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Mahakipawa Estuary

Fine-Scale Monitoring and Broad-Scale Habitat Mapping 2017

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Executive Summary

Introduction

SLR Consulting NZ Ltd (SLR) was engaged by Marlborough District Council (MDC) to undertake broad-scale mapping and fine-scale monitoring of Mahakipawa Estuary during the summer of 2017. The aim of the monitoring was to provide baseline data regarding the estuary's habitats, vegetation, sediment chemistry and composition, and macroinvertebrate communities, from which to assess the current condition of the estuary. This report presents and analyses the monitoring results and discusses management options and recommendations.

Methodology

The sampling methodology applied, and the parameters sampled, were in accordance with the recommendations provided in the National Estuarine Monitoring Protocol (NEMP) and are detailed within the report.

Key findings

The broad-scale mapping showed:

- The intertidal area covered 137.52 ha and was dominated by soft/very soft mud (61%) followed by firm mud (17%). The high soft mud content classifies the estuary as high risk (BAND D);
- Vegetation was present in 25% of the intertidal area and nearly all of this was saltmarsh. Saltmarsh vegetation was predominately rushland (70%), dominated by *Juncus krausii*;
- Macroalgae and seagrass were both scarce;
- Mollusc patches, nearly all Pacific oysters (*Crassostrea gigas*), covered 17.79 ha, or 13% of the intertidal area; and
- Almost 95% of the terrestrial margin surrounding Mahakipawa Estuary was vegetated by either scrub/forest or grassland.

The fine-scale monitoring showed:

- Interstitial salinity ranged from 13.2 to 15.3 ppt at both Site A and Site B, indicating significant freshwater influence;
- The average depth of the anoxic layer at Site A was 2.7 cm and at Site B was ~7-10 cm (the depth of the anoxic layer was more difficult to measure at Site B and is therefore presented as a range). Redox potential measurements indicated minor stress (BAND B) on sensitive organisms at Site A and no stress (BAND A) on any aquatic organisms at Site B;
- Mud content at both sites was high, ranging from 46% - 65% indicating significant, persistent stress (BAND D) on a range of aquatic organisms;
- Total organic content and total nitrogen results indicated minor stress (BAND B) on sensitive organisms at Site A, and no stress (BAND A) on any organisms at Site B. Phosphorus measurements were considered to be moderate-high at both sites;
- None of the metals/metalloids analysed were present at levels exceeding ISQG-Low guideline values;
- Semi-organic volatile compounds and organotin concentrations were below the analytical detection limits;
- No microalgae, macroalgae or seagrass occurred at either site;
- Epifauna diversity was low (a total of four taxa across the two sites) and was dominated by the mudsnail *Amphibola crenata*; and
- NZ AMBI (AZTI Marine Biotic Index) values calculated from infauna data indicated minor to moderate stress (BAND B) on benthic fauna at both sites.

Executive Summary

Conclusion and recommendations

Results from the 2017 broad-scale mapping and fine-scale monitoring of Mahakipawa Estuary indicate that the main ecological risk is the high coverage of soft/very soft muddy sediments. The near-absence of seagrass and the low diversity of epifauna are likely being influenced by this high proportion of fine sediments. Low nitrogen concentrations and the lack of macroalgae suggest that the estuary is unlikely to be eutrophic, although phosphorus concentrations are higher than would perhaps be expected.

It is recommended that broad-scale mapping and fine-scale monitoring of Mahakipawa Estuary be repeated (at least) every five years, to track spatial and temporal changes in the estuary's condition. Management aims should focus on decreasing fine sediments within the estuary (particularly with respect to inputs), and encouraging the growth and spread of seagrass, both of which would enhance the ecological, recreational and aesthetic values of this valuable coastal ecosystem.

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1 INTRODUCTION

Marlborough District Council (MDC) Coastal Strategy (2012) identified broad-scale mapping and fine-scale monitoring of benthic intertidal habitats as a priority. Consequently, a schedule has been developed as part of MDC's overall coastal monitoring programme to ensure that all estuaries in Marlborough will be subject to mapping and monitoring by 2023. As part of this programme, MDC commissioned SLR Consulting New ZealandZ Ltd (SLR) to conduct broad-scale mapping and fine-scale monitoring of Mahakipawa Estuary during the summer of 2017. This monitoring was done in accordance with the National Estuarine Monitoring Protocol (NEMP; Robertson *et al*., 2002) and involved an assessment of the ecological condition of the estuary and the development of management recommendations.

1.1 Estuaries

An estuary can be described as "a partially enclosed body of water that is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixing of sea water with fresh water derived from land drainage" (Day, 1980). Estuarine ecosystems are critical transition zones where inputs of energy and matter from terrestrial, freshwater and marine environments are processed and transformed and can include habitats of rocky outcrops, sand dunes, seagrasses and salt marshes. Morphologically, estuaries are highly influenced by their location, wind, wave and tidal action, hydrology, sedimentation and erosion (Day, 1981).

Estuaries provide important feeding and nursery grounds for fish and bird species, and support a high diversity of flora and fauna including macro- and micro- algae, bacteria, seagrass, mangroves, phytoplankton, zooplankton, infauna, epifauna, fish and birds.

1.2 Threats to estuaries

Human activities have placed significant pressures on estuarine habitats. Such activities include increased: eutrophication and sewage inputs, habitat loss and alteration through development, input of chemical contaminants, risk of introduced species, input of debris/litter, and an increased risk of sea level rise. These activities can have adverse effects on estuarine ecosystems which may include loss of habitats and diversity, algal blooms, increased primary production, increased organic matter and hypoxic/anoxic conditions. These not only have direct ecological effects, but can also have significant indirect effects on the recreational, aesthetic and commercial value of an estuary.

1.2.1 Sedimentation

Sedimentation is a natural process and sediment can enter estuaries via rivers and tidal creek banks, or directly from coastal land and resuspended intertidal and subtidal deposits. However, the balance between sediment entering and exiting estuaries has been altered by human activities. Activities that result in increased sediment entering estuaries pose a threat to the physical, morphological, biological and ecological features of estuarine ecosystems. Habitat modification and development can increase erosion and change water-flow patterns and sediment movements, leading to the infilling of an estuary; although whether or not this occurs, will depend on many factors including wave, tide and wind action, water inputs from rivers, and water depth.

Adverse effects of sedimentation include smothering of the estuarine surface (and associated biota), changes in sediment physical and chemical properties (e.g. grain size, permeability, flux and contaminant concentration), feeding impacts on biota (e.g. clogging of filtering mechanisms), increased water turbidity, the potential for transport of contaminants, and decreased pH. The effects of sedimentation are strongly dependent on the depth and spatial extent of the deposited sediment, the temporal frequency of sedimentation events, the concentration of suspended sediment, and the resilience of the existing community.

1.2.2 Eutrophication

Eutrophication occurs when excess nutrients from terrestrial sources enter the coastal zone (Cloern, 2001). Increased nutrient levels lead to the increased production of particulate and dissolved organic matter that becomes degraded and causes lowered oxygen concentrations (Diaz & Rosenberg, 1995).

Nitrogen and phosphorus are generally the nutrients of concern in contributing to eutrophication and most commonly enter the marine environment via groundwater, fluvial and atmospheric inputs. Although nitrogen and phosphorus are required for growth and production, large quantities of these elements can have detrimental impacts on the structure and functioning of ecosystems. They can cause excessive amounts of primary production and respiration, and the generation of particulate matter. These, in turn, can lead to severely degraded sediment chemistry, suboxic and anoxic water and sedimentary habitats for biota, blooms of nuisance macroalgae, toxic phytoplankton blooms, reductions in faunal diversity, and changes in food web structure. The extent of these impacts, and their consequences, depend both on the type and quantity of the input, as well as the characteristics of the environment to which it enters (Cloern, 2001).

Where an estuary has been exposed to nutrient inputs over a prolonged period, legacy effects of nutrients stored in the sediments can occur (often along with high levels of sediment organic content and anoxic cohesive sediments). Effects are exaggerated in areas where tidal flows and circulation are low.

1.2.3 Habitat loss

There has been a rapid expansion of worldwide coastal populations in recent years and more than six billion people are expected to live in coastal areas by 2025 (Schwartz, 2005). As coastal populations have increased (and as they continue to increase), natural coastal ecosystems have been converted to urban developments. Areas which remain intact may still be affected by increased sediment runoff, and increased nutrient and sediment inputs from nearby developments. Diminished and degraded estuarine and margin habitats are less likely to support healthy and diverse biological communities and their aesthetic value may decline. Both of these factors will adversely affect coastal populations who place value on these areas for their economic, aesthetic, environmental and cultural wellbeing.

1.2.4 Toxic contamination/disease

Toxic substances can cause serious illness or death and may be poisonous, carcinogenic or harmful in other ways to living things. Heavy metals, semi-organic volatile and organotin compounds, pesticides and hydrocarbon products are examples of toxic substances that can pollute estuaries. These substances can enter an estuary via industrial/commercial discharges, runoff, roads, agricultural activities and stormwater drains. They have the potential to accumulate in plant and animal tissue and can bioaccumulate through the food web, where they may ultimately be consumed by humans and thus pose a health risk.

1.2.4.1 Heavy metals

Although many heavy metals are essential to plant and animal life, high concentrations of some metals (such as lead, copper, cadmium and zinc) can inhibit essential life functions and be toxic to organisms (Bryan, 1971). In estuaries, contamination by heavy metals can be a complex process involving physical, chemical, biological and anthropogenic processes, as well as site-specific characteristics, legacy effects and recent inputs. Note that a seemingly small factor, such as grain size, can have a large effect on the amount of contaminants being retained in the sediments, all other factors being equal. For example, finer grained sediments often have higher concentrations of heavy metals than sandier sediments on account of the coarser sediments having a larger surface area which binds metals less strongly.

1.2.4.2 Semi-volatile organic compounds and organotins

Organotin compounds were initially developed in the 1920s as moth-proofing agents but have since become more widely used as bactericides and fungicides, for the heat stabilistation of PVC, and in marine antifouling paints (Moore *et al*., 1991). The organotin tributyltin (TBT) has historically been used in antifouling paints and as such, is intended to be toxic to marine organisms. It can also contaminate estuaries and other waterways. Since 2008, however, TBT use in marine anti-fouling paints has been banned in New Zealand.

1.3 Objective and aims

The overall objective of this work was to provide valuable insight and advancements in the scientific understanding of the ecological condition of Mahakipawa Estuary. This work comprised an important part of MDC's overall coastal monitoring programme.

Specific aims were to:

- Undertake broad-scale mapping of Mahakipawa Estuary;
- Undertake fine-scale monitoring of Mahakipawa Estuary;
- Analyse and assess both broad- and fine- scale results and provide management recommendations; and
- Provide baseline data from which to assess the future condition of Mahakipawa Estuary.

1.4 Study site: Mahakipawa Estuary

Mahakipawa Estuary (also referred to as Mahakipawa Arm) is located in inner Pelorus Sound (**Figure 1**). It is situated slightly to the east of Havelock Estuary from which it is separated by two small saddles. Ecologically, Mahakipawa Estuary has strong links with Havelock Estuary, which is the largest wetland complex in the Marlborough Sounds (Davidson & Brown, 2000). Havelock Estuary, Mahakipawa Estuary and Kaiuma Bay form a complex estuarine delta system at the head of Pelorus Sound, with extensive intertidal flats and shallow subtidal areas linked by tidal channels. Collectively, these areas represent the largest estuarine area in the Marlborough Sounds and natural processes within the delta system are reported to be largely intact. The overall natural character rating of this delta is *High* (Boffa Miskell *et al*., 2014).

Mahakipawa Estuary is relatively small, covering an area of approximately 137 ha. In comparison, Havelock Estuary covers an area of approximately 800 ha. The estuary has one opening and is fed by two main creeks. Significant delta-tidal landforms are present at the head of Mahakipawa Estuary. The catchment is dominated by scrub/forest and grassland/pasture, and roads border part of the estuary margin on the southern edge.

Historically, gold was discovered at Mahakipawa in 1888; a section of two miles of creek bed at Cullens Creek in the Mahakipawa Estuary was worked for a short period. The estuary did, however, suffer from periodic flooding and associated debris, which had to be cleared to continue the workings. Gold-dredging also took place in Mahakipawa Estuary and this involved land clearance, including felling and milling of timber (Handley, 2015).

Today, pacific oyster (*Crassostrea gigas*) beds are found in Mahakipawa Estuary and these represent an important kaimoana source for local iwi. Ecologically, the hard structure of oysters also serves to stabilise the sediment which helps to improve water quality. The estuary also provides important habitat for roosting and/or visiting bird species, such as the endemic black-billed gull (*Larus bulleri*) (Brown, 2001) which is classified by the NZ Threat Classification System as "Nationally Critical" (Robertson *et al*., 2013). Aesthetically, the catchment area encompasses Queen Charlotte Drive, a section of which trails the southern edge of the estuary. This is a popular scenic drive for both locals and tourists.

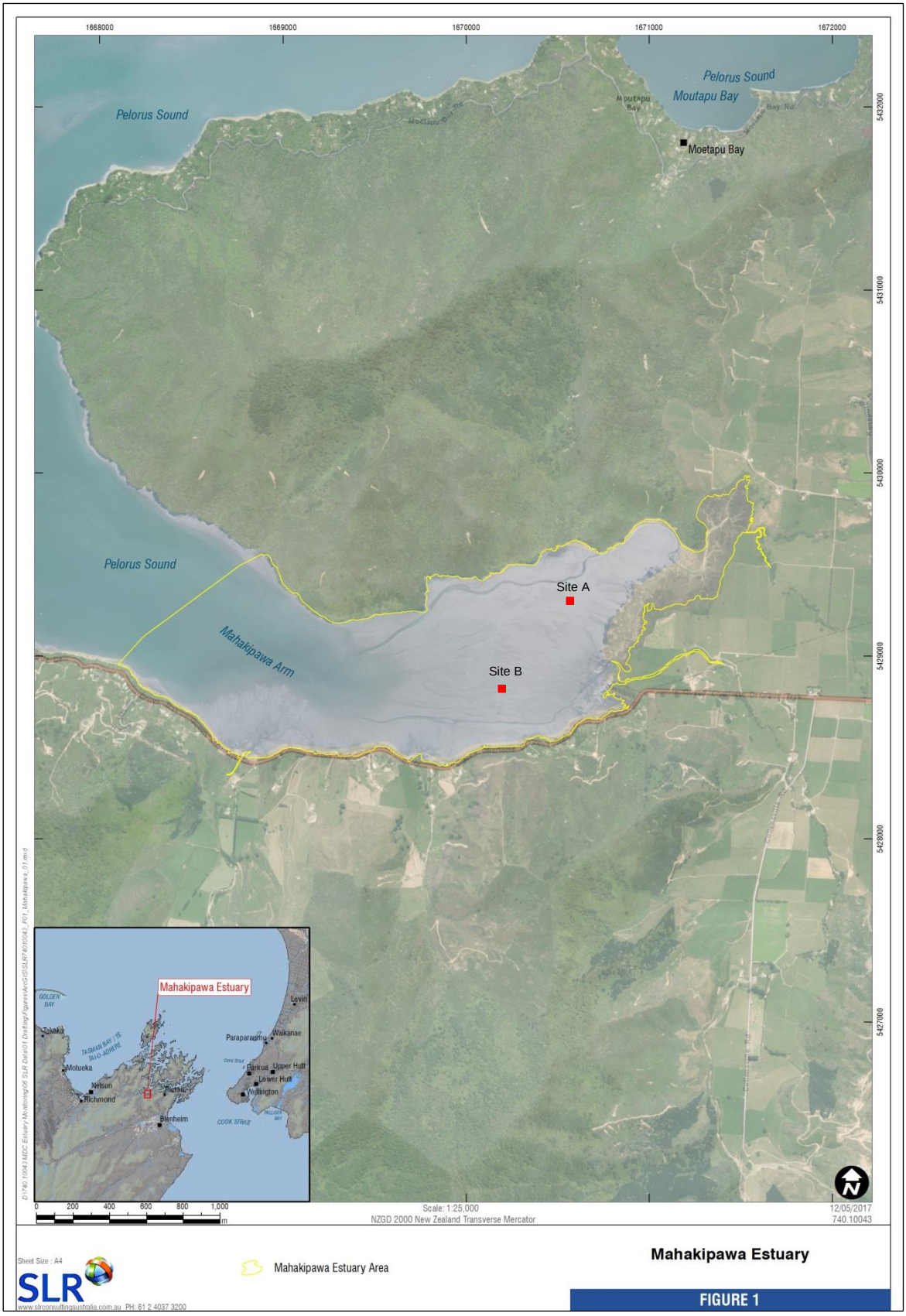


Figure 1 Location of Mahakipawa Estuary and the two fine-scale monitoring sites

2 METHODS

The monitoring approaches used followed the methods detailed in the NEMP (Robertson *et al*., 2002) and any advances made to this document since it was published. Methods/analyses applied in previous MDC commissioned estuarine monitoring reports were also followed for consistency.

2.1 Broad-scale mapping

2.1.1 Field methods

High resolution (5 cm/pixel) aerial images of Mahakipawa Estuary were taken using a fixed wing Unmanned Aerial Vehicle (UAV) at low tide during February 2017. These orthorectified images were then printed onto A3 sheets (scale 1:2500) and laminated.

On 16 March 2017 SLR marine scientists ground-truthed these aerial images by walking the majority of the exposed area of the estuary at low tide and recording the spatial extent and boundaries of the dominant habitats and substrates directly onto the laminated A3 sheets. The 200 m terrestrial boundary of the estuary was also assessed to determine the type of habitat surrounding the estuary. Dominant habitats and surface substrates which were >2 m in diameter and which were generally visible on the aerial photos were classified and recorded. The substrate and habitat classifications used were consistent with those described in the NEMP (Robertson *et al*., 2002).

An iPad featuring the iGIS app was also used during ground-truthing which provided real-time position tracking against the aerial photos. A dual SkyPro GPS receiver was used which, via BlueTooth, works in conjunction with the iPAD to provide higher accuracy with regards to positioning.

Georeferenced photographs from a representative selection of habitats within Mahakipawa Estuary were taken using the iPad app Theodolite. Theodolite takes geo-tagged images and provides a permanent record of location written onto photos, as well as the metadata, which allows for mapping of the georeferenced photos at a later date.

2.1.2 Analysis and reporting

Estuarine watercourses, substrates, vegetation, and habitat boundaries were manually digitised in ArcGIS 10.5. Boundaries were identified through combined interpretation of high resolution aerial photography and field observation data.

Maps and associated spatial datasets were produced indicating boundaries and coverage of intertidal substrates, macroalgal cover, seagrass cover, saltmarsh vegetation, mollusc patches and the land-use of the terrestrial margin.

