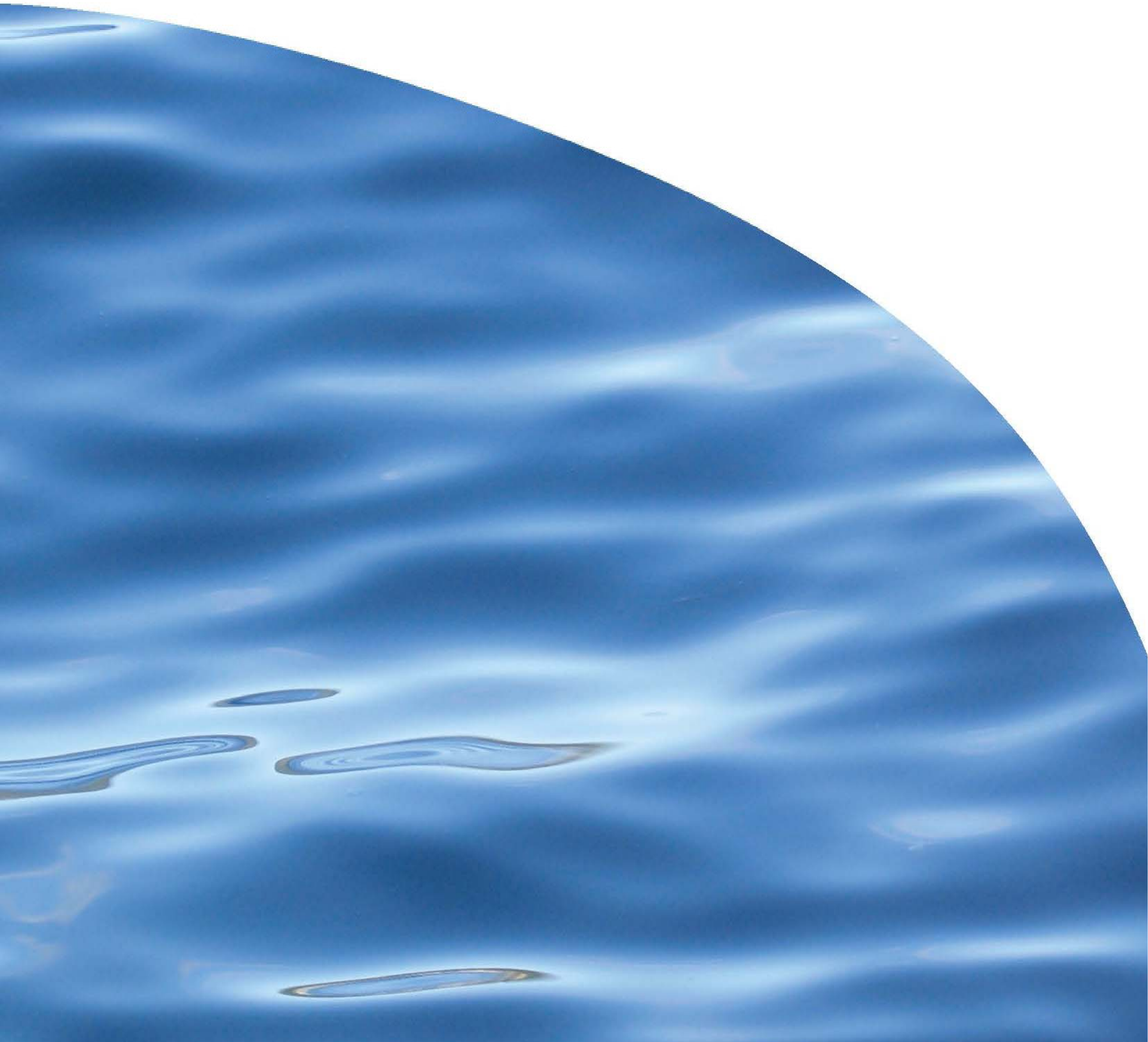
REPORT NO. 2741

STATE OF THE ENVIRONMENT MONITORING OF WAIRAU ESTUARY



STATE OF THE ENVIRONMENT MONITORING OF WAIRAU ESTUARY

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EXECUTIVE SUMMARY

Cawthron Institute (Cawthron) was commissioned by the Marlborough District Council (MDC) to undertake state of the environment monitoring of the Wairau Estuary. This comprised an assessment of estuary condition or 'health' following the standardised Estuary Monitoring Protocol (EMP) (Robertson *et al*. 2002) and involved two 'point in time' surveys of the estuary based on:

(1) Broad-scale vegetation and structural class habitat mapping (baseline for 2015[1]) - with the additional trial use of a drone for aerial photography.

(2) Fine-scale benthic surveys based on a suite of seabed characteristics at three reference sites within the estuary (baseline for 2015).

Further funding (Envirolink 1588-MLDC105) allowed Cawthron to gather reminisces of the Wairau Estuary from local community members.

The estuary monitoring provided a reference point from which to assess future changes within the Wairau Estuary and to compare against other New Zealand estuaries. Reminisces from local community members provided a valuable context for interpretation of this baseline. Implications for the overall condition or 'health' of the Wairau Estuary are discussed and recommendations are made for ongoing monitoring. This information will be incorporated into an estuarine monitoring programme as part of the MDC coastal monitoring strategy (Tiernan 2012).

SUMMARY OF THE CONDITION OF THE WAIRAU ESTUARY

Based on the EMP indicators of estuarine condition, and in comparison with the other New Zealand and overseas estuaries, the Wairau Estuary is exhibiting signs of being in a fair to compromised environmental condition. Together, the results, historical information and local reminisces indicate key estuary functions and values have been undermined. However, these findings should ultimately be considered in context to the 'choked' lagoon nature of the Wairau Estuary, which may be naturally attributed with characteristics and functions that vary from those associated with New Zealand estuaries typically assessed using the EMP. This is based on the following key findings that relate to estuarine condition.

[1] Mapping based on 2015 ground-truthing and 2011/12 aerial photos.

KEY FINDINGS OF 2015 BROAD-SCALE MAPPING OF VEGETATION AND STRUCTURAL CLASS HABITATS:

- The total Wairau Estuary habitat covered a relatively large area (1576 ha) compared to most other estuaries within the Nelson/Marlborough region. Due to the lagoon-like nature of the estuary, a large proportion (77%) of the total estuary was subtidal (permanently covered with water), and consequently the intertidal habitat (23%) was proportionally small.
- Vegetated habitats covered a relatively high proportion (over half) of the intertidal zone and were comprised largely of salt marsh. A large proportion of this salt marsh showed compromised intertidal function (*i.e*. had limited connectivity with the estuarine habitat). Macroalgae, primarily agar weed (*Gracilaria* sp.), were also present within the intertidal zone. Eelgrass meadows were absent, although they were likely to have been historically present.
- Unvegetated habitats covered just under half of the intertidal zone and were largely comprised of mud/sand substrates. Sand substrates were absent.
- High resolution photographs collected by drone improved the accuracy of habitat mapping details.

KEY FINDINGS OF 2015 FINE-SCALE BENTHIC SURVEYS OF THREE INTERTIDAL SURVEY SITES:

- No obvious signs of **pollution** (*e.g*. odours, visible scums from fats/oils or unnatural debris), were noted.
- Sediment core profiles showed no signs of excessive **oxygen depletion**. The profile characteristics were largely typical of other estuaries that, although exhibiting some indication of mild to moderate enrichment, were not seriously compromised in terms of oxygen levels. However, darker mud within cores from a site located along Te Aropipi Channel (Figure 1) did indicate moderate oxygen depletion. Darker mud within cores from a site in Big Lagoon was likely caused by historic accumulation of organic material.
- No nuisance-level **microalgal mat** development or excessive macroalgal coverage was observed on the sediment at the survey sites.
- **Sediments** at the two inner lagoon sites contained extremely high mud content. Sediment at the site closer to the estuary mouth (in the Te Aropipi Channel) contained a higher proportion of sand (compared to the inner lagoon sites) and was more representative of other NZ estuaries surveyed within the EMP.
- **Nutrient and organic contents** of the sediments at the Te Aropipi Channel and Upper Lagoon sites were within the range of other slightly-to-moderately organically enriched or naturally productive, NZ estuaries. The elevated nutrient and organic contents of sediment at the Big Lagoon site were indicative of organically enriched conditions.

- **Heavy metal** concentrations of cadmium, chromium, copper, lead and zinc within the sediment were all below the guideline levels often used to indicate biological effects. However, lead concentrations were slightly elevated compared to a number of other NZ estuaries. Nickel concentrations were above national standard trigger levels, although this is likely to be attributable to natural catchment sources.
- **Semi volatile organic compounds** (SVOCs) were all below detectable limits.
- Abundance and diversity of **infauna** (animals living within the sediment) at the two inner lagoon sites was low. This is likely due to a number of factors including the higher intertidal elevation of these sites where a limited tidal range results in reduced periods of inundation. The abundance and diversity of infauna at the Te Aropipi Channel site was more typical of other NZ estuaries surveyed within the EMP, with the exception of the dominance of gastropod (snail) and amphipod (sand hopper), rather than polychaete (worm) and bivalve (shellfish), taxa at this site

ESTUARY CONDITION

The general **broad-scale characteristics** of the estuary and its supra-littoral surrounds (vegetation fringe) provide evidence of a complex estuarine environment. The large expanse of vegetated habitat within the intertidal zone is a valuable ecological component of the estuary and likely to benefit its overall state of health. However, the following characteristics provide indication of an estuary in a compromised state of health:

- Limited connectivity between a large proportion of intertidal vegetation and the main estuary habitat may have resulted from enhanced sediment deposition within the upper intertidal zone and may limit important functioning.
- The absence of eelgrass beds (reported as present historically) is likely evidence of an altered ecological condition and reduced biodiversity within the estuary.
- Although further investigation is required, significant areas covered by a single species of red macroalgae (*Gracilaria* sp.) may also indicate reduced estuarine health.
- The large area of unvegetated mud / sand habitat and absence of sand habitat in the intertidal zone may indicate a reduction in ecological condition.
- The abundance of exotic grassland within the supra-littoral estuary margin represents a modification of the natural state of this habitat.

Based on the EMP suite of **fine-scale environmental indicators**, the Wairau Estuary was found to be in a fair to compromised state of health:

- Signs of reduced ecological condition were at least partly associated with the high-intertidal habitat characteristics at the two inner lagoon sites. These contained mud-dominated sediments that, due to a restricted tidal range, were limited in the inundation time that they received.

- Heavy metal levels within sediments did not appear to compromise estuarine health; however, slightly elevated nickel concentrations of natural origin indicated possible ecological effects. Although the analytical detection limits for some SVOC components were above potential ecological effects thresholds, no obvious impact levels were demonstrated.
- Nutrient and organic levels, as well as core profiles, indicated slight to moderate organic enrichment of sediments, although this was not considered to seriously compromise oxygen levels. At the time of the survey this did not result in nuisance micro / macro- algal blooms on the sediment surface.
- The abundance and diversity of animals living within and on top of the sediment was low at the two lagoon sites, indicating reduced ecological functioning. The abundance and diversity of animals living within the sediment at the Te Aropipi channel site was more typical of healthy estuarine ecosystems, although species composition was notably different.

SUMMARY AND RECOMMENDATIONS

The Wairau Estuary has natural (ecological and geological) and cultural / social values that are regionally, nationally, and possibly internationally, significant. Monitoring the health of the Wairau Estuary may be seen as important in the context of these values. Broad-scale mapping has provided valuable insight into the habitat features of the Wairau Estuary. Likewise, the fine-scale survey of physical, chemical and biological properties of benthic intertidal habitats has provided understanding of the environmental condition of three reference sites in the estuary. The combined results provide a baseline description of estuarine condition or ‘health’ that can be used as a benchmark for comparison with future repeat assessments.

Recommendations for ongoing monitoring include the following:

- Reassessment of baseline estuary characteristics at approximately five-year intervals in accordance with the EMP. We also note the potential applicability of conducting high-resolution mapping of defined high-value or at-risk areas using drone-operated low altitude photographic coverage at more frequent intervals.
- Inclusion of at least one additional intertidal site within the estuary that is more representative of other EMP-monitored New Zealand estuaries (*e.g*. with a higher sediment sand content).
- Incorporation of water and / or shellfish quality information into state of the environment reporting for the estuary.
- Investigation of the tidal range of salinities of overlying estuarine waters to complement interpretation of the ecological condition of the estuary.
- Monitoring of the coverage of potentially problematic macroalgal taxa over successive years.

- Investigation of the extent of habitat change over time by comparing boundaries detectable in historical aerial photographs. Review of historic literature to give greater understanding of the hydrological and ecological changes that have occurred within the estuary.
- Exploratory sampling of the subtidal benthic habitat to find reference sites appropriate for incorporation into the on-going fine-scale monitoring programme.
- Collection and analysis of long (*e.g*. >1 m) sediment cores for assessment of historical variations of sediment depositional rates.
- Engagement / consultation with local iwi to build on knowledge of the history and value of the Wairau Estuary.

Figure 1. Map of the Wairau Estuary.

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1. GENERAL INTRODUCTION

The intertidal[2] and supra-littoral[3] habitats associated with estuaries provide a link between terrestrial and marine environments. They are functionally important and provide a number of ecosystem services, including primary and secondary production, nutrient retention / processing and sediment trapping. These services contribute to the capacity of estuaries to function as a land / sea buffer that is critical to the sustainability of coastal ecosystems. Estuarine habitats are of high ecological value and contain resources of significant cultural, recreational and commercial worth.

In 2002, a standardised set of estuarine monitoring methodologies termed the Estuarine Monitoring Protocol or EMP (Robertson *et al*. 2002) was created by Cawthron as a tool to assess the environmental condition or 'health' of New Zealand estuaries. Use of this standardised protocol ensures long-term relevance of monitoring datasets, allowing comparisons of past monitoring efforts within an estuary as well as a means of cross-referencing with other estuaries that have been similarly assessed.

The EMP methodology includes three stages, the first being a general overview of background descriptive information and preparation of a preliminary decision matrix (DM) designed to facilitate community engagement with the monitoring process and prioritise monitoring efforts. The second and third stages involve broad-scale mapping of estuary habitats and fine-scale assessment of a suite of benthic characteristics at selected intertidal reference sites respectively. In combination, the results of these three stages are considered sufficient to indicate an overall level of estuarine condition and provide a point-in-time baseline for assessment of change over time.

Local reminisces of people with long-term ecological and customary knowledge is increasingly recognised and valued as a way to enable better understanding of long-term ecological change. This information can supplement scientific studies that seek to establish baselines from which to measure change.

1.1. Report scope and objectives

As part of their 2012 coastal monitoring strategy, the Marlborough District Council (MDC) aim to incorporate major estuaries within the Marlborough region into a long term monitoring programme. The MDC prioritised the Wairau Estuary (Figure 1) for monitoring in 2015. Cawthron Institute (Cawthron) was commissioned to conduct this work in March-May 2015.

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[2] Area of seabed between spring high and spring low tidal levels.
[3] Area of land above the spring high tide that borders the intertidal habitat.

Envirolink funding (1588-MLDC105) also allowed Cawthron to collect reminisces of the Wairau Estuary from selected local community members. This information was summarised and used to assist with the interpretation of biophysical information. A preliminary decision matrix, scoring the ecological status and values of the Wairau Estuary (Appendix 1), was created to facilitate community engagement and help prioritise the estuary for environmental monitoring.

The aim of this report was to use the EMP to provide a ‘point in time’ baseline of estuary characteristics with the purpose of indicating the environmental condition or ‘health’ of the estuary. As the first stage of the EMP was only partially completed, the report focuses on stages two (broad-scale habitat mapping) and three (fine-scale benthic surveys).

The overall scope and primary objectives of this work are outlined below.

- **Broad-scale vegetation and structural class habitat mapping for 2015 based on EMP protocol**

This includes a methodology outline along with results and discussion including comparisons with other estuaries within the region. Additional high resolution images collected by drone of a subset of the estuary, and a comparison of these with the aerial photos used for habitat mapping, were also included.

- **Fine-scale benthic surveys for 2015 based on EMP protocol**

This includes a methodology outline along with results and discussion (including comparison with other estuaries) from fine-scale surveys based on a suite of biological, chemical and physical indicators.

A DVD-ROM with access to a working version of the completed habitat maps, the full drone image and fine-scale survey results, is also provided.

- **Summary of estuary condition**

This includes a discussion of both broad-scale and fine-scale indicators of estuary condition, supplemented by information gathered from reminisces of local community members.

- **Recommendations for ongoing monitoring.**

This includes recommendations for future broad-scale and fine-scale monitoring and collection of supplemental information, as well as for future engagement with the local community.

1.2. Study area

Wairau Estuary (Figure 1) is 7.5 km south-east of Blenheim in the Marlborough region and is reported to be the largest estuary on the east coast of the South Island (Davidson *et al*. 2011). It was created when sea levels rose approximately 6500 years ago and coastal currents transported gravel and stones northwards, forming the 8-km long Wairau Boulder Bank that separates the estuary from Cloudy Bay. It is a complex system encompassing intertidal and shallow-subtidal[4] estuarine habitats with channels extending into expansive, shallow, lagoon-like arms with restricted tidal flushing[5]. According to the classification scheme proposed by Kirk & Lauder (2000) the Wairau Estuary can be described as a micro-tidal (tidal range < 2 m) 'choked' lagoon system. The intertidal zone is largely surrounded by exotic and native supra-littoral vegetation. It is influenced by both salt water, entering through the Wairau Bar, and fresh water, largely from the Wairau and Opawa Rivers. Tidal heights / times often vary from the outside coast due to physical restrictions of tidal flow and are also influenced by rain and wind.

The Wairau Estuary boasts national ecological significance (Davidson *et al*. 2011) and Cromarty & Scott (1995) argue that it also meets the criteria for international importance. Over ninety bird species have been recorded from the area with 27% of these listed as endangered, vulnerable or rare: *e.g*. black stilt (*Himantopus novaezelandiae*) and wrybill (*Anarhynchus frontalis*). The estuary is used by some bird species as a winter roosting site (*e.g.* black-fronted tern (*Chilodonias albostriatus*) and black-billed gull (*Larus bulleri*)), while others use it for breeding (*e.g*. red-billed gull – *Larus novaehollandiae scopulinus*) (Mike Bell, pers. comm.). The estuary also hosts international migratory waders such as eastern bar-tailed godwits (*Limosa lapponica baueri*). The estuary is a habitat for over 20 fish species, some of which utilise it as a nursery *e.g.* yellow-belly flounder and sand flounder (*Rhombosolea leporina* and *R. plebeia*) (Cromarty & Scott 1995). Expansive salt marsh flats are a significant ecological feature of the estuary (Davidson *et al.* 2011). The estuary also has national geological significance as its river mouth lagoon, bird's-foot delta and narrow boulder barrier provide some of the best examples of these geological features in New Zealand (Hayward *et al*. 1999).

[4] Area of land that is always covered by the sea.
[5] Tidal range within the Wairau Estuary varies from 0.4 – 1.1 m (Knox 1990).

Figure 1. Map of the Wairau Estuary.

The Wairau Estuary has extremely high cultural, historical and archaeological significance. It has a long history of human occupation as it is the oldest known site of Maori habitation in Marlborough (and possibly New Zealand). European settlement began in the 1840s (Marlborough District Council 2008). It is valued by humans for its cultural, aesthetic and scenic values, and as a place for recreational fishing, game bird hunting, walking, kayaking and bird watching.

Both naturally-occurring and human-related impacts have extensively modified the Wairau Estuary. This area has been subjected to structural alterations from historic earthquakes (Clark *et al.* 2015), and more recently the Marlborough (1848) and Wairarapa (1855) earthquakes have caused subsidence within the estuary (Basher *et al.* 1995). The following human-related activities have impacted the Wairau Estuary by modifying its natural geomorphological, hydrological and biological regimes.

- Pre-European Maori activities - land clearance and the creation of canals.
- European settlement - flood control including drainage ditches, stopbanks, river channel diversions and stabilisation of the river mouth bar entrance. This includes the creation of the Opawa Breach in 1917 and the Wairau Diversion in 1963 (Christensen & Doscher 2010).

- Changing land use activities within the Wairau River catchment e.*g*. recent large-scale conversion of horticultural and pastoral land to viticulture (Marlborough District Council 2008).
- Installation and expansion of the Blenheim Sewerage Treatment Plant (BSTP). The BSTP processes domestic sewerage as well as industrial waste such as that originating from wineries at the Riverlands Industrial Estate. Wastewaters are discharged into the Wairau Estuary only during ebb tide flows, thus directing flows seaward and preventing direct inflow to the estuary.

These modifications have likely had profound biophysical effects on the estuary including:

- Reduction and / or alteration of original wetland areas.
- Increased storm-related suspended sediment discharge from the catchment.
- Increased deposition of sediments within the estuary.
- Build-up of sediments along estuary margins (conversion of intertidal to terrestrial habitat).
- Altered plant and animal composition.
- Changes in nutrient loading and dynamics.

This has resulted in the overall degradation of estuarine function (Davidson *et al.* 2011) and the partial loss of connectivity of the estuarine system with the coastal-sea environment. Further detailed description of the Wairau Estuary and its impacts can be found in Knox (1983, 1990).

2. BROAD-SCALE HABITAT MAPPING

2.1. Introduction

Stage two of the EMP recommends the use of field-verified broad-scale mapping of habitat zones as a key component to monitoring estuary condition (Robertson *et al.* 2002). The broad-scale habitat mapping approach provides a description of the intertidal environment according to dominant habitat types based on substrate characteristics (*e.g*. mud, cobble, shellfish beds *etc*.) and the vegetation present (*e.g*. rushland, herbfield, macroalgal bed *etc*.) in order to develop a baseline map of the estuary. This involves the use of aerial photography together with detailed ground-truthing and digital mapping using Geographical Information System (GIS) technology.

Once a baseline map has been constructed, changes in the position and / or size of habitats can be assessed by repeating the mapping exercise over time and, where available, by comparison against historical information. This information can then be used to evaluate changes associated with natural perturbations, such as flood / climatic events and human impacts, such as land management practices (and related river water quantity and quality), on the structure of the intertidal ecosystem.

To accompany traditional broad-scale mapping techniques, Cawthron trialled the use of a drone to capture higher-resolution aerial photographs of a chosen subset of the estuarine habitat. The ultimate aim of using a drone was to investigate its potential to provide a more rapid detailed mapping output for regions of high value and / or potentially subject to short term disturbance effects.

2.2. Methods

2.2.1. Mapping of habitat areas

Aerial photography

Colour aerial photographs of the Wairau Estuary were taken between 2 December 2011 and 2 April 2012. These contained data sourced from Marlborough District Council under CC-BY, and the imagery was supplied as 0.40 m/pixel resolution (0.4 m GSD), 3-band (RGB) uncompressed GeoTIFF. Aerial photos from 2005 were referred to in order to determine the extent of any areas not covered by the 2011/12 photos.

High resolution (0.043 m/pixel) colour aerial photographs were also collected from an altitude of 120 m by a fixed-wing drone on 19 March 2015 between the times of 10:54 - 11:03 am. These were taken of a subset (31 ha) of the eastern side of the Upper Lagoon that encompassed subtidal (including a number of canals), intertidal and supra-littoral habitats (Figure 2).

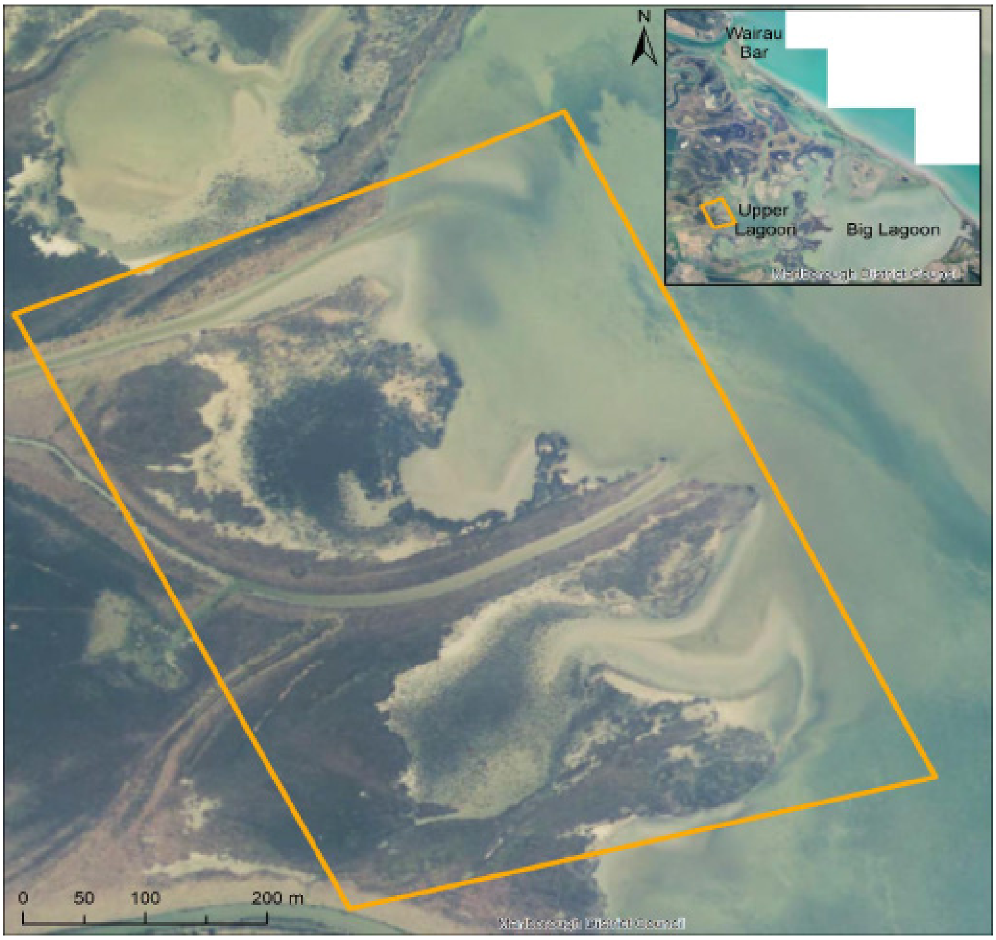

Figure 2. Map showing area within the Upper Lagoon where aerial photographs were collected by the drone (orange square), Wairau Estuary.

2.2.2. Ground-truthing of habitat features

By displaying different textural and tonal patterns, aerial photographs indicate the presence and spatial extent of different substrate and vegetation types. To identify the dominant habitats present and confirm the boundaries between them, field surveys were undertaken between March and May 2015 covering the majority of the estuary from approximately spring high to low tidal elevations. Dominant habitat types including various categories of bare and vegetated substrate were recorded directly onto laminated copies of the aerial photographs using the codes listed in (Appendix 3) and described in detail in (Appendix 4).[6]

The upper intertidal boundary was set at the apparent Mean High Water Spring (MHWS) and the lower boundary was set at approximately Mean Low Water Spring (MLWS). However the Wairau Estuary habitat is structurally complex and intertidal

[6] Throughout the report, '2015' in reference to the broad-scale mapping refers to the combined findings from the 2011/12 aerial photographs and the 2015 ground-truthing exercise.

boundary margins were often unclear. We subjectively based these boundaries on observations made by the field team during the ground-truthing exercise. In some cases, vegetation types normally classified as intertidal (*e.g*. herbfield, rushland) were excluded from the intertidal zone as they appeared to have limited connectivity with the estuarine habitat (*i.e.* were rarely, if at all, inundated), and were therefore regarded as terrestrial in function. A 10 m wide riparian strip above MHWS (called the supra-littoral fringe) was also assessed visually to enable general comment on the type of habitat surrounding the edge of the estuary.

2.2.3. Digitisation of habitat boundaries

Vegetation and substrate features were digitally mapped from the rectified photographs using ArcMap 10.2.2 GIS software. This procedure involved creating digital polygons of the field-verified habitat features as precisely as possible by tracing them directly from the aerial photographs within the GIS software. The software was then used to produce digital maps and calculate the area cover of each habitat type.

