Synoptic Subtidal of Waikawa Estuary

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Horizons Regional Council

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GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
LCDB	Land Cover Data Base
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
HRC	Horizons Regional Council
Pb	Lead
SOE	State of Environment (monitoring)
SSRTRE	Shallow Short-Residence Tidal River Estuary
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
Zn	Zinc

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EXECUTIVE SUMMARY

Background

Waikawa Estuary is a poorly flushed, shallow short-residence tidal river estuary (SSRTRE) whose mouth is intermittently open/closed. Broad scale mapping and synoptic sampling in 2016 indicated the presence of high nutrient enrichment, evident through extensive phytoplankton blooms visible in the water column, with widespread fine sediment (i.e. mud) deposits throughout the subtidal reaches of the middle estuary. The 2016 assessment recommended targeted subtidal monitoring of eutrophication and sedimentation indicators to collect data to assess long-term trends in trophic state. Subsequent monitoring in March 2018 repeated the 2016 broad scale intertidal habitat mapping (commonly only done every 5-10 years), and was supplemented by one-off water column and subtidal sediment quality sampling at three locations. The 2018 report found no evidence of primary eutrophication symptoms (i.e. nuisance phytoplankton and/or macroalgal growths), but concluded that the estuary had a high degree of eutrophic symptoms, based primarily on independently collected HRC water quality (chlorophyll-a) data.

In January 2019 a synoptic subtidal survey was undertaken to broadly map estuary depth, benthic substrate, seagrass extent; and to collect *in situ* water quality measures from a series of transects spaced longitudinally throughout the estuary. The aim was to delineate the spatial extent of any salinity or temperature stratification, oxygen depletion or phytoplankton blooms, and determine the nutrient enrichment (trophic) state of the estuary. Strong symptoms of eutrophication were found, evident through severely low oxygen levels extending over 9% of the subtidal estuary area, and large areas with poor sediment oxygenation.

In late 2019 Salt Ecology was commissioned by HRC to repeat the synoptic subtidal survey. The following report describes the methods and results of field sampling undertaken in January 2020, integrates previous results as appropriate, and makes recommendations for future monitoring and management.

Synthesis of key findings

In January 2020 field measurements of water and sediment quality were collected from 17 sites, and intertidal and subtidal substrate and vegetation mapped. Salinity stratification extended for ~4km upstream with freshwater on the surface and 16-32ppt salinity present in the deeper pools and on the river bed. Phytoplankton concentrations were elevated throughout the estuary, but contained no toxic species.

Water quality measurements showed dissolved oxygen was at severely low concentrations (0.2-1.0g/m^3 in deeper pools and below 4g/m^3 throughout most of the upper estuary). The presence of such low oxygen levels, even for a few hours over a tidal cycle, can cause severe adverse ecological effects, particularly to fish. Sediment oxygenation was also low, indicating the persistence of low oxygen conditions over prolonged periods.

The spatial extent of high enrichment conditions (i.e. low oxygen, elevated organic content, mud and nutrients) was ~2.7ha (40%) of the subtidal area, a large increase to the ~0.5ha (9%) recorded in 2019.

Subtidally, 68% of the sediments were mud-dominated mostly in the upper and middle estuary, and within deeper mid-channel sections of the lower estuary, while sands (71%) dominated intertidal substrate. Other results indicated that the estuary is unlikely to have any significant sediment contamination issues, while macrofaunal assemblages were relatively impoverished and dominated by pollution/disturbance tolerant species typical of SSRTREs. Subtidal seagrass (*Ruppia*) was widely distributed (0.3ha, 4.5%) growing to a depth of ~1.5m in the middle and upper estuary, with beds typically 1-2m wide. Salt marsh was not particularly extensive (1.2ha, 9% of the intertidal area) and was dominated by sedgeland (69%) and rushland (28%). Herbfield was sparse (3%). Overall the results indicate Waikawa Estuary is continuing to express strong symptoms of eutrophication, with large parts of the upper estuary currently experiencing severely low oxygen levels. These low levels result from excessive phytoplankton blooms responding to elevated inputs of nutrients and, to a lesser degree, sediments.

Recommendations:

In light of the significant eutrophication symptoms identified it is recommended that HRC consider the following:

1. Sampling be undertaken in the summer of 2021 to monitor the spatial extent and nature of eutrophication impacts. This should include boat-based sampling of subtidal sediments and water quality throughout the

subtidal reaches of the upper estuary. Ideally a second set of measures would be undertaken immediately following a flood event to determine the capacity for the estuary to flush out excessive sediments, nutrients and low oxygen waters.

2. Design and implement a long-term programme for regular monitoring of estuary condition linked to existing freshwater State of the Environment (SOE) monitoring. This work should include the deployment of water quality loggers in eutrophic parts of the estuary, more frequent field assessments utilising vertical profiling to characterise the nature and extent of the current problems, and amending the current HRC water quality programme to, at a minimum, record the halocline depth and measure the highest concentration of chlorophyll-a and the lowest concentration of dissolved oxygen in the water column at the two existing HRC estuary monitoring sites.
3. Undertake a bathymetric survey of the estuary to enable accurate delineation of areas likely to stratify, and to underpin hydrodynamic models HRC are currently considering using. These models will be used to estimate nutrient concentrations and predict ecological outcomes under changed nutrient and sediment management in the catchment.
4. Undertake an assessment of catchment sources of nutrients and sediments to the estuary to determine whether changes to current land management practices are likely to significantly improve ecological condition and to guide council management priorities.
5. From 3 and 4 above, establish limits for catchment sediment and nutrient inputs that will protect the estuary from degradation.
6. There is potential to restore or enhance many of the terrestrial salt marsh remnants currently isolated from tidal flows. The benefits of carbon sequestration, erosion protection and maintenance and enhancement of biodiversity through increasing salt marsh extent may exceed those of marginal grassland and HRC are encouraged to explore restoration opportunities with current land owners. GIS-based inundation mapping based on coastal LIDAR data can be used to highlight priority areas.

1. INTRODUCTION

1.1 BACKGROUND

Monitoring the ecological condition of estuarine habitats is critical to their management. Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Monitoring is primarily designed to detect and understand changes in key estuaries over time and determine catchment influences, especially those due to the input of nutrients and muddy sediments.

The Horizons Regional Council (HRC) programme includes monitoring in the region's larger estuaries; e.g. Manawatu and Whanganui, as well as smaller estuaries with developed catchments; e.g. Mowhanau, Kai iwi, Waikawa and Ohau. The latter are shallow short-residence tidal river estuaries (SSRTREs) which experience restricted flushing when their mouths undergo short periods of closure or restriction (days to weeks). This report describes monitoring of Waikawa Estuary.

The National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002a,b,c) is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results establish a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

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

A recently developed extension to the NEMP in New Zealand has been an Estuarine Trophic Index (ETI) (Robertson et al. 2016a, b; Zeldis et al 2017). The ETI describes methods and provides screening guidance for assessing where estuaries of different types (including SSRTREs) are positioned on a eutrophication gradient. It utilises several NEMP metrics, and describes additional metrics, which are applied both to the estuary as a whole (i.e. in a broad scale context), as well as at a site-specific level (i.e. in a fine scale context), with a focus on the most degraded 10% of the estuary.

Because SSRTREs commonly express symptoms of nutrient enrichment (eutrophication) and excessive sedimentation in the subtidal parts of the estuary (where sediment and nutrients concentrate), site-specific approaches beyond that described in the NEMP are needed in this type of estuary.

A typical way of modifying the NEMP approach for the assessment of SSRTREs is to use a series of cross-sectional transects, combined with assessment of broad and fine scale metrics which 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, benthic substrate, seagrass, and macroalgae, as well as delineating the spatial extent of phytoplankton blooms and any salinity or temperature stratification. Fine scale measures include *in situ* water and sediment quality measurements and the collection of sediment samples for laboratory analyses. This approach has been previously shown to be a robust way to quickly describe estuary habitat and characterise trophic status (e.g. Stevens and Robertson 2012, Stevens et al. 2016, Stevens 2019).

1.2 BACKGROUND TO WAIKAWA ESTUARY

Waikawa Estuary (Fig. 1) is a relatively long (>4km), poorly-flushed SSRTRE whose mouth is mostly open to the sea, but occasionally closes, and is commonly constricted by a build-up of beach sand. Sediments are dominated by marine sands throughout the lower estuary, becoming progressively muddier in the middle and upper estuary, particularly in subtidal zones. The seagrass Horse's mane weed (*Ruppia megacarpa*) is relatively widely distributed in the shallow (<1.5m) subtidal reaches of the middle and upper estuary.

Salt tolerant herbs (e.g. remuremu, *Selliera radicans*; primrose, *Samolus repens*) and rushes and sedges (e.g. sea rush, *Juncus krausii*; three square, *Schoenoplectus pungens* and lake clubrush, *Schoenoplectus validus*) grow along the margins of the middle and lower estuary near the open coast. Elsewhere, most margin vegetation comprises a narrow strip of freshwater species flanked by terrestrial grassland.

The middle and lower estuary is flanked by residential housing on the true left bank, and has high public use. The upper estuary is confined within steep sided, meandering, channelised river banks within grazed pastoral land.

When seawater is retained in the estuary it becomes brackish (very low salinity) and can stratify with denser (heavier) seawater being trapped beneath freshwater surface flows. Phytoplankton blooms (coffee-coloured cryptomonads) are common in the middle and upper estuary, particularly in the stratified bottom waters, and occasional nuisance opportunistic macroalgal blooms (e.g. *Ulva* spp.) can be present in the lower estuary (see Robertson & Stevens 2016).

The estuary has a moderate freshwater inflow (mean 1.9m^3/s) from a catchment dominated by lowland pastoral sheep, beef and dairy farming (46%), but with extensive native (27%) and exotic forest (10%) cover in the upper catchment (Fig. 2, Table 1).

Based on criteria in the ETI, Waikawa Estuary is rated as having a low vulnerability to catchment sediment impacts (predicted sediment load ~1.1 times the predicted natural load), but a high vulnerability to nutrient enrichment. NIWA's CLUES model predicts an estimated catchment Nitrogen (N) areal loading of 2246mgN/m^2/d, well above the tentative guideline of 250mgN/m^2/d for high susceptibility SSRTREs (Robertson & Stevens 2016).

1.3 PREVIOUS MONITORING

In 2016, Waikawa Estuary was synoptically assessed as part of an Ecological Vulnerability Assessment (EVA) of the estuaries on both coasts of the Horizons region to assess sediment and nutrient enrichment (eutrophication) risks (see Robertson & Stevens 2016). Although limited in scope, the study included visits to all of the larger and many of the smaller estuaries to rapidly characterise the prevailing sediment and nutrient status of each one, map key broad scale habitat features, and define ongoing monitoring priorities in a defensible manner.

Synoptic subtidal sampling in 2016 in support of the EVA found symptoms of high nutrient enrichment evident through phytoplankton blooms in the water column, and poorly oxygenated fine sediment throughout the subtidal reaches of the middle estuary. Consequently, Robertson and Stevens (2016) recommended targeted subtidal monitoring of eutrophication and sedimentation indicators on three transects in Waikawa Estuary to collect data to assess long-term trends in trophic state.

Subsequent monitoring of Waikawa Estuary commenced in March 2018, although the primary focus was to repeat the intertidal broad scale habitat mapping undertaken in 2016 (commonly only done every 5-10 years). This broad scale mapping was supplemented by one-off water and sediment quality sampling at three locations in the lower, middle and upper estuary (see Robertson & Robertson (2018) for details).

The 2018 subtidal water quality assessment considered there to be a low expression of water column eutrophication symptoms at the time of sampling based on low chlorophyll-a concentrations, no pronounced depression or super-saturation of dissolved oxygen, and the absence of any gross eutrophic zones (areas of high enrichment) at the three sites sampled. However, it was concluded that the subtidal estuary had a high degree of eutrophic symptoms based primarily on independently collected HRC water quality data (chlorophyll-a). Despite this, the estuary was rated as being in a 'moderate' condition overall.

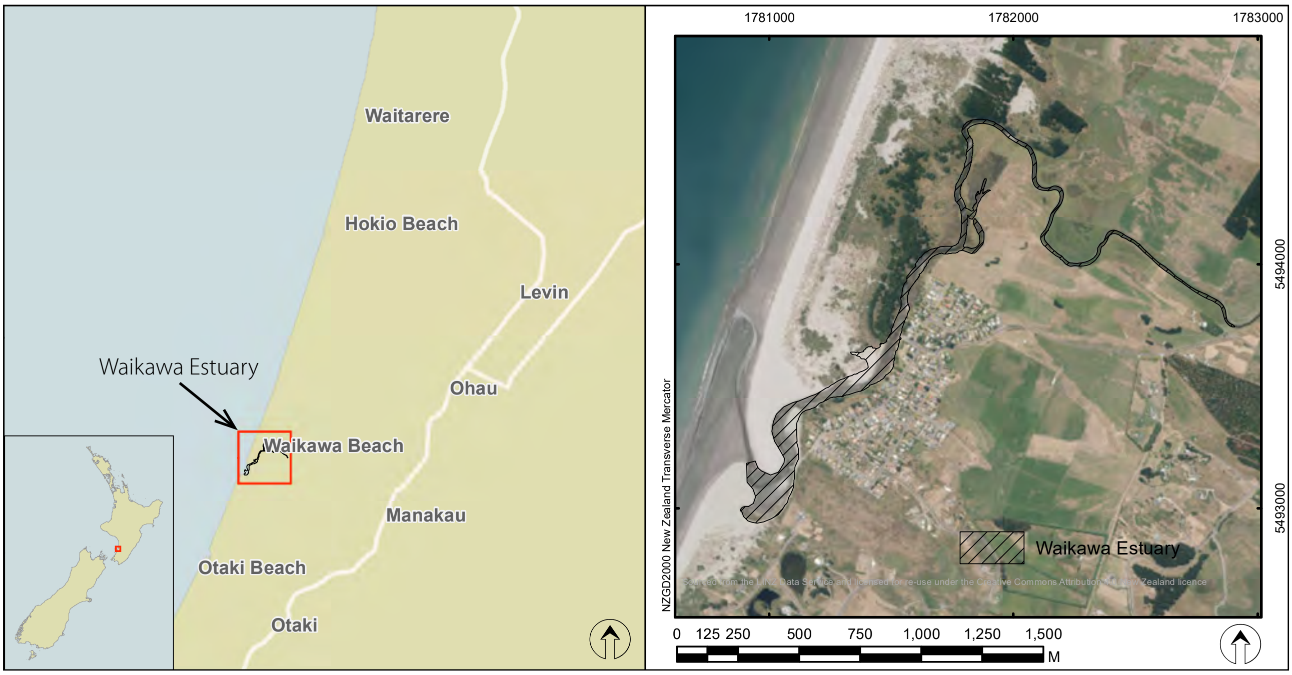


Fig. 1. Location map of Waikawa Estuary.

A further survey in January 2019 broadly mapped estuary depth, benthic substrate and seagrass extent; and collected *in situ* water quality measures from a series of transects spaced longitudinally throughout the estuary. The aim was to delineate the spatial extent of any salinity or temperature stratification, oxygen depletion, phytoplankton blooms, and determine the nutrient enrichment (trophic) state of the estuary. Results, presented in Stevens (2019), found strong symptoms of eutrophication with severely low oxygen levels in the subtidal waters of the middle estuary extending over 9% of the subtidal area. Sediment oxygenation was also poor, indicating prolonged periods of degraded water quality. The 2019 work identified inconsistencies between the 2016 and 2018 broad scale mapping results, and the dominant salt marsh features present in the estuary.

In late 2019, Salt Ecology was commissioned by HRC to repeat the synoptic subtidal survey, re-map intertidal features to resolve the uncertainties between the previous reports, and make recommendations for future monitoring and management.

Table 1. Summary of catchment land cover (LCDB5 2017/18), Waikawa Estuary.