Data outputs from the GIS analysis were examined to determine percentage cover of each substrate/vegetation/habitat type within Mahakipawa Estuary. These results were compared to Estuarine Trophic Index (ETI) risk indicator ratings as described by Robertson *et al*., (2016b) and/or ratings applied in previously commissioned MDC estuary reports. Comparisons with other Marlborough estuaries were also made.

2.2 Fine-scale monitoring

The fine-scale monitoring assessed the physical, chemical and biological components of Mahakipawa Estuary sediments. Here, the objective was to assess the extent of any ecological degradation of the estuary, resulting from stressors such as eutrophication, sedimentation and/or contamination. Fine-scale monitoring occurred on 24 January 2017.

2.2.1 Sites

Two sites (Site A and Site B) were selected for fine-scale monitoring (**Figure 1**). Site GPS coordinates are provided in **Appendix A**. Site A was located in the upper estuary, in a natural deposition area closer to the north eastern corner. This site was located in very soft mud and exposed to increased freshwater influences from White Pine Creek. Site B was positioned nearer the southern edge of the estuary in the mid-low tidal zone away from river mouths in unvegetated soft sediment.

2.2.2 Field monitoring and sampling protocols

At each site, a 60 m x 30 m grid, divided into twelve 15 m x 10 m plots (**Figure 2**) was marked out using transect tapes and temporary stakes. Ten of the 12 plots were randomly selected for the monitoring of infauna, epifauna, marine plants and sediment.

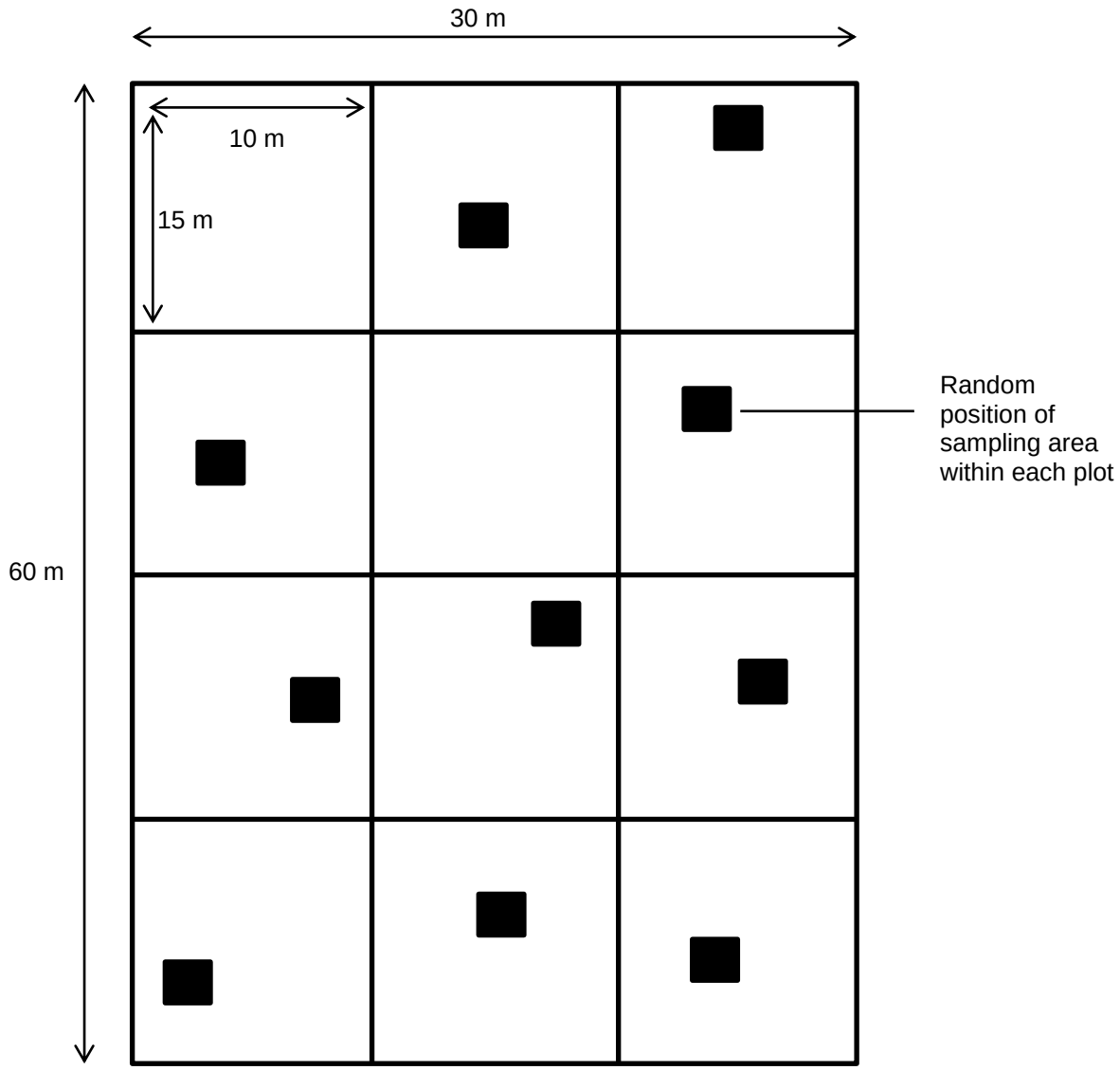


Figure 2 Grid sampling design for the fine-scaling monitoring

2.2.2.1 Salinity

One composite sample of interstitial water was collected at each site and salinity was measured by Hill Laboratories using a Conductivity Meter (WTW Cond 340i with nonlinear temperature 9-10 compensation according to EN 27 888) with a default detection limit of 0.2.

2.2.2.2 Sediment oxygenation

At each site, ten 60 mm diameter Perspex cores were collected: one in each of the ten randomly selected plots. Cores were collected to a depth of at least 15 cm and extruded onto a clean white plastic tray where they were split vertically into two halves and photographed alongside a ruler. The colour, texture, any odours and the apparent Redox Potential Discontinuity depth (aRPD), were recorded.

A digital waterproof Oxidation Reduction Potential (ORP) meter was also used to measure the amount of dissolved oxygen in the sediment. One ORP reading was obtained from each of the ten plots at each site.

2.2.2.3 Sediment physical and chemical properties

At each site, three sediment samples were collected and analysed for:

- Grain size;
- Total organic carbon (TOC);
- Total nitrogen (TN);
- Total phosphorus (TP); and
- Heavy metals: Hg, As, Cr, Cd, Cu, Pb, Ni, Zn.

Each of the three samples represented a composite: two samples were a composite of the top two cm of sediment from three plots, and the other a composite of the top two cm of sediment from the remaining four plots.

At each site, a further sample was collected for the analysis of semi-organic volatile compounds (including organotins). This sample represented a composite of each of the ten replicates sampled at that site.

2.2.2.4 Marine plants

No macro/micro- algae and/or seagrass occurred at either of the two sites in Mahakipawa Estuary. Had marine plants been present, the UK MarClim approach (MNCR, 1990) would have been used to provide a semi-quantitative assessment of marine plant (macro/micro algae and seagrass) cover.

2.2.2.5 Macroinvertebrate epifauna

At each site, ten 0.5 x 0.5 m (0.25 m^2) quadrats were randomly positioned – one within each of the ten randomly selected plots – and enumerated. This involved first taking a photo of each quadrat (for future reference) and then establishing counts of fauna >0.5 cm of each taxa occurring on the sediment surface within each quadrat. The number of crab burrows were also recorded.

2.2.2.6 Macroinvertebrate infauna

At each site, ten sediment cores were collected: one from each of the ten randomly selected plots. Cores were 130 mm diameter and 150 mm long. Each core sample was placed in a 0.5 mm nylon mesh bag and washed in the field until only the invertebrates and a small amount (fist sized) of sediment remained. This remaining sediment protected the integrity of the invertebrates. The invertebrates and sediment were transferred into a labelled plastic container, preserved with 70% ethanol and logged into SLR's Taxonomy Laboratory for processing. Note that "infauna" here also includes any epifauna present within a sediment core.

2.2.3 Laboratory processing

2.2.3.1 Sediment physical and chemical properties

Hill Laboratories provided testing of the sediment samples for sediment grain size, total organic content, heavy metal concentration, total nitrogen, total phosphorus and semi-organic volatile compounds (including organotins). The methods used by Hill Laboratories and their respective detection limits are shown in **Appendix B**.

2.2.3.2 Macroinvertebrate infauna

Macroinvertebrate samples were processed in SLR's Taxonomy Laboratory. Here, infauna were sorted and identified to the lowest practical taxonomic level, which was generally to genus and often to species. Precision at these taxonomic levels has been reported as sufficient for resolving community patterns (Agard *et al*., 1993; James *et al*., 1995) and reflecting species-level biodiversity in similar habitats (Gaston, 2000; Olsgard *et al*., 2003). Counts were made to determine taxon abundances per sample.

The 'Protocol for Processing, Identification and Quality Assurance of New Zealand Marine Benthic Invertebrate Samples' prepared by NIWA for Northland Regional Council (Hewitt *et al*., 2015) outlines a standard quality assurance protocol for marine benthic invertebrate samples and guidelines for taxonomic resolution and verification. SLR's taxonomists followed the quality assurance guidelines outlined in this document. As per the guidelines, for every 10 samples, one sample was randomly chosen for quality assurance (QA); QA results are provided in **Appendix H**.

2.2.4 Statistical analyses

2.2.4.1 Sediment

Sediment grain size, organic content, nutrient (TN, TP) and heavy metal data were each analysed using univariate general linear models (GLMs) with site as the categorical predictor variable. Where necessary, data was log-transformed to fulfil the assumptions of the model and post-hoc tests were performed to examine the directions of significant relationships. Bar graphs were produced in each case.

Sediment metal concentrations were compared against national sediment quality criteria (ANZECC, 2000). These criteria are based on statistical models of toxicity data for a wide range of contaminants, and aim to predict levels of contaminants in aquatic sediments above which adverse ecological effects may occur. The criteria are defined as Interim Sediment Quality Guideline–Low (ISQG-Low) and –high (ISQG-High) levels, which represent two distinct probability thresholds for possible and probable biological effects respectively. Where values are less than their respective ANZECC ISQG-Low values, there is low risk and no management action is required. Triggering ANZECC ISQG-High values indicates that the concentration of the contaminant is at a level where significant biological effects are expected to occur. Exceedance of the ISQG-High values suggests that adverse environmental effects are probably already occurring and are a prompt for management to address and remediate the issue.

2.2.4.2 Macroinvertebrate infauna and epifauna

The macroinvertebrate datasets were analysed using the PRIMER/PERMANOVA software package (PRIMER v6.1.16; PRIMER-E 2000; Clarke, 1993; Clarke & Warwick, 1994; Clarke & Gorley, 2006).

Univariate diversity indices (number of taxa S, total abundance N, Shannon-Wiener diversity H', and Pielou's evenness J') were calculated from the macrofauna abundance data (**Table 1**). NZ AMBI (AZTI Marine Biotic Index) scores were also calculated using NZ AMBI Biotic Index sensitivity groupings as described by Robertson *et al*., (2015).

Table 1 Description of macrofauna community characteristic indices

Index	Formula (where applicable)	Description
Number of Taxa (S)	Count of total number of different taxa identified within the *x* sample	Total number of taxa identified within a sample
Total Abundance (N)	Sum of all individual taxa abundances within the *x* sample	Total number/count of all organisms within a sample
Shannon Diversity (H')	$H' = -SUM [(p_i) \times \log_e (p_i)]$ p_i = Number of individuals of taxa i /total number of samples	A single value (log scale) that is used to describe the different types and numbers of organisms present within an assemblage. The index value increases as assemblages have greater numbers of taxa and when the numbers of individual organisms are more evenly distributed across the different taxa. Samples dominated by single taxa will have lower values towards zero.
Pielou's Evenness (J')	$J' = H'/ \log_e (S)$	A value theoretically between zero and one which indicates how evenly the number of individual organisms are distributed through the different taxa in an assemblage. High values (closer to 1) indicate an even spread amongst the taxa present, whereas a low value indicates an uneven spread or an assemblage highly dominated by only a few, or even a single taxa.

Multivariate non-metric multi-dimensional scaling (MDS) analyses were applied to visually display the differences between sites. These analyses were based on Bray-Curtis similarity matrices generated from square-root transformed abundance data.

A PERMANOVA (permutational multivariate analysis of variance) model (Anderson 2001; Anderson et al., 2008) was also applied to examine and quantify differences in communities between Site A and Site B (with 'Site' as a fixed factor).

To determine which taxa were contributing most to, or were most responsible for, any significant differences detected from the PERMANOVA analysis, the SIMPER procedure was performed. SIMPER analysis determines the contribution that each species/taxa makes to the average similarity of a group of samples.

2.2.5 Assessing estuarine condition

2.2.5.1 Condition ratings

Results were compared against ETI bands developed by Robertson *et al*., (2016b) for a number of parameters. There are four ETI bands (A, B, C, D) which span a risk gradient of Low (A) to High (D). Each band has associated quantitative values for the classification of different biological, physical and chemical parameters. The statistical outputs from Mahakipawa Estuary were compared with these bands to provide insight regarding estuarine condition and to indicate the risk of adverse ecological impacts.

2.2.5.2 Elucidating ecological relationships between different parameters

Analysing estuarine parameters separately provides important information; however, greater insights are obtained when ecological relationships between different parameters are subsequently analysed in a way which considers habitats, communities and ecological processes together. The success of ecosystem-based management is increased when a more holistic view is considered; this also provides councils with a more complete perspective when setting management priorities and goals.

Statistically, a range of analyses were performed to establish relationships between the different ecosystem components. Relationships between infauna/epifauna assemblages and the environmental data were analysed using the BEST function and DistLM analysis in PRIMER. These tools provided insight into the predictive effects of each variable on each other variable. Here, the environmental data values (TOC, TN, TN, grain size, heavy metals) were appropriately transformed and related to the invertebrate data using Euclidean distances. Vectors showing sediment predictor variables were also overlaid on the MDS plot to indicate the extent of any influence on the composition of faunal communities.

Scatterplots of different combinations of predictor and response variables were produced (e.g. mud content/TOC vs taxa richness/abundance) to further examine relationships. These provided valuable insights; for example, plotting percentage mud content vs taxa richness/abundance enabled examination of whether a ceiling factor exists, i.e. where mud content sets an upper limit to taxa richness/abundance.

3 RESULTS AND DISCUSSION

3.1 Broad-scale mapping

The substrates and vegetation present in the 137.5 ha of intertidal area within Mahakipawa Estuary, and the features present within the 234.7 ha terrestrial margin (200 m wide boundary), were mapped.

Summary maps are provided in this section for the six key broad scale features of interest: intertidal substrates, saltmarsh, macroalgae, seagrass, mollusc patches and the terrestrial margin. Tiled versions of each map, showing greater detail, are provided in **Appendix C**.

Table 2 presents a summary showing the total area, and percentage representation, of the key habitat features within the intertidal area of Mahakipawa Estuary. Vegetation was present in 25.31% of the intertidal area and nearly all of this was saltmarsh. Macroalgae and seagrass were both scarce.

Visual examples of the habitat types present in different regions of the estuary are shown in **Figure 3**. Additional georeferenced habitat photos are provided in **Appendix D**.

Table 2 Summary of the area covered by key habitat features in the intertidal area

	Area (ha)	% of Intertidal Area
Intertidal Area	**137.52**	**100**
Saltmarsh	34.70	25.23
Macroalgae	0.090	0.065
Seagrass	0.019	0.014
Mollusc patches	17.79	12.94

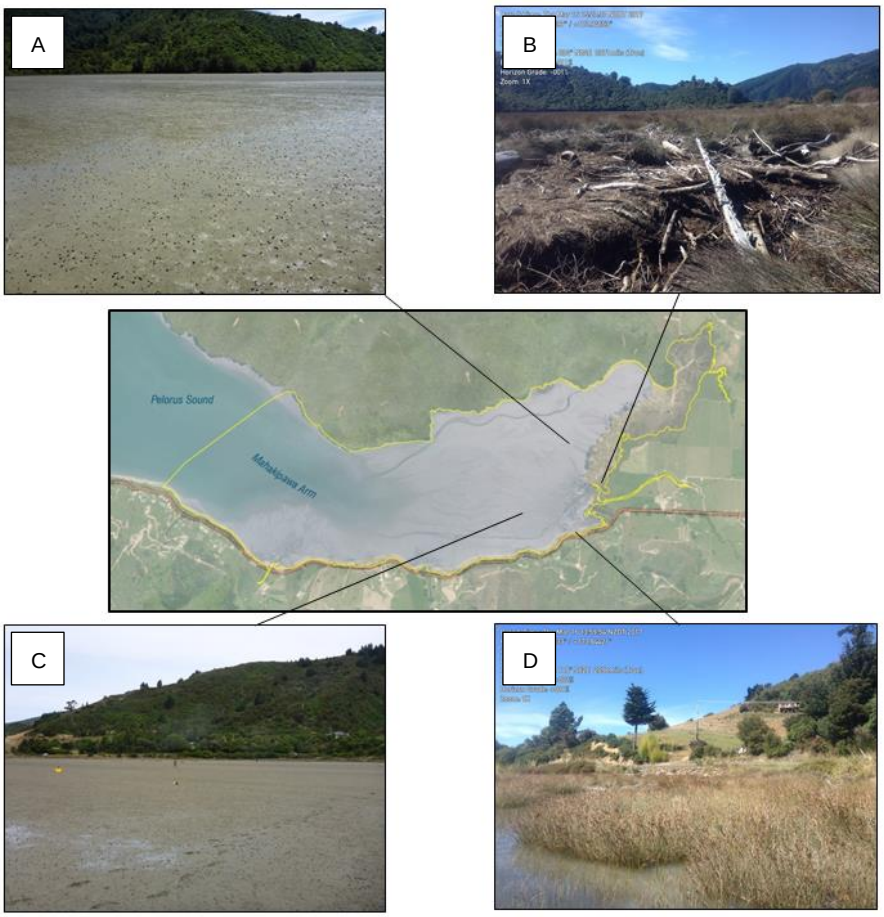


Figure 3 Representative habitats in different regions of Mahakipawa Estuary. A: Soft mud with *Amphibola crenata;* B: Wood debris and saltmarsh; C: Soft mud with forest/scrub in the distance; D: Saltmarsh.

3.1.1 Intertidal substrates and molluscs

The intertidal area was dominated by soft/very soft mud (61%) followed by firm mud (17%) (**Figure 4**; **Table 3**). Coarser sediment types, ranging from firm sandy mud to rocks, composed the remaining 22% of the intertidal area. Firmer mud generally occurred in the upper reaches of the estuary and was often found in areas where saltmarsh vegetation was present; however, soft mud dominated the area around the channels in this region. Photographic examples of soft mud habitat within Mahakipawa Estuary are shown in **Figure 5**.

