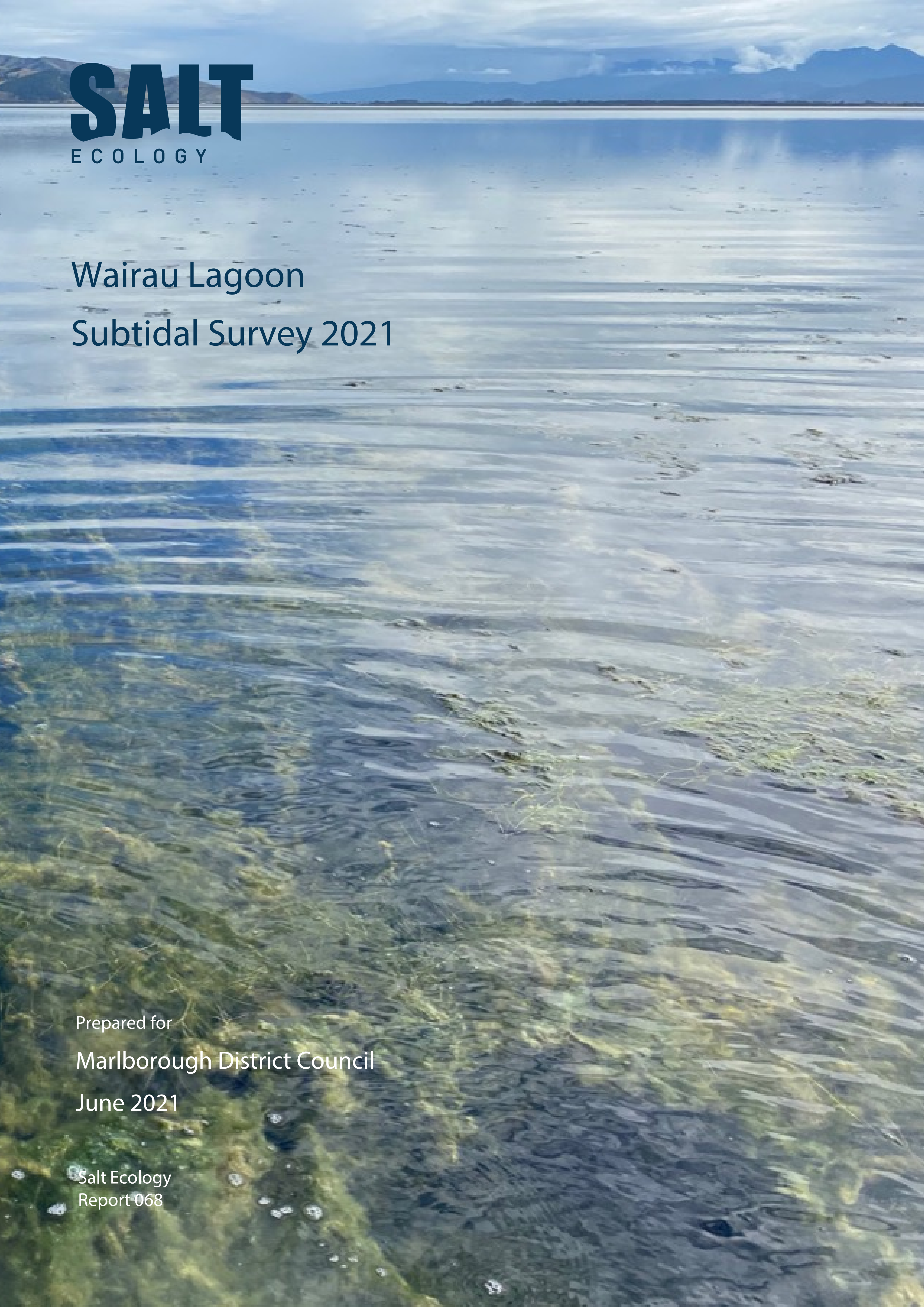

SALT
ECOLOGY

Wairau Lagoon
Subtidal Survey 2021

Prepared for

Marlborough District Council

June 2021

Salt Ecology
Report 068

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Cover photo: Subtidal macrophyte beds in Big Lagoon

Wairau Lagoon
Subtidal Survey 2021

Prepared by

Keryn Roberts, Leigh Stevens,
Megan Southwick and Barrie Forrest

for

Marlborough District Council

June 2021

keryn@saltecology.co.nz, +64 (0)21 029 48546

www.saltecology.co.nz

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GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
ETI	Estuary Trophic Index
GIS	Geographic Information System
HEC	High Enrichment Conditions (eutrophic area)
MDC	Marlborough District Council
NEMP	National Estuary Monitoring Protocol
SOE	State of the Environment (monitoring)

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SUMMARY

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The Wairau Lagoon (also known as Waikārapi or Vernon Lagoons), east of Blenheim, is comprised of three shallow (<0.5m) connected lagoons; Big Lagoon (~800ha), Upper Lagoon (~250ha) and Chandlers Lagoon (~100ha). A boulder bank separates the lagoon from the sea (Cloudy Bay) and a narrow channel (Te Aropipi Channel) links the lagoon to the Wairau River. The catchment is dominated by high producing pasture to the south (41%), orchard/vineyard or other perennial crops (24%) to the north, and is mostly native scrub or forest in the steeper upper catchment (13%).

In 2015, Marlborough District Council commenced intertidal monitoring of Wairau Lagoon as part of its State of the Environment monitoring programme. In 2015 intertidal habitat was found to be in a fair to compromised state of health with opportunistic macroalgae reported at nuisance levels near the entrance. Prior to 2015, other studies reported the decline and likely loss of high-value native macrophytes: horse's mane weed (*Ruppia*) and seagrass (*Zostera*). Such indicators suggest symptoms of nutrient enrichment may be increasing and, when combined with significant albeit largely historical modification of the adjacent salt marsh through drainage and reclamation, highlight that the estuary is under considerable stress.

Key Findings

In April 2021, to evaluate subtidal parts of the estuary, a survey was carried out to broadly map substrate types, depth and salinity and to assess the presence and extent of macrophytes and macroalgae. Water and sediment quality indicators of trophic enrichment (e.g. oxygen, nutrients, organic content and metal concentrations) were measured, in addition to the presence of any stratification or phytoplankton blooms. The key findings are presented below with results summarised using preliminary criteria for assessing estuary health (see table on following page):

- Subtidal substrate was mud-dominated (98.4% of the mapped area) with cobble (0.2%) and sand (1.4%) localised to the eastern lagoon margin and the well-flushed channels.
- Mud-dominated sediments were organically enriched and poorly oxygenated (i.e. aRPD <10mm), and the macrofaunal community was relatively impoverished.
- Extensive beds of high-value native macrophytes (*Ruppia, Chara, Nitella*) were present in the south-east of Big Lagoon covering an area of 199ha or 16.2% of the subtidal area.
- Concerningly, macrophyte beds were significantly impacted by extensive mats of filamentous green algae (*Cyanophyceae* and *Cladophora*). Filamentous algae was the most abundant vegetation type in the lagoon (499ha or 40.6% of the subtidal area) and was growing epiphytically on vegetation as well as on sediments.
- Nuisance blooms of macroalgae (*Agarophyton chilense*) with high biomass and >50% cover (80ha, 6.5% of the subtidal area) were prominent in the Te Aropipi channel near the entrance and in the western margin of Upper Lagoon.
- Despite these indicators of nutrient enrichment, water quality was relatively good throughout much of the lagoon but was 'fair' to 'poor' in the poorly flushed Upper Lagoon and Chandlers Lagoon.
- Sediment nutrient enrichment was evident at 73% of sites monitored and was rated 'fair' to 'poor' throughout Big Lagoon where the macrophyte beds were located. This likely reflects a combination of catchment sediment inputs as well as internal nutrient loading from the breakdown of macrophytes.

Overall, Wairau Lagoon retains ecologically significant areas of salt marsh, and the extensive macrophyte beds in Big Lagoon that are rare in a regional and national context. There was clear evidence of eutrophication from excessive nutrient supply indicating a need for more active management of nutrient and sediment loads if the high value habitats present are to be retained.

Summary of key indicator results and ratings

Indicator	Unit	Site	Value	2021 Rating
Broad scale indicators (estuary-wide)				
Mud-dominated substrate	% of estuary area >50% mud		98.5	Poor
Intertidal Seagrass	% decrease from baseline		100	Poor
High Enrichment Conditions	ha		~480	Poor
High Enrichment Conditions	% of estuary		~30	Poor
Water quality indicators (representing the most impacted 10% of the estuary)				
Dissolved oxygen (DO)	mg/L	Upper Lagoon (J4)	11.9[1]	Very Good
Phytoplankton (chl-a)	mg/m^3	Chandlers Lagoon (L5)	14.1	Fair
Total Nitrogen	mg/m^3	Upper Lagoon (J4)	370	Fair
Total Phosphorus	mg/m^3	Upper Lagoon (J4)	73	Poor
Sediment indicators (representing the most impacted 10% of the estuary)				
Mud content	%	Big Lagoon (L8)	95.2	Poor
aRPD depth	mm	73% of sites sampled	<10	Poor
TN	mg/kg	Big Lagoon (L8)	1700	Fair
TOC	%	Big Lagoon (L8)	1.28	Fair
As	mg/kg	Big Lagoon (L8)	5.5	Very Good
Cd	mg/kg	Big Lagoon (L8)	0.05	Very Good
Cr	mg/kg	Big Lagoon (L8)	21.0	Very Good
Cu	mg/kg	Big Lagoon (L8)	16.5	Very Good
Hg	mg/kg	Big Lagoon (L8)	0.08	Good
Ni	mg/kg	Big Lagoon (L8)	24.0	Fair
Pb	mg/kg	Big Lagoon (L8)	17.2	Very Good
Zn	mg/kg	Big Lagoon (L8)	67.0	Very Good

[1] Oxygen was over-saturated at the time of sampling indicating there was a high amount primary productivity (i.e., algae producing oxygen through photosynthesis). However, this can lead to adverse effects from strong diurnal fluctuations in oxygen if plants utilise more oxygen at night than they produce during the day.

Recommendations

1. Design a subtidal monitoring programme to monitor the health of the macrophyte beds and key indicators of eutrophication including sediment and water column nutrients, phytoplankton and dissolved oxygen (e.g. seasonal monitoring at representative locations), and the extent and impact of filamentous algal and macroalgal beds at 5-yearly intervals using broad scale mapping techniques.
2. Assess catchment sources of nutrients and sediments to the lagoon to determine whether changes to current land management practices are likely to significantly improve ecological condition and to guide council management priorities.
3. Establish objectives for catchment sediment and nutrient inputs that will protect the Wairau Lagoon from further degradation.
4. Map the extensive areas of intertidal salt marsh vegetation adjacent to Wairau Lagoon (including areas not assessed previously), taking into account areas where salt marsh would benefit from reconnection to the estuary, to prevent further loss and to build resilience with expected sea level rise.
5. Review the suitability of fine scale monitoring in the intertidal areas of the lagoon before undertaking any further work. Cawthron Site C in the lower estuary is considered suitable for long-term monitoring, however it is recommended Sites A and B in Big Lagoon and Upper Lagoon be discontinued.
6. Investigate current and historic sedimentation rates and sources to the lagoon.

1. INTRODUCTION

Marlborough District Council (MDC) undertakes long-term monitoring of the coastal marine area as part of its State of the Environment monitoring programme. Since 2011, the estuarine component has focused on establishing baseline measures of ecological condition in representative estuaries and bays throughout the region (e.g. Kaiuma, Mahakipawa, Havelock, Waikawa, Okiwa, Anakiwa, Mahau, Tuna, Duncan, Harvey, Broughton, Ngakuta, Shakespeare, Whatamango) using methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c).

The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries. The results provide a valuable basis for establishing a benchmark of estuarine health in order to better understand human influences, particularly catchment influences related to the input of nutrients and muddy sediments, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.

Fine scale monitoring of intertidal estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

This report describes the assessment of the Wairau Lagoon (a.k.a. Waikārapi or Vernon Lagoons), a large estuary that discharges to Cloudy Bay east of Blenheim. Unlike most other estuary types in the region, the Wairau Lagoon comprises a group of shallow inter-connected lagoons that receive variable levels of freshwater flushing and is artificially open to the sea. When open the estuary is influenced by tidal changes in water level and intrusion of saline waters. Partial constriction of the estuary entrance due to longshore drift can reduce flushing increasing the lagoons susceptibility to nutrient retention and eutrophication.

The intertidal broad and fine scale NEMP approaches outlined above have been applied in Wairau Lagoon in a previous survey by Berthelson et al. (2015). However, in estuarine lagoons, such as Wairau, symptoms of nutrient enrichment (eutrophication) and excessive sedimentation tend to express most strongly in sub-tidal areas, therefore monitoring approaches in addition to those described in the NEMP are needed to fully characterise this type of estuary.

A typical way of modifying the NEMP approach for the assessment of estuarine lagoons is to use transect or grid-based site sampling, combined with the assessment of broad and fine scale metrics. These approaches and metrics can be repeated over time and scaled up or down to address specific issues, as necessary.

Broad scale measures include synoptic mapping of estuary depth, salinity or temperature stratification, benthic substrate type, macrophyte, seagrass and macroalgal cover, as well as delineating the spatial extent and composition of phytoplankton. Fine scale measures include *in situ* water and sediment quality measurements, in particular dissolved oxygen, and the depth to the apparent sediment Redox Potential Discontinuity (aRPD).

The addition of the subtidal components to NEMP monitoring have been previously shown to be a robust way to quickly describe estuarine lagoon habitat and characterise trophic status (e.g. Forrest & Stevens 2019a-c; Stevens & Robertson 2012; Stevens et al., 2020).

The current report describes the methods and results of subtidal monitoring undertaken at Wairau Lagoon on 19-22 April 2021 (Fig. 1). The primary purpose of the work was to characterise the presence and extent of macrophytes, macroalgae and fine sediments, determine the presence of subtidal stratification or phytoplankton blooms, and assess the overall trophic state of the estuary.

Wairau Lagoon, shags roosting in lower estuary (bottom)

1.1 BACKGROUND TO WAIRAU LAGOON

Previous reports (e.g. Berthelsen et al., 2015; Davidson et al., 2011; Hayward et al., 2010; Knox 1983 & 1990; Walls 1976) present background information on Wairau Lagoon, which is paraphrased (and expanded in places) below.

Wairau Lagoon, east of Blenheim, is comprised of three shallow (<0.5m) connected lagoons; Big Lagoon (~800ha), Upper Lagoon (~250ha) and Chandlers Lagoon (~100ha; Hayward et al., 2010; Fig 1). A boulder bank separates the lagoon from the sea (Cloudy Bay) and a narrow channel (Te Aropipi Channel) links the lagoon to the Wairau River. The estuary mouth, to the north of the boulder bank, has been artificially stabilised to create a permanent opening. However, in unstable sea conditions longshore drift can temporarily restrict the estuary entrance (Knox 1990).

Seawater enters the lagoons through the narrow Te Aropipi Channel. The flushing potential and extent of seawater influence is determined variably by the Wairau River discharge, the estuary entrance and wind generated circulation. For example, high flows in the Wairau River limits seawater ingress and reduces the tidal influence on the lagoons, decreasing water column salinity and the flushing potential of the lagoon. During periods of limited flushing the lagoons are more susceptible to nutrient problems.

Flood protection works (partial diversion of the Wairau River, stabilisation of the estuary mouth, drainage ditches, stop banks), wastewater discharge to the estuary and changing land use in the catchment have all altered the natural geomorphological, hydrological and ecological nature of the lagoon system (Berthelsen et al., 2015).

Up until 1958, large beds of the native seagrass 'horse's mane weed' (*Ruppia* sp.) were present in Big Lagoon, before declining (Walls 1976). *Ruppia* is a keystone species in that is helps to stabilise sediment, oxygenate water and sediment, maintain high water clarity (by limiting sediment resuspension) and assimilate terrestrial nutrient inputs. It is also an important food source for waterfowl and provides habitat for fish and macroinvertebrates. While Knox (1983) commented on the presence of *Ruppia* spp. in the lagoon (as a possible internal nutrient source), it was not recorded as being widespread. To our knowledge no records exist of its presence in the lagoon after the 1983 study.

Knox (1983) also recorded beds of seagrass (*Zostera* sp.) in the lagoon where exposure, substrate and salinity conditions were suitable. In a subsequent study, Knox (1990) reported *Zostera* as common in water, with the location of beds appearing to be most likely near the entrance. Berthelsen et al., (2015) found no seagrass (either *Ruppia* or *Zostera*) in their survey of the lagoon, suggesting a drastic decline since the Knox surveys (1983 & 1990). Berthelsen et al., (2015) hypothesised that hydrodynamic changes, increased sedimentation, and displacement by macroalgae led to the significant loss of seagrass.

Green macroalgae *Ulva* spp. (sea lettuce), which has the potential to form nuisance blooms under elevated nutrient conditions, was first reported in the lagoon in 1965 (R. Mason cited in Walls 1976) and was reported again in 1983, 1990, 2005 and 2011 (Knox

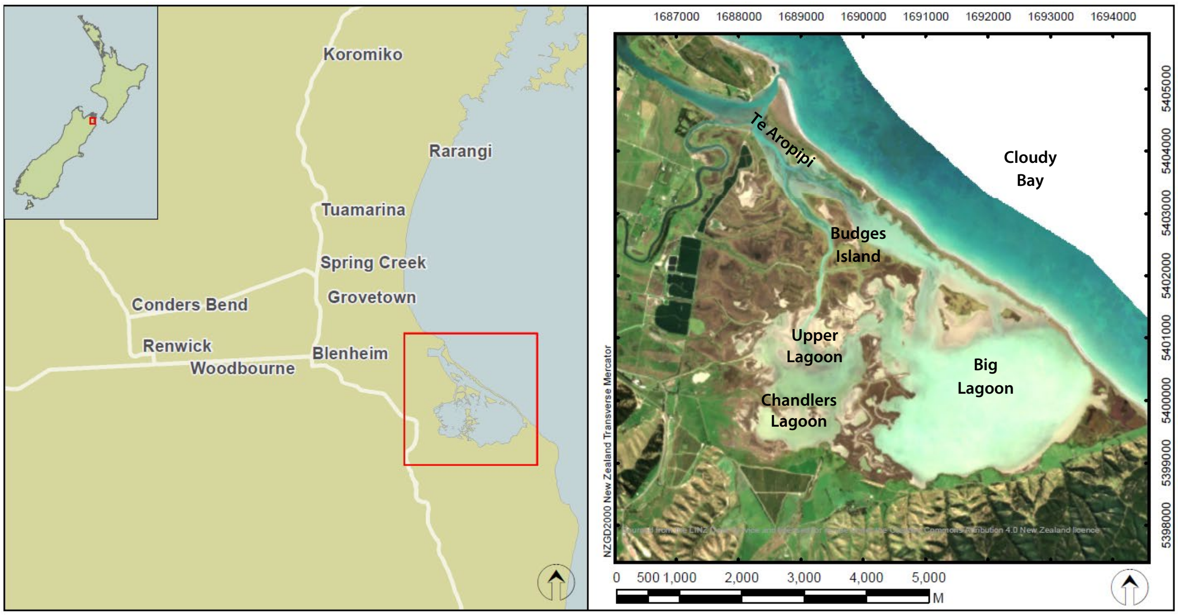
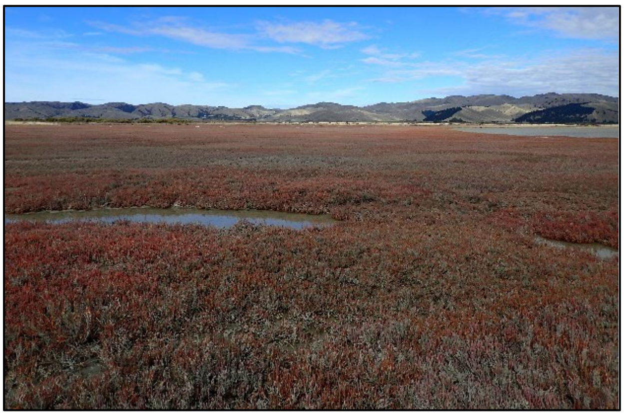


Fig 1. Location of Wairau Lagoon.

1983; 1990; Berthelsen et al., 2015). However, *Ulva* was not recorded in 2015, suggesting its abundance and distribution in Wairau Lagoon changes over time (Berthelsen et al., 2015). Anecdotal reports indicate the red macroalgae *Agarophyton chilense* (formerly known as *Gracilaria chilensis*) appeared more recently in the estuary (Berthelsen et al., 2015). In 2015, *Agarophyton* covered 22ha (6% of the intertidal area) and 85ha of the subtidal habitat, with dense attached beds prominent in the Te Aropipi Channel near the entrance (Berthelsen et al., 2015).

Salt marsh bordering Wairau Lagoon is extensive and dominated by extensive areas of low-growing herbfield species glasswort *(Sarcocornia quinqueflora*), and smaller areas of taller rushland. Historically, large tracts of salt marsh have been cleared or drained for pasture or localised infrastructure development (e.g. the Blenheim Wastewater Treatment Plant – WWTP; see photos). Remaining salt marsh, while extensive, is compromised in many areas by reduced connectivity with the main estuary due to the presence of flood banks and flapgates on drains to prevent seawater inflow. Furthermore, the modified margins limit both the habitat currently available for salt marsh, and the ability for it to naturally migrate inland in response to predicted future sea level rise.

The 58,555ha surrounding catchment is dominated by high producing pasture to the south (41%) and orchard/vineyard or other perennial crops (24%) to the north. The steeper upper catchment is dominated by manuka and/or kanuka (10%), fragments of indigenous forest (3%) and low producing grassland in the foothills (4%); see Fig. 2, Table 1). Note, the lagoon catchment was considered to exclude the Wairau River catchment upstream of the diversion as most of the river flow was assumed to discharge directly to Cloudy Bay and bypass the lagoon.



Herbfield species glasswort (*Sarcocornia quinqueflora*)

Upper lagoon salt marsh extent 1966 (left) and 2019 (right). Image source Retrolens and Google Earth.

Table 1. Summary of catchment land cover (LCDB5 2017/18), Wairau Lagoon.

LCDB (2017/18) Catchment Land Cover	Ha	%
1 Built-up Area (settlement)	1671	2.9
2 Urban Parkland/Open Space	307	0.5
6 Surface Mine or Dump	38	0.1
16 Gravel or Rock	104	0.2
20 Lake or Pond	203	0.3
21 River	167	0.3
30 Short-rotation Cropland	1119	1.9
33 Orchard/Vineyard/Other Perennial Crop	13867	23.7
40 High Producing Exotic Grassland	24032	41.0
41 Low Producing Grassland	2550	4.4
43 Tall Tussock Grassland	736	1.3
45 Herbaceous Freshwater Vegetation	198	0.3
46 Herbaceous Saline Vegetation	520	0.9
50 Fernland	839	1.4
51 Gorse and/or Broom	589	1.0
52 Manuka and/or Kanuka	5869	10.0
54 Broadleaved Indigenous Hardwoods	1592	2.7
58 Matagouri or Grey Scrub	94	0.2
64 Forest - Harvested	70	0.1
68 Deciduous Hardwoods	254	0.4
69 Indigenous Forest	1715	2.9
71 Exotic Forest	1958	3.3
Grand Total	**58555**	**100**

The Wairau Lagoon, however, remains a nationally significant ecological area with over 90 species of birds recorded including endangered, vulnerable, or rare species and several fish species (including flounder and eels). The lagoon and bar system is also of very high archeological significance being one of the oldest known sites of Maori habitation in New Zealand (Knox 1983). The lagoon has natural (ecological and geological), cultural and social values.

