 | 9.80 | - | 29.00 | 6.50 | 44 |
| | B | X | <0.1 | 66.0 | 33.9 | - | 870 | 550 | 999 | - | - | - | - | - | - | 0.018 | 27.00 | 6.30 | - | 17.00 | 4.20 | 29 |
| | | Y | <0.1 | 53.5 | 46.5 | - | 720 | 600 | 999 | - | - | - | - | - | - | 0.014 | 26.00 | 5.80 | - | 16.00 | 3.90 | 28 |
| | | Z | <0.1 | 63.4 | 36.6 | - | 680 | 520 | 999 | - | - | - | - | - | - | 0.011 | 26.00 | 5.00 | - | 16.00 | 3.60 | 25 |
| 2018 | A | X | 0.5 | 83.9 | 15.6 | 0.60 | <500 | 690 | 10 | - | - | - | - | - | 5.80 | 0.037 | 41.00 | 9.90 | <0.02 | 21.00 | 6.90 | 40 |
| | | Y | 0.3 | 85.0 | 14.7 | 0.45 | 600 | 710 | 10 | - | - | - | - | - | 6.70 | 0.040 | 43.00 | 10.40 | <0.02 | 23.00 | 6.70 | 43 |
| | | Z | 1.1 | 87.9 | 11.0 | 0.35 | <500 | 600 | 10 | - | - | - | - | - | 6.00 | 0.036 | 42.00 | 9.00 | <0.02 | 21.00 | 5.70 | 38 |
| | B | X | 0.2 | 74.1 | 25.8 | 0.38 | <500 | 630 | 30 | - | - | - | - | - | 6.10 | 0.019 | 31.00 | 6.20 | <0.02 | 15.30 | 4.60 | 30 |
| | | Y | 0.2 | 70.1 | 29.7 | 0.36 | <500 | 580 | 30 | - | - | - | - | - | 6.10 | 0.017 | 31.00 | 5.70 | <0.02 | 14.90 | 4.40 | 29 |
| | | Z | <0.1 | 74.3 | 25.7 | 0.39 | <500 | 620 | 30 | - | - | - | - | - | 6.60 | 0.017 | 27.00 | 5.80 | <0.02 | 14.70 | 4.30 | 29 |
| 2019 | A | X | 0.3 | 91.5 | 8.2 | 0.29 | 500 | 610 | 20-30 | 90 | -71 | -53 | -81 | -74 | 6.90 | 0.032 | 35.00 | 10.50 | 0.03 | 23.00 | 5.70 | 40 |
| | | Y | <0.1 | 88.4 | 11.5 | 0.35 | 800 | 650 | 23-33 | 73 | 0 | -20 | -85 | -82 | - | - | - | - | - | - | - | - |
| | | Z | 0.1 | 87.0 | 12.8 | 0.39 | 1000 | 640 | 30-40 | -60 | -48 | -31 | -71 | -68 | - | - | - | - | - | - | - | - |
| | B | X | <0.1 | 64.3 | 35.7 | 0.36 | 800 | 620 | 20-30 | -15 | -71 | -92 | -54 | - | 6.20 | 0.019 | 27.00 | 6.20 | 0.03 | 16.60 | 4.10 | 30 |
| | | Y | <0.1 | 62.7 | 37.2 | 0.47 | 900 | 650 | 15-20 | 46 | -67 | -39 | -34 | - | - | - | - | - | - | - | - | - |
| | | Z | 0.4 | 75.2 | 24.5 | 0.38 | 1000 | 520 | 10-18 | 16 | -54 | -51 | -6 | - | - | - | - | - | - | - | - | - |
| 2020 | A | X | 0.4 | 87.4 | 12.2 | 0.37 | <500 | 660 | 10-52 | 0 | -3 | -35 | -41 | -11 | 5.20 | 0.031 | 27.00 | 10.20 | <0.02 | 19.70 | 5.40 | 38 |
| | | Y | 0.1 | 86.6 | 13.2 | 0.42 | <500 | 600 | 25-42 | -10 | 20 | 0 | -22 | -92 | - | - | - | - | - | - | - | - |
| | | Z | <0.1 | 87.3 | 12.6 | 0.43 | <500 | 660 | 22-33 | 81 | 15 | -27 | 4 | 4 | - | - | - | - | - | - | - | - |
| | B | X | 0.1 | 71.3 | 28.5 | 0.51 | <500 | 590 | 55-75 | -26 | -20 | 7 | 106 | 202 | 6.40 | 0.018 | 23.00 | 7.50 | <0.02 | 14.70 | 4.00 | 30 |
| | | Y | <0.1 | 72.6 | 27.3 | 0.37 | <500 | 670 | 35-55 | 82 | 7 | 73 | 33 | 112 | - | - | - | - | - | - | - | - |
| | | Z | <0.1 | 67.8 | 32.1 | 0.36 | <500 | 600 | 28-46 | -4 | 164 | 20 | 83 | 193 | - | - | - | - | - | - | - | - |
| | | DGV | | | | | | | | | | | | | 20 | 1.5 | 80 | 65 | 0.15 | 21 | 50 | 200 |
| | | GV-high | | | | | | | | | | | | | 70 | 10 | 370 | 270 | 1 | 52 | 220 | 410 |

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# Appendix 5. Macrofauna core raw data for all years