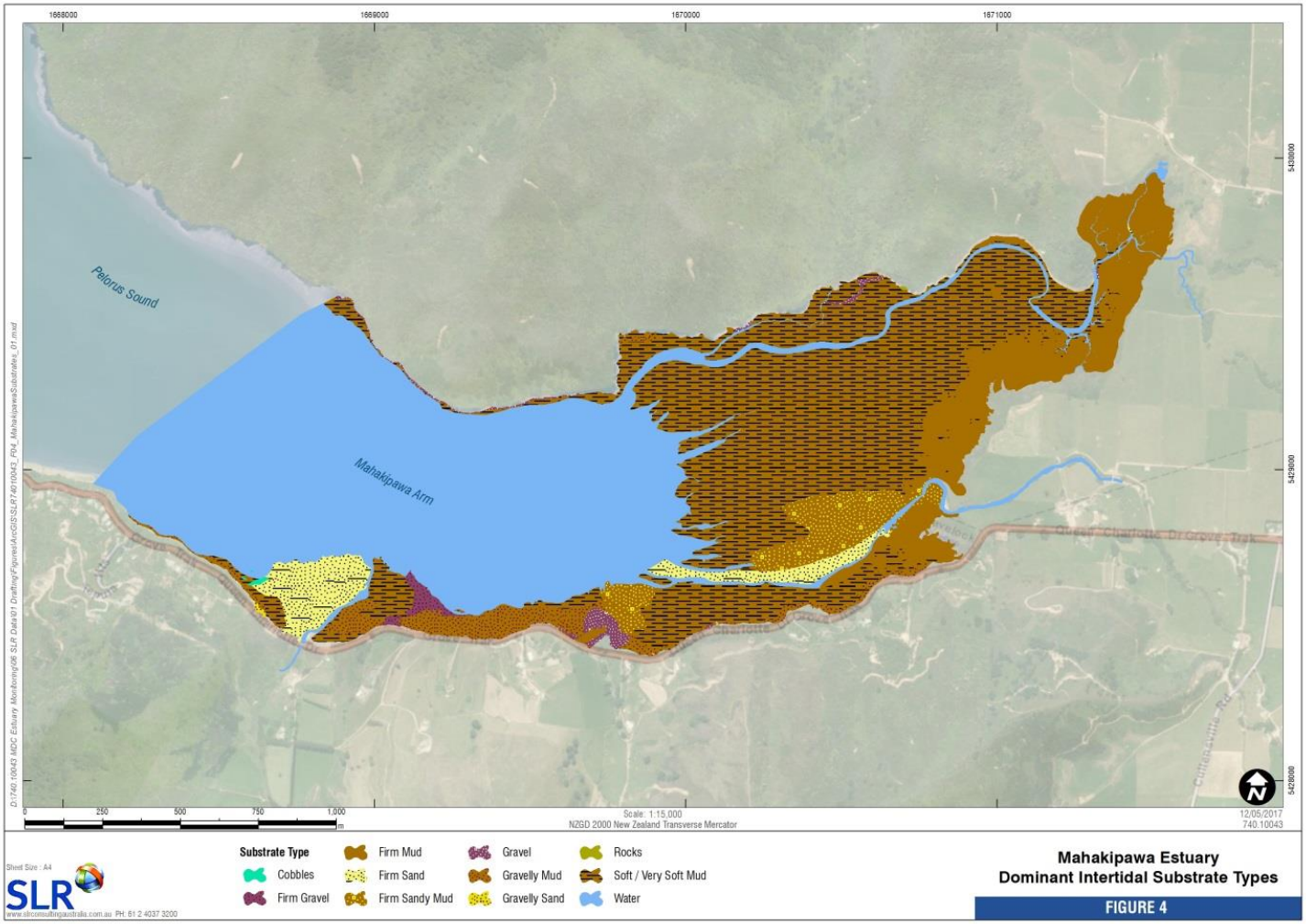


Figure 4 Substrates present in the intertidal area of Mahakipawa Estuary

Table 3 The area and percentage cover of substrates in the intertidal area of Mahakipawa Estuary

Substrate	Total area (ha)	Percentage cover
Soft/Very Soft Mud	84.56	61.49
Firm Mud	23.61	17.17
Firm Sandy Mud	9.43	6.86
Firm Sand	8.88	6.46
Gravelly Mud	7.87	5.72
Gravel	1.88	1.37
Firm Gravel	1.09	0.79
Cobbles	0.11	0.08
Gravelly Sand	0.08	0.06
Rocks	0.02	0.02
Total	**137.52**	**100.00**

Figure 5 Soft mud habitats in Mahakipawa Estuary

The proportion of the estuary covered by soft/very soft mud was high compared to some other Marlborough estuaries; for example, Shakespeare Bay (6% soft mud/sand; Berthelsen *et al*., 2016), Whangarae Estuary (9.5% soft/very soft mud; Robertson & Stevens, 2016a) and Waikawa Estuary (7.7% soft/very soft mud; Stevens & Robertson, 2016). However, the soft/very soft mud coverage in Mahakipawa Estuary was lower than that in neighbouring Havelock Estuary, where >75% of the intertidal area was reported to consist of soft/very soft mud (Stevens & Robertson, 2014).

The high proportion of soft mud in Mahakipawa Estuary indicates that there is, or has historically been, considerable sediment deposition coupled with low flushing rates and less dynamic processes.

Ecologically, sediment composition will influence infaunal and epifaunal community composition. More discussion on these issues is provided in **Sections 3.2.4 and 3.2.5**.

In accordance with Robertson *et al*., (2016b), when the percentage of the intertidal area covered in soft mud exceeds 15%, the estuary is classified as being ***high risk*** (BAND D). There is likely to be significant persistent stress on a range of aquatic organisms as well as local extinctions of keystone species and loss of ecological integrity (Robertson *et al*., 2016b).

One intertidal species that appears to be doing well is the Pacific oyster (*Crassostrea gigas*) which occurred in 17.8 ha (12.9%) of the intertidal area (**Figure 6**). This invasive species tends to favour soft mud habitats and has also been recorded in nearby Havelock Estuary where their abundance has increased over time. Pacific oysters are an important recreational food source for local iwi who harvest them from Mahakipawa Estuary.

A small patch of mussels (0.02 ha) was recorded, attached to rocks, on the northern edge of the estuary (**Figure 6**).

3.1.2 Seagrass

Seagrass plays an important role in stabilising sediments, reducing water movement, providing habitat for invertebrates, structuring benthic communities and influencing ecosystem functioning due to its high productivity. It is, however, sensitive to fine sediments, pollution, eutrophication, disturbance, poor oxygenation, high organic content of sediments and other changes in the physical environment (Waycotta *et al*., 2009).

Seagrass (*Zostera muelleri*) occurred in only one small patch in the upper estuary, on the edges of, and within, a small channel (**Figure 7**). This patch covered 0.02 ha and the cover of seagrass within this area was 60-80%. The near-absence of seagrass within Mahakipawa Estuary most likely relates to the high mud content of the sediments present in the majority of the estuary, low flushing rates and associated poor water quality (all of which are inter-linked). This lack of seagrass is a management concern and, as discussed later in the report, a management goal may be to increase its abundance within the estuary. However, this is not something to be tackled in isolation, rather it is likely to occur as a consequence of addressing the key issue of reducing the high amounts of fine sediments present within, and entering, the estuary.

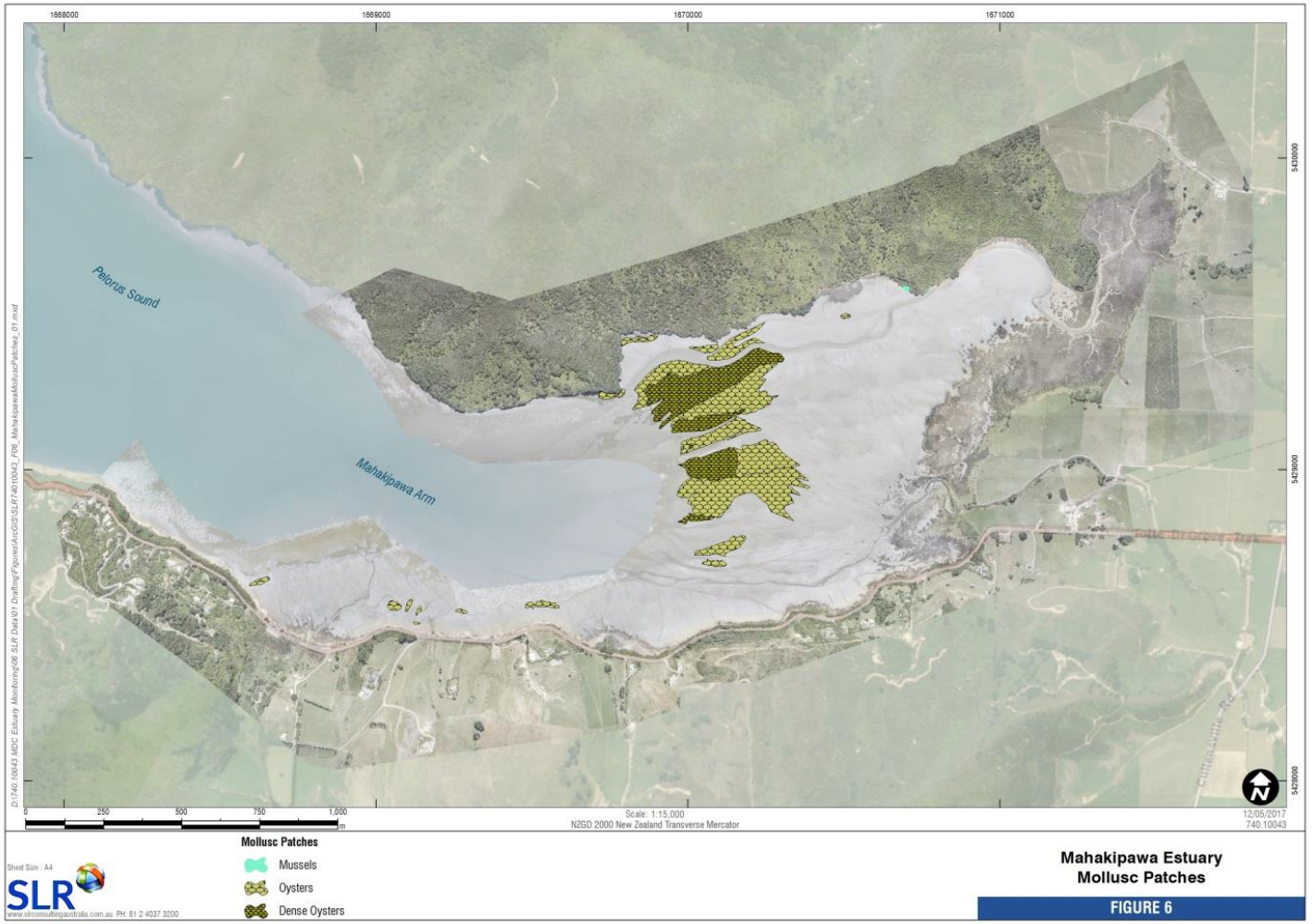


Figure 6 Mollusc presence in Mahakipawa Estuary

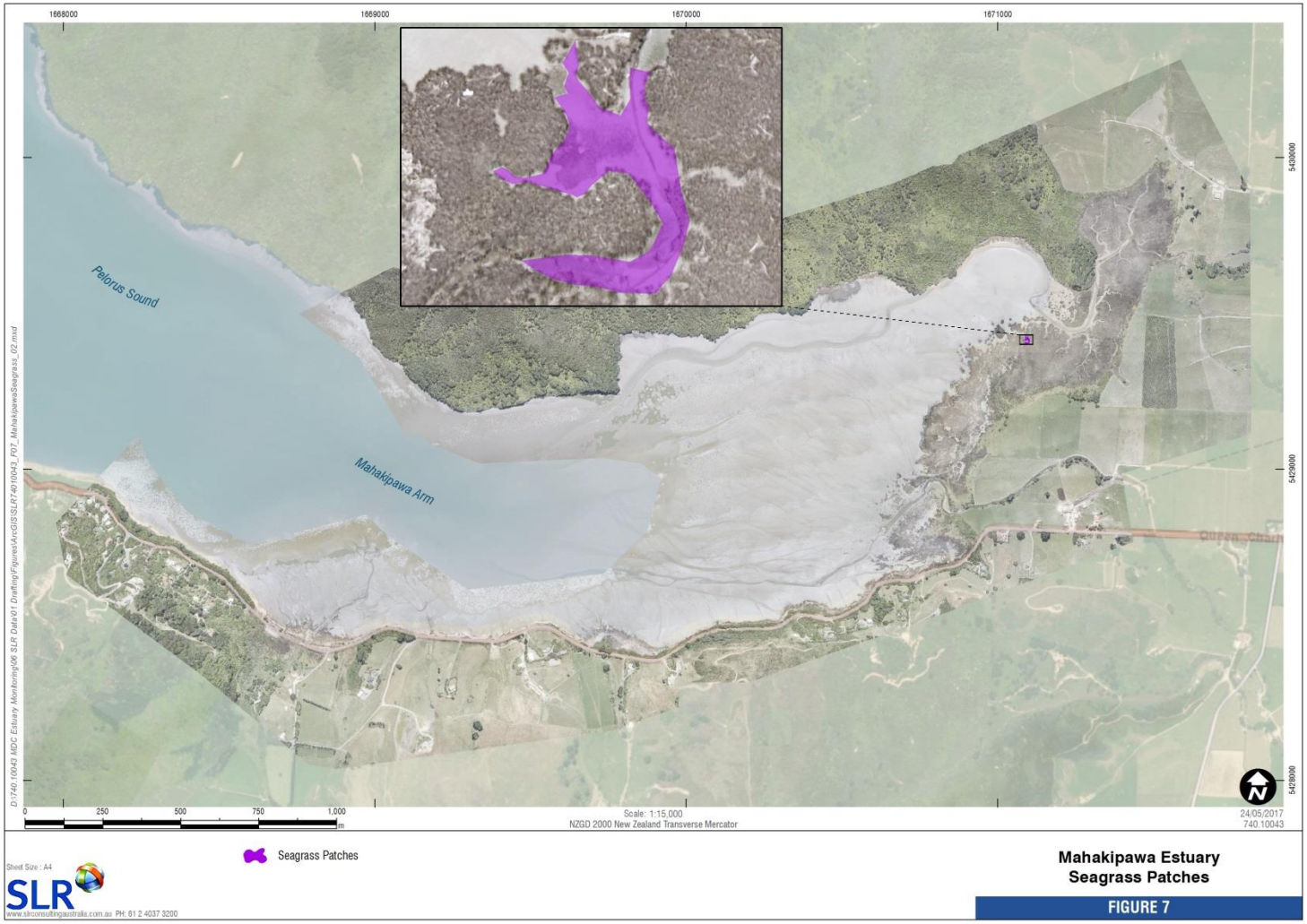


Figure 7 Seagrass areas present within Mahakipawa Estuary

3.1.3 Macroalgae

Only small areas of nuisance macroalgae were found within Mahakipawa Estuary (**Figure 8**), with macroalgae present in only 0.065% of the intertidal area. In total, three patches of macroalgae were recorded: one patch of *Ulva* sp. covering 0.07 ha, a patch of *Gracilaria chilensis* covering 0.0025 ha, and a third patch consisting of both *Ulva* sp. and *G. chilensis* covering 0.02 ha. The cover of macroalgae in all of these areas was 60-80% and all macroalgae was found attached to substrate.

The species of *Ulva* found in Mahakipawa Estuary was not the foliose *Ulva lactuca*, which is often present in New Zealand estuaries, rather the tubular *U. compressa*/*U. intestinalis* forms. These are often considered 'more favourable' as the 'sheet-like' appearance of *U. lactuca* can smoother the sediment surface and is more likely to contribute to anoxic and azoic sediments.

Macroalgae, particularly *Ulva* sp., flourishes in eutrophic conditions and its absence suggests that the estuary is not being subjected to high nutrient inputs and consequently there is little indication that it is eutrophic. This is also supported by the fine-scale monitoring nutrient results (see **Section 3.2.2.2.3**).

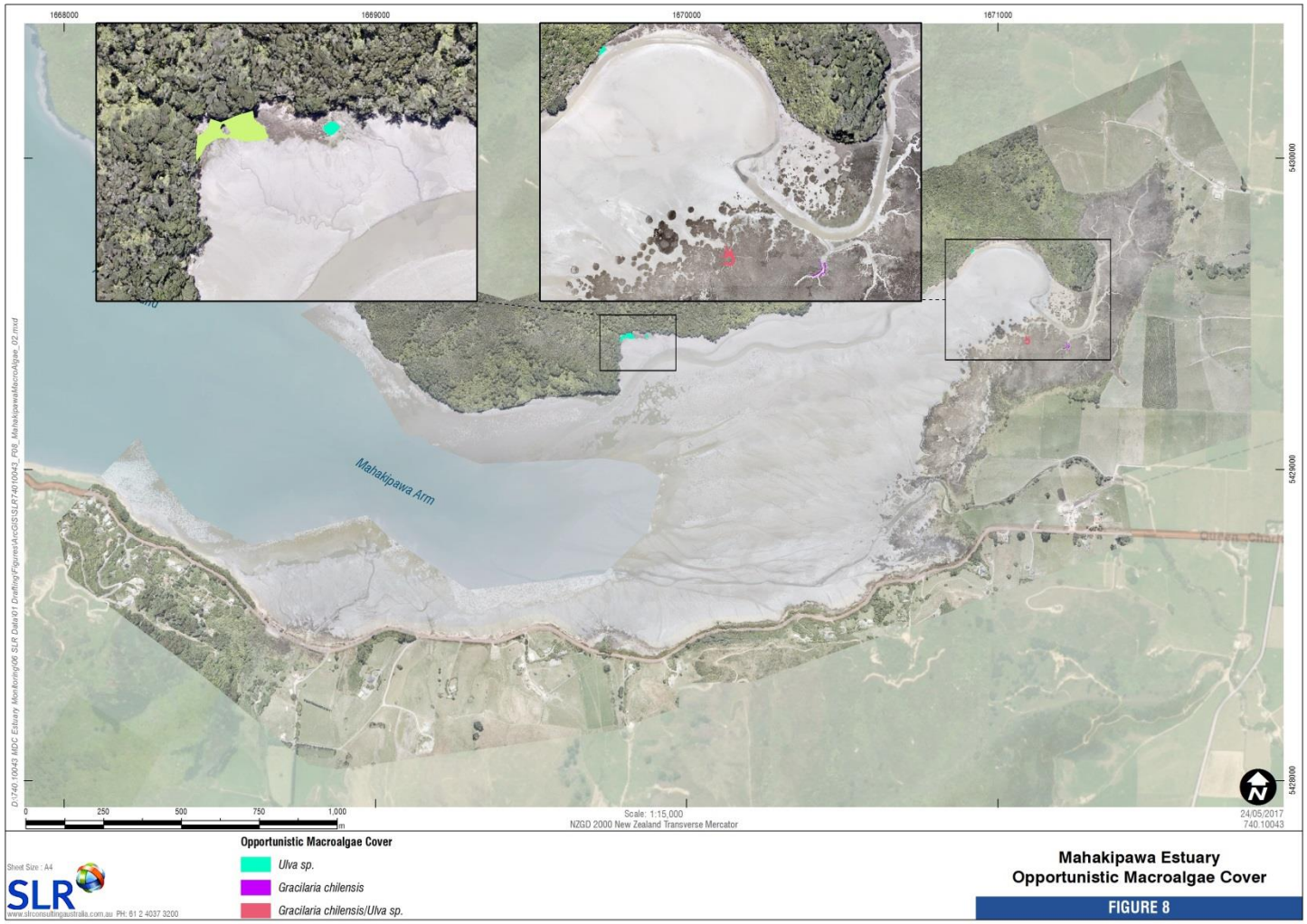


Figure 8 Macroalgae present within Mahakipawa Estuary

3.1.4 Saltmarsh

Saltmarsh vegetation occurs in the upper intertidal zone and provides important transitional habitat between an estuary and its terrestrial margin. Plants in this area are adapted to tolerate fluctuations in salinity and water level. Like seagrass habitats, saltmarsh areas are highly productive and provide food and habitat for a range of organisms, particularly juvenile fish and crustaceans. They also trap nutrients and sediments and consequently help to protect the estuary from eutrophication, sedimentation and erosion.