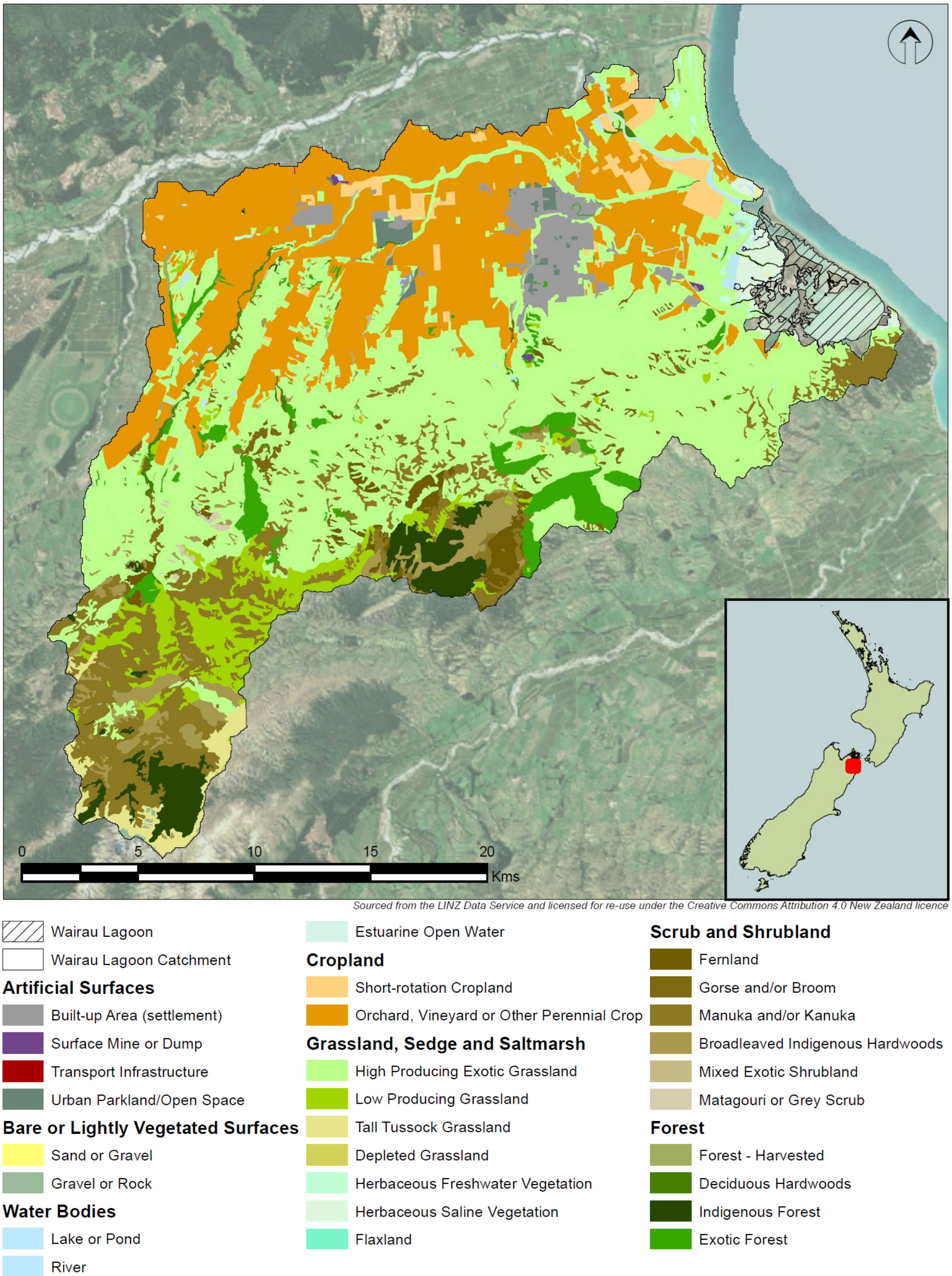


Fig 2. Wairau Lagoon and surrounding catchment land use classifications from LCDB5 (2017/18) database.

2. METHODS

2.1 OVERVIEW

The focus of the current survey of Wairau Lagoon was to map the dominant subtidal habitat features (substrate and vegetation) and quantify the ecological condition of the subtidal reaches using a suite of environmental indicators (Table 2). Where applicable, the current survey was compared to previous assessments, e.g. Berthelsen et al. (2015); Knox (1983 & 1990).

2.2 BROADSCALE MAPPING METHODS

The type, presence and extent of substrate, macroalgae or seagrass reflects multiple factors, including the combined influence of sediment deposition, nutrient availability, salinity, water quality, clarity and hydrology. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to the small-scale temporal variation associated with instantaneous water quality measures.

Assessment criteria, developed largely from previous broad scale mapping assessments, were used to help assess estuary condition (e.g. Fig. 3, Table 3). Additional details on specific broad scale measures are provided below. While the intertidal areas, salt marsh and the terrestrial margin were observed during the survey detailed mapping was outside the scope of the current study and therefore the methods are not described here.

NEMP broad scale methods (Appendix 1) were used to map and categorise estuary substrate and vegetation. The mapping procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology. Broad scale mapping was undertaken using 0.2m/pixel rural aerial photos flown in 2015/16 and sourced from ESRI online New Zealand imagery. Ground truthing was undertaken by experienced scientists who assessed the estuary on foot and by boat to map the spatial extent of dominant vegetation and substrate (see Appendix 10). Because of the large size (>1000ha) and shallow nature of the lagoon, a lightweight flat-bottomed Huntercraft lake boat with a recessed outboard jet motor was used for the majority of the sampling (Southern Waterways).

As poor water clarity was anticipated to preclude direct visual assessments for much of the subtidal area, a 500m grid system was overlain on the lagoon (see Fig. 4). At each designated station, subtidal areas were visited and assessed using a combination of grab sampling (custom-built hoe) or wading, with water and sediment quality measurements used to characterise estuary health.

Where there was a distinct change in either substrate or vegetation cover, additional stations were added at higher resolution to better delineate the boundaries between features (i.e. ~250m resolution). At 68 sites, substrate type and the percent cover of any macroalgae, seagrass, macrophyte or filamentous algae species were recorded. Water quality and sediment quality measures were also collected at 58 sites, as described in Section 2.3.

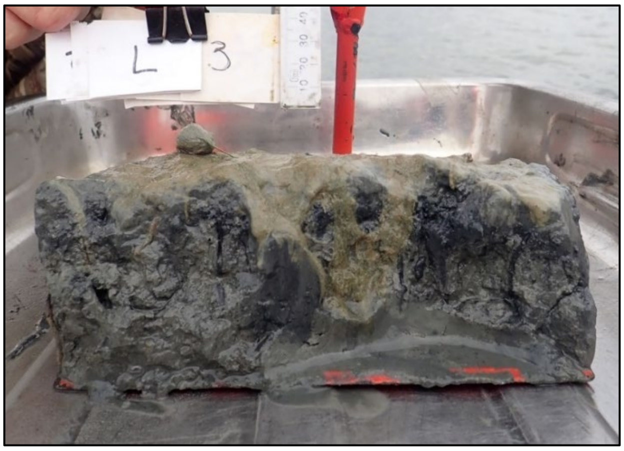
For areas where water clarity allowed direct visual observation (primarily shallow areas near the entrance), vegetation and substrate features were drawn directly onto laminated aerial photographs, with station data recorded electronically in the Fulcrum app (see section 2.4). The broad scale features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features, e.g. macroalgae, and its underlying substrate type.

For subtidal areas that could not be directly observed, the sample data were imported into GIS (ArcMap 10.6) and interpolated using the 'Spline with Barriers' tool. Combined with a barrier polygon representing the subtidal boundary (see Appendix 11), point data values for salinity (ppt), dissolved oxygen (% saturation), phytoplankton (mg/m^3), total macroalgae (% cover), total macrophyte (% cover) and filamentous green algae (% cover) were used to create an output raster with a cell size of 10 metres for each layer.

Contours along classification breaks were created using the 'Contour' tool for each raster surface. These delineated areas were cross-checked against field observations and used to calculate vegetation summary statistics. This method provides a probable area of cover based on the comprehensive grid sampling undertaken.

2.2.1 Substrate classification

Appendix 1 summarises the key NEMP classes used to define estuarine substrate in the current report. Substrate classification is based on the dominant surface features present; e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories based on sediment 'muddiness' and assessed by an experienced field observer taking into account the textural and firmness characteristics of the substrate. The field-based assessment was subsequently cross-checked against the results of grainsize (percent mud/ sand/ gravel) analyses at 7 locations (see Appendix 8). The primary indicator used to assess sediment mud impacts is the area (horizontal extent) of mud-dominated sediment.



Site L3 substrate type soft mud (>90% mud)

entrainment (>30mm rooted depth) status was recorded.

Eroded bed of *Agarophyton* on the intertidal flat of Te Aropipi Channel

Underwater photo of dense subtidal *Agarophyton*

2.2.2 Macroalgae

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature. When present, the mean percent cover of discrete macroalgal patches was visually assessed using the 6-category percent cover rating scale presented in Fig 3 as a guide. In representative patches biomass (wet weight) and

2.2.3 Seagrass

The NEMP provides no guidance on the assessment of seagrass beyond recording its presence when it is a dominant surface feature. Consequently, the mean percent cover of discrete seagrass patches was visually assessed based on the 6-category percent cover rating scale presented in Fig 3.

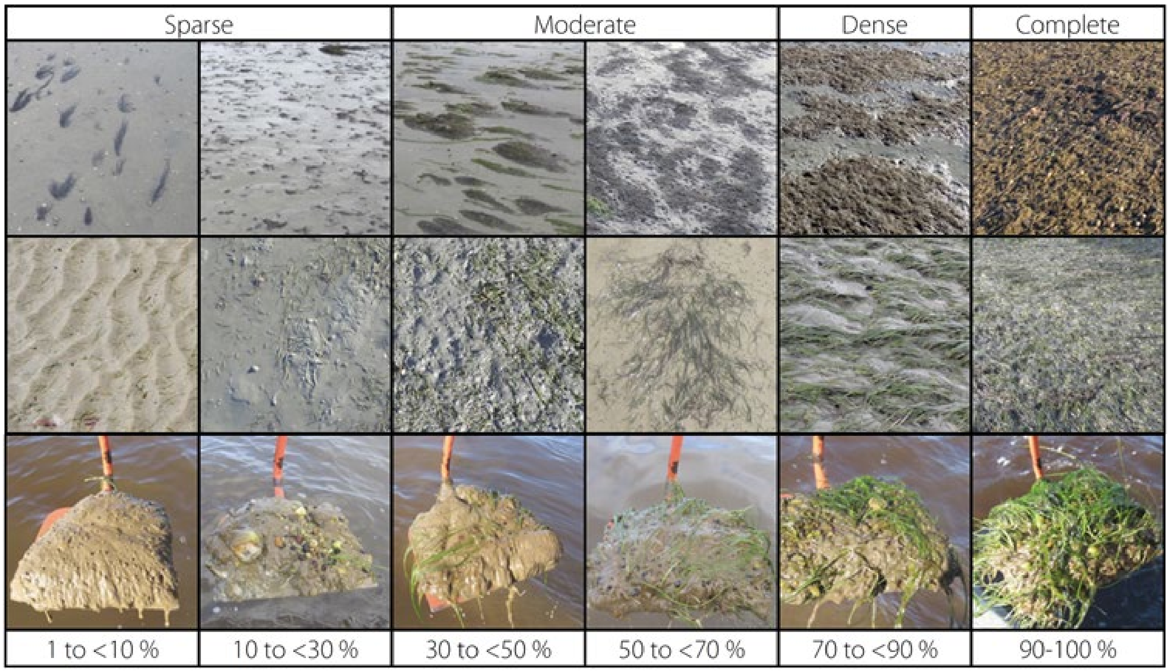


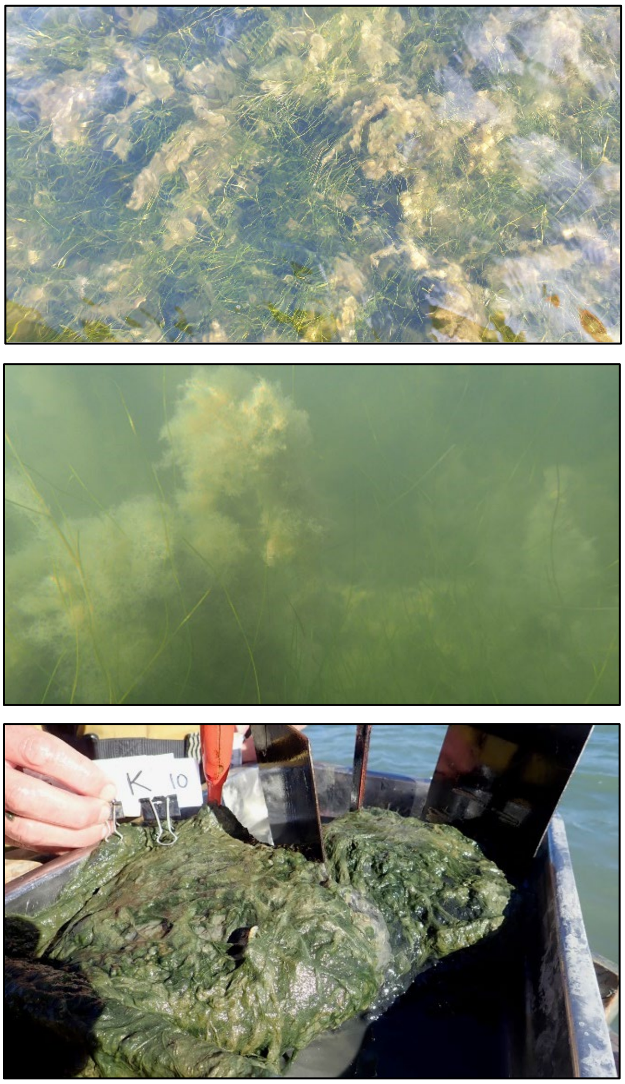
Fig 3. Visual rating scale for percentage cover estimates for macroalgae (top), seagrass (middle) and macrophyte (bottom). Modified from FGDC (2012).

2.2.4 Macrophytes

The NEMP provides no guidance on the assessment of macrophytes. As such, the relative abundance of and percent cover of different macrophyte species was recorded using the categories in Fig 3 as a guide. The method has been previously applied in other lagoon surveys (e.g. Forrest & Stevens 2019a-c).

2.2.5 Filamentous algae

The cover of filamentous algae was recorded using the principles outlined in the previous sections and the percent cover categories in Fig 3. As filamentous algae were commonly present growing as an epiphyte on other vegetation, it was assessed independently of seagrass or macrophytes to ensure that the presence of all taxa were recorded.



Surface view (top), underwater photo (middle) and hoe sample (bottom) of Ruppia sp. with of epiphytic filamentous algae

2.3 SUBTIDAL SURVEY

Water and sediment quality were recorded at 58 subtidal sites, distributed in a grid system as discussed in Section 2.2 (see Fig 4, Appendix 9). For logistical and safety reasons, sampling of the upper lagoons was primarily conducted on the incoming tide. The tidal range at the Wairau Bar (estuary entrance) across the four days of sampling was 0.29-1.37m, reflecting neap tides, the predicted spring tidal range for the area is 0.03-1.65m (NIWA Tide Forecaster).

At all sites, the subtidal habitat was assessed by either wading or by sampling from a boat, to measure the following variables:

- Water depth
- Secchi disk clarity
- Surface and bottom water quality variables: temperature, salinity, pH, dissolved oxygen, chlorophyll-a
- Thermocline depth (if present)
- Halocline depth (if present)
- Substrate type
- Depth in the sediment of the apparent Redox Potential Discontinuity (aRPD)
- At five sites (C3, F7, J4, J11 and L8) a sample was collected for water quality (nutrient concentrations) and sediment quality (i.e. heavy metals, nutrients, organic content)
- At two sites (F7 and J11) a phytoplankton sample was collected
- At 15 sites (C2, C3, D4, F7, G9, I2, I3, I7, J4, J8, J11, L4, L8, M10.5, N10.5) the macroinvertebrate assemblage was assessed

Big Lagoon, standing on the boulder bank looking toward the lagoon

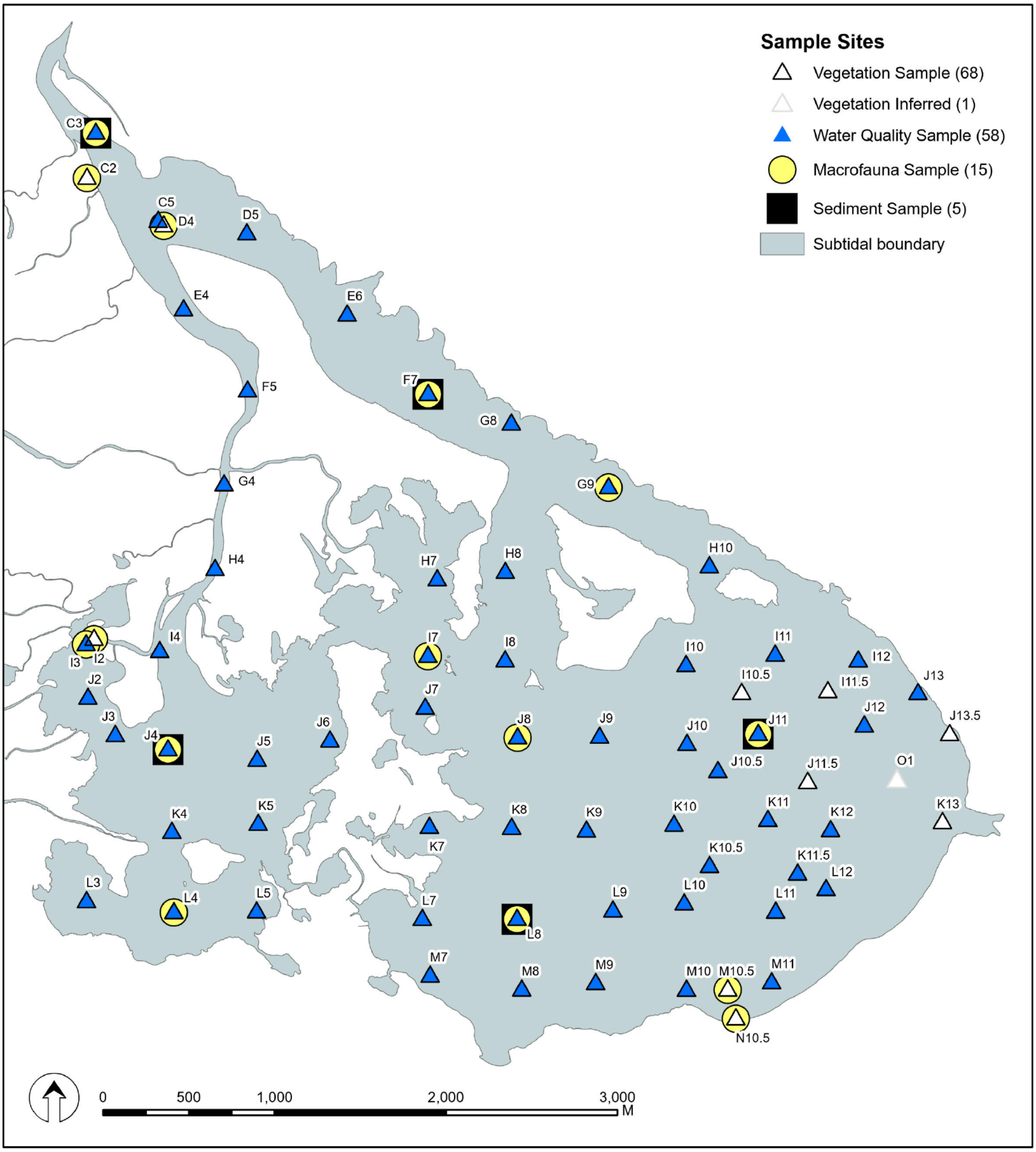


Fig 4. Location of sampling points in Wairau Lagoon. The legend denotes the information and/or samples collected at each site.

Wairau Bar entrance at high tide

2.3.1 Water column indicators

In situ parameters

At each sampling location, water quality measures were taken from ~20cm below the water surface. For sites >0.5m deep a bottom measurement ~20cm above the bottom sediment surface was taken to assess whether there was any salinity or temperature stratification. Water column measures of pH, salinity, dissolved oxygen (DO), temperature and chlorophyll-a (as an indicator of phytoplankton presence) were made using a YSI Pro10 meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Care was taken not to disturb bottom sediments before sampling. A description of water column and sediment parameters is provided in Table 2.

Thermocline and halocline depths, where present, were recorded as the average depth of abrupt changes in temperature and salinity, respectively, recorded on the up- and down-cast meter deployments. A modified (pole-mounted) secchi disk was used to measure vertical water clarity to the nearest centimetre.

Phytoplankton

To assess whether potentially toxic phytoplankton were present in the estuary, grab samples were collected from sites F7 and J11. At each station two samples were collected directly into laboratory supplied sample containers. One sample was un-preserved and one preserved with Lugols solution. All samples were stored in a dark environment, before being sent overnight on ice to NIWA, Hamilton for analysis.

Water column nutrient concentrations

At sites C3, F7, J4, J11 and L8 a grab sample for water column nutrient concentrations was collected. The RJ Hills sample bottle was rinsed three times in site water and then the sample collected. The samples were stored on ice, and sent to RJ Hill Laboratories for analysis of:

- Total Nitrogen (TN) and dissolved inorganic nitrogen (ammoniacal-N, nitrate, nitrite)
- Total Phosphorus (TP) and dissolved reactive phosphorus (DRP)

2.3.2 Sediment indicators

At each sampling location, a substrate sample was collected using a custom-built hoe sampler. At the surface, sediment quality was assessed in situ for substrate type (as described in 2.2.1) and sediment oxygenation.

Sediment analyses

At sites C3, F7, J4, J11 and L8 a composite sediment sample from three separate grabs (~250g in total) was collected from the sediment surface (to 20mm depth). Sediment samples were placed directly into laboratory supplied sample containers, stored on ice, and sent to RJ Hill Laboratories for analysis of:

- Particle grain size (% mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm)
- Organic matter (total organic carbon, TOC)
- Nutrients (total nitrogen, TN; total phosphorus, TP)
- Sediment metals and metalloids (As, Cd, Cr, Cu, Pb, Hg, Ni and Zn)

Details of laboratory methods and detection limits are provided in Appendix 4. A description of each sediment quality indicator is provided in Table 2.

Sediment oxygenation

The apparent Redox Potential Discontinuity (aRPD) depth was assessed at all locations from representative sediment samples. The depth of the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour) was recorded. Sediments were considered to have poor oxygenation if the aRPD was consistently shallower than 10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments.

Example of colour difference between brown surface oxygenated sediments and black anoxic sediment, site J7

Table 2. Description of water column, sediment and habitat indicators used in Wairau Lagoon 2021

Water quality indicators	
Secchi depth visibility	Field indicator of water clarity and potential for light penetration into the water column.
Chlorophyll-a (phytoplankton)	Field measure that provides a proxy indicator for phytoplankton biomass.
Water column nutrients	Total nitrogen (TN) and total phosphorus (TP) concentrations help to characterise the trophic status of shallow lakes and lagoons.
Dissolved oxygen	Field indicator of oxygen saturation (algal productivity) or depletion (organic decay).
Salinity	Field indicator of the extent of seawater influence.
Sediment indicators	
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated.
Sediment nutrients & organic matter	Total nitrogen (TN), total phosphorus (TP and Total Organic Content (TOC) reflect the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.
Trace metals	Common toxic contaminants (arsenic, copper, chromium, cadmium, lead, mercury, nickel, zinc) generally associated with human activities.
Depth of apparent redox potential discontinuity layer (aRPD)	Subjective time-integrated measure of the enrichment state of sediments according to the visual transition between oxygenated surface sediments and deeper deoxygenated black sediments. The aRPD generally gets closer to the sediment surface as organic matter loading increases.
Biological indicators	
Macrofauna	The abundance, composition and diversity of macrofauna, especially the infauna living with the sediment, are commonly used indicators of estuarine health.
Habitat indicators	
Macrophytes	Shallow lakes and lagoons with low nutrient status may have the entire bed covered by macrophytes, with the cover decreasing as a system becomes increasingly nutrient enriched and eutrophic. As enrichment increases, epiphytic plants, or growths of opportunistic benthic macroalgae in the case of lagoons, may become more prevalent and macrophyte abundance may decline.
Opportunistic Macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

Entrance to the Big Lagoon, Wairau Lagoon

2.3.3 Macrofauna

The abundance, composition, and diversity of macrofauna, especially the infauna living within the sediment, are commonly used indicators of estuarine health. Sediment to ~150mm deep from at least three separate grabs was collected from 15 sites (see Fig. 4) and combined to make a composite sample of ~2L. Where needed, additional grabs were collected until the required sediment volume was obtained. Collected sediment was placed within a 0.5mm sieve bag, which was gently washed in site water to remove fine sediment. Because of the sampling methodology (grab sample rather than core) the assessment is only intended as a qualitative measure to assess the health of the benthic community and prevailing sediment conditions.

The retained animals were subsequently preserved in a 75% isopropyl alcohol and 25% seawater mixture for later sorting by Salt Ecology staff and taxonomic identification by Sarah Hailes and Barry Greenfield, NIWA. The macrofauna present in each sample, as well as the range of different species (i.e. richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments.