Classification and definition of habitat types

The classification of substrate and habitat features is based on the estuarine national classification system (with adaptations), which was developed under the Ministry for the Environment Sustainable Management Fund programme (Monitoring Changes in Wetland Extent: An Environmental Performance Indicator for Wetlands) by Lincoln Environmental, Lincoln. The classification system for wetland types is based on the Atkinson System (Atkinson 1985) and covers four levels, ranging from broad- to fine-scale (Appendices 3 and 4). The broad-scale mapping focusses on Levels III (Structural Class) and IV (Dominant Cover). Substrate classification is based on surface layers only and does not consider underlying substrate (*e.g.* gravel fields covered by sand would be classed as sand).

The classification of soft sediment substrates as described in the EMP (Robertson *et al*. 2002), has been problematical for a number of reasons. Most importantly, it is not possible to distinguish boundaries for these categories visually from aerial photographs. This necessitates highly detailed ground-truthing, which is not always feasible in large estuaries. At best, the distinction amongst these categories can be subjective as they are determined by noting the “softness” of the sediment while carrying out the ground-truthing exercise. In particular, the distinction between firm, soft and very soft mud / sand substrata can be affected by the amount of interstitial water present at the time of the survey. In order to further assess the utility of these categories for broad-scale mapping of the Wairau Estuary, a calibration experiment was undertaken. Composite samples of the top 10 cm of sediment were collected from a range of representative mudflat locations (Appendix 5) and characterised according to a detailed grain size analytical procedure. Descriptions using EMP classifications of this sediment were compared between those subjectively determined from field observations and those based on the analytical grain size analysis results.

Habitat codes and terminology

Dominant biota with a spatial coverage greater than 2 m in diameter was classified using an interpretation of the Atkinson (1985) system. In this report, biota and substrata are listed in order of dominance as described below:

- Individual plant species are coded using the two first letters of their Latin genus and species names: *e.g.* Pldi = *Plagianthus divaricatus* (ribbonwood), Lesi = *Leptocarpus similis* (jointed wire rush).
- Subdominant species are indicated by an underscore (_): *e.g*. Lesi_Pldi = Pldi is subdominant to Lesi. The classification is based on the subjective observation of which vegetation is the dominant or subdominant species within the patch, and not on percent cover.

Individual features in the GIS maps have been labelled in the same manner as that described above.

2.3. Results and Discussion

2.3.1. Estuary habitat and substrate characteristics

A total of 1576 ha of estuary habitat was mapped within the Wairau Estuary, the intertidal area of which comprised 359 ha (Tables 1 and 2). Detailed maps show the estuary areas covered by the dominant substrate and vegetation types (Figures 3 and 4). An additional 59 ha of supra-littoral margin (a 10 metre strip above the high tide mark) was also mapped (See section 2.3.2). We note that some small habitat areas cannot be seen at the scale of the maps; however, these areas are quantified in Appendices 6 and 7. Individual GIS layers can be accessed and evaluated through the DVD-ROM in Appendix 8.

In terms of overall size the Wairau Estuary is large compared to many other prominent Marlborough / Nelson estuaries, with the exception of Waimea Inlet which is approximately twice as big (Table 3). The Wairau Estuary is reported to be the largest estuary on the east coast of the South Island (Davidson *et al*. 2011), highlighting its significance on a regional and national scale. However, intertidal habitat in the Wairau Estuary comprised only 23% of the total estuary, a proportionally small area compared to other Nelson / Marlborough estuaries (Table 3). Subtidal habitat accounted for 1218 ha (77%) of the total estuary area (Table 1). The subtidal area was proportionally very large compared to other estuaries in the surrounding region (Table 3). This is due to the reduced tidal range and flushing that is a feature of the Wairau Estuary ‘choked’ lagoon system.

Vegetated habitat covered 193 ha (12%), and unvegetated habitat covered 166 ha (11%), of the total estuary area (Table 1). However, when only the intertidal zone is considered, vegetated and unvegetated habitat coverage was 54% and 46%

respectively (Table 2). Compared to other estuaries within the Nelson / Marlborough region, the proportion of vegetated habitat in the intertidal zone is very high (Table 4).

Table 1. Key broad-scale habitats within the total Wairau Estuary area (subtidal and intertidal) in 2015.

Habitat Groupings	Area (ha)	% Total Estuary Area
Water	1217.61	77.25
Unvegetated habitats	165.51	10.50
Vegetated habitats	193.00	12.25
Total area of estuary	1576.12	

Table 2. Breakdown of intertidal broad-scale habitats within the Wairau Estuary in 2015.

Habitat Groupings	Area (ha)	% Total Intertidal Area
Unvegetated habitats	**165.51**	**46.17**
Cobble field	0.96	0.27
Gravel field	0.94	0.26
Woody debris (driftwood)	2.12	0.59
Man-made structures	0.027	0.008
Mud/sand habitats	**161.46**	**45.04**
Firm mud/sand	57.15	15.93
Soft mud/sand	104.31	29.09
Vegetated habitats	**193.00**	**53.83**
Herbfield	156.82	43.74
Rushland	8.98	2.50
Grassland	5.38	1.50
Estuarine shrubs	0.21	0.06
Macroalgal bed	21.61	6.03
Total intertidal area	**358.52**	

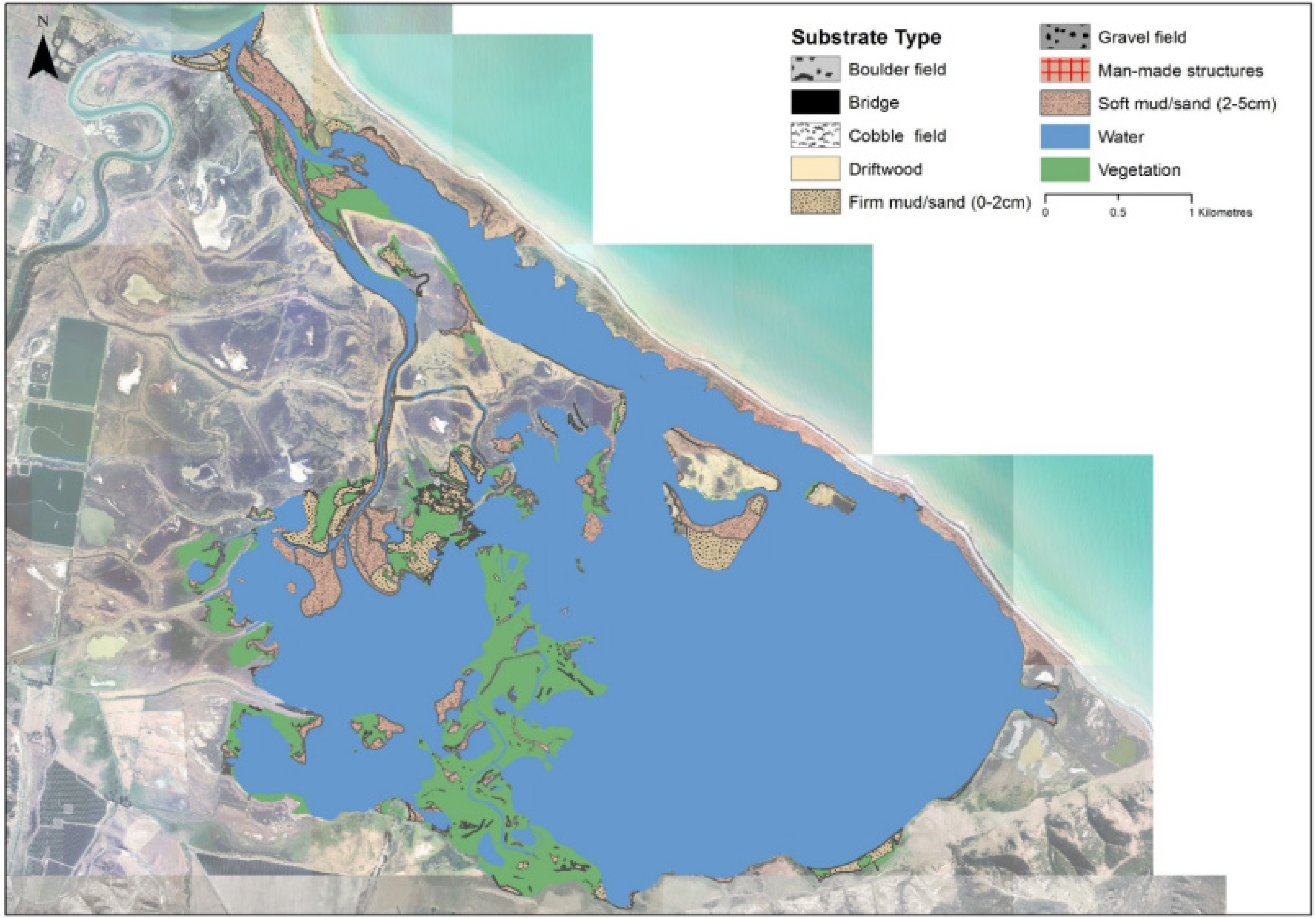

Figure 3. Aerial photograph of the Wairau Estuary showing digitised substrate characteristics in 2015.

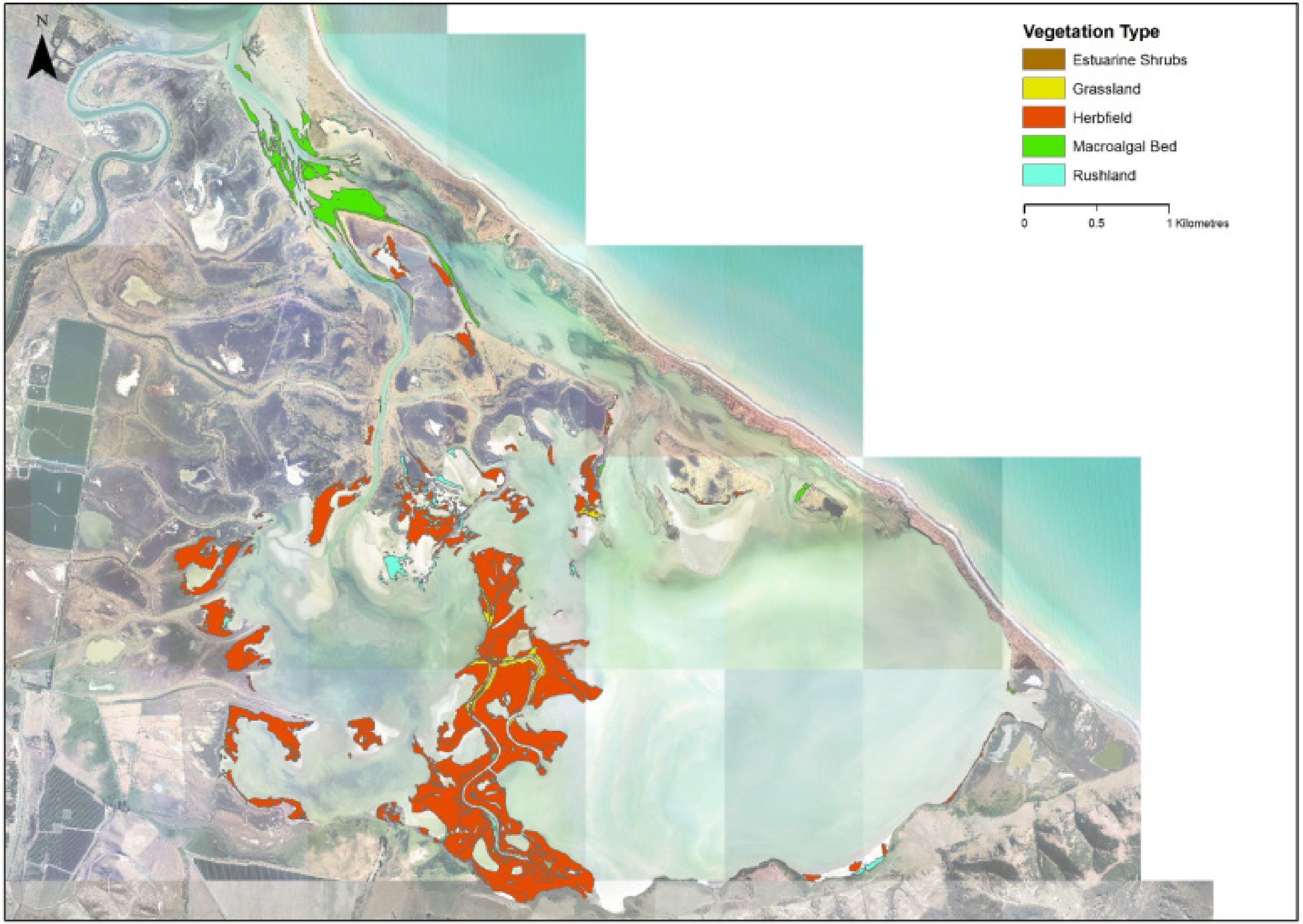

Figure 4. Aerial photograph of the Wairau Estuary showing digitised vegetation present in 2015.

Unvegetated habitats

The Wairau Estuary intertidal zone contained no sand habitat. Except for Havelock Estuary, this is in contrast to the other Nelson / Marlborough estuaries in Table 4, all of which contain sand habitat that proportionally comprises between 10-32% of intertidal habitat. Instead, unvegetated habitats within the Wairau Estuary intertidal zone were dominated by mud / sand substrates (162 ha, 45%) (Table 2, Figure 5). The proportional area of mud / sand substrates within the intertidal zone of the Wairau Estuary is comparable to other Nelson / Marlborough estuaries (26–71%) (Table 4).

Although further definition in classification of the soft sediment habitats is difficult because the boundaries are not often discernible on the aerial photographs, we attempted this through detailed ground-truthing. However, we note that our sediment classification categories (firm mud / sand and soft mud / sand - Appendix 4) using EMP protocol are subjective. This is indicated by the results from our sediment grain size calibration experiment where sediments classified using EMP protocol during field observations displayed highly variable proportions of mud, particularly in relation to their described softness (Table 5). This highlights the need to interpret grain size classifications with caution and suggests that the separation of these classifications may not be of ecological significance. However, muddy substrates as a whole are often indicative of reduced biodiversity and ecological health within estuarine environments. Muddy (classified as mud / sand) substrates within the Wairau Estuary intertidal zone comprised of 104 ha (29%) soft mud / sand and 57 ha (16%) firm mud / sand (Table 2).

Although these soft sediment habitats are classed as “unvegetated”, they harbour a surface community of benthic microalgae, primarily diatoms[7]. These communities are described in detail in section 3.3.3.

Hard substrates within the intertidal zone of the Wairau Estuary covered only a relatively small area (4 ha, 1%) (Table 2). These substrates consisted of cobble / gravel fields (2 ha, 0.5%) primarily located along the edge of the boulder bank, as well as woody debris (driftwood) piled up along estuary margins (Figure 6). Cobble / gravel fields within some other Nelson / Marlborough estuaries comprised a higher proportion of the intertidal zone (5-12%) compared to those within the Wairau Estuary (Table 4).

No Pacific oysters were observed within the Wairau Estuary during the current survey. Pacific oysters (*Crassostrea gigas*) have been in the Nelson / Marlborough region since the early 1980s (Bull 1981) and have subsequently colonised a number of estuaries (*e.g*. Gillespie 2009, Gillespie *et al.* 2011a and 2011b, Stevens & Robertson 2014). They are known to significantly alter the natural and biological characteristics

[7] A group of unicellular planktonic or benthic marine microalgae that have cell walls containing silica. They can also occur in freshwater and terrestrial environments.

of estuary habitats and may compete with other suspension-feeding organisms (*e.g.* cockles).

Table 3. A comparison of the percent coverage (of the total estuary habitat) of key broad-scale features in the Wairau Estuary with other Nelson / Marlborough estuaries.

Habitat	Wairau Estuary 2015 (%)*	Nelson Haven 2009 (%)[A]*	Delaware Inlet 2009 (%)[B*]	Waimea Inlet 2006 (%)[C]	Ruataniwha 2002 (%)[D]	Moutere 2004 (%)[E]	Havelock Estuary 2014 (%)[F]
Water	77.3	31.5	6.2	11.8	15.9	7.5	30
Unvegetated	10.5	53.10	74.7	77.0	68.7	81.4	45[8]
Vegetated	12.3	15.4	19.1	11.1	15.4	11.1	25[9]
Total area of estuary (ha)	**1576**	**1242**	**353**	**3345**	**863.5**	**762**	**801**

* Supra-littoral fringe habitats were removed from Wairau Estuary, Nelson Haven, Delaware Inlet and Havelock Estuary areas of the current comparison.
A Gillespie *et al*. 2011a
B Gillespie *et al*. 2011b
C Clark *et al*. 2008
D Robertson *et al*. 2002
E Stevens & Robertson 2014

Table 4. A comparison of the percentage coverage (of the intertidal zone only) of dominant vegetated and unvegetated habitats in the Wairau Estuary with other Nelson / Marlborough estuaries.

Habitat	Wairau Estuary 2015 (%)*	Nelson Haven 2009 (%)[A]*	Delaware Inlet 2009 (%)[B*]	Waimea Inlet 2006 (%)[C]	Ruataniwha 2002 (%)[D]	Moutere 2004 (%)[D]	Havelock Estuary 2014 (%)[E]
Unvegetated	**46.17**	**77.52**	**79.64**	**87.30**	**81.68**	**88.00**	**64.07**[8]
Mud/sand habitats	45.02	48.61	26.44	64.97	40.43	71.35	51.50[8]
Sand habitats	0.00	22.19	31.77	12.24	29.49	9.95	0.00
Gravel/cobble	0.53	4.82	8.32	9.75	11.77	6.49	8.50
Vegetated	**53.83**	**22.48**	**20.36**	**12.59**	**18.31**	**12.00**	**35.93**[9]
Herbfield	43.74	0.73	1.92	5.22	0.48	4.11	1.38
Reedland	0.00	0.00	0.21	0.00	0.00	0.00	0.01
Rushland	2.51	0.07	4.80	3.51	15.93	6.05	33.98
Seagrass meadow	0.00	14.01	1.39	0.68	1.66	0.11	3.84[9]
Sedgeland	0.00	0.00	0.05	0.01	0.00	0.00	0.02
Total intertidal area of estuary (ha)	**358.52**	**850.77**	**331.11**	**2950.29**	**726.20**	**704.85**	**565**

* Supra-littoral fringe habitats were removed from Wairau Estuary, Nelson Haven, Delaware Inlet and Havelock Estuary areas of the current comparison.
A Gillespie *et al*. 2011a, B Gillespie *et al*. 2011b, C Clark *et al*. 2008, D Robertson *et al*. 2002, E Stevens & Robertson 2014

8 Includes cover of seagrass and macroalgae.
9 Excludes cover of seagrass and macroalgae.

Figure 5. Unvegetated intertidal habitat consisting of mud / sand substrate in the Big Lagoon, Wairau Estuary 2015.

Figure 6. Cobble field and woody debris (driftwood) along the inner margin of the Wairau Estuary Boulder Bank, 2015.

Table 5. Results from a sediment grain size calibration experiment where composite samples of the top 10 cm of sediment from a range of representative soft sediment locations were characterised according to a detailed grain size analytical procedure. Sediment description using EMP classification based on field observations and analytical grain-size calibration results, are included. Grain size is defined as: mud < 63 µm (bolded in table), sand > 63 µm < 2 mm and gravel > 2 mm < 20 mm (Robertson *et al*. 2002). Site descriptions and locations provided in Appendix 5.

Grain size/dry matter	**Units**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
EMP description according to field observations		VSM-Very soft mud/sand	VSM-Very soft mud/sand	SM- soft mud/sand	SM- soft mud/sand	FM- firm mud/sand	FM- firm mud/sand	SMS- soft mud/sand	FMS- firm mud/sand	FMS- firm mud/sand
Fraction >/= 500 µm	g/100g dry wt	0.1	3.6	0.1	0.2	0.2	0.2	2.8	2.4	0.2
Fraction >/= 250 µm	g/100g dry wt	0.2	5.5	0.3	1.1	0.5	0.3	4.6	4.1	0.5
Dry Matter	g/100g as rcvd	73	51	71	77	69	81	55	50	75
Fraction >/= 2 mm	g/100g dry wt	< 0.1	0.5	< 0.1	0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1
Fraction < 2 mm, >/= 1 mm	g/100g dry wt	< 0.1	1.2	< 0.1	< 0.1	< 0.1	< 0.1	1	0.8	< 0.1
Fraction < 1 mm, >/= 500 µm	g/100g dry wt	< 0.1	1.9	< 0.1	< 0.1	0.2	< 0.1	1.7	1.5	< 0.1
Fraction < 500 µm, >/= 250 µm	g/100g dry wt	0.1	1.9	0.2	0.9	0.3	< 0.1	1.8	1.7	0.3
Fraction < 250 µm, >/= 125 µm	g/100g dry wt	2.1	6.6	0.9	9.4	1.3	6.6	8.8	5.9	5.7
Fraction < 125 µm, >/= 63 µm	g/100g dry wt	24.9	10.5	7.1	29.5	7.6	35.6	12.6	9.1	18.3
Fraction < 63 µm	**g/100g dry wt**	**72.8**	**77.4**	**91.6**	**60**	**90.6**	**57.5**	**74.1**	**80.9**	**75.6**
Dry Matter	g/100g as rcvd	73	51	71	77	69	81	55	50	75
EMP description based on grain-size calibration		Mud/sand*	Mud/sand*	Mud/sand*	Mud/sand*	Mud/sand*	Mud/sand*	Mud/sand*	Mud/sand*	Mud/sand*

* Due to the small proportion of grains larger than 2 mm, the subdominant habitat would be gravel field.

Vegetated habitats

The most extensive vegetated habitat within the Wairau Estuary intertidal zone was salt marsh, which encompassed a number of vegetation classes. The most abundant of these was herbfield (157 ha, 44%) (Figure 7), primarily glasswort (*Sarcocornia quinqueflora*) (Figure 8, Table 2). The next most abundant was rushland (9 ha, 3%), primarily sea rush (*Juncus kraussii*) (Figure 8). Grassland, dominated by tall fescue (*Festuca arundinacea*), also covered 5 ha (2%) of intertidal habitat. Herbfield and rushland generally comprise significant proportions of salt marsh habitat within other Nelson / Marlborough estuaries (Table 4). These upper intertidal habitats are functionally important in that they are areas of active production and decomposition (Gillespie & MacKenzie 1981). They also act as a filter at the land sea interface and can assimilate inorganic nutrients and trap fine sediment. The high proportion (compared to other Nelson / Marlborough estuaries) of salt marsh within the intertidal zone makes it an ecologically significant component of the Wairau Estuary.

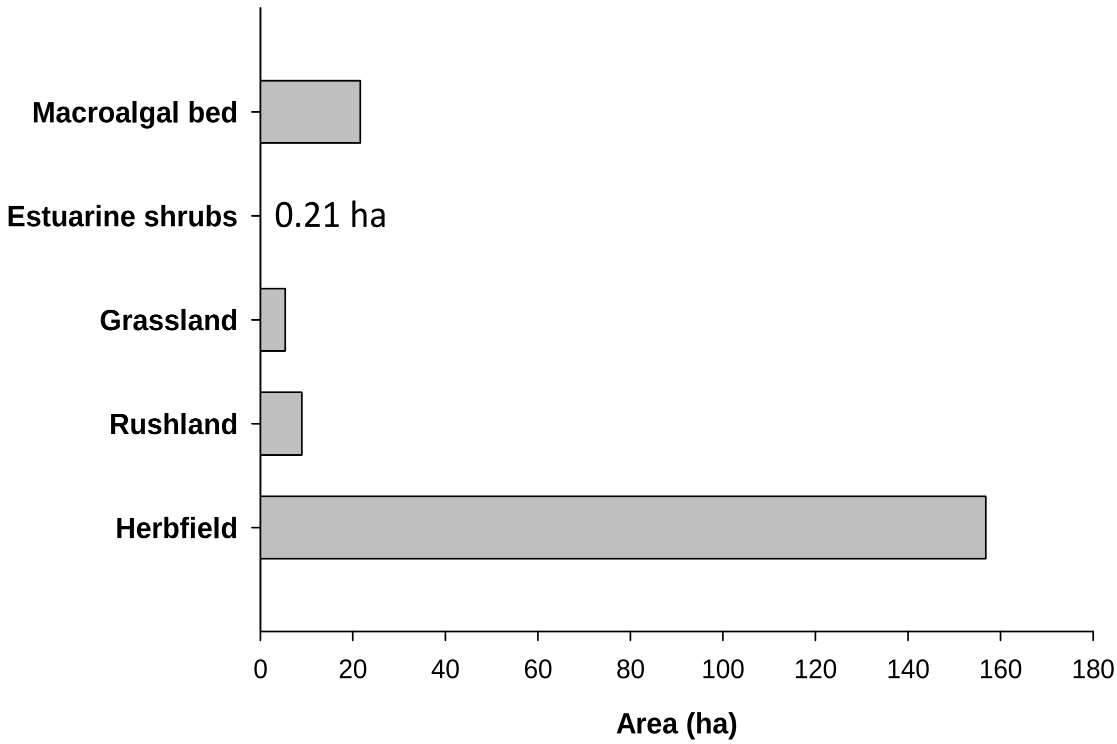

Figure 7. The overall area (ha) of vegetated habitats mapped within the Wairau Estuary, 2015[1].

Figure 8. Expansive salt marsh habitat dominated by glasswort (*Sarcocornia quinqueflora*) (top) and often containing sea rush (*Juncus kraussii*) (bottom), Wairau Estuary 2015.

The boundary between intertidal and supra-littoral zones was often unclear (see methods). A large proportion of vegetated habitat within the intertidal zone (and to a lesser extent in the supra-littoral) was considered unlikely to serve important ecological functions due to its apparent disconnection from the main estuary habitat (Figure 9). Vegetation within these regions appears to be in transition between estuarine and terrestrial habitat. In the intertidal zone these included herbfield (119 ha) and rushland (8 ha). In the supra-littoral fringe these included herbfield (14 ha), rushland (8 ha), and grassland (0.2 ha). The transition of vegetation from intertidal to terrestrial habitat may have been altered in response to changing sediment depositional rates within upper intertidal regions.

Cord grass (*Spartina* spp.) is an invasive maritime grass that was introduced in the early 1990s to assist with land reclamation (Brown & Raal 2013). It traps sediments and can form dense swards in New Zealand estuaries. Although cord grass used to be present in the Wairau Estuary, it was reportedly eradicated from the area in 1999 (Brown & Raal 2013) and was not observed during the current survey.