Saltmarsh vegetation covered 34.7 ha, and 25% of the intertidal area in Mahakipawa Estuary. Interestingly, saltmarsh coverage in Havelock Estuary was also recorded to be 25% (Stevens & Robertson, 2014) indicating similarities between these neighbouring systems. In accordance with the rating system used for Havelock Estuary (Stevens & Robertson, 2014) the high percentage of saltmarsh habitat in Mahakipawa Estuary corresponds to it having a ***low*** estuary condition risk indicator rating. The percentage of saltmarsh habitat in Mahakipawa Estuary was also higher than in other Marlborough estuaries (e.g. Shakespeare, Waikawa and Whangarae Estuaries) where broad-scale mapping has been undertaken.

Saltmarsh habitat was most abundant in the upper reaches of Mahakipawa Estuary and consisted of herbfield, rushland, reedland, tussockland, sedgeland and scrub (**Figure 9**). The contribution of each of these to the total area covered by saltmarsh is shown in **Table 4**. A comprehensive list of the saltmarsh species comprising each of these categories, and the area and percentage cover of specific saltmarsh species, is provided in **Table 5**.

Rushland was the dominant saltmarsh vegetation occurring within the estuary, contributing to almost 70% of the total saltmarsh cover. The searush *Juncus kraussii* contributed to 57% of the total area covered by rushland in the estuary, followed by areas where *both J. krausii* and *Leptocarpus similis* (jointed wirerush) occurred, which made up an additional 41% of total rushland area.

Table 4 The area and percentage cover of the different saltmarsh habitats within Mahakipawa Estuary

Saltmarsh	Area (ha)	% Cover
Rushland	24.14	69.59
Rushland/Reedland/Scrub	2.02	5.81
Scrub/Rushland	1.88	5.41
Reedland/Scrub/Forest	1.78	5.13
Rushland/Reedland	1.67	4.83
Herbfield/Rushland	1.43	4.13
Herbfield	0.79	2.26
Rushland/Sedgeland	0.21	0.62
Scrub/Reedland	0.21	0.61
Reedland/Scrub/Rushland	0.21	0.59
Scrub	0.16	0.46
Reedland	0.12	0.33
Sedgeland	0.06	0.16
Reedland/Scrub/Tussockland	0.01	0.04
Reedland/Tussockland	0.01	0.02
Total	**34.69**	**100**

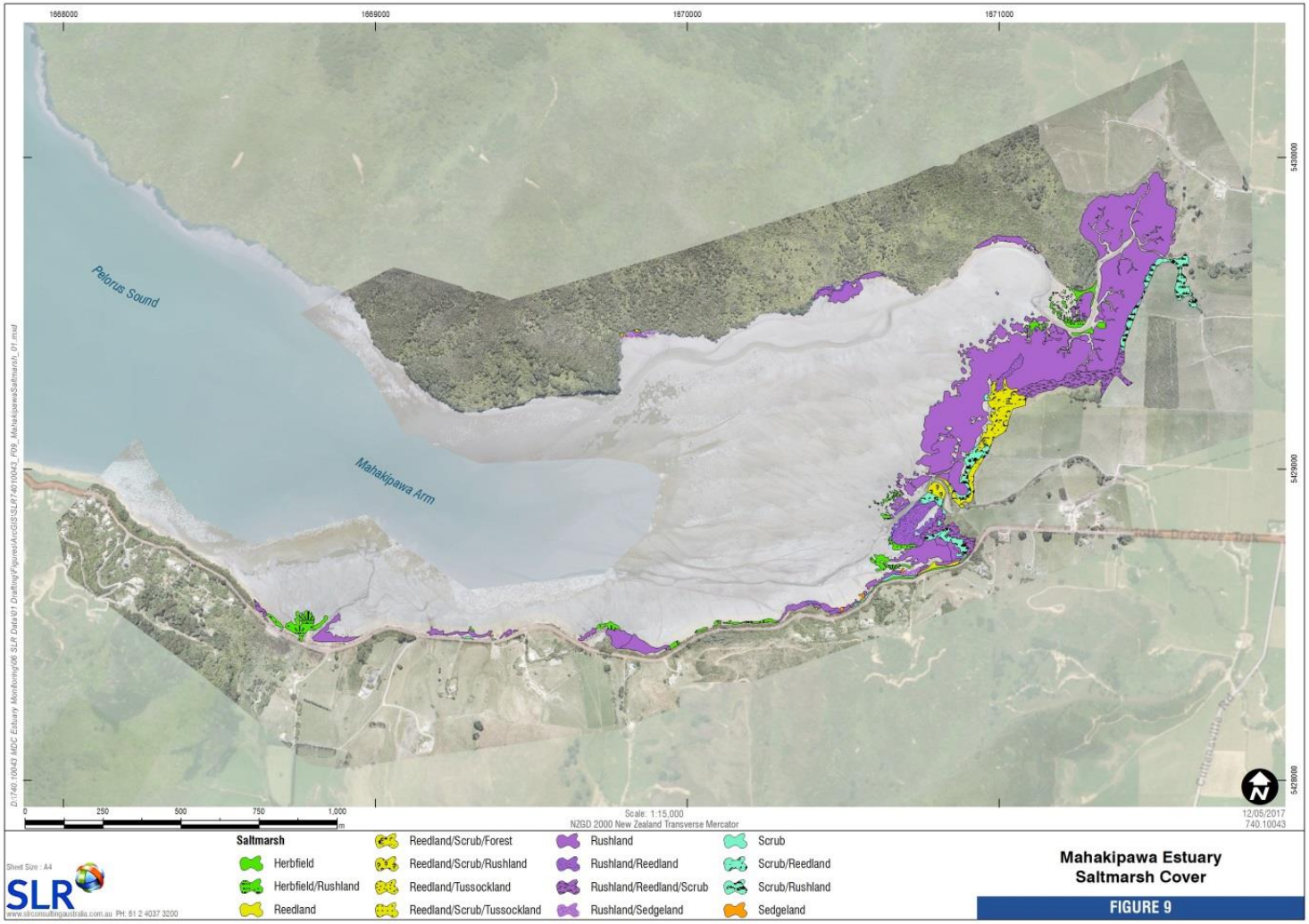


Figure 9 Saltmarsh vegetation within Mahakipawa Estuary

Table 5 The area and percentage cover of individual saltmarsh species in Mahakipawa Estuary

Saltmarsh Type	Taxa	Common Name	Area (ha)	Total Area Covered by Saltmarsh Type (ha)	Contribution to Saltmarsh Type (%)	Contribution to Total Saltmarsh Area (%)
Herbfield	*Samolus repens*	Primrose	0.72		91.60	
	Selliera radicans	Remuremu	0.07	**0.79**	8.40	**2.27**
Herbfield/Rushland	*Samolus repen/Juncus kraussii*	Primrose/Searush	1.43	**1.43**	100.00	**4.15**
Reedland	*Typha orientalis*	Raupo	0.11		91.45	
	Glyceria maxima	Reed sweetgrass	0.01	**0.12**	8.55	**0.34**
Reedland/Scrub/Forest	*Glyceria maxima/Plagianthus divaricatus*/forest	Reed sweetgrass/Saltmarsh ribbonwood/Forest	1.78	**1.78**	100.00	**5.15**
Reedland/Scrub/Rushland	*Glyceria maxima*/Ulex europaeus/*Leptocarpus similis*/*Calluna vulgaris*	Reed sweetgrass/Gorse/Jointed wirerush/Heather	0.21	**0.21**	100.00	**0.59**
Reedland/Scrub/Tussockland	*Glyceria maxima/Ulex europaeus/Phormium tenax*	Reed sweetgrass/Gorse/New Zealand Flax	0.01	**0.01**	100.00	**0.04**
Reedland/Tussockland	*Typha orientalis/Phormium tenax*	Raupo/New Zealand Flax	0.01	**0.01**	100.00	**0.02**
Rushland	*Juncus kraussii*	Searush	13.72		56.87	
	Juncus kraussii/Leptocarpus similis	Searush/Jointed wirerush	9.93		41.18	
	Leptocarpus similis	Jointed wirerush	0.37		1.54	
	Juncus pallidus	Pale rush	0.10	**24.12**	0.41	**69.72**
Rushland/Reedland	*Juncus kraussii/Glyceria maxima*	Searush/Reed sweetgrass	1.63		97.36	
	Leptocarpus similis/Juncus kraussii/Glyceria maxima	Jointed wirerush/Searush/Reed sweetgrass	0.04	**1.67**	2.64	**4.84**
Rushland/Reedland/Scrub	*Leptocarpus similis/Glyceria maxima/Plagianthus divaricatus*	Jointed wirerush/Reed sweetgrass/Saltmarsh ribbonwood	1.94	**1.94**	100.00	**5.61**
Rushland/Sedgeland	*Juncus kraussii/Leptocarpus similis/Schoenoplectus pungens*	Searush/Jointed wirerush/Three-square	0.12		56.11	
	Juncus kraussii/Leptocarpus similis	Searush/Jointed wirerush	0.06		26.40	
	Leptocarpus similis/Schoenoplectus pungens/Juncus kraussii/Isolepis cernua	Jointed wirerush/Three-square/Searush/Slender clubrush	0.04	**0.21**	17.49	**0.62**
Scrub	*Plagianthus divaricatus*	Saltmarsh ribbonwood	0.09		53.88	
	Plagianthus divaricatus/Muehlenbeckia complexa	Saltmarsh ribbonwood/Maidenhair vine	0.06		34.60	
	Ulex europaeus	Gorse	0.02	**0.16**	11.52	**0.46**
Scrub/Reedland	*Glyceria maxima/Ulex europaeus/Plagianthus divaricatus*	Reed sweetgrass/Gorse/Saltmarsh ribbonwood	0.19		90.44	
	Ulex europaeus/Glyceria maxima	Gorse/Reed sweetgrass	0.02	**0.21**	9.56	**0.61**
Scrub/Rushland	*Plagianthus divaricatus/Leptocarpus similis*	Saltmarsh ribbonwood/Jointed wirerush	1.30		69.32	
	Plagianthus divaricatus/Leptocarpus similis/Juncus kraussii	Saltmarsh ribbonwood/Jointed wirerush/Searush	0.51		27.12	
	Plagianthus divaricatus/Juncus kraussii	Saltmarsh ribbonwood/Searush	0.07	**1.88**	3.56	**5.43**
Sedgeland	*Schoenoplectus pungens*	Three-square	0.03		55.92	
	Schoenoplectus pungens/Juncus kraussii	Three-square/Searush	0.02	**0.06**	44.08	**0.16**
Total				**34.59**		**100**

3.1.5 Terrestrial margin

The terrestrial margin was dominated by grassland (48.3%) and forest/scrub (47.4%) habitat types (**Figure 10**). These vegetated habitats covered 224.6 ha within the 200 m terrestrial margin. A breakdown of all the features occurring within the terrestrial margin is shown in **Table 6**.

The northern side of the estuary was entirely forest/scrub habitat which consisted of a mix of native and exotic plants. Grassland habitat occurred on the southern and eastern boundaries of the estuary. Buildings, generally residential houses, were present mainly on the southern side of the estuary, accessible from Queen Charlotte Drive. An area of wood debris occurred also on the southern edge between the road and estuarine intertidal habitat.

Vegetated margin habitats are important as they help to protect estuaries, particularly with regards to assimilating sediments and consequently reducing the amount of fine particles entering the estuary. Although almost 95% of the terrestrial margin surrounding Mahakipawa Estuary was vegetated (classifying it as ***Low Risk*** (Stevens & Robertson, 2014)) it must be acknowledged that there are differences in the functional importance of the densely vegetated scrub/forest areas on the northern and south-western edges of the estuary, and the grassland/pasture areas on the southern edge and in the upper reaches. As most of the inputs into the estuary will be occurring via the rivers in the upper reaches, it is more optimal to have dense areas of forest/scrub vegetation in these areas as grassland here will not be as effective in filtering sediments/nutrients and preventing them from entering the estuary. However, having any sort of vegetation present in the terrestrial margin is much more beneficial ecologically than having an unvegetated margin habitat.

Table 6 The area and percentage cover of the features occurring within the 200 m terrestrial margin

Terrestrial Margin	Area (ha)	% Cover
Grassland	113.30	48.28
Forest / Scrub	111.34	47.44
Road	8.21	3.50
Building	1.45	0.62
Wood Debris	0.20	0.083
Farm Dam	0.11	0.047
Carpark	0.061	0.026
Concrete Wall	0.010	0.004
Total	**234.67**	**100**

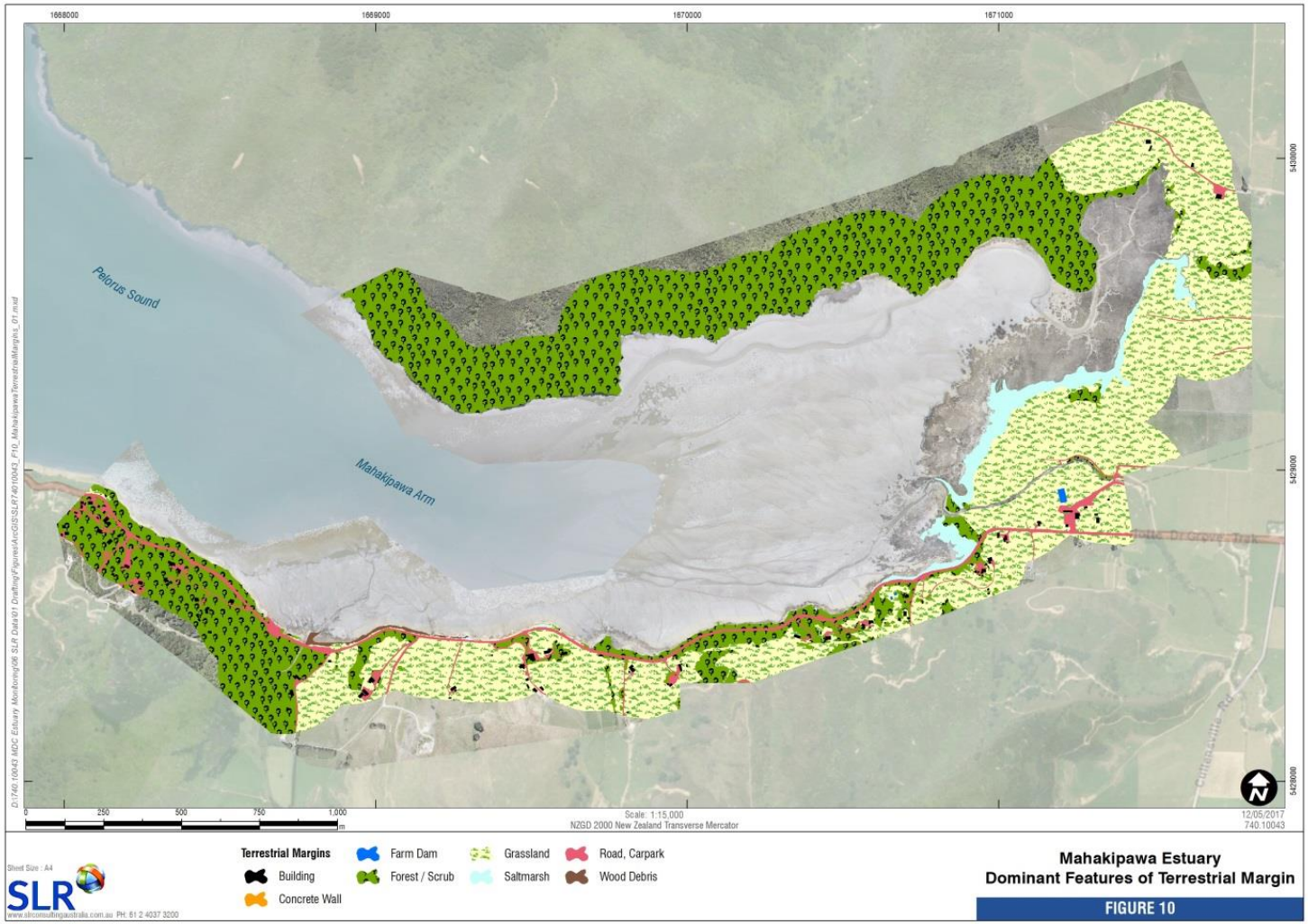


Figure 10 Terrestrial margin habitats around Mahakipawa Estuary

3.2 Fine-scale monitoring

3.2.1 Salinity

Interstitial water salinity was 13.2 and 15.3 ppt at Site A and Site B respectively. These values indicate the water at these sites is likely to be brackish (full seawater has a reading of approximately 35 ppt). The slightly lower measurement at Site A probably reflects the greater influence of freshwater at this site from riverine inputs at the head of the estuary.

These results are lower than those recorded in recent fine-scale monitoring surveys in Havelock Estuary (Robertson & Robertson, 2014) and other Marlborough estuaries, suggesting increased freshwater influence to Mahakipawa Estuary. The NEMP recommends that salinity be over 20 ppt in order to compare fine-scale monitoring results among estuaries. This is because of the influence that salinity can have on estuarine ecology. Due to the low salinity measurements in Mahakipawa Estuary, comparisons throughout this section must therefore be interpreted with caution.

3.2.2 Sediments

3.2.2.1 Sediment oxygenation

Sediment oxygenation can be quantified by measuring the apparent Redox Potential Discontinuity depth (aRPD), a recognisable division zone sometimes occurring between the surface oxidised (aerobic) sediments and the underlying sediments that have reduced oxygen levels. There is often a distinct colour change at the aRPD. Where the aRPD is at or near the surface, sediments are likely to be in a poor condition, supporting fewer taxa. This usually occurs in eutrophic or polluted areas, or where sediments have been smothered, for example, by dense macroalgal cover.