2.4 DATA RECORDING AND QA/QC

Field measurements were recorded electronically in templates that were custom-built using software available at www.fulcrumapp.com. Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position for that record (e.g. a sediment sample).

Data analysis, statistics and graphing were carried out in R version 4.0.3 and GIS ArcMap 10.6. Water and sediment samples sent for analysis at RJ Hill Laboratories were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors.

2.5 ASSESSMENT OF ESTUARY CONDITION

In addition to our expert interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas. These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3.

The condition ratings used in the current report were derived primarily from the Estuary Trophic Index (ETI; Robertson et al. 2016b) and subsequent revisions (Zeldis et al. 2017). The ETI provides screening guidance for assessing where an estuary is positioned on a eutrophication gradient. It includes site-specific thresholds for aRPD, dissolved oxygen, and phytoplankton concentrations, generally using spot measures from within the most degraded 10% of the estuary. We adopted the ETI thresholds for present purposes except for;

i. % mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016);

ii. aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012);

Furthermore, an assessment of water column nutrients was made using the National Policy Statement for Freshwater Management (2020) attribute tables for Total Nitrogen and Total Phosphorus, acknowledging that the results from a one-off survey do not meet the statistical requirements of the attribute.

As many of the scoring categories in Table 3 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

View across the eastern end of Big Lagoon

Table 3. Condition ratings used to characterise estuarine health. See footnotes and Appendix 2 for explanation of the origin or derivation of the different metrics.

Indicator	Unit	Very good	Good	Fair	Poor
Broadscale Indicators[1]					
Intertidal seagrass	% decrease from baseline	< 5	≥ 5 to 10	≥ 10 to 20	≥ 20
High Enrichment Conditions	ha	<0.5	≥0.5 to 5	≥5 to 20	≥20
High Enrichment Conditions	% of estuary	<1	≥1 to 5	≥5 to 10	≥10
Water quality indicators[2]					
Dissolved oxygen (DO)[a]	mg/L	≥5.5	≥5.0	≥4.0	<4.0
Phytoplankton (chl-a)[a]	mg/m^3	<5	≥5 to <10	≥10 to <16	≥16
Total Nitrogen[b]	mg/m^3	≤160	>160 to ≤350	>350 to ≤750	>750
Total Phosphorus[b]	mg/m^3	≤10	>10 to ≤20	>20 to ≤50	>50
Sediment indicators[2]					
Mud content[a]	%	<5	5 to <10	10 to <25	≥25
aRPD depth[c]	mm	≥50	20 to <50	10 to <20	<10
TN[a]	mg/kg	<250	250 to <1000	1000 to <2000	≥2000
TOC[a]	%	<0.5	0.5 to <1	1 to <2	≥2
Sediment Trace elements[3]					
As	mg/kg	<10	10 to <20	20 to <70	≥70
Cd	mg/kg	<0.75	0.75 to <1.5	1.5 to <10	≥10
Cr	mg/kg	<40	40 to <80	80 to <370	≥370
Cu	mg/kg	<32.5	32.5 to <65	65 to <270	≥270
Hg	mg/kg	<0.075	0.075 to <0.15	0.15 to <1	≥1
Ni	mg/kg	<10.5	10.5 to <21	21 to <52	≥52
Pb	mg/kg	<25	25 to <50	50 to <220	≥220
Zn	mg/kg	<100	100 to <200	200 to <410	≥410

1. Subjective indicator thresholds derived from previous broad scale mapping assessments.

2. Ratings derived or modified from: [b]Robertson et al. (2016) with modification for mud content described in Appendix 2, [a]NPSFM (2020), [c]FGDC (2012).

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

Confluence of Wairau River and the Lagoon near the estuary entrance

3. RESULTS

3.1 BROADSCALE MAPPING

3.1.1 Bathymetry

Fig 6 shows the approximate low tide depth of Wairau Lagoon recorded at each of the sampling stations. Not unexpectedly, the Upper Lagoon areas were very shallow: Big Lagoon max. depth 0.6m, Chandlers Lagoon max. depth 0.2m and Upper Lagoon max. depth 0.3m, and the lagoons showed little variation in depth. Deeper water was confined to the relatively narrow channels of the lower estuary.

For illustrative purposes, the GIS-based spline interpolation was used to highlight relative differences in water depth to assist in understanding potential explanatory variables with regard to the presence of macrophytes (Fig. 5). Because the data used for bathymetry were based on random grid sampling sites, there is no information on depth between points. Because the open lagoon areas were relatively uniform this approach is likely representative in the lagoons. However, the narrow and deeper Te Aropipi Channel areas were not targeted by the grid sampling stations and therefore the interpolated depth contours do not accurately reflect mid-channel depths or capture gradients in depth between the mid-channel and the bank.

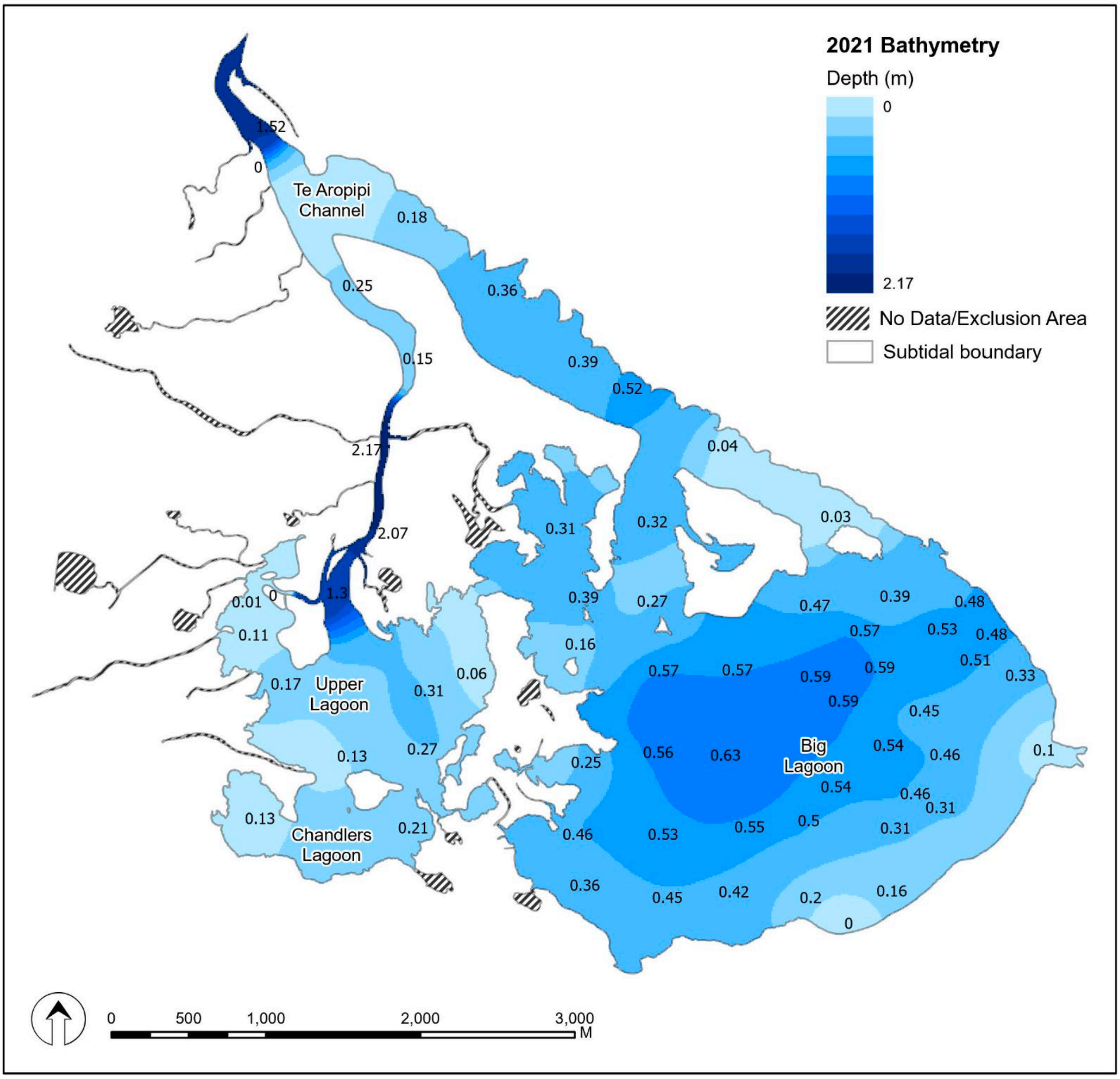


Fig 5. Wairau Lagoon Bathymetry, April 2021 (corrected to low tide on the day of sampling*).

**Time and depth were collected in Wairau Lagoon at each grid sampling point. Depth was corrected to low tide based on time using the rule of twelfths. The minimum low tide height in the lagoon was delayed when compared to the estuary entrance, therefore the correction assumed a 2-hour lag time for low tide in the lagoons and a 1-hour lag-time for low tide in the channels based on observations in the field.*

3.1.2 Subtidal substrate

Table 4 and Fig 6 show subtidal substrate in the Wairau Lagoon was dominated by mud (>90% sediment mud content), with small component of cobble and gravel field. The latter was largely present as a narrow band along the edge of the Wairau Bar boulder bank overlapping with the intertidal margin. Below ~0.5m deep, there was a sharp transition to soft or very soft muds. In areas where current flows were higher relative to surrounding areas in the lagoon, there was generally a reduction in mud content, but sediments remained mud-dominated (>50-90% mud). Within the narrow channels subjected to regular flushing, sediments were relatively firm. However, deposition of fine sediments was apparent on the margins of the shallow subtidal channels, and within submerged salt marsh or macroalgae.

Because of the dominance of fine sediment in the lagoons, any disturbance of the seabed results in waters becoming turbid. Given the relatively large fetch and shallow depths present, wind generated waves are likely to result in turbid conditions for much of the time. This in turn is likely to limit the areas that rooted macrophytes are able to establish, as a consequence of light limitation in deeper areas.

However, rooted macrophytes can grow in areas where light does not regularly reach the bottom if they extend far enough from the seabed toward the surface to get sufficient light. In this situation, the presence of macrophytes can have a strong influence on the turbidity by stabilising the sediments with their root masses, dampening the effects of waves and facilitating the trapping and deposition of suspended sediment. Such influences provide a positive feedback beneficial to macrophyte growth. However, where rooted macrophytes are lost, there is often a rapid cascading effect where the loss of sediment stabilisation quickly leads to turbid conditions where macrophytes can no longer grow (Turner & Shwarz 2006 and references therein).

Table 4. Summary of dominant subtidal substrate, Wairau Lagoon April 2021.

Substrate Class	Ha	%
Cobble field	1.9	0.2
Firm Sand (0-10% mud)	3.4	0.3
Mobile Muddy Sand (>10-25% mud)	9.4	0.8
Firm Muddy Sand (>10-25% mud)	4.6	0.4
Soft Sandy Mud (>50-90% mud)	113.1	9.2
Soft/Very soft Mud (>90% mud)	1093.3	89.2
Total	**1226**	**100**

Gravel/cobble on lagoon margin

Dense macrophyte cover suppresses sediment re-suspension and traps fine sediment helping maintain clear waters

Turbid water column due to resuspension of fine sediments

Example of soft mud substrate in Big Lagoon

Shallow water with clear (left) and turbid (right) water column. Note the very small change in wave energy needed to resuspend fine sediment

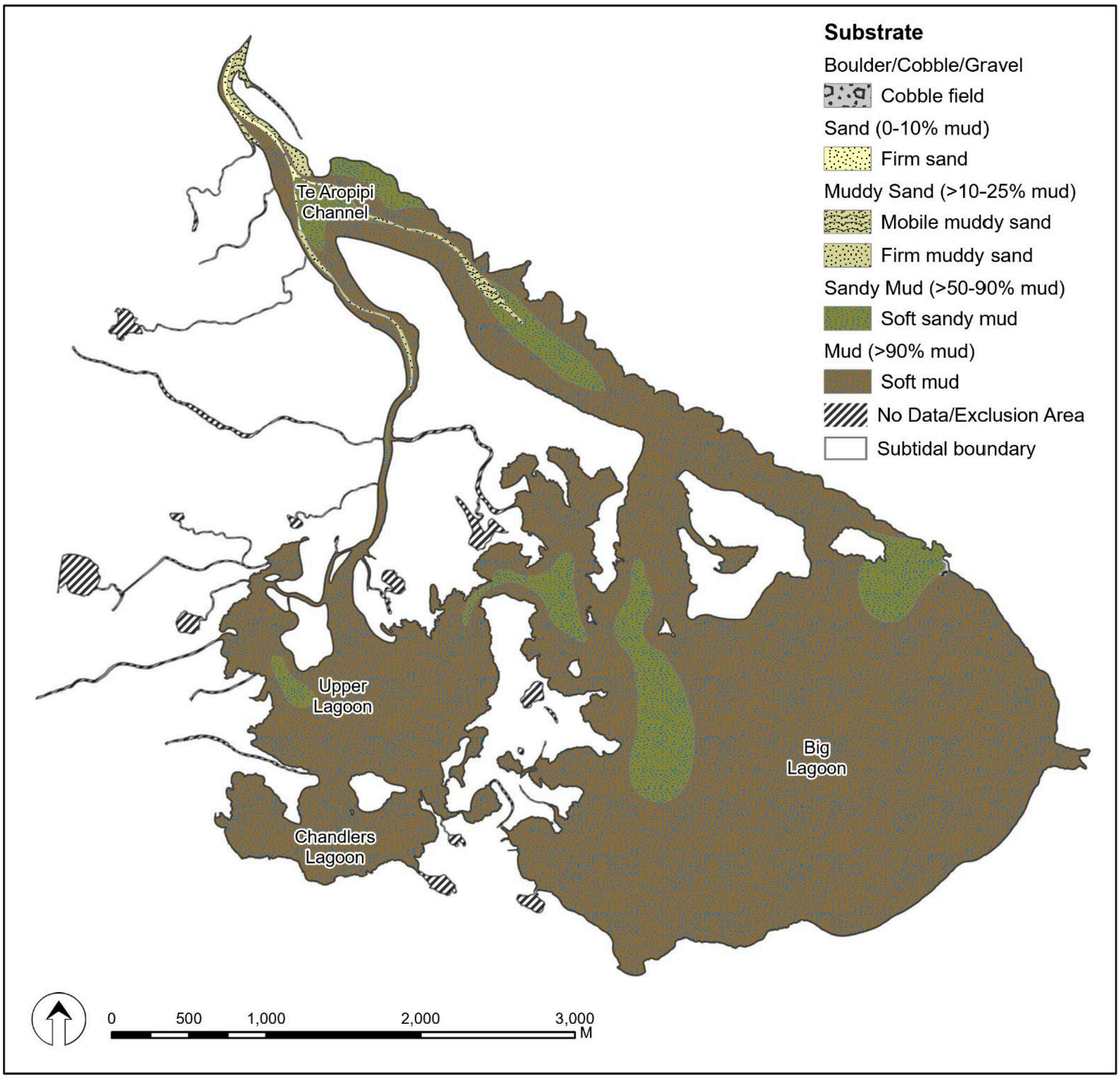


Fig 6. Map of subtidal substrate in Wairau Lagoon, April 2021.

3.1.3 Intertidal substrate

While not a focus of the current report, intertidal flats close to the estuary entrance and along the true right bank of the Te Aropipi channel were dominated by firm muddy sand (mud content 10-25%) and mobile sands (mud content <10%), with evidence of recent scouring across the flats, e.g. widespread sand ripples and deposition of large debris (i.e, trees and logs) on the flats.

Mobile sands on lower intertidal flats near entrance

The true left bank of the Te Aropipi Channel at the location of the intertidal Cawthron fine scale Site C was classified as firm muddy sand (mud content 10-25%). The same area was classified by Berthelsen et al. (2015) as soft sandy mud (mud content >50%). Based on photos in Berthelsen et al., (2015), the change in substrate appears to be due to scouring of fine sediment from the intertidal flats since 2015 rather than any difference in classification. Soft sandy muds remained relatively widespread near the channel in shallow subtidal areas.

Intertidal flats on Te Aropipi channel near Cawthron Site C

Closer to the Big Lagoon entrance, in Chandlers Lagoon and Upper Lagoon, the intertidal areas were predominantly firm sandy mud (mud content >50-90%) and firm mud (>90% mud). This is consistent with lower flow velocities in lagoons and settling of fine sediments. Trapping of fine sediment in adjacent salt marsh would also contribute to the higher mud content in the area.

Firm mud (top) and firm sandy mud (bottom) in Upper Lagoon

Eroding banks contribute fine sediment to the estuary

Hard substrates (i.e. gravel and cobble) were localised to the margin connected to the boulder bank separating the lagoon and the ocean.

3.1.4 Subtidal macroalgae

Table 5 and Fig 7 summarise macroalgal cover in Wairau Lagoon for April 2021. As discussed in the methods, in turbid subtidal waters which could not be directly visually assessed, macroalgal extent was mapped by spatial interpolation from grab sampling results. This method was applied throughout the lagoons and deeper parts of Te Aropipi Channel. However, where macroalgal beds could be directly observed, e.g. shallow parts of Te Aropipi Channel and Upper Lagoon, these were mapped directly. The data were then combined with the directly mapped areas clipped to the interpolated coverage.

Table 5. Summary of subtidal macroalgal cover, Wairau Lagoon April 2021.

Percent Cover Category	Ha	%
Complete (>90%)	21.8	1.8
Dense (70 to <90%)	26.8	2.2
High-Moderate (50 to <70%)	31.1	2.5
Low-Moderate (30 to <50%)	30.9	2.5
Sparse (10 to <30%)	106.2	8.7
Very sparse (1 to <10%)	180.4	14.7
Trace (<1%)	829.1	67.6
Total	**1226**	**100**

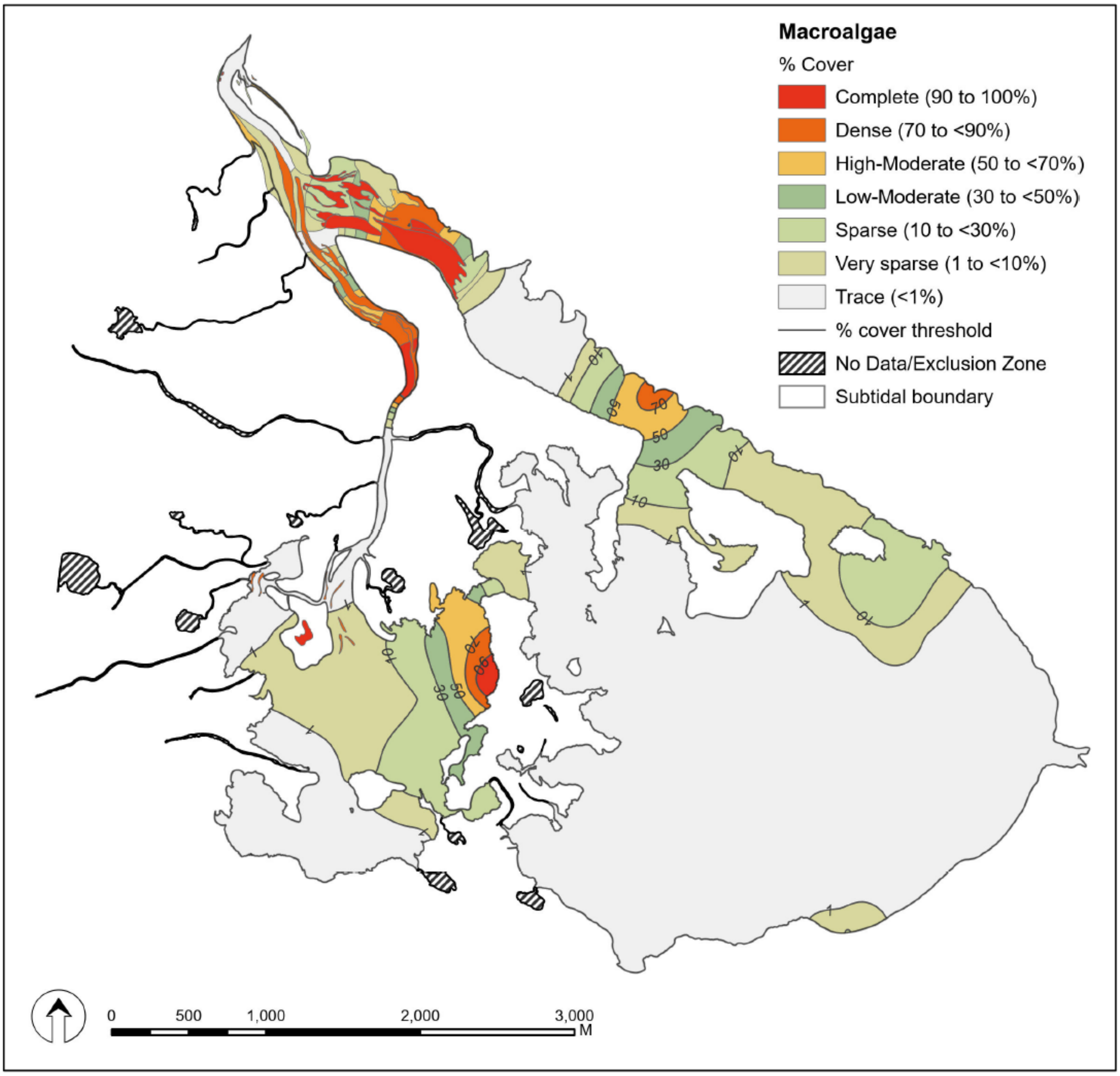


Fig 7. Distribution and percent cover of subtidal macroalgae in Wairau Lagoon, April 2021.

The results (Table 5, Fig. 7) show that macroalgal cover was <1% across 829.1ha (67.6%) of the subtidal area and very sparse (1 to <10%) across a further 180.4ha (14.7%). The areas with the lowest macroalgal cover were Chandlers Lagoon (largely unvegetated) and Big Lagoon, where other vegetation types (macrophytes or filamentous algae) were prominent. When macroalgae was present, the dominant species was *Agarophyton chilense*, with only small low-cover patches of *Ulva*.

Macroalgae was present across most of the Upper Lagoon (Fig. 7), with high cover concentrated along the eastern shore. Here biomass was high, and sediments were in a poor condition showing signs of oxygen depletion and organic enrichment (see photo Site J6).

Dense macroalgal cover at site J6 near the channel connecting Upper Lagoon to Big Lagoon

Near the confluence of the Te Aropipi Channel and the Big Lagoon (see photo) macroalgal cover was sparse (10 to <30%), with patches of high cover adjacent to the coastal boulder bank (Fig. 7).

The densest macroalgal beds, i.e. >50% cover, were present in localised patches on the margins of Te Aropipi Channel west of Budges Island, and within the narrow channel between there and Upper Lagoon (see photos). These beds comprised 79.7ha (6.5%) and were characterised by very high biomass growths (up to 6000g/m^2) growing entrained within the sediments and trapping soft muds. Thresholds used in New Zealand to assess benthic impacts rate biomass >500g/m^2 as 'poor' and >1450g/m^2 as 'bad' (Plew et al. 2020), indicating the current growths are significantly elevated (Fig. 8) and likely to be causing ecological degradation in localised areas.

This finding is generally consistent with Berthelsen et al., (2015) who reported ~85ha of subtidal macroalgae (*Agarophyton*) from this part of the lagoon. However, the extent of the beds in 2021 had reduced slightly and this appears likely due to recent scouring of subtidal beds with gaps appearing among what were previously intact macroalgal patches evident on older aerial photos.

Dense *Agarophyton* collected from the channel margins near site D4 by Budges Island

Where gaps occurred, the sediment surface was appreciably lower (e.g. ~20-50cm) than within the adjacent *Agarophyton* beds, and the sediments were firm and generally sand-dominated as opposed to soft and mud-dominated. This primarily reflects the capacity of entrained *Agarophyton* to trap and retain fine sediments.

Sparse macroalgal cover at Site I11 in the Big Lagoon

The recent reduction of subtidal beds also appeared to be mirrored in the intertidal zone. Berthelsen et al. (2015) reported that beds of macroalgae (*Agarophyton*) covered ~21ha (6% of the intertidal area) and were located primarily on the intertidal flats of the true left bank near Site C, and the western end of Budges Island.

However, it appears there has been significant scouring on the intertidal flats near the entrance compared to previous surveys with no appreciable intertidal beds of macroalgae present in April 2021 (see adjacent photos).