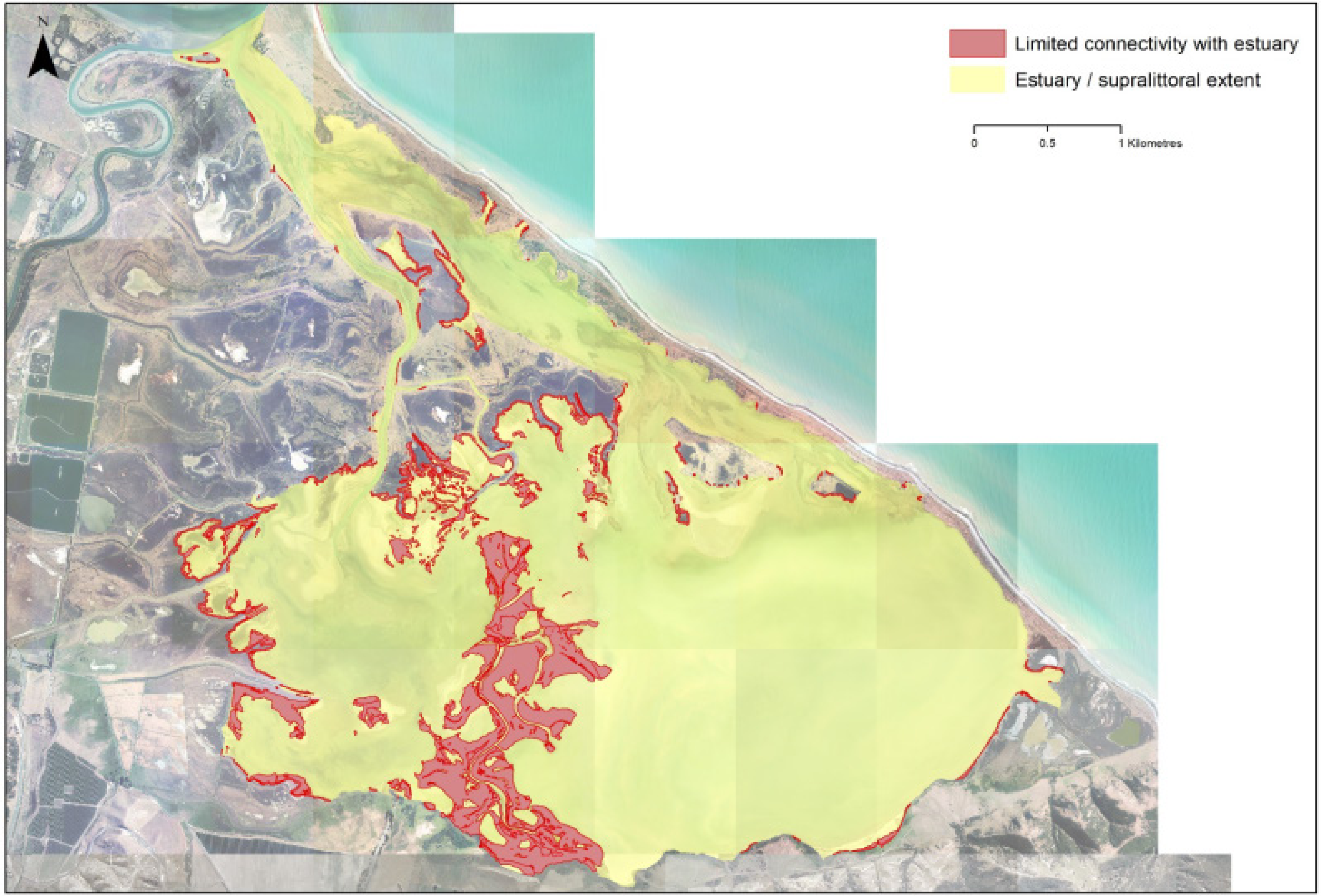

Figure 9. Map of the Wairau Estuary showing areas of intertidal and supra-littoral vegetation that exhibit compromised intertidal function (*i.e.* have limited connectivity with the main estuary habitat).

Macroalgal beds covered 22 ha (6%) of intertidal (Table 2), and 85 ha of subtidal, estuary habitat. Agar weed, tentatively identified as *Gracileria chilensis*, was the dominant macroalgal taxon within the Wairau Estuary. Agar weed formed beds attached to the seabed, particularly within the Te Aropipi Channel (Figure 10). However, it was also detached in some areas and observed drifting freely into shallow water and washed up in piles along the estuary margin (Figure 10). The agar weed beds appear to be relatively stable. Ground-truthing in 2015 confirmed their location to be similar to those in the 2011/12 aerial photographs.

Figure 10. Agar weed (*Gracilaria* sp.) beds growing within the Wairau Estuary (top), and washed up in piles along the edge of the intertidal region (bottom), 2015.

Although apparently native to New Zealand, this red algal species may be a relatively recent feature within the Wairau Estuary reflecting modified hydrodynamic conditions and / or increasing nutrient concentrations in overlying estuarine waters. During a discussion with long-time resident Ron Perano he commented that he had not seen this seaweed in the estuary in the past (see Appendix 2). A detailed ecological survey carried out in 1982 by Canterbury University (Knox 1983) also made no mention of its presence in the estuary. Agar weed can form dense beds in low intertidal and shallow subtidal regions of low current energy. Major increases in habitat coverage and productivity of agar weed in the Wairau Estuary may have had significant ecological ramifications, some potentially beneficial and some detrimental to natural ecosystem function. For example, agar weed can benefit biodiversity by adding structural complexity to otherwise relatively homogenous soft-bottom systems. It also provides food and shelter for a variety of estuarine fish and small invertebrates.

Agar weed can significantly alter the nutrient cycling characteristics and trophic dynamics of an estuary. Dense beds decrease light intensity reaching the seabed, increase the likelihood of sediment anoxia and change water movement patterns, which in turn affects sedimentation rates. Thus the expansion of *Gracilaria* beds may have resulted in a decline in production of other species of macro / micro algae and / or the disappearance of eelgrass meadows (see below). Investigations of the ecological effects of *Gracilaria vermiculophylla* in Europe have demonstrated negative effects on native seagrass beds of *Zostera marina* (Martínez-Lüscher & Holmer 2010).

Macroalgae can grow rapidly and are often dominant features of estuaries during summer months. Opportunistic species (*e.g. Ulva* spp.) can reach problem densities under enriched conditions. The results of the ground-truthing exercise (undertaken in March-May 2015), combined with information from historical aerial photographs and a discussion with Ron Perano, indicate that macroalgal abundance and type can vary over time within the estuary. For example, no sea lettuce (*Ulva* sp.) was recorded during ground-truthing in 2015; however, sea lettuce patches were present in other years as evidenced in 2005 and 2011/12 aerial photographs. More detailed assessments would be required to quantify temporal changes in macroalgal coverage within the Wairau Estuary (see report recommendations, section 5).

No eelgrass was seen during the current survey. This is in contrast to a number of other estuaries within the Nelson / Marlborough region that all contained at least some eelgrass habitat (Table 4). The presence of eelgrass (*Zostera muelleri*) within the Wairau Estuary was noted by Knox (1983). Ron Perano also recalled the existence of large eelgrass meadows within the Big Lagoon (Appendix 2). This suggests that the extent of eelgrass may have declined drastically, even completely, within the past 80 years. Although eelgrass possibly still exists subtidally within the estuary, this is improbable due to the likely soft mud nature of benthic sediments and reduced light at the seabed caused by poor water clarity. In New Zealand, sedimentation and nutrient enrichment are the major environmental stressors attributed to eelgrass decline (Matheson *et al*. 2009). Although we can only speculate, it is likely that hydrodynamic changes and increased sediment detrimentally impacted the historic eelgrass beds within the Wairau Estuary.

2.3.2. Supra-littoral fringe (estuary margin habitats)

The supra-littoral fringe covered 59 ha in total and was dominated by vegetated habitats (59 ha, 99%) (Table 6, Figures 11-12). This consisted largely of grassland (28 ha, 48%), primarily tall fescue (*F. arundinacea*) and exotic pasture grass (Figure 13). Supra-littoral vegetation also included herbfield (15 ha, 25%), primarily glasswort (*S. quinqueflora*), and rushland (8 ha, 14%), primarily sea rush (*J. kraussii*). Terrestrial shrub/scrub/forest, tussockland and reedland also made small contributions to vegetated supra-littoral habitat. As previously mentioned, intertidal and supra-littoral boundaries were often unclear. The herbfield and rushland areas, technically intertidal habitat, within the supra-littoral fringe were subjectively included due to their apparent limited connectivity with the main estuary habitat (Figure 9) (see section 2.2.2).

Vegetated habitats within the supra-littoral fringe help protect estuarine habitats by serving as a buffer zone around the estuary edge. However, the high abundance of exotic grasses (*e.g*. tall fescue and pasture grass) within the Wairau Estuary supra-littoral fringe is evidence of habitat modification and may contribute to reduced bank stabilisation and trapping of sediments before they enter the estuary.

Only a small amount of unvegetated habitat (0.4 ha, 0.6%) covered the supra-littoral fringe. This comprised a combination of water (*e.g*. channels / standing pools), hard (*e.g*. cobbles and boulders) and soft (mud/sand) substrates, and man-made structures (Table 6).

Table 6. Key habitats mapped within the Wairau Estuary supra-littoral fringe in 2015[1].

Habitat Groupings	Area (ha)	% Total Supra-littoral Area
Water	**0.01**	**0.02**
Unvegetated habitats	**0.35**	**0.58**
Mud/sand habitats	0.11	0.18
Cobble and boulder field	0.12	0.21
Man-made structures	0.12	0.20
Vegetated habitats	**59.00**	**99.39**
Grassland	28.24	47.56
Herbfield	14.74	24.83
Rushland	8.19	13.80
Estuarine shrub	2.14	3.60
Reedland	1.18	1.99
Terrestrial shrub/scrub/forest	2.08	3.50
Tussockland	2.44	4.10
Total area of supra-littoral	**59.36**	

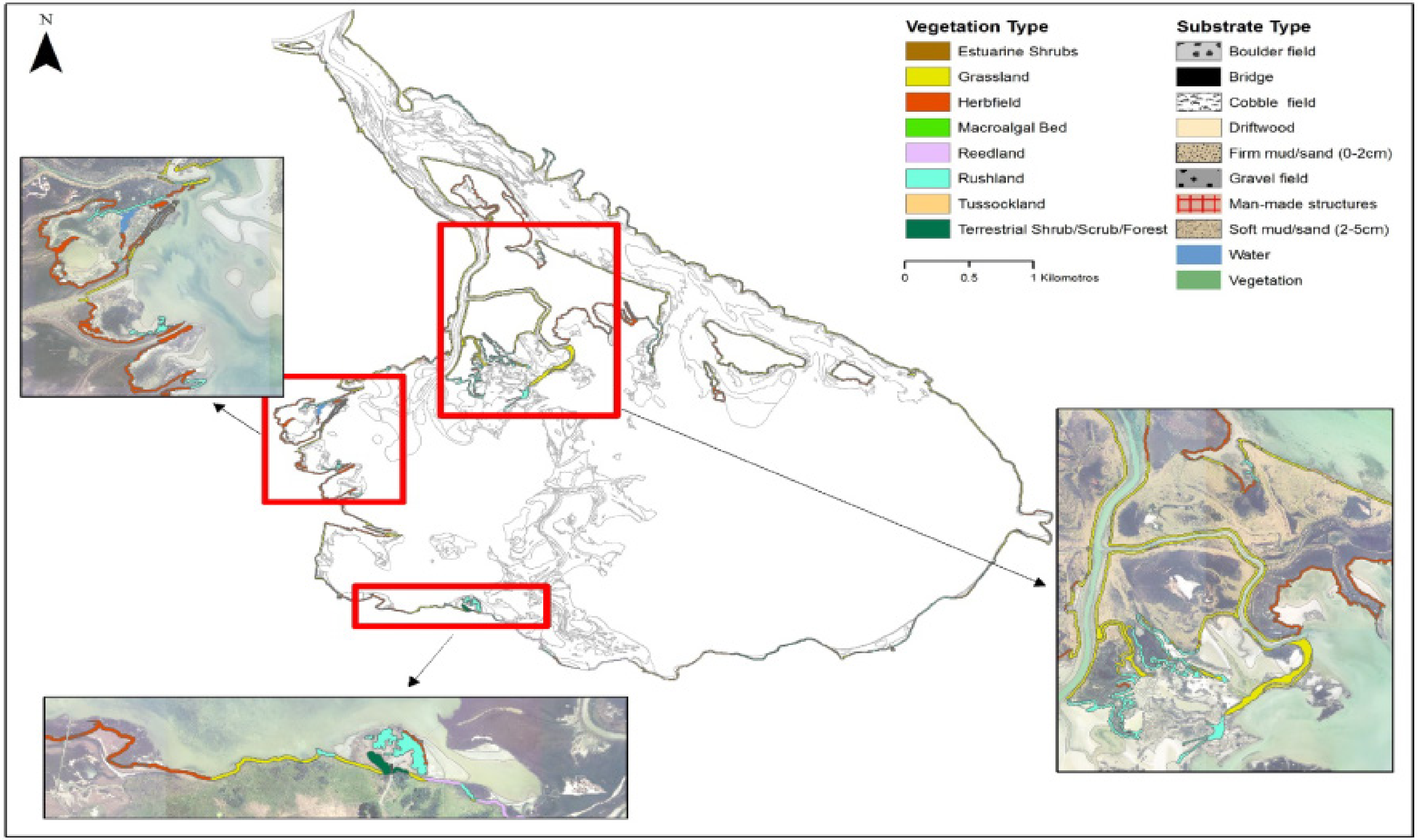

Figure 11. Map of the Wairau Estuary (2015[1]) showing the dominant habitat present in subsections of the supra-littoral fringe.

Figure 12. The area of vegetated habitats mapped within the supra-littoral fringe, Wairau Estuary, 2015[1]. Note that rushland and herbfield are intertidal, and not technically supra-littoral, habitats.

Figure 13. Supra-littoral fringe along the Wairau Estuary margin (in 2015) showing vegetation containing exotic grass (left), as well as herbfield (*S. quinqueflora*) and tall fescue grass (*F. arundinacea*) (right).

2.3.3. High-definition habitat mapping

In comparison to aerial photographs, the high resolution drone photographs (Figure 14) improved the accuracy of habitat mapping details within a subset of the Wairau Estuary. An image of the full drone coverage area can be viewed in Appendix 8. High quality output and relative cost effectiveness makes this an exciting new technique that could be successfully utilised to provide high quality mapping data at relatively short notice. This would be particularly useful for priority areas within the estuary that are of high value or that have been subject to short term disturbance *e.g*. flash flood or pollution incident.

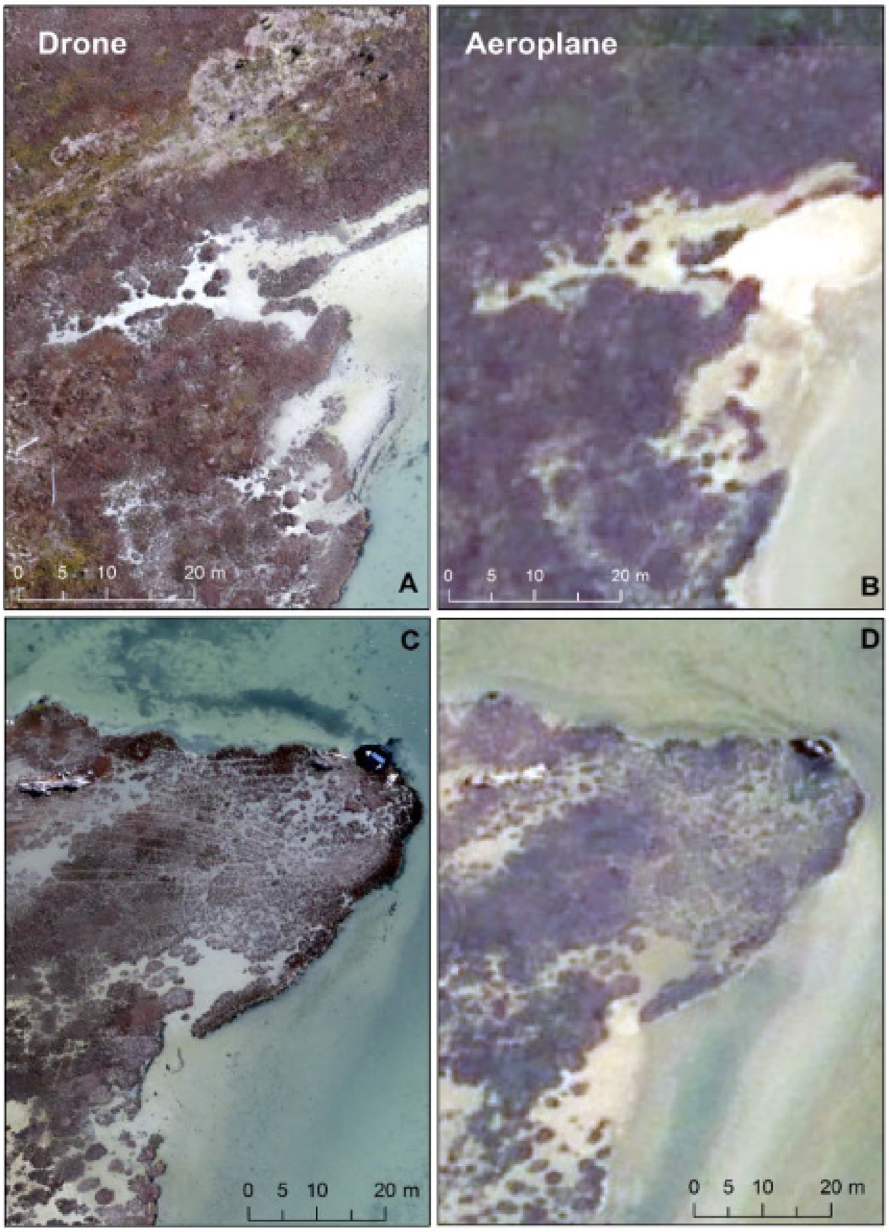

Figure 14. High resolution (0.043 m/pixel) photographs of subsets of the Wairau Estuary collected by fixed wing drone on 19 March 2015 (A, C). The 2011/12 aerial photographs of the same area are provided for comparison (B, D).

3. FINE-SCALE BENTHIC SURVEYS

3.1. Introduction

Stage three of the EMP outlines fine-scale benthic surveys that comprise the analysis of a suite of characteristics indicative of estuarine health. This is generally conducted at sites representative of major substrate types within an estuary. The aim is to provide a 'point in time' baseline for a range of benthic health indicators of estuary condition that can be used to monitor change over time. This also provides a means of cross-referencing with other similar estuaries for which comparable data is available.

3.2. Methods

3.2.1. Site selection and sampling design

Consultation with MDC resulted in the choice of three representative survey sites within the Wairau Estuary for fine-scale benthic sampling (Figure 15). These were situated on largely unvegetated tidal flats at approximately mid-low to low tidal elevations. Site A was positioned at the northern side of Upper Lagoon (Figure 16), Site B was located at the southern end of Big Lagoon, and Site C was positioned at the west side of the Te Aropipi Channel. Sites A and B were much further from the tidal outlet, the Wairau Bar, than Site C and as a consequence receive reduced tidal flushing.

Fine-scale sampling was carried out on 20 and 24 March according to procedures modified slightly from those of the EMP. At each location, a 30 x 60 m area containing twelve 150 m^2 (10 x 15 m) grids was marked out to achieve ten replicates per location (Figure 15). A limited amount of sampling space at Site B (due to limited tidal range within the Big Lagoon) necessitated modification of the sampling design to consist of two areas, measuring 15 x 60 m, positioned end on end parallel to the shoreline.

A 0.25 m^2 quadrat was placed randomly within 10 of 12 grid rectangles. The quadrats were photographed to provide a visual record and any obvious signs of pollution in the site location were noted. All remaining samples were collected adjacent to the quadrats (Figure 15).

Cores for sediment profile descriptions were collected with 62 mm diameter Perspex tubes pushed to a depth of at least 150 mm into the seabed. These cores were extruded onto a white viewing tray, sectioned longitudinally and photographed alongside a ruler. Sediment colour and texture profiles were described and the depth of any apparent redox discontinuity layer (RDL) was recorded.

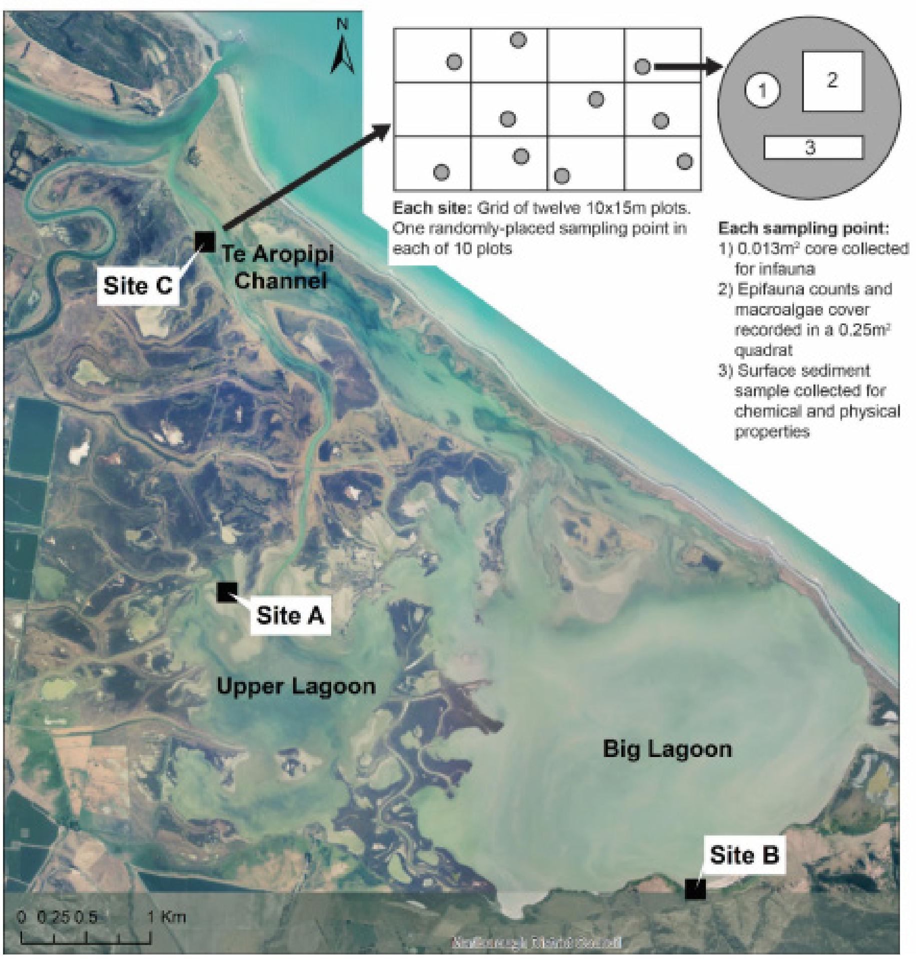

Figure 15. Map of the Wairau Estuary showing locations of the fine-scale benthic survey sites and the sampling layout (modified from Robertson *et al*. 2002). GPS coordinates of the corner points for each study site are listed in (Appendix 9).

Samples for physical and chemical analyses (Table 7) were scraped from the top 25 mm of sediment, returned to the laboratory and stored at either 4 ºC or -20 ºC depending on storage requirements, until analysed. Three composite samples were prepared for analyses by mixing replicates numbered 1-3, 4-6 and 7-10. A single site composite of all 10 replicate plots was prepared for analyses of semi-volatile organic compounds (SVOCs). The individual replicates were retained for later analyses in the event that high variability amongst composites was encountered.

To measure salinity, interstitial water (water seeping into core holes) was collected as a single composite for each site, returned to the laboratory and analysed using an ATI Orion (model 162) salinity meter.

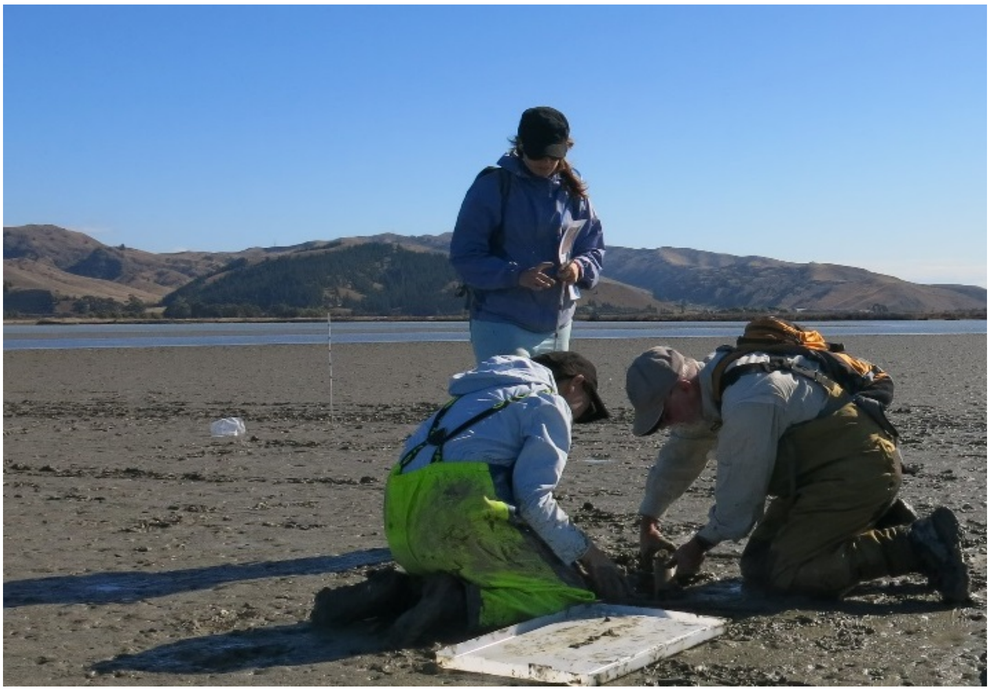

Figure 16. A field team collecting fine-scale samples at reference Site A in Wairau Estuary, 2015.

Observations around each site were made regarding the development of microalgal mats, detected as patchy yellow / green colouration on the surface of the sediment. If mats were detected, further sampling would be initiated for analysis of chlorophyll *a*[10] (chl-a) to provide a quantitative measure of mat density. This would involve slicing the top five mm of sediment from a 15 mm-diameter syringe barrel core collected from three randomly selected positions within the site. Since microalgal densities are known to be extremely variable, core positions would be intentionally selected to sample regions of visible yellow / green colouration in order to estimate maximum chl-*a* concentrations.

Any visible epibiota[11] within the 0.25 m^2 quadrats were identified and recorded. Crab and polychaete burrows / cases were also included in epibiota descriptions. Infauna[12] were collected by inserting a 130 mm diameter core to a depth of ≥100 mm into the sediment. The core contents were gently washed through a 0.5 mm mesh sieve attached to one end of the core and the residual was preserved with 95% ethanol (plus 5% Glyoxal) in seawater for later sorting, identification and counting. Five infaunal replicates (replicates 1, 3, 5, 7 and 9) were analysed for each of the three sites. The remaining samples were retained for later analysis in the event that high within-site variability was encountered.

[10] Photosynthetic pigment often used as a proxy for estimating phytoplankton or benthic microalgal biomass.
[11] Plants and animals on the sediment surface. This includes macrofauna and signs of them *e.g*. crab burrows.
[12] Animals living within the sediment matrix.

3.2.2. Sediment analyses

Sediments were analysed for a range of physical and chemical indicators of estuary condition (Table 7). The ANZECC (2000) Sediment Quality Guidelines were used to assess and interpret the contaminant status of the observed metals concentrations. The guidelines are risk-based criteria developed from a wide range of international data for different contaminants. For a range of contaminants, they specify an ISQG-Low (Interim Sediment Quality Guideline – Low) trigger level, representing a 10% probability that a significant toxicity measure will occur in sensitive species, and an ISQG-High value, representing a 50% probability. So, in terms of an expected observable biological effect attributable to the contaminant in question, the –Low level equates to a possible occurrence and the –High level, a probable occurrence. The guidelines do not account for the range of sediment types but it is typically accepted that the more bioavailable adsorbed contaminant fraction is associated with the high specific surface area of fine sediments. The trigger values are conservative criteria for sediment quality that, if complied with, ensure that specified environmental values are protected. However, the converse is not necessarily true (*i.e.* exceeding trigger values does not necessarily indicate environmental damage). The intent of these values is to act as a trigger for more intensive assessment if they are exceeded.

Table 7. Analytical methods and detection limits for sediment physical and chemical indicators (undertaken by Hills Laboratories).

Parameter	Method	Detection Limit
Grain Size	Wet sieving, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt
Total Organic Carbon	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]	-
Total Nitrogen	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]	-
Total Phosphorus	Dried sample, sieved as specified (if required). 2-4, 7-12 Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt
Chlorophyll *a*	Limnology & Oceanography 1967 No 12	-
Metals/Metalloid:		
Arsenic	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Cadmium	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Chromium	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Copper	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Nickel	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Lead	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Zinc	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
SVOCs	Sonication extraction, GPC cleanup, GC-MS FS analysis. Tested on as received sample.	0.1 - 6 mg/kg dry wt

3.2.3. Benthic biological community structure

Epibiota data were generally described, while the more comprehensive infauna data were evaluated according to a variety of statistical descriptors of community structure (Table 8). The number of infauna taxa (richness), the number of infauna individuals (abundance) and diversity (H') were calculated as an average (based on five replicate samples) for each site. The value for the diversity index (H') is dependent on the number and abundance of taxa sampled for a given data set. Values typically range between 0 (indicating low community diversity) and 4 (high diversity).