| Main_group | Taxa | Habitat | EG | 2008_02 A1 | 2008_02 A2 | 2008_02 A3 | 2008_02 A4 | 2008_02 A5 | 2008_02 A6 | 2008_02 A7 | 2008_02 A8 | 2008_02 A9 | 2008_02 A10 | 2008_02 B1 | 2008_02 B2 | 2008_02 B3 | 2008_02 B4 | 2008_02 B5 | 2008_02 B6 | 2008_02 B7 | 2008_02 B8 | 2008_02 B9 | 2008_02 B10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anthozoa | Anthopleura aureoradiata | Epibiota | III | | | | | | | | | | | | | | | | | | | | |
| Anthozoa | Edwardsia sp.1 | Epibiota | II | 9 | 12 | 4 | 3 | 12 | 5 | 2 | 5 | 12 | 9 | 4 | 4 | 2 | 1 | 2 | | | | | 1 |
| Gastropoda | Amphibola crenata | Epibiota | III | | | | | | | | | | | 1 | | 5 | 3 | 6 | 3 | | | | 3 |
| Gastropoda | Cominella glandiformis | Epibiota | III | 1 | | | | | 1 | 2 | | | | | | | | | | | | | |
| Gastropoda | Diloma subrostrata | Epibiota | II | | | | | | | | 1 | | | | | | | | | | | | |
| Gastropoda | Notoacmea sp. | Epibiota | II | | | | | | | | | | | | | | | | | | | | |
| Gastropoda | Potamopyrgus estuarinus | Epibiota | III | 2 | | | 1 | | | | | | | | | | | 1 | | | | 1 | 1 |
| Gastropoda | Zeacumantus lutulentus | Epibiota | II | | | | | | | | | | 1 | | | | | | | | | | |
| Maxillopoda | Austrominius modestus | Epibiota | II | | | | | | | | | 5 | | | | | | | | | | | |
| Amphipoda | Amphipoda sp.2 | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Amphipoda | Paracorophium excavatum | Infauna | IV | 1 | | 1 | 1 | 1 | 1 | | | | | 1 | 5 | 39 | 2 | 4 | 4 | 1 | 1 | 3 | 1 |
| Amphipoda | Phoxocephalidae sp.1 | Infauna | II | | | 1 | 1 | 1 | | | 1 | 1 | | | 1 | 1 | | | | | | | |
| Bivalvia | Arthritica sp.1 | Infauna | IV | | | | 6 | 1 | | | | 5 | | 3 | 2 | 1 | | | 1 | | | 3 | 4 |
| Bivalvia | Austrovenus stutchburyi | Infauna | II | 26 | 12 | 7 | 11 | 1 | 13 | 12 | 7 | 14 | 4 | | | | | | | | | | |
| Bivalvia | Cyclomactra tristis | Infauna | I | | | | | | | | | | | | | | | | | | | | |
| Bivalvia | Hiatula sp.1 | Infauna | NA | | | | | | | | | | | | | | | | | | | | |
| Bivalvia | Macomona liliana | Infauna | II | 7 | 3 | 3 | 7 | | 4 | 10 | 10 | 7 | 1 | | | | | | | | | | |
| Bivalvia | Paphies australis | Infauna | II | | | 1 | | | | | | | | | | | | | | | | | |
| Copepoda | Copepoda sp.1 | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Copepoda | Copepoda sp.2 | Infauna | II | | | | | | 1 | | | | | | | | | | | | | | |
| Decapoda | Austrohelice crassa | Infauna | V | | | | | | 2 | | | | | 1 | 1 | | 1 | | 2 | | | | |
| Decapoda | Halicarcinus whitei | Infauna | III | | | | 1 | | | | | | | | | | | | | | 1 | | |
| Decapoda | Hemiplax hirtipes | Infauna | V | | | | 1 | | 1 | 1 | | | 3 | | | | | | | | | | |
| Isopoda | Exosphaeroma sp.1 | Infauna | V | | | | | | | | | | | | | | | | | | | 1 | |
| Nemertea | Nemertea sp.1 | Infauna | III | 2 | 1 | 1 | 1 | | | 1 | 1 | 1 | | | | | | | | | | | |
| Nemertea | Nemertea sp.2 | Infauna | III | | 1 | 1 | | | | | | | | | | | | | | | | | |
| Nemertea | Nemertea sp.3 | Infauna | III | 1 | | | | | 1 | | | | | | | | | | | | | | |
| Oligochaeta | Oligochaeta sp.1 | Infauna | III | | 2 | | | | | | 1 | | | 12 | | 4 | 13 | 7 | 22 | 1 | 21 | 2 | 17 |
| Polychaeta | Aonides trifida | Infauna | I | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Armandia maculata | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Axiothella serrata | Infauna | II | 3 | 3 | 1 | 4 | 1 | 4 | 15 | 4 | 3 | | | | | | | | | | | |
| Polychaeta | Boccardia (Paraboccardia) acus | Infauna | II | | | | | | | | | 1 | | | | | | | | | | | |
| Polychaeta | Boccardia (Paraboccardia) syrtis | Infauna | II | | | | 1 | | | | | 1 | | | | | | | | | | | |
| Polychaeta | Capitella sp.1 | Infauna | IV | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | | | | 1 | | | | | | |
| Polychaeta | Disconatis accolus | Infauna | I | 1 | 1 | 1 | 1 | | | 1 | 1 | 2 | | | | 2 | | | | 2 | | | |
| Polychaeta | Glycera lamelliformis | Infauna | III | | | | | | | | 1 | | | | | | | | | | | | |
| Polychaeta | Heteromastus filiformis | Infauna | III | 8 | 9 | 2 | 9 | 2 | 3 | 6 | | | | | | | | | | | | | |
| Polychaeta | Nereididae (unidentifiable) | Infauna | NA | | 1 | | | | | | | | | | | | 1 | | | | | | |
| Polychaeta | Nicon aestuariensis | Infauna | III | | 1 | | | | | | | | | | | | | | | | | | |
| Polychaeta | Orbinia papillosa | Infauna | I | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Orbiniidae (unidentifiable) | Infauna | NA | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Paradoneis sp.1 | Infauna | III | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Pectinaria australis | Infauna | III | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Perinereis vallata | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Prionospio aucklandica | Infauna | II | 12 | 4 | 2 | 17 | 4 | 6 | 7 | 5 | 6 | 1 | | | | 1 | | | | | | |
| Polychaeta | Scolecolepides benhami | Infauna | IV | | | | | | | | 1 | 1 | | | | 1 | | | | | | | |
| Polychaeta | Scoloplos cylindrifer | Infauna | I | | 1 | | | | | 1 | | 1 | | | | | | | | | | | |
| Polychaeta | Nereididae (unidentified juveniles) | Infauna Juvenile | NA | 2 | | 1 | 1 | 1 | 2 | 1 | | | | 1 | | 1 | | 1 | 1 | | | | 1 |
| Decapoda | Unidentified decapod megalopa | Larva | NA | | | 4 | | | 1 | | 1 | | 1 | | | | | | | | | | |
| Diptera | Diptera sp.1 | Terrestrial | II | | | | | | | | | | | | | | | 1 | | | | | |
| Diptera | Diptera sp.2 | Terrestrial | II | | | | | | | | | | | | | | | | | | | 1 | 1 |
| | | | **Sum taxa** | 14 | 11 | 12 | 16 | 8 | 14 | 12 | 15 | 14 | 9 | 8 | 4 | 9 | 8 | 7 | 6 | 3 | 3 | 6 | 9 |
| | | | **Sum individuals** | 76 | 49 | 28 | 66 | 23 | 45 | 59 | 41 | 60 | 22 | 24 | 12 | 56 | 23 | 22 | 33 | 4 | 23 | 11 | 30 |

| Main_group | Taxa | Habitat | EG | 2018_01A1 | 2018_01A2 | 2018_01A3 | 2018_01A4 | 2018_01A5 | 2018_01A6 | 2018_01A7 | 2018_01A8 | 2018_01A9 | 2018_01A10 | 2018_01B1 | 2018_01B2 | 2018_01B3 | 2018_01B4 | 2018_01B5 | 2018_01B6 | 2018_01B7 | 2018_01B8 | 2018_01B9 | 2018_01B10 | 2018_10A1 | 2018_10A2 | 2018_10A3 | 2018_10B1 | 2018_10B2 | 2018_10B3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anthozoa | Anthopleura | Epibiota | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 7 | 3 |  |  |  |  |
| Anthozoa | Edwardsia sp | Epibiota | II |  |  | 1 |  | 3 |  |  |  | 2 |  |  | 8 | 4 | 2 |  |  | 1 | 2 | 1 | 1 |  | 1 |  |  |  |  |
| Gastropoda | Amphibola c | Epibiota | III |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 1 | 3 |  |  |  |  |  |  | 3 |  |  |
| Gastropoda | Cominella g | Epibiota | III |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 | 5 |  |
| Gastropoda | Diloma subr | Epibiota | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |
| Gastropoda | Notoacmea | Epibiota | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
| Gastropoda | Potamopyrg | Epibiota | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Gastropoda | Zeacumantu | Epibiota | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 2 |  |  |  |  |
| Maxillopoda | Austrominiu | Epibiota | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |
| Amphipoda | Amphipoda | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |
| Amphipoda | Paracorophi | Infauna | IV |  |  |  |  |  |  |  |  |  |  |  |  | 14 |  |  |  |  |  |  |  |  |  |  |  | 29 | 22 |
| Amphipoda | Phoxocephe | Infauna | II | 3 |  | 1 |  |  | 1 |  |  | 1 |  |  | 3 | 1 |  |  | 1 |  |  |  |  | 10 | 5 | 8 | 2 | 4 | 5 |
| Bivalvia | Arthritica sp | Infauna | IV |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 2 | 2 |  |
| Bivalvia | Austrovenu | Infauna | II |  |  | 2 |  | 3 |  | 2 |  | 2 | 2 |  |  |  |  |  |  |  |  |  |  | 2 | 3 | 3 | 4 |  |  |
| Bivalvia | Cyclomactr | Infauna | I |  |  |  | 1 |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| Bivalvia | Hiatula sp. 1 | Infauna | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Bivalvia | Macomona | Infauna | II | 1 |  | 5 |  | 4 |  | 1 |  |  | 3 |  |  |  |  |  |  | 1 |  |  |  |  | 7 | 2 | 9 | 1 | 1 |
| Bivalvia | Paphies aus | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 7 |  |  |  |  |  |
| Copepoda | Copepoda s | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Copepoda | Copepoda s | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Decapoda | Austrohelic | Infauna | V |  | 1 |  |  |  | 1 | 1 |  |  |  |  | 2 | 2 |  |  | 1 | 1 |  |  |  |  |  | 1 | 1 |  |  |
| Decapoda | Halicarcinus | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Decapoda | Hemiplax hi | Infauna | V |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Isopoda | Exosphaeroi | Infauna | V | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Nemertea | Nemertea sp | Infauna | III |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Nemertea | Nemertea sp | Infauna | III |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |
| Nemertea | Nemertea sp | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Oligochaeta | Oligochaeta | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| Polychaeta | Aonides trifi | Infauna | I |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |
| Polychaeta | Armandia m | Infauna | II |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Axiothella s | Infauna | II | 3 |  | 4 |  | 1 | 1 |  |  |  | 1 |  | 1 | 1 | 1 |  |  |  |  |  |  | 1 |  |  |  |  |  |
| Polychaeta | Boccardia (F | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Boccardia (F | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Capitella sp. | Infauna | IV |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Disconatis a | Infauna | II | 1 |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |
| Polychaeta | Glycera lam | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 | 1 | 2 |  |  |  |
| Polychaeta | Heteromast | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 14 | 5 | 2 |  |  |  |
| Polychaeta | Nereididae ( | Infauna | NA |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Nicon aestu | Infauna | III |  |  | 3 |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 1 |  |  |  | 1 |  |  |  | 1 |  |
| Polychaeta | Orbinia pap | Infauna | I |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |
| Polychaeta | Orbiniidae (I | Infauna | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Paradoneis | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Pectinaria a | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |
| Polychaeta | Perinereis v | Infauna | II | 1 |  | 1 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 2 |  |  |  |  |
| Polychaeta | Prionospio z | Infauna | II |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 27 | 8 | 2 |  |  |  |
| Polychaeta | Scolecolepi | Infauna | IV |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 3 |  |  |  |
| Polychaeta | Scoloplos c | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 2 |  |  | 1 | 3 |
| Polychaeta | Nereididae ( | Infauna Juve | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Decapoda | Unidentified Larva |  | NA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Diptera | Diptera sp. 1 | Terrestrial | II | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 1 | 1 |
| Diptera | Diptera sp. 2 | Terrestrial | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| | **Sum taxa** | | | 7 | 1 | 10 | 1 | 6 | 3 | 3 | 0 | 4 | 5 | 2 | 4 | 6 | 3 | 1 | 3 | 6 | 2 | 1 | 1 | 15 | 14 | 10 | 9 | 8 | 6 |
| | **Sum individuals** | | | 11 | 1 | 20 | 1 | 13 | 3 | 4 | 0 | 6 | 8 | 2 | 14 | 23 | 4 | 1 | 3 | 8 | 3 | 1 | 1 | 79 | 42 | 25 | 29 | 44 | 33 |