Photographs of the sediment cores collected at each site are provided in **Appendix E**. At Site A, a medium – strong anoxic odour was recorded. The average redox depth at this site was 2.7 cm; the top layer of sediment was typically light brown coloured very soft mud which then became anoxic beyond the aRPD. Other than in Core 1, where a dead bivalve was present at a depth of 6-8 cm, there was no other evidence of any live or dead biological material in the cores. The sediment texture was a fairly uniform soft fine-grained mud often with a clayey consistency.

No odour could be detected from the sediment at Site B. Overall there was a general trend of light brown sediment occurring in the top ~7-10 cm, followed by an anoxic black layer. However, the presence of the anoxic layer was often difficult to detect and/or classify as it did not generally occur as a distinct layer, rather there was mixing of darker and lighter sediments before the deeper sediments became progressively darker. Sediments at this site were coarser (sandier) than those at Site A and layers of gravel, shells and pieces of woody debris were present in some cores.

The depth of the anoxic layers at Site A and Site B are likely to represent ***low ecological risk***, based on Hargrave *et al.,* (2008).

Figure 11 shows the redox potential (mV) in the upper 3 cm of sediment at each site. Based on risk indicator ratings reported in Robertson *et al*., (2016b) (and based on Hargrave *et al*., 2008), these results indicate ***minor stress on sensitive organisms (BAND B)*** at Site A and ***no stress on any aquatic organisms (BAND A)*** at Site B.

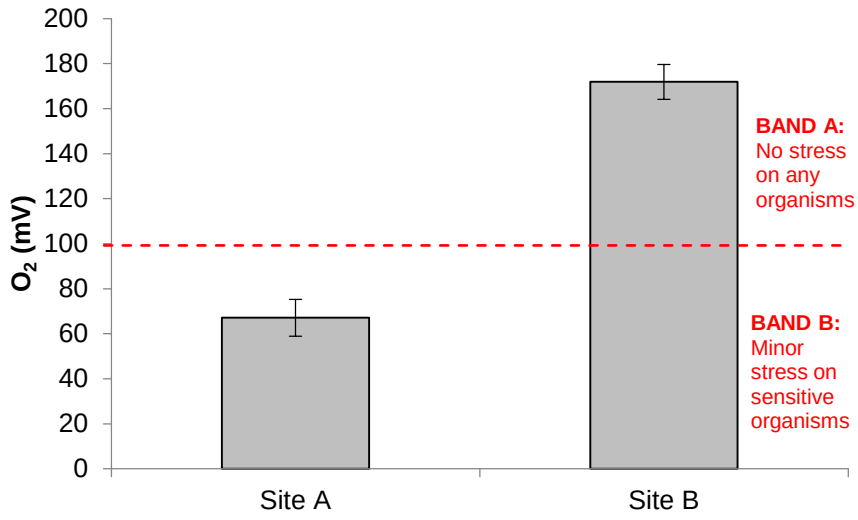


Figure 11 Average (±SE) oxygen concentration in sediments at Site A and Site B in Mahakipawa Estuary. Red dashed line shows the boundary between Band A (>+100) and Band B (-50 to +100) ETI bands. N=10.

3.2.2.2 Sediment physical and chemical properties

3.2.2.2.1 Grain size

Texture, i.e. grain size, is the most fundamental physical property of sediment. It is an important parameter to measure because natural processes and anthropogenic activities can change the grain size composition of sediment. Grain size data can also be analysed in combination with other data (e.g. benthic community composition) to gain insights into the mechanisms facilitating temporal and spatial variability.

The grain size composition of a site ('how muddy it is') is often related to circulation patterns, the amount of circulation, wave and current action and how exposed and developed the area is. Muddy sediments, which often dominate in eutrophic and more degraded estuaries, will typically be 'sticky', cohesive and more tightly packed than sandier/coarser sediments. This has implications for the recovery time of contaminated sediments.

The grain size composition of the sediments varied between sites (**Figure 12)**. Muddy sediments (<63 µm) had a greater representation at Site A, with mud contributing to 65% of the total sediment composition, compared to 46% at Site B. The very fine sand fraction of the sediment at Site B was, however, larger than at Site A (35% versus 22%). Eighteen percent of Site B sediment was composed of grain sizes >125 µm (i.e. fine sand and larger) compared to 12.7% at Site A. The high mud content at both sites classified them both as ***BAND D*** (>25%) in accordance with the ETI band thresholds proposed by Robertson *et al.,* (2016b). These authors describe BAND D as where there is '*significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity, especially if nutrient loads excessive'.* The mud content at Mahakipawa Estuary was higher than that reported at Havelock Estuary in the 2014 fine-scale monitoring survey (Robertson & Robertson, 2014).

Site A is located in a natural deposition zone where it receives fine grained sediments via riverine inputs. It is also exposed to less dynamic processes, such as reduced tidal flows and flushing, meaning that less sediment is transported away from this site. In comparison, Site B is situated in the more energetic mid-low intertidal zone; this site also receives less sediment from the terrestrial environment. Mahakipawa Estuary is located in a somewhat developed catchment and this will also be contributing to the high mud content occurring within the sediments.

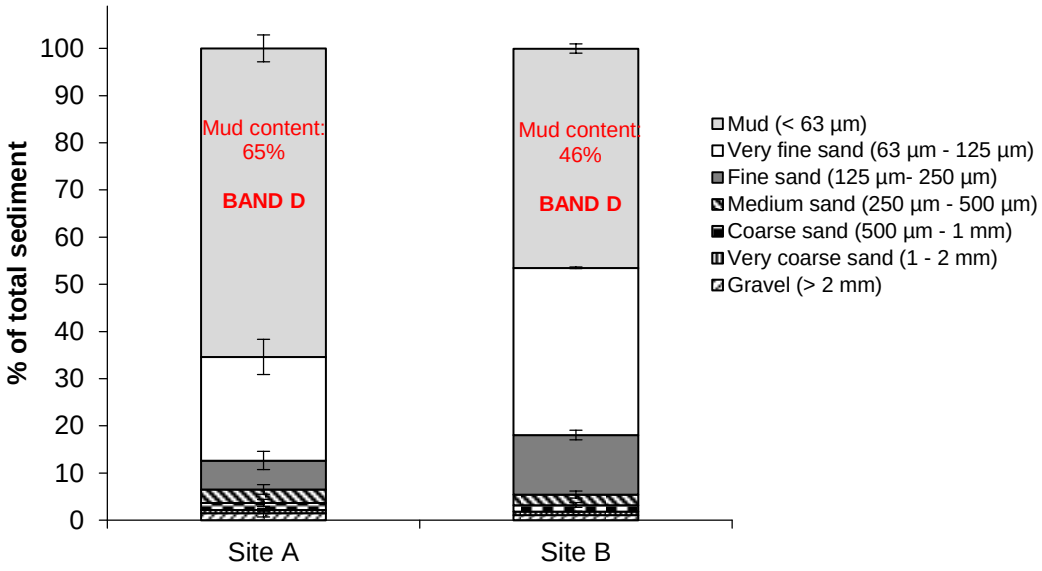


Figure 12 Average (±SE) sediment grain size composition at Site A and Site B in Mahakipawa Estuary ranging from finest sediments (top bar) to coarsest sediments (bottom bar). N=3.

3.2.2.2.2 Total organic carbon (TOC)

Total organic carbon (TOC), a proxy for sediment organic content, represents a measure of the relative state of organic enrichment in benthic habitats and may reflect the macrofauna and organic detritus present. It is an important parameter to measure because increases in organic matter production and retention can cause excessive organic enrichment (i.e. high levels of organic content) of benthic sediment, which may result in hypoxic (low oxygen) or anoxic (oxygen depleted) conditions. This can adversely affect benthic communities by reducing diversity and increasing the abundance of opportunistic species, as well as altering trophic relationships. Low tidal flows and poor circulation often lead to increased TOC levels. Additionally, in areas where macroalgal cover is, or has historically been high, TOC will be elevated.

Total organic carbon was higher in the sediments at Site A than at Site B (**Figure 13**). This probably reflects the increased amount of organic matter present in the upper estuary in the form of debris/detritus which has broken down and become incorporated in the sediment. This site is closer to the head of the estuary where more organic matter is likely to enter through terrestrial runoff. As there was little evidence of macroalgae in the estuary, it is unlikely that this is contributing to the increased organic carbon at Site A (although any historical presence of macroalgae may have become incorporated into the sediment).

The results for Site A and Site B showed TOC levels were indicative of ***minor stress on sensitive aquatic organisms (BAND B)*** and ***no stress on any organisms (BAND A)*** respectively, in accordance with Robertson *et al.,* (2016b). Results at Mahakipawa Estuary in 2017 were similar to those at Havelock Estuary recorded in the 2014 survey (Robertson & Robertson, 2014).

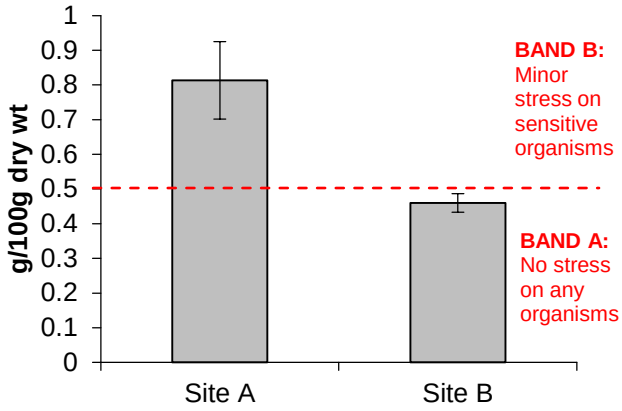


Figure 13 Average (±SE) total organic content at Site A and Site B in Mahakipawa Estuary. Red dashed line shows the boundary between BAND A (<0.5%) and BAND B (0.5 – 1%) ETI bands. N=3.

3.2.2.2.3 Nutrients: total nitrogen (TN) total phosphorus (TP)

Total nitrogen levels at Sites A and B were classified as causing ***minor stress on sensitive aquatic organisms (BAND B)*** (Robertson et al., 2016b; **Figure 14**) and were similar to levels found in Havelock Estuary in 2014 and other Marlborough estuaries. ETI bands have not yet been developed for total phosphorus (**Figure 15**); however, the values in Mahakipawa Estuary could be considered as moderate – high when compared to other Marlborough estuaries. Total phosphorus concentrations at Mahakipawa Estuary were higher than levels found in Havelock Estuary in 2014 (Robertson & Robertson, 2014).

Overall the nutrient results suggest that nutrient loading to Mahakipawa Estuary may be causing low – moderate stress on sensitive organisms. Nitrogen concentrations indicate that eutrophication is unlikely to be having an adverse impact on the estuary; however, phosphorus levels were considered to be moderate-high, based on the risk rating categories applied for Havelock Estuary by Robertson & Robertson (2014). Although this may indicate that phosphorus is having adverse effects on the estuarine ecology (for example, contributing to the reduced oxygen availability within the sediments and/or influencing macroinvertebrate community composition), it is important to note that nitrogen, not phosphorus, is usually the primary cause of eutrophication in estuaries (Howarth & Marino, 2006). Furthermore, there is no evidence of algal blooms in Mahakipawa Estuary, one of the key indicators of eutrophication, and as such, the current phosphorus levels are unlikely to be of concern.

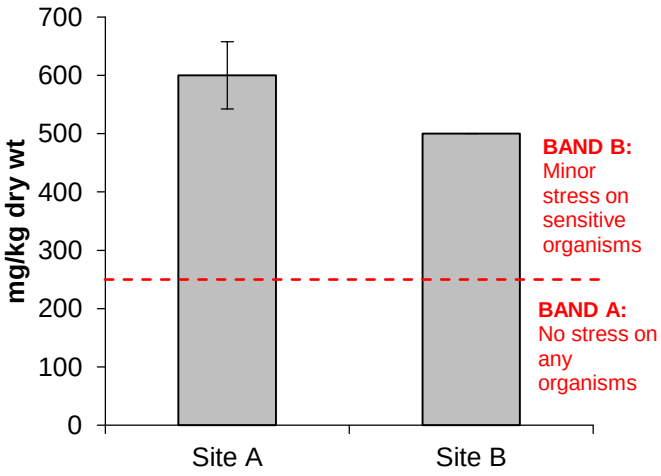


Figure 14 Average (±SE) total nitrogen concentrations at Site A and Site B in Mahakipawa Estuary. N=3.

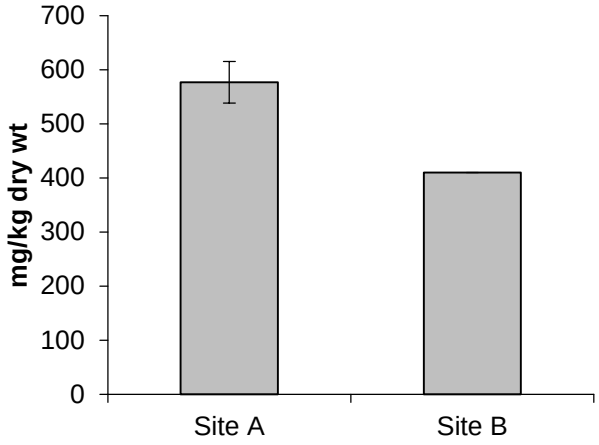


Figure 15 Average (±SE) total phosphorus concentrations at Site A and Site B in Mahakipawa Estuary. N=3.

3.2.2.2.4 Contaminants

Heavy metals/metalloids

Although average heavy metal/metalloid concentrations were higher at Site A than at Site B for all of the metals tested (**Figure 16**), none of these differences were statistically significant. This reflects the variability in concentrations of each metal/metalloid within each site being greater than the difference among sites.

Concentrations of all metals/metalloids were well below ISQG-Low trigger levels, with the exception of nickel at Site A. Here, although average nickel concentrations remained below ISQG-Low trigger levels, they were close to the low limit. Elevated nickel concentrations at Havelock Estuary (Robertson & Robertson, 2014) and Whangarae Estuary (Robertson & Stevens, 2016) in the 2014 and 2016 fine-scale monitoring surveys respectively, have been attributed to nickel run-off from the catchment, which is thought to be geologically enriched in this metal (Rattenbury *et al.,* 1998).

There was no evidence to suggest that any of the metals tested were present at high enough levels to pose any ecological toxicity effects in Mahakipawa Estuary.

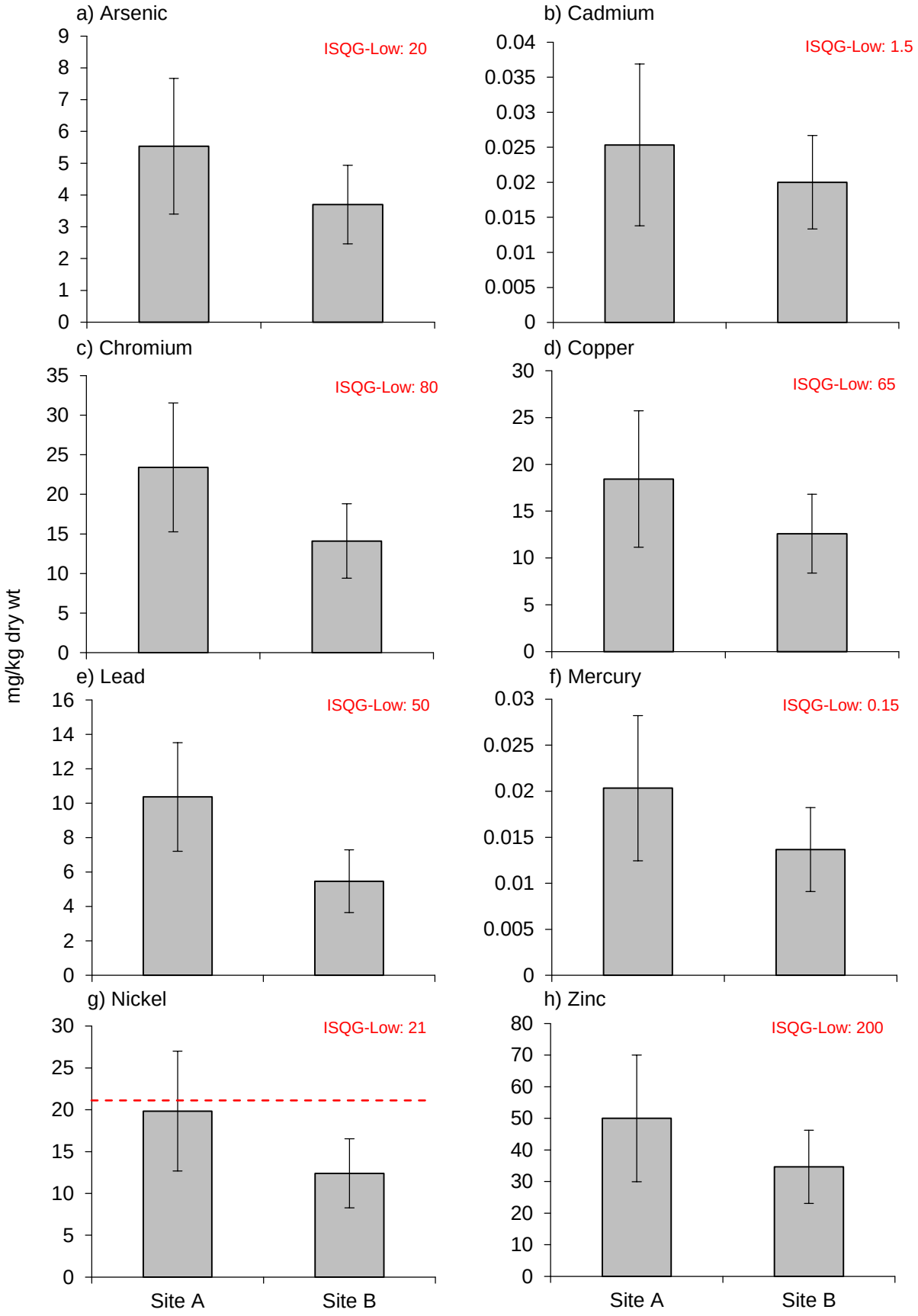


Figure 16 Average (±SE) heavy metal concentrations at Site A and Site B in Mahakipawa Estuary. N=3.

Semi-volatile organic compounds

The concentrations of over 70 semi-volatile organic compounds and organotins were analysed in sediment samples from Site A and Site B. In all cases, concentrations were found to be below the analytical detection limits and did not exceed ANZECC guidelines (where guideline values were available). This suggests that contamination levels within the estuary were low and are unlikely to be having any adverse ecological effects. A full list of results is provided in **Appendix F**.

3.2.3 Marine plants

The term 'marine plants' used in this report includes macroalgae, microalgae and seagrass.