A non-metric, multi-dimensional scaling (MDS) ordination procedure, based on Bray-Curtis similarities (Bray & Curtis 1957), was used to evaluate variations in the community structure of infauna. A square-root transformation was applied to the infauna data during this process to down-weigh the influence of the most dominant species (Clarke & Warwick 1994). The major species contributing to similarities and / or dissimilarities within and between groups were identified using SIMPER analysis (Clarke & Warwick 1994). All multivariate analyses were conducted using the software package PRIMER v.6 (Clarke & Gorley 2006).

Table 8. Statistical descriptors of infauna community structure.

Descriptor	Equation	Description
No. taxa (richness)	Count (taxa)	Total number of taxa in a sample.
No. individuals (abundance)	Sum (individuals)	Total number of individual organisms in a particular sample or area.
Diversity (H')	H' = -SUM(P*i**loge(P*i*)) Where P is the proportion of the total count arising from the *i*th species	Shannon-Wiener diversity index ($\log_e$ base). A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of taxa and the relative distribution of individual organisms amongst the taxa. The index ranges from 0 for communities containing a single taxa to high values (> 5) for communities containing many taxa and each with a small number of individuals

3.3. Results and Discussion

3.3.1. General signs of pollution

General visual characteristics of the habitats surveyed are shown in Appendices 10–12. No obvious signs of pollution *e.g.* objectionable odours, visible scums from fats, oils or unnatural debris, were noted at any of the survey locations.

3.3.2. Sediment core profiles

The EMP includes a description of the stratification of colour and texture within sediment core profiles, with particular attention paid to the occurrence of any black (anoxic[13]) zones. Where these occur, the average depth of the lighter-coloured surface layer is recorded as the depth of the apparent redox discontinuity layer (RDL) —defined as the transitional zone between aerobic (oxygenated) sediments and anaerobic (deoxygenated) sediments.

Representative photos of core profiles from the three fine-scale survey sites (A, B and C) are shown in Figure 17. No black anoxic zones or hydrogen sulphide (H_2S) odours were detected within the cores taken from Site A (Appendix 13). All cores from Site A uniformly consisted of grey / brown mud throughout the depth profile. Cores at Site B consisted of darker mud than the other two sites (Appendix 14). However, this appears more likely due to the higher organic content and lower moisture content, rather than anoxic conditions. This is consistent with there being no noticeable H_2S odours present. At Site B, the lighter (usually brown / black) coloured layer at the surface ranged to depths of 0.5 - 11 cm (average of ~ 3.9 cm) indicating a highly variable apparent RDL within that range. This was generally followed by a darker (blackened) layer that often contained lighter (brown / rust) coloured streaks. At Site C, a subtle colour gradation in all cores (Appendix 15) suggested the presence of an undefined-subsurface layer of reduced oxygen. At this site, the lighter coloured (brown, sometimes merging into grey) mud layer ranged between depths from 0.5 to 2 cm, with an average RDL depth of 1.3 cm. Deeper than this, the mud became gradually darker (grey / black) in colour indicating moderate oxygen depletion. Once again, no H_2S odours were detected during sampling.

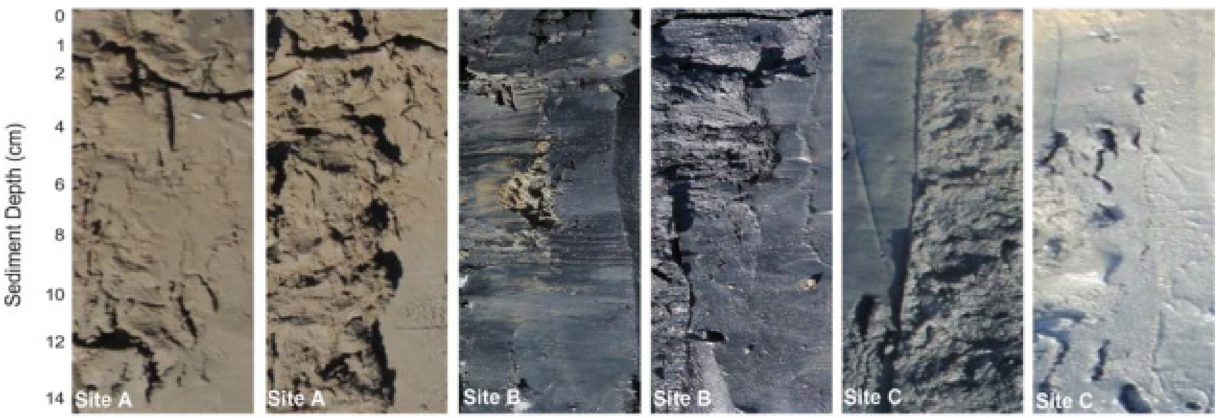

Figure 17. Representative sediment core profiles from fine-scale survey sites A, B and C within the Wairau Estuary, 2015.

[13] Devoid of dissolved oxygen as opposed to 'oxic' indicating sufficient dissolved oxygen availability for animal life.

3.3.3. Sediment characteristics

The physical and chemical properties of the three Wairau Estuary sites (Appendix 16) are summarised and compared with previously reported values for other New Zealand estuarine sites in Table 9.

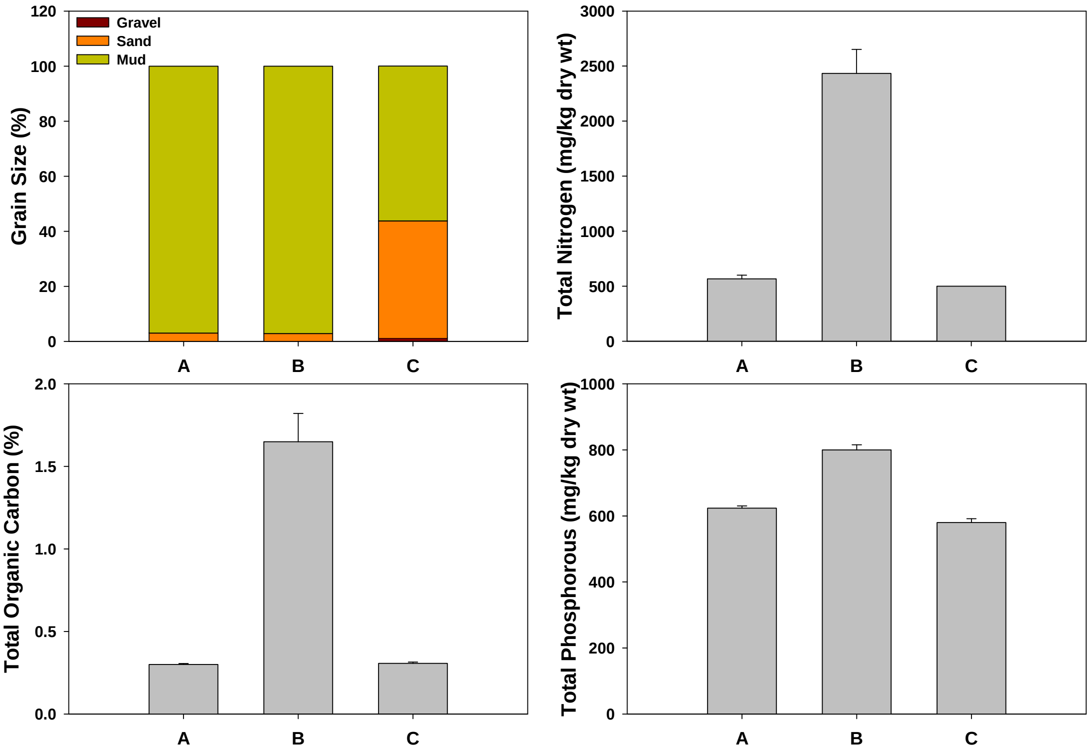

Figure 18. Average grain size and nutrient / organic values of sediment at three fine-scale survey sites (A, B and C) in the Wairau Estuary, 2015. *n* = 3 and error bars are ± standard error.

Grain size distribution and salinity

Particle size analyses confirm that sediments from Sites A and B were composed of 97% mud and 3% sand, while sediments from Site C were composed of 56% mud and 43% sand (Table 9, Figure 18). The sediment mud contents recorded at Sites A and B were higher than values reported for most other estuaries surveyed using the EMP, which generally contained a higher percentage of sand.

Salinity values of sediment interstitial waters at Sites A, B and C were 51.8, 42.7 and 39.6 psu[14] respectively. As full seawater would typically have a salinity reading ~35 psu, these higher values indicate little freshwater influence and / or an evaporation effect at the time of sampling.

[14] Practical salinity units.

Table 9. Comparison of average (n = 3) particle size and nutrient characteristics of sediments sampled during the present survey with previously reported values for other New Zealand estuaries. Sites where mud comprises a higher proportion of the sediment than sand are shaded. The described condition is based on the tabulated subset of indicators only.

Location	Sand	Mud	TN	TP	TN:TP	TOC	AFDW	Condition
Wairau Estuary (present study)	**%**	**%**	**mg kg^{-1}**	**mg kg^{-1}**	**Molar**	**%**	**%**	
Site A	3.0	97.0	567	623	2.0	0.3[15]	2.6	Slight to moderately enriched; mud impacted
Site B	2.8	97.2	2433	800	6.7	1.7[15]	6.3	Enriched; mud impacted
Site C	42.6	56.3	500	580	1.9	0.3[15]	2.6	Slight to moderately enriched
Other NZ estuaries								
Nelson Haven (2012)[a]	86.7	12.0	275.6	338.9	1.8		1.4	Relatively undisturbed, naturally productive
Delaware Inlet (mud-dominated, site A)[b]	26.1	73.3	823	587	3.1		3.4	Relatively undisturbed, naturally productive
Delaware Inlet (sand-dominated, sites B, C)[c]	88.1	11.4	282	558	0.5		2.2	Relatively undisturbed, naturally productive
Moutere (sites A, B)[d]	88.0	12.0	339	530	1.4		1.6	Slight to moderately enriched
Orowaiti (sites A, B)[e]	42.0	53.0	529	938	1.9		3.2	Slight to moderately enriched
Kaipara (Otamatea Arm sites A, B)[f]	27.2	67.7	1850	503	8.1		6.3	Moderately enriched
Ohiwa (sites B, D)[g]	87.0	11.0	524	248	4.7		1.7	Slight to moderately enriched
Ruataniwha (sites A, B, C)[g]	86.0	9.0	263	458	1.3		1.2	Slightly enriched
Waimea (sites B, C)[g]	87.0	13.0	304	377	1.8		1.0	Slight to moderately enriched
Havelock (sites A-D)[g]	56.4	42.3	891.5	397.5	-	0.8	-	Slight to moderately enriched
Avon-Heathcote (sites A, B, C)[g]	94.0	5.0	301	327	2.0		1.8	Moderately enriched
Waimea[h]	NA	82.5	4340	1063	8.9		9.1	Highly enriched

a Mean of three sites collected in sand-dominated and eelgrass habitats (Gillespie *et al*. 2012).
b Mean of one mud-dominated site sampled in 2009 (Gillespie *et al.* 2009).
c Mean of two sand-dominated sites sampled in 2009 (Gillespie *et al.* 2009).
d Slightly modified estuary near Motueka, affected by food processing industry wastes and urban runoff (Gillespie & Clark 2006).
e Slightly modified estuary near Westport (Gillespie & Clark 2007).
f Subset of mud-dominated sites from an inter-estuary comparison, 2001 (Robertson *et al.* 2002).
g Mean of four mud-dominated sites sampled in 2015 (Stevens & Robertson 2015).
h Mudflat affected by a freezing works effluent, 1981 (Gillespie & MacKenzie 1990).

[15] For the three Wairau Estuary sites, TOC was converted to AFDW according to the following equation derived from the data of Golder Associates (2012): AFDW = TOC0.526 × 4.835.

Nutrient and organic composition

Total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC) in sediments are indicators of organic nutrient enrichment that are often closely linked with sediment grain size characteristics. In general terms, higher nutrient and organic concentrations are usually associated with muddier substrata. Sediment characteristics observed at the Wairau Estuary sites are compared with those reported for other New Zealand estuaries in Table 9.

The mean sediment TOC concentrations were relatively low at Sites A and C (both measured at 0.3%) (Figure 18). These values were similar to those reported for the Waimea Inlet (~0.5%) in Robertson & Robertson (2014), and lower than those for Havelock Estuary (mean of 0.8%) (Table 9). However TOC values were elevated at Site B (1.7%) indicating enriched conditions. This may reflect reduced flushing within the lagoon-like habitat and that microbial decomposition rates are possibly lower. Microbial decomposition may have been inhibited due to the higher than normal elevation (relative to the tide) of the site and consequently its reduced inundation time.

The mean sediment TN concentration at Site B (2433 mg kg^{-1}) was considerably elevated (Figure 18) indicating significantly enriched conditions. Those recorded for Sites A and C (567 and 500 mg kg^{-1} respectively) were indicative of slightly to moderately enriched conditions as defined by Robertson *et al*. (2002), or naturally productive conditions as defined by Gillespie *et al.* (2009). The higher TN concentrations at Site B are consistent with the higher TOC values measured there (Figure 18). Knox (1983) also observed this relationship within Wairau Estuary sediments. Concentrations of TP were high at Site B (800 mg kg^{-1}) and moderately high at Sites A and C (623 and 580 mg kg^{-1} respectively) in comparison to other New Zealand estuaries (Table 9).

Molar TN:TP ratios[16] in sediments from sites A and C were similar to those reported for other New Zealand estuaries (Table 9) suggesting that nitrogen is likely more limiting than phosphorus for photosynthetic production at these sites. However, the TN:TP ratio calculated for Site B was somewhat higher than expected, possibly related to lower than normal denitrification[17] rates or the release of phosphorus under historically anoxic conditions. In general, these results, in conjunction with those found in other New Zealand estuaries, suggest that nitrogen loading is likely to stimulate algal growth more than phosphorus input.

[16] The stoichiometric atomic ratio of nitrogen to phosphorus for phytoplankton is generally considered to be around 16:1. In estuarine sediment this ratio is seldom greater than 10:1 indicating that nitrogen is likely to be relatively more limiting than phosphorus for the growth of benthic microalgae.

[17] The conversion of nitrate and nitrite to N_2 gas which is largely inert and unavailable for photosynthesis. The conversion is facilitated by specialised microbes and is generally favoured within the RDL.

Metals / Metalloids

All three Wairau Estuary sites showed low levels of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn) compared to ANZECC (2000) ISQG trigger values and other New Zealand and overseas estuaries, including some that had been contaminated to varying degrees (Table 10). However, nickel (Ni) concentrations (21-28 mg kg^{-1}) reached or exceeded the ANZECC (2000) ISQG-low trigger value (21 mg kg^{-1}) and were elevated compared to nickel concentrations recorded from a number of other New Zealand estuaries. Lead (Pb) concentrations (11-20 mg kg^{-1}) did not exceed the ANZECC (2000) ISQG-low trigger value (50 kg^{-1}) although they were elevated compared to a number of other New Zealand estuaries.

High sediment Ni concentrations have also been reported for other coastal and estuarine locations in the Marlborough / Nelson region (*i.e*. Waimea Inlet, Havelock Estuary, Moutere Inlet and Nelson Haven) and linked to natural catchment geological characteristics (Robertson *et al.* 2002; Gillespie & Asher 2004; Gillespie & Clark 2006; Gillespie *et al*. 2012). The catchment for the Wairau Estuary includes a portion of the Richmond Range (Basher *et al.* 1995), which comprises a natural mineral belt (Robertson *et al.* 2002).

Elevated sediment Pb concentrations have not generally been found in other Marlborough / Nelson estuaries surveyed using the EMP, including Nelson Haven, Waimea Inlet, Havelock Estuary (Table 10) and Moutere Inlet (Gillespie & Clark 2006). The source of the slightly elevated levels of Pb in the Wairau Estuary is unknown and would require further investigation to determine.

With the exception of Ni, for which high values can be attributable to the runoff from the mineral belt, and Pb, which was only slightly elevated, Wairau Estuary sediment metal concentrations were generally similar to (or lower than) the range reported for a variety of other New Zealand estuaries (Table 10). In comparison with reported values for some overseas estuaries, the New Zealand estuaries generally had much lower sediment metal concentrations.

Semi-volatile Organic Compounds

Semi-volatile organic compounds (SVOCs) are organic compounds with moderate to low vapour pressures. This group of contaminants can result from a broad range of potential anthropogenic activities and includes polycyclic aromatic hydrocarbons (PAHs), biocides (including herbicides and insecticides), plasticising compounds (*e.g.* phthalates), phenolics and various solvent components.

Table 10. Concentrations of trace metals in sediments from Wairau Estuary and a selection of New Zealand and overseas estuaries that have been contaminated to varying degrees. Some values drawn from other studies are approximate as they were estimated from figures.

Location		**As** mg kg^{-1}	**Cd** mg kg^{-1}	**Cr** mg kg^{-1}	**Cu** mg kg^{-1}	**Pb** mg kg^{-1}	**Ni** mg kg^{-1}	**Zn** mg kg^{-1}
ANZECC (2000) ISQG-Low		*20*	*1.5*	*80*	*65*	*50*	*21*	*200*
ANZECC (2000) ISQG-High		*70*	*10*	*370*	*270*	*220*	*52*	*410*
Wairau Estuary (present study)	**Site A**	3.8	0.03	15.7	10.3	10.7	20.6	46.3
	Site B	7.8	0.07	20.6	19.0	19.8	23.3	61.3
	Site C	4.6	0.03	17.4	11.0	11.5	28.3	50.7
EMP development study	Otamatea Arm		0.4	20.5	13.8	11.4	9.4	54.5
	Ohiwa		0.1	7.4	4.0	3.4	3.9	27.7
	Ruataniwha		0.1	24.0	7.1	4.7	13.7	37.5
	Waimea		0.3	67.6	9.6	7.4	72.5	41.8
	Havelock		0.04	43.2	13.5	7.1	37.4	40.5
	Avon-Heathcote		0.1	15.6	3.2	6.3	6.6	38.3
	Kaikorai		0.1	48.4	16.8	45.3	15.6	184.2
	New River		0.1	11.1	3.8	0.7	5	17.1
Other NZ sites	Delaware Inlet		<0.1	42.9	11.0	3.8	17.1	45.3
	Moutere Inlet		<0.01	31.7	6.1	4.2	67.3	25.9
	Nelson Haven (2012)		<0.1	22.1	5.5	3.8	23.9	24.3
	Tamaki A (E1)			14.5	27.8	132.1	56.9	136.1
	Tamaki B (E2)			20.6	26.1	72.9	6.6	167
	Tamaki C (E3)			17.3	29.4	69.7	9.3	173
	Tamaki D (E4)			35.9	38.5	145.2	12.8	233
	Manukau (rural catch)		0.03		20	9	15	114
	Manukau (industrial catch)		0.25		90	58	14	285
	Waitemata Harbour		<0.5	52	60	65	28	161
	Lampton Harbour, Wellington			91	68	183	21	249
	Porirua Harbour, Wellington			20	48	93	20	259
	Aparima Estuary		0.067	15	12	11	10	49
	Mataura Estuary		0.024	7.1	6.6	6.2	6	27
Overseas sites	Delaware Bay, USA		0.24	27.8	8.3	15		49.7
	Lower Chesapeake Bay, USA		0.38	58.5	11.3	15.7		66.2
	San Diego Harbour, USA		0.99	178	218.7	51		327.7
	Salem Harbour, USA		5.87	2296.7	95.1	186.3		238
	Rio Tinto Estuary, Spain		4.1		1400	1600		3100
	Restronguet Estuary, UK		12.0	1060	4500	1620		3000
	Nervión Estuary, Spain		0.2-15	50-300	50-350	50-400	20-100	200-2000
	Sorfjord, Norway		850		12000	30500		118000

Sources: Gillespie & Clark (2006), Gillespie *et al.* (2009), Gillespie *et al.* (2012), Glasby *et al.* (1988), Glasby *et al.* (1990), Jezus-Belzunce *et al.* (2001), Kennish (1997), Robertson (1995), Robertson *et al.* (2002), Roper *et al.* (1988), Stevens & Robertson 2015, Stoffers *et al.* (1986), Thompson (1987).

The SVOC analysis suite targeted 75 individual compounds of varying toxicity (Appendix 17). The sediment concentrations of all SVOCs were below analytical detection limits (ADL) at the three Wairau Estuary fine-scale survey sites.

Detection limits for the 17 SVOC analytes which are listed by the ANZECC (2000) guidelines were frequently greater than the corresponding ISQG-Low trigger values (Appendix 18). In the case of the five organochlorine compounds (DDT, DDD, DDE, dieldrin and endrin), the discrepancy with ISQG-Low was between two and four orders of magnitude, and greater than an order of magnitude for ISQG-High. While the ADL also exceeded ISQG-Low for five of the twelve ANZECC-listed PAHs the discrepancy was less than an order of magnitude and exceeded a factor of two only for acenaphthene and fluorene.

It should be noted that for the samples from sites A and C, normalisation to 1% organic carbon would have the effect of reducing the effective value of the guideline to a third of its listed value, exacerbating the discrepancy.

The fact that no analytes were above the SVOC ADL in the samples, (including none of the seven PAHs for which ADL was less than ISQG-Low) suggests that general levels of contamination are low in these sediments. The presence of multiple lines of evidence adds further weight to such a finding. The metals results, which are also broadly indicative of anthropogenic inputs, do not suggest significant contamination issues. Neither do the biological communities associated with these sediments suggest that a significant toxicity effect is present.

Microalgae

Microalgae, which colonise the entire benthic surface area of a tidal inlet, are the major primary producers over large areas of intertidal sand and mud flats (Gillespie & MacKenzie 1981). These can provide a significant beneficial contribution to the coastal food web due to the large area they occupy. Under conditions of excessive enrichment; however, prominent green-to-olive mats may develop to a level that can result in a degradation of estuarine health or condition.

Microalgal mat development was not evident at any of the three Wairau Estuary sites; however, casual observation in other regions of open tidal flats revealed visible low-density patches (Figure 19).

Figure 19. Patches of low density microalgal mat on open tidal flats within the Wairau Estuary, 2015.

3.3.4. Epibiota communities

Animals

Animal taxa were rare on the sediment surface at Sites A and B with only signs of crabs (crab holes – average of 29 and 53 per quadrat respectively) observed at these sites (Appendices 10 and 11). The dry and strongly saline conditions on the sediment surface at these upper intertidal locations are likely to have been unsuitable for most other animal taxa. Three animal species, the deposit feeding[18] gastropod *Amphibola crenata*, the suspension feeding[19] cockle *Austrovenus stutchburyi* and the scavenger feeding[20] burrowing mud crab *Austrohelice crassa*, along with signs of crabs (*i.e*. crab holes – average of 6 per quadrat), were found at Site C (Table 11, Figure 20, Appendix 12). The occurrence of cockles at Site C is likely due in part to the higher sand (lower mud) content at this site, as this species is sensitive to high levels of mud (Robertson *et al*. 2015). Common crab species in NZ estuaries have a positive response to mud (Robertson *et al*. 2015), which corresponds to the presence of crab holes at Sites A and B where mud made up a large component of the sediment.

[18] Animals that feed on particulate organic matter on or within the sediment.
[19] Animals that filter out suspended organic particles from the water for their nutrition.
[20] Animals that feed on dead and decomposing plant and/or animals.

Table 11. Average abundance per quadrat (0.25m^2) of animal species and crab holes on the sediment surface at fine-scale survey Site C in the Wairau Estuary. Quadrat photos are available in Appendix 12.

Species	Common name	Feeding type	Abundance
Amphibola crenata	Mud snail	Surface deposit feeder	9.1
Austrovenus stutchburyi	Cockle	Surface suspension feeder	27.5
Austrohelice crassa	Burrowing mud crab	Surface scavenger	0.3
Crab holes		Surface scavenger	5.8

Figure 20. The three animal species found on the sediment surface at Wairau Estuary fine-scale survey site C. From left: the gastropod *Amphibola crenata*, the cockle *Austrovenus stutchburyi* and the burrowing mud crab *Austrohelice crassa*.

Macroalgae

The distribution of macroalgae was variable between sites with no species observed at Site A. A small amount of agar weed (*Gracilaria* sp.) was observed at Sites B (0-26% coverage) and C (0-8% coverage) (Appendices 11 and 12). The agar weed observed at Site B was unattached to the seabed indicating that it was produced elsewhere in the estuary and washed into the site location.

3.3.5. Infaunal communities

Overall, 22 infaunal taxa were recorded living within the sediment matrix of the three Wairau Estuary sites combined, with total numbers of taxa per core ranging from 1-15 (Appendix 19). Infaunal assemblages at mud-dominated sites in the Upper and Big Lagoons (Sites A and B) were very low in abundance, richness and diversity (Table 12, Figure 21). Cores at Site A contained only four polychaete taxa and at Site B cores contained only one amphipod (Amphipoda) and one crab (*A. crassa*) taxa. The number of individuals within these taxa were few and consequently average Shannon-Weiner diversity scores per site were also low (0.14), indicating a limited spread of individuals amongst the different taxa. The abundance, richness and diversity of taxa at these two sites were much lower than observed from many other estuaries within the nearby Nelson / Marlborough region, *e.g*. Delaware Inlet (Gillespie *et al.* 2009), Waimea Inlet (Robertson & Robertson 2014), and Nelson Haven (Gillespie *et al*. 2012). The reduced abundance and diversity of infauna at Sites A and B is likely due to the high mud content and unique habitat characteristics (*e.g.* reduced period of inundation and small tidal range) associated with these two inner lagoon sites.

Infaunal assemblages at the sandier Site C (within the Te Aropipi Channel and closer to the mouth of the Wairau Estuary) contained animals from a wider range of taxonomic groups (Table 12). The most abundant species at this site was *Potamopyrgus estuarinus* (Figure 22), a small estuarine snail often associated with muddy sediments. Amphipods (including corophiids) and oligochaetes were the next most abundant taxa. The bivalve *Arthritica bifurca* was also relatively common. Nine polychaete taxa were represented at Site C, including three that are indicative of organically enriched conditions (*i.e. Prionospio* sp., *Heteromastus filiformis* and *Capitella* sp.). However all polychaetes were low in abundance, with the ragworm species *Nicon aestuariensis* the most common of these (average 2.6 per core).

The dominance of gastropod and amphipod taxa at Site C is in contrast to the infaunal assemblages dominated by polychaetes and bivalves that are typical of estuaries within the Nelson / Marlborough region; *e.g.* Nelson Haven (Gillespie *et al.* 2012) Delaware Inlet (Gillespie *et al.* 2009), and other EMP-monitored NZ estuaries (Robertson *et al*. 2002).

Known infauna feeding types were relatively varied at Site C and included deposit feeders, scavengers, predators, suspension feeders and omnivores (Table 12). At the inner lagoon sites A and B, known feeding types were limited to deposit feeding and scavenging respectively. The wider variety of feeding types at Site C suggests an increased level of ecological functioning. This is also indicated by the higher animal numbers at this site as abundance can drive ecological functioning (Hewitt *et al*. 2008).

Table 12. All infaunal taxa from the three fine-scale survey sites in Wairau Estuary, 2015. Data are represented as average abundance per core ($0.0133 m^2$), $n = 5$ at Sites A, B and C.