LCDB5 (2017/18) Catchment land cover		Ha	%
1	Built-up Area (settlement)	61	0.8
10	Sand or Gravel	73	0.9
16	Gravel or Rock	8	0.1
20	Lake or Pond	6	0.1
21	River	6	0.1
22	Estuarine Open Water	1	0.01
30	Short-rotation Cropland	116	1.5
33	Orchard, Vineyard/Other Perennial Crop	2	0.0
40	High Producing Exotic Grassland	3607	45.6
41	Low Producing Grassland	182	2.3
45	Herbaceous Freshwater Vegetation	83	1.1
50	Fernland	6	0.1
51	Gorse and/or Broom	10	0.1
52	Manuka and/or Kanuka	61	0.8
54	Broadleaved Indigenous Hardwoods	599	7.6
56	Mixed Exotic Shrubland	1	0.01
64	Forest - Harvested	116	1.5
68	Deciduous Hardwoods	31	0.4
69	Indigenous Forest	2147	27.1
71	Exotic Forest	798	10.1
Grand Total		7914	100

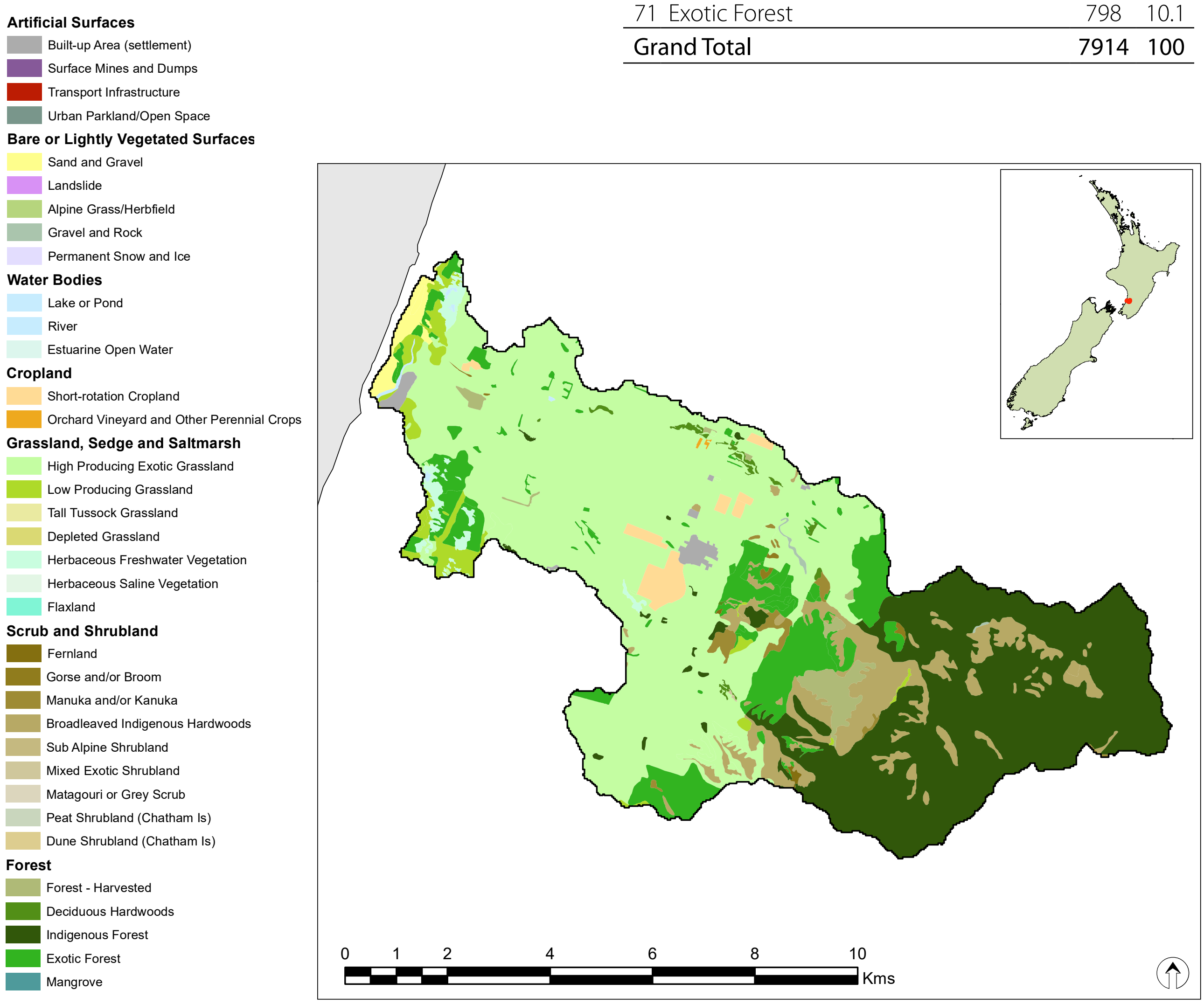


Fig. 2. Map of catchment land cover (LCDB5 2017/18), Waikawa Estuary.

2. METHODS

2.1 OVERVIEW

Because the intertidal part of the estuary had previously been mapped (e.g. Robertson & Stevens 2016, Robertson & Robertson 2018), the primary focus of the current synoptic survey was on quantifying the ecological condition of the subtidal reaches using a transect based approach involving wading or grab sampling from a boat at multiple locations (see Fig. 3). At the same time, intertidal substrate and salt marsh was re-mapped.

The estuary boundaries were defined based on the ETI (Robertson et al. 2016a) as the area between the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt) and seaward to a straight line between the outer headlands where the angle between the head of the estuary and the two outer headlands is <150°.

2.2 BROAD SCALE METHODS

The type, presence and extent of substrate, salt marsh, macroalgae or seagrass reflects multiple factors, for example the combined influence of sediment deposition, nutrient availability, salinity, water quality, clarity and hydrology. As such, broad scale

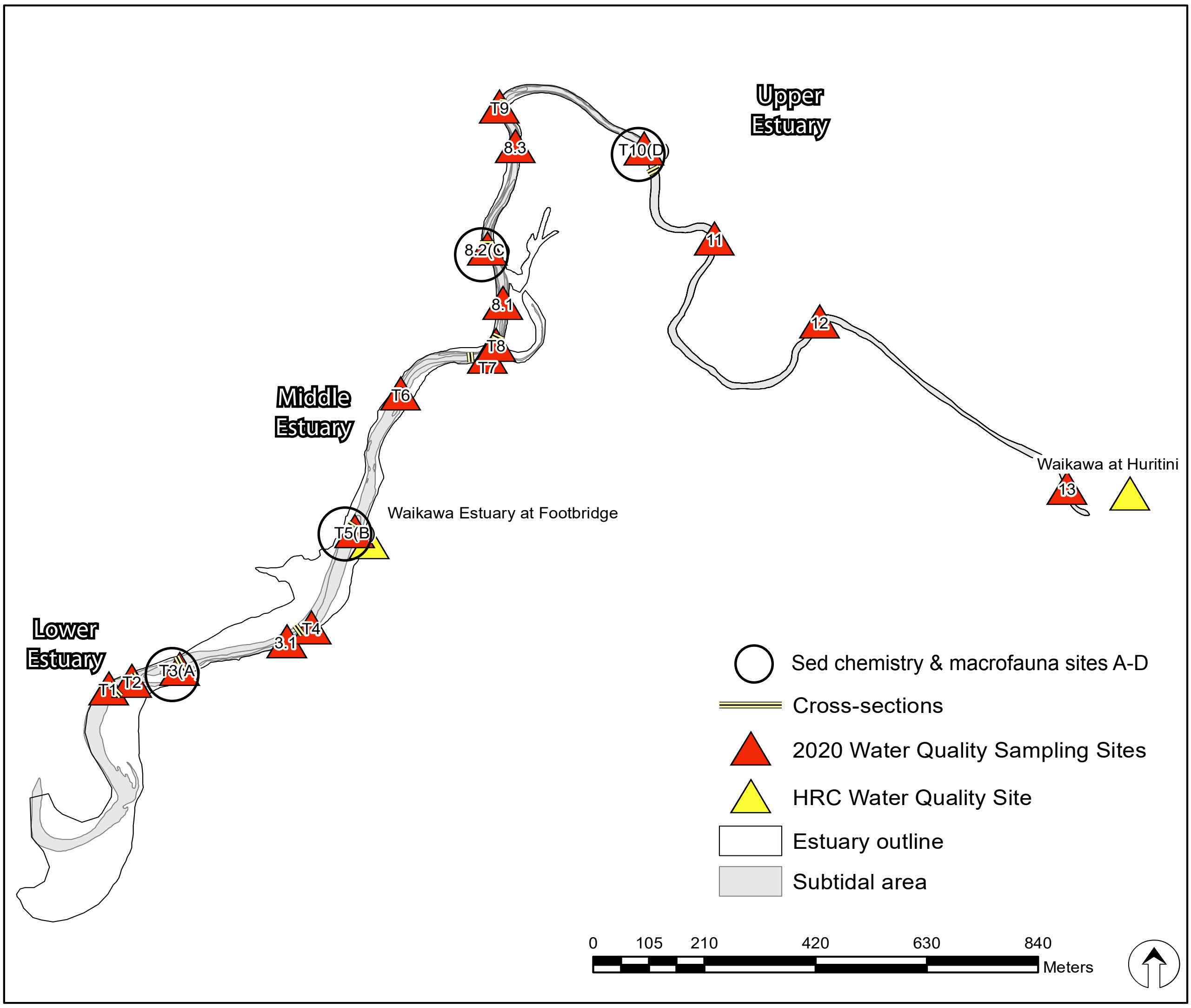


Fig. 3. Location of estuary cross-sections and synoptic water and sediment sampling sites.

At each transect a cross-section was surveyed in 2019 and 2020, and at each sampling site, water quality was measured, seagrass mapped, and bottom sediment condition assessed. Sediment samples were collected for chemical analysis of grain size, nutrients, organic content and metals from the deepest part of the cross-section at T3 (A), T5(B) and T10(D) replicating sites X, Y and Z in Robertson and Robertson (2018). An additional sample was collected from the upper estuary ('C') where the most degraded sediment conditions were encountered.

mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to small scale temporal variation associated with instantaneous water quality measures.

NEMP methods (Appendix 1) were used to map and categorise intertidal 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 0.3m/pixel rural aerial photos flown in the summer of 2016-2017 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. Subtidal areas were assessed using a combination of grab sampling, wading and underwater video, with water and sediment quality measurements also used to indicate the spatial extent of degraded sediments or bottom water. When present, macroalgae and seagrass patches were mapped to the nearest 10% using a 6-category rating scale as a guide to describe percentage cover (see Fig. 4).

In the field, features were drawn directly onto laminated aerial photographs. 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. salt marsh, and its underlying substrate type. Assessment criteria, developed largely from previous broad scale mapping assessments, apply thresholds for helping to assess estuary condition (Table 2). Additional details on specific broad scale measures are provided below.

Substrate classification

Appendix 1 summarises the key NEMP classes used to define estuarine habitats in the current report. Substrate classification is based on the dominant surface substrate features present; e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories based on sediment 'muddiness', assessed according to subjective field-based assessment of textural and firmness characteristics. The primary indicator used to assess sediment mud impacts is the area (horizontal extent) of mud-dominated sediment.

Sedimentation rate

Because sediment naturally settles and accumulates in estuaries, estuarine communities have an inherent capacity to assimilate inputs from terrestrial catchments. However, when natural terrestrial inputs are accelerated through human-induced land change, sedimentation rates can exceed the assimilation capacity of the estuary, leading to increased muddiness and smothering of habitats. Where long-term measurements of sedimentation rate changes are not available, the ETI uses a desktop approach of the ratio between predicted natural inputs and predicted current inputs to rate the likely susceptibility of an estuary to sediment problems.

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 to the nearest 10% using the 6-category percent cover rating scale presented in Fig. 4 as a guide.

The ETI has adopted the use of the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) for macroalgal assessment. The OMBT is a 5-part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which rates macroalgal condition within overall quality status threshold bands (bad, poor, good, moderate, high). The integrated OMBT index provides a comprehensive measure of the combined influence of macroalgal growth and distribution in the estuary and is applied where macroalgal cover exceeds 5%.

Seagrass

The NEMP provides no guidance on the assessment of seagrass beyond recording its presence when it is a dominant surface feature. When present, the mean percent cover of discrete seagrass patches was visually assessed to the nearest 10% using the 6-category percent cover rating scale presented in Fig. 4 as a guide. Percent change from recorded baseline values are used to assess temporal changes.

High Enrichment Conditions (HEC)

This is an integrated measure of the combined presence of indicators likely to result in adverse ecological outcomes. Referred to alternatively as gross eutrophic zones (GEZs) in the ETI (Zeldis et al. 2017), sites expressing HECs have sediments with elevated organic content (>1% Total Organic Carbon (TOC) and/or dense macroalgal cover (>50%), combined with an elevated mud content (≥25% mud) and low sediment oxygenation (apparent Redox Potential Discontinuity (aRPD) <10mm) or water column oxygenation (<4g/m³). Once high organic and nutrient enrichment conditions establish, they are generally difficult to reverse and are likely to cause significant adverse ecological impacts on sediment-dwelling animals.

2.3 SUBTIDAL SEDIMENT AND WATER QUALITY ASSESSMENT

A range of sediment and water quality indicators were measured to characterise habitat features and prevailing conditions. Sediment indicators, such as oxygenation, enrichment and mud content, provide relatively stable integrated measures of prevailing environmental conditions. Water quality measures are instantaneous and reflect ambient conditions and tidal state and can be highly variable. Therefore a combined meso-scale approach based on *in situ* measurements and laboratory analyses was used that can be repeated over time and scaled up or down to address specific issues as necessary. In this case it was supplemented with monthly water quality data collected by HRC in the Waikawa River and Estuary.

2.3.1 Sites and sampling

Seventeen subtidal sites were distributed relatively evenly throughout the estuary (Fig. 3). Sampling was conducted on 18 January 2020 around low tide to enable the best delineation of stratified bottom waters retained in the estuary. The tidal range on the day of sampling was 0.8-1.8m, reflecting neap tides, and was approximately half the predicted spring tidal range of 0.4-2.3m (NIWA online tide forecaster).

At ten sites, a cross-sectional transect established in 2019 was revisited and subtidal habitat assessed by either wading or by sampling from a dinghy, to measure the following variables:

- Channel width
- Water depth
- Secchi disk clarity
- Surface & bottom water quality variables: temperature, salinity, pH, dissolved oxygen, chlorophyll-a
- Thermocline depth
- Halocline depth
- Substrate type
- Depth in the sediment of the apparent Redox Potential Discontinuity (aRPD)
- Seagrass and macroalgae (percent cover)

To increase spatial resolution between established transects, seven additional water and sediment quality sites were added in 2020.

2.4 IN SITU FIELD MEASURES

2.4.1 Cross-section profiling

The longitudinal channel profile of the estuary and channel cross-section depths were assessed using a depth sounder mounted on the stern of an inflatable dinghy or, in shallow areas, a graduated surveying pole. The 2020 survey found there was no significant change to the 2019 data and, as such, cross-sections were not re-plotted.