SALT ECOLOGY

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| Main_group | Taxa | Habitat | EG | 2019_01 A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anthozoa | Anthopleura aureoradiata | Epibiota | III | | | | | | | | | | | | | | | | | | | | |
| Anthozoa | Edwardsia sp. 1 | Epibiota | II | | | | | | | | | | | | | | | | | | | 1 | 2 |
| Gastropoda | Amphibola crenata | Epibiota | III | | | | | | | | | | | | | | | | | | | 1 | 1 |
| Gastropoda | Cominella glandiformis | Epibiota | III | 1 | | 1 | | | | | | | | | | | | | | | | | |
| Gastropoda | Diloma subrostrata | Epibiota | II | | | | 3 | | | | | | | | | | | | | | | | |
| Gastropoda | Notoacmea sp. | Epibiota | II | | | | | | | | | 1 | | | | | | | | | | | |
| Gastropoda | Potamopyrgus estuarinus | Epibiota | III | | | | | | | | | 1 | | | | | | | | | | | |
| Gastropoda | Zeacumantus lutulentus | Epibiota | II | | | 5 | | 1 | | | | | | | | | | | | | | | |
| Maxillopoda | Austrominius modestus | Epibiota | II | | | 1 | | 7 | | | | | | | | | | | | | | | |
| Amphipoda | Amphipoda sp. 2 | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Amphipoda | Paracorophium excavatum | Infauna | IV | | | 5 | | | | | | | | 11 | 40 | 88 | 3 | 3 | 8 | 8 | 3 | 2 | 19 |
| Amphipoda | Phoxocephalidae sp. 1 | Infauna | II | | | | | | 2 | | 1 | 1 | | | 1 | | | 1 | | 4 | | | |
| Bivalvia | Arthritica sp. 1 | Infauna | IV | 1 | | 5 | | | | | | | | 11 | 1 | 8 | | | 1 | 14 | 3 | | |
| Bivalvia | Austrovenus stutchburyi | Infauna | II | 2 | 1 | 5 | | 2 | 3 | 1 | 4 | 2 | 1 | | | | 2 | 1 | | | | | |
| Bivalvia | Cyclomactra tristis | Infauna | I | | | | | | | | | | 1 | | | | | | | | | | |
| Bivalvia | Hiatula sp. 1 | Infauna | NA | | | | | | | | | | | | | | | | | | | | |
| Bivalvia | Macomona liliana | Infauna | II | 6 | 13 | 10 | 3 | 2 | 8 | 1 | 2 | 2 | 7 | | | | 1 | | | | | | |
| Bivalvia | Paphies australis | Infauna | II | | | 1 | | | | | | | | | | | | | | | | | |
| Copepoda | Copepoda sp. 1 | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Copepoda | Copepoda sp. 2 | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Decapoda | Austrohelice crassa | Infauna | V | | 2 | | | | | 2 | 2 | 2 | 1 | 2 | 1 | | 2 | 1 | 2 | | 1 | 3 | 3 |
| Decapoda | Halicarcinus whitei | Infauna | III | | | 3 | | | | | | | | | | | | | | | | | |
| Decapoda | Hemiplax hirtipes | Infauna | V | | | | | | | | | | | | | | | | | | | | |
| Isopoda | Exosphaeroma sp. 1 | Infauna | V | | | | | | | | | | | | | | | | | | | | |
| Nemertea | Nemertea sp. 1 | Infauna | III | | | | | | 1 | 2 | | | 1 | | | | | | | | 1 | | |
| Nemertea | Nemertea sp. 2 | Infauna | III | | 1 | 1 | | | | | | | | | | | | | | | | | |
| Nemertea | Nemertea sp. 3 | Infauna | III | | | | | | | | | | | | | | | | | | | | |
| Oligochaeta | Oligochaeta sp. 1 | Infauna | III | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Aonides trifida | Infauna | I | | | 6 | | | 1 | | | 1 | 1 | | | | | | | | | | |
| Polychaeta | Armandia maculata | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Axiothella serrata | Infauna | II | | | 1 | 1 | | 2 | | | | 1 | | | | | | | | | | |
| Polychaeta | Boccardia (Paraboccardia) acus | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Boccardia (Paraboccardia) syrtis | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Capitella sp. 1 | Infauna | IV | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Disconatis accolus | Infauna | I | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Glycera lamelliformis | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Heteromastus filiformis | Infauna | III | | | | | | 1 | | | | | | | | | | | | | | |
| Polychaeta | Nicon aestuariensis | Infauna | NA | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Nereididae (unidentifiable) | Infauna | III | | | | | | | 1 | | | | | | | | | | | | | |
| Polychaeta | Orbinia papillosa | Infauna | I | | | | | | | | | | | 2 | 1 | 2 | | | | | | | |
| Polychaeta | Orbiniidae (unidentifiable) | Infauna | NA | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Paradoneis sp. 1 | Infauna | III | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Pectinaria australis | Infauna | III | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Perinereis vallata | Infauna | II | | | | | | | | | | | | | | | | | | | | |
| Polychaeta | Prionospio aucklandica | Infauna | II | | | 4 | | | | | | | 1 | | | | | | | | | | |
| Polychaeta | Scolecolepides benhami | Infauna | IV | 1 | | 1 | | | | | | | | | | | | | | 1 | | | |
| Polychaeta | Scoloplos cylindrifer | Infauna | I | | | | | | | | | | | | | | | | | | | | |
| Decapoda | Nereididae (unidentified juveniles) | Infauna Juvenile | NA | 2 | | 1 | 1 | | 1 | | | 1 | 1 | 2 | | | 1 | 1 | 1 | 3 | 1 | | |
| Decapoda | Unidentified decapod megalopa | Larva | NA | | | | | | | | | | 1 | | | | | | | | | | |
| Diptera | Diptera sp. 1 | Terrestrial | II | | | | | 2 | | | | | | | | | | | | | | | |
| Diptera | Diptera sp. 2 | Terrestrial | II | | | | | | | | | | | | | | | | | | | | |
| | Sum taxa | | | 6 | 4 | 14 | 5 | 5 | 8 | 5 | 4 | 7 | 8 | 5 | 7 | 8 | 6 | 5 | 5 | 7 | 5 | 4 | 4 |
| | Sum individuals | | | 13 | 17 | 45 | 9 | 14 | 19 | 7 | 9 | 10 | 14 | 28 | 46 | 103 | 10 | 8 | 16 | 37 | 9 | 7 | 25 |