Photos showing unvegetated intertidal flats on the true right (top) and true left (bottom) west of Budges Island

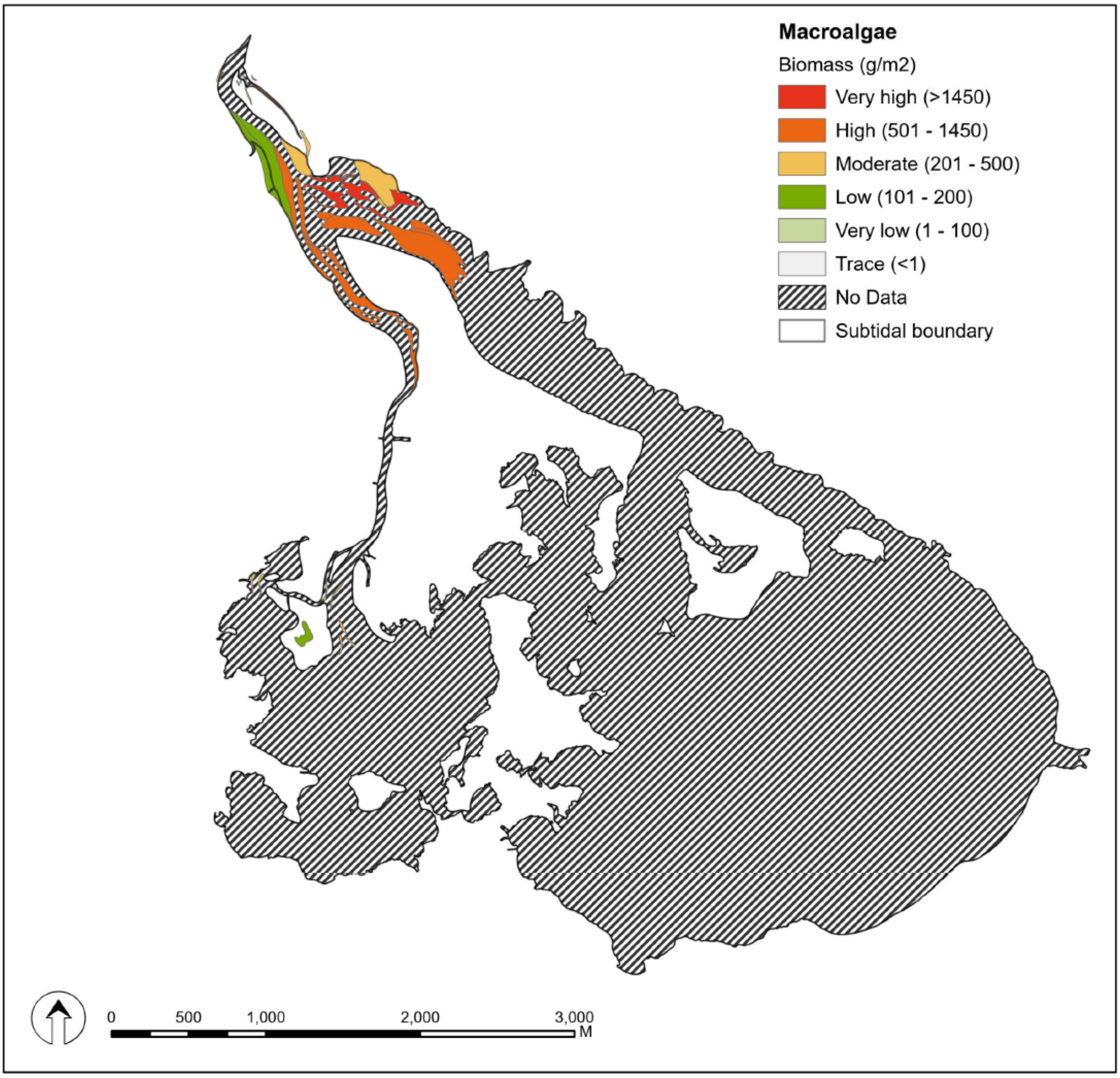


Fig 8. Distribution and biomass of subtidal macroalgae in Wairau Lagoon, April 2021.

3.1.5 Subtidal macrophytes

Table 6 and Fig. 9 summarise macrophyte cover in Wairau Lagoon in April 2021. Extensive beds of horse's mane weed (*Ruppia*) were recorded in Big Lagoon, particularly in the east. Complete cover (>90%) was recorded across 54.6ha or 4.5% of the subtidal area and >50% cover was recorded across 198.8ha or 16.2% of the subtidal area. Sparse growth was present to the west, and also north near the confluence with the Te Aropipi Channel.

Both *Ruppia polycarpa* and *Ruppia megacarpa* were recorded with *R. polycarpa* being dominant. Two other species of macrophyte, *Chara corallina* and *Nitella* sp., were present, but uncommon. Macrophytes were not recorded in Chandlers Lagoon, Upper Lagoon or the lower Te Aropipi Channel.

Table 6. Summary of subtidal macrophyte cover, Wairau Lagoon April 2021.

Percent cover category	Ha	%
Absent or trace (<1%)	684.0	55.8
Very sparse (1 to <10%)	142.2	11.6
Sparse (10 to <30%)	138.7	11.3
Low-Moderate (30 to <50%)	62.8	5.1
High-Moderate (50 to <70%)	60.4	4.9
Dense (70 to <90%)	83.8	6.8
Complete (>90%)	54.6	4.5
Total	**1226**	**100**

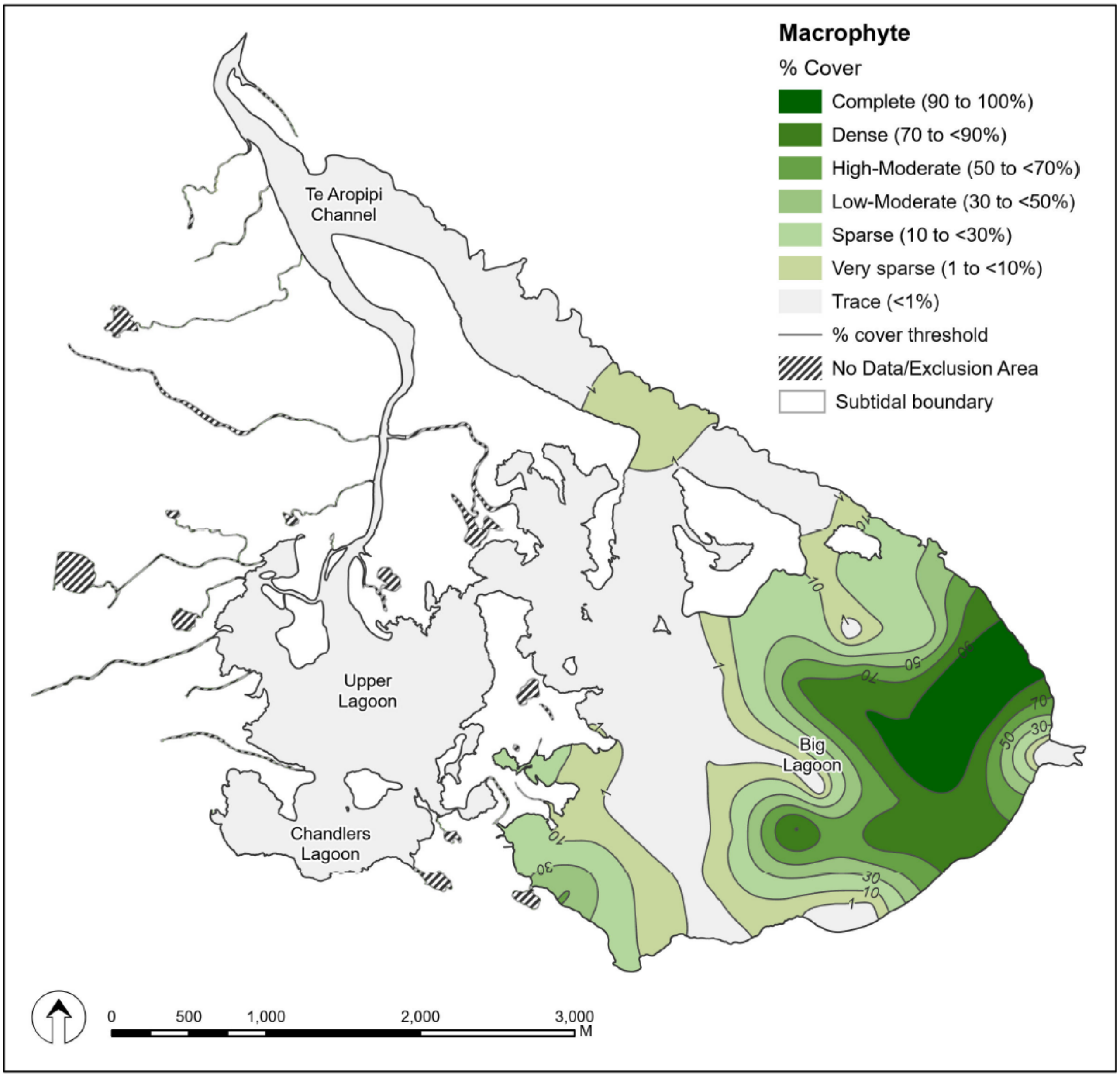


Fig 9. Distribution and cover of subtidal macrophytes in Wairau Lagoon April 2021.

Beach-cast *Ruppia*, present adjacent to mapped beds but absent elsewhere, suggests the current mapping has likely delineated all the major areas of macrophyte growth in the lagoon.

Ruppia at Site J12 mixed with filamentous algae

The presence of dense and extensive macrophyte beds was unexpected based on the previous lagoon survey by Berthelsen et al. (2015) who hypothesised the presence of subtidal vegetation (e.g. seagrass or macrophytes) in the lagoon was improbable due to the likely soft mud nature of benthic sediments and reduced light at the seabed caused by poor water clarity. However, extensive beds of *Ruppia* were recorded in Big Lagoon in 1958, and while declining after that time (Wells 1976), *Ruppia* was observed by Knox (1983). It is highly unlikely that the *Ruppia* recorded in April 2021 are beds that have newly established since 2015. They more likely reflect beds that have persisted over time, but due to a combination of limited sampling effort, difficulty of access, and study scope and objectives, have simply not been observed.

No seagrass (*Zostera muelleri*) was recorded from the estuary in 2021 (either subtidally or intertidally). This is consistent with the findings of Berthelsen et al. (2015) who hypothesised that hydrodynamic changes, increased sedimentation, and displacement by macroalgae led to the significant loss of previous seagrass. However, as it is unclear where the previously reported seagrass beds were located, it is not possible to easily determine which factors may be primarily responsible for either the absence or loss of seagrass.

Complete (>90%) filamentous algae cover, Site I11


Dense *Ruppia* with epiphytic filamentous algae growth


Looking down at the extensive macrophyte cover and filamentous algae in Big Lagoon

3.1.6 Subtidal filamentous green algae

Table 7 and Fig. 10 summarise filamentous green algal cover. It was by far the most widespread plant in the lagoon growing as smothering mats on bare sediments and epiphytically on *Ruppia* and macroalgae. The filamentous algae were a mix of two main species, *Cyanophyceae* a filamentous blue-green algae and *Cladophora*, with *Cyanophyceae* being the most abundant. Complete cover (>90%) was recorded across 219.8ha or 17.9% of the subtidal area and 50-90% cover was 278.7ha or 22.8% of the subtidal area. Areas with <1% cover were relatively sparse (283.7ha or 23.1% of the subtidal area) and found mainly in Te Aropipi Channel. In addition, Fig. 10 shows filamentous algae was growing in the same location as macrophytes (Fig. 9), present as either dense mats or growing epiphytically (see photos on previous page). The extent and cover of filamentous algae reflects significant degradation of the lagoon.

Table 7. Summary of filamentous algae cover, Wairau Lagoon April 2021

Percent cover category	Ha	%
Complete (>90%)	219.8	17.9
Dense (70 to <90%)	161.4	13.2
High-Moderate (50 to <70%)	117.3	9.6
Low-Moderate (30 to <50%)	150.8	12.3
Sparse (10 to <30%)	142.9	11.6
Very sparse (1 to <10%)	150.4	12.3
Absent or trace (<1%)	283.7	23.1
Total	**1226**	**100**

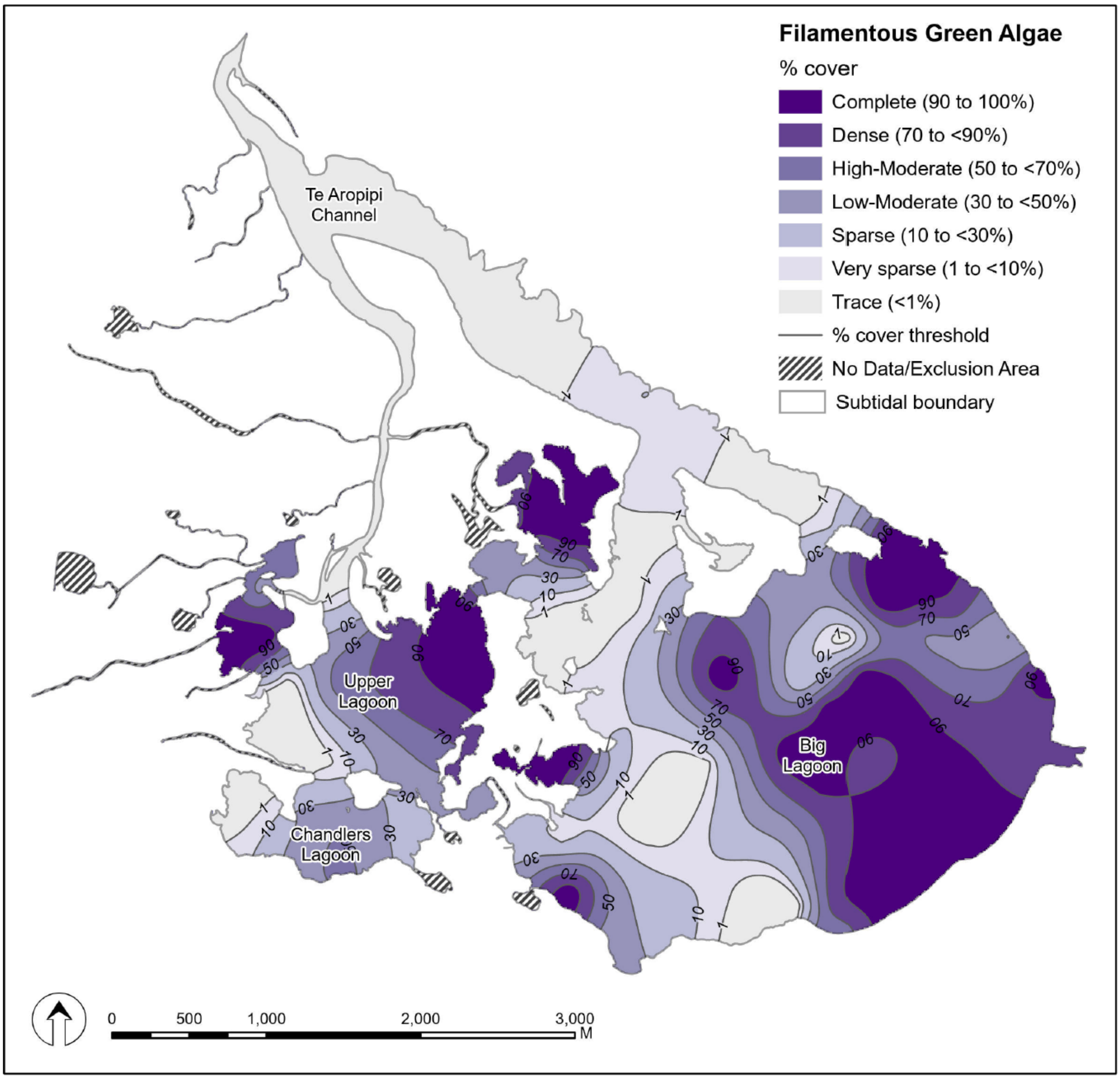


Fig 10. Distribution and cover of subtidal filamentous green algae in Wairau Lagoon, April 2021.

3.2 WATER QUALITY

3.2.1 In situ parameters

In situ water quality parameters are summarised in Figs 11, 12 and 13 with raw data in Appendix 5.

Temperature ranged from 12.2 to 17.3°C in the surface waters of Wairau Lagoon, with cooler temperatures monitored in the morning and temperature increasing throughout the day. There was no vertical stratification of temperature.

Salinity ranged from 13.7‰ near a freshwater inflow up to 29.6‰ on the incoming high tide. In sheltered parts of Chandlers Lagoon and the western side of Big Lagoon, flushing appears limited with more saline water concentrated in these areas (salinity range 26.2 – 28.7‰; Fig. 11). Upper Lagoon is influenced by several small freshwater inputs which contribute to a decrease in the measured salinity range from 25.9 to 22.3‰. In Big Lagoon, where dense macrophyte cover was recorded, salinity ranged from 20.9 to 24.7‰. Marginally lower salinities in the macrophyte beds likely reflect reduced circulation, where water velocities are dampened by the macrophytes, and flushing is reduced.

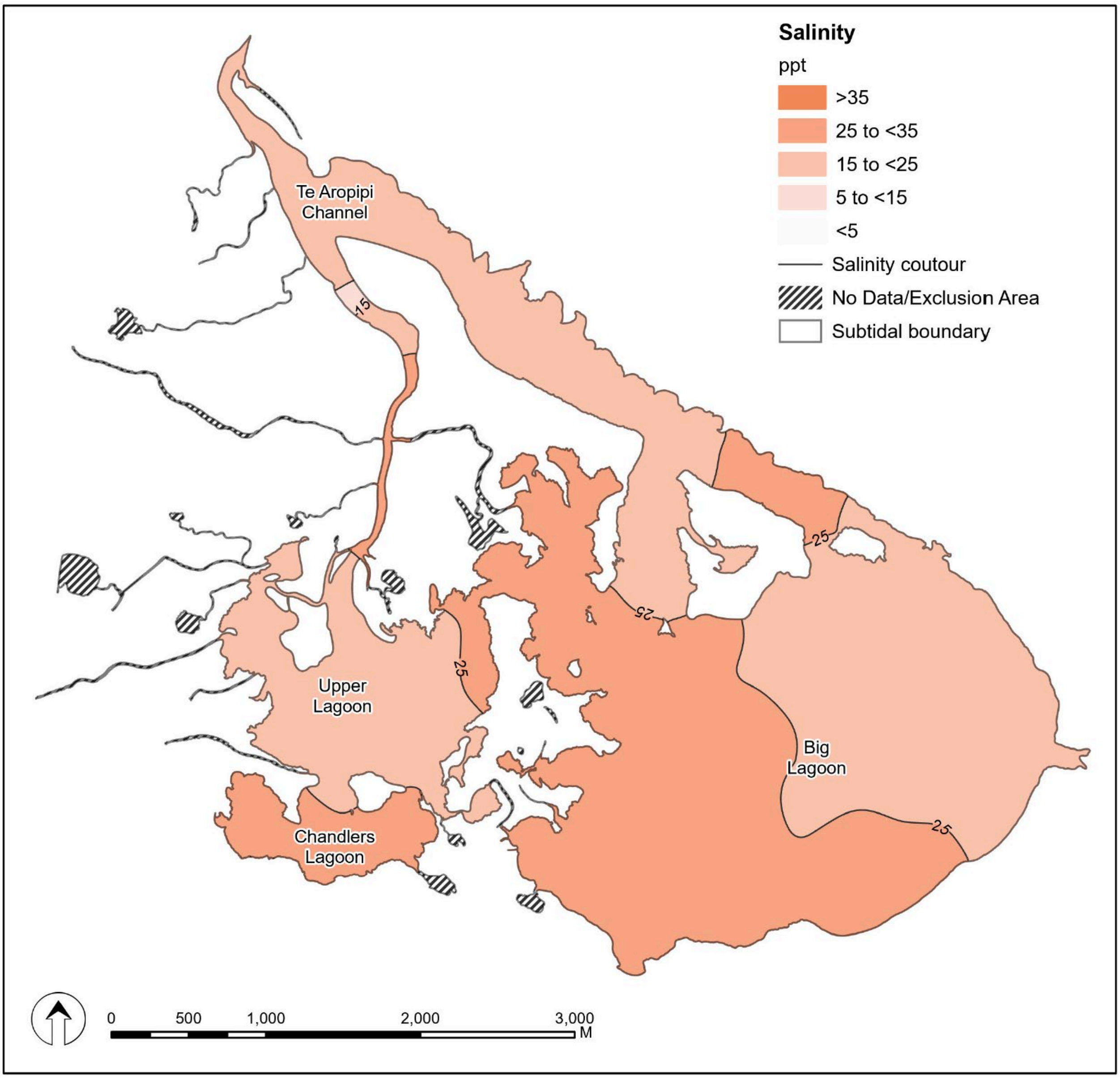


Fig 11. Spatial representation of salinity (ppt) in the Wairau Lagoon, April 2021.

Dissolved oxygen was over-saturated (>100% saturation) at 49 of the 58 water quality sites (Fig. 12). Dissolved oxygen is controlled by several factors; including, stratification, physical aeration and production and consumption processes (i.e., photosynthesis and respiration). Consistent with the macrophytes, filamentous algae, macroalgae and phytoplankton recorded in the lagoon, the dissolved oxygen concentrations likely reflect high rates of photosynthesis, a process where plants produce oxygen. Dissolved oxygen concentration ranged from 7.4 to 13.7mg/L a condition rating of 'very good'. However, it is important to note that over-saturation of oxygen can indicate strong diurnal fluctuations in oxygen may occur if plants utilise more oxygen at night than they produce during the day.

Epiphytic filamentous algae growing on *Ruppia,* both plants can produce oxygen through photosynthesis

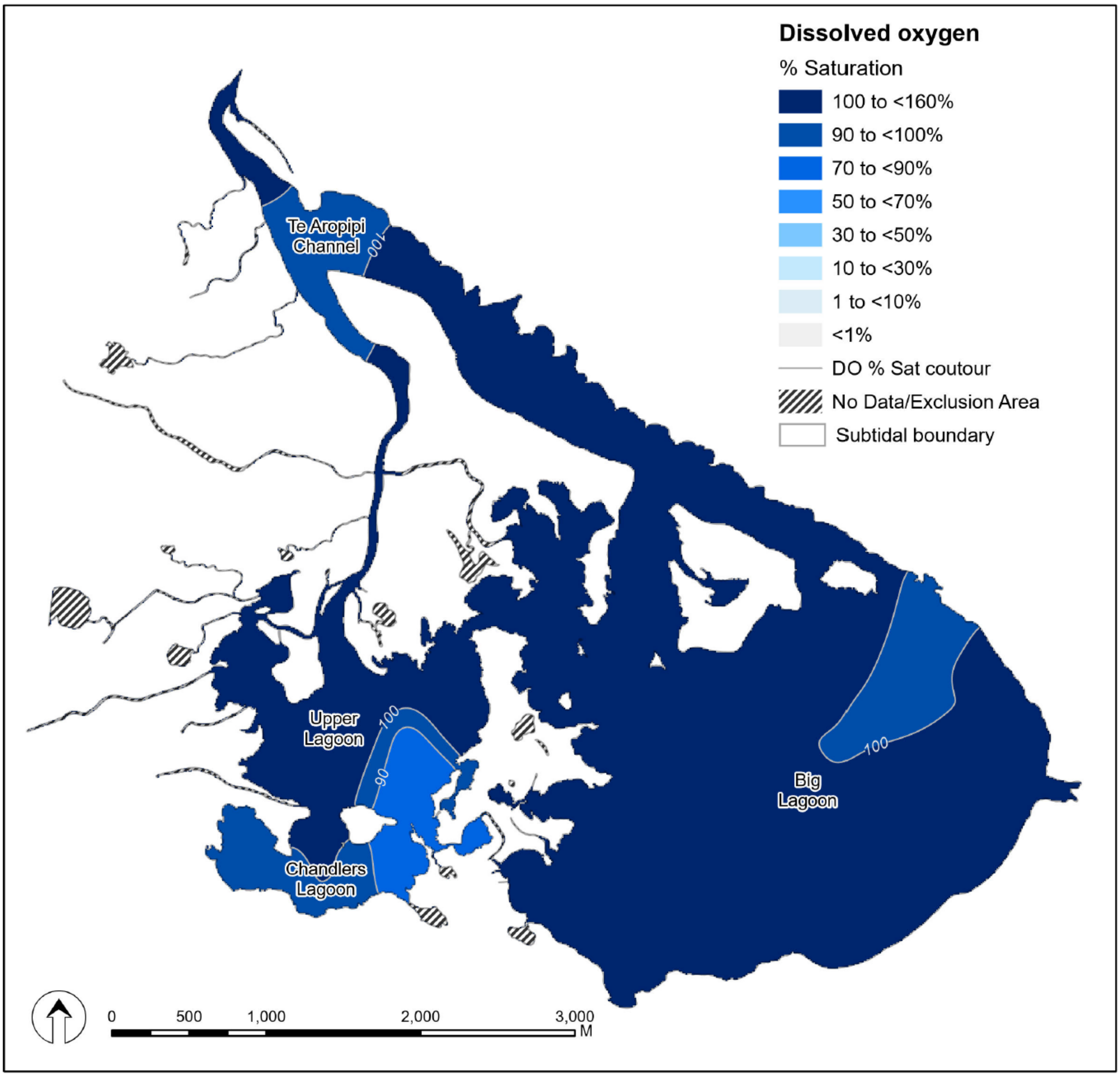


Fig 12. Spatial representation of dissolved oxygen (% saturation) in the Wairau Lagoon, 2021.