2.4.2 Water column indicators

At the deepest point along each cross-section, water quality measures of pH, salinity, dissolved oxygen (DO), temperature and chlorophyll-a (as a measure of phytoplankton biomass) were made using a YSI

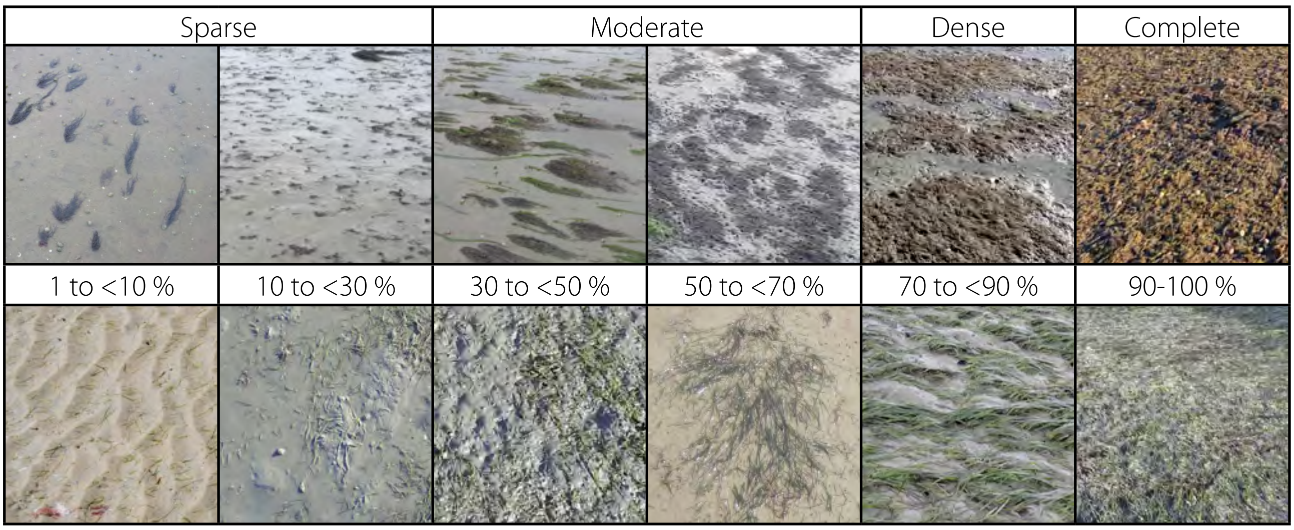
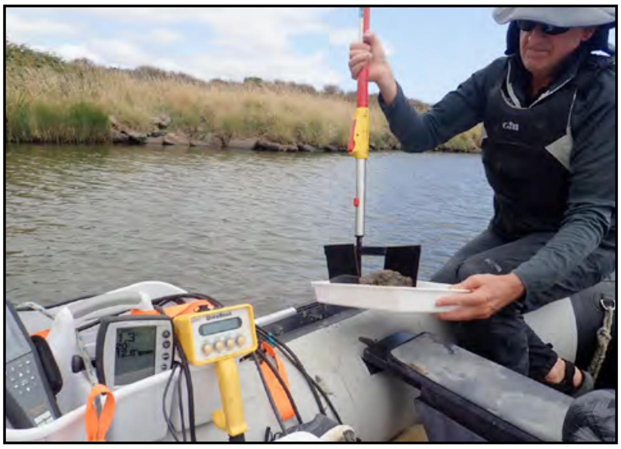


Fig. 4. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom).
Modified from FGDC (2012).

Pro10 meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Water measurements were collected ~20cm below the water surface, and ~20cm above the sediment surface, with care taken not to disturb bottom sediments before sampling.



Subtidal sampling used a modified benthic hoe sampler or a box core, and a suite of water quality instruments

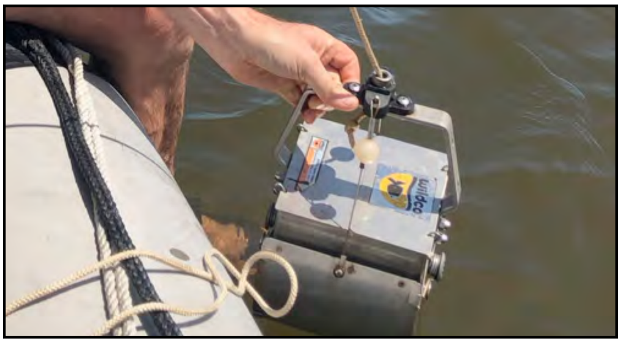
A key focus of the current work was defining the depth and extent of salinity stratification and measuring water quality above and below the halocline (freshwater to seawater interface). If the water column was stratified, thermocline and halocline depths were recorded as the average depth of abrupt changes in temperature and salinity, respectively, recorded on the up- and down-cast meter deployments. A modified (pole-mounted) secchi disk approach was used to measure vertical water clarity to the nearest centimetre.

Although subject to high spatial and temporal variation, water column measures provide a useful tool for the synoptic appraisal of ecological condition. Salinity measures provide a simple way for determining the upstream extent of the estuary and indicate where stable areas of saline water may be trapped, with phytoplankton potentially able to grow and bloom in the retained water. Chlorophyll-a indicates the presence and biomass of phytoplankton which can be high in situations where nutrient supply is elevated and flushing is low. The nutrients facilitate rapid algal growth but when algal blooms crash and die, they deplete dissolved oxygen levels which can adversely impact both sediment-dwelling and water column communities, and are a primary cause of most fish kills.

To assess whether potentially toxic phytoplankton were present in the estuary, a single grab sample was collected from an area where high phytoplankton growth was indicated by chlorophyll-a readings. The sample was collected directly into laboratory-supplied sample containers, stored on ice, and sent overnight to NIWA, Hamilton for analysis.

2.4.3 Sediment indicators

On each transect, multiple sediment samples were collected using a modified benthic hoe or remote grab sampler. At the surface samples were assessed for substrate type, and seagrass, macroalgal or microalgal cover as described in Section 2.2.



A box core was used to collect sediment in deep water

A modified benthic hoe was used to collect sediment from water <3m deep

Sediment aRPD was assessed in representative samples to determine whether there were any significant areas where sediment oxygenation was depleted close to the surface.

The apparent Redox Potential Discontinuity (aRPD) depth is a subjective measure of the enrichment state of sediments according to 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). The aRPD depth provides an easily measured, time integrated, and relatively stable measure of the sediment oxygenation conditions that animal communities are predominantly exposed to.

Examples of well oxygenated sandy sediment with aRPD >150mm (left) and poorly oxygenated muddy sediment with aRPD <5mm (right).

Sediments were considered to have poor oxygenation if the aRPD was consistently shallower than 5mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. As significant sampling effort is required to map subsurface conditions accurately, the broad scale approach is intended to be used as a preliminary screening tool to determine the need for additional sampling effort.

2.5 LABORATORY MEASURES

2.5.1 Sediment sampling and analysis

At the deepest point at stations T3(A), T5(B), 8.2(C) and T10 (D) (see Fig. 3), 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) and metals and metalloids (arsenic, copper, chromium, cadmium, lead, mercury, nickel, zinc). Details of laboratory methods and detection limits are provided in Appendix 2.

2.5.2 Particle grain size

Particle grain size indicates the relative proportion of fine-grained sediments that have accumulated within estuary sediments. In general terms, increased muddiness correlates to reduced sediment oxygenation due to limited diffusion among the tightly packed mud matrix. Increasing mud also causes a change in sediment animal communities, with sensitive species like pipi preferring low (<10%) mud environments, and communities becoming dominated by mud-tolerant organisms when mud levels exceed 25%.

2.5.3 Sediment nutrients and organic carbon

Total nitrogen (TN) and total phosphorus (TP) concentrations reflect estuary trophic status and the potential for algal blooms and other symptoms of enrichment to occur and persist. The ETI uses measures of TN from the most impacted 10% of an estuary to rate likely enrichment, while the ratio of TN and TP can be used to indicate which nutrient may be limiting to algal growth (almost always nitrogen in estuaries). Total organic carbon (TOC) provides a measure of the organic material present in sediments. When this exceeds ~1%, sediment oxygen declines. Under anoxic conditions bacteria can break down organic material producing sulphides which, as well a having a strong odour, are toxic to most sediment dwelling animals.

2.5.4 Sediment metals and metalloids

Metals and metalloids provide a relatively cheap indicator for screening for the presence of common toxic contaminants associated with human activities. They are used to determine whether more intensive investigations of sediment contamination are deemed necessary.

2.5.5 Sediment macrofauna

The abundance, composition and diversity of macrofauna, especially the infauna living within the sediment, are commonly-used indicators of estuarine health. Three samples were collected from each of the four sites using a remote grab. A sub-sample (130mm diameter core x 150mm deep) was taken from the grab and placed within a 0.5mm sieve bag, which was gently washed in the field to remove fine sediment. If insufficient sediment was collected within a single grab, additional grabs were collected and material combined until the required sediment volume was obtained.

The retained animals were preserved in a 75% isopropyl alcohol and 25% seawater mixture for later sorting by Salt Ecology staff and taxonomic identification by Gary Stephenson, Coastal Marine Ecology Consultants (CMEC). The 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.

Sieved macrofauna collected from a box core.

2.6 DATA RECORDING, QA/QC AND ANALYSIS

The ability to correctly identify and map broad scale intertidal features is primarily determined by the resolution of available photos, the extent of ground truthing undertaken to validate features visible on photos, and the experience of those undertaking the mapping. In most instances features with readily defined edges such as rushland, rockfields, dense seagrass, etc. can be mapped at a scale of ~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse seagrass beds, or where there is a transition between features that appear visually similar, e.g. sand, muddy sand, mud. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground truthed, but accuracy is unlikely to be better than ±20-50m for such features when relying on photos alone.

Subtidal sampling relies on benthic assessment using remote sampling means including underwater cameras and grab sampling, with interpolation between sampling points. Accuracy thus reflects sampling intensity.

In 2020, broad scale intertidal and subtidal habitat features were recorded on a combination of laminated aerial photographs and waterproof paper, and used with georeferenced field photos to digitise habitat features. Following digitising, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes), and calculate areas and percentages used in summary tables. Using these same tools, the 2016 (Wriggle) and 2018 (Robertson Environmental) GIS layers were similarly checked for any errors in basic geometry (e.g. overlapping polygons), and updated to fix any identified issues. Where discrepancies were identified between GIS data and hard copy reports, the underpinning GIS data were re-analysed to produce revised summary statistics.

Further, the 2016 and 2018 substrate types were updated to reflect the revised classifications presented in Appendix 1. The original classification codes have been retained in the GIS attribute tables with any changes shown alongside. In addition, detailed metadata describing data sources and any changes made have been provided with each GIS layer produced and supplied to HRC.

All subtidal sediment and macrofaunal samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. In 2019 and 2020, field water quality 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 core). Field data were exported to Excel, together with data from the sediment and macrofaunal analyses.

To assess changes and minimise the risk of data manipulation errors, Excel sheets for the different data types and years were imported into the software R 3.6.0 (R Core Team 2019) and merged by common sample identification codes.

All summaries of univariate responses (e.g. totals, means ±1 standard error) were produced in R, including tabulated or graphical representations of data from laboratory sediment quality analyses, and macrofauna. Where results for sediment quality parameters were below analytical detection limits, averages were calculated using half the detection limit value, according to convention.

Before macrofaunal analyses, the data were screened to remove species that were not regarded as a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g. terrestrial beetles).

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

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

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

2.7 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 2.

The condition ratings used in the current report were derived primarily from the 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 percent mud, TOC, TN, aRPD, metals, dissolved oxygen, phytoplankton concentrations, generally using spot measures from within the most degraded 10% of the estuary. The ETI also contains metrics intended to be applied to the estuary as a whole (i.e. in a broad scale context), e.g. the extent of mud, macroalgae or sedimentation rates. We adopted those thresholds for present purposes, except: (i) for percent mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016c); and (ii) for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012).

The condition rating categories for trace metals and metalloids are benchmarked to ANZG (2018) sediment quality guidelines as described in Table 2. The Default Guideline Value (DGV) and Guideline Value-High (GV-high) specified in ANZG are thresholds that can be interpreted as reflecting the potential for 'possible' or 'probable' ecological effects, respectively. Until recently, these thresholds were referred to as ANZECC (2000) Interim Sediment Quality Guideline low (ISQG-low) and Interim Sediment Quality Guideline high (ISQG-high) values, respectively.

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of areas with High Enrichment Conditions (HEC) was evaluated.

In addition, previous assessments of estuarine condition have proposed preliminary criteria for the extent of salt marsh, densely vegetated terrestrial margin, and percent change from baseline measures (e.g. Stevens 2018, Stevens & Forrest 2019). These thresholds are also applied as appropriate.

As many of the scoring categories in Table 2 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).

Table 2. Summary of condition ratings referred to in the present report.

Indicator	Unit	Very Good	Good	Fair	Poor
Sediment quality					
Mud content[1]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to ≤ 20	≤ 10
Total nitrogen (TN)[1]	mg/kg	< 250	250 to < 1000	1000 to < 2000	≥ 2000
Total organic carbon (TOC)[1]	%	< 0.5	0.5 to < 1	1 to < 2	≥ 2
Sediment trace elements[2]					
As	mg/kg	< 10	10 - < 20	20 - < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 - < 1.5	1.5 - < 10	≥ 10
Cr	mg/kg	< 40	40 - < 80	80 - < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 - < 65	65 - < 270	≥ 270
Pb	mg/kg	< 25	25 - < 50	50 - < 220	≥ 220
Hg	mg/kg	< 0.075	0.075 - < 0.15	0.15 - < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 - < 21	21 - < 52	≥ 52
Zn	mg/kg	< 100	100 - < 200	200 - < 410	≥ 410
Water quality					
Dissolved oxygen (DO)[1]	g/m^3	≥ 5.5	≥ 5.0	≥ 4.0	< 4.0
Phytoplankton (chl-a)[1]	mg/m^3	≤ 5	≥ 5 to < 10	≥ 10 to < 16	≥ 16
Broad scale spatial indicators					
Mud-dominated substrate[3]	% of intertidal area >50% mud	< 1%	1-5%	> 5-15%	> 15%
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥ 0.8 - 1.0	≥ 0.6 - < 0.8	≥ 0.4 - < 0.6	0.0 - < 0.4
Seagrass[3]	% decrease from baseline	< 5%	5%-10%	> 10-20%	> 20%
Salt marsh extent (current)[3]	% of intertidal area	> 20%	> 10-20%	> 5-10%	0-5%
Historical salt marsh extent[3]	% of historical remaining	≥ 80-100	≥ 60-80	≥ 40-60	< 40
200m terrestrial margin[3]	% densely vegetated	≥ 80-100	≥ 50-80	≥ 25-50	< 25
High Enrichment Conditions[1]	ha	< 0.5ha	≥ 0.5-5ha	≥ 5-20ha	≥ 20ha
High Enrichment Conditions[1]	% of estuary	< 1%	≥ 1-5%	≥ 5-10%	≥ 10%
Sedimentation rate[1*]	CSR:NSR ratio	1 to 1.1	1.1 to 2	2 to 5	> 5

1. General indicator thresholds derived from a New Zealand Estuarine Tropic Index, with adjustments for aRPD and mud content as described in the main text. See text for further explanation of the origin or derivation of the different metrics.

2. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good: < 0.5 x DGV; Good: 0.5 x DGV to < DGV; Moderate: DGV to < GV-high; Poor: ≥ GV-high.

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

**CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)*


Sediment sampling in the lower estuary


Raised sand bank and herbfield in the lower estuary


Discoloured waters indicating the presence of phytoplankton downstream of site T5


Fringing sedgeland in the middle estuary


Reinforced banks in the modified middle estuary


Lush three-square growing in the upper estuary


Channelised banks in the upper estuary


Waikawa River near the upper extent of salinity intrusion

3. RESULTS

3.1 BROAD SCALE MAPPING

A summary of the 2020 broad scale mapping results is presented in Table 3. The mapped estuary area covered 13ha and extended 4km upstream from the entrance. At the upper extent the estuary remained stratified with seawater trapped below freshwater.