| Main_group | Taxa | Habitat | EG | 2020_01 A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anthozoa | Anthopleura aureoradiata | Epibiota | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 1 | 1 | 1 | 1 |
| Anthozoa | Edwardsia sp. 1 | Epibiota | II |  |  | 1 |  |  |  |  |  |  |  | 1 |  |  |  |  |  | 1 |  |  |  |
| Gastropoda | Amphibola crenata | Epibiota | III |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 1 |  |  |  |
| Gastropoda | Cominella glandiformis | Epibiota | III | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Gastropoda | Diloma subrostrata | Epibiota | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Gastropoda | Notoacmea sp. | Epibiota | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Gastropoda | Potamopyrgus estuarinus | Epibiota | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |
| Gastropoda | Zeacumantus lutulentus | Epibiota | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Maxillopoda | Austrominius modestus | Epibiota | II |  |  |  | 5 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Amphipoda | Amphipoda sp. 2 | Infauna | II |  |  |  |  |  |  | 1 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| Amphipoda | Paracorophium excavatum | Infauna | IV | 10 | 2 | 7 | 3 | 6 | 5 | 2 | 4 | 12 | 8 | 6 | 7 | 36 | 9 | 22 | 28 | 15 | 27 | 58 | 42 |
| Amphipoda | Phoxocephalidae sp. 1 | Infauna | II |  | 3 | 1 | 3 | 6 | 5 | 9 | 4 |  | 8 | 3 | 5 | 6 | 4 | 3 | 1 | 2 | 1 |  |  |
| Bivalvia | Arthritica sp. 1 | Infauna | IV |  |  |  |  |  |  |  |  |  |  | 9 | 5 |  |  |  |  |  |  |  | 3 |
| Bivalvia | Austrovenus stutchburyi | Infauna | II | 3 | 1 | 1 | 2 | 1 | 1 | 2 |  | 1 | 1 |  |  | 2 |  | 1 |  |  | 1 |  |  |
| Bivalvia | Cyclomactra tristis | Infauna | I |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Bivalvia | Hiatula sp. 1 | Infauna | NA |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Bivalvia | Macomona liliana | Infauna | II | 8 | 10 | 9 | 3 | 6 | 2 | 1 | 3 | 9 | 8 |  |  |  |  |  |  |  |  |  |  |
| Bivalvia | Paphies australis | Infauna | II |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |
| Copepoda | Copepoda sp. 1 | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |
| Copepoda | Copepoda sp. 2 | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Decapoda | Austrohelice crassa | Infauna | V | 1 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 1 |  | 1 | 4 | 1 | 2 | 4 | 5 | 1 | 2 |  | 2 |
| Decapoda | Halicarcinus whitei | Infauna | III | 1 |  |  |  | 1 |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| Decapoda | Hemiplax hirtipes | Infauna | V |  |  |  |  |  |  | 1 |  |  | 1 |  |  |  |  |  |  |  |  |  |  |
| Isopoda | Exosphaeroma sp. 1 | Infauna | V |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Nemertea | Nemertea sp. 1 | Infauna | III |  |  | 1 |  |  |  |  |  | 1 | 1 |  |  |  |  |  |  |  |  |  |  |
| Nemertea | Nemertea sp. 2 | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |
| Nemertea | Nemertea sp. 3 | Infauna | III |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  | 1 |  |  |  |
| Oligochaeta | Oligochaeta sp. 1 | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Aonides trifida | Infauna | I | 8 | 10 | 8 | 1 | 4 |  |  | 3 | 5 | 1 |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Armandia maculata | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Axiothella serrata | Infauna | II | 12 | 14 | 7 | 6 | 18 | 3 | 1 | 9 | 14 | 5 |  |  | 5 |  |  |  |  |  |  |  |
| Polychaeta | Boccardia (Paraboccardia) acus | Infauna | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Boccardia (Paraboccardia) syrtis | Infauna | II | 1 | 3 |  |  | 1 |  |  |  | 2 |  | 1 |  |  |  | 1 |  |  |  |  |  |
| Polychaeta | Capitella sp. 1 | Infauna | IV |  |  |  | 1 | 1 |  |  |  | 1 | 1 |  |  |  |  | 1 |  |  |  |  |  |
| Polychaeta | Disconatis accolus | Infauna | I |  |  | 1 | 1 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Glycera lamelliformis | Infauna | III | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Heteromastus filiformis | Infauna | III | 2 | 1 | 2 | 3 |  | 1 |  | 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Nereididae (unidentifiable) | Infauna | NA |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
| Polychaeta | Nicon aestuariensis | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Orbinia papillosa | Infauna | I |  |  |  |  |  | 1 |  | 1 |  |  |  |  |  |  |  |  |  |  | 1 |  |
| Polychaeta | Orbiniidae (unidentifiable) | Infauna | NA |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Paradoneis sp. 1 | Infauna | III |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Pectinaria australis | Infauna | III |  |  |  |  | 1 |  |  | 2 |  | 3 |  |  |  |  |  | 2 |  |  |  |  |
| Polychaeta | Perinereis vallata | Infauna | II |  |  |  | 1 |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Prionospio aucklandica | Infauna | II | 26 | 12 | 4 | 6 | 7 |  |  | 2 | 7 | 1 |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Scolecolepides benhami | Infauna | IV |  |  | 1 |  |  |  |  | 1 |  | 2 |  | 1 |  |  |  |  |  |  |  |  |
| Polychaeta | Scoloplos cylindrifer | Infauna | I |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Polychaeta | Nereididae (unidentified juveniles) | Infauna Juvenile | NA |  |  |  | 2 | 2 |  | 1 | 1 |  | 1 | 3 | 1 |  | 2 |  | 2 |  | 1 | 1 | 2 |
| Decapoda | Unidentified decapod megalopa | Larva | NA |  |  |  | 1 | 1 |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  | 1 |
| Diptera | Diptera sp. 1 | Terrestrial | II |  |  |  |  | 1 |  | 1 |  |  |  |  |  | 2 | 1 | 2 | 1 |  |  |  | 2 |
| Diptera | Diptera sp. 2 | Terrestrial | II |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Sum taxa |  |  | 13 | 12 | 13 | 12 | 16 | 8 | 9 | 13 | 12 | 14 | 7 | 7 | 8 | 6 | 9 | 7 | 7 | 9 | 6 | 8 |
|  | Sum individuals |  |  | 76 | 62 | 46 | 34 | 57 | 16 | 20 | 31 | 56 | 37 | 24 | 30 | 60 | 20 | 36 | 40 | 30 | 37 | 63 | 54 |

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# Appendix 6. Macrofauna core taxonomy QA/QC results and preliminary sampling adequacy assessment

## A6.1 Taxonomy QA/QC

In the taxonomic QA/QC assessment, Salt Ecology picked the macrofauna from each sieved sample. The 10 routine samples were then sent for taxonomic identification to Gary Stephenson (Coastal Marine Ecology Consultants; CMEC), with an additional core sample from plot Y5 sent to NIWA. Results below compare the two providers for each site separately.