3.2.2 Phytoplankton

Fig. 13 groups the measured phytoplankton (chlorophyll-a) concentrations in Wairau Lagoon into condition bands (Table 3) and presents data spatially. Raw data are presented in Appendix 5. The main channels and Big Lagoon were rated 'very good' indicating chlorophyll-a was low (<5mg/m^3). Higher phytoplankton concentrations were recorded in sheltered areas and backwaters that are poorly flushed, including parts of Chandlers Lagoon and Upper Lagoon, these areas were rated 'good' to 'fair'. No problem blooms of phytoplankton were recorded in the lagoon and although *Cyanophyceae*, a filamentous blue-green algae was observed, no potentially toxic species of algae were recorded in the phytoplankton samples (Appendix 6).

Chandlers Lagoon, ankle deep water at mid tide.

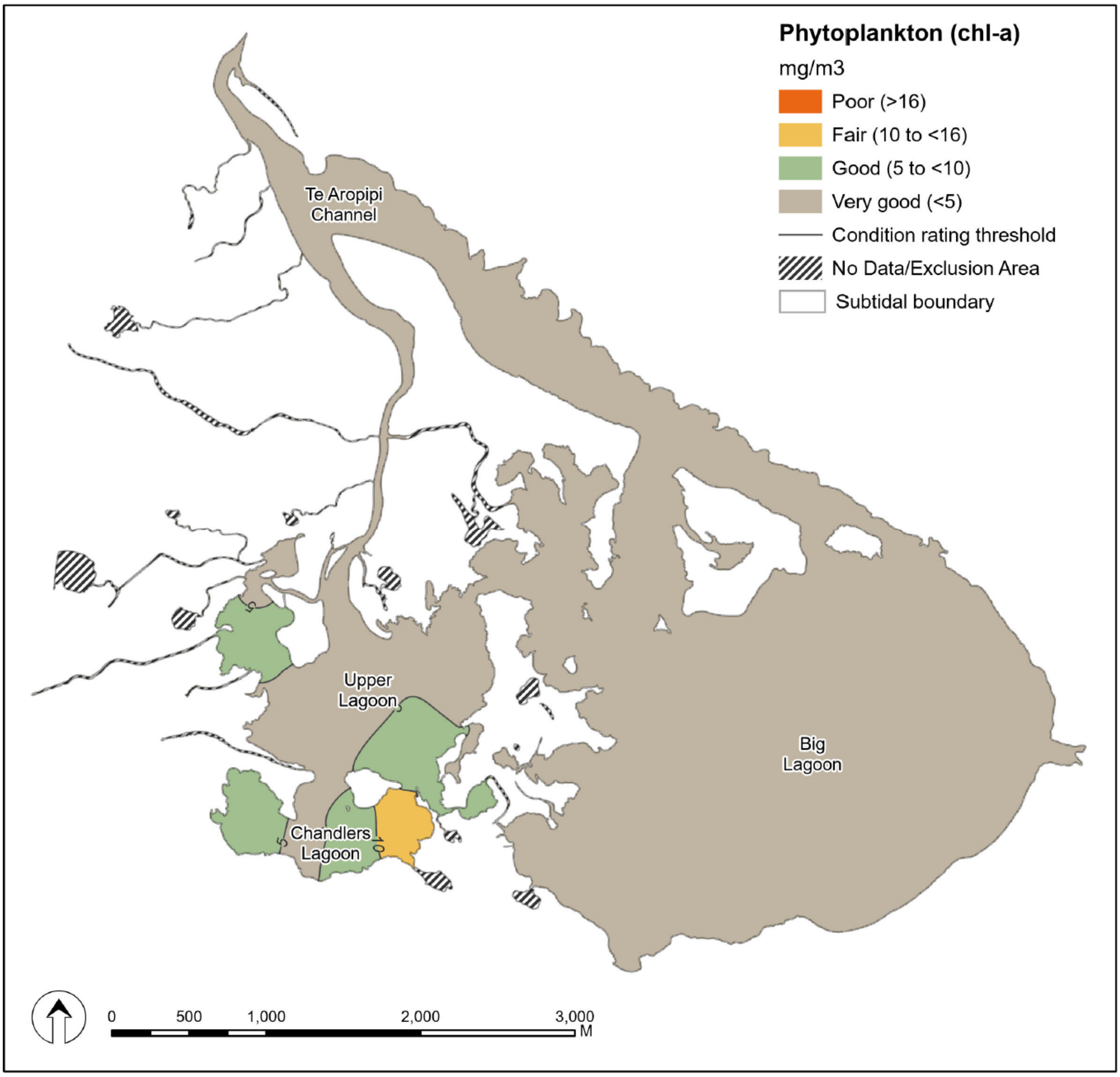


Fig 13. Spatial representation of phytoplankton (chl-a) concentrations in Wairau Lagoon, 2021.

3.2.3 Water column nutrients

A grab sample was analysed for water column nutrient concentrations at five sites (C3, F7, J4, J11 and L8 – Fig. 4). Total Nitrogen (TN) in the Upper Lagoon (J4) was rated 'fair' and the two sites in the Big Lagoon (L8 and J11) were rated 'good' (Table 8). At these sites TN comprised of particulate and organic nitrogen with dissolved inorganic nitrogen (DIN) contributing <5% of the TN.

DIN is a bioavailable form of nitrogen (i.e. nutrients that are taken up by plants) and is the sum of ammoniacal nitrogen, nitrite and nitrate. In the Upper Lagoon and Big Lagoon DIN was negligible, likely reflecting rapid uptake of DIN by plants (i.e., phytoplankton, filamentous algae and macrophytes). Spot measures of nutrient concentrations are likely to underestimate actual nutrient availability in the system owing to rapid uptake by plants.

Site F7 located in the wide channel at the entrance to Big Lagoon was rated 'good' for TN. With a small component of the TN made up of ammoniacal nitrogen and nitrate.

Site C3, (Te Aropipi Channel) had lower TN than all other sites, a condition rating of 'very good'. TN was made up of 39% DIN (mainly nitrate). This area is subjected to strong tidal flows on the incoming and outgoing tides and is more influenced by seawater than the other lagoon sites.

Total phosphorus (TP) was lowest at Site J11 (Big Lagoon), and rated 'very good'. The site comprised high macrophyte cover with water clarity reaching to the bottom of the lagoon on the day of sampling (noting it was a very calm day with little wind). DRP, a bioavailable form of phosphorus, only made up a small fraction of TP because any available DRP was likely utilised by macrophytes and filamentous algae in the area. In contrast water clarity was poor at Site L8 in Big Lagoon where no vegetation was present. Most of the TP was made up of particulate phosphorus consistent with visible suspended sediments and DRP was below detection, a rating of 'good'. The two channel sites (C3 and F7) were rated 'good' for TP with DRP ranging from 31 to 55% of TP.

Consistent with higher TN recorded in the Upper Lagoon (Site J4), water column TP was rated 'poor'. With TP comprising 51% DRP. Upper Lagoon is highly productive with both filamentous algae and higher concentrations of phytoplankton recorded in the area.

Te Aropipi Channel looking toward Wairau Estuary

3.3 SEDIMENT QUALITY

A summary of the April 2021 composite sediment sample data collected at five sites (see Fig. 4) is presented in Table 9.

Table 8. Sediment grainsize, nutrient, aRPD, trace metal and metalloid data for composite samples collected at five sites in April 2021. Colours represent condition bandings in Table 3.

Site	Area	TN	Ammoniacal nitrogen	Nitrite	Nitrate	DIN*	TP	DRP	DRP
		mg/m³	mg/m³	mg/m³	mg/m³	% of TN	mg/m³	mg/m³	% of TP
J4	Upper Lagoon	370	7	<1	<1	2	73	37	51
L8	Big Lagoon	280	<5	<1	<1	0	16	<1	0
J11	Big Lagoon	220	10	<1	<1	5	7	1.2	17
C3	Te Aropipi Channel	123	<5	1.7	46	39	19	11	55
F7	Channel	230	18	1.1	8.8	12	19	5.9	31

**DIN = dissolved inorganic nitrogen (ammoniacal nitrogen + nitrate + nitrate)*

3.3.1 Sediment Grainsize

In Upper Lagoon (J4) and Big Lagoon (L8 and J11) the mud content was high, a condition rating of 'poor'. These areas represent depositional zones. Site F7 represents a site within deepest part of the wide channel connected to Big Lagoon. At this site the mud content was high (75.8%; a condition rating of 'poor'). Site C3, in the Te Aropipi Channel between the lagoon and the estuary was sand-dominated and had a low mud content, a condition rating of 'good'. This is consistent with the high flow velocities through the narrow channel and limited settling of fine sediments in this area.

3.3.2 Total organic carbon and nutrients

In general, lower mud content corresponded to lower Total Organic Carbon (TOC) and nutrients (TN and TP). In Upper Lagoon (J4) and the Ta Aropipi Channel site closest to Big Lagoon (F7), TOC was rated 'very good' and TN 'good'. TP was lower than the muddiest sites, however no condition rating has been developed for sediment TP.

The two Big Lagoon sites (J8 and J11) had moderate TOC and TN, a condition rating of 'fair'. TP ranged between 620 – 640mg/kg. The high levels of TOC and nutrients are correlated with a very high mud content (>95% mud). Although the source of sediment inputs will contribute to its quality, higher TOC and nutrient concentrations recorded in the Big Lagoon compared to other parts of the estuary indicate a possible internal source of carbon and nutrients (i.e., decomposing algae and macrophytes) in this area.

In Te Aropipi Channel (C3), the sand dominated site had lower TOC (a condition rating of 'very good'), TN (a condition rating of 'good') and TP (no rating available).

Sediment quality sites corresponding to the sites in Table 5

Table 9. Sediment grainsize, nutrient, aRPD, trace metal and metalloid data for composite samples collected at five sites in April 2021. Colours represent condition bandings in Table 3.

Site	Area	Mud %	TOC %	TN mg/kg	TP* mg/kg	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
J4	Upper Lagoon	81.5	0.42	600	520	3.4	0.026	15.7	8.1	0.08	22.0	9.1	47.0
L8	Big Lagoon	95.2	1.28	1700	620	5.5	0.050	21.0	16.5	0.08	24.0	17.2	67.0
J11	Big Lagoon	96.7	1.14	1400	640	5.6	0.062	24.0	22.0	0.11	25.0	21.0	80.0
C3	Te Aropipi Channel	7.9	0.20	<500	550	6.1	0.022	15.9	5.9	0.04	21.0	7.4	41.0
F7	Channel	75.8	0.36	<500	490	4.4	0.021	15.8	8.8	0.04	23.0	9.8	49.0

*< values below lab detection limit *No condition rating has been developed for Total Phosphorus*

3.3.3 The Metals and Metalloids

Table 9 shows that metal concentrations at all sites were generally low and rated 'very good'. The three muddiest sites (J4, J8 and J11 in Big Lagoon) had slightly higher concentrations of mercury (Hg) that the other sites, but a condition rating of 'good'. This may simply reflect that the muddier sediments at these sites contain more fine particles which have a greater surface area for contaminant adsorption. At all sites Nickel (Ni) was elevated, a condition rating of 'fair'. Exceedance of the Default Guideline Value (the 'fair' threshold; Table 3) set in the ANZG (2018) sediment quality guidelines indicates nickel is at levels where ecological effects may be observed. However, Berthelsen et al., (2015) attributed higher nickel concentrations in the sediment to a natural source from the catchment.

Fine sediments suspended in the water column after disturbance from wading

3.3.4 Sediment Oxygenation

Sediment oxygenation was measured at all vegetation monitoring sites (68 in total). Raw data are presented in Appendix 5 and Table 10 summarises the data by substrate type and aRPD condition rating band. Of the 68 sites monitored, 73% recorded an aRPD <10mm corresponding to a condition rating of 'poor'. The substrate type M90_100 (>90% mud) accounted for 87% of 'poor' sites indicating low sediment oxygenation was strongly associated with muddy sediments. Of the remaining sites, 24% were rated 'fair', 3% rated 'good'.

Table 10. Summary of sites within an aRPD condition rating band for each substrate type.

	aRPD (mm)	≥50	20 to <50	10 to <20	<10
Substrate Type	S0_10	-	-	-	-
	MS10_25	-	-	1	-
	SM50_90	-	-	3	6
	M90_100	-	2	12	43
	Total Sites	0	2	16	49
	% sites	0	3	24	73

3.4 MACROFAUNA

A qualitative assessment of sediment dwelling organisms was made at 15 sites (Fig. 4). The purpose was to assess community composition in response to prevailing sediment conditions. Results are summarised in Fig 14, Table 11 and Appendix 7.

The results show that the macrofaunal assemblage is relatively impoverished. In total only 22 species or higher taxa of benthic infauna were recorded. Intertidal richness was <9 and subtidal richness was <11 species at all sites. In general, more enriched soft muds had more pollution tolerant species.

Across the three intertidal sites (C2, I2 and N10.5), abundance and richness varied. There was very low species richness (<3 species) and abundance (<6 individuals) recorded at Upper Lagoon Site I2 (Cawthron Site A) and Big Lagoon Site N10.5 (Cawthron Site B) (Fig 14). These results were comparable to the low richness and abundance recorded in the 2015 Cawthron survey (Berthelsen et al. 2015), with similar pollution tolerant species present e.g. *Scolecolepides benhami* and *Amphipoda* sp. The low richness and abundance likely reflect the high mud content associated with the two intertidal sites.

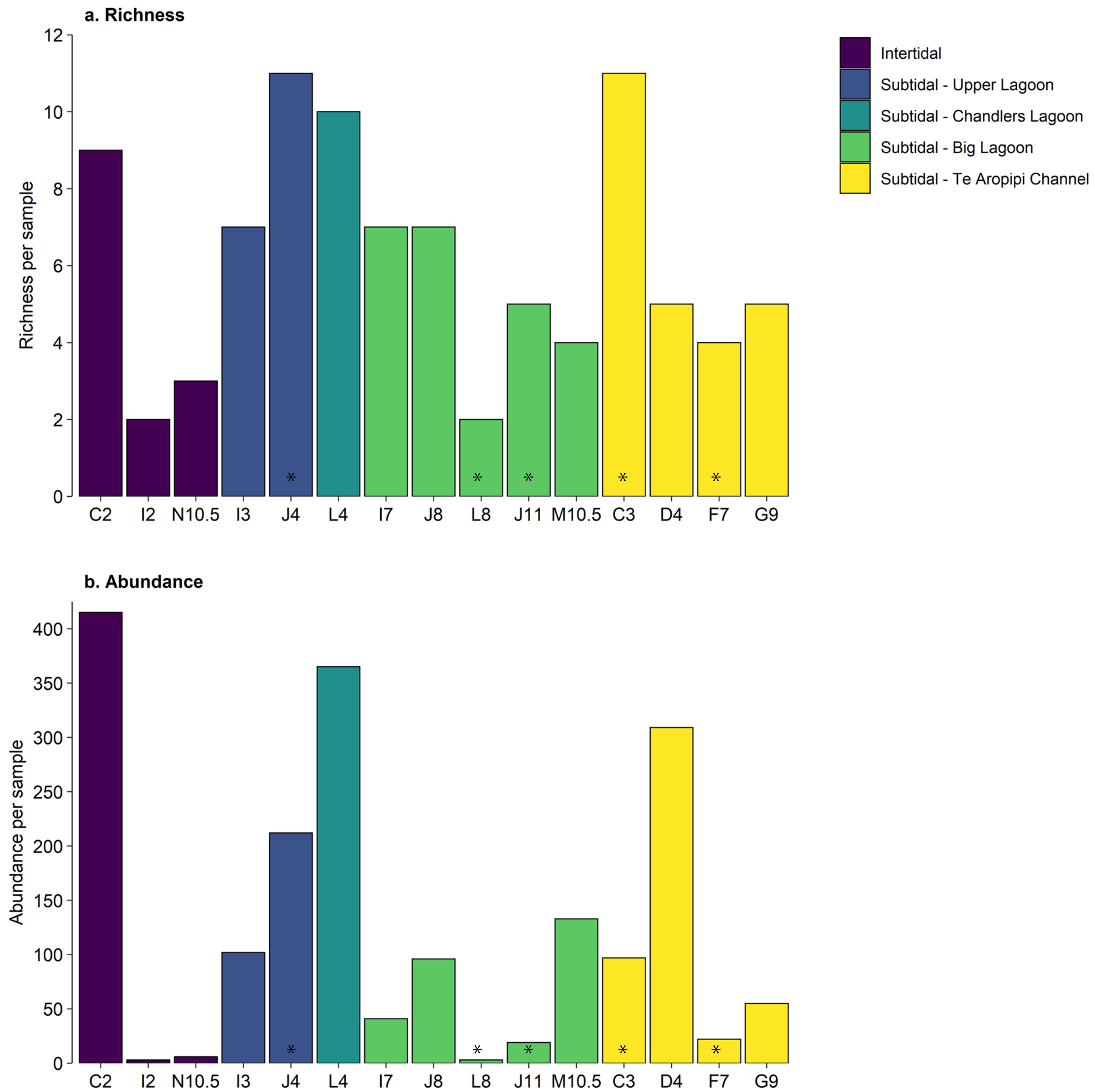
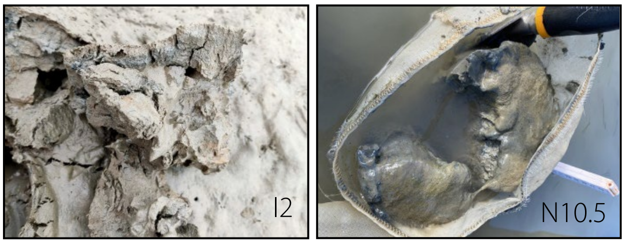


Fig 14. Sediment macrofauna taxon richness and abundance per site. Data are indicative only given the qualitative nature of sampling. *denotes samples that have associated sediment quality.



Substrate at intertidal sites I2 (Cawthron A) and N10.5 Cawthron B). Site N10.5 was sampled mid-tide.

Site C2 (Cawthron Site C), near the estuary entrance, was more diverse with 9 species recorded; however fewer species were recorded in 2021 compared to 2015 (21 species). This difference could relate to variable and relatively low sampling effort (1 composite core in 2021 versus 5 individual cores in 2015). This is supported by 9 taxa being represented by a single individual in 2015 suggesting sampling effort was insufficient to reliably characterise the site. However, results could also indicate a shift in the macrofauna community. Similar to 2015 the small estuarine snail *Potamopyrgus estuarinus* (116 individuals) and *Amphipoda* sp (281 individuals) were most abundant. Both species are tolerant to pollution, eutrophication in particular, with ecological sensitivity groups of EG-III and EG-IV, respectively. *Arthritica bifurca* a small bivalve and the more sensitive cockle, *Austrovenus stutchburyi,* were present in low numbers. Like 2015, small eutrophication tolerant (EG-V) crabs were recorded at the site (*Hemiplax hirtipes* and *Austrohelice crassa*).


Intertidal Site C2 (Cawthron Site C)

The subtidal sites were dominated by soft enriched muds (aRPD <10mm at 9 out of 12 sites). Upper Lagoon Site J4 and Chandlers Lagoon Site L4 recorded the highest richness out of the mud-dominated sites. The sediments were low in oxygen (aRPD of 1mm), had 50% filamentous algae cover and were highly enriched. The species recorded at these two sites were predominantly eutrophication tolerant, with ecological sensitivity groups of EG-III and EG-IV. Pollution-tolerant worms (Oligochaeta, *Capitella* spp. and *Scolecolepides benhami)* that can survive in low oxygen environments were present in high abundances. The pollution tolerant Amphipoda *Paracorophium excavatum*, the small estuarine snail *Potamopyrgus estuarinus* and the small bivalve *Arthritica bifurca* were also present.

Substrate at the subtidal sies J4 and L4, aRPD 1mm

Site I3 in the north of Upper Lagoon, close to intertidal site I2 (Cawthron Site A) was not as enriched as nearby sites J4 and L4, and while similar species were recorded, fewer pollution-tolerant worms were present. Amphipoda (*Paracorophium excavatum*) *and* the small estuarine snail (*Potamopyrgus estuarinus*) were the dominant species.

Substrate at the subtidal site I2

Species richness and abundance in Big Lagoon varied depending on substrate type, sediment enrichment and vegetation cover. Sites I7 and J8 had similar substrate types (sandy mud, 50 to 90% mud content). Site I7 was located between Upper Lagoon and Big Lagoon and Site J8 in the main body of the lagoon. While similar species richness and abundance were recorded at the two sites, the dominant species present differed. *Arthritica bifurca*, a tolerant bivalve (EG-IV) was the dominant species at Site I7, not present at Site L8. The pollution tolerant (EG-III) oligochaete worm was the dominant species at L8, not present at Site I7.

Site I7 and J8 in Big Lagoon, Site I7 had no vegetation cover and Site J8 had 20% filamentous green algae cover. Both sites were sandy mud (50-90% mud content)

Site L8, located in the south-west of Big Lagoon, was comprised of very enriched soft muds (>95%; Table 5), and only recorded 2 species and 3 individuals. The pollution-tolerant Amphipoda *Paracorophium excavatum* and the small estuarine snail *Potamopyrgus estuarinus*.

Site J11, located in the *Ruppia* beds in Big Lagoon, had a thick mat of filamentous algae present, and very soft mud substrate with aRPD at 5mm. Abundance was low (19 individuals) with the more sensitive Amphipoda *Josephosella awa* present and the pollution-tolerant *Nemertea* being the most abundant. The Isopod *Astellota* (found only at one other site) was present in low abundance.

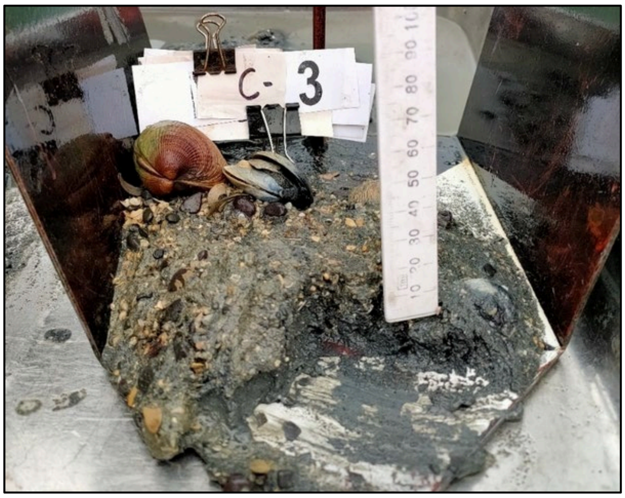
Site J11, dense *Ruppia* and filamentous cover, very soft mud and a shallow aRPD

Site M10.5, on the southern margin of the Big Lagoon, comprised very soft mud (>90% mud content) with a shallow aRPD. The Amphipoda *Josephosella awa* and Oligocheate were present but the most abundant species was *Scolecolepides benhami,* a polychaete that is tolerant to pollution (EG-IV).

Three channel sites (D4, F7 and G9) comprised high mud contents (>50% mud) and recorded similar species to other muddy lagoon sites.

Site M10.5 (top left) lower Big Lagoon and three channel sites D4 (top right), F7 (bottom left) and G9 (bottom right)

The highest species richness was recorded nearest to the estuary entrance in the well-flushed, bare sand of Te Aropipi Channel (Site C3). The sensitive (EG-II) Amphipoda *Josephosella awa* was the most abundant species present, along with cockles *(Austrovenus stutchburyi),* pipi *(Paphies australis)* and the polychaete worm *Prionospio aucklandica* (EG-II).