Table 3. Summary of dominant broad scale features, Waikawa Estuary 2020.

a. Area Summary	ha	%
Intertidal area	6.3	48.6
Subtidal area	6.7	51.4
Total estuary area	13.0	100

b. Key intertidal features	ha	%*
Salt marsh	1.2	9.1
Macroalgal beds (>50% cover)	0	0
Mud-dominated sediment (%)	1.0	16.5
**% of 6.3ha intertidal area*		

c. Key subtidal features	ha	%*
Mud-dominated sediment (%)	4.5	67.9
Zone of low O_2	2.7	40.1
Seagrass (*Ruppia*) cover	0.3	4.5
**% of 6.7ha subtidal area*		

Intertidal substrate was dominated by sand (71%) with a low (<10%) mud content, which was found primarily near the estuary entrance (Fig 5). Within the subtidal zone (Fig. 6), 68% of the sediments were mud-dominated (i.e. >50% mud content). Mud-dominated areas were most widespread in the upper and middle estuary, and within deeper mid-channel sections of the lower estuary

In the lower estuary (T1 to T4) the channel profile was generally wide (25-30m) and shallow (<1m deep) - see Fig. 7, with the dominant marine sand substrate likely deposited through a combination of tidal and wind blown deposition. Small bands of cobble were present along the true left bank where they have been placed historically to minimise erosion, and small rock groynes have been built to deflect the river flow seaward and away from residential areas.

Heading upstream, the middle estuary was more riverine in nature with small areas of muddy sands present along narrowing intertidal margins. Sediments became progressively muddier with increasing distance upstream. Between sites T5 and T7 the river channel narrowed to ~15m wide and became deeper, particularly on bends where pools 1.5-2m deep at low tide were present (Figs 7 and 8). Intertidal areas were small and mostly supported salt marsh (discussed further below). Rip-rap rock flood protection was present on the river bend at T7, with several small areas of rock protection also present on the true left between T5 and T6.

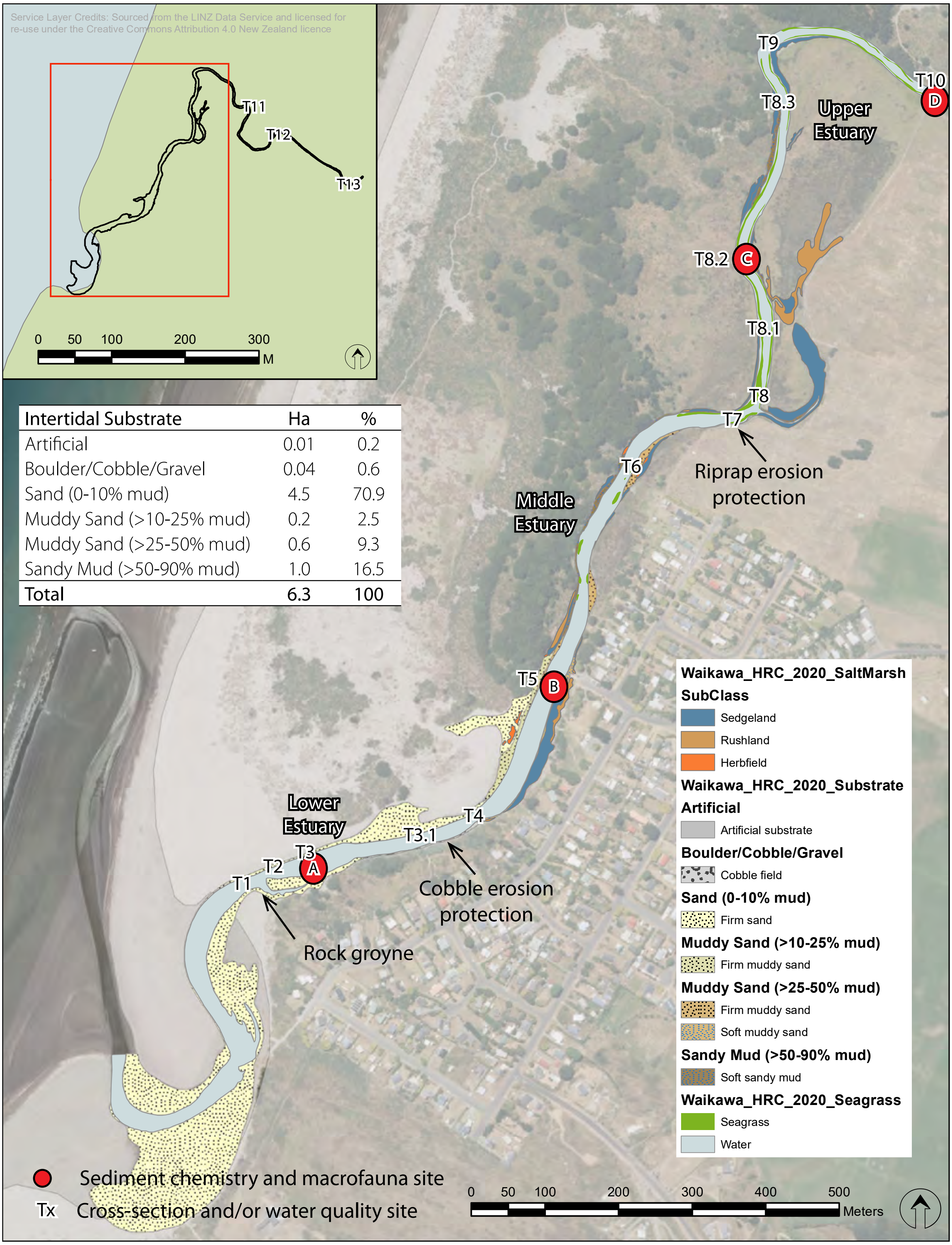
Between T7 and T9, the estuary further narrowed to 8-10m wide, but several deeper (2-4m deep) pools remain on the bends in the river (Fig. 8). Upstream of T9 the estuary was <8m wide, and became steep-sided with a relatively constant depth of 1.5-2m for its remaining ~2km extent.

Seagrass (*Ruppia*) was relatively widely distributed in the subtidal reaches of the middle and upper estuary, with beds starting to appear as isolated patches ~100m upstream of the footbridge in the middle estuary (T5), before becoming common on both sides of the upper channel between T7 and T10 (see Fig. 5). Poor water clarity limited the ability to assess seagrass in January 2020 but it was not observed upstream of T10 during the sampling undertaken. The seagrass present covered 0.3ha (4.5%) of the subtidal zone and extended to a depth of ~1.5m, with beds typically 1-2m wide. Seagrass was not mapped in the broad scale assessment of the estuary undertaken in 2018 (Robertson & Robertson 2018).

Intertidal salt marsh (Table 4) was not particularly extensive (1.2ha, 9% of the intertidal area) and was dominated by sedgeland (69%) and rushland (28%). Herbfield was sparse (3%), being most common in the sandy sediments near the coastal dunes.

Table 4. Summary of dominant salt marsh cover, Waikawa Estuary 2020.

Class, Dominant and primary subdominant species	Ha	%
Sedgeland	**0.8**	**69.3**
Schoenoplectus pungens (Three square)	0.3	29.3
Cotula coronopifolia (Bachelor's button)	0.01	0.6
Juncus kraussii (Searush)	0.004	0.3
Schoenoplectus validus (Lake clubrush)	0.3	26.1
Spartina anglica (Cord grass)	0.02	1.3
Schoenoplectus validus (Lake clubrush)	0.01	1.0
Isolepis prolifera (Budding clubrush)	0.1	6.4
Spartina anglica (Cord grass)	0.1	4.3
Rushland	**0.3**	**28.0**
Juncus kraussii (Searush)	0.01	0.6
Apodasmia similis (Jointed wirerush)	0.3	21.3
Festuca arundinacea (Tall fescue)	0.04	3.4
Plagianthus divaricatus (Salt marsh ribbonwood)	0.03	2.7
Herbfield	**0.03**	**2.7**
Cotula coronopifolia (Bachelor's button)	0.01	0.6
Samolus repens (Primrose)	0.02	1.7
Schoenoplectus validus (Lake clubrush)	0.004	0.4
Grand Total	**1.2**	**100**



Intertidal Substrate	Ha	%
Artificial	0.01	0.2
Boulder/Cobble/Gravel	0.04	0.6
Sand (0-10% mud)	4.5	70.9
Muddy Sand (>10-25% mud)	0.2	2.5
Muddy Sand (>25-50% mud)	0.6	9.3
Sandy Mud (>50-90% mud)	1.0	16.5
Total	6.3	100

Fig. 5. Map showing broad scale results for salt marsh, seagrass and intertidal substrate.

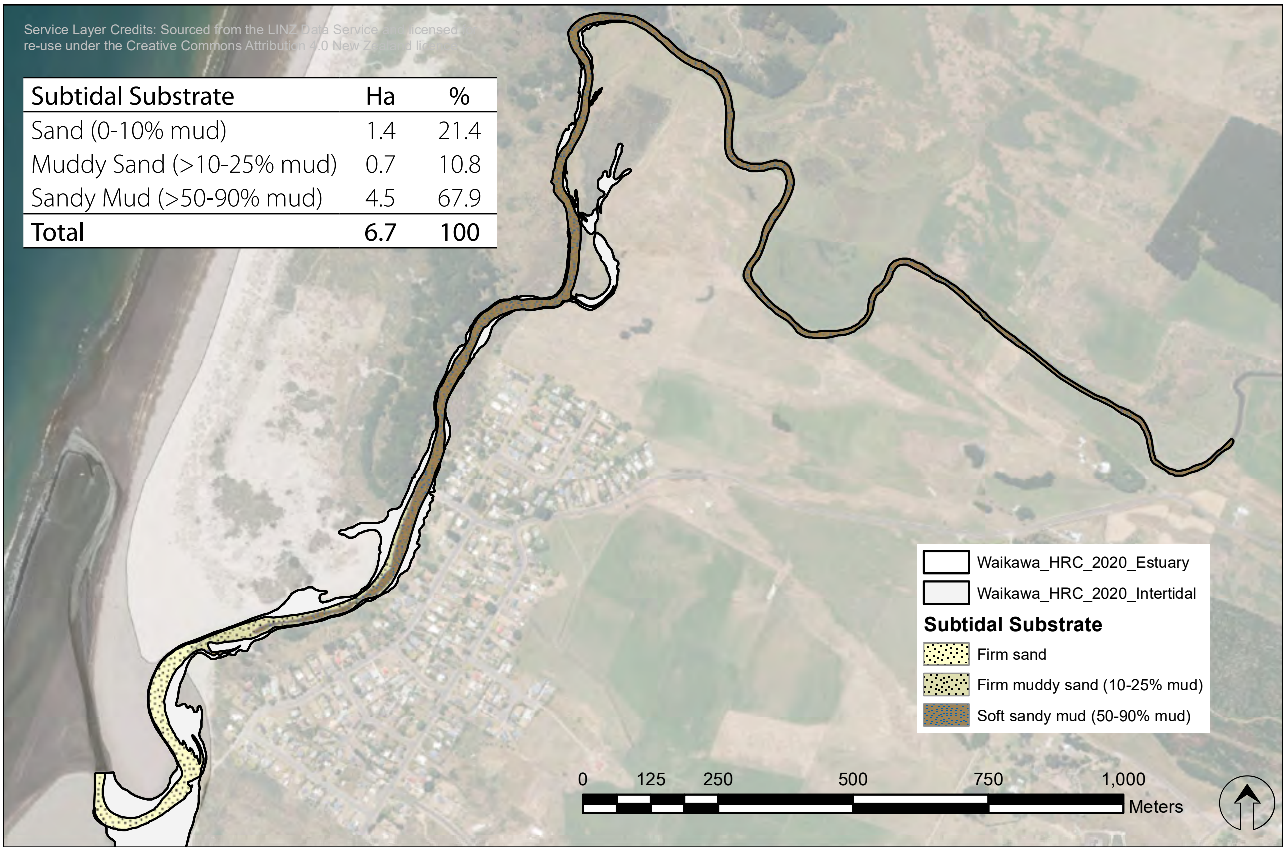


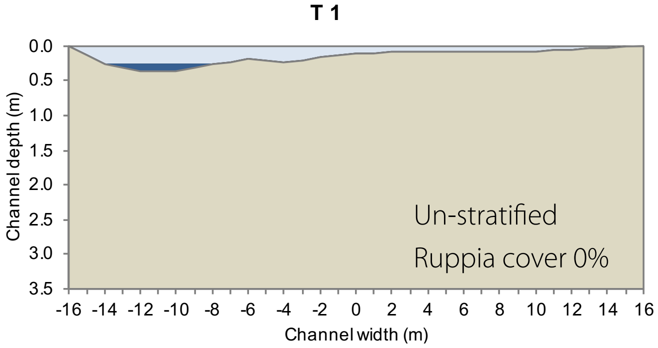
Fig. 6. Map showing broad scale subtidal substrate composition.

The salt marsh areas remaining connected to estuarine flows were confined to narrow bands along the upper intertidal reaches with sedgeland (primarily three square) growing along the lower edge and rushland (sea rush and jointed wire rush) nearer the terrestrial margins. Common salt-tolerant species were scarce upstream of T9 with vegetation being dominated by freshwater species. This part of the upper estuary has near vertical banks and the plants present were most commonly growing semi-submerged in bands ~0.5m 1m wide with pasture immediately on their terrestrial margin (Figs 8 and 9).

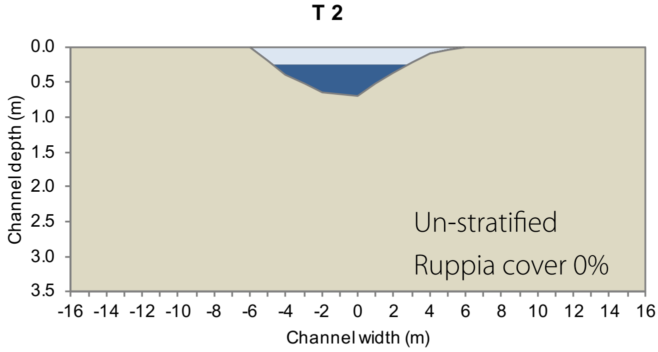
The introduced cord grass *Spartina* was present in several places in the middle estuary between T5 and T9, and became more widespread upstream of T9.

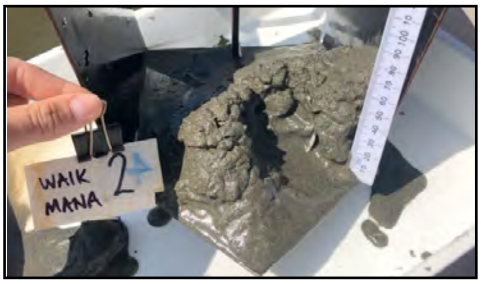
Fig. 9 summarises the land cover in the 200m terrestrial margin of the estuary based on LCDB classifications. Land cover was dominated by high producing grassland (42%) flanking both sides of the upper estuary, and low producing grassland (25%) located predominantly on the coastal margins and dune systems. Unvegetated sand (9%) and exotic forest (9%) were also prominent in this area. The built-up settlement of Waikawa covered 9% on the east side of the middle estuary. The total area of the 200m terrestrial margin considered to be densely vegetated was 12.8%.

Modification of much of the margin has cut off many areas of former salt marsh from regular tidal flows and these remnants are now very much terrestrial in nature with introduced grasses and weeds common. Approximately 5.2ha was classified as having saline or wetland vegetation reflecting areas that have an intermittent or past connection to the estuary.