As indicated in the Table A6.1.1 below, for each site species richness and abundance in the QA/QC sample assessed by NIWA were within the range of other samples sent to CMEC. NIWA found two specimens of a small bivalve, *Leptomya retiaria*, that has not previously been described from any of the Motupipi fine scale surveys. It is possible that this result reflects a difference in taxonomic classification between the providers rather than a new record. The greater overall richness of species described by CMEC in Table A6.1.1 simply reflects the greater number of samples assessed.

Overall, the species complement was judged as very similar between the two providers with many apparent differences likely explained by the following:

(i)     Species likely missed by chance due to their low density. For example, the CMEC assessment of 10 cores describes many species whose mean density was <1/core. As such, it is not surprising that not all these species were detected in the NIWA QA/QC process.

(ii)    Subtle differences between providers in the naming of taxa that are very probably the same species, e.g. *Edwardsia* sp. vs *Edwardsia* sp. 1; *Axiothella serrata* vs *Axiothella* sp.

(iii)   Different levels of taxonomic resolution attempted. For example, among the taxa that are those that are time-consuming to identify (especially crustaceans), for which CMEC has focused on using consistent 'placeholder' names. During the QA/QC process, NIWA took some of these to a more detailed level of taxonomic resolution; e.g. The CMEC-named amphipod Phoxocephalidae sp. 1 is most likely what NIWA have called *Torridoharpinia hurleyi*.

In order to be certain that the above assumptions are correct, it would be necessary for the same voucher specimens to be compared among the taxonomic providers. This depth of assessment was beyond the present scope, but would be a useful subsequent step towards developing a reference collection for Motupipi Estuary.

## A6.2 Macrofauna sampling adequacy

The NEMP approach recommends 10 macrofauna core samples to be collected per site, with the replication effort based on a detailed analysis of a national dataset as part of the original study (and driven primarily by sediment chemistry as opposed to macrofauna). It was beyond the present scope to undertake a comprehensive re-assessment, but some simple methods can be applied to evaluate whether the number of macrofauna core samples taken is sufficient to capture the main species present in Motupipi Estuary or, alternatively, whether sampling effort could be reduced without losing important information.

To make this assessment, species accumulation curves were constructed for each year-site combination using a permutation-based method available in Primer 7. This method determines the increasing total number of different species observed (S_obs), as samples are successively pooled. The number of species for each of sample numbers 1-10 is the average based on 999 random selections from the total number of samples. This approach produces a smoothed S_obs curve, with S at sample 10 being the total actual number sampled for that fine scale site and survey year.

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# Table A6.1.1 Macrofaunal QA/QC results and provider comparison

## Site A

| Taxa | Site A CMEC (mean, n=10) | Site A NIWA (n=1) | Comment |
|---|---|---|---|
| Amphipoda sp. 2 | 0.9 | | Likely a chance miss due to low density |
| Aonides trifida | 4 | 2 | |
| Arthritica bifurca | | 2 | Likely a chance miss (present Site A other years, also Site B) |
| Austrohelice crassa | 1.6 | 1 | |
| Austrominius modestus | 0.6 | | Likely a chance miss due to low density |
| Austrovenus stutchburyi | 1.3 | 5 | |
| Axiothella serrata | 8.9 | | Assumed NIWA Axiothella sp. |
| Axiothella sp. | | 11 | Assumed CMEC Axiothella serrata |
| Boccardia (Paraboccardia) syrtis | 0.7 | | Likely a chance miss due to low density |
| Cominella glandiformis | 0.1 | | Likely a chance miss due to low density |
| Copepoda sp. 1 | 0.1 | | Likely a chance miss due to low density |
| Diptera sp. 1 | 0.2 | | Likely a chance miss due to low density |
| Disconatis accolus | 0.5 | | Likely a chance miss due to low density |
| Edwardsia sp. 1 | 0.2 | | Likely a chance miss due to low density |
| Glycera lamelliformis | 0.3 | | Likely a chance miss due to low density |
| Halicarcinus whitei | 0.3 | 2 | |
| Hemiplax hirtipes | 0.2 | | Likely a chance miss due to low density |
| Heteromastus filiformis | 1.5 | 5 | |
| Hiatula sp. 1 | 0.2 | | Likely a chance miss due to low density |
| Leptomya sp. | | 2 | New for Motupipi |
| Macomona liliana | 5.9 | 14 | |
| Nemertea | | 1 | Assumed CMEC Nemertea sp. 1 or 3 |
| Nemertea sp. 1 | 0.1 | | Assumed NIWA Nemertea |
| Nemertea sp. 3 | 0.2 | | Assumed NIWA Nemertea |
| Nereididae (unidentified juveniles) | 0.9 | | Likely a chance miss due to low density |
| Nicon aestuariensis | | 1 | Likely a chance miss (present Site A other years, also Site B) |
| Orbinia papillosa | 0.4 | | Likely a chance miss due to low density |
| Paracorophium excavatum | 0.4 | | Likely a chance miss due to low density |
| Pectinaria australis | 0.6 | | Likely a chance miss due to low density |
| Phoxocephalidae sp. 1 | 6.1 | | Assumed NIWA Torridoharpinia hurleyi |
| Prionospio aucklandica | 6.5 | 12 | |
| Scolecolepides benhami | 0.4 | | Likely a chance miss due to low density |
| Torridoharpinia hurleyi | | 4 | Probably CMEC Phoxocephalidae sp. 1 |
| Unidentified decapod megalopa | 0.4 | | Likely a chance miss due to low density |
| **Number of taxa** | **28** | **13** | **(CMEC range 8-16 taxa/core)** |
| **Sum abundance** | **44** | **62** | **(CMEC range 16-76 individuals/core)** |

## Site B

| Taxa | Site B CMEC (mean, n=10) | Site B NIWA (n=1) | Comment |
|---|---|---|---|
| Amphibola crenata | 0.3 | 2 | |
| Arthritica bifurca | | 3 | Assumed CMEC Arthritica sp. 1 |
| Arthritica sp. 1 | 3.7 | | Assumed NIWA Arthritica bifurca |
| Austrohelice crassa | 2.3 | 1 | |
| Austrovenus stutchburyi | 0.3 | 1 | |
| Axiothella serrata | 0.5 | | Likely a chance miss due to low density |
| Boccardia (Paraboccardia) syrtis | 0.2 | | Same as NIWA Boccardia syrtis |
| Boccardia syrtis | | 1 | Same as CMEC Boccardia (Paraboccardia) syrtis |
| Capitella sp. 1 | 0.1 | | Likely a chance miss due to low density |
| Copepoda sp. 2 | 0.1 | | Likely a chance miss due to low density |
| Cyclomactra tristis | 0.1 | | Likely a chance miss due to low density |
| Diptera sp. 1 | 0.1 | | Likely a chance miss due to low density |
| Diptera sp. 2 | 0.8 | | Likely a chance miss due to low density |
| Edwardsia sp. | | 2 | Assumed CMEC Edwardsia sp. 1 |
| Edwardsia sp. 1 | 2.3 | | Assumed NIWA Edwardsia sp. |
| Nemertea sp. 2 | 0.1 | | Likely a chance miss due to low density |
| Nemertea sp. 3 | 0.1 | | Likely a chance miss due to low density |
| Nereididae (unidentified juveniles) | 1.2 | | Likely a chance miss due to low density |
| Nicon aestuariensis | 0.1 | | Likely a chance miss due to low density |
| Oligochaeta | | 3 | Likely a chance miss (present both site in other years) |
| Paracorophium excavatum | 25 | 12 | |
| Phoxocephalidae sp. 1 | 1.8 | | Likely a chance miss due to low density |
| Potamopyrgus estuarinus | 0.1 | | Likely a chance miss due to low density |
| Scolecolepides benhami | 0.1 | | Likely a chance miss due to low density |
| Unidentified decapod megalopa | 0.1 | | Likely a chance miss due to low density |
| **Total number of taxa** | **21** | **8** | **(CMEC range 6-9 taxa/core)** |
| **Sum of abundance** | **39** | **25** | **(CMEC range 20-63 individuals/core)** |

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If sampling has adequately captured all species at the site, the curve would reach an asymptote, with no further species detected with subsequent sampling. Due to the presence of uncommon or rare species, an asymptote is unlikely to ever be reached in practice, i.e. due to chance sampling of such species with increasing effort, as evidenced in the CMEC vs NIWA comparison above. However, methods are available that estimate the species richness that corresponds to the point where the asymptote is theoretically reached. For present purposes, we use two species estimation methods from Primer 7, a non-parametric bootstrap method (referred to here as S1) and a parametric Michaelis-Menton model (referred to here as S2).