Benthic microalgae are microscopic unicellular protists that occur in the top few millimetres of sediment in soft-sediment environments, particularly estuaries. They are important primary producers and can account for >50% of primary production; they can also increase the cohesiveness of surface sediments and play an important role in influencing both the micro-environment and ecosystem functioning through the uptake of sediment and water-column nutrients (Underwood & Kromkamp, 1999).

Ulva sp. and *Gracilaria chilensis* are common New Zealand estuarine macroalgae. They often proliferate during summer months due to increased irradiance and warmer seawater temperatures which facilitate the germination and growth of propagules, resulting in a higher biomass.

The presence of seagrass is often indicative of a more 'pristine' (or less eutrophic) area as seagrass is generally sensitive to pollution, sedimentation, disturbance and other changes in the physical environment. High levels of nutrient loading also reduce seagrass growth rates and survival.

No microalgae, macroalgae or seagrass occurred at either Site A or Site B in Mahakipawa Estuary. The absence of nuisance macroalgae is positive as it indicates that the estuary is not subject to excessive nutrient inputs. However, the absence of seagrass suggests that the sediment conditions are not favourable enough for this species to survive.

3.2.4 Epifauna

Epifauna are animals living on the sediment surface, or attached to other organisms or substrates on the sediment surface. Different types of macroinvertebrates tolerate different environmental conditions and levels of pollution/disturbance; examining the abundance and diversity of benthic macroinvertebrate communities in an aquatic habitat provides an indication of its condition.

Only four epifauna taxa were recorded at the two sites sampled in Mahakipawa Estuary. Photographs of all epifauna quadrats are provided in **Appendix G**. At both sites, the mudsnail *Amphibola crenata* was dominant, averaging 29.5 and 48.1 individuals at Site A and Site B respectively (**Figure 17**). *Amphibola crenata* is a pulmonate gastropod endemic to New Zealand (Little *et al*., 1985). Larvae of this species spend several weeks at sea before settling in the upper reaches of estuaries and other soft sediment habitats (Pilkington & Pilkington, 1982). Adults can be abundant on both mud and sand flats in inlet, estuarine, salt marsh and mangrove habitats where they deposit feed on exposed sediment surface organic matter during low tide.

Amphibola crenata can be classified as *Abundant* at both of the Mahakipawa Estuary sites, based on SACFOR Density Scales (Hiscock, 1996; Hiscock, 1998). In the 2014 fine-scale monitoring survey of Havelock Estuary, *A. crenata* was also found to be *Abundant* at each site sampled (Robertson & Robertson, 2014). *Amphibola crenata* is classified into NZ AMBI Group 3 (Robertson *et al*., 2015), where it is described as being widely tolerant of mud and organic enrichment.

The low epifaunal taxa richness at Mahakipawa Estuary suggests that the conditions (e.g. sediment mud content) are not suitable for many other epifuanal taxa (e.g. *Cominella glandiformis*, *Zeacummantus* sp., *Notoacmea helmsi*, *Diloma subrostrata* etc) which are often present in New Zealand estuaries.

In addition to *A. crenata*, one tunnelling mud crab, *Austrohelice crassa*, was recorded at Site A, and one amphipod was found at Site B. Crab burrows were counted, however their presence was not used to provide a direct measure of crab abundance but rather to provide an indication of the relative density between the two sites.

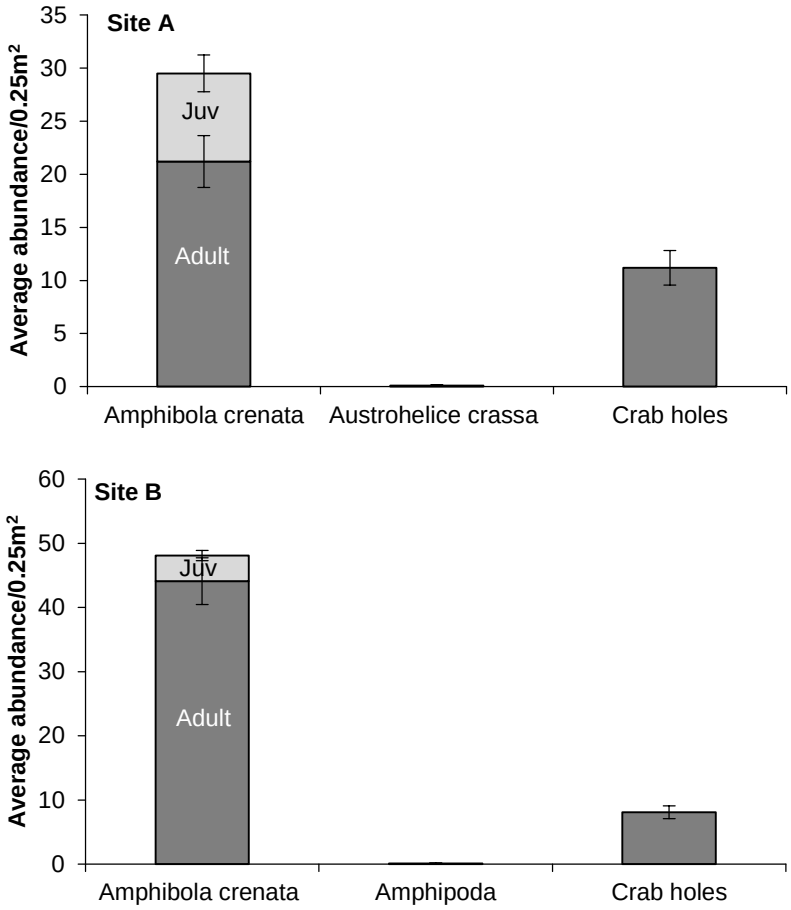


Figure 17 Average abundance (±SE) of epifauna taxa found at Site A and Site B in Mahakipawa Estuary. N=10.

3.2.5 Infauna

Infauna are benthic macroinvertebrates (>0.5 mm) occurring within the sediment. They can provide important information on habitat quality and environmental conditions, particularly relating to changes in nutrient concentrations and sediment contamination and deposition. This is because a number of taxa exhibit different levels of resilience and sensitivity to environmental conditions/stressors and thus fluctuations in their abundance can be linked to the presence of a stressor. As such, determining community taxonomic composition and abundance of benthic macroinvertebrate communities can provide useful information regarding the impact of anthropogenic activities or natural changes on the ecosystem.

Overall, 22 infauna taxa were found at Site A and 21 taxa at Site B. The proportion of the community consisting of each taxonomic group varied by site and is shown in **Figure 18**. At both sites, bivalves were the most prevalent taxonomic group; however, bivalves contributed to almost half (47%) of the community at Site A versus just over a quarter (27%) of the community at Site B. The abundance of polychaetes at Site B was similar to that of bivalves at this site, whereas polychaetes were less prevalent within the community at Site A. The representation of gastropods and amphipods was similar among sites.

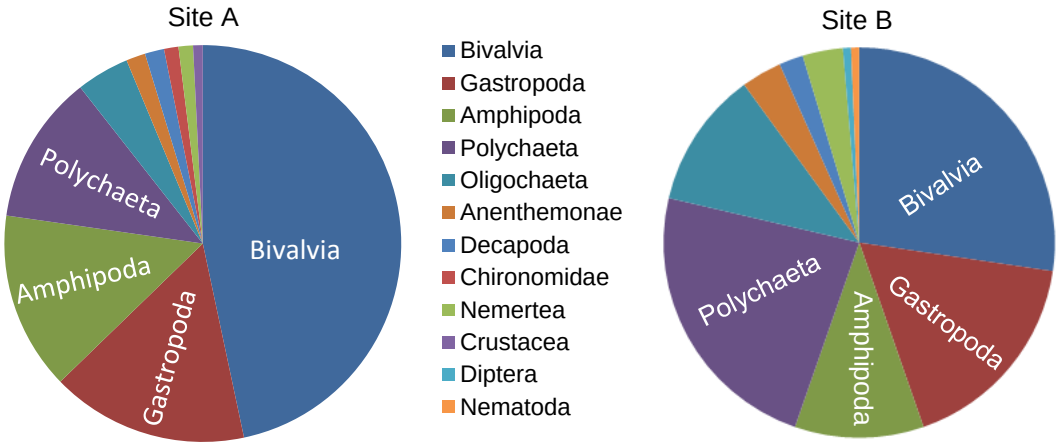


Figure 18 Proportion of infauna taxa belonging to each taxonomic group across all samples collected at Site A and Site B at Mahakipawa Estuary. N=10.

The five most numerically abundant taxa for each site during the 2017 survey are listed in **Table 7** and **Table 8** shows the general classification and trophic group of each of the taxa reported in these tables. Photographs of some of the most abundant taxa at Mahakipawa Estuary are provided in **Figure 19**.

Table 7 The five taxa with the highest abundances at Site A and Site B at Mahakipawa Estuary. Numbers represent average abundances per core sample.

Five most abundant taxa at Site A	Site A Abundance	Five most abundant taxa at Site B	Site B Abundance
Arthritica bifurca	9.8	*Arthritica bifurca*	2.7
Phoxocephalidae	2.8	*Amphibola crenata*	2.3
Potamopyrgus estuarinus	1.8	Oligochaeta	1.7
Amphibola crenata	1.7	Maldanidae	1.5
Austrovenus stutchburyi	1.5	Amphipoda	1.1

Table 8 General classification and trophic group of each of the taxa reported in Table 7

Taxa	General Classification	General Trophic Group
Amphibola crenata	Gastropoda	Deposit feeder
Amphipoda	Crustacea: Amphipoda	Scavenger
Arthritica bifurca	Bivalvia	Deposit feeder
Austrovenus stutchburyi	Bivalvia	Deposit feeder
Maldanidae	Polychaeta: Maldanidae	Deposit feeder
Oligochaeta	Oligochaeta	Deposit feeder
Phoxocephalidae	Crustacea: Amphipoda	Carnivorous
Potamopyrgus estuarinus	Gastropoda	Grazer

a) *Arthritica bifurca*

b) Phoxocephalidae

c) *Potamopyrgus estuarinus*

d) Maldanidae

e) *Austrovenus stutchburyi*

f) Amphibola crenata

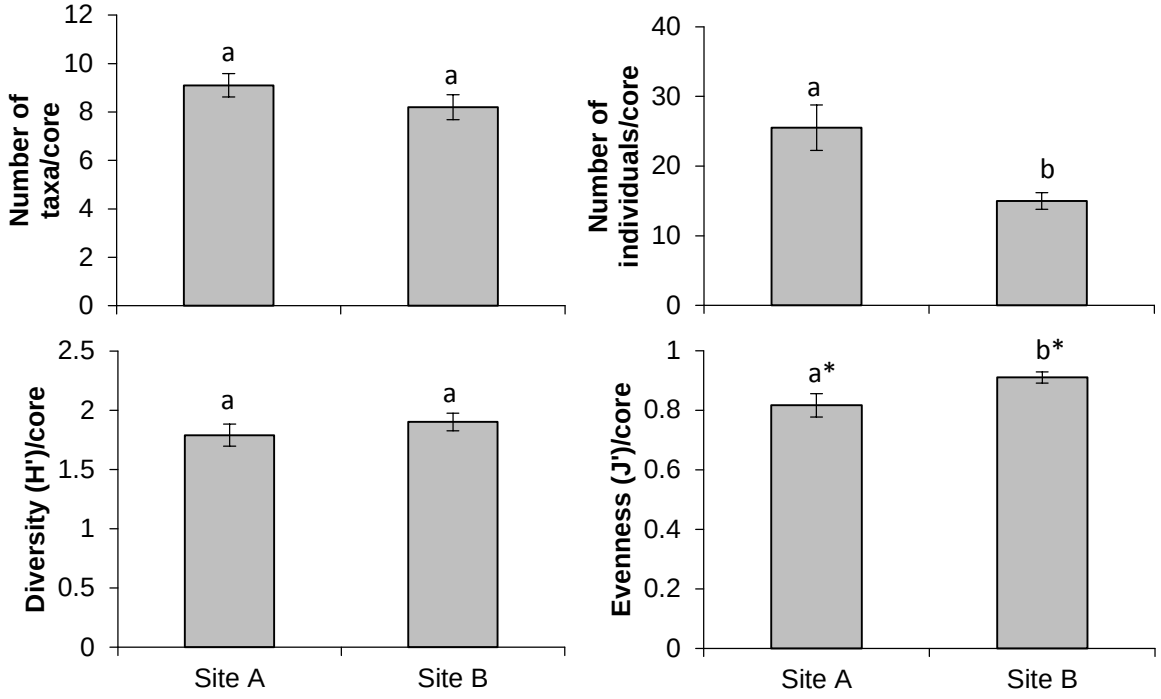
Figure 19 Photographs of some common taxa found in Mahakipawa Estuary

Univariate indices (total number of taxa, total abundance, Shannon-Wiener diversity and Pielou's evenness) describing the benthic macroinvertebrate communities at Site A and Site B are displayed in **Figure 20**.

There were no significant differences in the number of infauna taxa recorded at Site A (9.1 taxa/core) and Site B (8.2 taxa/core). These results were similar to the number of taxa found in Havelock Estuary in the 2014 fine-scale survey (Robertson & Robertson, 2014).

The number of individuals per core did, however, differ significantly between sites with more individuals found at Site A than at Site B. Again, these values, as well as the diversity results, were similar to those obtained in the 2014 Havelock Estuary survey.

Evenness values were relatively high, particularly at Site B. This indicates that infauna abundances are fairly evenly distributed across the different taxa present in the samples, with no notable dominance by any single taxa (low evenness indicates communities are being numerically dominated by a large number of individuals from a few taxa, rather than fewer individuals spread more evenly across all the taxa present).



**Although significant (p=0.044), this significance test did not fulfil the homogeneity assumption (Cochrans C test was significant) of the general linear model applied, even following log transformation of the data. Reducing the p-value to 0.01, as is often done in such cases, makes the differences among sites non-significant.*

Figure 20 Average values (±SE) per core for the number of taxa, number of individuals, Shannon-Wiener Diversity Index and Pielous's evenness per core at Site A and Site B in Mahakipawa Estuary. For each graph, different letters denote statistically significant differences among sites. N=10.

Mahakipawa Estuary infauna assemblage data from 2017 was statistically investigated using non-metric multi-dimensional scaling (MDS) (**Figure 21**). Distance on the MDS plot is relative and has no quantitative meaning; the idea being to visualise the data to get a sense of how near or far the points are from each other. Every MDS plot has an associated stress value which quantitatively reflects the difficulties involved with compressing the data into two dimensions. Where the best possible configuration in two dimensions produces a poor, highly distorted, representation of the data, the stress value will be high. The stress value of 0.24 in **Figure 21** is high and as such, indicates that caution must be taken when interpreting the overall community differences represented by the two dimensional plot.

The placement and spread of Site A and Site B data in **Figure 21** shows that there were different communities present at each site, but with some similarities. The communities displayed similar amounts of heterogeneity between sites.

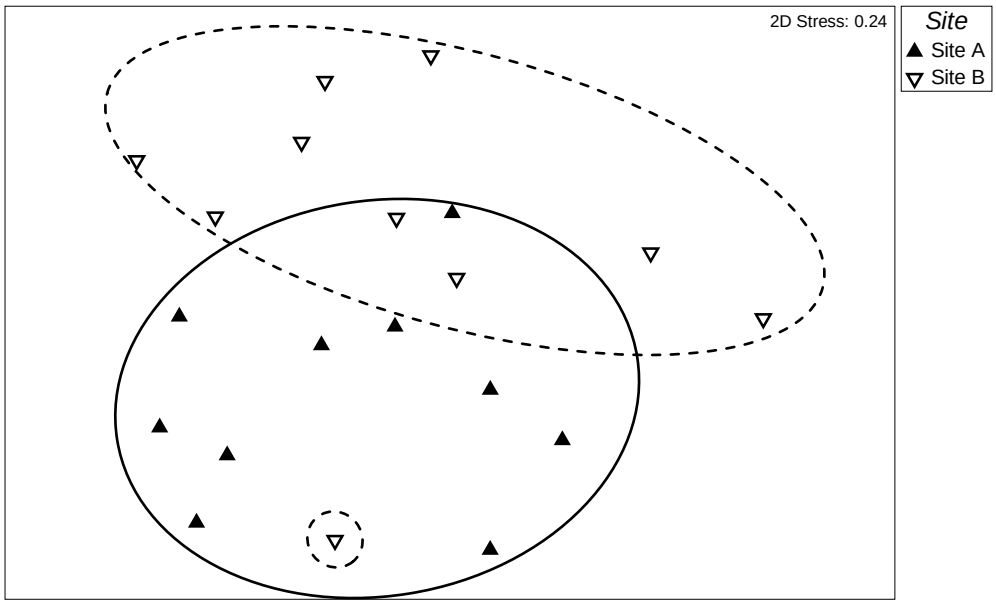


Figure 21 A two-dimensional plot of the multidimensional scaling (MDS) results of infauna taxa sampled at Site A and Site B at Mahakipawa Estuary. Ordinations are based on square-root transformed infauna data using Bray-Curtis similarities.

A PERMANOVA (permutational multivariate analysis of variance) model was applied to further examine differences in communities between Site A and Site B and found significant differences (Pseudo-F=2.0; p= 0.043). Taxa contributing most to the distinct differences observed between sites were then analysed using SIMPER analysis. SIMPER analysis showed that the average dissimilarity among Site A and Site B was 57.28 (i.e. the communities at each site were 42.72% similar). For comparison, the average similarity within Site A was 46.61%; and within Site B was 45.45%. This means that the variation between the two sites was very similar to the variation within sites.

The top five taxa identified to be contributing most to the dissimilarity in community composition between Site A and Site B are shown in **Table 9**.

Table 9 Top five taxa identified using SIMPER analysis as contributing most to the dissimilarity in community composition between Site A and Site B at Mahakipawa Estuary.

Taxa	Av.Abund Site A	Av.Abund Site B	Contrib%	Cum.%
Arthritica bifurca	2.81	1.4	12.21	12.21
Phoxocephalidae	1.39	0.44	8.38	20.59
Maldanidae	0.24	0.99	6.74	27.32
Amphibola crenata	1.04	1.32	6.61	33.94
Oligochaeta	0.86	1.01	6.04	39.98

NZ AMBI scores were calculated using NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al., (2015). Eighty-five percent of the taxa found at Mahakipawa Estuary in 2017 were able to be classified in NZ-AMBI groups. A full taxa list including AMBI-group classifications is provided in **Appendix H**. NZ AMBI Biotic Coefficients (Robertson et al., 2016c) were calculated for each site and these, as well as their corresponding risk ratings, are shown in **Table 10**.

Table 10 NZ AMBI Biotic Coefficients calculated in accordance with Robertson et al., (2016c) for Site A and Site B in Mahakipawa Estuary.