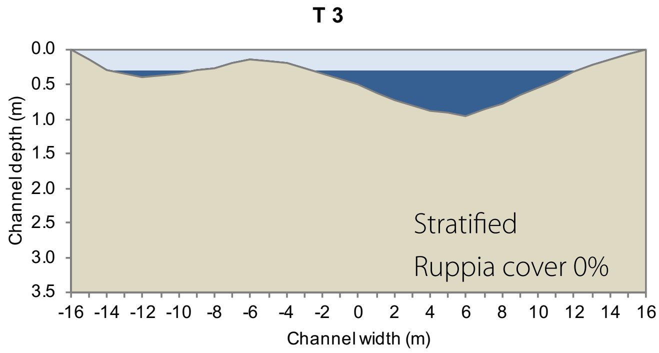


T1 Firm sand, aRPD >50mm

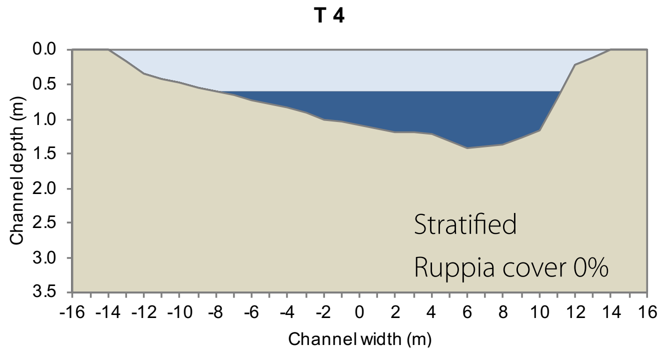




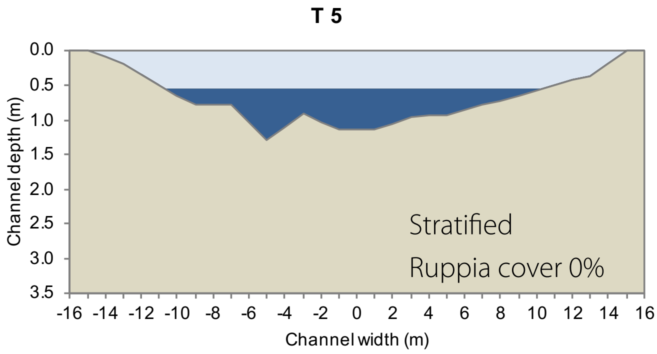
T2 Mobile sand, aRPD >50mm



T3 Soft mud, aRPD 23mm

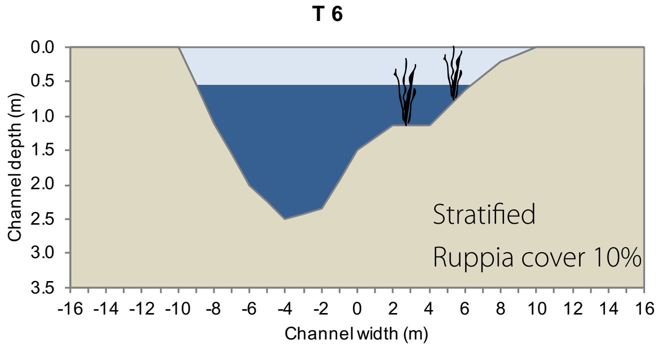


T4 Firm mud/sand, aRPD 15mm

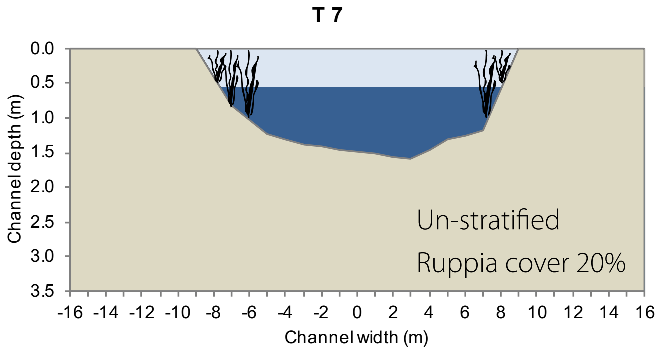


T5 Soft mud, aRPD 15mm

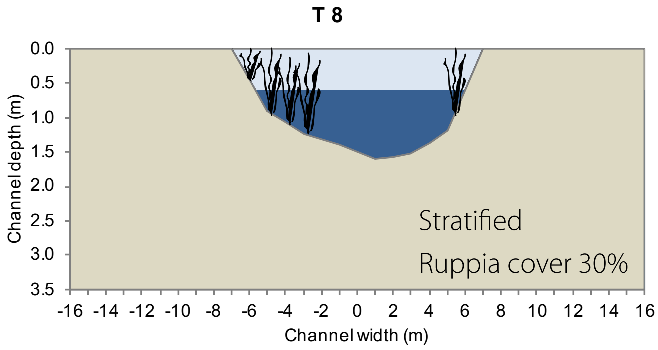
Fig. 7. Cross-section of the lower to middle Waikawa Estuary showing bed height, presence of salinity stratification, extent of seagrass (*Ruppia*) cover, substrate type and aRPD depth.

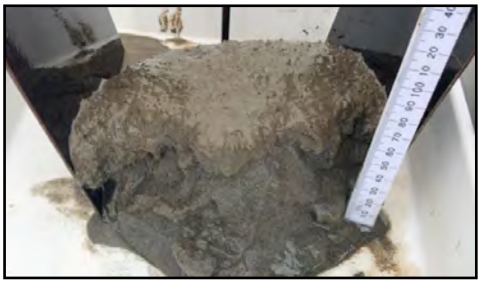


T6 Very soft mud, aRPD 5mm

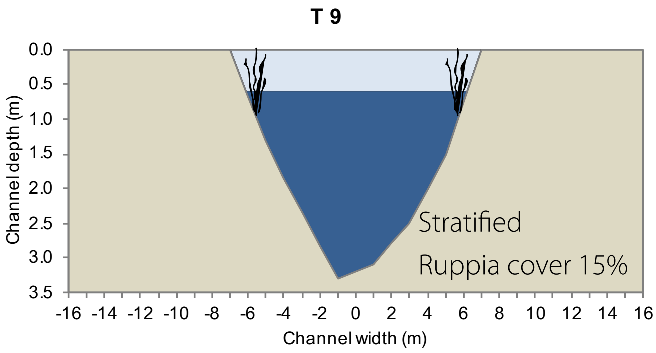


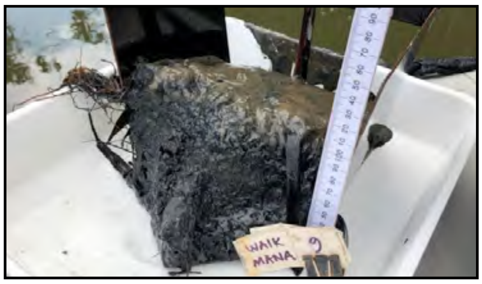
T7 Soft mud, aRPD 2mm



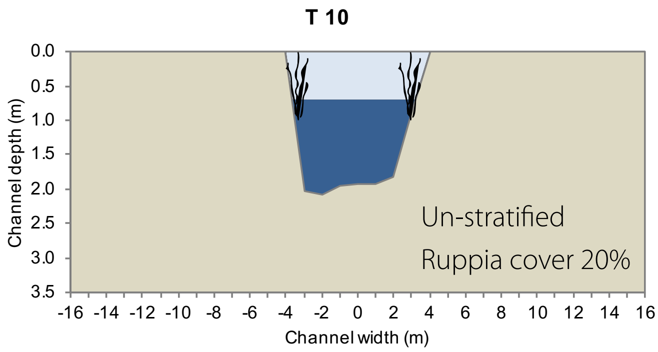


T8 Soft mud, aRPD 20mm



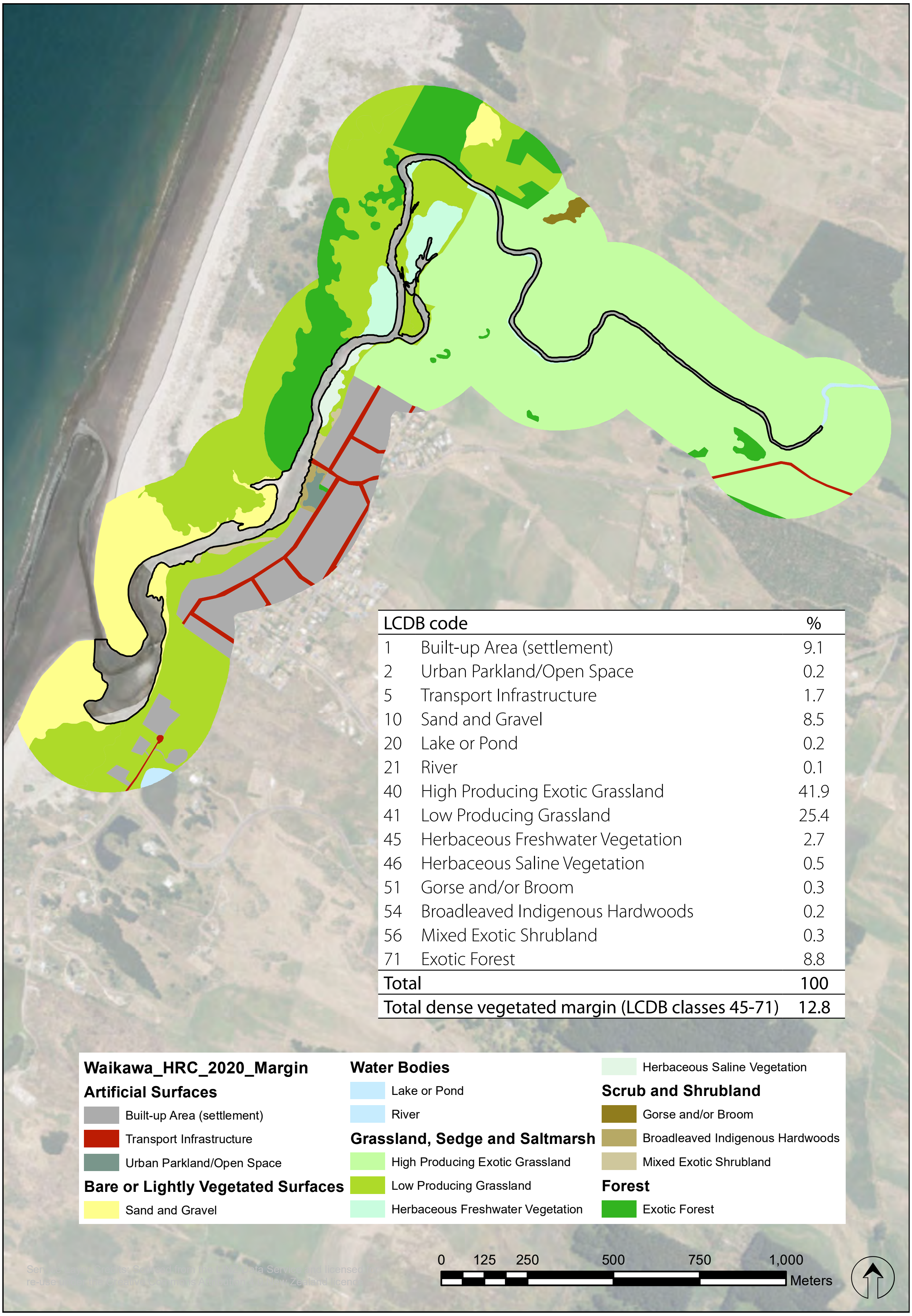


T9 Very soft mud, aRPD 1mm



T10 Soft mud, aRPD 10mm

Fig. 8. Cross-section of the middle to upper Waikawa Estuary showing bed height, presence of salinity stratification, and extent of seagrass (*Ruppia*) cover, substrate type and aRPD depth.



LCDB code		%
1	Built-up Area (settlement)	9.1
2	Urban Parkland/Open Space	0.2
5	Transport Infrastructure	1.7
10	Sand and Gravel	8.5
20	Lake or Pond	0.2
21	River	0.1
40	High Producing Exotic Grassland	41.9
41	Low Producing Grassland	25.4
45	Herbaceous Freshwater Vegetation	2.7
46	Herbaceous Saline Vegetation	0.5
51	Gorse and/or Broom	0.3
54	Broadleaved Indigenous Hardwoods	0.2
56	Mixed Exotic Shrubland	0.3
71	Exotic Forest	8.8
Total		100
Total dense vegetated margin (LCDB classes 45-71)		12.8

Fig. 9. Land cover of the 200m terrestrial margin of Waikawa Estuary, Jan. 2020.

3.2 WATER QUALITY

Fig. 10 presents a schematic longitudinal cross-section of the estuary from the open coast to the upstream Waikawa River illustrating how seawater can be trapped beneath surface freshwater flows, particularly in deeper pools. These deeper parts of the estuary tend to be those that experience the greatest water quality degradation, as stratification of the water column increases the retention time of bottom waters and facilitates the growth of phytoplankton. These areas are also commonly the least well flushed and most favourable for the settlement of sediments and organic matter.

Results of field measurements collected in Jan. 2019 and Jan. 2020 are presented in Tables 5 and 6 respectively, and Figs 11 and 12 plot surface and bottom water measurements of temperature, salinity, chlorophyll-a and dissolved oxygen, and halocline depths.

With regard to salinity, the main difference between the 2019 and 2020 results was an increase in the upstream extent of seawater intrusion in 2020. In 2019 seawater extended ~2.2km upstream (to between sites T9 and T10) with the halocline at T9 relatively deep (2.2m). In 2020, seawater extended >4km upstream with the halocline 0.7m deep at T9 and 1.2m deep at Site 13, indicating a much larger volume of seawater in the estuary in 2020. No comparison can be made with the 2018 results of Robertson and Robertson (2018) as the depth of stratification was not reported, and the upstream extent of salinity intrusion was not measured.

HRC has monitored water quality monthly from 2006-2020. At site 'Waikawa at Huritini', located immediately upstream of Site 13 (see Fig 3), no saline intrusion has been detected in surface waters (measured at 0.2m deep). However, as the vertical profile is not measured by HRC, it is not possible to assess the frequency of seawater intrusion at this site. As vertical stratification was measurable in Jan 2020 under relatively low flow conditions at low tide during a neap tidal period, it is expected that seawater intrusion and stratification is likely to be common.

The significant increase in seawater intrusion to that measured previously greatly increases the extent of the estuary that is potentially exposed to impacts from degraded water quality.

Such impacts are readily apparent with severely depleted dissolved oxygen concentrations measured in stratified bottom waters in both 2019 and 2020 (Figs 11a and 12a respectively). The 'poor' threshold is <4g/m^3 for dissolved oxygen, with several sites (in particular the deeper pools) having dissolved oxygen concentrations of <1g/m^3.

Bottom water dissolved oxygen and sediment oxygenation (aRPD depth) data were used to map areas subject to depleted oxygen levels (shown in Fig. 13). The results indicated that ~2.7ha (40%) of the sub-

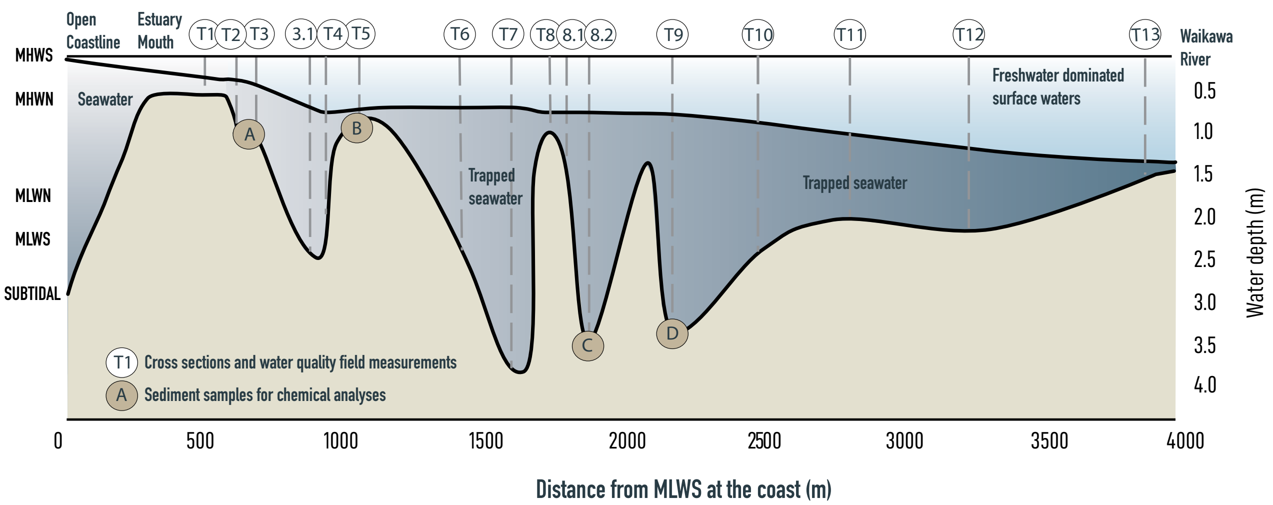


Fig. 10. Simplified longitudinal cross-section of lower Waikawa Estuary showing bed height, sediment sampling locations and location of channel cross-sections.