Site C3 comprised bare sand substrate, cockles and pipi visible in the sample

Table 11. Description of the sediment-dwelling species that were consistently the most abundant at one or more sites. EG refers to the ecological sensitivity grading, with EG-I describing sensitive species and EG-V species tolerant to pollution. Images are illustrative only.

		Intertidal Sites			Upper Lagoon		Chand. Lagoon	Big Lagoon					Te Aropipi Channel					
Main group & species	EG	C2	I2	N10.5	I3	J4	L4	I7	J8	L8	J11	M10.5	C3	D4	F7	G9	Description	Image
Substrate type*		fM90	fM90	sM90	sM90	sM90	sM90	vsSM	vsSM	sM90	sM90	sM90	fS	sM90	sSM	sM90		
Amphipoda, *Josephosella awa*	II	0	0	0	0	8	75	0	7	0	9	32	38	0	0	1	Amphipods are shrimp-like crustaceans. This is an unknown species with a laterally compressed body. The adjacent image is illustrative.	
Amphipoda, *Paracorophium excavatum*	IV	281	0	1	45	93	51	16	16	2	0	0	5	252	7	3	Shrimp-like corophioid amphipods are opportunistic tube-dwelling species that can occur in high densities in mud and sand habitats, often in estuaries subjected to disturbance and low salinity water.	
Bivalvia, *Arthritica bifurca*	IV	2	0	0	2	11	40	19	0	0	0	0	0	1	0	1	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.	
Cirripedia, *Austrominius modestus*	NA	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	A small barnacle occurring in estuaries and harbours and can tolerate brackish and muddy waters. Able to survive on a range of substratum (rock, invertebrates, algae etc) if the conditions are suitable.	
Gastropoda, *Potamopyrgus estuarinus*	III	116	0	0	40	67	22	1	7	1	0	0	11	54	10	48	Small endemic estuarine snail, requiring brackish conditions. Feeds on decomposing matter, bacteria, and algae. Tolerates mud and organic enrichment.	
Oligochaeta, *Oligochaeta sp.*	III	0	1	0	2	20	32	0	56	0	1	13	11	0	4	0	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered very pollution tolerant.	
Polychaeta *Capitella spp.*	IV	0	0	0	0	4	46	0	7	0	0	0	0	0	0	0	Opportunistic polychaete tolerant to stressful conditions. Often found in polluted waters and mud rich environments.	
Polychaeta *Scolecolepides benhami*	IV	0	2	0	11	2	88	0	0	0	0	87	0	0	0	0	A spionid, surface deposit feeder that is rarely absent in sandy/mud estuaries.	

*fS = firm sand; sSM = soft sandy mud, mud content 50-90%, vsSM = very soft sandy mud; mud content 50-90%; fM90 = firm mud, 90-100% mud content; sM90 = soft mud, 90-100% mud content

Sand (<10% mud)	Sandy Mud (50-90%)	Mud (90-100%)

4. KEY FINDINGS

The dominant features assessed as part of the survey carried out from 19-22 April 2021 in Wairau Lagoon are summarised in Table 12 and the assessment against preliminary broad scale condition ratings are summarised in Table 13. Water quality and sediment quality are summarised in Table 14 and rated against the preliminary condition ratings (see Table 3 for details on condition ratings).

The subtidal extent of the estuary is ~1259ha of which 1226ha was assessed, with the remaining 32.5ha (comprising ponds, narrow channels and streamways among salt marsh) excluded from the assessment. The intertidal extent was not mapped as part of the current survey but was estimated by Berthelsen et al. (2015) to be 359ha with an additional 59ha mapped as supratidal habitat (see Appendix 12). These estimates appear to exclude large areas of tidally connected salt marsh contiguous to the lagoon (see Appendix 13).

Table 12. Summary of dominant broad scale features as a percentage of the total subtidal area, Wairau Lagoon 2021.

Key subtidal habitat features	Ha	%
Mud-dominated sediment (≥50%)	1206	98.4
Seagrass (≥50% cover)	0.0	0.0
Macroalgal beds (≥50% cover)	63.6	5.2
Macrophyte beds (≥50% cover)	198.8	16.2
Filamentous Green (≥50% cover)	498.5	40.6

Subtidal substrate was fairly uniform with mud-dominated (>50% mud) sediments comprising 98.4% of the mapped area, with sand-dominated sediments (1.4%) being largely limited to high flow channel areas near the entrance, and cobble (0.2%) in a narrow band along the edge of the coastal boulder bank between the lagoon and the sea. These results are broadly consistent with those reported by Knox (1983) based on earlier work of Black (1978).

Surprisingly, extensive beds of native macrophytes were recorded in Big Lagoon in April 2021. Both *Ruppia polycarpa* and *Ruppia megacarpa* were recorded along with two other species of macrophyte, *Chara corallina* and *Nitella* sp. No seagrass (*Zostera*) was observed.

Extensive beds of *Ruppia* were recorded in Big Lagoon in 1958 but were noted as subsequently declining (Wells 1976). They were observed by Knox (1983) but were not recorded in the estuary-wide intertidal broad scale habitat mapping of Berthelsen et al. (2015) who hypothesised the presence of vegetation (e.g. seagrass or macrophytes) in the lagoon was improbable due to the likely soft mud nature of benthic sediments and reduced light at the seabed caused by poor water clarity.

Given the extent and density of macrophyte cover in April 2021, it is highly unlikely that the macrophyte beds have become newly established since 2015. It is more likely that beds that have persisted over time and have simply not been observed due to a combination of limited sampling effort, difficulty of access, and different objectives of previous studies.

The finding of extensive beds of *Ruppia* is significant as such habitat has been lost from many of the coastal lagoons and lakes in New Zealand that have developed catchments. *Ruppia* is an ecologically important habitat, providing refuge for invertebrates and fish and a food source for invertebrates and waterfowl (Robertson et al. 2011 and references therein). It is better able to tolerate fluctuating levels of salinity than many other macrophyte species allowing it to survive in coastal lagoons. *Ruppia* regulates water quality through the uptake of nutrients in the water column, minimising phytoplankton growth. The root systems stablilise sediments and the emergent stems dampen flows and wind turbulence, minimising sediment resuspension. Biological and physical effects of

Table 13. Summary of key broad scale indicator results and ratings.

Broad scale Indicators	Unit	Value	2021
Mud-dominated substrate	% of estuary area >50% mud	98.5	Poor
Intertidal Seagrass	% decrease from baseline	100[1]	Poor
Macrophyte Cover	% decrease from baseline	-	Baseline 16.2% recorded in 2021
High Enrichment Conditions	ha	~480*	Poor
High Enrichment Conditions	% of estuary	30*	Poor

Condition rating thresholds are reported in Table 3.

*Estimated value from sites with ≥50% cover of filamentous algae or macroalgae and aRPD <10mm. % of estuary was calculated based on the combined subtidal and intertidal area from Berthelsen et al. (2015).

[1]Reflects 100% loss of seagrass previously recorded in Knox (1983).

Ruppia on the sediment and the water column mean water clarity is generally good when it is present. This was reflected in the results of the current study with water clarity generally reaching to the lagoon bottom among the macrophyte beds, but being significantly more turbid in unvegetated areas.

If conditions become unsuitable for *Ruppia* growth, the system is at risk of 'flipping' from a predominantly clear-water state to an undesirable turbid, phytoplankton-dominated state that is very difficult to reverse (Robertson et al. 2011). An example of this has occurred in Te Waihora/Lake Ellesmere where macrophyte beds died back due to poor water quality, destabilising the sediment and releasing nutrients into the water column via decomposing plant material, fueling further phytoplankton growth. Te Waihora is now turbid and prone to frequent phytoplankton blooms compromising the ecological health of the system (Gibbs & Norton 2012).

While much of upper reaches of Wairau Lagoon are unvegetated with waters regularly turbid due to the resuspension of the extensive mud-dominated sediment present, there can be no doubt that the presence of 199ha of rooted macrophyte beds significantly reduces the impact of sediment and nutrients in the Lagoon.

However, these macrophyte beds appear to be under considerable stress due to extensive blooms of filamentous algae (e.g. *Cyanophyceae* and *Cladophora*). These blooms were present at >50% cover across 499ha, 40.6% of the subtidal area, growing epiphytically on rooted vegetation and on sediments (see photos this page).

Floating filamentous algae mat, Wairau Lagoon

The extensive presence of filamentous algae is likely a response to elevated nutrient concentrations in the lagoon. When nutrients are plentiful, excessive growths of nuisance species can shade underlying plants. Such light limitation can limit their growth and lead to the eventual collapse of aquatic plant systems, and with it their ability to stabilise sediments and assimilate nutrients.

The widespread presence of filamentous blooms was reflected in very high dissolved oxygen in the water column, with disturbance of the mats often releasing trapped air bubbles. This indicates that not only is the lagoon highly productive, but there is a high risk of large diurnal fluctuations in oxygen levels due to oxygen consumption at night. This can have significant adverse effects on fish in particular (Franklin 2014).

Epiphytic filamentous algae growing on *Ruppia sp.*

Near complete surface cover of filamentous algae growing on *Ruppia sp.*

Water column measurements had relatively low phytoplankton concentrations indicating the lagoon has not undergone a switch to a phytoplankton-dominated system. This is a positive sign, but it is important to note that sampling was not undertaken during the peak growing season (summer). Increased phytoplankton growth under optimal conditions (e.g. high nutrients, warm temperatures, sunlight) can increase water column turbidity, minimising the amount of light able to penetrate through the water column limiting macrophyte growth. Persistent phytoplankton issues could put the lagoon at risk of flipping, as discussed previously. Monitoring seasonal changes and gaining a better understanding of the water exchange within the lagoon will help determine the potential risk to the lagoon.

At this point in time, widespread filamentous algae, and elevated nutrient concentrations in Upper Lagoon and Chandlers Lagoon (rated 'fair' and 'poor') and elevated phytoplankton in Chandlers Lagoon (rated 'fair') indicate these areas are under significant stress and that there is a relatively high potential for problems to occur.

This potential is further reiterated by the nutrient enrichment evident in the mud-dominated lagoon sediments, with poor oxygenation (aRPD ≤10mm) observed at 73% of sites monitored. Low oxygen conditions in the sediments can significantly alter biogeochemical processes, including the cessation of nitrogen pathways (e.g. nitrification) and the release of sediment-bound nitrogen and phosphorus into the water column, further exacerbating nutrient related issues (e.g. phytoplankton and filamentous algal growth). Increased sediment muddiness and the depletion of sediment oxygen also leads to the loss of more sensitive macroinvertebrate species, many of which are important bioturbators helping turn over sediment and maintain oxygenation. Persistent low oxygen conditions can also lead to the formation of sulfides which can be toxic to fish and invertebrates. The enriched sediments in Wairau Lagoon generally supported a relatively impoverished macrofauna community comprised of pollution tolerant species (EG-III to EG-IV) present in low abundance and richness.

In addition to the above, nuisance blooms of macroalgae (*Agarophyton chilense*) associated with high biomass, high cover and poor sediment conditions were present in the Te Aropipi channel and east Upper Lagoon. These patches (≥50% cover) although comprising only a small area relative to the size of the lagoon (80ha, 6.5%) reinforce that the lagoon is expressing signs of eutrophication in multiple ways.

Table 14. Condition rating for sites that represent the worst 10% of the estuary. Sediment quality was poorest in Big Lagoon and water quality was poorest in Upper Lagoon and Chandlers Lagoon.

Indicator	Unit	Site	Value	2021
Water quality indicators				
Dissolved oxygen (DO)	mg/L	Upper Lagoon (J4)	11.89	Very Good
Phytoplankton (chl-a)	mg/m^3	Chandlers Lagoon (L5)	14.1	Fair
Total Nitrogen	mg/m^3	Upper Lagoon (J4)	370	Fair
Total Phosphorus	mg/m^3	Upper Lagoon (J4)	73	Poor
Sediment indicators				
Mud content	%	Big Lagoon (L8)	95.2	Poor
aRPD depth	mm	73% of sites sampled	<10	Poor
TN	mg/kg	Big Lagoon (L8)	1700	Fair
TOC	%	Big Lagoon (L8)	1.28	Fair
Sediment Trace elements				
As	mg/kg	Big Lagoon (L8)	5.5	Very Good
Cd	mg/kg	Big Lagoon (L8)	0.05	Very Good
Cr	mg/kg	Big Lagoon (L8)	21.0	Very Good
Cu	mg/kg	Big Lagoon (L8)	16.5	Very Good
Hg	mg/kg	Big Lagoon (L8)	0.08	Good
Ni	mg/kg	Big Lagoon (L8)	24.0	Fair
Pb	mg/kg	Big Lagoon (L8)	17.2	Very Good
Zn	mg/kg	Big Lagoon (L8)	67.0	Very Good

Positively, no significant contamination of subtidal sediment by metals was detected with sites rated 'good' to 'very good' and at levels below expected ecological effects. One exception was nickel (rated 'fair') for which slightly elevated concentrations can be attributed to natural catchment sources (Berthelsen et al. 2015).

5. SUMMARY

Overall, Wairau Lagoon retains ecologically significant areas of salt marsh, and extensive macrophyte beds in Big Lagoon that are rare in a regional and national context. It remains a nationally significant ecological area for birds and fish, however its natural, cultural and social values are compromised by its current ecological condition.

There is clear evidence of eutrophication from excessive nutrient supply through the presence of extensive beds of nuisance macroalgal growth in Te Aropipi Channel, and most particularly widespread filamentous algal growth in the lagoon areas that is currently smothering high value macrophyte beds and causing sediment degradation. Poor water quality in Upper Lagoon and Chandlers Lagoon, excessive muddiness, elevated sediment nutrients in Big Lagoon, and impoverished macrofaunal communities in poorly oxygenated, muddy sediments all indicate a need for more active management of nutrient and sediment loads if the high value habitats present are to be retained.

Areas of significant erosion on the southern hills bordering Wairau Lagoon

6. RECOMMENDATIONS

Overall, Wairau Lagoon represents an estuary in relatively good health, with extensive high value salt marsh and subtidal macrophyte beds present. However, on top of historic losses of seagrass and salt marsh habitat, there are multiple indicators of eutrophication in the Lagoon that are a cause for concern. Based on the findings of the current survey it is recommended that MDC consider the following in order to appropriately manage sediment and nutrient inputs to the lagoon so that eutrophic conditions do not worsen or expand and the macrophyte beds are protected from further degradation:

1. Design a subtidal monitoring programme to monitor the health of the macrophyte beds and key indicators of eutrophication including sediment and water column nutrients, phytoplankton and dissolved oxygen (e.g. seasonal monitoring at representative locations), and the extent and impact of filamentous algal and macroalgal beds (e.g. 5-yearly broad scale mapping).
2. Assess catchment sources of nutrients and sediments to the lagoon to determine whether changes to current land management practices are likely to significantly improve ecological condition and to guide council management priorities.
3. Establish objectives and limits for catchment sediment and nutrient inputs that will protect the Wairau Lagoon from further degradation.
4. Map the extensive areas of intertidal salt marsh vegetation adjacent to Wairau Lagoon (including areas not assessed previously), taking into account areas where salt marsh would benefit from reconnection to the estuary, to prevent further loss and to build resilience with expected sea level rise.
5. Review the suitability of fine scale monitoring in the intertidal areas of the lagoon before undertaking any further work. Cawthron Site C in the lower estuary is considered suitable for long-term monitoring, however it is recommended Sites A and B in Big Lagoon and Upper Lagoon be discontinued.
6. Investigate current and historic sedimentation rates and sources to the lagoon.

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APPENDICES

APPENDIX 1. BROADSCALE HABITAT CLASSIFICATION DEFINITIONS

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP (Robertson et al. 2002) with minor modifications as listed.
Revised substrate classes were developed by Salt Ecology to more accurately classify fine unconsolidated substrate.
Terrestrial margin vegetation was classified using the field codes included in the Landcare Research Land Cover Database (LCDB5) - see following page.

VEGETATION (mapped separately to the substrates they overlie and ordered where commonly found from the upper to lower tidal range).

Estuarine shrubland: Cover of estuarine shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh (density at breast height).

Tussockland: Tussock cover is 20-100% and 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 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*.

Sedgeland: Sedge cover (excluding tussock-sedges and reed-forming sedges) is 20-100% and exceeds that of any other growth form or bare ground. "Sedges have edges". If the stem is clearly triangular, it's a sedge. If the stem is flat or rounded, it's probably a grass or a reed. Sedges include many species of *Carex, Uncinia*, and *Scirpus*.

Grassland[1]: Grass cover (excluding tussock-grasses) is 20-100% and exceeds that of any other growth form or bare ground.

Introduced weeds[1]: Introduced weed cover is 20-100% and exceeds that of any other growth form or bare ground.

Reedland: Reed cover is 20-100% and 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 round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha, Bolboschoenus, Scirpus lacutris*, *Eleocharis sphacelata*, and *Baumea articulata*.

Lichenfield: Lichen cover is 20-100% and exceeds that of any other growth form or bare ground.

Cushionfield: Cushion plant cover is 20-100% and 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.

Rushland: Rush cover (excluding tussock-rushes) is 20-100% and exceeds that of any other growth form or bare ground. A tall grass-like, often hollow-stemmed plant. Includes some species of *Juncus* and all species of *Apodasmia (Leptocarpus)*.

Herbfield: Herb cover is 20-100% and exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.

Seagrass meadows: Seagrasses are the sole marine representatives of the Angiospermae. 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 and are mapped.

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. Macroalgal density, biomass and entrainment are classified and mapped.

Note NEMP classes of Forest and Scrub are considered terrestrial and have been included in the terrestrial Land Cover Data Base (LCDB) classifications.

[1]Additions to the NEMP classification.

SUBSTRATE (physical and zoogenic habitat)

Sediment texture is subjectively classified as: **firm** if you sink 0-2 cm, **soft** if you sink 2-5cm, **very soft** if you sink >5cm, or **mobile** - characterised by a rippled surface layer.

Artificial substrate: 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. Commonly sub-grouped into artificial: substrates (seawalls, bunds etc), boulder, cobble, gravel, or sand.

Rock field: Land in which the area of basement rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

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

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

Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Sand: Granular beach sand with a low mud content 0-10%. No conspicuous fines evident when sediment is disturbed.

Sand/Shell: Granular beach sand and shell with a low mud content 0-10%. No conspicuous fines evident.

Muddy sand (Moderate mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >10-25%). Granular when rubbed between the fingers, but with a smoother consistency than sand with a low mud fraction. Generally firm to walk on.

Muddy sand (HIgh mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >25-50%). Granular when rubbed between the fingers, but with a much smoother consistency than muddy sand with a moderate mud fraction. Often soft to walk on.

Sandy mud (Very high mud content): Mud/sand mixture dominated by mud (i.e. >50%-90% mud). Sediment rubbed between the fingers is primarily smooth/silken but retains a granular component. Sediments generally very soft and only firm if dried out or another component, e.g. gravel, prevents sinking.

Mud (>90% mud content): Mud dominated substrate (i.e. >90% mud). Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out or another component, e.g. gravel, prevents sinking.

Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.

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

Shell bank: Area that is dominated by dead shells

Table of modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.096m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Firm shell/sand	fSS
		Mobile sand	mS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Firm muddy shell/sand	fSS10
		Mobile muddy sand	mMS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Firm muddy shell/sand	fSS25
		Mobile muddy sand	mMS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Mud (M)	Mud (>90%)	Firm mud	fM90
		Soft or very soft mud	sM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Sabellid field	TUBE
Artifical Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aBF
		Cobble field	aCF
		Gravel field	aGF
		Sand field	aSF

Artificial Surfaces
1 Built-up Area (settlement)
2 Urban ParklandOpen Space
5 Transport Infrastructure
6 Surface Mines and Dumps
Bare or Lightly Vegetated Surfaces
10 Sand and Gravel
12 Landslide
14 Permanent Snow and Ice
15 Alpine Grass/Herbfield
16 Gravel and Rock
Water Bodies
20 Lake or Pond
21 River
Cropland
30 Short-rotation Cropland
33 Orchard Vineyard & Other Perennial Crops
Grassland, Sedge and Saltmarsh
40 High Producing Exotic Grassland
41 Low Producing Grassland
43 Tall-Tussock Grassland
44 Depleted Grassland
45 Herbaceous Freshwater Vegetation
46 Herbaceous Saline Vegetation
Scrub and Shrubland
47 Flaxland
50 Fernland
51 Gorse and/or Broom
52 Manuka and/or Kanuka
54 Broadleaved Indigenous Hardwoods
55 Sub Alpine Shrubland
56 Mixed Exotic Shrubland
58 Matagouri or Grey Scrub
Forest
64 Forest - Harvested
68 Deciduous Hardwoods
69 Indigenous Forest
71 Exotic Forest

APPENDIX 2. INFORMATION SUPPORTING CONDITION RATINGS

Sediment Mud Content

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more sticky and cohesive, and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon, and sediment bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations and, on intertidal flats of estuaries, can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

Apparent Redox Potential Discontinuity (aRPD)

aRPD depth, the visually apparent transition between oxygenated sediments near the surface and deeper more anoxic sediments, is a primary estuary condition indicator as it is a direct measure of time integrated sediment oxygenation. Knowing if the aRPD is close to the surface is important for three main reasons:

The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species. The tendency for sediments to become anoxic is much greater if the sediments are muddy. Anoxic sediments contain toxic sulphides and support very little aquatic life. As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, becomes released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (greater than 3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to less than 1cm (Jørgensen & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

Opportunistic Macroalgae

The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with high mud and low oxygen conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014; Robertson et al 2016a,b; Zeldis et al. 2017), with results combined with those of other indicators to determine overall condition.

Seagrass

Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent are likely to indicate an increase in these types of pressures. The assessment metric used is the percent change from baseline measurements.

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APPENDIX 3. MACROPHYTE SPECIES IDENTIFICATION

Species	Type	Status
Ruppia polycarpa (Horse's mane weed)	Emergent	Native

R. polycarpa is a surface-flowering, submerged, aquatic annual or perennial herb. Stems grow to 50cm long, depending on water depth. Vegetative buds (turions) can be formed in some ephemeral habitats. It grows in fresh to hypersaline coastal lakes, lagoons and estuaries and is relatively common in the 0-1.5m depth range (depending on water clarity). It grows in sandy sediments, and has distinctive flowers terminal on white stalks.

Species	Type	Status
Ruppia megacarpa (Horse's mane weed)	Emergent	Native

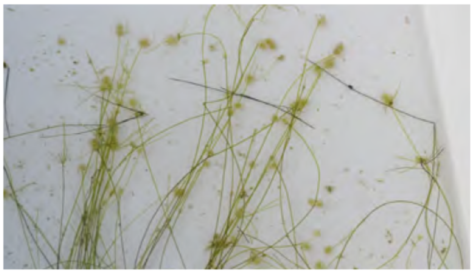
R. megacarpa is a surface-flowering, submerged, aquatic perennial herb. Common in relatively shallow (~2m) permanent water (salinity range 5-46 PSS), although seeds require salinities in the lower end of range to germinate. Grows slowly and matures later, producing fewer, larger seeds than *R. polycarpa*. Seeds germinate and form seedlings in spring, with flowering and fruiting occur in summer and autumn.

Species	Type	Status
Chara corallina	Charophyte	Native

C. corallina is a widespread submerged bottom-dwelling green charophyte algal species, that superficially resembles flowering aquatic plants. Plants are stout and crisp with turgid segments and pinched nodes, pale to bright green. The conspicuous antheridia (male sex organs) are spherical and bright orange or yellow when mature. There are no stem divisions. It is widespread in the North and South Islands.

Species	Type	Status
Nitella sp.	Charophyte	Native

Nitella is a widespread bottom-dwelling, green charophyte algal species that superficially resembles flowering aquatic plants. It sometimes creates dense carpets on freshwater or slightly saline lagoon beds, reaching depths of 30m in some clear lakes. It is a long stringy looking plant without leaves. Stems "pop" if squeezed.