	Site A	Site B
NZ AMBI Biotic Coefficient (average)	3.14	2.66
Standard Error	0.16	0.13
Range	2.28 – 3.84	2.04 – 3.3
Risk Rating	BAND B: *Minor to moderate stress on benthic fauna. Community tolerant of slight organic enrichment and moderate muds.*	BAND B: *Minor to moderate stress on benthic fauna. Community tolerant of slight organic enrichment and moderate muds.*

3.2.5.1 Elucidating ecological relationships between different indicators

Scatterplots of percentage mud content and TOC versus infauna taxa richness and number of individuals showed high variability and no clear patterns or indication of a ceiling factor, whereby mud content sets an upper limit to taxa richness/abundance.

Figure 22 shows that salinity, mud content, TOC, TP, and the metals lead, copper, chromium, arsenic, cadmium and zinc were correlated with differences in infaunal community composition among sites for Spearman's correlations >0.4.

Further analyses (BEST, DISTLM) were performed to statistically examine linkages between abiotic variables and the patterns observed in infauna assemblages. For the BEST analysis, the correlation values between the environmental variables and the infauna assemblage patterns were low, with even the best variable combinations explaining less than 25% of the community patterns. DISTLM analysis showed significant effects of mud content, lead and salinity on community composition; however, the proportions of these results were very low (<0.10). As such, these results indicate that infauna assemblage patterns may be being influenced by another factor or factors that were not measured during the survey, or that the sample size was not sufficient to elucidate any strong relationships.

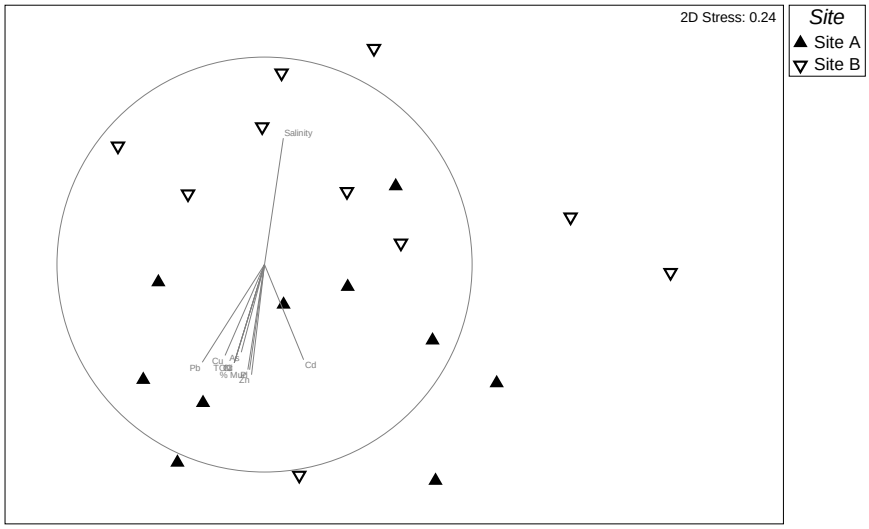


Figure 22 MDS plot showing infaunal community composition at Site A and Site B with vectors overlaid to show the predictor variables driving composition for Spearman's correlations >0.4.

4 SUMMARY AND RECOMMENDATIONS

Broad-scale mapping and fine-scale monitoring results for Mahakipawa Estuary in 2017 are summarised in **Table 11** and **Table 12** respectively.

The key ecological risk identified was the high sediment mud content which is likely to be contributing to the near-absence of seagrass within the estuary and the low diversity of epifauna. The location of Mahakipawa Estuary, at the head of Pelorus Sound, makes it susceptible to reduced tidal flows which limits the amount of flushing. The consequence of this is that fine sediments entering the estuary via rivers and terrestrial runoff are more likely to accumulate once they enter the estuary: this is reflected in the high mud content present in the estuary sediments.

The absence of nuisance algae and the low nitrogen concentrations within the estuary suggests that it is not subject to eutrophication. Phosphorus concentrations were, however, identified as being moderate-high which may reflect legacy effects and/or recent inputs. But concentrations are unlikely to be of concern as nitrogen, not phosphorus, is usually the limiting nutrient for eutrophication in estuaries.

Table 11 Summary of the broad-scale mapping results. Results of concern are shown in bold.

	% coverage	Ecological Assessment
Substrate: Soft/Very Soft Mud	61.59%	**High risk**
Mollusc patches	12.94%	Low risk
Seagrass	0.014%	**High risk**
Macroalgae	0.065%	Low risk
Saltmarsh	25.23%	Low risk
Terrestrial Margin Vegetation	95.72%	Low risk

Table 12 Summary of the fine-scale monitoring results. Results of concern are shown in bold.

Category	Indicator	Site A	Site B
Water (Interstitial)	Salinity	Brackish	Brackish
Sediment	Oxygenation: aRPD	Low Risk	Low Risk
Sediment	Oxygenation: mV	BAND B	BAND A
Sediment	Mud Content	**BAND D**	**BAND D**
Sediment	Total Organic Content	BAND B	BAND A
Sediment	Heavy Metals	All below ISQG-Low values	All below ISQG-Low values
Sediment	SVOC/Organotins	All below detectable limits	All below detectable limits
Sediment	Total Nitrogen	BAND B	BAND B
Sediment	Total Phosphorus	Moderate-High	Moderate
Macroalgae	Abundance/Cover	None	None
Microalgae	Cover/Density	None	None
Seagrass	Abundance/Cover	**None**	**None**
Epifauna	Number of taxa	**Very low diversity**	**Very low diversity**
Infauna	NZ AMBI Biotic Coefficient	BAND B	BAND B

Although relatively small, Mahakipawa Estuary provides important ecological, cultural, food gathering and aesthetic ecosystem services for the animals, plants, algae, iwi, locals and visitors which use, visit and/or rely on its habitat. The monitoring results from this report provide a good basis for establishing the current condition of the estuary and information from which to discuss and establish management goals. Here, suitable management targets may be to aim for a desired set of ecosystem characteristics, such as:

- improved sediment health with respect to decreased sediment mud content (this will include examining sediment inputs);

- increased faunal diversity;
- growth and spread of seagrass; and
- more attractive conditions for increased recreational usage, such as swimming, windsurfing, kiteboarding, fishing, shell-fish gathering and/or picnicking.

Management decisions and goals must take into account the priorities of different stakeholders and user groups, as well as the resources available. This may require managers to consider difficult questions such as 'what components of the ecosystem should we be most concerned about.' Clearly, the answers to such a question will be subjective and may differ considerably among different stakeholder groups. The success of ecosystem-based management then becomes an issue of setting and achieving the best set of outcomes for all parties involved. To achieve this, a holistic approach that considers habitats, communities and processes over a wide range of spatial and temporal scales and that incorporates research carried out over all levels of ecological organisation is required.

It is recommended that fine-scale monitoring of Mahakipawa Estuary be repeated every five years as recommended in the EMP. If funds/resources are available, more frequent monitoring, even just of specific indicators, will assist in tracking temporal and spatial changes in the estuary's condition.

5 ACKNOWLEDGMENTS

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6 REFERENCES

Agard, J.B.R., Gobin, J., & Warwick, R.M. (1993). Analysis of marine microbenthic community structure in relation to pollution, natural oil seepage and seasonal disturbance in a tropical environment (Trinidad, West-Indies). *Marine Ecology Progress Series, 92*, 233-243.

Anderson, M.J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology, 26*(1), 32-46.

Anderson, M.J., Gorley, R.N., & Clarke, K.R. (2008). PERMANOVA+ for PRIMER: Guide to software and statistical methods. PRIMER-E, Plymouth, UK, 214p.

ANZECC. (2000). Australian and New Zealand guidelines for fresh and marine water quality Volume 1. National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Berthelsen, A., Clement, D., & Gillespie, P. (2016). Shakespeare Bay Estuary Monitoring 2016. Prepared for Marlborough District Council. Cawthron Report No. 2833. 40 p. plus appendices.

Boffa Miskell et al. (2014). *Natural Character of the Marlborough Coast: Defining and Mapping the Marlborough Coastal Environment*. Prepared for (MDC) by Boffa Miskell Limited, Lucas Associates, Department of Conservation, Taramoa Ltd, Landcare Research and Shona McCahon.

Brown, D. (2001). Black-billed gulls hawking cicadas over shrubland. *Notornis, 48*(2), 111-112.

Bryan, G. W. (1971). The effects of heavy metals (other than mercury) on marine and estuarine organisms. *Proceedings of the Royal Society B*, *177*, 389-410.

Clarke, K. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology, 18*(1), 117-143.

Clarke, K.R., & Warwick, R.M. (1994). Change in marine communities: An approach to statistical analysis and interpretation. Plymouth Marine Laboratory, Plymouth, UK, 144p.

Clarke, K.R., & Gorley, R.N. (2006). *PRIMER v6: User Manual/Tutorial*. PRIMER-E, Plymouth.

Cloern, J. E. (2001). Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series, 210,* 223-253.

Davidson, R.J., & Brown, D.A. (2000). *A report on the ecology of Havelock Estuary. Pelorus Sound, Marlborough Sounds*. Prepared by Davidson Environmental Limited for Marlborough District Council.

Day, J.H. (1980). What is an estuary. *South African Journal of Science, 76*, 198-198.

Day, J.H. (1981). *Estuarine Ecology: With particular reference to southern Africa*. Rotterdam, The Netherlands: A.A. Balkema.

Diaz, R.J., & Rosenberg, R. (1995). Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. In A. D. Ansell, R. N. Gibson, & M. Barnes (Eds.), *Oceanography and Marine Biology - an Annual Review*, Vol 33.

Gaston, K.J. (2000). Biodiversity: Higher taxon richness. *Progress in Physical Geography, 24,* 117-127.

Handley, S. (2015). *The history of benthic change in Pelorus Sound (Te Hoiere), Marlborough*. NIWA Client report NEL2015-001 prepared for Marlborough District Council 47p.

Hargrave, B.T., Holmer, M., & Newcombe, C.P. (2008). Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. *Marine Pollution Bulletin, 56*(5), 810–824.

Hewitt, J.E., Hailes, S.F., & Greenfield, B.L. (2015) Protocol for Processing, Identification and Quality Assurance of New Zealand Marine Benthic Invertebrate Samples. Report prepared by NIWA for Northland Regional Council.

Hiscock, K. (ed.). (1996). Marine Nature Conservation Review: rationale and methods. Coasts and seas of the United Kingdom. MNCR Series. Joint Nature Conservation Committee, Peterborough.

Hiscock, K. (1998). In situ survey of subtidal (epibiota) biotopes using abundance scales and check lists at exact locations (ACE surveys). Version 1 of 23 March 1998. In: Biological monitoring of marine Special Areas of Conservation: a handbook of methods for detecting change. Part 2. Procedural guidelines (ed. K. Hiscock). Joint Nature Conservation Committee, Peterborough.

Howarth, R.W.R., & Marino, R. (2006). Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: Evolving views over three decades. *Limnology and Oceanography, 51(1),* 364-376.

James, R.J., Smith, M.P.L., & Fairweather, P.G. (1995). Sieve mesh size and taxonomic resolution needed to describe natural spatial variation of marine macrofauna. *Marine Ecology Progress Series, 118*, 187-198.

Keeley, N.B., Forrest, B.M., Crawford, C., & Macleod, C.K. (2012). Exploiting salmon farm benthic enrichment gradients to evaluate the regional performance of biotic indices and environmental indicators. *Ecological Indicators, 23*, 453-466.

MNCR. (1990). UK Nature Conservancy Council. *Marine Nature Conservation Review* (MNCR).

Moore, D.W., Dillon, T.M., & Suedel, B.C. (1991). Chronic toxicity of tributyltin to the marine polychaete worm, *Neanthes arenaceodentata*. *Aquatic Toxicology, 21,* 181-198.

Olsgard, F., Brattegard, T., & Holthe, T. (2003). Polychaetes as surrogates for marine biodiversity: Lower taxonomic resolution and indicator groups. *Biodiversity and Conservation, 12,* 1033-1049.

Pilkington, M.C., & Pilkington, J.B. (1982). The planktonic veliger of *Amphibola-crenata* (Gmelin). *Journal of Molluscan Studies, 48,* 24-29.

Rattenbury, M.S., Cooper, R.A., & Johnston, M.R. (compilers). (1998). Geology of the Nelson area. Institute of Geological & Nuclear Sciences 1:250000 geological map 9. 1 sheet + 67 p. Lower Hutt, New Zealand: Institute of Geological & Nuclear Sciences.

Robertson, B.P., Gardner, J.P.A., & Savage, C. (2015). Macrobenthic - mud relations strengthen the foundation for benthic index development: A case study from shallow, temperate New Zealand estuaries. *Ecological Indicators, 58*, 161-174.

Robertson, B.P., Gardner, J.P.A., Savage, C., Roberston, B.M., & Stevens, L.M. (2016c). Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. *Ecological Indicators, 69,* 595-605.

Robertson, B.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., Thompson, S.J., & Tuckey, B.J. (2002). Estuarine environmental assessment and monitoring: A national protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93 p. Part B. 159 p. Part C. 40 p plus field sheets.

Robertson, B.M., & Robertson, B. (2014). Havelock Estuary: Fine Scale Monitoring 2014. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

Robertson, B.M., & Stevens, L.M. (2016a). Whangarae Estuary: Fine Scale Monitoring 2016. Report prepared by Wriggle Coastal Management for Marlborough District Council. 28p.

Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., & Oliver, M. (2016b). NZ Estuary Trophic Index Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420. 68p.

Robertson, H.A., Dowding, J.E., Elliott, G.P., Hitchmough, R.A., Miskelly, C.M., O'Donnell, C.F.J., Powlesland, R.G., Saga, P.M., Scofield, R.P., & Taylor, G.A. (2013). Conservation Status of New Zealand Birds, 2012. *New Zealand Threat Classification Series 4*, Department of Conservation, Wellington, New Zealand.

Schwartz, M. L. (2005). *Encyclopedia of coastal science*. The Netherlands: Springer.

Stevens, L., & Robertson, B. (2014). Havelock Estuary 2014 broad scale habitat mapping. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

Stevens, L.M., & Robertson, B.M. (2016). Waikawa Estuary (Marlborough): Broad Scale Habitat Mapping 2016. Report prepared by Wriggle Coastal Management for Marlborough District Council. 27p.

Underwood, G.J.C., & Kromkamp, J. (1999). Primary production by phytoplankton and microphytobenthos in estuaries. Pages 93-153 *in* D. B. Nedwell and D. G. Raffaelli, editors. Advances in Ecological Research, Vol 29: Estuaries.

Waycotta, M., Duarte, C.M., Carruthers, T.J.B., et al. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, *106*, 12377–12381.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group). (2014). UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Retrieved from http:// www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

FINE-SCALE MONITORING SITE GPS COORDINATES

	Corner 1	Corner 2	Corner 3	Corner 4
Site A	41°17'6.09"S 173°50'37.68"E	41°17'6.64"S 173°50'36.52"E	41°17'8.31"S 173°50'37.87"E	41°17'7.59"S 173°50'38.85"E
Site B	41°17'21.15"S 173°50'23.69"E	41°17'21.14"S 173°50'26.28"E	41°17'22.12"S 173°50'26.26"E	41°17'22.16"S 173°50'23.64"E

FINE-SCALE MONITORING ANALYTICAL METHODOLOGY DETAILS

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 clean 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.

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
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%.	-	1-6
Dry Matter (Env)	Dried at 103°C for 4-22hr (removes 3-5% more water than air dry) , gravimetry. US EPA 3550. (Free water removed before analysis).	0.10 g/100g as rcvd	7-8
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-6
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	1-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
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	1-6
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	1-6
7 Grain Sizes Profile*		-	1-6
Semivolatile Organic Compounds Trace in Soil by GC-MS	Sonication extraction, GPC cleanup, GC-MS FS analysis. Tested on as received sample	0.10 - 6 mg/kg dry wt	7-8
Tributyl Tin Trace in Soil samples by GCMS	Solvent extraction, ethylation, SPE cleanup, GC-MS SIM analysis. Tested on dried sample	0.003 - 0.007 mg/kg dry wt	7-8
7 Grain Sizes Profile			
Dry Matter	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
Fraction < 2 mm, >/= 1 mm*	Wet sieving using dispersant, 2.00 mm and 1.00 mm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 1 mm, >/= 500 µm*	Wet sieving using dispersant, 1.00 mm and 500 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 500 µm, >/= 250 µm*	Wet sieving using dispersant, 500 µm and 250 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 250 µm, >/= 125 µm*	Wet sieving using dispersant, 250 µm and 125 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 125 µm, >/= 63 µm*	Wet sieving using dispersant, 125 µm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
Salinity*	Conductivity Meter (WTW Cond 340i with nonlinear temperature compensation according to EN 27 888). APHA 2520 B 22nd ed. 2012.	0.2	9-10

HABITAT MAPS TILED VERSIONS

Tiled versions of habitat maps for substrates, saltmarsh, macroalgae, seagrass, mollusc patches and the terrestrial margin are provided on the DVD-ROM inside the back over of this report, in the folder titled: *Appendix C*. These provide greater detail than the summary graphs presented in the body of this report.

GEOREFERENENCED HABITAT PHOTOS

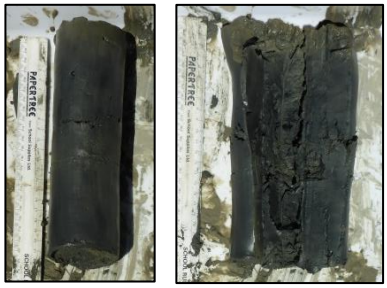
Georeferenced habitat photos (in addition to those presented in the body of this report) are provided on the DVD-ROM inside the back cover of this report in the folder titled: *Appendix D*.