Taxa	Common Name	Feeding Type	Site A	Site B	Site C
Amphipoda					
Corophiidae	Amphipod (family)	-	0	0	21.8
Phoxocephalidae	Amphipod (family)	-	0	0	0.2
Amphipoda	Unidentified Amphipods	-	0	0.4	44.6
Bivalvia					
Arthritica bifurca	Small bivalve	Subsurface deposit feeder	0	0	12.8
Austrovenus stutchburyi	Cockle	Surface suspension feeder	0	0	2.4
Copepoda	Copepods	-	0	0	0.2
Decapoda					
Austrohelice crassa	Tunnelling Mud Crab	Surface scavenger	0	2.6	0.4
Hemiplax hirtipes	Stalk-eyed Mud Crab	Surface scavenger	0	0	1.4
Gastropoda					
Amphibola crenata	Mud Snail	Surface deposit feeder	0	0	0.2
Potamopyrgus estuarinus	Estuarine snail	Surface deposit feeder	0	0	106.2
Nemertea	Proboscis worms	Surface predator	0	0	0.2
Oligochaeta	Oligochaete worms	Subsurface deposit feeder	0	0	20.6
Polychaeta					
Paraonidae		Subsurface deposit feeder	0	0	0.2
Prionospio sp.		Surface deposit feeder	0.2	0	0.2
Scolecolepides benhami		Subsurface deposit feeder	1.2	0	0.8
Scolecolepides sp.		Subsurface deposit feeder	0.2	0	0
Capitella sp.		Subsurface deposit feeder	0	0	0.4
Heteromastus filiformis		Subsurface deposit feeder	0	0	0.2
Maldanidae	Bamboo worm	Subsurface deposit feeder	0	0	0.2
Nereididae (juvenile)		Omnivorous	0	0	0.2
Nicon aestuariensis		Omnivorous	0	0	2.6
Cirratulidae		Deposit feeder	0.4	0	1

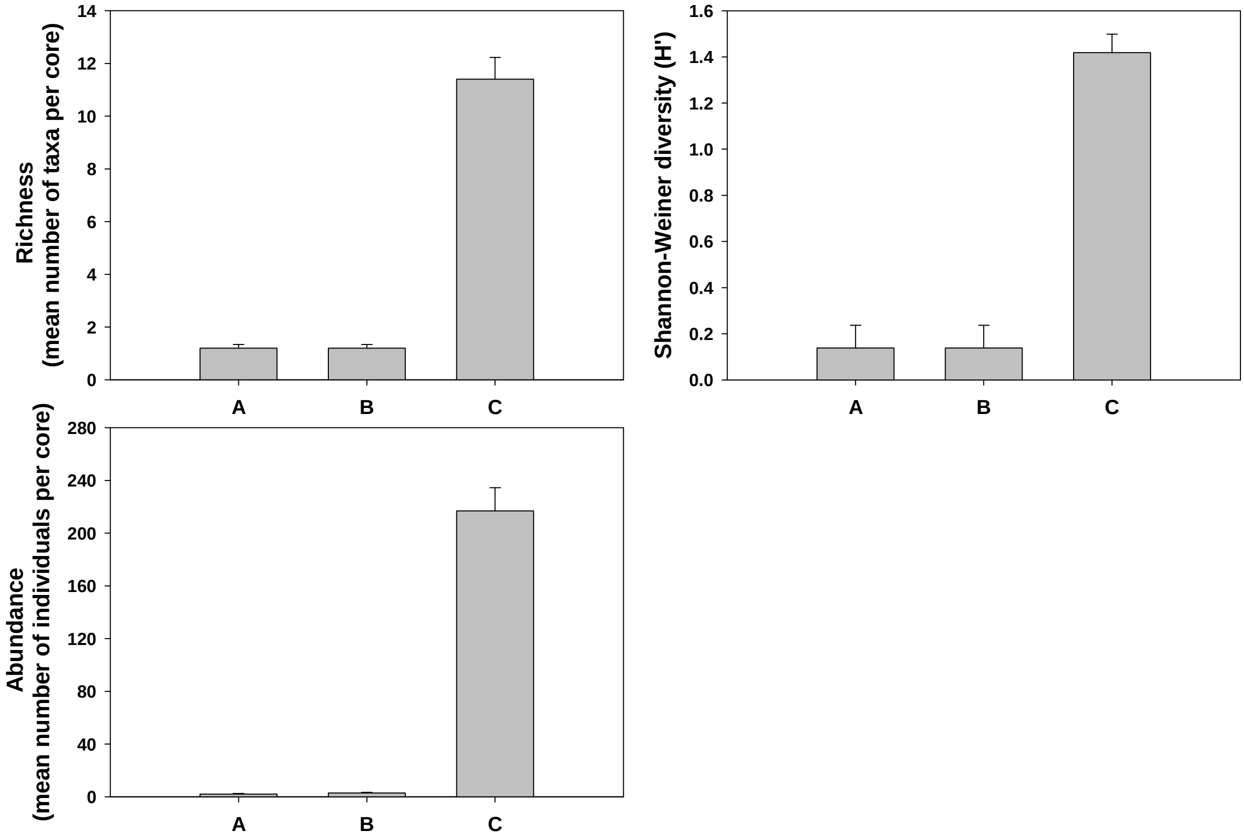

Figure 21. The average richness, abundance and diversity of infauna at three fine-scale survey sites in the Wairau Estuary, 2015. Data are mean values ± standard error, n = 5 at Sites A, B and C.

Figure 22. Two of the more abundant infauna taxa found at Wairau Estuary fine-scale survey sites: the estuarine snail *Potamopyrgus estuarinus* (left) and an amphipod of the family Corophiidae (right).

The composition of animals living within the sediment matrix of the Wairau Estuary varied between Sites A, B and C. In multivariate space, infaunal assemblages from different cores formed distinct groups for Sites B and C (Figure 23). These were much more dispersed for Site A, although still separate from Sites B and C. Infaunal assemblages from cores within the same site were low in similarity at Site A (13%) and high in similarity for Sites B and C (72 and 76% respectively) (Appendix 20). Site A was distinguished by the polychaetes *Scolecolepides benhami* and Cirratulidae. Site B was distinguished by *A. crassa*, and Site C by *P. estuarinus*, Amphipoda and Oligochaeta. Average dissimilarities of infaunal assemblages between all combinations of sites were high (>96%).

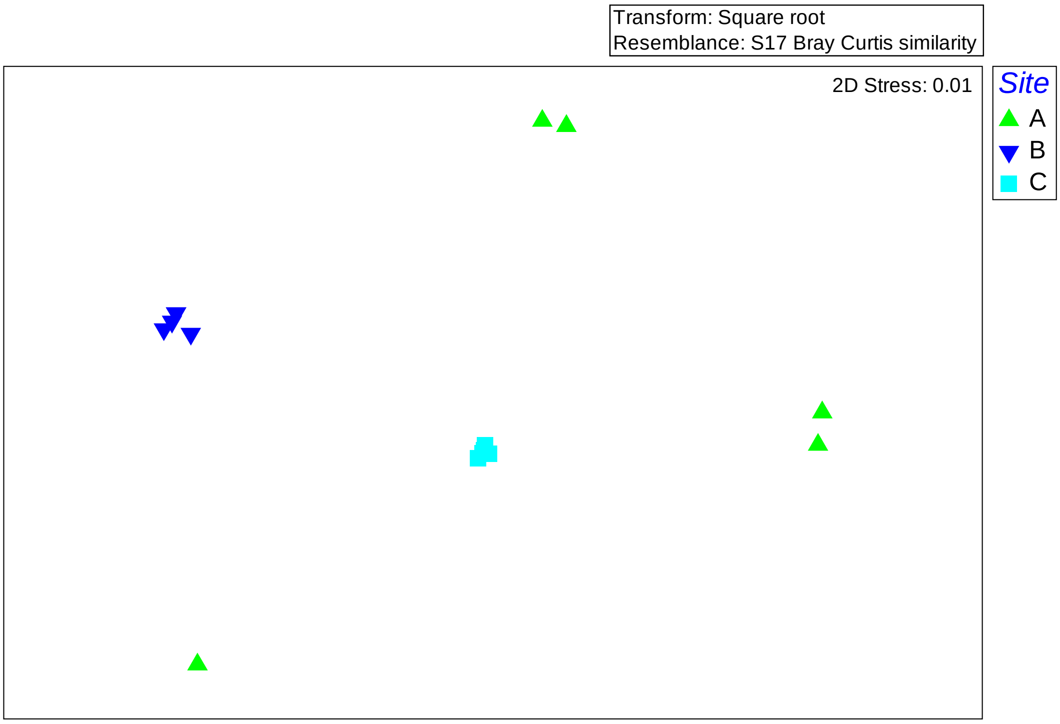

Figure 23. Multi-dimensional scaling (MDS) ordination showing similarity of Wairau Estuary fine-scale survey sites in 2015 based on their infaunal species composition (2-D stress = 0.01), *n* = 5 at Sites A, B and C.

4. DISCUSSION OF ESTUARY CONDITION

The EMP (Robertson *et al*. 2002) states that a more comprehensive summary of estuarine health is gained when the results of all three components of the EMP are considered together. The condition of the Wairau Estuary, based on conclusions drawn from broad-scale and fine-scale assessments (sections 2 and 3), is discussed further below. We note that comparing the relative 'health' based on broad- and fine-scale features of estuaries is not a straightforward process due to differences in influencing factors *e.g*. freshwater inflow rate, tidal flushing regime, geology and catchment characteristics. Hence, varying results do not necessarily mean one estuary is 'healthier' than another. We also note that when making comparisons it is important to recognise that the Nelson / Marlborough estuaries surveyed do not represent completely unmodified ('pristine') conditions. However, a general comparison between both local and regional estuaries can indicate trends and potentially signify problem areas that require further investigation.

4.1. Habitat structural composition

4.1.1. Vegetative cover

Upper intertidal (fringing) salt marsh habitats are functionally important due to being areas of active production which contribute to the detrital food web and are areas of enhanced decomposition and nutrient cycling processes (Gillespie & MacKenzie 1981). Salt marsh habitats act as a buffer at the land-sea interface and can intercept inorganic nutrients and trap fine sediment from catchment runoff. Compared to other Nelson / Marlborough estuaries, the Wairau Estuary intertidal zone contained a very high proportion of vegetation (54%), which was dominated by salt marsh. Due to the functional benefits provided by salt marsh habitats (mentioned above), the large relative size of these within the Wairau Estuary, makes them an ecologically significant component of the estuary that is likely to make a contribution towards its overall health. However, limited connectivity between a large proportion of intertidal salt marsh and the main estuary habitat may result from enhanced sediment deposition within the upper intertidal zone and could limit important ecological functioning.

Macroalgal blooms, often stimulated under enriched conditions, can result in a number of problems (*e.g*. smothering of sediments and eelgrass beds, reduced benthic light) that have negative implications for ecosystem health. However, in some instances macroalgae can benefit estuarine ecosystems (Thomsen 2010) by increasing productivity, biodiversity and habitat availability within estuaries. Agar weed (likely *Gracilaria chilensis*), was the dominant macroalgal taxon within much of the Wairau Estuary. It may have become abundant within the estuary relatively recently, potentially in response to altered hydrodynamic conditions and / or elevated nutrient levels. Although agar weed may have positive impacts on estuarine ecology, its impacts could also be negative and increased abundance of this species could indicate reduced ecological health of the estuary.

Patches of bright green macroalgae (*e.g*. *Ulva* spp.) are likely to be temporally variable within the estuary as these were noted in the 2005 and 2011/12 aerial photos but not recorded during ground-truthing in 2015. We note that macroalgal production and coverage can vary considerably both spatially and temporally. Consequently, although *Gracilaria* sp. and other opportunistic macroalgal taxa such as *Ulva* spp. (sea lettuce) may have the potential to reach nuisance proportions, the likelihood of this occurring in the Wairau Estuary could not be adequately assessed through the single point-in-time survey.

Eelgrass beds are recognised as having high ecological and biodiversity values (van Houte-Howes *et al*. 2004). Although their photosynthetic contribution can be relatively modest (Gillespie & MacKenzie 1981), they provide a stable physical habitat and a localised food source to support a diverse community of animals including a variety of fish species. Eelgrass also helps filter nutrients and sediments, thereby maintaining water quality. They are sensitive to macroalgal overgrowth, sediment deposition and reduced water quality conditions, therefore making them a good indicator of estuary health.

No eelgrass was observed during the current survey. Eelgrass is likely to have been historically present within the Wairau Estuary (Knox 1983, Ron Perano pers. comm.), indicating that this valuable habitat has drastically declined (and potentially been completely lost) within the past 80 years. Loss of this habitat is likely evidence of altered ecological condition and decreased biodiversity within the estuary. Reduction in the coverage of eelgrass meadows is also a concern for other Nelson / Marlborough estuaries (*e.g*. Gillespie *et al*. 2009, Gillespie *et al*. 2011a).

Vegetation within the supra-littoral fringe can help to protect estuarine habitats by acting as a buffer zone. Vegetated habitats dominate (99%) the Wairau Estuary supra-littoral fringe, however this vegetation comprises a high proportion of exotic grasses (*e.g*. tall fescue and pasture grass). This is evidence of modification from pre-existing natural land to sea succession, and may have resulted in reduced bank stabilisation and a limited ability to trap sediments before they enter the estuary.

4.1.2. Muddy Substrata

The deposition of land-derived sediments in estuarine intertidal zones is a natural process that occurs wherever there is substantial freshwater inflow. The rate of deposition within an estuary will depend on the sediment loading characteristics of the inflow stream(s), the hydrodynamic characteristics of the receiving environment and the characteristics of margin habitats *e.g*. marshes, riparian vegetation. In many catchments throughout New Zealand (including the Wairau Estuary catchment) human activities have resulted in increased erosion and flushing of fine-grained terrigenous sediments into the coastal environment (Figure 24). The resulting acceleration of sedimentation rates and increases in habitat 'muddiness' can be a serious threat to estuarine health (Thrush *et al*. 2004) and has potential to also impact wider coastal waters (Figure 25).

Figure 24. Wairau Lagoon in flood, 2008. Image supplied by Marlborough District Council.

Unvegetated habitats within the Wairau Estuary intertidal zone contained no sand substrates and were instead dominated by mud/sand substrates. By comparison to other New Zealand estuaries, this dominance of mud/sand is likely to have reduced biodiversity and estuarine health within the Wairau Estuary. The proportion of mud/sand substrate within the overall Wairau Estuary intertidal zone (45%) is comparable to that in other Nelson / Marlborough estuaries (27–71%) that range from being relatively healthy to exhibiting reduced function in respect to the mud/sand substrates they contain.

Figure 25. Satellite image of flood event on Wairau Estuary at high tide 17 May 2011. Note outwelling sediment plume into Cloudy Bay.

4.1.3. Exotic species

Exotic species can detrimentally affect native estuarine organisms (Ruiz *et al*. 1997), influence ecosystem processes, and modify the natural characteristics of an estuary (Ruesink *et al*. 2005). Recognised exotic species were largely non-existent in the intertidal habitats of the Wairau Estuary and no Pacific oyster or cord grass (*Spartina* spp.) were observed during the current survey. However, the high proportion of exotic plant species within the supra-littoral zone is evidence that anthropogenic activities have altered natural land to sea succession (see above).

4.2. Hardening of the land-sea interface

In most New Zealand estuaries, modification or development of the surrounding land has resulted in a loss of connectivity with freshwater and coastal wetland habitats. These wetland regions process inorganic nutrients, thereby reducing the potential for macro/micro algal blooms, and are important sources of dissolved and particulate organic materials that contribute beneficially to the coastal food web. They also provide habitat for a variety of birds and a wide range of fish and invertebrate species including some that migrate across salinity gradients as part of their life cycle.

The large-scale draining and clearing of the extensive wetland system that originally surrounded much of the Wairau Estuary has dramatically reduced wetland extent (Knox 1990), largely replacing it with agricultural farmland. This is likely to have reduced the functional benefits provided by this habitat (*e.g*. processing of inorganic nutrients, trapping sediments, providing animal habitat).

4.3. Sediment characteristics

4.3.1. Signs of pollution

Unnatural odours, visible scums from fats, oils or human-associated debris indicates pollution, which may be detrimental to the health of organisms living on or within the sediment. None of these pollution indicators were observed at the sites assessed during the fine-scale benthic surveys.

4.3.2. Oxygen depletion

When overly organically enriched, muddy sediments can be depleted of oxygen, creating anoxic conditions that adversely impact infaunal communities (Borja *et al*. 2000). The apparent depth of the RDL is the transitional zone between aerobic (oxygenated) sediments and anaerobic (deoxygenated) sediments (Robertson *et al*. 2002). RDL depth is a strong indicator of estuarine condition as it gauges how close to the sediment surface oxygen depletion is occurring.

Sediment core profiles from fine-scale benthic surveys showed no signs of excessive oxygen depletion (*e.g*. black anoxic zones at, or near, the sediment surface with characteristic hydrogen sulphide odour). The profile characteristics were largely typical of other estuaries. Although exhibiting some indications of mild organic enrichment, sediments do not appear seriously compromised in terms of oxygen levels. However, darker mud within Site C (within the Te Aropipi Channel) cores did indicate moderate oxygen depletion with an average apparent RDL depth of 1.3 cm. Darker mud (with an average apparent RDL of 3.9 cm) within the Site B (Big Lagoon) cores was likely caused by historic accumulation of organic material, and lower moisture, content rather than existing anoxic conditions. The darkened profiles may have been a relic of previous anoxia occurring during wetter (*e.g*. high rainfall or extreme spring tidal) conditions.

4.3.3. Mud content and salinity

Increased mud content can alter sediment characteristics through a variety of mechanisms (*e.g*. reducing its ability to be oxygenated and increasing its contaminant-binding capacity). Mud content is also a strong determinant of benthic community composition (Thrush *et al*. 2003), and at high levels is a serious threat to estuarine health (Thrush *et al*. 2004). Although reasonably oxygenated, sediments at inner lagoon sites A and B contained extremely high mud content. This, in conjunction with other factors, has likely affected infaunal community structure with resulting loss of biodiversity. Sediment at Site C (within the Te Aropipi channel) contained a higher proportion of sand and was more representative of other New Zealand estuaries surveyed within the EMP.

Most estuarine animals are tolerant of a wide range of salt concentrations. Low salinity values (<10 psu) indicate a large freshwater influence while high values (>30 psu) indicate a large marine influence. Extreme values at either end of the range; however, have the potential to significantly influence taxa distribution (*e.g.* Jones & Simons 1982). The high values recorded in sediment interstitial waters of the lagoon fine-scale sites A and B (>40 psu) may have been at least partly responsible for the very low infauna diversity and abundance observed there.

4.3.4. Nutrient and organic enrichment

Excessively high levels of TN, TP and TOC can lead to enriched (and potentially eutrophic) conditions. The process of eutrophication is indicated by a variety of symptoms (*e.g*. macroalgal or microalgal blooms, anoxic sediment, sulphide toxicity), which can adversely impact animal communities (Paerl 2006).

Nutrient and organic contents of the sediments at Sites A and C were within the range of other slight to moderately enriched, or naturally productive, New Zealand estuaries. The elevated nutrient and organic contents of sediment at Site B were indicative of enriched conditions. The Big and Upper lagoons may be susceptible to eutrophication, due to the combined effects of nutrient and organic loading and their decreased flushing capacity (Knox 1983). Elevated organic contents may also potentially be caused by lower microbial decomposition rates, which could have been inhibited due to the higher than normal tidal elevation and reduced inundation time at the lagoon sites.

4.3.5. Metals and SVOCs

Metals / metalloids and SVOCs can be highly toxic to marine life (Bryan 1971, Mucha *et al*. 2003, Moore *et al.* 2002). Animals belonging to higher trophic levels can also be adversely impacted through bioaccumulation of some of these contaminants.

In the Wairau Estuary sediments tested during the fine-scale surveys, cadmium, chromium, copper, lead and zinc concentrations were all below guideline levels that are often used to indicate biological effects. Lead concentrations were slightly elevated compared to a number of other New Zealand estuaries. Nickel concentrations were above ANZECC low trigger levels, although this is likely to be attributable to natural catchment sources. SVOC pollutants were all below detectable limits and, although the detection limits for some of these were above potential ecological effects thresholds, no obvious impact levels were demonstrated..

4.3.6. Micro / macro algae

Microalgae are the major primary producers over large otherwise unvegetated areas of intertidal sand and mud substrates (Gillespie & MacKenzie 1981). These can provide a significant beneficial contribution to the coastal food web due to the large area they occupy. Under conditions of excessive organic enrichment, however, prominent green-to-olive mats may develop to a level that can result in a degradation of estuarine health or condition. Macroalgal blooms may also be stimulated by elevated organic enrichment.

No nuisance-level microalgal mat development or excessive macroalgal coverage was observed at intertidal sites during the current fine-scale benthic survey (although see notes on macroalgae above). However, as previously mentioned, macroalgal production and coverage can vary considerably both spatially and temporally, and the likelihood of nuisance blooms occurring in the Wairau Estuary could not be adequately assessed through a single point-in-time survey, as reported here.

4.4. Benthic animal communities

Benthic estuarine animal species often vary in their sensitivities to a range of sediment characteristics (*e.g*. mud content, salinity, contaminant levels). Therefore the composition, abundance and diversity of these communities are often used to indicate estuarine health (Borja *et al.* 2000).

The reduced abundance and diversity of infauna at fine-scale survey sites A and B suggest reduced biological functioning at these inner lagoon sites. This is likely due, primarily, to the higher elevation lagoon-like habitat associated with these sites where a limited tidal range results in reduced periods of inundation. However the high mud content of the sediments may also have contributed. The abundance, richness and diversity of animal communities at Site C were more typical of other New Zealand estuaries surveyed within the EMP, with the exception of the dominance of gastropod and amphipod, rather than polychaete and bivalve, taxa at this site.

4.5. Summary

Based on the EMP indicators of estuarine condition, the combined findings of the current broad- and fine-scale surveys of the Wairau Estuary, in comparison with the other New Zealand and overseas estuaries, indicate this estuary is exhibiting signs of being in a fair to compromised ecological condition. Together, the results, historic information and local reminisces indicate key estuary functions and values have been undermined. However, these findings should ultimately be considered in context to the ‘choked’ lagoon nature of the Wairau Estuary, which may be naturally attributed with characteristics and functions that vary from those associated with New Zealand estuaries typically assessed using the EMP.

The general broad-scale characteristics of the Wairau Estuary and its supra-littoral surrounds provide evidence of a complex, estuarine environment. The large expanse of vegetated habitat within the intertidal zone is a valuable ecological component of the estuary and likely to benefit its overall health. However, the following characteristics provide indication of an estuary in a compromised state of health. Limited connectivity between a large proportion of intertidal salt marsh and the main estuary habitat may have resulted from enhanced sediment deposition within the upper intertidal zone and may limit important functioning. The absence of eelgrass beds (observed to be present historically) is likely evidence of an altered ecological condition and reduced biodiversity within the estuary. Although further investigation is required, significant areas covered by a single species of red macroalgae (*Gracilaria* sp.) may also indicate reduced estuarine health. Large areas of unvegetated mud/sand habitat and the absence of sand habitat within the intertidal zone may indicate reduced ecological health. The abundance of exotic grassland within the supra-littoral is a modification of the natural state of this habitat.

Based on the EMP suite of fine-scale environmental indicators, the Wairau Estuary was found to be in a fair to compromised state of health. Signs of reduced ecological function were at least partly associated with the limited inundation received by the two inner lagoon sites due to their elevated position relative to the tide. These contained mud-dominated sediments that, due to a restricted tidal range, were limited in the inundation time that they received. Heavy metal levels within sediments did not appear to compromise estuarine health. However, slightly elevated nickel concentrations of natural origin indicated ‘possible’ ecological effects. Although the detection limits for some SVOC components were above potential ecological effects thresholds no obvious impact levels were demonstrated. Nutrient and organic levels, as well as core profiles, indicated slight to moderate enrichment of sediments. At the time of the survey, this did not result in nuisance micro / macro algal blooms on the sediment surface at reference sites. The abundance and diversity of benthic animals was low at the lagoon sites, indicating reduced ecological functioning. The abundance and diversity of infauna within the Te Aropipi channel site was more typical of healthy estuarine ecosystems, although species composition was notably different.

5. RECOMMENDATIONS FOR ONGOING MONITORING

The Wairau Estuary has natural (ecological and geological) and cultural / social values that are regionally, nationally, and possibly internationally, significant. Monitoring the health of the Wairau Estuary may be seen as important in the context of these values. Regular monitoring of estuarine condition would alert managers of any future changes and provide useful information for directing management decisions (see Appendix 1).

Broad-scale mapping has provided valuable insight into the habitat features of the Wairau Estuary. Likewise, the fine-scale survey of physical, chemical and biological properties of benthic intertidal habitats has provided understanding of the condition or 'health' of reference sites in the estuary. The combined results have provided a baseline description of habitat condition that can be used as a benchmark for comparison with future repeat assessments.

The extent to which habitat alteration will continue in the future is unknown, but will likely be confounded by predicted sea level rise and increased storm frequency in association with global warming. We therefore recommend the continuation of broad-scale habitat mapping surveys. The Wairau Estuary is already prioritised by MDC to be included within its monitoring programme. As part of this, we suggest reassessment of baseline estuary characteristics at approximately five-year intervals in accordance with the EMP. To complement traditional broad-scale mapping techniques we also note the potential applicability of conducting high-resolution mapping of defined high-value or at-risk areas using drone-operated low altitude photographic coverage at more frequent intervals.

We also recommend the continuation of fine-scale benthic surveys at approximately 5-year intervals as part of the full EMP monitoring programme. To build on the results from this report we suggest the inclusion of at least one additional intertidal site within the estuary that is more representative of other EMP-monitored New Zealand estuaries (*e.g*. with a higher sediment sand content). Further exploration of sediment types within the estuary would need to be conducted to determine this.

The interpretive value of the benthic monitoring approach proposed here would benefit from additional investigation focused on overlying waters. Existing models may be used to broadly estimate estuary nutrient and suspended sediment loadings and hydrodynamic (mixing) properties. Interviews with local residents indicate that shellfish are gathered recreationally within the estuary, suggesting the need to incorporate water and / or shellfish quality information (*e,g,* faecal indicator bacteria concentrations) into state of the environment reporting for Wairau Estuary.

Most estuarine biota are euryhaline in nature. That is, they are tolerant to a wide range of brackish to full seawater salinities. However, the high salinities recorded for sediment surficial waters of Upper and Big Lagoon survey sites may have significantly limited benthic animal communities. Further investigation of the tidal range of salinities of overlying estuarine waters would complement interpretation of the ecological condition of these partially ‘ponded’ lagoons.

The area coverage and density of opportunistic macroalgal taxa (*e.g*. *Ulva* spp. and *Gracilaria* sp.) are strong indicators of ecological conditions within an estuary. Historical aerial photos from 2005 and 2011/12 of the Wairau Estuary indicate that these may vary temporally and spatially. We recommend that monitoring for coverage of these potential problem taxa be undertaken during successive years over the summer period, when conditions are usually most favourable for their growth. This will be required in order to better document the extent of macroalgal growth and explore the potential for over-enrichment within the estuary. This could be undertaken by collecting photographs of specific regions of the estuary where accumulations of these taxa have been observed previously. However, agar weed may be a more permanent feature (*i.e*. less seasonal variation) suggesting that assessment of long term change using existing aerial photographs or possibly satellite imagery may be appropriate.

Storm-related suspended sediment discharges and bank erosion, in conjunction with sediment resuspension / mobilisation and deposition along estuary margins, may have considerably altered habitat structure in the past and is continuing. Modification to the Wairau Estuary by human activity (*e.g.* creation of the Wairau Diversion) and natural events (*e.g*. earthquake and tsunami) is likely to have strongly influenced the above processes. The extent of habitat change over time could be investigated by comparison of boundaries detectable in any suitable historical aerial photographs that are available. A thorough review of historic literature may also give greater understanding of the hydrological and ecological changes that have occurred within the estuary and would provide context to the findings of our current baseline survey.

Due to the shallow lagoon-like nature and reduced intertidal area associated with much of the Wairau Estuary, a large component of the overall habitat is classed as subtidal. To create a better understanding of estuary condition, further characterisation of the large subtidal component of the Wairau Lagoons would be required. Therefore we suggest undertaking exploratory sampling of the subtidal benthic habitat to find reference sites appropriate for incorporation into the on-going fine-scale monitoring programme. This could potentially be achieved using Dual-Frequency Identification Sonar (DIDSON) to survey transects across the estuary benthic habitat. DIDSON collects acoustic signals of the seafloor and can differentiate between different structural habitat classifications. As this method can be conducted from a flat-bottomed boat at high tide, it could be particularly useful given the shallow nature of the subtidal habitat. Sonar coverage in conjunction with calibration analyses of key indicators at specific transect sites would significantly add to the understanding of subtidal soft sediment lagoon habitat.

As the sediments within the Wairau Estuary fine-scale sites contained a high mud proportion we suggest that the collection and analysis of long (>1 m) sediment cores be undertaken for assessment of historical variations of sediment depositional rates. Although settlement plates could be utilised in order to determine shorter-term sediment accumulation rates at specific locations within the estuary, we would not recommend this because of the likelihood that sediment redistribution within the estuary and high short term variability would make useful interpretation of results tenuous. Although this approach may provide interpretable data at semi-protected locations that are subject to a less dynamic hydrodynamic regime, the results generally do not usefully inform management decisions.