APPENDIX 4. RJ HILL LABORATORY METHODS

Sample Type: Saline			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
Total Nitrogen Digestion	Caustic persulphate digestion. APHA 4500-N C 23rd ed. 2017.	-	6-10
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	6-10
Total Nitrogen	Alkaline persulphate digestion, automated Cd reduction/sulphanilamide colorimetry. APHA 4500-N C & 4500-NO3- I (modified) 23rd ed. 2017.	0.010 g/m³	6-10
Total Ammoniacal-N	Saline sample. Phenol/hypochlorite colorimetry. Flow injection analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH_3 H 23rd ed. 2017.	0.005 g/m³	6-10
Nitrite-N	Saline sample. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.0010 g/m³	6-10
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m³	6-10
Nitrate-N + Nitrite-N	Saline sample. Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.0010 g/m³	6-10
Dissolved Reactive Phosphorus	Saline sample. Molybdenum blue colorimetry. Flow injection analyser. APHA 4500-P G 23rd ed. 2017.	0.0010 g/m³	6-10
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H 23rd ed. 2017.	0.004 g/m³	6-10

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
Environmental Solids Sample Drying	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-5
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	1-5
Dry Matter for Grainsize samples (sieved as received)	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-5
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-5
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-5
Total Nitrogen	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-5
Total Organic Carbon	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-5
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.8 mg/kg dry wt	1-5
3 Grain Sizes Profile as received			
Fraction >/= 2 mm	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-5
Fraction < 2 mm, >/= 63 µm	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-5

APPENDIX 5. WATER COLUMN & SEDIMENT QUALITY DATA

Station	Date	Time (NZST)	Latitude	Longitude	Tide height	Depth (m)	Temp (°C)	DO (% sat)	DO (mg/L)	Salinity (‰)	pH	chl-a (mg/m^3)	Secchi depth (m)	Max depth (m)	Sediment texture	Sediment Type	aRPD (mm)
C3	20/04/2021	16:52	-41.5105	174.0613	mid	0.2	15.1	121.5	10.85	19.53	8.69	0.8	0.65	1.65	firm	S0_10	ind
C5	21/04/2021	15:34	-41.5151	174.0659	high	0.2	15.7	91.6	8.28	21.23	8.35	0.4	0.5	0.5	soft	SM50_90	15
D5	21/04/2021	15:56	-41.5157	174.0720	high	0.2	15.6	104.7	9.12	21.44	8.35	0.8	0.5	0.5	very soft	M90_100	10
E4	21/04/2021	15:08	-41.5197	174.0677	high	0.2	15.5	96	8.65	13.68	8.49	0.4	0.7	0.7	very soft	M90_100	15
E6	19/04/2021	16:39	-41.5198	174.0791	low	0.2	15.3	116.2	10.2	22.08	8.58	1.7	0.42	0.42	firm	MS10_25	10
F5	21/04/2021	14:59	-41.5239	174.0722	high	0.2	15.7	107.1	9.06	26.36	8.37	0.8	0.6	0.6	very soft	M90_100	8
F7	19/04/2021	16:07	-41.5240	174.0848	low	0.2	15.8	124.2	10.74	22.41	8.59	1.7	0.35	0.55	soft	SM50_90	15
G4	21/04/2021	14:14	-41.5289	174.0706	high	0.2	15.8	120	9.9	29.55	8.41	0.7	0.75	2.7	soft	SM50_90	3
G8	20/04/2021	16:26	-41.5255	174.0904	high	0.2	13.8	113.1	10.08	24.11	8.63	2.7	0.5	0.65	very soft	M90_100	3
G9	20/04/2021	16:08	-41.5287	174.0975	high	0.2	13.6	102.8	9.13	25.23	8.58	2.8	0.31	0.31	very soft	M90_100	20
H4	21/04/2021	14:32	-41.5333	174.0701	high	0.2	15.7	113.7	9.49	29.14	8.38	1	0.5	2.6	very soft	M90_100	1
H7	20/04/2021	15:28	-41.5337	174.0856	high	0.2	14.2	150.2	13	27.03	9.07	1.9	0.42	0.42	very soft	M90_100	0
H8	19/04/2021	15:53	-41.5333	174.0904	low	0.2	16.6	107.8	9.1	23.75	8.56	2	0.4	0.4	very soft	M90_100	5
H10	20/04/2021	15:44	-41.5328	174.1046	high	0.2	13.8	102.8	9.08	25.18	8.65	2.6	0.3	0.3	very soft	M90_100	10
I3	20/04/2021	13:11	-41.5373	174.0611	high	0.2	13.8	108.1	9.58	23.87	8.78	2.2	0.15	0.15	very soft	M90_100	10
I4	20/04/2021	14:23	-41.5376	174.0663	high	0.2	13.3	110.8	10.09	22.25	8.64	1.6	0.45	1.45	very soft	M90_100	0
I7	20/04/2021	15:14	-41.5377	174.0851	high	0.2	14.1	121.3	10.53	26.23	8.91	3.2	0.35	0.5	soft	SM50_90	5
I8	19/04/2021	15:38	-41.5379	174.0904	low	0.2	16.6	115.8	9.76	24.97	8.68	2.4	0.35	0.35	soft	SM50_90	5
I10	19/04/2021	15:11	-41.5380	174.1030	low	0.2	17.3	130.8	10.79	24.64	8.77	2	0.35	0.55	very soft	M90_100	3
I11	19/04/2021	10:24	-41.5374	174.1093	mid	0.2	12.8	103.2	9.53	21.88	8.8	1	0.5	0.5	very soft	SM50_90	1
I12	19/04/2021	9:42	-41.5377	174.1151	mid	0.2	12.4	94.1	8.79	20.86	8.84	1	0.55	0.55	very soft	M90_100	1
J2	20/04/2021	12:29	-41.5401	174.0613	high	0.2	13.1	104.9	9.48	23.08	8.84	9.3	0.25	0.25	very soft	M90_100	5
J3	20/04/2021	12:21	-41.5421	174.0632	mid	0.2	13.2	118.7	10.7	23.28	8.93	4.2	0.31	0.31	soft	SM50_90	5
J4	20/04/2021	11:51	-41.5428	174.0669	high	0.2	13.6	132.1	11.89	23.53	8.93	2.2	0.3	0.3	very soft	M90_100	1
J5	20/04/2021	9:27	-41.5433	174.0732	low	0.2	12.3	87.5	8.15	23.77	8.59	5.02	0.35	0.35	very soft	M90_100	3
J6	20/04/2021	14:42	-41.5422	174.0783	high	0.2	14	154.9	13.67	25.93	8.83	1.5	0.2	0.2	very soft	M90_100	1
J7	20/04/2021	15:02	-41.5404	174.0849	high	0.2	14.1	130.1	11.35	26.22	8.8	3.8	0.3	0.3	very soft	M90_100	3
J8	19/04/2021	15:26	-41.5419	174.0913	low	0.2	16.8	116.6	9.93	26.26	8.81	0.4	0.25	0.65	very soft	SM50_90	10
J9	19/04/2021	15:18	-41.5418	174.0971	low	0.2	15.5	129.8	11.08	25.08	8.87	2.2	0.35	0.65	very soft	M90_100	10
J10	19/04/2021	15:00	-41.5422	174.1032	high	0.2	15.1	122	10.66	24.35	8.81	1.4	0.45	0.71	very soft	M90_100	15
J10.5	21/04/2021	11:13	-41.5436	174.1054	mid	0.2	14.5	97.9	8.45	23.78	8.72	1.2	0.65	0.65	very soft	M90_100	3
J11	19/04/2021	10:39	-41.5416	174.1081	mid	0.2	13.1	97	8.88	22.34	8.84	1	0.7	0.7	very soft	M90_100	3
J12	19/04/2021	9:27	-41.5410	174.1156	mid	0.2	12.2	100.1	9.36	21.78	8.82	1	0.58	0.58	very soft	M90_100	1
J13	19/04/2021	9:59	-41.5393	174.1193	mid	0.2	12.6	127.9	11.86	22.46	9.37	1	0.55	0.55	very soft	M90_100	1
K4	20/04/2021	11:03	-41.5472	174.0673	mid	0.2	12.8	110.2	10.1	23.33	8.77	4.3	0.2	0.2	very soft	M90_100	10
K5	20/04/2021	9:48	-41.5467	174.0733	low	0.2	12.3	81.2	7.48	24.13	8.57	6.6	0.31	0.31	very soft	M90_100	8
K7	19/04/2021	14:25	-41.5467	174.0853	high	0.2	16.4	125.3	10.46	26.72	8.81	1.1	0.37	0.37	very soft	M90_100	0
K8	19/04/2021	14:33	-41.5466	174.0910	high	0.2	15.3	114.3	9.69	26.87	8.81	2.2	0.35	0.68	very soft	SM50_90	5
K9	19/04/2021	14:42	-41.5468	174.0963	high	0.2	15.2	109.1	9.37	25.57	8.86	2.9	0.25	0.75	very soft	M90_100	2
K10	19/04/2021	14:50	-41.5464	174.1023	high	0.2	15.5	126.6	10.82	25.12	8.98	1.2	0.65	0.7	very soft	M90_100	1
K10.5	21/04/2021	11:20	-41.5485	174.1048	mid	0.2	13.9	104.1	9.36	23.86	9.19	1.1	0.6	0.6	very soft	M90_100	5
K11	19/04/2021	11:03	-41.5461	174.1089	mid	0.2	13.3	110.9	10.1	22.67	8.98	0.9	0.65	0.65	very soft	M90_100	1
K11.5	21/04/2021	11:31	-41.5489	174.1110	mid	0.2	14.5	114.2	9.99	22.61	9.24	1.1	0.52	0.52	very soft	M90_100	1
K12	19/04/2021	12:13	-41.5466	174.1133	high	0.2	13.9	115.5	10.27	23.47	9.26	0.7	0.6	0.6	very soft	M90_100	1
L3	20/04/2021	10:44	-41.5510	174.0614	low	0.2	13.6	92.3	8.58	28.69	8.76	5.4	0.2	0.2	very soft	M90_100	1
L4	20/04/2021	10:28	-41.5513	174.0675	low	0.2	12.3	100.1	9.15	25.39	8.68	5.4	0.25	0.25	very soft	M90_100	1
L5	20/04/2021	10:01	-41.5513	174.0732	low	0.2	12.2	80.8	7.35	27.24	8.59	14.1	0.25	0.25	very soft	M90_100	1
L7	19/04/2021	13:53	-41.5515	174.0849	high	0.2	15.8	127.7	10.8	27.02	8.86	0.9	0.6	0.6	very soft	M90_100	1
L8	19/04/2021	14:07	-41.5513	174.0911	high	0.2	15.1	108.4	9.32	25.64	9.02	1.4	0.3	0.67	very soft	M90_100	10
L9	19/04/2021	13:15	-41.5509	174.0980	high	0.2	14.7	109	9.36	26.74	9.08	2	0.28	0.7	very soft	M90_100	2
L10	19/04/2021	13:07	-41.5505	174.1031	high	0.2	14.7	145.3	12.66	24.76	9.15	1.6	0.65	0.65	very soft	M90_100	1
L11	19/04/2021	11:19	-41.5509	174.1095	mid	0.2	13.8	119.5	10.48	27.93	9.3	0.8	0.45	0.45	very soft	M90_100	2
L12	19/04/2021	12:04	-41.5497	174.1130	high	0.2	14.6	131	11.45	24.63	9.35	1.2	0.45	0.45	very soft	M90_100	2
M7	19/04/2021	13:43	-41.5545	174.0854	high	0.2	15.5	137	11.48	27.89	8.92	0.7	0.5	0.5	very soft	M90_100	1
M8	19/04/2021	13:34	-41.5552	174.0919	high	0.2	15.2	110.9	9.44	27.23	8.92	1.1	0.45	0.6	very soft	M90_100	15
M9	19/04/2021	13:26	-41.5548	174.0970	high	0.2	15.2	108	9.99	26.52	8.92	3	0.25	0.57	very soft	M90_100	5
M10	19/04/2021	12:49	-41.5551	174.1034	high	0.2	15.5	110.9	9.44	25.93	8.99	1.6	0.35	0.35	very soft	M90_100	10
M11	19/04/2021	11:40	-41.5547	174.1098	high	0.2	14.8	122.8	10.61	26.36	9.09	1.5	0.3	0.3	very soft	M90_100	3

APPENDIX 6. PHYTOPLANKTON RESULTS

Algal Cell Count Report

NIWA
Taihoro Nukurangi

Salt Ecology
21 Mount Vernon Place, Nelson 7010
C/-Tauhinau Road
Wellington

Attention: Leigh Stevens

Sample Information

Client description:	J11 WAIR- MARL	Laboratory ID:	2021000529/AS13208
Client ID:	J11	Date received:	21/04/2021
Date sampled:	19/04/2021	Date analysed:	27/04/2021
Time sampled:	10:44	Sample Type:	Recreation / Contact

Sample Results

Potentially toxic (blue-green) species	Cells per mL	Potential toxins produced by genus (if known)
Not Detected		

Dominant species (inc non toxic)	Cells per mL	Phyla
Flagellates/Unicells <5um	14	Flagellates/Unicells
Tintinnopsis fimbriata cf. fimbriata	3	Ciliophora (Spirotrichea, Tintinnida)
Ciliates Ciliates	2	Ciliophora (Ciliates)
Chaetoceros sp.	1	Diatoms (Bacillariophyceae)
Gyrodinium sp.	<1	Dinoflagellates (Dinoflagellata)
Nitzschia sp.	<1	Diatoms (Bacillariophyceae)
Navicula sp.	<1	Diatoms (Bacillariophyceae)

Sample analysed as received by the laboratory in accordance with NIWA Algal services, SOP#1-7; Microscopic analysis of settled sample following the Utermöhl/Nauwerck method. This document may only be reproduced with permission from NIWA. Part reproduction or alteration of this document is prohibited.

Date of Issue: **28/04/2021**

Authorised by: Karl Safi
Key Tech Personnel, Algal Services

Signature:

www.niwa.co.nz

Accreditation is limited to cyanobacterial (blue-green algal) count and indentification only.

National Institute of Water & Atmospheric Research Ltd
Algal Services
Gate 10, Silverdale Road, Hamilton
P O Box 11-115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151

Page 1 of 1

Algal Cell Count Report

Salt Ecology
21 Mount Vernon Place, Nelson 7010
C/-Tauhinau Road
Wellington

Attention: Leigh Stevens

Sample Information

Client description:	F7 WAIR- MARL	Laboratory ID:	2021000529/AS13209
Client ID:	F7	Date received:	21/04/2021
Date sampled:	19/04/2021	Date analysed:	27/04/2021
Time sampled:	16:10	Sample Type:	Recreation / Contact

Sample Results

Potentially toxic (blue-green) species	Cells per mL	Potential toxins produced by genus (if known)
Not Detected		

Dominant species (inc non toxic)	Cells per mL	Phyla
Flagellates/Unicells <5um	61	Flagellates/Unicells
Ciliates Ciliates	1	Ciliophora (Ciliates)
Surirella sp.	<1	Diatoms (Bacillariophyceae)
Pseudo-nitzschia sp.	<1	Diatoms (Bacillariophyceae)
Nitzschia sp.	<1	Diatoms (Bacillariophyceae)
Navicula sp.	<1	Diatoms (Bacillariophyceae)
Gyrosigma sp.	<1	Diatoms (Bacillariophyceae)
Grammatophora sp.	<1	Diatoms (Bacillariophyceae)
Cocconeis sp.	<1	Diatoms (Bacillariophyceae)

Accreditation is limited to cyanobacterial (blue-green algal) count and indentification only.

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National Institute of Water & Atmospheric Research Ltd
Algal Services
Gate 10, Silverdale Road, Hamilton
P O Box 11-115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151

Algal Cell Count Report

Salt Ecology
21 Mount Vernon Place, Nelson 7010
C/-Tauhinau Road
Wellington

Attention: Leigh Stevens

Sample Information

Client description:	F7 WAIR- MARL	Laboratory ID:	2021000529/AS13209
Client ID:	F7	Date received:	21/04/2021
Date sampled:	19/04/2021	Date analysed:	27/04/2021
Time sampled:	16:10	Sample Type:	Recreation / Contact

Sample analysed as received by the laboratory in accordance with NIWA Algal services, SOP#1-7; Microscopic analysis of settled sample following the Utermöhl/Nauwerck method. This document may only be reproduced with permission from NIWA. Part reproduction or alteration of this document is prohibited.

Date of Issue: **28/04/2021**

Authorised by: Karl Safi
Key Tech Personnel, Algal Services

Signature:

ACCREDITED TESTING LABORATORY

Accreditation is limited to cyanobacterial (blue-green algal) count and indentification only.

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National Institute of Water & Atmospheric Research Ltd
Algal Services
Gate 10, Silverdale Road, Hamilton
P O Box 11-115, Hamilton, New Zealand
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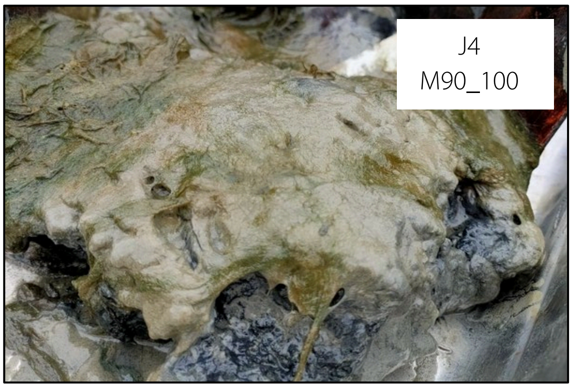
APPENDIX 7. RAW MACROFAUNA DATA APRIL 2021

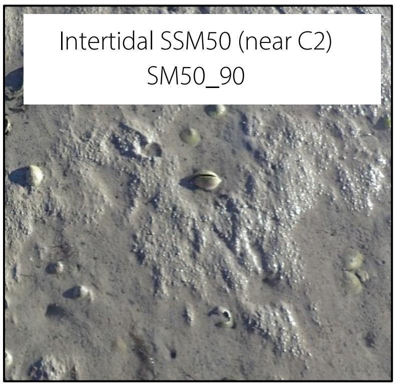
Main group	Taxa	Habitat	EG	C2	C3	D4	F7	G9	I2	I3	I7	J11	J4	J8	L4	L8	M10.5	N10.5
Cirripedia	*Austrominius modestus*	epibiota	NA	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	*Amphibola crenata*	epibiota	III	1	0	0	1	0	0	1	0	0	2	0	1	0	0	0
Gastropoda	*Potamopyrgus estuarinus*	epibiota	III	116	11	54	10	48	0	40	1	0	67	7	22	1	0	0
Amphipoda	*Josephosella awa*	infauna	II	0	38	0	0	1	0	0	0	9	8	7	75	0	32	0
Amphipoda	*Paracorophium excavatum*	infauna	IV	281	5	252	7	3	0	45	16	0	93	16	51	2	0	1
Amphipoda	*Paramoera chevreuxi*	infauna	II	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalvia	*Arthritica bifurca*	infauna	IV	2	0	1	0	1	0	2	19	0	11	0	40	0	0	0
Bivalvia	*Austrovenus stutchburyi*	infauna	II	5	5	0	0	0	0	0	1	0	0	2	0	0	0	0
Bivalvia	*Paphies australis*	infauna	II	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	*Chironomidae*	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Decapoda	*Austrohelice crassa*	infauna	V	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Decapoda	*Hemigrapsus crenulatus*	infauna	II	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Decapoda	*Hemigrapsus sexdentatus*	infauna	NA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda	*Hemiplax hirtipes*	infauna	V	3	0	0	0	2	0	0	1	1	2	0	0	0	0	0
Isopoda	*Asellota*	infauna	NA	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
Isopoda	*Exosphaeroma planulum*	infauna	V	5	1	0	0	0	0	0	2	0	0	1	0	0	0	0
Nemertea	*Nemertea*	infauna	III	0	0	0	0	0	0	0	1	7	0	0	0	0	0	4
Oligochaeta	*Oligochaeta*	infauna	III	0	11	0	4	0	1	2	0	1	20	56	32	0	13	0
Polychaeta	*Boccardia syrtis*	infauna	II	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0
Polychaeta	*Capitella spp.*	infauna	IV	0	0	0	0	0	0	0	0	0	4	7	46	0	0	0
Polychaeta	*Microspio maori*	infauna	I	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	*Nicon aestuariensis*	infauna	III	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	*Polydora cornuta*	infauna	III	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Polychaeta	*Prionospio aucklandica*	infauna	II	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	*Scolecolepides benhami*	infauna	IV	0	0	0	0	0	2	11	0	0	2	0	88	0	87	0
Diptera	*Ephydrella sp.*	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

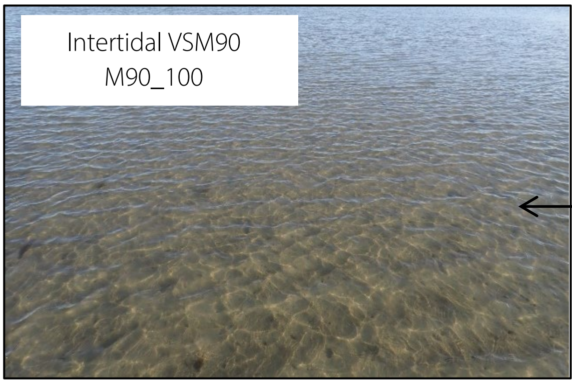
APPENDIX 8. SUBSTRATE VALIDATION

Seven samples were collected and analysed for grain size to provide validation of the subjective substrate classifications (Appendix 1) applied in the field. A grain size sample is collected by scraping the top ~2cm of the sediment surface. It can therefore include underlying substrate different to that apparent at the surface, and on which the mapping classification is based. Commonly this results in muddy surface deposits being 'diluted' with coarser underlying sediments and can result in the measured mud content being lower than the field classification. Of the seven validation samples analysed, samples matched the field classification for 4 out of 7 and were within 10% mud for 3 out of 7. Photos from the sample sites and wider area have been reassessed to confirm the classification of substrate type where the validation samples were >10% mud (see example photos below).

Site	Area	Measured % Mud	Field assessed %mud	Sediment texture	Sediment Type	Validation
J4	Upper Lagoon	81.5	>90%	very soft	M90_100	<10% out
L8	Big Lagoon	95.2	>90%	very soft	M90_100	✓
J11	Big Lagoon	96.7	>90%	very soft	M90_100	✓
C3	Te Aropipi Channel	7.9	<10%	firm	S0_10	✓
F7	Channel	75.8	50 to 90%	soft	SM50_90	✓
Intertidal SSM50 (near C2)	Te Aropipi Channel	42.0	50 to 90%	soft	SM50_90	<10% out
Intertidal VSM90 (south of C2 closer to channel)	Te Aropipi Channel	85.9	>90%	very soft	M90_100	<5% out







When soft mud substrate is disturbed

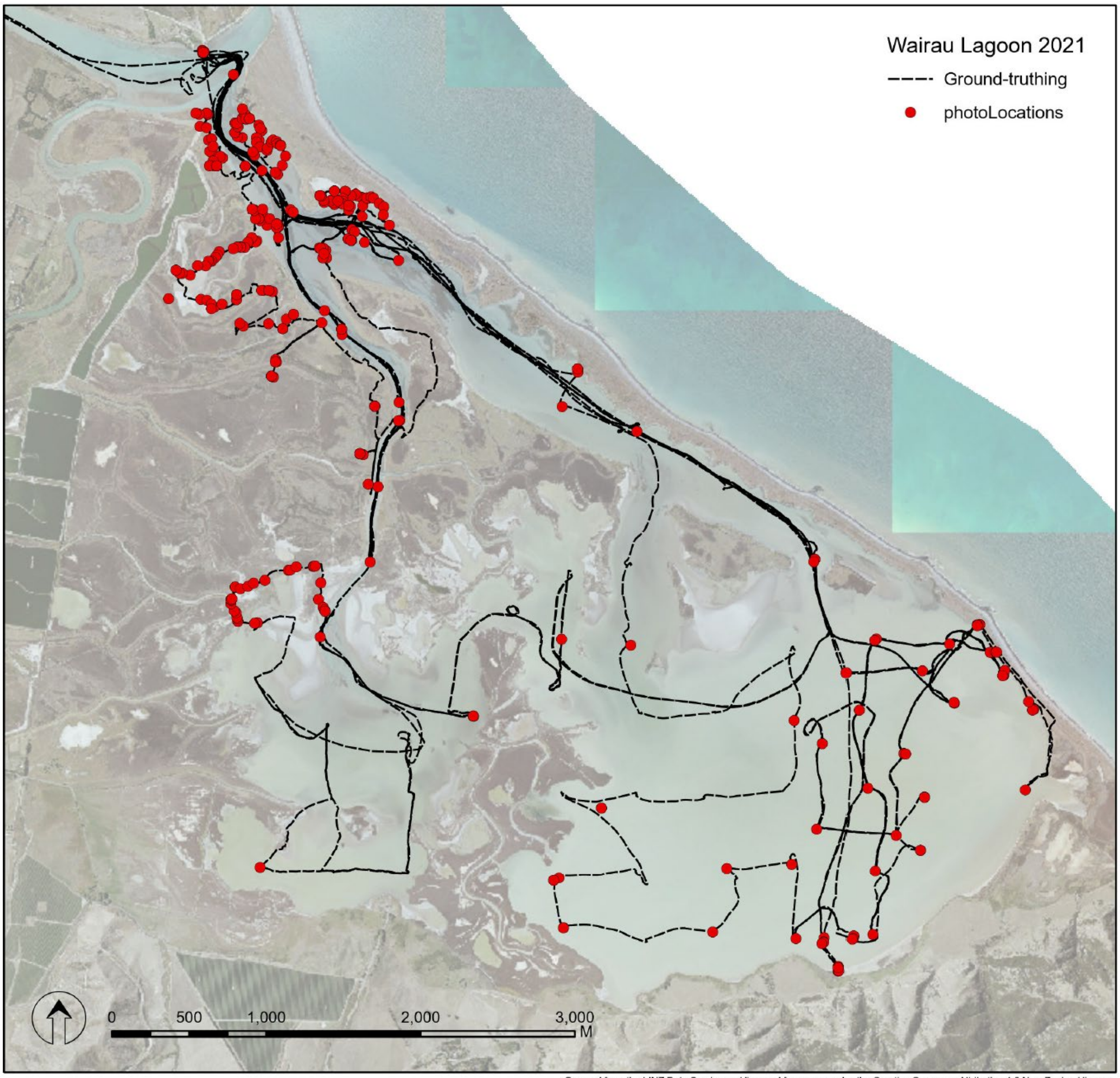
APPENDIX 9. SPOT LOCATIONS FOR WATER QUALITY, BROAD SCALE MAPPING AND BATHYMETRY

Water quality sites. Image source Fulcrum and 2021 Google Imagery.