SEDIMENT CORE PHOTOGRAPHS

Site A:

Core 1

Core 2



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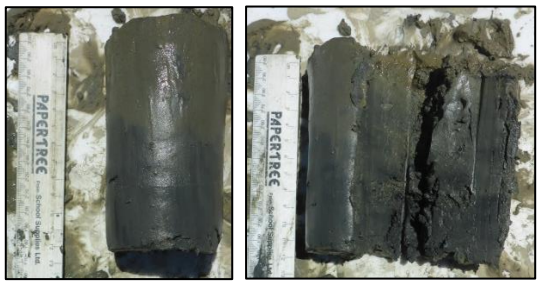

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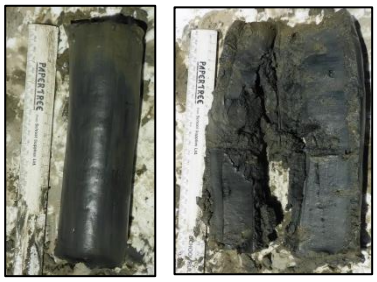
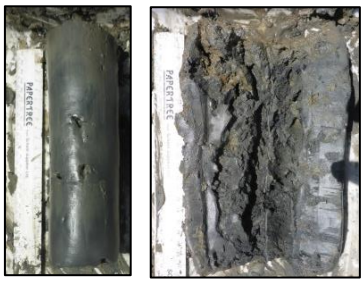


Core 5

Core 6

Core 7

Core 8



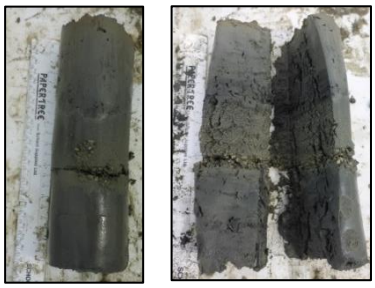
Core 9

Core 10

SEDIMENT CORE PHOTOGRAPHS

Site B:

Core 1



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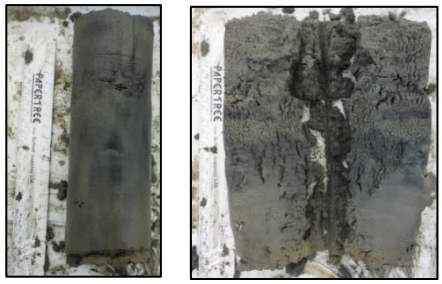

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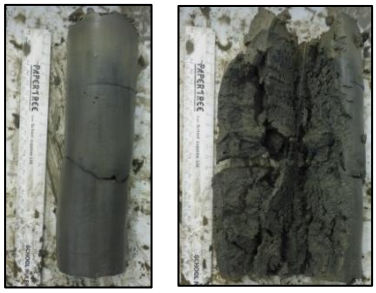

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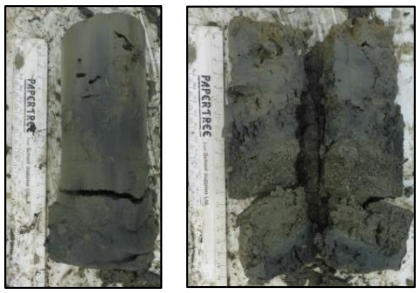

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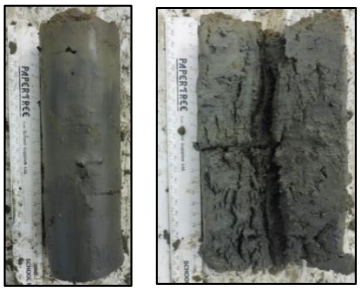

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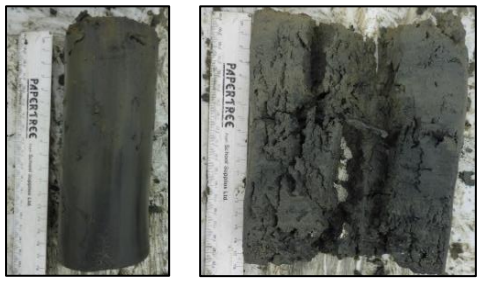

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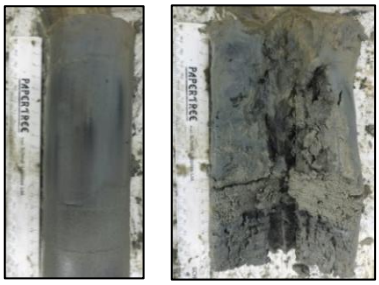

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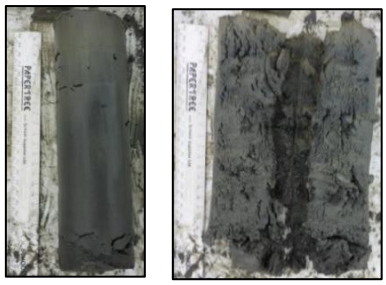
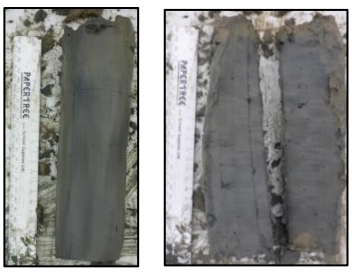


Core 9



Core 10

FINE-SCALE SEDIMENT MONITORING RESULTS

	Site A			Site B		
	1-3	**4-6**	**7-10**	**1-3**	**4-6**	**7-10**
% mud (<63 µm)	62.9	71.1	62.3	44.9	46.2	48.3
% very fine sand (<125 µm, >/= 63 µm)	17.4	19.1	29.3	35.2	35.8	35.4
% fine sand (<250 µm, >/= 125 µm)	9.6	6	2.9	13.9	13.3	10.6
% medium sand (<500 µm, >/= 250 µm)	4.7	2.5	1.2	3.1	0.7	2.8
% coarse sand (<1 mm, >/= 500 µm)	3	0.7	0.8	0.9	2.4	0.9
% very coarse sand (<2 mm, >/= 1 mm)	1.3	0.3	0.5	0.7	0.6	0.9
% gravel (>/= 2 mm)	1.2	0.3	3	1.2	1.1	1
TOC (g/100g dry wt)	0.59	0.94	0.91	0.5	0.47	0.41
TN (g/100g dry wt)	0.05	0.07	0.06	< 0.05	< 0.05	< 0.05
TP (mg/kg dry wt)	500	620	610	410	410	410
Cd (mg/kg dry wt)	0.02	0.026	0.03	0.023	0.017	0.02
Cr (mg/kg dry wt)	19.2	27	24	15.3	13.7	13.3
Cu (mg/kg dry wt)	16.7	19.6	19	12.8	12.8	12.2
Ni (mg/kg dry wt)	16.5	23	20	13.1	12.4	11.7
Pb (mg/kg dry wt)	14.4	8.5	8.2	5.5	5.6	5.3
Zn (mg/kg dry wt)	45	54	51	36	34	34
As (mg/kg dry wt)	4.7	5.8	6.1	3.5	3.9	3.7
Hg (mg/kg dry wt)	0.013	0.022	0.026	0.017	0.013	0.011

	Site A	Site B
Salinity	13.2	15.3

O_2	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Site A	20	85	87	71	80	30	61	59	75	103
Site B	188	210	168	127	180	177	141	169	196	163

	Site A	Site B
Dry Matter	67	72
Haloethers		
Bis(2-chloroethoxy) methane	< 0.10	< 0.10
Bis(2-chloroethyl)ether	< 0.10	< 0.10
Bis(2-chloroisopropyl)ether	< 0.10	< 0.10
4-Bromophenyl phenyl ether	< 0.10	< 0.10
4-Chlorophenyl phenyl ether	< 0.10	< 0.10
Nitrogen Containing Compounds		
N-Nitrosodiphenylamine + Diphenylamine	< 0.16	< 0.15
2,4-Dinitrotoluene	< 0.2	< 0.2
2,6-Dinitrotoluene	< 0.2	< 0.2
Nitrobenzene	< 0.10	< 0.10
N-Nitrosodi-n-propylamine	< 0.16	< 0.15
Organochlorine Pesticides		
Aldrin	< 0.10	< 0.10
alpha-BHC	< 0.10	< 0.10
beta-BHC	< 0.10	< 0.10
delta-BHC	< 0.10	< 0.10
gamma-BHC (Lindane)	< 0.10	< 0.10
4,4'-DDD	< 0.10	< 0.10
4,4'-DDE	< 0.10	< 0.10
4,4'-DDT	< 0.2	< 0.2
Dieldrin	< 0.10	< 0.10
Endosulfan I	< 0.2	< 0.2
Endosulfan II	< 0.5	< 0.5
Endosulfan sulphate	< 0.2	< 0.2
Endrin	< 0.16	< 0.15
Endrin ketone	< 0.2	< 0.2
Heptachlor	< 0.10	< 0.10
Heptachlor epoxide	< 0.10	< 0.10
Hexachlorobenzene	< 0.10	< 0.10
Polycyclic Aromatic Hydrocarbons		
Acenaphthene	< 0.10	< 0.10
Acenaphthylene	< 0.10	< 0.10
Anthracene	< 0.10	< 0.10
Benzo[a]anthracene	< 0.10	< 0.10
Benzo[a]pyrene (BAP)	< 0.10	< 0.10
Benzo[b]fluoranthene + Benzo[j]fluoranthene	< 0.10	< 0.10
Benzo[g,h,i]perylene	< 0.10	< 0.10
Benzo[k]fluoranthene	< 0.10	< 0.10
1&2-Chloronaphthalene	< 0.10	< 0.10
Chrysene	< 0.10	< 0.10
Dibenzo[a,h]anthracene	< 0.10	< 0.10
Fluoranthene	< 0.10	< 0.10
Fluorene	< 0.10	< 0.10
Indeno(1,2,3-c,d)pyrene	< 0.10	< 0.10
2-Methylnaphthalene	< 0.10	< 0.10
Naphthalene	< 0.10	< 0.10
Phenanthrene	< 0.10	< 0.10
Pyrene	< 0.10	< 0.10

	Site A	Site B
Phenols		
4-Chloro-3-methylphenol	< 0.5	< 0.5
2-Chlorophenol	< 0.2	< 0.2
2,4-Dichlorophenol	< 0.2	< 0.2
2,4-Dimethylphenol	< 0.4	< 0.4
3 & 4-Methylphenol (m- + p-cresol)	< 0.4	< 0.4
2-Methylphenol (o-Cresol)	< 0.2	< 0.2
2-Nitrophenol	< 0.4	< 0.4
Pentachlorophenol (PCP)	< 6	< 6
Phenol	< 0.2	< 0.2
2,4,5-Trichlorophenol	< 0.2	< 0.2
2,4,6-Trichlorophenol	< 0.2	< 0.2
Plasticisers		
Bis(2-ethylhexyl)phthalate	< 0.5	< 0.5
Butylbenzylphthalate	< 0.2	< 0.2
Di(2-ethylhexyl)adipate	< 0.2	< 0.2
Diethylphthalate	< 0.2	< 0.2
Dimethylphthalate	< 0.2	< 0.2
Di-n-butylphthalate	< 0.2	< 0.2
Di-n-octylphthalate	< 0.2	< 0.2
Other Halogenated Compounds		
1,2-Dichlorobenzene	< 0.16	< 0.15
1,3-Dichlorobenzene	< 0.16	< 0.15
1,4-Dichlorobenzene	< 0.16	< 0.15
Hexachlorobutadiene	< 0.16	< 0.15
Hexachloroethane	< 0.16	< 0.15
1,2,4-Trichlorobenzene	< 0.10	< 0.10
Other SVOC		
Benzyl alcohol	< 1.0	< 1.0
Carbazole	< 0.10	< 0.10
Dibenzofuran	< 0.10	< 0.10
Isophorone	< 0.10	< 0.10
Tributyl Tin		
Dibutyltin (as Sn)	< 0.005	< 0.005
Monobutyltin (as Sn)	< 0.007	< 0.007
Tributyltin (as Sn)	< 0.004	< 0.004
Triphenyltin (as Sn)	< 0.003	< 0.003

FINE-SCALE MONITORING QUADRAT PHOTOGRAPHS

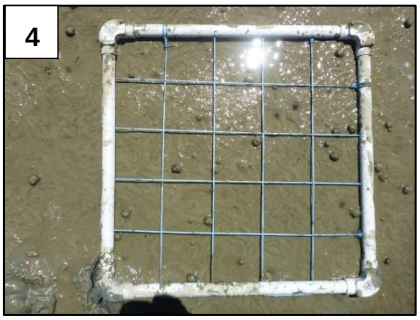
Site A:

1

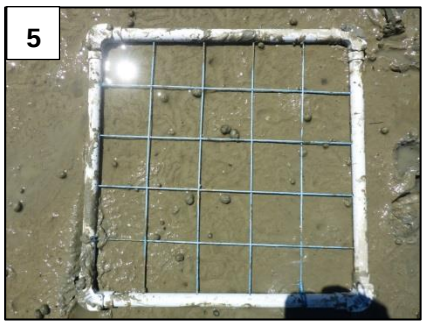
2

3

4



5



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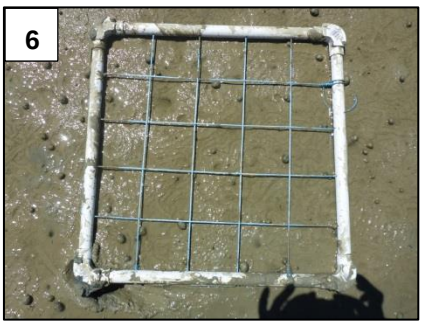
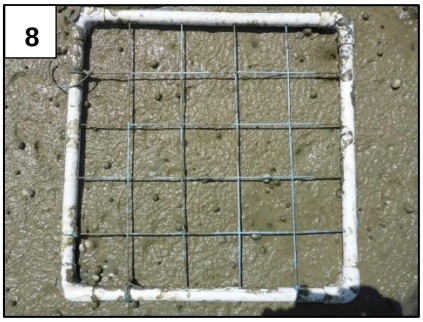


7

8



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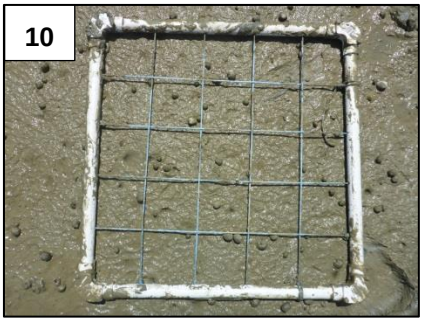
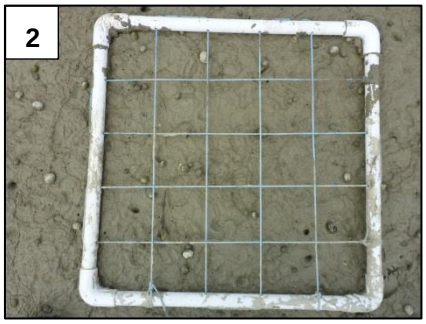
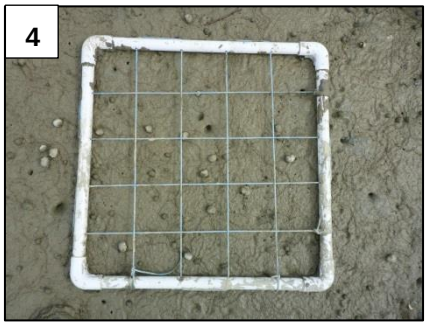
10

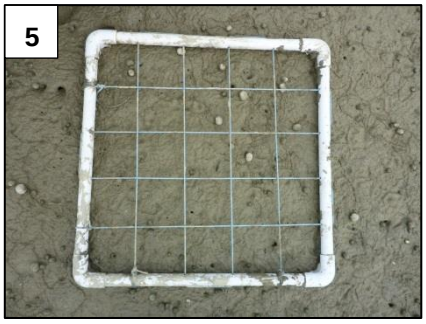


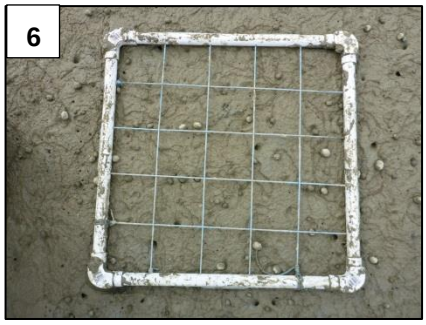
FINE-SCALE MONITORING QUADRAT PHOTOGRAPHS

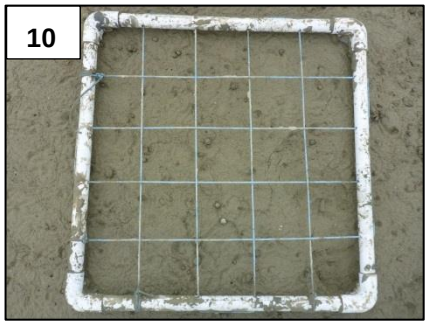
Site B:











FINE-SCALE MONITORING MACROINVERTEBRATE DATA

Epifauna:

Site A Epifauna Taxa	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Amphibola crenata (>5 mm)	20	19	17	12	22	26	15	26	16	39
Amphibola crenata (<5 mm)	3	13	4	5	3	14	16	15	6	4
Austrohelice crassa (juv)	0	0	0	0	0	0	0	0	0	1
Crab holes	15	17	15	3	11	5	18	12	9	7
Site B Epifauna Taxa	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**	**Plot 6**	**Plot 7**	**Plot 8**	**Plot 9**	**Plot 10**
Amphibola crenata (>5 mm)	48	42	60	35	39	42	28	67	39	41
Amphibola crenata (<5 mm)	7	4	7	2	6	3	0	6	1	4
Amphipoda	0	1	0	0	0	0	0	0	0	0
Crab holes	10	4	12	5	7	7	11	13	5	7

Infauna:

	NZ AMBI	Site A Plot 1	Site A Plot 2	Site A Plot 3	Site A Plot 4	Site A Plot 5	Site A Plot 6	Site A Plot 7	Site A Plot 8	Site A Plot 9	Site A Plot 10	Site B Plot 1	Site B Plot 2	Site B Plot 3	Site B Plot 4	Site B Plot 5	Site B Plot 6	Site B Plot 7	Site B Plot 8	Site B Plot 9	Site B Plot 10
Aonides trifida	1						1														
Maldanidae	1		2			1						3	3		3	3	1	1		1	
Polynoidae	1											1	1								
Austrovenus stutchburyi	2	1	2		1	2	2	3		2	2		2	3	1	2			1	1	1
Copepoda	2			1	1																
Edwardsia sp.	2			2					1		1			2					1	1	1
Mactra sp.	2	1			2			1						1							
Nematoda	2																				1
Paphies australis	2						1			1		1			1						
Phoxocephalidae	2	1	3	2		2	3		1	10	6		1					2		1	1
Amphibola crenata	3			1		2	4	1	1	3	5	6	3	1	3		4		2	2	2
Cominella glandiformis	3	1				1		1	1	1	1	1									
Halicarcinus whitei	3			1						1				1							
Heteromastus filiformis	3															1	3				
Nemertea	3	1						1		1				1	1	1	1	1			
Nereididae (juv)	3					4	5	2	2			1		2		2		1		1	
Nicon aestuariensis	3	1	2		3		1	2		1			1				1		1	3	1
Oligochaeta	3	1	3	1	1	2	2			1		4	1		1		1	1	7	2	
Potamopyrgus estuarinus	3	10		1	4	1	2					1					1				
Arthritica bifurca	4	9	17	5	9	1	26	23	2	2	4	2	2	8	5	3	1	4		2	
Scolepoledes benhami	4	1	1																		
Austrohelice crassa	5				1	1								1						1	
Amphipoda		1		4	1				1		2		1	1		3	1	2	1	2	
Dolichopodidae																					1
Orthacladiinae			1	2																	
Polychaeta				2																	

QA:

	Sample	Taxonomist 1	Taxonomist 2	Pass Criteria	Reference	Site A	Site B
Picking	Site A Plot 3	Celine Dufour	Jen Skilton	≥95%	Hewitt et al. (2015)	PASS	PASS
Identification	Site B Plot 10	Celine Dufour	Jen Skilton	See Hewitt et al. (2015)	Hewitt et al. (2015)	PASS	PASS