Fig. A6.2 below shows the S_obs curves for each site-year, and Table A6.2.1 shows the two estimates of 'true' species richness for each site year, and the proportion of that richness captured with increasing sampling effort. As expected, Fig. A6.2 shows that the cumulative species richness curve is generally still slowly increasing at 10 samples (although the curve is generally reasonably flat). Table A6.2.1 suggests that at 10 samples, the number of species being detected is between ~64% and 92% of the estimated maximum, with the means being 87.2 for the S1 estimate and 80.2 for S2.

One way to interpret the results is that it would take >10 samples before actual richness approached the estimated total for a given year-site. However, it will be the rare species that are represented with increasing sampling effort, with the most dominant species collected with far fewer cores. As there are ever diminishing returns with increased effort, and the chance presence/absence of rarer species can be difficult to interpret ecologically, a complementary and defensible way to consider sampling adequacy is to focus on richness among the most dominant species.

For this purpose, we used k-dominance plots (not presented here) to assess the number of species for a given year-site that captured at least 90% of total abundance, and assessed the percentage of total year-site richness that this number of species represented. From that information, we then used the median of the S1 and S2 total richness estimates from Table A6.2.1 to determine the minimum number of samples required to reach that percentage for each year-site combination. The results are given in Table A6.2.2.
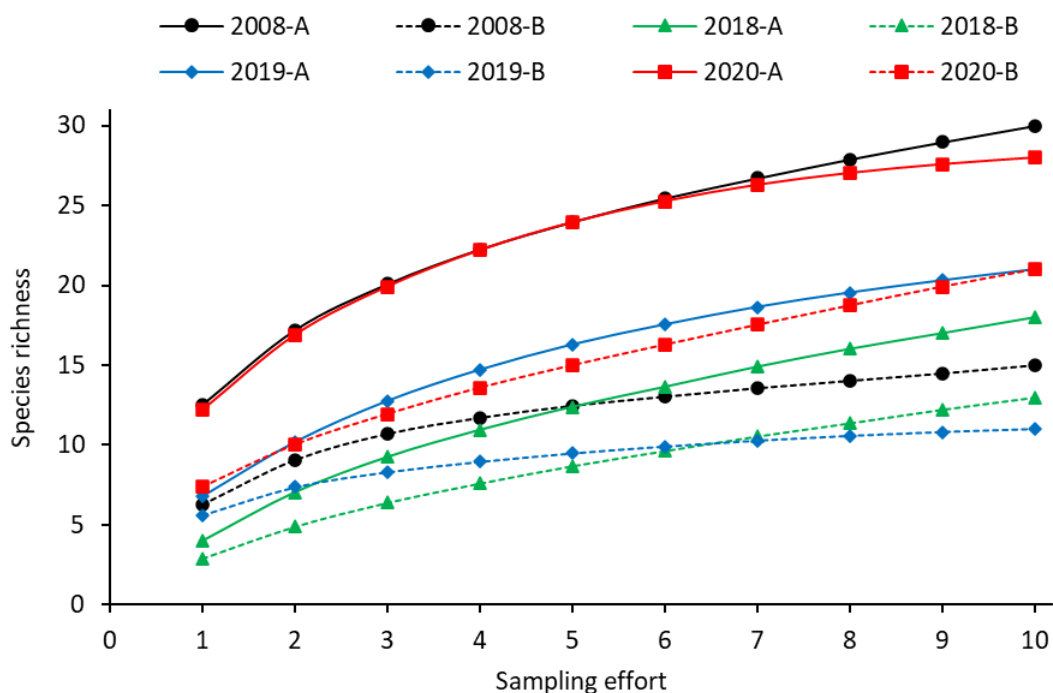


**Fig. A6.2 Cumulative species richness in relation to sampling effort for each year-site.**

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**Table A6.2.1 Macrofaunal sampling species richness estimates and percentage of theoretical richness captured in relation to sampling effort. Median % is median of the two columns to the left, and is use in Table A6.2.2 to determine minimum sample size (see text for details).**

| 2008A | S1 estimate = 33.9, S2 estimate = 33.8 | | | | | 2008B | S1 estimate = 16.8, S2 estimate = 17.1 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % | Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % |
| 1 | 12.5 | 41.8 | 36.9 | 37.0 | 37.0 | 1 | 6.3 | 41.7 | 37.3 | 36.5 | 36.9 |
| 2 | 17.2 | 57.3 | 50.7 | 50.9 | 50.8 | 2 | 9.1 | 60.4 | 53.9 | 52.8 | 53.4 |
| 3 | 20.1 | 67.0 | 59.2 | 59.4 | 59.3 | 3 | 10.7 | 71.3 | 63.7 | 62.4 | 63.1 |
| 4 | 22.3 | 74.2 | 65.6 | 65.8 | 65.7 | 4 | 11.7 | 78.0 | 69.7 | 68.3 | 69.0 |
| 5 | 24.0 | 79.9 | 70.7 | 70.9 | 70.8 | 5 | 12.5 | 83.0 | 74.2 | 72.7 | 73.5 |
| 6 | 25.5 | 84.9 | 75.1 | 75.3 | 75.2 | 6 | 13.0 | 86.9 | 77.6 | 76.1 | 76.8 |
| 7 | 26.7 | 89.0 | 78.8 | 79.0 | 78.9 | 7 | 13.6 | 90.4 | 80.8 | 79.1 | 80.0 |
| 8 | 27.9 | 93.0 | 82.3 | 82.5 | 82.4 | 8 | 14.0 | 93.5 | 83.6 | 81.9 | 82.7 |
| 9 | 29.0 | 96.6 | 85.4 | 85.7 | 85.6 | 9 | 14.5 | 96.5 | 86.3 | 84.5 | 85.4 |
| 10 | 30.0 | 100.0 | 88.5 | 88.7 | 88.6 | 10 | 15.0 | 100.0 | 89.4 | 87.5 | 88.5 |

| 2018A | S1 estimate = 21.8, S2 estimate = 28.2 | | | | | 2018B | S1 estimate = 15.9, S2 estimate = 20.4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % | Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % |
| 1 | 4.0 | 22.2 | 18.4 | 14.2 | 16.3 | 1 | 2.9 | 22.2 | 18.1 | 14.2 | 16.2 |
| 2 | 7.1 | 39.2 | 32.4 | 25.0 | 28.7 | 2 | 4.9 | 37.6 | 30.7 | 24.0 | 27.3 |
| 3 | 9.3 | 51.4 | 42.5 | 32.8 | 37.7 | 3 | 6.4 | 49.2 | 40.1 | 31.4 | 35.8 |
| 4 | 11.0 | 60.9 | 50.3 | 38.8 | 44.6 | 4 | 7.6 | 58.5 | 47.7 | 37.3 | 42.5 |
| 5 | 12.4 | 68.9 | 57.0 | 43.9 | 50.5 | 5 | 8.7 | 66.9 | 54.6 | 42.7 | 48.6 |
| 6 | 13.6 | 75.8 | 62.7 | 48.4 | 55.5 | 6 | 9.6 | 74.2 | 60.5 | 47.4 | 54.0 |
| 7 | 14.9 | 82.8 | 68.5 | 52.8 | 60.7 | 7 | 10.6 | 81.2 | 66.3 | 51.9 | 59.1 |
| 8 | 16.0 | 89.0 | 73.6 | 56.8 | 65.2 | 8 | 11.4 | 87.6 | 71.5 | 55.9 | 63.7 |
| 9 | 17.0 | 94.5 | 78.1 | 60.3 | 69.2 | 9 | 12.2 | 94.1 | 76.8 | 60.1 | 68.5 |
| 10 | 18.0 | 100.0 | 82.7 | 63.8 | 73.2 | 10 | 13.0 | 100.0 | 81.6 | 63.9 | 72.7 |