The sea is shown on the left and the Waikawa River on the right. Where sand builds up at the mouth of the estuary, a raised sill is present which constricts the flow of water to the sea. Tidal seawater floods into the estuary at high tide, and freshwater and seawater mix and flow out at low tide. Because seawater is more dense than freshwater, freshwater floats on top of seawater. This can trap seawater where it can support the growth of phytoplankton blooms causing water quality to degrade. This commonly occurs in deeper pools in the upper estuary under periods of low flow.

Table 5. Summary of 2019 field measurements collected at each sampling site. Refer to Fig. 3 for site locations.

Survey date: 2/02/2019

Station	T1	T2	T3(A)	T4	T5(B)	T6	T7	T8	8.2(C)	T9	T10(D)
NZTM East	1781080	1781099	1781195	1781403	1781516	1781596	1781737	1781796	1781767	1781799	1782086
NZTM North	5493384	5493419	5493434	5493531	5493717	5493993	5494059	5494089	5494281	5494560	5494425
Distance from mouth (m)	550	590	680	920	1150	1440	1600	1670	1870	2170	2535
Measurement depth (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Temperature (°C)	23.3	23.2	23.8	23.9	23.5	22.9	21.7	21.2	20.3	20.3	20.1
DO saturation (%)	81	80	80	75	70	84	79	87	85	85	86
DO conc (g/m^3)	6.9	6.8	6.7	6.2	5.9	6.9	7.0	7.9	7.6	7.7	7.8
Salinity (ppt)	0.6	0.6	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1
pH	8.1	8.1	8.1	7.8	8.1	8.4	8.0	8.1	8.9	7.9	8.2
Chlorophyll-a (mg/m^3)	1	1	1	1	1	1	0	0	0	0	0
Stratified	no	no	yes	yes	yes	yes	no	yes	yes	yes	no
Halocline depth (m)	na	na	0.8	1.2	1.2	1.7	na	1.5	2.1	2.0	na
Thermocline depth (m)	na	na	0.8	1.2	1.2	1.7	na	1.5	0	0	na
Measurement depth 2 (m)	na	na	0.9	1.3	1.25	2.0	na	1.35	2.2	2.2	na
Temperature 2 (°C)	na	na	22.6	22.6	22.5	20.3	na	20.0	20.2	20.2	na
DO saturation 2 (%)	na	na	73	40	58	14.3	na	80	15	7	na
DO conc 2 (g/m^3)	na	na	6.2	3.1	5.0	1.0	na	7.1	0.9	0.5	na
Salinity 2 (ppt)	na	na	1.5	20.4	0.5	25.7	na	0.1	25.9	25.9	na
pH 2	na	na	7.6	7.4	7.8	7.4	na	7.9	7.3	7.1	na
Chlorophyll-a 2 (mg/m^3)	na	na	2	5	1	17	na	0	20	7	na
Secchi depth (m)	>0.4	>0.7	0.9	0.9	0.9	1.2	1.1	1.0	1.2	1.5	1.4
Max depth (m)	0.4	0.7	1.0	1.4	1.3	2.5	1.6	1.6	2.3	3.3	1.9
Channel width (m)	32	11	32	27	30	20	18	13	18	12	7
Sediment texture	Firm	Mobile	Soft	Firm	Soft	Very Soft	Very Soft	Soft	Very Soft	Very Soft	Soft
Sediment type	S0_10	S0_10	MS25_50	MS25_50	SM50_90	SM50_90	SM50_90	SM50_90	SM50_90	SM50_90	SM50_90
aRPD depth (mm)	50	50	23	15	15	5	2	20	0	1	10

S0_10=sand (<10% mud), MS10_25=muddy sand (10-25% mud), MS25_50=muddy sand (25-50% mud), SM50_90=sandy mud (50-90% mud)

Indet.=indeterminate, na=not applicable/not assessed

Channelised upper estuary upstream of T10

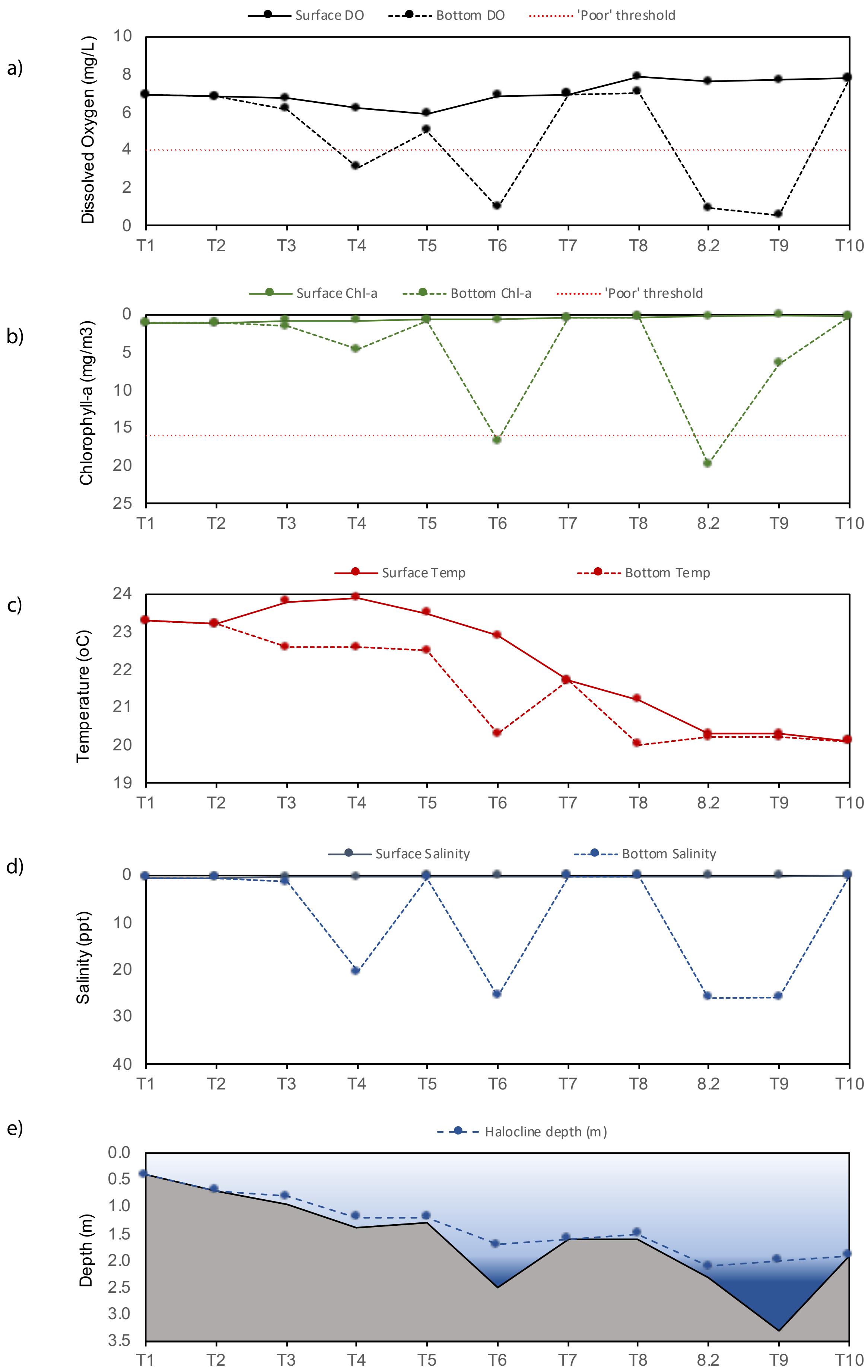


Fig. 11. Water quality measurements collected in Jan 2019 showing surface and bottom water results for: a) dissolved oxygen; b) chlorophyll-a; c) temperature; d) salinity; and e) halocline depth.

Table 6. Summary of 2020 field measurements collected at each sampling site. Refer to Fig. 3 for site locations.

Survey date: 18/01/2020

Station	T1	T2	T3(A)	3.1	T4	T5(B)	T6	T7	T8	8.1	8.2(C)	8.3	T9	T10(D)	11	12	13
NZTM East	1781056	1781099	1781189	1781392	1781438	1781520	1781607	1781771	1781787	1781800	1781770	1781823	1781793	1782066	1782199	1782397	1782865
NZTM North	5493402	5493417	5493440	5493495	5493522	5493713	5493984	5494057	5494081	5494163	5494270	5494473	5494551	5494469	5494291	5494127	5493798
Distance from mouth (m)	550	590	680	890	950	1150	1440	1640	1670	1750	1870	2080	2170	2500	2770	3350	3950
Measurement depth (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Temperature (°C)	18.2	17.8	18.3	19.2	18.9	19.2	21.5	20.9	21.4	21.4	21	20.8	20.7	20.2	19.7	18.6	17.8
DO saturation (%)	87	82	87	91	96	87	93	90	79	77	73	72	63	69	70	80	96.7
DO conc (g/m^3)	8.0	7.7	8.0	8.2	8.7	7.9	8.1	7.6	6.9	6.8	6.5	6.4	6.1	6.2	6.3	7.5	9.13
Salinity (ppt)	2.7	2.2	2.1	1.8	1.7	1.5	1.4	2.8	1.3	1.2	1.2	1.0	1.0	0.8	0.7	0.3	0.12
pH	7.9	7.7	8.0	8.5	8.0	8.3	8.1	8.6	8.5	8.1	8.2	8.2	8.1	7.8	8.1	8.3	7.66
Chlorophyll-a (mg/m^3)	3	3	4	3	3	2	2	2	2	2	2	1	1	1	1	1	1
Stratified	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Halocline depth (m)	0.25	0.25	0.3	0.55	0.6	0.55	0.55	0.55	0.6	0.6	0.6	0.6	0.6	0.7	0.8	1.0	1.2
Thermocline depth (m)	0.25	0.25	0.3	0.55	0.6	0.55	0.55	0.55	0.6	0.6	0.6	0.6	0.6	0.7	0.8	1.0	1.2
Measurement depth 2 (m)	0.5	0.8	0.95	2.0	1.0	0.8	2.2	3.0	1.4	0.9	3.1	1.2	2.8	2	1.8	1.7	1.3
Temperature 2 (°C)	20.2	18.3	18.4	19.2	21.1	22.3	20.8	18.7	21.8	21.6	19.3	20.9	20.1	21.6	21.2	20.4	18.8
DO saturation 2 (%)	105	85	63	39	108	103	16	14	120	121	3	75	16	49	55	43	35
DO conc 2 (g/m^3)	8.6	6.3	4.8	2.8	8.2	8.3	1.2	1.0	8.4	9.3	0.2	6.8	0.8	3.6	4.0	3.2	2.8
Salinity 2 (ppt)	16.2	30.2	30.2	31.9	28.1	23.7	30.2	28.7	25.5	21.8	29.4	22.4	26.8	24.4	24.4	22.4	19.3
pH 2	7.8	7.6	7.5	7.5	7.8	7.7	7.4	7.5	7.7	7.5	7.3	7.2	7.1	7.0	7.3	7.0	6.7
Chlorophyll-a 2 (mg/m^3)	18	35	14	4	46	35	11	3	26	19	20	12	4	5	7	11	10
Secchi depth (m)	>0.6	0.85	0.95	0.9	0.95	>0.9	1.1	1.1	1.0	1.0	1.1	1.2	1.1	1.2	1.2	1.1	1.2
Max depth (m)	0.6	1.0	1.0	2.3	1.1	0.9	2.4	3.5	1.4	1.0	3.2	1.3	3.1	2.2	1.9	2.0	1.4
Channel width (m)	32	11	32	18	27	30	20	18	13	19	18	14	12	7	10	10	8
Sediment texture	Firm	Firm	Firm	Very Soft	Soft	Very Soft	Very Soft	Very Soft	Very Soft	Very Soft	Very Soft	Very Soft	Very Soft	Soft	Firm	Firm	Firm
Sediment type	S0_10	S0_10	S0_10	SM50_90	MS25_50	MS25_50	SM50_90	SM50_90	SM50_90	SM50_90	SM50_90	SM50_90	M90_100	MS10_25	S0_10	S0_10	SM50_90
aRPD depth (mm)	>80	>70	>60	3	60	55	20	999	>70	10	10	10	1	indet	indet	indet	indet

S0_10=sand (<10% mud), MS10_25=muddy sand (10-25% mud), MS25_50=muddy sand (25-50% mud), SM50_90=sandy mud (50-90% mud)

Indet.=indeterminate, na=not applicable/not assessed

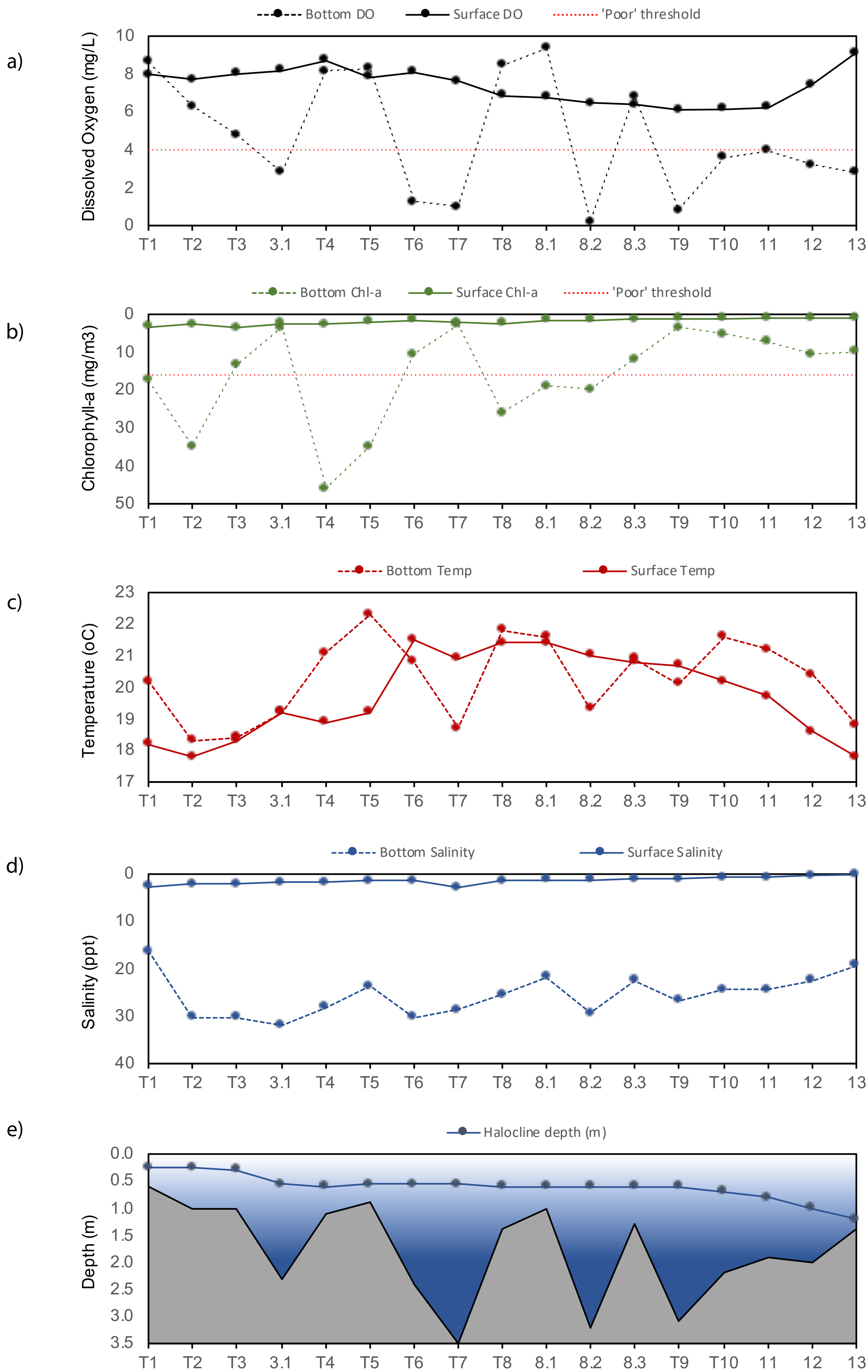


Fig. 12. Water quality measurements collected in Jan 2020 showing surface and bottom water results for: a) dissolved oxygen; b) chlorophyll-a; c) temperature; d) salinity; and e) halocline depth.