Reminisces, based on long-term ecological knowledge, of the Wairau Estuary were gained through interviews / consultation with four local residents. The preliminary decision matrix was used to provide a framework to facilitate this engagement. The local reminisces provided a valuable context for interpretation of the findings from our current ‘point in time’ survey. It also ‘personalised’ the estuary, highlighting its importance to individuals as a place of memory and life style. The Wairau Estuary has extremely high Maori cultural value. We recommend engagement / consultation with local iwi to build on knowledge of the history and value of the Wairau Estuary. Te Runanga a Rangitane o Wairau will be invited to partner with MDC for the next scheduled estuary monitoring in 2020, and to share whatever information on the ecological history that they feel is necessary (Steve Urlich, MDC, pers.comm.). Benefit could also be gained by progressing iwi estuary monitoring, similar to that trialled by Walker (2009) within the Nelson region. This could provide a better framework for including cultural input, assessment and advice into estuarine monitoring surveys.

In summary, the main recommendations for ongoing monitoring include the following:

- Reassessment of baseline estuary characteristics at approximately five-year intervals in accordance with the EMP. We also note the potential applicability of conducting high-resolution mapping of defined high-value or at-risk areas using drone-operated low altitude photographic coverage at more frequent intervals.
- Inclusion of at least one additional intertidal site within the estuary that is more representative of other EMP-monitored New Zealand estuaries (*e.g*. with a higher sediment sand content).
- Incorporation of water and / or shellfish quality information into state of the environment reporting for Wairau Estuary.
- Investigation of the tidal range of salinities of overlying estuarine waters to complement interpretation of the ecological condition of the estuary.
- Monitoring of the coverage of potentially problematic macroalgal taxa over successive years.
- Investigation of the extent of habitat change over time by comparing boundaries detectable in historical aerial photographs. Review of historic literature to give

greater understanding of the hydrological and ecological changes that have occurred within the estuary.

- Exploratory sampling of the subtidal benthic habitat to find reference sites appropriate for incorporation into the on-going fine-scale monitoring programme.
- Collection and analysis of long (*e.g.* >1 m) sediment cores for assessment of historical variations of sediment depositional rates
- Engagement / consultation with local iwi to build on knowledge of the history and value of the Wairau Estuary.

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8. APPENDICES

Appendix 1. Preliminary Decision Matrix (DM) for the Wairau Estuary.

A flexible tool, the ‘Decision Matrix’ (DM) spreadsheet is included here to give a rapid, broad overview of estuary characteristics / values / known impacts and provide a basis for monitoring priority by way of comparison with other estuaries within the region or district. The estimated scores are from the authors’ perspective, and are meant to provide context for engagement/consultation to achieve a broader outlook (*e.g.* from the community, iwi and various environmental interest groups). They can be re-evaluated periodically to assess changes reflecting new information (*e.g*. monitoring results) and / or changing values. Local knowledge can be particularly valuable by way of providing a reality check to the assigned preliminary DM scores and identifying changes over time that may influence monitoring priorities. The DM could be implemented for all estuary locations under consideration by MDC for future SOE monitoring sites.

Notes:

1. The Wairau Estuary is evaluated partly according to the existing degree of modification/adverse impact. Other estuaries might be evaluated according to the degree that they remain in a ‘pristine’ state. The higher the final score the higher the priority for SOE monitoring and/or management intervention.
2. Where there was insufficient information to confidently assign a score, the value was entered in red.
3. The Wairau Estuary could be considered a "choked" lagoon system due to constricted tidal flows. Such systems can be more vulnerable to catchment land-use effects, sediment, nutrient and contaminant discharges and sea level rise than "normal" estuaries.
4. The weighting factor is based on a subjective 1-5 scale and the total scores are calculated automatically.

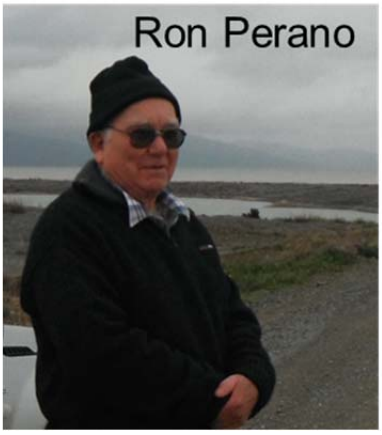
WAIRAU LAGOONS		**DECISION MATRIX FOR PRIORITISING ESTUARIES FOR STATE OF ENVIRONMENT MONITORING**								
	Estuary Assessment Factor	**Explanation**	**Scoring Schedule**	***Preliminary Scoring***			***Consultative Scoring***			***Notes***
A. Existing Estuary Physical Characteristics				**Score**	**Weighting factor**	**Total**	**Score**	**Weighting factor**	**Total**	
1	Area of estuary (ha)	Value of an estuary increases with the area of the resource.	1 = <500 ha, 2 = 500-2500 ha, 3 =>2500 ha.	3	5	15				1576 ha
2	Area of the estuary catchment	Estuaries with large catchment areas draining into them will be at greatest risk of land use effects.	1 = <100 km^2, 2 = 100-500 km^2, 3 = >500 km^2	3	3	9				4165 km^2
3	Flushing time (days)	Flushing time is the average period during which a quantity of freshwater derived from a stream or seepage remains in the estuary. The very well-flushed estuaries will be least at risk from build-up of contaminants.	1 = < 3 days, 2 = 3-10 days, 3 = >10 days	2	3	6				Low flushing in lagoons
4	Freshwater input (litres/s)/Area of estuary (ha) ratio	Estuaries with a high FW inflow/Area ratio have a large freshwater influence resulting in higher risk of catchment-related impacts.	1 = <10, 2 = 10-100, 3 = >100.	3	4	12				194435 /1576 = 123
B. Natural Character and Values										
5	Wetland and wildlife status	Estuaries are often important habitat for coastal fish, migratory birds and/or rare plant and animal species. Estuaries may therefore have significant conservation value and are sometimes assigned regulatory status.	1 = low, 2 = medium, 3 = high wetland and wildlife status	3	5	15				Regulatory status?
6	Recreational use	An estuary can be a significant social resource, used for water sports, food gathering, sightseeing, *etc.*	1 = low utilisation for recreation, 2 = moderate, 3 = high utilisation for recreation	3	5	15				Walking track, kayaking, hunting
7	Cultural signifcance	The values of tangata whenua, including the issue of mana whenua (customary authority) may be significant to an estuary. Estuaries may have a high cultural value if they are or were a traditional food-gathering site, papa taakoro or of other cultural importance.	1 = low perceived cultural significance, 2 = medium, 3 = high perceived cultural significance	3	5	15				1st Maori landing on S Isl.
8	Commercial use	An estuary can be a commercial resource with economic importance (*e.g* . for shellfish/fish harvesting, aquaculture, ecotourism, waste disposal *etc.*)	1 = low commerical use, 2 = moderate, 3 = high commercial use	2	2	4				Ecotourism, waste disposal
9	Perceived value by the communities in the region	Estuaries may have high aesthetic and amenity value to surrounding residential communites. They may also be important for education, tourism, or significant to the communities' natural character or identity.	1 = low perceived value by communities, 2 = medium, 3 = high perceived value by communities	3	5	15				Community consultation?
10	Diversity of intertidal habitat	Estuaries with the broadest array of intertidal habitats have the greatest potential for high intertidal biodiversity and therefore have greatest ecological value to a region. Habitats include: rushes, reeds, seagrasses, tussocks, herbfields, scrub, rock, cobble, gravel, mobile sand, sand, shell, muddy sand, soft muds, shellfish beds, sabellid beds.	1 = limited array of habitats, 2 = moderate array of habitats, 3 = most common habitats present and in good condition	2	5	10				Coarse-grained sediments, eelgrass under-represented
11	Extent of fish/shellfish resources	Occurrence of fish and shellfish resources in or near an estuary enhances its value. A drop in abundance and diversity could result from a deterioration in estuarine function.	1 = low or no fish and shellfish resources, 2 = medium abundance/diversity, 3 = High abundance and/or diversity	3	5	15				Cockle beds, whitebait, coastal fish ?
12	Scientific investigation/education	Scientific understanding and community awareness are essential for managing estuaries sustainably. Some estuaries may provide useful study locations (*e.g* . due to location, estuary type, existing impacts, pristine qualities, *etc* .).	1 = low, 2 = medium, 3 = high scientific/educational value.	3	5	15				Unique estuary morphology, historical timeline
13	Estuary effects on land prices	Lands surrounding estuaries are often sought after for residential or industrial development and can therefore demand higher prices.	1 = little or no effect on land prices, 2 = moderate effect, 3 = strong effect	3	5	15				Unknown
C. Characteristics that Indicate an existing or potential adverse impact (See Note 3)										
14	Proportion of urban/Industrial landuse in the estuary catchment	Modified catchments are likely to pose greatest risk of impact to an estuary. Urban and industrial contaminants include heavy metals, nutrients, organochloride pesticides *etc.*	1 = low , 2 = medium, 3 =high extent of urban/industrial landuse	2	5	10				May be more appropriate to also consider estuary margins
15	Proportion of agricultural landuse in the estuary catchment	Modified catchments are likely to pose greatest risk to an estuary from contaminant entry. Agricultural run-off has been attributed to increased sedimentation, nutrients and contaminants in estuaries.	1 = low , 2 = medium, 3 = high extent of agricultural landuse	2	3	6				May be more appropriate to also consider estuary margins
16	Proportion of exotic forest landuse in the estuary catchment	Modified catchments are likely to pose greatest risk to an estuary from contaminant entry. Exotic forestry can impact on estuaries by causing increased erosion of the catchment and increased sedimentation in the estuary.	1 = low , 2 = medium, 3 = high extent of exotic forest landuse	3	3	9				Rough estimate only
17	Proportion of modified to unmodified estuary catchment	The least modified catchments are likely to pose least risk to an estuary from contaminant entry.	1 = high, 2 = medium, 3 = low extent of unmodified catchment	2	3	6				Rough estimate only
18	Point Source effluents	Presence of point source discharges of wastewater (municipal, industrial and/or agricultural) into an estuary pose a high risk of contaminant entry.	1 = very low or no discharges, 2 = moderate discharges, 3 = extensive discharges.	2	5	10				Blenheim Sewage Treatment Plant: storm water discharges
19	Aquaculture Licences	Presence of aquaculture activities in an estuary provides a greater risk of contaminant entry and other impacts (*e.g.* biosecurity risk and impingement on the natural and aesthetic values of an estuary).	1 = none existing and no known potential, 2 = none existing but potential for future development, 3 = existing aquaculture licences .	2	1	2				*Gracilaria* potential?
20	Extent of risk of accidental spills	Accidental spillage of hazardous wastes (*e.g* . oil) lowers values in an estuary.	1 = low risk, 2 = medium risk, 3 = high risk of accidental spills	3	3	9				
21	Percentage of intertidal area comprised mud-dominated substrate.	Estuaries with a high proportion of muddy habitat are likely more prone to sedimentation effects.	1 = <5%, 2 = 5-20%, 3 = >20%	3	5	15				45%; High but may be typical for choked lagoon systems
22	Extent of nuisance macro and micro-algal blooms	Excessive macrolgal (seaweed) growth (*e.g. Ulva* sp.) indicate nutrient enrichment. This can have widespread adverse ecological and aesthetic effects.	1 = no incidence , 2 = occasional incidence, 3 = frequent incidence and/or large areas of nuisance macroalgae	2	4	8				*Gracilaria, Ulva?*
23	Extent of invasive species	Occurrence of exotic invasive species can threaten the natural character and biodiversity of an estuary (*e.g.* Pacific oyster, *Spartina* sp.)	1 = no known invasive species, 2 = low colonisation of invasive species, 3 = large colonisation of invasive species	2	5	10				Estuary margins
24	Extent of water clarity problems	Widespread water clarity problems (*e.g.* after heavy rain and/or wind events) lower the perceived value of an estuary, have an adverse social effect and adversely effect aquatic ecosystems.	1 = zero or rare , 2 = occasional, 3 = frequent water clarity problems	3	4	12				Probably frequent
25	Extent of faecal contamination problems	Widespread faecal contamination problems lower estuary values. Problems are indicated by high faecal coliforms and enterococci in the water column and shellfish, illness or perceived health risk.	1 =zero or rare, 2 = moderate, 3 = high faecal contamination problems	2	5	10				Unknown
26	Extent of nuisance odour problems	Nuisance odour problems, (e.g. from effluent, decomposing macroalgae, anaerobic sediments, *etc.)* lower estuary values.	1 = zero or rare, 2 = occasional, 3 = frequent nuisance odour problems	2	5	10				Unknown
27	Extent of toxicity problems	Widespread sediment contamination (*e.g.* metals, organics, sulphide, ammonia) lower estuary values. Toxicity problems can occur in the water and/or sediment, and may have extensive adverse effects for the biological communities.	1 = zero or low, 2 = moderate, 3 = high incidence or extent of toxicity problems	1	3	3				No evidence
28	Solid waste/litter	The presence of solid waste (*e.g.* refuse/litter) lowers estuary values.	1 = zero or low, 2 = medium 3 = high occurrence of solid waste	2	2	4				
D. Historical perspective										
29	Extent of modification of estuary hydrodynamic characteristics	The water circulation patterns of estuaries can be modified in a variety of ways, both natural and human induced, having profound effects on both the estuarine and greater coastal ecosystem (*e.g* . the deposition and/or mobilisation of sediments and contaminants) .	1 = zero to low, 2 = moderate, 3 = large extent of modification of hydrodynamic characteristics	3	5	15				Natural & human induced
30	Extent of estuary margin alteration (*e.g.* reclamation)	Estuaries where margins have been altered and/or reclamation has been undertaken have less value and a decreased ability to assimilate contaminant entry and increased erosion and sedimentation processes.	1 = low, 2 = medium, 3 = high extent of margin alteration	3	5	15				Historical mapping
31	Extent of reduction of vegetated habitat	Estuaries where vegetated (*e.g.* saltmarsh, sea grass, *etc* .) habitats have been reduced or reclaimed have lower ecolgical value, fewer feeding and nursery habitat for animal species, and a decreased ability to assimilate contaminant and sediment entry. These habitats act as coastal buffers.	1 = habitat extent unaltered, 2 = moderately reduced, 3 = severely reduced	2	5	10				Historical mapping
32	Extent of accelerated changes in habitat structure (e.g. increased muddiness).	Ssediment trapping is a natural function of estuaries and long term change can therefore be seen as a natural progression. However excelerated suspended sediment input and deposition can result in an unacceptable alteration of estuarine habitat structure and function.	1 = low, 2 = medium, 3 = high rate of change.	3	5	15				Core profile dating
	Total Score	**Notes: (1). This estuary is evaluated partly according to the existing degree of modification/adverse impact. The higher the final score the higher the priority for SOE monitoring and/or management intervention. (2). Where there was insufficient information to confidently assign a score, the value was entered in red. (3). The Wairau Estuary could be considered a "choked" lagoonal system due to constricted tidal flows. Such systems can be more vulnerable to catchment land-use effects, sediment, nutrient and contaminant discharges and sea level rise than "normal" estuaries. (4). Weighting factor based on a subjective 1-5 scale.**				**340**				

Appendix 2. Summary of local reminisces on the ecology of the Wairau Estuary.

Local reminisces of Wairau Estuary

The notes below, grouped into categories, have been taken from interviews with **Ron Perano** and **Will Parsons** on 5 June 2015 and **Brin Williman** on 30 June 2015. All of these men have considerable knowledge of the Wairau Estuary. Ron, who is now 80 years old, grew up on the Wairau Estuary. Until 1958 he lived with his family in a house next to the boulder bank, close to the mouth of the Wairau Estuary. His father was a fisherman in Cloudy Bay and his family farmed sheep on the boulder bank. He spent much of his childhood playing within the estuary. Will has been going into the estuary since 2004 and has run an ecotourism kayaking business (Driftwood Eco-tours) within the estuary since 2006/2007. Brin is a rivers engineer and has worked for the Council in the Marlborough region for over 40 years. **Paul Leedom**, a farmer who has been living at and managing the Vernon Station (situated along the southern side of the Wairau Estuary) since June 2004, has also contributed his knowledge.

The initials at the end of each note indicate which man made the comment it is based on.



Fish

- Could always get flounder, and the occasional trout in the net too. The fishing boats used to tie up to the old wharf and when they were cleaning the fish all of the yellow-eyed mullet would come around the boats, we would use the mullet as bait when hand lining for groper. No flounder in Big Lagoon but there were flounder in the channels and up the Opawa. No snapper in the lagoon **RP.**
- I can remember in the 40s and 50s whitebait used to go up the Opawa and turn around and go back again. We believed they went up the river and found something they didn't like and turned around. If you turn your net around you will catch them. I think there is the same amount of whitebait coming over the bar as

there was in the 40s but there were only a handful of people catching them, now there could be a couple of hundred people catching them. So that's why they think there is less. Cos when we were kids we had the south side the boulder bank side all to ourselves but now there could be 20 people or more there sometimes. I think the same amount of whitebait is spread around more people **RP**.

- Big whitebait spawning area by Will's house. I think a lot of white bait spawning areas- farming has become more intensive and cattle go into those areas more than they used to **RP**.
- I have seen a large jellyfish in the estuary and I have seen dogfish but believe they have got caught within the estuary **WP**.

Shellfish

- Lots of cockles in estuary (including up by the Waverley) - don't have to go down very deep and you can scoop them up with your hand – I have eaten cockles and some of them are big, not polluted, I have taken them home and eaten them. There are very few pipi **WP**.
- The pipi bed is still there but it has changed, now there is the occasional pipi but not many. When we were kids we used to go and get half a tin full of cockles and eat them on the fire on the beach **RP**.

Birds

- When I was young we could buy rights to collect swans' eggs in the estuary **RP**.
- There used to be a lot of bitterns on the Opawa River banks **RP**.
- Always godwits in the estuary, big area of dry ground and by the side of the islands is where they used to feed, they burrow right down and feed on eelworms **RP**. Godwits still appear to be in the same place where they are now **WP**.
- Spoonbills are a relatively recent arrival from Australia, we used to get a few Kotuku (white herons) **RP**. Spoonbills arrived in the early 1960's in the lower lagoons **WP**.
- No duck shooting in the lagoon in my younger days because it was all a sanctuary, there is far less ducks than what there used to be because there used to be a lot of grain, wheat and barley, grown on the plains. But now it is all grapes **RP**.
- I too believe there are less native ducks around but this is probably due to less grain crops in the surrounding district, thou the other game birds seem to populate **PL**.
- A lot of the dotterels have disappeared, there used to be heaps of them. However banded dotterels are starting to show up by the new ponds where the glasswort has come back again **WP**.
- One of the great things about that new wetland on the northern side is the number of bitterns that have been seen and that is a very healthy sign to me **WP**.

Macroalgae and eelgrass

- Lots of brown fluffy weed [*Gracilaria*] now present and when I was young there was none of it, none at all **RP.**
- Since the diversion channel was put in, over the years, all eelgrass has gone from the Big Lagoon (hundreds of acres of it). It used to be thick in the Big Lagoon. The swans used to pull up the eelgrass [*Zostera* sp.] and make nests of it **RP.**
- Diversion channel from the Wairau down towards to Rarangi Beach, 100% sure that it was supposed to be a permanent weir—to be at a height that when the Wairau River got to a certain height it overflowed and the diversion channel came into action—the weir was never ever put in. The diversion has changed the whole ecology of the area because the water was continuously going out of the diversion—not as much freshwater going out over the Wairau Bar. Either the effluent from the sewerage ponds going into the Opawa and/or the lack of freshwater going over the bar has upset ecology of estuary. That is why the eelgrass died and why the *Gracilaria* has come in **RP**.
- Never any sea lettuce [*Ulva* sp.] there **RP**.

Invasive species

- Neither Will nor Ron knew where *Spartina* [cord grass] was in the estuary or had seen any signs of Pacific oysters.
- Between the period 2004-2010 the lagoons were treated regularly by helicopter to eradicate the Southern Saltmarsh Mosquito (SSM) with follow up monitoring, but we still from time to time see large mosquitos **PL**.

Pollution

- Up until recently effluent discharge went into the Opawa **RP**.
- That has been stopped for over 12 months now, I think the quality of the water in the Opawa has definitely improved, in saying that there is less trout but that could be for all sorts of reasons **WP**.
- Prior to the Marlborough regions grape harvest each year the wineries use a chemical wash to flush out their holding tanks *et cetera* and this is pumped to the MDC industrial waste oxidation pond and treated (how exactly I am not sure) before being released on the ebb tides. This I believe changes the lagoon water pH and the end result from my observations is the wild bird population namely Canadian geese, black swans, paradise duck *et cetera* from the lagoons congregate around Vernon Station's water troughs and drink heavily plus foul the surrounding ground. This lasts sometimes 3-6 weeks. Since the MDC has upgraded the oxidation ponds with the extended wetland areas in recent years these noticeable effects have been reduced dramatically **PL**.

Tidal flushing

- Is the lagoon more out of sync with the tide than it used to be? **RP** yes I think it probably is because when we used to go out up in the lagoons collecting swans' eggs, to get the most water, we used to leave home just before high tide, and we had to row everywhere in those days, it would probably take us an hour and a half to get around the islands and when we did it was high tide—probably about a 2 hour difference.
- We get caught out numerous times kayaking, thinking it is low tide at the bar and the lagoon has just started to flow out, it flows out for a considerable point of time while the tide is coming in the lagoon is still draining **WP**.

Changes in sediment characteristics and channel/bank morphology

- After the big earthquake in 1855 the Wairau Plains went down four feet. The Port of Blenheim was at the Wairau Bar but after the big earthquake the ships could get right up to Blenheim because there was four feet more water. My late brother-in-law's grandfather could remember after the earthquake—they lived about halfway down the Opawa River—they saw the tide run up the Opawa River for the first time **RP**.
- The Wairau Bar has changed significantly in shape over time [see photos directly below]. There used to be a timber wall, built by the Barton Brothers in the 1930s situated on the northern side of the entrance to the bar. The old bar had a side channel off the rock wall road which was once part of it. The new bar has built out by several hundred metres over the years and the location of the outlet has changed— this may be because the rock wall has slowed the gravels going past the mouth. Part of the old bar exit is now a pond **RP**.

Aerial photos supplied by Marlborough District Council.

- Spent a lot of time as kids playing in the estuary—not in the Upper Lagoon but yes in the Big Lagoon. Used to be able to walk all over the Big Lagoon which was knee deep at mid-tide **RP**.
- Northeast of the house there was a big area of mud flat that the tide never came over, that is now all gone and before they put the rock wall in, there used to be a big long shingle spit that was one-half to three-quarters of a mile to the northwest. When they put the rock wall in it stopped the shingle spit from building up. And then all of the beach sort of moved out and then the spit started to form again and then they put the extension to the rock wall in the past five years and now it doesn't build up. When the shingle spit built up it stopped the flood getting out of the river. The Wairau River Board used to bring a bulldozer and dig a channel through the spit right up to the top of the beach. And they used to put timber slabs on it to stop the sea washing over and filling it in. When the flood was due to come down the Wairau they would send a bulldozer and dog those timber slabs away and dig a channel out and the flood went straight out. One day there was heavy rain and there was a major flood due—the river board didn't bring the bulldozer to dig the channel so my sister and I went down with shovels and dug it through by hand and next morning it had scoured out by 50-60 yards **RP**.
- I have seen a sand spit build up right down past the Waverley Point, occasionally they would put a gravel weir across the Wairau diversion and the next flood washes it away, I and my brother Ted are of the opinion that when the weir is working the sand spit builds up. When they put the gravel weir across it disappears **RP**.
- The lagoon edge is getting higher as mud levels rise. Deep channel by The Islands – gone now. You could row clinker dinghy in the area but all soft mud now and can only take a shallow aluminium dinghy. Used to be hard but now it is soft mud **RP**.
- The Waverley wreck has moved down the channel over time, 1939 big flood- Waverley moved to current position and more alteration of the Te Aropipi channel occurred- this channel is filling in quickly. Where Waverley is now there used to be 2-2.5 m of water alongside, but it ain't there now—it is nowhere as deep as it used to be. The way that the lagoons and channel are filling in now, in 20 years' time it will be a wetland **RP**.
- Each trip I do in the estuary, the tidal flow banks and the mud it seems to move around all the time, the channels are always slightly in a different place, it was deep the day before and the next day you go in it has changed. It changes particularly in the area where the Opawa and the Wairau meet **WP**.
- Huge amount of erosion happening on the Opawa River bank—English grasses [*e.g.* tall fescue] can't stabilize the bank and it collapses every day. Up here where we have the sedges and rushes growing there is no erosion going on at all. The Opawa River for kayaking is getting shallower and shallower because it is getting wider and wider **WP**.

- The key thing to me that I notice all the time is erosion, and that's very evident, very strong, there is a lot of breakdown of lots of these channels, even channels that were cut by the Maori people as well, they are getting wider and wider and the mud is building up **WP**.
- I would expect that ecological values of the 25 km^2 estuary should be strongly influenced by water parameters. These parameters being salinity, tidal range and regularity, and silt deposition. These parameters will have changed - and continue to be changed - by Council river control works over the years to control flooding and improve drainage. Some for the ecological betterment perhaps, and some perhaps for the worse. In particular 2 large "structures" have been built (and modified). Firstly the guide bank at the mouth of the Wairau. Council's construction of this in 1960 was effective at making a very efficient river mouth entry. This resulted in transmitting full open sea tidal cycle range into the estuary/lagoons. This will result in full range tidal cycle and salinity consistency. Prior to this the mouth was usually inefficient with a long bar stretching to the north. Full tidal cycle would not have been transmitted to the lagoon, and instead the lagoon being held at close to high tide levels much of the time; and inconsistent salinity levels. This guide bank was losing its effectiveness by 2005. The guide bank was therefore lengthened in 2009, and is proving effective again. Secondly the Wairau Diversion was cut through as a narrow pilot channel in 1964. The effect of the Wairau Diversion is to reduce flows in the Lower Wairau - especially flood flows. The initial pilot channel enlarged by scouring over the years. It was not till the early 1970s that the Diversion was beginning to have an effect. The mid 1990s saw considerably more enlargement of the Diversion, and reduction in flood flows in the Lower Wairau. This reduction in flood flows resulted in deposition of silt in the Lower Wairau - up to 1.5 metres depth - including at the confluence area of the lagoon outlet/Opawa River/Wairau River. In 2009 a control structure was built at the head of the Diversion that directs most flows down the Lower Wairau, and saves the Diversion mainly for large flood flows. The Lower Wairau is now scouring the deposited silts in the Lower Wairau and confluence of Wairau and lagoons. About 10 years ago we installed a culvert through the base of the old guide bank to rewater through daily tidal flows a small remnant lagoon/old river channel to the north and improve its ecology. A cursory look at [aerial] photos shows little change in lagoon pattern – suggesting that minimal sedimentation has taken place **BW**.

Change in vegetation

- The vegetation on the surrounding hills and valleys has been like that ever since I can remember—no more no less **RP**.
- Thirty-odd years ago I got totara logs from the estuary, I think that the totara grew there cos they were all laying the same way, the small part of the tree was facing southeast, parallel with the channel. The totara were maybe around four feet through. I also got another big totara log off of lower Dillons Point, it would have

been about 2 meters in diameter, we got a log around 6 meters long and two shorter ones. I am sure that log grew there as on the bottom of it there was bits of bracken fern and sticks where the log had fallen on it and it hadn't rotted away **RP**.

- The cattle used to go down to the river. In the time that the council has removed cattle from the council side of the area the amount of natural vegetation has expanded dramatically, and that is where the river is stable and that is why I say where native vegetation is it is pretty stable **WP**.
- Glasswort has increased since they put the new ponds in, on the left hand side. Dramatic improvement of it where they have cleared that land away to build the ponds, great to see in my opinion **WP**.

Algal blooms

- I have seen blooms in the Lower Opawa and that's really upset me, up to one hundred meters long and a rich rusty colour, in summer months **WP**.