| 2019A | S1 estimate = 24.0, S2 estimate = 27.0 | | | | | 2019B | S1 estimate = 11.9, S2 estimate = 12.0 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % | Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % |
| 1 | 6.8 | 32.2 | 28.2 | 25.0 | 26.6 | 1 | 5.6 | 51.1 | 47.1 | 46.9 | 47.0 |
| 2 | 10.2 | 48.4 | 42.4 | 37.6 | 40.0 | 2 | 7.4 | 66.9 | 61.7 | 61.4 | 61.5 |
| 3 | 12.7 | 60.7 | 53.2 | 47.2 | 50.2 | 3 | 8.3 | 75.5 | 69.5 | 69.2 | 69.4 |
| 4 | 14.7 | 70.0 | 61.4 | 54.4 | 57.9 | 4 | 8.9 | 81.3 | 74.9 | 74.6 | 74.8 |
| 5 | 16.3 | 77.6 | 68.0 | 60.3 | 64.1 | 5 | 9.5 | 86.1 | 79.3 | 79.0 | 79.2 |
| 6 | 17.5 | 83.6 | 73.3 | 64.9 | 69.1 | 6 | 9.9 | 90.0 | 82.9 | 82.6 | 82.8 |
| 7 | 18.6 | 88.8 | 77.8 | 69.0 | 73.4 | 7 | 10.3 | 93.4 | 86.1 | 85.7 | 85.9 |
| 8 | 19.5 | 93.1 | 81.6 | 72.3 | 76.9 | 8 | 10.6 | 96.1 | 88.6 | 88.2 | 88.4 |
| 9 | 20.3 | 96.7 | 84.8 | 75.2 | 80.0 | 9 | 10.8 | 98.3 | 90.5 | 90.2 | 90.4 |
| 10 | 21.0 | 100.0 | 87.7 | 77.7 | 82.7 | 10 | 11.0 | 100.0 | 92.1 | 91.8 | 91.9 |

| 2020A | S1 estimate = 30.3, S2 estimate = 32.6 | | | | | 2020B | S1 estimate = 25.1, S2 estimate = 24.3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % | Sample number | S_obs | S_obs (% total) | S_obs as % of S1 | S_obs as % of S2 | Median % |
| 1 | 12.2 | 43.6 | 40.2 | 37.4 | 38.8 | 1 | 7.4 | 35.1 | 29.4 | 30.3 | 29.9 |
| 2 | 16.9 | 60.3 | 55.7 | 51.8 | 53.8 | 2 | 10.0 | 47.7 | 40.0 | 41.2 | 40.6 |
| 3 | 19.9 | 71.2 | 65.7 | 61.1 | 63.4 | 3 | 11.9 | 56.8 | 47.6 | 49.1 | 48.4 |
| 4 | 22.2 | 79.3 | 73.2 | 68.1 | 70.7 | 4 | 13.6 | 64.7 | 54.2 | 55.9 | 55.0 |
| 5 | 24.0 | 85.5 | 79.0 | 73.5 | 76.2 | 5 | 15.0 | 71.4 | 59.8 | 61.7 | 60.7 |
| 6 | 25.3 | 90.2 | 83.3 | 77.5 | 80.4 | 6 | 16.3 | 77.5 | 64.9 | 67.0 | 65.9 |
| 7 | 26.3 | 93.9 | 86.7 | 80.6 | 83.7 | 7 | 17.5 | 83.4 | 69.9 | 72.1 | 71.0 |
| 8 | 27.0 | 96.5 | 89.2 | 82.9 | 86.0 | 8 | 18.7 | 89.2 | 74.7 | 77.1 | 75.9 |
| 9 | 27.6 | 98.5 | 91.0 | 84.6 | 87.8 | 9 | 19.9 | 94.8 | 79.4 | 81.9 | 80.7 |
| 10 | 28.0 | 100.0 | 92.3 | 85.9 | 89.1 | 10 | 21.0 | 100.0 | 83.7 | 86.4 | 85.1 |

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**Table A6.2.2 Determination of minimum sample size (rounded up to the nearest whole number) needed to capture the most abundant taxa, using a threshold cumulative abundance value of 90%. See text for details.**

| Year-site | Site S | # S to achieve >90% of N | % of Site S | Sample min |
|---|---|---|---|---|
| 2008A | 30 | 13 | 43 | 2 |
| 2008B | 15 | 7 | 47 | 2 |
| 2018A | 18 | 12 | 67 | 9 |
| 2018B | 13 | 9 | 69 | 9 |
| 2019A | 21 | 13 | 62 | 5 |
| 2019B | 11 | 5 | 45 | 1 |
| 2020A | 28 | 16 | 57 | 2 |
| 2020B | 21 | 6 | 29 | 1 |

S = richness (no. of taxa), N = abundance

Note: Oct 2018 validation samples (n=3) not included

The likelihood of a species being detected is assumed to be directly proportional to its abundance, so defining the number of species required to capture >90% of a site's abundance allows minimum sampling effort to be defined. Table A6.2.2 shows that, across all year-site combinations, when between 5 and 16 of the most dominant species have been sampled, greater than 90% of site abundance is also represented. At the 90% threshold these figures represent 29 to 69% of the total richness.

Accordingly, the sampling effort required to achieve these richness targets can be ballparked from Table A6.2.1 (from median% column), and is highly variable. In some situations, a single core can adequately capture 90% of species abundance (e.g. Site B in 2019 and 2020), whereas at the upper end 9 cores are needed. However, the latter relates to the atypical 2018 surveys described in the main report where a change in provider may have significantly influenced results.

On the basis of the other survey years, however, we can be reasonably confident that reducing sampling effort in future surveys will not appreciably compromise the ability to reliably assess key changes in the macrofaunal assemblage. Even though some of the uncommon species may be missed, these do not greatly contribute to determination of temporal change anyway. This assertion is supported by the verification survey conducted in October 2018 where, despite only three samples being collected, results were highly similar to other years in terms of richness abundance and macrofaunal composition (e.g. see Fig. 11 of main report).

To achieve a reasonable balance between capturing the most abundant taxa, as well as most of the less common ones, it is recommended that the macrofaunal sampling effort in future surveys be reduced to 9 cores. This will ensure comparability of future sampling results with existing data from Motupipi Estuary (and among estuaries regionally and even nationally), and will provide sufficient sampling effort to account for years when the assemblage is reasonably species-poor and a greater number of cores is needed. This approach has the additional benefits of reducing cost and providing a more balanced sampling design with a 3 x 3 layout of sampling plots, rather that the subsampling of 10 plots with the 3 x 4 present layout (see Fig. 3 of the main report).

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# Appendix 7. Macrofauna core multivariate analysis result details

In order to explore the differences and similarities among sites and surveys in terms of the entire macrofaunal assemblage, an nMDS ordination was undertaken on zone-aggregated samples, to enable comparison with sediment quality data. The nMDS plots shown in Fig. 15 of the main report place samples of similar macrofauna composition close to each other in a 2-dimensional biplot, with less similar samples being further apart. The cluster pattern illustrates some of the fundamental differences in the species composition of the two sites that were described om the main report.

Samples within each site had a similarity index of at least 60% (see Fig. 15a). The SIMPER analysis revealed the species or higher taxa that characterise each sample grouping, generally highlighting that the temporal differences within each site often reflect shifts in the dominance of one species over another. In terms of dissimilarity among SIMPER groups, two of the aggregated samples for 2018 full survey (i.e. from sampling zones Y & Z) cluster as being highly distinct from the other samples and survey years, reflecting the notably impoverished macrofauna in 2018 that was described above. From Table A7.1 below, it is evident that the 2018 Site B cluster was 83% dissimilar to the same site in other survey years. In 2018, the small disturbance-tolerant species that were typical of Site B were not recorded or were in greatly reduced abundance.