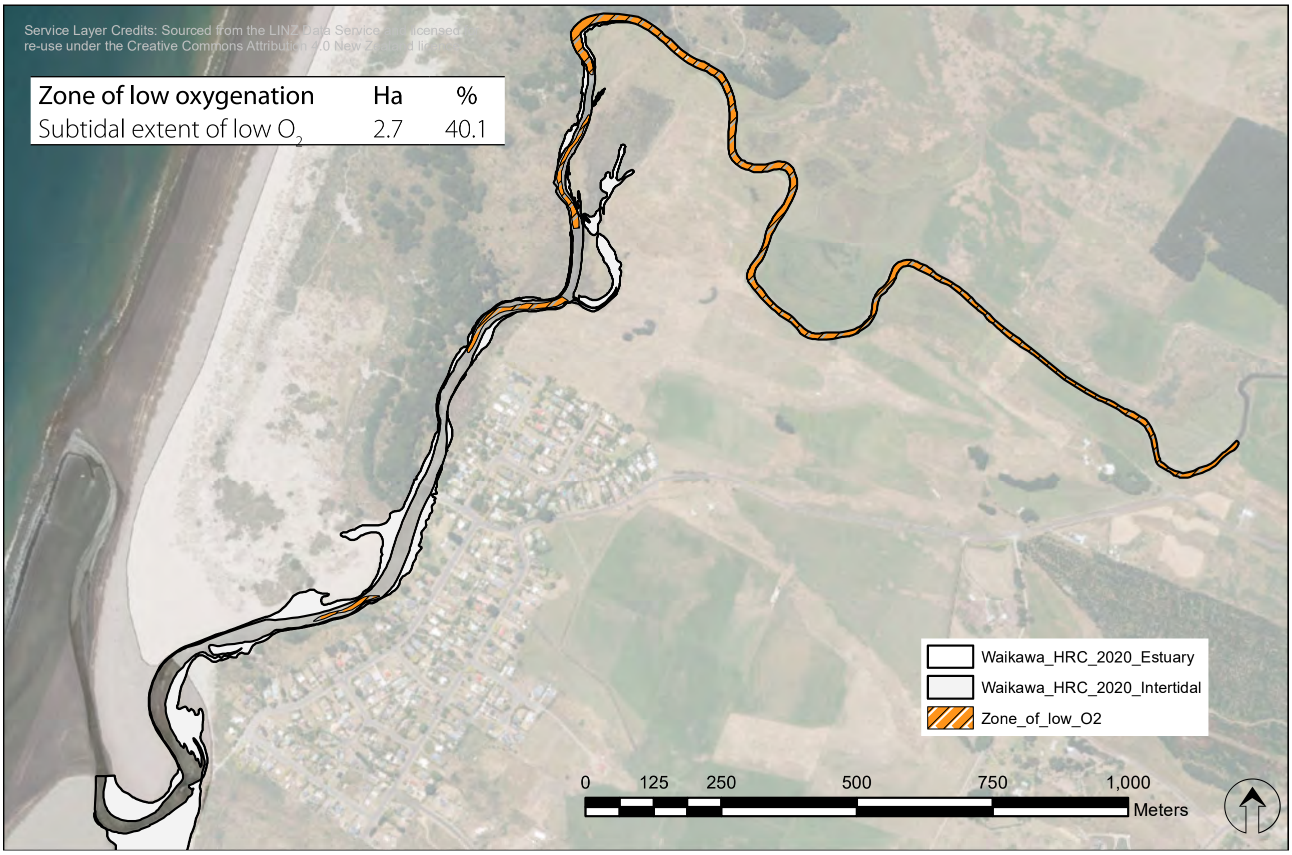


Fig. 13. Map showing broad scale sub-tidal bottom water oxygenation.

Bottom water oxygenation was measured in situ and used alongside sediment aRPD measurements to assess the extent of sub-tidal oxygen depletion. Although instantaneous measures are subject to high temporal and spatial variance, they still provide a useful synoptic tool for assessing estuary condition.

tidal area had very low oxygen levels at the time of sampling. This is a large increase to the 0.5ha (9%) recorded in 2019. No assessment was made of sub-tidal condition in 2018. The area of high enrichment conditions reflected by these results substantially exceeds the 'poor' threshold of 10% included in the ETI (Robertson et al. 2016b).

Phytoplankton concentrations, assessed *in situ* by the fluorescence of chlorophyll present in the algae (i.e. chlorophyll-a measurement), were low in surface waters in both 2019 (<1mg/m^3) and 2020 (1-4 mg/m^3), but relatively high (3-46mg/m^3) in the deeper stratified bottom waters. Surface waters were in the 'very good' ETI rating category, while many of the bottom water sites were in the 'poor' category. It is important to note however that chlorophyll-a maxima commonly occur near the halocline and will not necessarily be captured by surface and bottom water sampling. These blooms were identified as being non-toxic and dominated by *Prymnesium parvum/Rhinomonas* spp. with smaller numbers of flagellates/unicells and various dinoflagellates and diatoms (Appendix 2)

In 2019, temperatures were warmer in the shallower parts of the lower estuary, and 2-3°C cooler in the up-stream sections where flow from the Waikawa River dominates (Fig 11c). A much more variable pattern was evident in 2020 with cooler temperatures near the coast and in the upstream Waikawa River, and warmer temperatures between sites T4 and T10. At most sites surface and bottom water temperatures were within 2°C and although bottom waters were more variable in temperature than surface waters, no distinct thermocline was present.

3.3 SEDIMENT PHYSICAL AND CHEMICAL CHARACTERISTICS

A summary of the 2020 composite sediment sample data collected from four sites is provided in Table 7 (see Appendix 2 for raw data from the laboratory and Fig. 3 for site locations). Data from 2018 and 2019 are also presented for comparative purposes. Site C was located in sediments assessed as representing the most impacted 10% of the estuary in 2020 and used in the calculation of a NZ ETI score for the estuary (further described in Section 3.4). Sediment measures summarised in Table 7 were collected from the deepest point in the channel.

3.3.1 Sediment grain size

Laboratory analyses revealed that in the lower estuary (Site A) the mud fraction was very low (<2%) in both 2018 and 2019, but was higher in 2020 (8.4%). In the middle and upper estuary (Sites B-D) mud content was higher (17-68%) but showed variance between years suggesting both erosion and deposition of fine material is relatively common (Fig. 14).

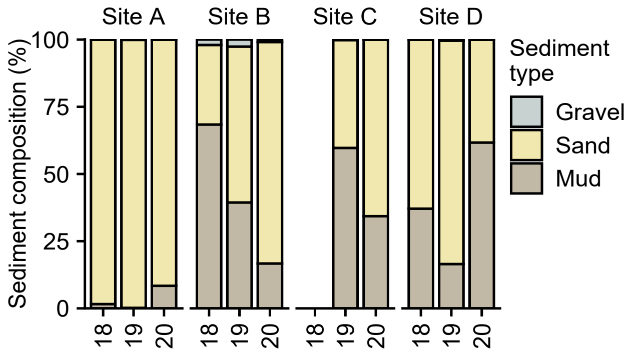


Fig. 14. Sediment particle grain size analysis, showing site-averaged percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm).

3.3.2 Total organic carbon and nutrients

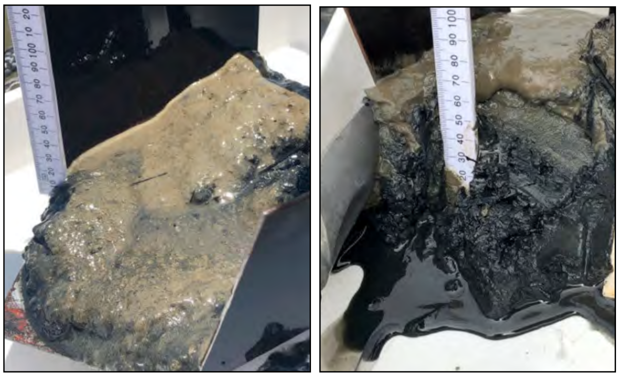
Total organic carbon (TOC) and nutrient (TN and TP) values were generally correlated with sediment grain size, being highest in the muddier sediments.

The highest values in 2020 were at Site D. Values at this site were relatively low in 2019. This site is located in a relatively straight stretch of the upper estuary and is likely to scour out during flood events but accumulate sediment and organic material at other times when flow velocities are lower.

3.3.3 Redox status

The depth to the apparent Redox Potential Discontinuity (aRPD) transition was deepest at Site A (23->60mm), a condition rating of 'good' or 'very good'. At Site B, aRPD was 10-15mm in 2018 and 2019, resulting in a condition rating of 'fair', and 55mm in 2020, giving a rating of 'very good'. Further upstream at sites C and D, aRPD depth was <10mm, and rated 'poor'.

The aRPD horizon was closely correlated with sediment grain size, being deeper in more porous sandy sediments which enable much greater oxygenation of the sediment matrix than occurs in enriched muddy sediments. This result is evident from core photographs in Figs 7 and 8. The photos below illustrate the finding that in many parts of the estuary a shallow layer of brown oxic mud was present overlying oxygen-reduced black-coloured sediment.



Oxic brown surface muds over black anoxic sediment at Sites 3.1 (left) and 8.2(C) (right)

Table 7. Sediment grain size, nutrient, aRPD, trace metal and metalloid results for composite samples collected at four sites in 2020, and showing comparison with 2018 and 2019 results.

Site	Year	Mud %	TOC %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	AMBI na
A	2018	1.6	0.10	< 500	280	>30	3.4	< 0.010	7.4	2.6	< 0.02	7.2	3.2	23.0	-
	2019	0.2	< 0.05	< 500	270	23	3.0	< 0.010	7.4	2.5	< 0.02	6.0	2.9	23.0	-
	2020	8.4	0.13	< 500	300	>60	3.5	< 0.010	8.0	3.0	< 0.02	7.0	3.6	26.0	4.4
B	2018	68.4	3.00	2100	760	10	6.4	0.072	14.2	10.6	0.12	14.0	14.0	59.0	-
	2019	39.4	0.76	700	520	15	4.7	0.018	12.5	5.7	0.03	9.3	7.1	42.0	-
	2020	16.7	0.50	< 500	420	55	3.7	0.020	10.0	6.0	0.03	8.0	6.0	33.0	4.3
C	2018	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2019	59.7	1.36	1200	560	0	5.0	0.029	14.0	6.7	0.05	10.3	9.0	48.0	-
	2020	34.3	0.95	700	530	10	4.1	0.019	11.0	6.0	0.09	9.0	7.7	43.0	4.4
D	2018	37.1	1.12	700	440	10	3.1	0.044	10.4	7.3	0.07	10.4	10.0	46.0	-
	2019	16.5	0.69	600	530	10	3.9	0.027	11.7	5.5	0.05	9.8	9.8	49.0	-
	2020	61.7	2.10	1600	640	indet.	5.1	0.042	16.0	10.0	0.08	13.0	11.3	54.0	3.3

< All values below lab detection limit. Indet.=indeterminate

Refer to Fig. 3 for site locations and Table 2 for condition rating colour codes and thresholds.

It is apparent from Figs 7 and 8 that the aRPD is not always well-defined, even in relatively muddy sediments. Factors such as bioturbation (e.g. by worms, shellfish, crabs) can lead to mixing of oxic surface sediments with deeper oxygen-reduced sediments. Furthermore, as there is inherent subjectivity in aRPD measurement, variability across surveys due to interpretation can be expected. As such, it is only gross differences in aRPD that are meaningful.

3.3.4 Trace contaminants

Trace metal and metalloid concentrations were low at all sites, and less than ANZG (2018) DGV values (Table 7). There has been no meaningful change evident over the three years of sampling, suggesting no significant contaminant sources to the estuary.

3.3.5 Sediment macrofauna

In 2020 an assessment was made of the sediment dwelling community present at each of the four sediment chemistry sites. The purpose was to collect basic information on the type of species present in different parts of the estuary and to use the community composition to assess prevailing sediment conditions. Results are summarised in Table 8 and Fig. 15 with raw data in Appendix 3.

Table 8. Description of the sediment-dwelling species that were consistently the most abundant at one or more sites.

Main group & species	Site A	Site B	Site C	Site D	Description	
Amphipoda (*Paracorophium* sp. 1)	1085	899	403	30	Shrimp-like crustaceans. This is an opportunistic tube-dweller that can occur in high densities in mud and sand habitats, often in estuaries subjected to disturbance and low salinity.	
Decapoda (*Halicarcinus whitei*)	18	3	2	0	A species of pillbox crab. Lives in intertidal and subtidal sheltered and predominantly sandy environments.	
Gastropoda (*Potamopyrgus estuarinus*)	24	2466	375	164	Small endemic estuarine snail, requiring brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Tolerant of muds and organic enrichment.	
Isopod (*Pseudaega* sp. 1)	28	0	0	0	Marine isopods are in the same group as slaters. This genus is typically found on exposed sandy beaches, hence is likely to have been carried to Site A by wave surge or overwash during spring tides.	
Oligochaete worms (Oligochaeta sp. 1)	0	102	2	150	Marine oligochaetes are in the same group as terrestrial earthworms. Deposit feeders that are generally considered very pollution tolerant.	
Polychaete worm (*Capitella* sp. 1)	0	0	0	18	Subsurface deposit feeder, and a common indicator of organic enrichment. Is a dominant inhabitant of sediments polluted heavily with organic matter.	
Polychaete worm (*Scolecolepides benhami*)	0	24	1	13	A spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark.	
Polychaete worm (Spionidae sp. A)	58	0	0	0	A spionid worm, which may have been carried to Site A by wave surge or overwash during spring tides.	

Results show the macrofaunal assemblages to be relatively impoverished. In total only 19 species or higher taxa were recorded, with four of these taxa likely to have been washed into the estuary from the sea rather than being resident species.

Mean species richness was low (2-8 species/core), and abundance was variable and driven primarily by the presence of the amphipod *Paracorophium* or the estuarine snail *Potamopyrgus* which, when present, tended to be in high numbers (Fig. 15, Table 8).