Broad scale mapping spot locations. Image source Fulcrum and 2021 Google Imagery.

Bathymetry spot locations. Image source Fulcrum and 2021 Google Imagery.

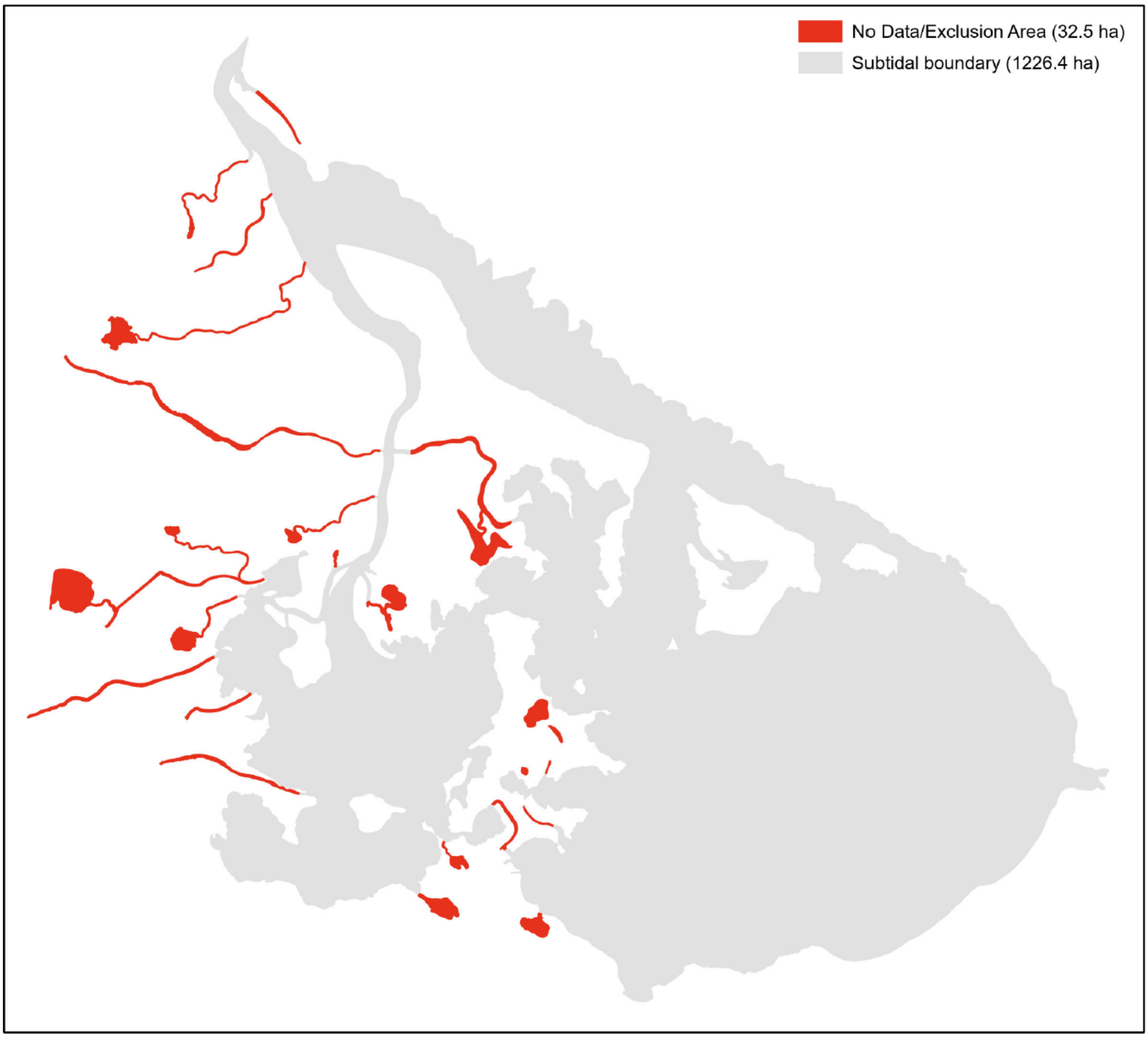
APPENDIX 10. GROUND TRUTHING WAIRAU LAGOON APRIL 2021



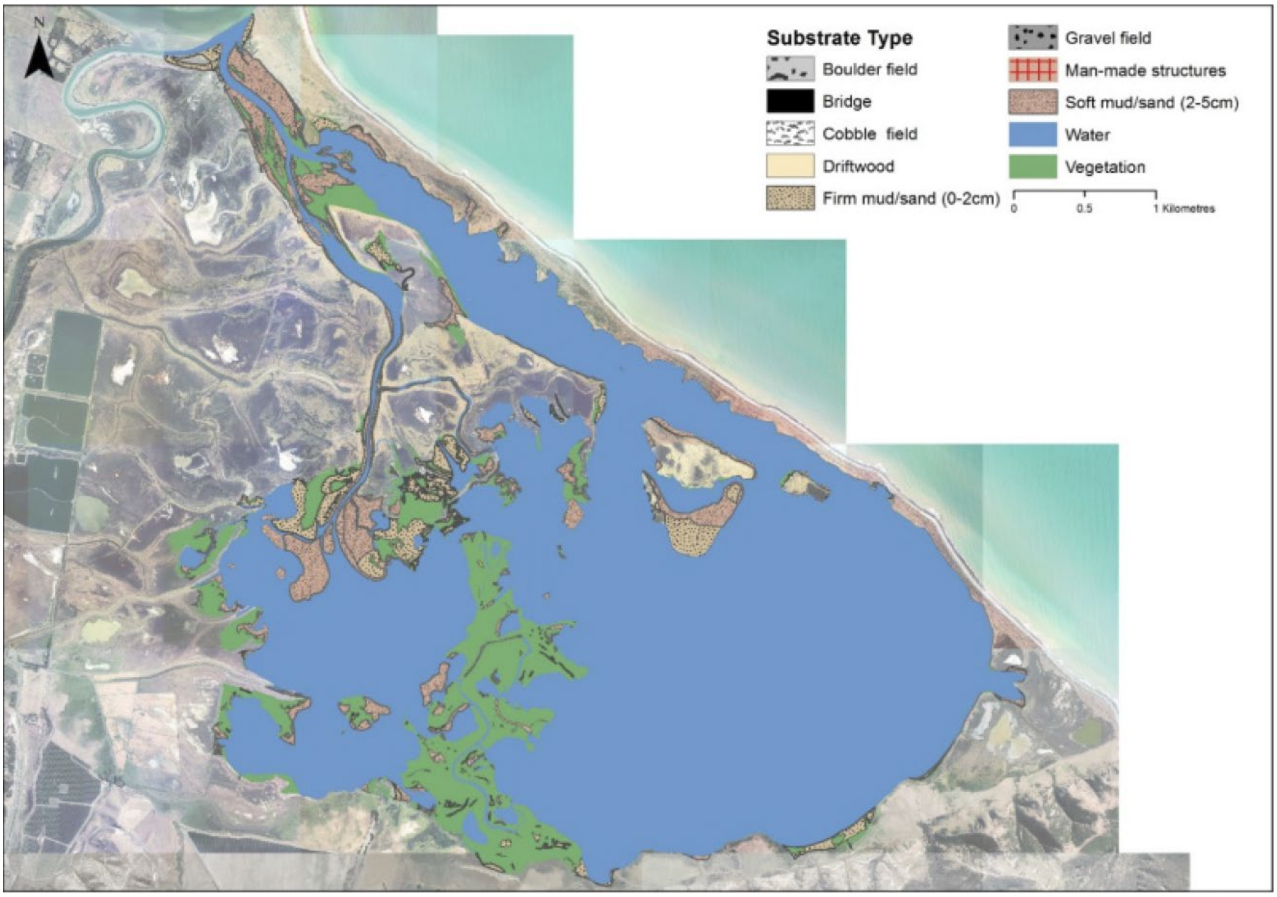
Note, only a sub-set of field photo locations are shown above.

APPENDIX 11. AREAS EXCLUDED FROM THE PRESENTATION OF DATA

The areas highlighted in red were not ground-truthed as they were outside the scope of what could be surveyed. They represent a mix of subtidal areas dominated by freshwater inflows (i.e. stream channels) and intertidal flats. They were excluded from the presentation of the subtidal and intertidal data.



APPENDIX 12. 2015 BROAD SCALE MAPPING EXTENT



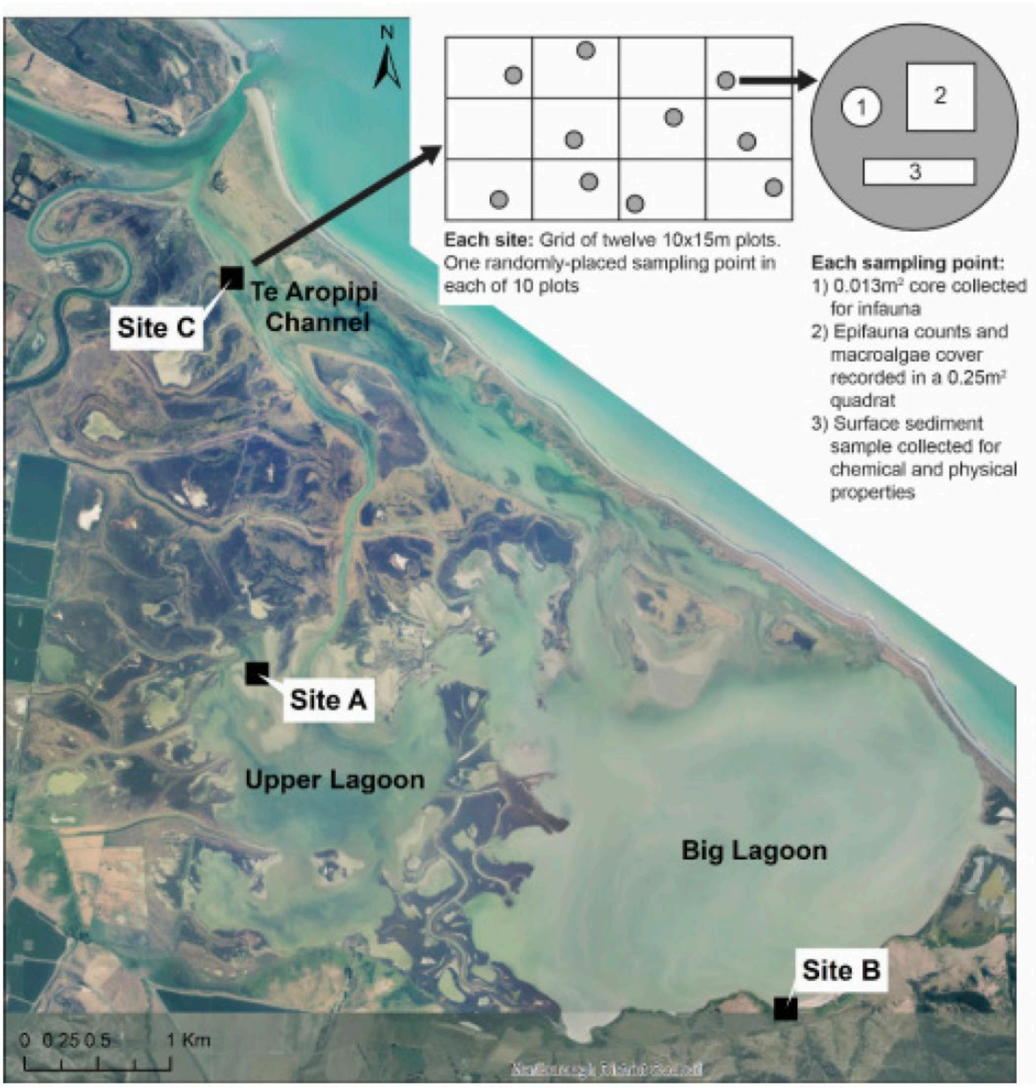
Berthelsen et al. (2015) map of the intertidal substrate and vegetation in Wairau Lagoon. Subtidal features (the blue area labelled water) were not mapped, and this subtidal component was the focus of the current study. Note some intertidal areas were also evaluated in the current study on order to make recommendations on future monitoring (see Appendix 13).

APPENDIX 13. MONITORING RECOMMENDATIONS

As an adjunct component of the current study MDC requested Salt Ecology to informally assess the previous fine and broad scale intertidal data to determine whether changes or additions may need to be made to future monitoring. The specific considerations were whether there may be more representative fine scale monitoring sites that have sediment macrofaunal communities suitable for inclusion in a long-term monitoring programme, and to assess whether the broad scale salt marsh mapping had adequately captured the key features present. These aspects are discussed below.

Fine scale monitoring

In 2015, Cawthron established three fine scale sites in Wairau Lagoon (Sites A to C, Fig. 15). Berthelsen et al. (2015) noted that Sites A and B were mud-dominated with a very low macrofauna diversity and abundance, whereas Site C was more consistent with other NZ estuaries surveyed using the NEMP. Berthelsen et al. (2015) recommended an additional intertidal site with a higher sand content be included in the monitoring to facilitate comparisons with other estuaries, and the current sites be monitored at 5-year intervals.



Map of the Wairau Estuary showing fine-scale benthic survey sites (source Berthelsen et al. 2015)

As the NEMP is designed to monitor the dominant representative habitat of an estuary, selecting sites based on habitat present in other estuaries is inappropriate. Even if the NEMP provided guidance on a "standard" habitat type to monitor in an estuary, as Wairau Lagoon is very different to most other estuaries, direct comparisons are not particularly relevant. Furthermore, as the vast majority of Wairau Lagoon is subtidal, fine scale monitoring, if considered necessary, would ideally focus effort in the subtidal reaches.

To that end, 15 composite macrofauna cores were collected - 12 from subtidal areas and 3 from the Cawthron intertidal sites - to assess whether there were suitable macrofauna communities to monitor.

Consistent with Berthelsen et al. (2015) Sites A and B were found to be low in diversity and abundance, noting that the reported coordinates did not match sites maps in Berthelsen et al. (2015) therefore there was some uncertainty regarding where the sites were located. Site A (I2) was firm mud (>90% mud) and Site B (N10.5) was soft mud (>90% mud). While mud-dominated sediments are characteristic of the intertidal flats, and the results provide insight into the ecology of the mudflats, the intended purpose of fine scale monitoring is to assess estuary health and detect signs of eutrophication owing to increases in sediment, nutrients, and other contaminants. The mud-dominated sediments at Sites A and B mean the infauna community is already so impoverished that it is unlikely that any changes owing to catchment inputs or shifts in lagoon condition will be detected at these sites.

Site C is located on the well flushed intertidal flats toward the Te Aropipi channel. The infauna community comprises both pollution tolerant and sensitive species and the mud content is lower than the inner lagoon sites. While the site is not necessarily representative of the inner lagoon, water from the Wairau Estuary and Ōpaoa River and the lagoons flush over the site meaning it could provide some insight into changes in sediment condition and water quality.

It is recommended monitoring of Sites A and B be discontinued and Site C be maintained for ongoing monitoring. However, in 2015 although 10 samples were collected, only 5 per site were analysed. At Site C, 9 taxa were recorded as single individuals indicating significantly more sampling effort would be needed to reliably sample the sediments at Site C. Other intertidal sites within the lagoons were explored during the survey, however because the intertidal areas are muddy (>90% mud), similar to the Cawthron Sites A and B there would be no significant benefit in monitoring other intertidal sites within the lagoon.

Salt marsh

While broadscale habitat mapping of the estuary margins was not included in the current survey, MDC requested Salt Ecology review the salt marsh mapping undertaken in 2015 to determine whether it appropriately captured salt marsh extent. Our assessment found that Berthelsen et al. (2015) excluded many areas of the intertidal salt marsh vegetation based on limited connectivity with the estuarine habitat. However, there appeared to be limited consistency in why areas were included or excluded. For example, there were instances of salt marsh being included on one side of a tidal channel, but excluded on the other side, despite having identical tidal connectivity. There were also areas clearly connected to the lagoon that were not mapped, including the salt marsh present along the boulderbank margin, and several islands within the lagoon.

Notwithstanding these issues, extensive tidal channels, small shallow tidal lagoons and salt marsh surround Wairau Lagoon. While some areas appear to be partially disconnected due to elevation (as evident by the establishment of terrestrial grasses) there are extensive areas of salt marsh, predominantly herbfield (glasswort; *Sarcocornia quinqueflora*; see photos), that are currently un-mapped. It is important to map existing areas of salt marsh vegetation to understand and prevent future salt marsh losses.

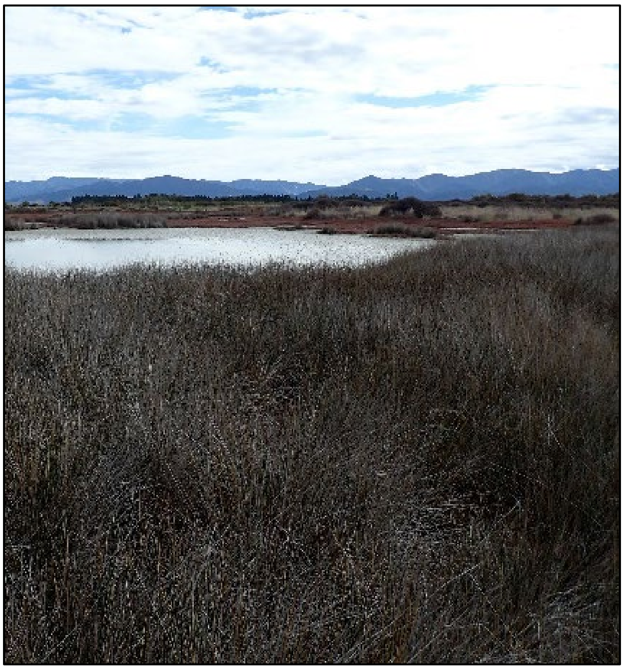
Extensive herbfield (glasswort, *Sarcocornia quinqueflora*) not included in 2015 mapping

Salt marsh habitats are one of the most productive habitats on Earth. They support multiple food webs and play an important role in atmospheric gas regulation, with their prolific plant growth creating 'carbon sinks' where carbon dioxide is absorbed as part of plant photosynthesis, and terrestrial and estuarine-derived carbon is deposited and locked up in the estuary sediment. They also provide tremendous additional benefits for humans including flood and erosion control, maintenance of water quality, nutrient and sediment assimilation, and a wide variety of opportunities for recreation.

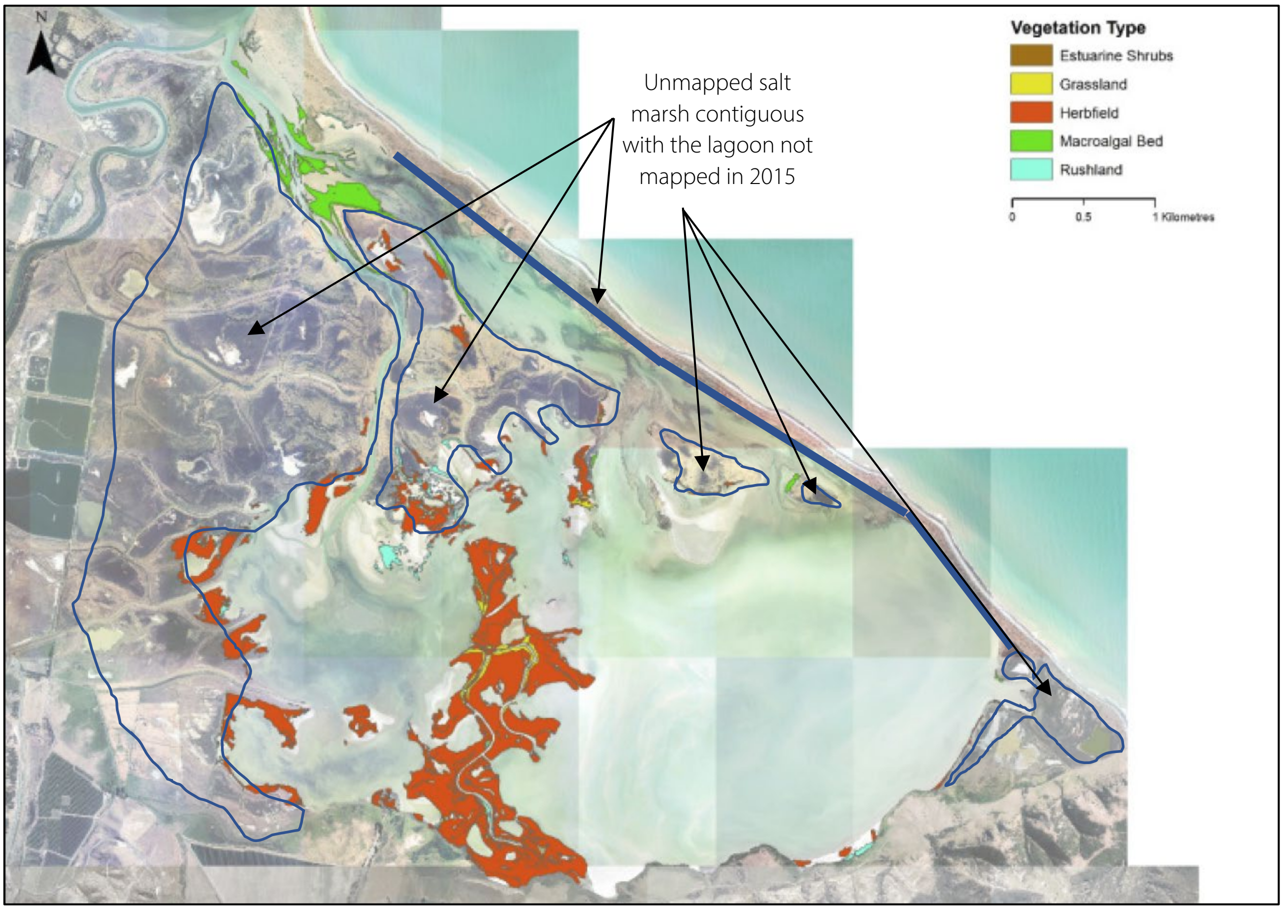
We recommend re-mapping the extensive areas of salt marsh vegetation adjacent to Wairau Lagoon, taking into account the level of connectivity to assess areas where salt marsh would benefit from reconnection to the estuary. Note all photos presented were taken in areas not mapped in 2015. It is also noted that MDC have LiDAR data available for this area and it is likely to be suitable for use in defining areas currently tidally inundated, as well as areas that may be inundated in response to predicted future sea level rise.

Channels amongst salt marsh habitat extend a significant distance from the lagoon

Grasses establishing between glasswort (*Sarcocornia quinqueflora*)



Shallow intertidal flats close to the waste water treatment plant dominated by herbfield species glasswort (*Sarcocornia quinqueflora*) and sea rush (*Juncus kraussii*)



Areas of salt marsh vegetation adjacent to Wairau Lagoon recommended for inclusion in future broad scale habitat mapping (approximate areas marked by the blue lines). These areas were excluded from the 2015 mapping.

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