The general differences between the main site groups were most closely correlated with sediment grain size, with the BIOENV procedure (see methods section of the main report) revealing %mud to be the single variable that most strongly explained the overall patterns (Pearson correlation coefficient, $r^2 = 0.54$). Increasing mud content was strongly associated with the left-right separation of each site-zone in the nMDS (Pearson $r^2 = 0.85$), reflecting the increase in mud content from Site A to B. Although the association between trace metals and macrofaunal patterns was weak-to-moderate (Pearson $r^2$ 0.17 to 0.30) for individual analytes, the concentrations recorded were strongly associated with the left-right separation in the nMDS (Pearson $r^2 = 0.78$ to 0.97). This result reflects that metal concentrations at Site A were consistently greater than at Site B. There was little association (Pearson $r^2 < 0.2$) between trophic state indicators (aRPD, TN, TP) and macrofaunal patterns (Fig. 15b), which is consistent with the absence of any symptoms of excessive sediment enrichment.

**Table A7.1. Triangular matrix of Bray-Curtis dissimilarity scores among SIMPER groups described in Fig. 15a of main report. Codes refer to sites and survey years. The X, Y and Z annotated to the 2018 Site B samples reflect that samples from zones Y and Z formed a separate cluster to zone X samples.**

| Group | A08+20 | B08+18X +19+20 | A18 | B18YZ |
|---|---|---|---|---|
| A08+20 | - | - | - | - |
| B08+18X +19+20 | 62 | - | - | - |
| A18 | 70 | 74 | - | - |
| B18YZ | 92 | 83 | 71 | - |
| A19 | 52 | 71 | 50 | 88 |

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# Appendix 8. Motupipi River transect cross-sections

Depths are referenced to Mean Low Water Spring tide.
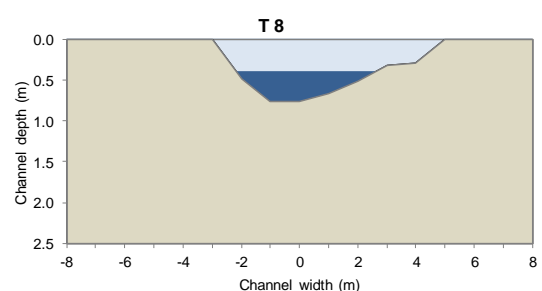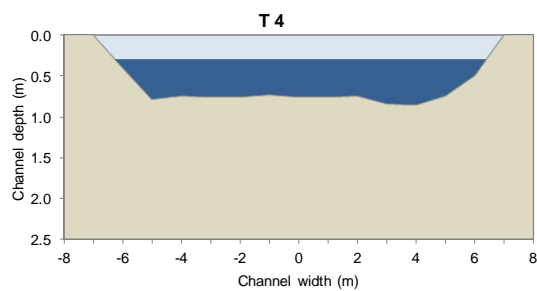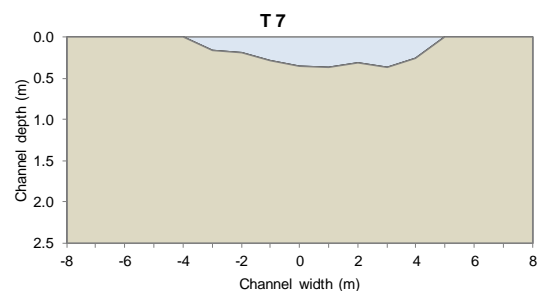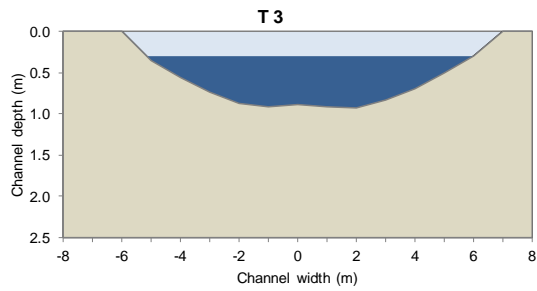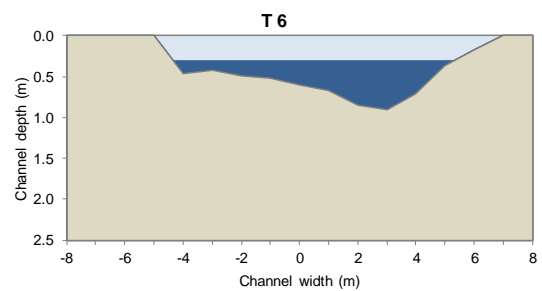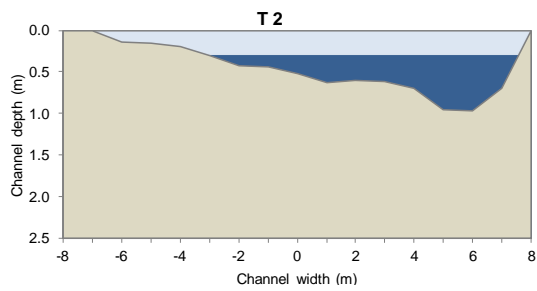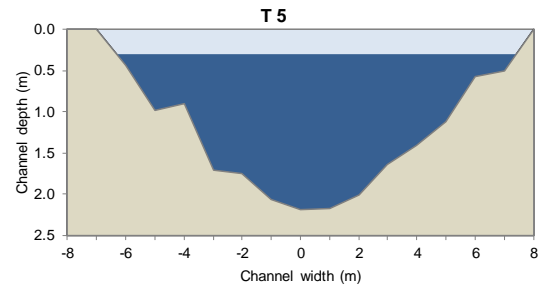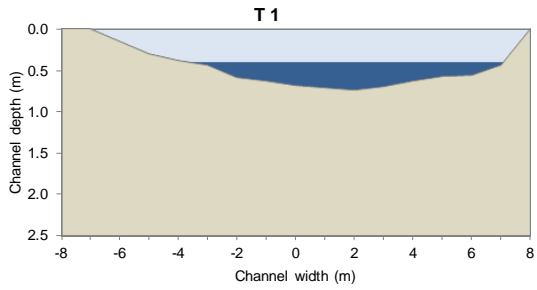
# Appendix 9. Sediment and Nutrient modelling outputs

| Data source | Motupipi Estuary | West arm | East arm | Total estuary |
| --- | --- | --- | --- | --- |
| Stevens & Robertson 2015 | Estuary Area (Ha) | 47.9 | 111.8 | 160 |
| Hicks et al. 2019 | Mean freshwater flow ($m^3$/s) | 0.65 | 0.38 | 1.03 |
| Hicks et al. 2019 | Catchment Area (Ha) | 2488 | 1591 | 4080 |
| NIWA CLUES model | Catchment nitrogen load (TN/yr) | 31.3 | 12.2 | 43.5 |
| NIWA CLUES model | Catchment phosphorus load (TP/yr) | 2.3 | 2.2 | 4.5 |
| Hicks et al. 2019 | Catchment sediment load (KT/yr) | 1.7 | 1.7 | 3.4 |
| NIWA CLUES model | Estimated N areal load in estuary (mg/$m^2$/d) | 179 | 30 | 74 |
| NIWA CLUES model | Estimated P areal load in estuary (mg/$m^2$/d) | 13 | 5 | 8 |
| Hicks et al. 2019 | CSR:NSR ratio | 1.5 | 1.4 | 1.4 |
| modified from previous | CSR/NSR ratio with 50% natural wetland attenuation | 2.9 | 2.7 | 2.8 |
| Hicks et al. 2019 | Trap efficiency (sediment retained in estuary) | 0.87 | 0.87 | 0.87 |
| Hicks et al. 2019 | Estimated rate of sed. trapped in estuary (mm/yr) | 2.1 | 0.9 | 1.2 |

CLUES version 10.3, Run date: April 2020

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