Hydrogen sulphide (rotten egg) odour

- No odours when we were living there **RP.**
- From 2004-2010 the lagoons and MDC oxidation gave off an unpleasant odour more noticeable in NW winds and perhaps in the autumn months PL.

General comments

- A dray load of special bricks was deposited at the mouth of the Awatere, which subsequently turned up off the bar illustrating the power of the currents from farther south. This includes material from the Clarence and Waima rivers. This pre-dated the Marlborough District Council's formation in 1991 but the date is unknown **RP**.

Appendix 3. Classification of estuarine habitat types (adapted UNEP-GRID classification).

Level I Hydrosystem	Level IA SubSystem	Level II Class	Level III Structural Class	Level IV Dominant Cover	Habitat Code
Estuary (alternating saline and freshwater)	Intertidal/ supratidal	Saltmarsh	Shrub/Scrub/Forest	*Beilschmiedia tawa* "Tawa"	Beta
				Cordyline australis "Cabbage tree"	Coau
				Cytisus scoparius "Broom"	Cysc
				Dodonea viscosa "Akeake"	Dovi
				Exotic scrub/shrub/trees	Esst
				Knightia excelsa "Rewarewa"	Knex
				Leptospermum scoparium, "Manuka"	Lesc
				Metrosideros excelsa " Pohutukawa"	Meex
				Myoporum laetum "Ngaio"	Myla
				Native scrub/shrub/trees	Nsst
				Olearia solandri "Coastal tree daisy"	Olso
				Ozothamnus leptophyllus 'Tauhinu"	Ozle
				Ulex europaeus, "Gorse"	Uleu
				Unidentified trees	Untr
			Estuarine Shrubland	*Plagianthus divaricatus*, "Saltmarsh ribbonwood"	Pldi
				Muehlenbeckia complexa	Muco
			Tussockland	*Carex* spp. "Sedge"	Casp
				Cortaderia selloana "Pampas grass"	Cose
				Cortaderia sp. "Toetoe"	Cosp
				Phormium tenax, "New Zealand flax"	Phte
				Stipa stipoides	Stst
			Grassland	*Ammophila arenaria* "Marram grass"	Amar
				Festuca arundinacea, "Tall fescue"	Fear
				Exotic grass	Expg
			Sedgeland	*Cyperus eragrostis* "Umbrella sedge"	Cyer
				Schoenoplectus pungens "Three-square"	Scpu
			Rushland	*Isolepis nodosa*, "Knobby club rush"	Isno
				Juncus kraussii, "Sea rush"	Jukr
				Leptocarpus similis, "Jointed wire rush"	Lesi
			Reedland	*Typha orientalis* "Raupo"	Tyor
			Herbfield	*Carpobrotus edilus* "Ice Plant"	Caed
				Cirsium vulgare "Scotch thistle"	Civu
				Samolus repens, "Primrose"	Sare
				Sarcocornia quinqueflora, "Glasswort"	Saqu
				Selliera radicans, "Remuremu"	Sera
				Suaeda novae-zelandiae "Sea Blite"	Suno
				Triglochin striata "Arrow grass"	Trst
			Introduced weeds	Unidentified Introduced Weeds	Inwe
				Atriplex prostrata	Atpr
				Lycium ferocissimum "Boxthorn"	Lyfe
				Rubus fruticosus "Blackberry"	Rufr
		Eelgrass meadow	Eelgrass meadow	*Zostera sp*, "Eelgrass"	Zosp
		Macroalgal bed	Macroalgal bed	*Gracilaria chilensis*	Grch
				Ulva sp, "Sea lettuce"	Ulsp
		Woody debris *i.e.* driftwood	Piles of woody debris		Dfwd
		Artificial Structure	Man-made structure		MM
			Road		Road
			Bridge		Brg
		Mud/sandflat	Firm sand		FS
			Soft sand		SS
			Firm mud		FM
			Firm mud/sand		FMS
			Soft mud/sand		SM
			Very soft mud/sand		VSM
		Stonefield	Cobble field		CF
			Gravel field		GF

Level I Hydrosystem	Level IA SubSystem	Level II Class	Level III Structural Class	Level IV Dominant Cover	Habitat Code
		Man-made	Boulder-field (man-made)		BFmm
			Bridge		Brg
			Road		Road
		Shellfish field	Shell bank		Shel
		Worm field	Sabellid field		Tube
	Subtidal	Water	Water		Wter

Appendix 4. Definitions of classification Level III Structural Class modified from Robertson *et al*. (2002).

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are classified as trees.
Treeland: Cover of trees in canopy 20-80%. Trees are woody plants >10cm dbh.
Scrub: Woody vegetation in which the cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (*cf.* FOREST). Shrubs are woody plants <10 cm dbh.
Shrubland: Cover of shrubs in canopy 20-80%. Shrubs are woody plants <10 cm dbh.
Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.
Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of *Cortaderia*, *Gahnia*, and *Phormium*, and in some species of *Chionochloa*, *Poa*, *Festuca*, *Rytidosperma*, *Cyperus*, *Carex*, *Uncinia*, *Juncus*, *Astelia*, *Aciphylla*, and *Celmisia*.
Grassland: Vegetation in which the cover of grass in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground. Tussock-grasses are excluded from the grass growth-form.
Sedgeland: Vegetation in which the cover of sedges in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it is probably a grass or a reed, if the stem is clearly triangular, it is a sedge. Sedges include many species of *Carex*, *Uncinia*, and *Scirpus*. Tussock-sedges and reed-forming sedges (*cf.* REEDLAND) are excluded.
Rushland: Vegetation in which the cover of rushes in the canopy is 20-100% and in which the rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in the rush growth form are some species of Juncus and all species of, Leptocarpus. Tussock-rushes are excluded.
Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either hollow or have a very spongy pith. The flowers will each bear six tiny petal-like structures – neither grasses nor sedges will bear flowers. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata.*
Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.
Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and in which the herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not identified as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.
Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and in which the lichen cover exceeds that of any other growth form or bare ground.
Seagrass meadows: Seagrasses (including eelgrass) are the sole marine representatives of the class Angiospermae. They all belong to the order Helobiae, in two families:

Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries.

Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain chlorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope.

Firm mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When walking on the substrate you will sink 0-2 cm.

Soft mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When walking on the substrate you will sink greater than 2 cm.

Mobile sand: The substrate is clearly recognised by the granular beach sand appearance and the often rippled surface layer. Mobile sand is continually being moved by strong tidal or wind-generated currents and often forms bars and beaches. When walking on the substrate you will sink less than 1 cm.

Firm sand: Firm sand flats may be mud-like in appearance but are granular when rubbed between the fingers, and solid enough to support an adult's weight without sinking more than 1-2 cm. Firm sand may have a thin layer of silt on the surface making identification from a distance impossible.

Soft sand: Substrate containing greater than 99% sand. When walking on the substrate you will sink greater than 2 cm.

Stone field/Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) and/or bare stones (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Stonefields and gravelfields are named based on which form has the greater ground cover. They are named from the leading plant species when plant cover of ≥1%.

Cobble field: Land in which the area of unconsolidated cobbles/stones (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Cobble fields are named from the leading plant species when plant cover of ≥1%.

Boulder field: Land in which the area of unconsolidated bare boulders (>200 mm diam.) exceeds the area covered by any one class of plant growth-form. Boulderfields are named from the leading plant species when plant cover is ≥1%.

Rock/Rock field: Land in which the area of residual bare rock exceeds the area covered by any one class of plant growth-form. Cliff vegetation often includes rocklands. They are named from the leading plant species when plant cover is ≥1%.

Woody debris (*i.e.* driftwood): Pieces of woody debris of various sizes piled together.

Man-made structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

Cockle bed: Area that is dominated primarily by dead cockle shells.

Mussel reef: Area that is dominated by one or more mussel species.

Oyster reef: Area that is dominated by one or more oyster species.

Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.

Appendix 5. Site description and location for sediment grain size calibration experiment within the Wairau Estuary, 2015.

Site	1	2	3	4	5	6	7	8	9
Description	Kidney ponds/wetlands at SE corner of Boulder Bank	Kidney ponds/wetlands at SE corner of Boulder Bank	Kidney ponds/wetlands at SE corner of Boulder Bank	The Islands/SE corner of larger island	The Islands/SE corner of larger island	Off large Budges Island at end of sediment spit	Off large Budges Island close to channel	Off large Budges Island close to channel	Off large Budges Island close to channel
Latitude	-41.5453	-41.5453	-41.5453	-41.5341	-41.5343	-41.5398	-41.537	-41.5369	-41.5369183
Longitude	174.1252	174.1253	174.1249	174.1014	174.1011	174.0705	174.0677	174.0683	174.067916

Appendix 6. Unvegetated substrate present in the Wairau Estuary, 2015[1].

Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% Total Intertidal	Area (Ha) Supra-littoral
Driftwood			**2.12**	**1.28**	**0.30**
	Driftwood		0.97		0.30
		Cobble Field	1.02		
		Firm mud	0.05		
		Gravel field	0.02		
		Juncus kraussii (Searush)	0.06		
		Sarcocornia quinqueflora (Glasswort)	0.01		
Boulder Field			**0.00**	**0.00**	**0.10**
	Boulder Field				
		Gravel field			0.10
Cobble Field			**0.96**	**0.58**	**0.02**
	Cobble Field		0.48		0.02
		Driftwood	0.23		
		Gravel field	0.25		
Firm Mud and Sand			**57.15**	**34.53**	**0.10**
	Firm Mud and Sand		52.77		0.08
		Cobble Field	0.38		
		Driftwood	1.34		
		Gracilaria chilensis	0.43		
		Sarcocornia quinqueflora (Glasswort)	2.23		0.02
Soft Mud and Sand			**104.31**	**63.02**	**0.42**
	Soft Mud and Sand		103.85		0.42
		Gracilaria chilensis	0.42		
		Sarcocornia quinqueflora (Glasswort)	0.04		
Gravel field			**0.94**	**0.57**	**0.00**
	Gravel field		0.15		
		Cobble Field	0.34		
		Driftwood	0.40		
		Firm mud	0.04		
		Firm mud and sand	0.01		

Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% Total Intertidal	Area (Ha) Supra-littoral
Man-Made Structures			**0.03**	**0.02**	**0.12**
	Man-Made Structures		0.02		0.06
		Bridge	0.01		0.05
		Road			0.01
Water			**1217.61**		**0.30**
	Water		1132.53		0.30
		Gracilaria chilensis	84.97		
		Ulva lactuca (macroalgae)	0.11		
Grand Total			**165.51**	**100.00**	**1.06**

Overall Summary		
Unvegetated Substrata	165.51	
Estuarine Vegetation	193.00	58.87
Grand Total	**358.51**	**60.23**

Appendix 7. Vegetated substrate present in the Wairau Estuary, 2015[1].

Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% Total Intertidal	Area (Ha) Supra-littoral
Estuarine Shrubs			**0.21**	**0.11**	**2.11**
	Plagianthus divaricatus (Saltmarsh ribbonwood)		0.01		
		Festuca arundinacea (tall fescue grass)	0.07		0.74
		Juncus kraussii (Searush)	0.13		0.64
		Olearia sandri (Coastal tree daisy)			0.03
		Ozothamnus leptophyllus (Cassina, Tauhinu)			0.06
		Ulex europaeus (Gorse)			0.55
	Muehlenbeckia complexa				
		Ulex europaeus (Gorse)			0.05
		Plagianthus divaricatus (Saltmarsh ribbonwood)			0.04
Grassland			**5.38**	**2.78**	**27.67**
	Festuca arundinacea (Tall fescue)		0.01		0.74
		Juncus kraussii (Searush)	0.69		4.19
		Leptocarpus similis (Jointed wirerush)	0.05		
		Plagianthus divaricatus (Saltmarsh ribbonwood)	4.63		10.94
		Cirsium vulgare (Scotch thistle)			0.03
		Exotic pasture grass			4.91
		Exotic scrub/shrub/trees			0.01
		Ozothamnus leptophyllus (Cassina, Tauhinu)			0.58
		Phormium tenax (NZ Flax)			0.26
		Sarcocornia quinqueflora (Glasswort)			0.72
		Ulex europaeus (Gorse)			2.68
	Exotic pasture grass				0.04
		Exotic scrub/shrub/trees			0.21
		Festuca arundinacea (tall fescue grass)			1.74
		Firm mud			0.62
Herbfield			**156.82**	**81.25**	**15.06**
	Sarcocornia quinqueflora (Glasswort)		32.66		1.97
		Atriplex prostrata	0.22		0.35
		Exotic pasture grass	1.02		4.26
		Festuca arundinacea (Tall fescue grass)	0.00		1.24
		Firm Mud	64.58		1.69
		Gravel field	0.11		
		Juncus kraussii (Searush)	40.72		1.11
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.87		1.02
		Selliera radicans (Remuremu)	16.28		2.84
		Soft mud/sand (2-5cm)	0.30		0.02
		Triglochin striata (Arrow-grass)			0.03
	Selliera radicans (Remuremu)				
		Festuca arundinacea (Tall fescue grass)	0.06		
		Atriplex prostrata			0.02
		Sarcocornia quinqueflora (Glasswort)			0.51

Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% Total Intertidal	Area (Ha) Supra-littoral
Macroalgal bed			**21.61**	**11.20**	
	Gracilaria chilensis				
		Cobble field	0.33		
		Firm mud	0.75		
		Soft mud/sand (2-5cm)	6.33		
		Ulva sp. (Sea lettuce)	8.03		
		water	0.20		
	Ulva sp. (Sea lettuce)				
		Soft mud/sand (2-5cm)	0.42		
		Gracilaria chilensis	5.55		
Reedland			0.00	**0.00**	1.02
	Typha orientalis (Raupo)				
		Juncus kraussii (Searush)			0.38
		Phormium tenax (NZ Flax)			0.64
Rushland			**8.98**	**4.65**	**9.18**
	Juncus kraussii (Searush)		0.55	**0.15**	0.38
		Festuca arundinacea (tall fescue grass)	0.40	**0.11**	1.54
		Firm mud	0.62	**0.17**	0.00
		Plagianthus divaricatus (Saltmarsh ribbonwood)	1.52	**0.42**	4.32
		Sarcocornia quinqueflora (Glasswort)	5.51	**1.54**	2.80
		Exotic scrub/shrub/trees			0.01
		Phormium tenax (NZ Flax)			0.12
	Leptocarpus similis (Jointed wirerush)				
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.38	**0.11**	
Terrestrial Shrub/Scrub/Forest			**0.00**	**0.00**	**1.95**
	Myoporum laetum (Ngaio)				0.08
	Ozothamnus leptophyllus (Cassina, Tauhinu)	*Ulex europaeus* (*Gorse*)			0.02
		Plagianthus divaricatus (Saltmarsh ribbonwood)			0.01
	Unidentified trees				0.07
	Ulex europaeus (Gorse)				0.07
		Festuca arundinacea (tall fescue grass)			0.23
		Juncus kraussii (Searush)			0.26
		Muehlenbeckia complexa			0.01
		Phormium tenax (NZ Flax)			0.68
		Plagianthus divaricatus (Saltmarsh ribbonwood)			0.52
Tussockland			**0.00**	**0.00**	**1.88**
	Phormium tenax (NZ Flax)				0.02
		Festuca arundinacea (tall fescue grass)			0.01
		Juncus kraussii (Searush)			1.10
		Ozothamnus leptophyllus (*Cassina, Tauhinu*)			0.49
		Ulex europaeus (*Gorse*)			0.26
Grand Total			**193.00**	**100.00**	**58.86**

Overall Summary		
Unvegetated Substrata	165.51	1.06
Estuarine Vegetation	193.00	
Grand Total	**358.51**	**60.22**

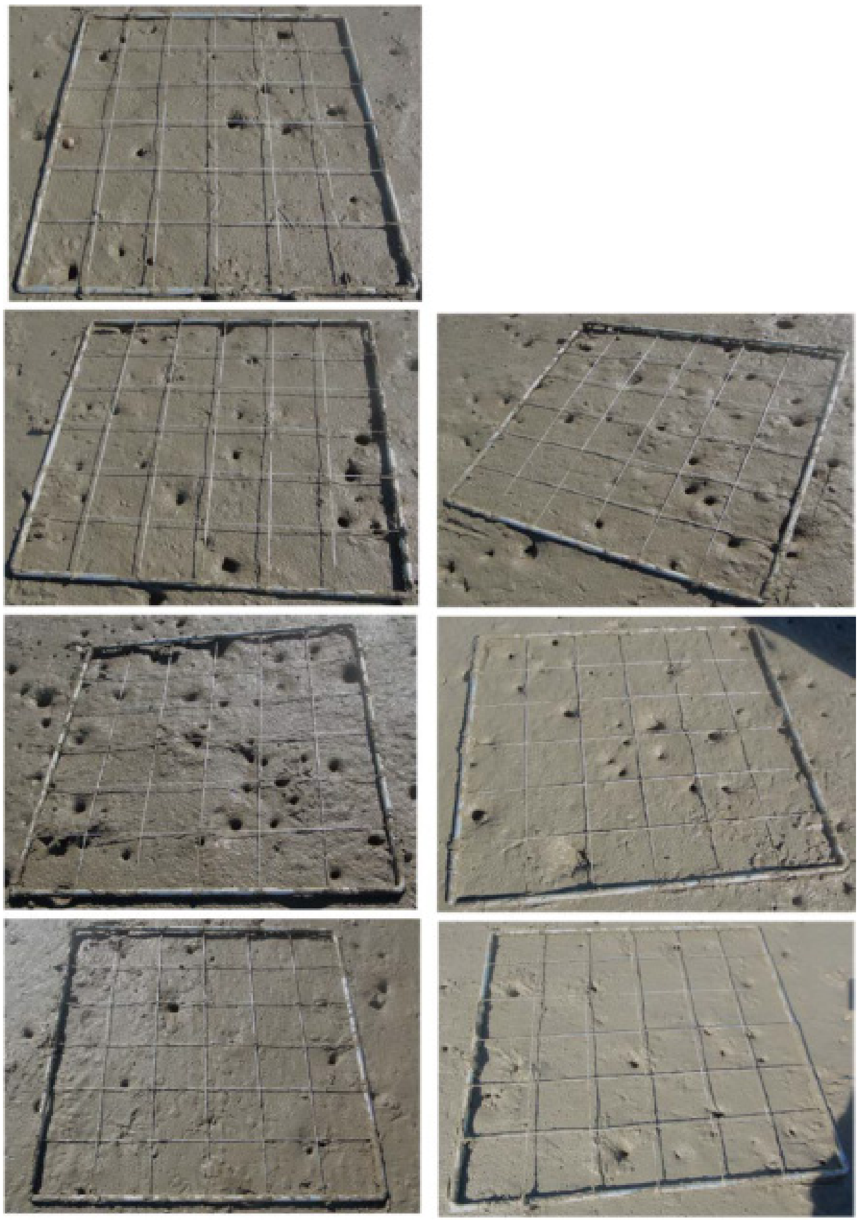
Appendix 8. DVD-ROM file containing a working version of the 2015 broad-scale habitat maps of Wairau Estuary (entitled “Broad-scale intertidal habitat mapping for Wairau Estuary: 2015). This DVD-ROM also contains the 2015 aerial image collected by drone of a subset of the Wairau Estuary (entitled “Drone image of a subset of the Wairau Estuary: March 2015”) and results from the Wairau Estuary 2015 fine-scale surveys (entitled “Fine-scale indicator results for Wairau Estuary: 2015”).

(See inside back cover)

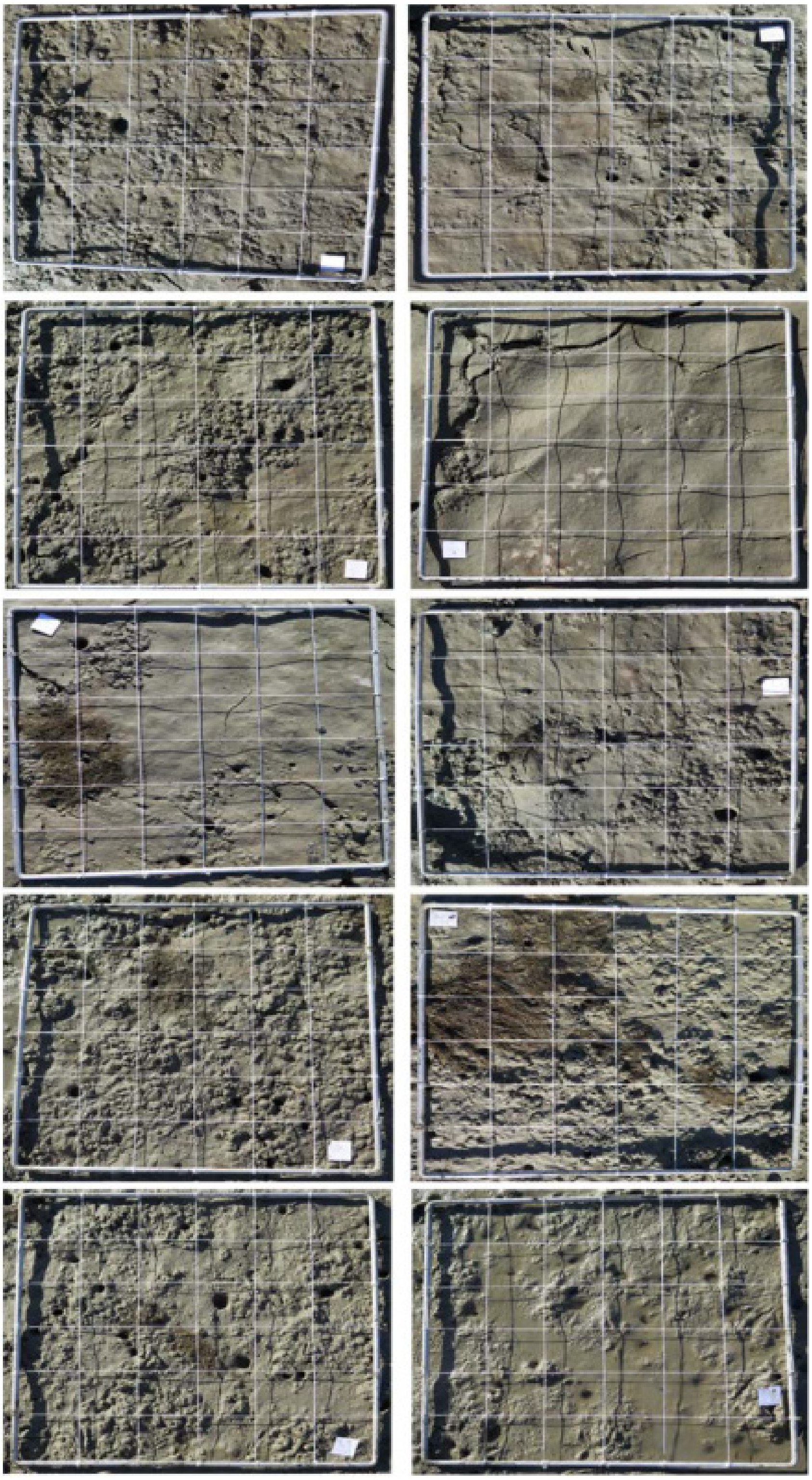
Appendix 9. Position (latitude and longitude) of the four corners of each Wairau Estuary sampling location (reference site) used for fine-scale surveys in 2015.

Site	Latitude	Longitude
A	-41.5365921	174.0631065
	-41.5366268	174.0636043
	-41.5368979	174.0635742
	-41.5368785	174.0630886
B	-41.5564951	174.1078391
	-41.5565901	174.1078801
	-41.556638	174.106672
	-41.5567740	174.1066743
C	-41.5124507	174.0611291
	-41.5120931	174.0609504
	-41.5122579	174.0606156
	-41.5125792	174.0607919

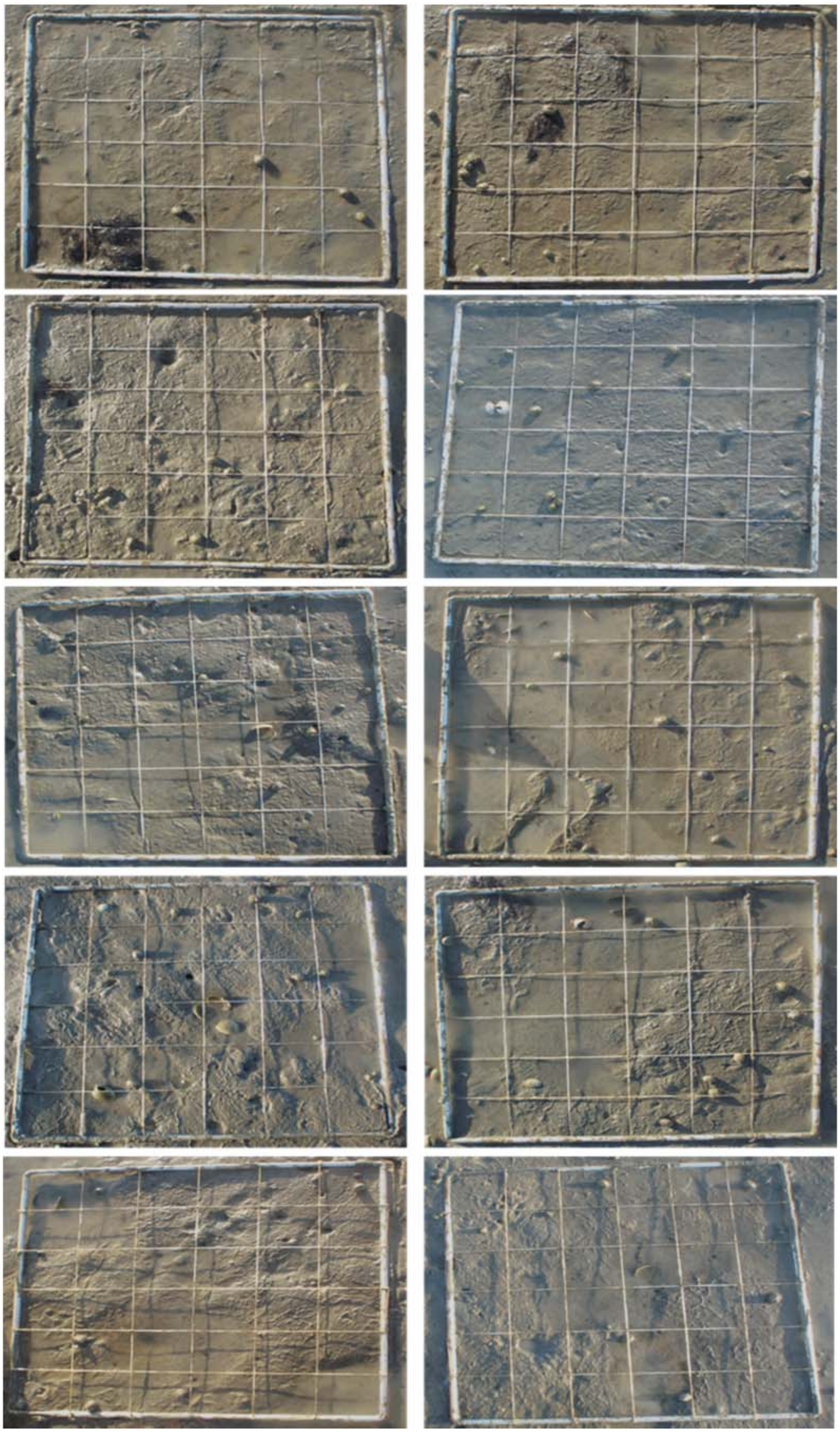
Appendix 10. Quadrat photos of Wairau Estuary fine-scale survey **Site A** (inside Upper Lagoon), 2015. Note: Photos 1-3 are missing.



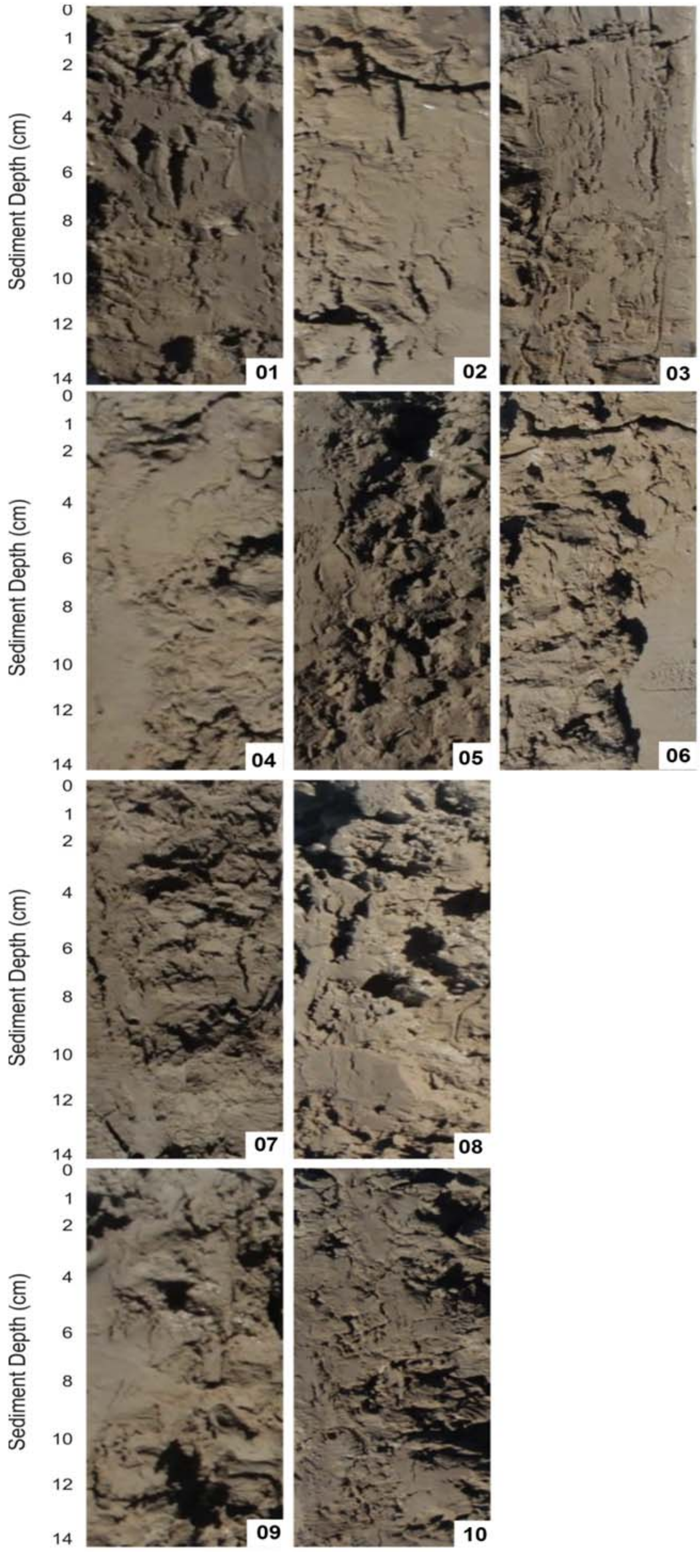
Appendix 11. Quadrat photos of Wairau Estuary fine-scale survey **Site B** (inside Big Lagoon), 2015.



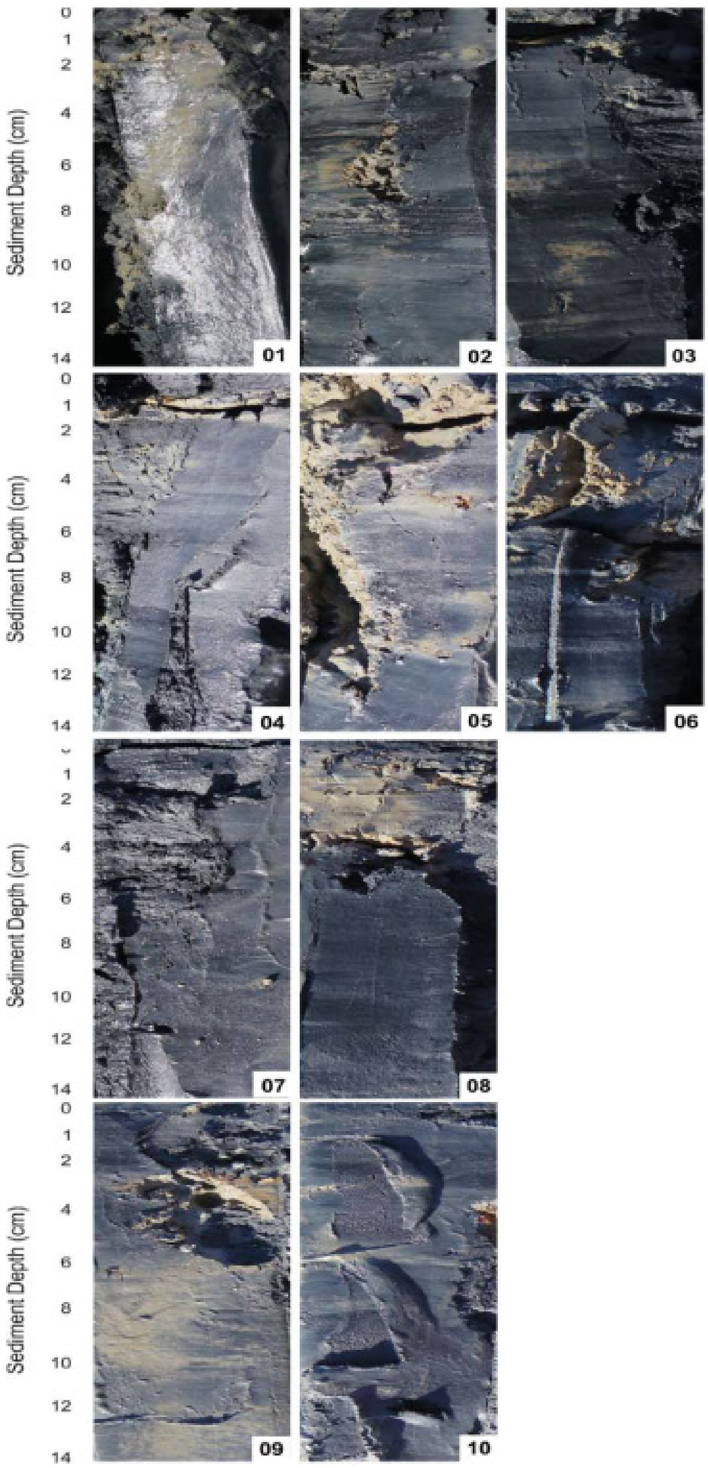
Appendix 12. Quadrat photos of Wairau Estuary fine-scale survey **Site C** (within the Te Aropipi Channel), 2015.



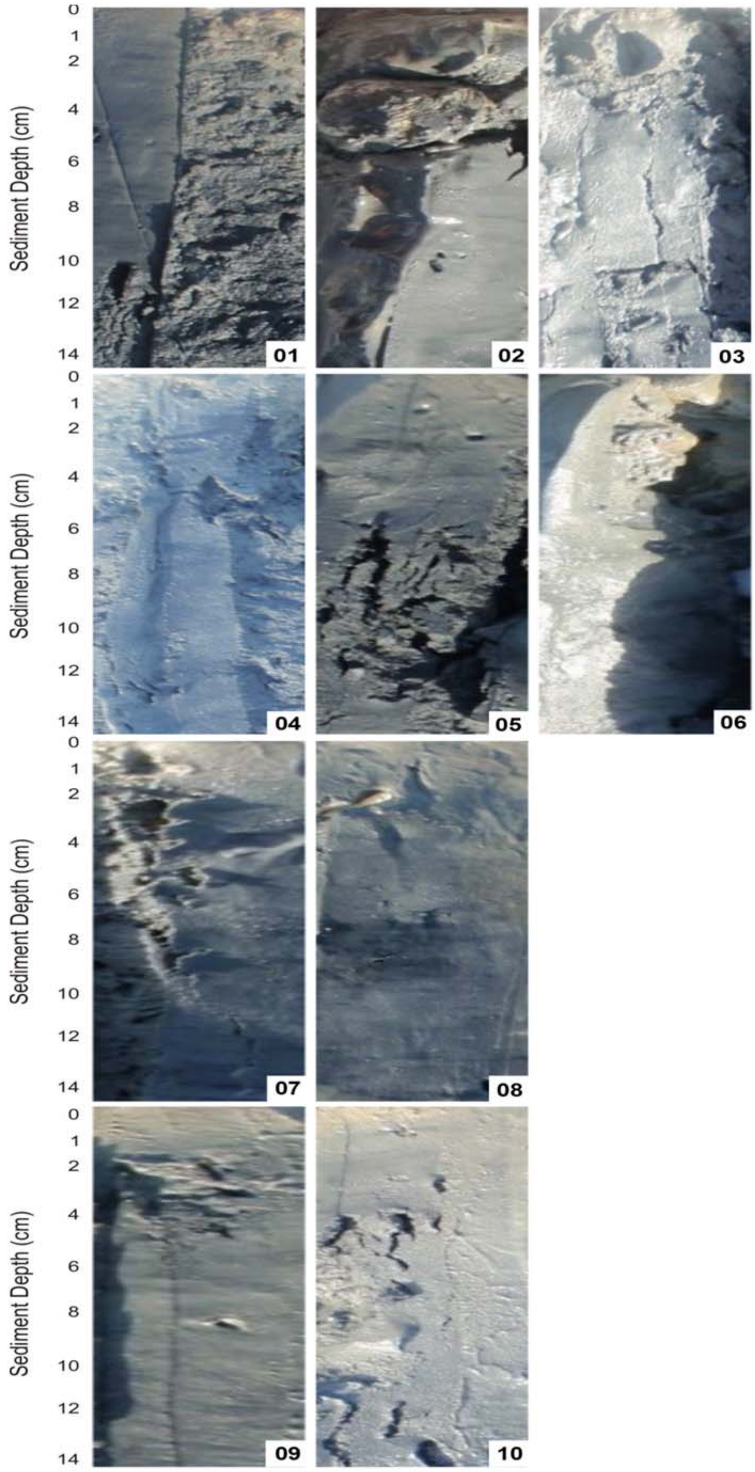
Appendix 13. Sediment cores from Wairau Estuary survey **Site A** (inside Upper Lagoon), laid out according to their spatial location on the sampling grid, 2015. The ruler on the left is in centimetres with 0 cm representing the surface.



Appendix 14. Sediment cores from Wairau Estuary fine-scale survey **Site B** (inside Big Lagoon), laid out according to their spatial location on the sampling grid, 2015. The ruler on the left is in centimetres with 0 cm representing the surface.



Appendix 15. Sediment cores from Wairau Estuary survey **Site C**, laid out according to their spatial location on the sampling grid, 2015. The ruler on the left is in centimetres with 0 cm representing the surface.



Appendix 16. Physical and chemical properties of sediments from three replicate samples collected from three fine-scale survey sites within the Wairau Estuary, 2015.

Site replicates	Gravel	Sands	Silt&Clay	Arsenic	Cd	Cr	Cu	Pb	Ni	Zn	TP	TN	TOC
Site A	(%)	(%)	(%)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	mg/kg dry wt	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(%)
1	< 0.1	3.70	96.30	3.80	0.03	16.00	10.40	10.70	21.00	47.00	610.00	500.00	0.29
2	< 0.1	2.70	97.30	3.70	0.03	15.20	10.10	10.30	19.90	45.00	630.00	600.00	0.30
3	< 0.1	2.50	97.50	4.00	0.02	15.80	10.50	11.10	21.00	47.00	630.00	600.00	0.31
Average	< 0.1	2.97	97.03	3.83	0.03	15.67	10.33	10.70	20.63	46.33	623.33	566.67	0.30
SD		0.64	0.64	0.00	0.00	0.42	0.21	0.40	0.64	1.15	11.55	57.74	0.01
Min	< 0.1	2.50	96.30	3.70	0.02	15.20	10.10	10.30	19.90	45.00	610.00	500.00	0.29
Max	< 0.1	3.70	97.50	4.00	0.03	16.00	10.50	11.10	21.00	47.00	630.00	600.00	0.31

	Gravel	Sands	Silt&Clay	Arsenic	Cd	Cr	Cu	Pb	Ni	Zn	TP	TN	TOC
Site B	(%)	(%)	(%)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	mg/kg dry wt	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(%)
1	< 0.1	3.00	97.00	7.40	0.06	19.90	17.40	18.30	22.00	59.00	780.00	2000.00	1.31
2	< 0.1	3.40	96.50	8.30	0.07	21.00	19.70	20.00	24.00	62.00	830.00	2700.00	1.79
3	< 0.1	2.00	98.00	7.80	0.07	21.00	20.00	21.00	24.00	63.00	790.00	2600.00	1.85
Average	< 0.1	2.80	97.17	7.83	0.07	20.63	19.03	19.77	23.33	61.33	800.00	2433.33	1.65
SD		0.72	0.76	0.00	0.00	0.64	1.42	1.37	1.15	2.08	26.46	378.59	0.30
Min	< 0.1	2.00	96.50	7.40	0.06	19.90	17.40	18.30	22.00	59.00	780.00	2000.00	1.31
Max	< 0.1	3.40	98.00	8.30	0.07	21.00	20.00	21.00	24.00	63.00	830.00	2700.00	1.85

	Gravel	Sands	Silt&Clay	Arsenic	Cd	Cr	Cu	Pb	Ni	Zn	TP	TN	TOC
Site C	(%)	(%)	(%)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	mg/kg dry wt	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(mg/kg dry wt)	(%)
1	0.30	38.60	61.10	5.10	0.03	18.10	11.60	12.20	29.00	52.00	600.00	500.00	0.32
2	0.70	49.40	49.90	4.30	0.03	16.70	10.40	10.90	28.00	49.00	560.00	500.00	0.29
3	2.50	39.70	57.80	4.40	0.03	17.30	11.10	11.40	28.00	51.00	580.00	500.00	0.31
Average	1.17	42.57	56.27	4.60	0.03	17.37	11.03	11.50	28.33	50.67	580.00	500.00	0.31
SD	1.17	5.94	5.76	0.00	0.00	0.70	0.60	0.66	0.58	1.53	20.00	0.00	0.02
Min	0.30	38.60	49.90	4.30	0.03	16.70	10.40	10.90	28.00	49.00	560.00	500.00	0.29
Max	2.50	49.40	61.10	5.10	0.03	18.10	11.60	12.20	29.00	52.00	600.00	500.00	0.32

Appendix 17. Concentrations of semi-volatile organic compounds within the three Wairau Estuary fine-scale survey sites, 2015. Concentrations are expressed as mg/kg dry. wt.

	Site A	Site B	Site C
Haloethers			
Bis(2-chloroethoxy) methane	< 0.17	< 0.3	< 0.17
Bis(2-chloroethyl)ether	< 0.17	< 0.3	< 0.17
Bis(2-chloroisopropyl)ether	< 0.17	< 0.3	< 0.17
4-Bromophenyl phenyl ether	< 0.17	< 0.3	< 0.17
4-Chlorophenyl phenyl ether	< 0.17	< 0.3	< 0.17
Nitrogen containing compounds			
3,3'-Dichlorobenzidine	< 0.9	< 1.1	< 0.9
2,4-Dinitrotoluene	< 0.4	< 0.5	< 0.4
2,6-Dinitrotoluene	< 0.4	< 0.5	< 0.4
Nitrobenzene	< 0.17	< 0.3	< 0.17
N-Nitrosodi-n-propylamine	< 0.4	< 0.5	< 0.4
N-Nitrosodiphenylamine	< 0.4	< 0.5	< 0.4
Organochlorine Pesticides			
Aldrin	< 0.17	< 0.3	< 0.17
alpha-BHC	< 0.17	< 0.3	< 0.17
beta-BHC	< 0.17	< 0.3	< 0.17
delta-BHC	< 0.17	< 0.3	< 0.17
gamma-BHC (Lindane)	< 0.17	< 0.3	< 0.17
4,4'-DDD	< 0.17	< 0.3	< 0.17
4,4'-DDE	< 0.17	< 0.3	< 0.17
4,4'-DDT	< 0.4	< 0.5	< 0.4
Dieldrin	< 0.17	< 0.3	< 0.17
Endosulfan I	< 0.4	< 0.5	< 0.4
Endosulfan II	< 0.5	< 0.5	< 0.5
Endosulfan sulphate	< 0.4	< 0.5	< 0.4
Endrin	< 0.4	< 0.5	< 0.4
Endrin ketone	< 0.4	< 0.5	< 0.4
Heptachlor	< 0.17	< 0.3	< 0.17
Heptachlor epoxide	< 0.17	< 0.3	< 0.17
Hexachlorobenzene	< 0.17	< 0.3	< 0.17
Polycyclic Aromatic Hydrocarbons			
Acenaphthene	< 0.10	< 0.11	< 0.10
Acenaphthylene	< 0.10	< 0.11	< 0.10
Anthracene	< 0.10	< 0.11	< 0.10

	Site A	Site B	Site C
Benzo[a]anthracene	< 0.10	< 0.11	< 0.10
Benzo[a]pyrene (BAP)	< 0.17	< 0.3	< 0.17
Benzo[b]fluoranthene + Benzo[j]fluoranthene	< 0.17	< 0.3	< 0.17
Benzo[g,h,i]perylene	< 0.17	< 0.3	< 0.17
Benzo[k]fluoranthene	< 0.17	< 0.3	< 0.17
2-Chloronaphthalene	< 0.10	< 0.11	< 0.10
Chrysene	< 0.10	< 0.11	< 0.10
Dibenzo[a,h]anthracene	< 0.17	< 0.3	< 0.17
Fluoranthene	< 0.10	< 0.11	< 0.10
Fluorene	< 0.10	< 0.11	< 0.10
Indeno(1,2,3-c,d)pyrene	< 0.17	< 0.3	< 0.17
2-Methylnaphthalene	< 0.10	< 0.11	< 0.10
Naphthalene	< 0.10	< 0.11	< 0.10
Phenanthrene	< 0.10	< 0.11	< 0.10
Pyrene	< 0.10	< 0.11	< 0.10
Phenols			
4-Chloro-3-methylphenol	< 0.5	< 0.5	< 0.5
2-Chlorophenol	< 0.2	< 0.3	< 0.2
2,4-Dichlorophenol	< 0.2	< 0.3	< 0.2
2,4-Dimethylphenol	< 0.4	< 0.4	< 0.4
3 & 4-Methylphenol (m- + p-cresol)	< 0.4	< 0.5	< 0.4
2-Methylphenol (o-Cresol)	< 0.2	< 0.3	< 0.2
2-Nitrophenol	< 0.4	< 0.5	< 0.4
Pentachlorophenol (PCP)	< 6	< 6	< 6
Phenol	< 0.4	< 0.5	< 0.4
2,4,5-Trichlorophenol	< 0.4	< 0.5	< 0.4
2,4,6-Trichlorophenol	< 0.4	< 0.5	< 0.4
Plasticisers			
Bis(2-ethylhexyl)phthalate	< 0.7	< 0.9	< 0.7
Butylbenzylphthalate	< 0.4	< 0.5	< 0.4
Di(2-ethylhexyl)adipate	< 0.2	< 0.3	< 0.2
Diethylphthalate	< 0.4	< 0.5	< 0.4
Dimethylphthalate	< 0.4	< 0.5	< 0.4
Di-n-butylphthalate	< 0.4	< 0.5	< 0.4
Di-n-octylphthalate	< 0.4	< 0.5	< 0.4
Other Halogenated compounds			
1,2-Dichlorobenzene	< 0.4	< 0.5	< 0.4
1,3-Dichlorobenzene	< 0.4	< 0.5	< 0.4
1,4-Dichlorobenzene	< 0.4	< 0.5	< 0.4
Hexachlorobutadiene	< 0.4	< 0.5	< 0.4
Hexachlorocyclopentadiene	< 0.9	< 1.1	< 0.9
Hexachloroethane	< 0.4	< 0.5	< 0.4

	Site A	Site B	Site C
1,2,4-Trichlorobenzene	< 0.17	< 0.3	< 0.17
Other SVOC			
Benzyl alcohol	< 1.7	< 3	< 1.7
Carbazole	< 0.17	< 0.3	< 0.17
Dibenzofuran	< 0.17	< 0.3	< 0.17
Isophorone	< 0.17	< 0.3	< 0.17

Appendix 18. Analytical results (mg/kg dry wt.) for polycyclic aromatic hydrocarbons (PAHs) and ANZECC (2000) listed organochlorine pesticides (OCPs) within sediments from the three Wairau Estuary fine-scale survey sites. Analytes for which ANZECC (2000) lists guideline values are shaded grey. Black-shaded cells designate an ADL below the corresponding ISQG-L criterion for the analyte. Note that since all analytes were below ADL, normalisation to 1% organic carbon (as specified by ANZECC) has not been applied.

	Site A	Site B	Site C	*ISQG-L*	*ISQG-H*
Total Organic Carbon	0.3	1.65	0.31		
Organochlorine Pesticides					
4,4'-DDD	**< 0.17**	**< 0.3**	**< 0.17**	*0.002*	*0.02*
4,4'-DDE	**< 0.17**	**< 0.3**	**< 0.17**	*0.0022*	*0.027*
4,4'-DDT	**< 0.4**	**< 0.5**	**< 0.4**		
Total DDT isomers*				*0.0016*	*0.046*
Dieldrin	**< 0.17**	**< 0.3**	**< 0.17**	*0.00002*	*0.008*
Endrin	**< 0.4**	**< 0.5**	**< 0.4**	*0.00002*	*0.008*
Polycyclic Aromatic Hydrocarbons					
Naphthalene	< 0.1	< 0.11	< 0.1	*0.16*	*2.1*
2-Methylnaphthalene	< 0.1	< 0.11	< 0.1		
Acenaphthylene	**< 0.1**	**< 0.11**	**< 0.1**	*0.044*	*0.64*
Acenaphthene	**< 0.1**	**< 0.11**	**< 0.1**	*0.016*	*0.5*
2-Chloronaphthalene	< 0.1	< 0.11	< 0.1		
Fluorene	**< 0.1**	**< 0.11**	**< 0.1**	*0.019*	*0.54*
Anthracene	**< 0.1**	**< 0.11**	**< 0.1**	*0.085*	*1.1*
Phenanthrene	< 0.1	< 0.11	< 0.1	*0.24*	*1.5*
Pyrene	< 0.1	< 0.11	< 0.1	*0.665*	*2.8*
Fluoranthene	< 0.1	< 0.11	< 0.1	*0.6*	*5.1*
Benzo[a]anthracene	< 0.1	< 0.11	< 0.1	*0.261*	*1.6*
Chrysene	< 0.1	< 0.11	< 0.1	*0.384*	*2.8*
Benzo[a]pyrene (BAP)	< 0.17	< 0.3	< 0.17	*0.43*	*1.6*
Benzo[b]fluoranthene + Benzo[j]fluoranthene	< 0.17	< 0.3	< 0.17		
Benzo[k]fluoranthene	< 0.17	< 0.3	< 0.17		
Indeno(1,2,3-c,d)pyrene	< 0.17	< 0.3	< 0.17		
Benzo[g,h,i]perylene	< 0.17	< 0.3	< 0.17		
Dibenzo[a,h]anthracene	**< 0.17**	**< 0.3**	**< 0.17**	*0.063*	*0.26*

* In the environment, DDT breaks down to DDD, then DDE. So the total DDT content of a soil sample should include the sum of six compounds (4,4'-DDT, 4,4'-DDD, 4,4'-DDE and their corresponding 2,4'- isomers). However, because the 2,4'-isomers only comprise a small percentage of the overall total, the 2,4'-DDD and 2,4-DDE isomers are not included when analysing for total DDT. http://www.hill-laboratories.com/page/pageid/2145845731/Soil_Testing_for_DDT_in_Dairy_Soil

Appendix 19. Infauna taxa and abundance within replicate cores collected at three Wairau Estuary fine-scale survey sites, 2015.

		Site A					Site B					Site C				
Taxa	**Common Name**	**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**
Nemertea	Proboscis worms														1	
Gastropoda																
Amphibola crenata	Mud Snail											1				
Potamopyrgus estuarinus	Estuarine snail											93	149	94	107	88
Bivalvia																
Arthritica bifurca	Small bivalve											8	5	7	39	5
Austrovenus stutchburyi	Cockle											3	3	1	2	3
Oligochaeta	Oligochaete worms											14	10	19	40	20
Polychaeta																
Paraonidae																1
Prionospio sp.				1								1				
Scolecolepides benhami					5	1								2	1	1
Scolecolepides sp.		1														
Capitella sp.															2	
Heteromastus filiformis															1	
Maldanidae	Bamboo worm											1				
Nereididae (juvenile)												1				
Nicon aestuariensis												1	5	1	5	1
Cirratulidae		1	1									1	1		3	
Amphipoda																
Corophiidae	Amphipod (family)											25	6	45	14	19
Phoxocephalidae	Amphipod (family)											1				
Amphipoda	Unidentified Amphipod										2	11	14	50	94	54
Decapoda																
Austrohelice crassa	Tunnelling Mud Crab						4	1	4	2	2				1	1
Hemiplax hirtipes	Stalk-eyed Mud Crab											1	2	3		1
Copepoda	Copepods											1				

Appendix 20. SIMPER analysis of infauna data (square-root transformed) from three Wairau Estuary fine-scale survey sites, 2015. Cut off for low contributions is 90%. *n = 5* for Sites A, B and C.

Group A

Average similarity: 12.85

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirratulidae	0.4	6.67	0.32	51.89	51.89
Scolecolepides benhami	0.65	6.18	0.32	48.11	100

Group B

Average similarity: 71.79

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Austrohelice crassa	1.57	71.79	4.85	100	100

Group C

Average similarity: 75.75

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Potamopyrgus estuarinus	10.25	26.53	10.63	35.03	35.03
Amphipoda	6.23	12.49	2.92	16.49	51.52
Oligochaeta	4.41	10.15	8.73	13.4	64.92
Corophiidae	4.45	9.51	3.65	12.56	77.48
Arthritica bifurca	3.24	6.53	11.27	8.62	86.1
Austrovenus stutchburyi	1.52	3.73	3.44	4.92	91.02

Groups A & B

Average dissimilarity = 100.00

Species	Group A Av.Abund	Group B Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Austrohelice crassa	0	1.57	49.3	3.74	49.3	49.3
Scolecolepides benhami	0.65	0	18.57	0.75	18.57	67.88
Cirratulidae	0.4	0	12.7	0.76	12.7	80.58
Prionospio sp.	0.2	0	7.37	0.48	7.37	87.95
Amphipoda	0	0.28	6.72	0.49	6.72	94.67

Groups A & C

Average dissimilarity = 97.22

Species	Group A Av.Abund	Group C Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Potamopyrgus estuarinus	0	10.25	27.68	4.68	28.47	28.47
Amphipoda	0	6.23	16.07	3.34	16.53	45
Corophiidae	0	4.45	11.86	2.97	12.2	57.2
Oligochaeta	0	4.41	11.48	9.29	11.81	69.01
Arthritica bifurca	0	3.24	8.2	3.38	8.43	77.44
Austrovenus stutchburyi	0	1.52	4.12	3.63	4.24	81.68
Nicon aestuariensis	0	1.49	3.98	2.28	4.09	85.77
Hemiplax hirtipes	0	1.03	2.93	1.71	3.01	88.78
Scolecolepides benhami	0.65	0.68	2.16	1.13	2.22	91.01

Groups B & C

Average dissimilarity = 96.62

Species	Group B Av.Abund	Group C Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Potamopyrgus estuarinus	0	10.25	27.38	4.7	28.34	28.34
Amphipoda	0.28	6.23	15.17	2.97	15.7	44.04
Corophiidae	0	4.45	11.73	2.97	12.14	56.18
Oligochaeta	0	4.41	11.36	9.18	11.76	67.94
Arthritica bifurca	0	3.24	8.11	3.36	8.4	76.34
Austrovenus stutchburyi	0	1.52	4.08	3.64	4.22	80.56
Nicon aestuariensis	0	1.49	3.93	2.28	4.07	84.63
Austrohelice crassa	1.57	0.4	3.19	1.7	3.3	87.93
Hemiplax hirtipes	0	1.03	2.9	1.71	3	90.93