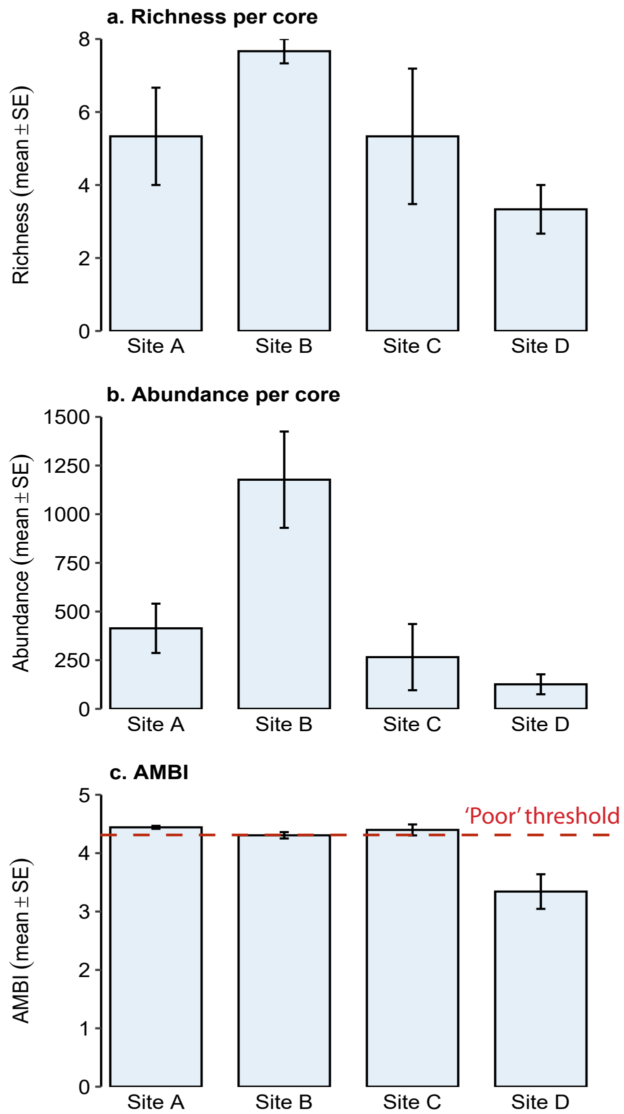


Fig. 15. Patterns (mean ± SE) in taxon richness, abundance and AMBI score per core.

The type of species present differed between sites. Site A included the four taxa likely to have been washed in from the sea (*Pseudaega* sp. 1, Spionidae sp. A and two Amphipoda). Pipi (*Paphies australis*) were the only deeper sediment dwelling species present with other taxa primarily surface dwelling species (e.g. *Paracorophium* and the estuarine snail *Potamopyrgus*).

Further upstream, Site B was the most diverse of the sites sampled. Pipi were present and anecdotally appear to be more abundant than the sampling results indicate at this site. Other taxa included the freshwater snail *Zemelanopsis trifasciata*, high numbers of *Paracorophium* and *Potamopyrgus,* and the polycheatae worms *Scolecolepides benhami and* Spionidae sp. A., all of which are relatively tolerant to pollution or disturbance.

Site C, which was very degraded in 2019, had a very sparse infaunal community with most species present being surface or shallow burrowing species. This is consistent with the anoxic sediments found at this site (see Section 3.3.1). The site with the lowest richness and abundance was Site D in the upper estuary, with the few animals present being pollution or disturbance tolerant species.

The AMBI biotic health index scores for the sites (shown in Fig 15) rate Sites A-C 'poor' and Site D 'fair'. The latter score is driven primarily by the absence of the pollution tolerant amphipod *Paracorophium* and the dominance of the moderately sensitive estuarine snail *Potamopyrgus,* most likely due to the strong freshwater influence at this site. As such the AMBI score at Site D does not accurately reflect the degraded sediment conditions present.

3.4 INTERPRETATION OF ECOLOGICAL HEALTH AGAINST CONDITION RATINGS

Broad scale spatial indicators and general indicators used to assess estuary condition and calculate an ETI score are summarised in Table 9. Broad scale indicators are assessed on an estuary-wide basis, whereas many metrics within the ETI use spot measures from within the most degraded 10% of the estuary. On the basis of poor sediment quality and very low dissolved oxygen concentrations identified in 2019, Site C was considered representative of the most impacted 10% of the estuary.

Sediment quality

As discussed previously, Table 7 summarises the ecological condition scores for key indicators of sediment chemistry comparing 2018, 2019 and 2020 results. Sediment quality was rated 'good' or 'very good' for trace contaminants and indicates that the estuary is unlikely to have any significant sediment contamination issues. Enrichment indicators, e.g. TOC, TN, aRPD, mud content, and AMBI biotic index scores, were less consistent but overall indicated that the middle and upper estuary is expressing signs of excessive enrichment.

However, the sediment chemistry results are spatially and temporally variable, and while empirical data are highly valuable, they do not always reveal the true condition of the estuary. For example, sediment quality results at Site C in 2020 were relatively good with comparatively low mud, TOC and TN concentrations (Table 7). The improvements compared to 2019 are likely to be temporary, which highlights the temporal variability present in the estuary. Based on these sediment chemistry results, an apparent improvement is suggested, but the continued presence of sediments with very low sediment oxygenation, few macrofauna and extremely low (0.2g/m^3) overlying water column dissolved oxygen concentrations confirm that Site C remains representative of the most impacted 10% of the estuary.

Temporal variability is likely to result primarily from flood events which will scour and redistribute fine sediment within the estuary and facilitate its export to the open coast. Localised accumulation will then likely occur under intervening low flow conditions, contributing to variation in the measured sediment chemistry results.

Water quality

Water quality indicators for dissolved oxygen and phytoplankton were both rated 'poor'. Bottom water dissolved oxygen concentrations were extremely low at many sites, particularly in the stratified deeper parts of the estuary where sediment oxygenation was also poor, and phytoplankton were measured in concentrations indicating bloom conditions. These results indicate there are sufficient nutrients and suitable growing conditions in the estuary to support phytoplankton blooms.

This conclusion is primarily based on synoptically measured chlorophyll-a and dissolved oxygen concentrations, and expert judgement of the enrichment status of the bottom sediments, rather than nutrient measurements. Nutrient measurements can be misleading when assessing eutrophication, particularly under bloom conditions, as nutrient concentrations may not reflect nutrient presence or availability.

Table 9. Summary of broad scale spatial indicators and general indicators reflecting the most impacted 10% of the estuary.

Indicator	Unit	State	2020 Rating	Data source
Sediment Quality				
Mud content	%	16	Fair	Current report (Site C)
aRPD depth	mm	10	Poor	Current report (Site C)
Total nitrogen	mg/kg	700	Good	Current report (Site C)
Total organic carbon	%	0.95	Good	Current report (Site C)
Trace elements	mg/kg	low	Very Good	Current report (Site C)
Water Quality				
Dissolved oxygen	mg/L	0.2	Poor	Current report (Site C)
Phytoplankton (chl-a)	mg/m^3	20#	Poor	Current report (Site C)
Broad scale spatial indicators				
Mud-dominated substrate	% of estuary >50% mud	5.5ha 42%	Poor	Current report
Macroalgae (OMBT)	EQR	1	Very Good	Default score as no macroalgae
Seagrass	% decrease from baseline	0.3ha	Very Good	Stevens (2019)
Salt marsh extent (current)	% of intertidal area	9	Fair	Current report
Historical salt marsh extent	% of historical remaining	<25	Poor	Estimated from 2020 survey
High Enrichment Conditions	ha or % of subtidal estuary	2.7ha, 40%	Poor	Current report
200m terrestrial margin	% densely vegetated	12	Poor	Current report
Sedimentation rate	CSR:NSR ratio	1.1	Very Good	Hicks et al (2019)

Refer to Fig. 3 for site locations and Table 2 for condition rating colour codes and thresholds.

Sediment and water quality indicators use Site 'C' data unless noted otherwise.

#Summer 2020 data comprise 4 samples collected from Dec 2019 to March 2020 by HRC from 0.2m at site T5 site "Waikawa at Footbridge", and 36 spot samples measured 0.2m from the surface and 0.2m from the bottom by Salt Ecology at 18 sites throughout the estuary on 18 Jan 2020.

Water column nutrient concentrations can be significantly influenced by nutrient uptake during algal growth, and nutrient release following algal decay. As such, a phytoplankton bloom has the capacity to use all the available nutrients in the water column indicating low nutrient conditions (and a low risk of algal blooms), when in fact nutrient levels may not be at all limiting. Further, the decay of a bloom may transfer much of the nutrient load into the sediment where it may become largely unavailable to fuel phytoplankton blooms, but can contribute to significant sediment degradation or fuel macroalgal or benthic microalgal blooms.

As such, it is important that the various available strands of evidence are considered in assessing overall condition. In doing this, effort was made to use HRC water quality data (summarised in Appendix 4) collected ~monthly over many years from sites located in both the middle and upper estuary. However, it was apparent that phytoplankton presence and concentration in the estuary was likely to be significantly under represented by the HRC data as sampling has only been undertaken at the surface (0.2m deep), and thus does not capture deeper phytoplankton blooms that occur. As discussed in the results, stratification of the estuary is common, and phytoplankton blooms are often concentrated near the halocline, rather than at the surface. As the halocline is variable in depth and extent through the estuary, it is likely that the current sampling design often fails to detect blooms when they are present. Further, because the sampling is from a fixed depth, it provides no information on where the peak chlorophyll-a concentrations are in the water column, nor whether or not they have been sampled, meaning estimates of actual impact are likely to be, at best, inconsistent. Another limitation is that chlorophyll-a is only measured in the middle estuary (T5), and not in the upper estuary. This means that there is no ability to determine whether blooms are developing within the estuary, or washing in from upstream areas. Another compounding difficulty in interpreting the results is the need to account for tidal influence at the time of sampling. While it is possible to sort data based on salinity, the degree to which the halocline is being sampled, and thus the extent of saline influence is difficult to determine from the available data. These factors could easily be addressed through minor modifications to the sampling programme.

Broad scale spatial indicators

In relation to mud extent, broad scale data show that the estuary condition rating was 'poor' but predicted catchment sediment inputs were relatively close to natural loads and thus rated 'very good'. In other words, while the predicted sediment loads to the estuary are relatively low, the estuary is clearly able to trap and retain fine sediment. This is reflected in the mud-dominated habitat extending across 5.5ha (42%) of the total estuary area, and comprising 68% of the subtidal area. Overall, ongoing inputs of fine mud are likely to see the estuary remain relatively muddy, but deposition rates will likely be moderated by the channelised nature of the estuary facilitating intermittent flushing under high flows.

This may also explain the general absence of nuisance macroalgae which were not observed in the summer surveys undertaken in 2018, 2019 or 2020 (a rating of 'very good'). While small areas of macroalgae (*Ulva* spp.) were growing along the margins of the lower estuary in 2016, biomass was low (e.g.<200g/m^2), and algae was not entrained (growing within sediments), and therefore likely to be readily flushed from the estuary under high flow conditions.

The salt marsh extent (1.2ha, 9%) was rated 'fair', and the estimated reduction from historical extent was rated 'poor'. As noted in Section 1.3, one of the reasons for undertaking repeat broad scale intertidal mapping in 2020 was to address inconsistencies between the 2016 and 2018 mapping results. These were found to relate primarily to differences in the 2018 GIS files and the summary report supplied by Robertson Environmental. The current work provides updated GIS files for the estuary.

The integrated metric of high enrichment conditions (i.e. the spatial extent of low oxygen, elevated TOC, high mud and nutrients) indicated ~40% of the subtidal estuary was in a poor state with widespread impacts.

Overall, the ETI score for the estuary, calculated using Table 9 data and NIWAs online Tool 2 calculator was 0.88, which corresponds to a rating of 'poor', the same rating as recorded in 2018 and 2019.

This 'poor' rating is scored despite the primary driver of the ETI score being phytoplankton biomass which is likely to be under-represented by the current HRC sampling programme.

4. SYNTHESIS AND RECOMMENDATIONS

4.1 SYNTHESIS OF KEY FINDINGS

In 2020 seawater extended ~4km upstream from the entrance with stratified seawater was trapped below freshwater throughout the 13ha estuary. Subtidally, 68% of the sediments were mud-dominated, mostly in the upper and middle estuary, and within deeper mid-channel sections of the lower estuary, while sands (71%) dominated intertidal substrate. Salt marsh was not particularly extensive (1.2ha, 9% of the intertidal area) and was dominated by sedgeland (69%) and rushland (28%). Herbfield was sparse (3%). Subtidal seagrass (*Ruppia*) was widely distributed (0.3ha, 4.5%) in the middle and upper estuary growing to a depth of ~1.5m, with beds typically 1-2m wide.

Subtidal sediment chemistry results indicate that the estuary is unlikely to have any significant sediment contamination issues while macrofaunal assemblages were relatively impoverished and dominated by disturbance tolerant species. In total only 19 species or higher taxa were recorded, with four taxa likely to have been washed into the estuary from the sea.

Water quality measurements in Jan 2020 showed phytoplankton present throughout the estuary and dissolved oxygen levels at severely low concentrations (0.2-1.0g/m^3) in deeper pools and below the ETI threshold for 'poor' (<4g/m^3) throughout most of the upper estuary. These degraded conditions were not apparent in the monthly HRC water quality monitoring results due to limitations with the current sampling programme. The presence of such low oxygen levels, even for as few as several hours over a tidal cycle will cause severe adverse ecological effects, particularly to fish (see Franklin (2014) for further background). Sediment oxygenation was also low indicating the persistence of low oxygen conditions over prolonged periods. The spatial extent of high enrichment conditions (HEC; low oxygen, elevated TOC, mud and nutrients) was ~2.7ha (40%) of the subtidal area, a large increase to the ~0.5ha (9%) recorded in 2019.

Overall the results indicate that the estuary is continuing to express strong symptoms of eutrophication with large parts of the upper estuary currently adversely impacted by elevated catchment inputs of nutrients and, to a lesser degree, sediments.

4.2 RECOMMENDATIONS

In terms of SOE estuary monitoring, Waikawa Estuary has now been assessed on four occasions in the last five years. The first two surveys focused on intertidal areas, while the latter two have focused on subtidal areas. In light of the significant eutrophication symptoms identified it is recommended that HRC consider the following:

1. Sampling be undertaken in the summer of 2021 to monitor the spatial extent and nature of eutrophication impacts. This should include boat-based sampling of subtidal sediments and water quality throughout the subtidal reaches of the upper estuary. Ideally a second set of measures would be undertaken immediately following a flood event to determine the capacity for the estuary to flush out excessive sediments, nutrients and low oxygen waters.
2. Design and implement a long-term programme for regular monitoring of estuary condition linked to existing freshwater SOE monitoring. This work should include the deployment of water quality loggers in eutrophic parts of the estuary, more frequent field assessments utilising vertical profiling to characterise the nature and extent of the current problems, and amending the current HRC water quality programme to, at a minimum, record the halocline depth and measure the highest concentration of chlorophyll-a and the lowest concentration of dissolved oxygen in the water column at the two existing HRC estuary sites.
3. Undertake a bathymetric survey of the estuary to enable accurate delineation of areas likely to stratify, and to underpin hydrodynamic models HRC are currently considering using. These models will be used to estimate nutrient concentrations and predict ecological outcomes under changed nutrient and sediment management in the catchment.
4. Undertake an assessment of catchment sources of nutrients and sediments to the estuary to determine whether changes to current land management practices are likely to significantly improve ecological condition and to guide council management priorities.
5. From 3 and 4 above, establish limits for catchment sediment and nutrient inputs that will protect the estuary from degradation.
6. There is potential to restore or enhance many of the terrestrial salt marsh remnants currently isolated from tidal flows. The benefits of carbon sequestration, erosion protection and maintenance and enhancement of biodiversity through increasing salt marsh extent may exceed those of marginal grassland and HRC are encouraged to explore restoration opportunities with current land owners. GIS-based inundation mapping based on coastal LIDAR data can be used to highlight priority areas.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP 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.

Habitat classification and mapping

Broad-scale surveys involve describing and mapping estuaries according to the dominant surface habitat features (substrate and vegetation) present. The mapping procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats can be monitored by repeating the mapping exercise.

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system defined in the NEMP (Robertson et al. 2002), whereby dominant estuarine plant species were used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock) (Table A1.1). Vegetation was coded using the two first letters of the genus and species, e.g. sea rush *Juncus kraussii*, was coded as Jukr. Plants were listed in order of dominance with subdominant species placed in parentheses, e.g. Jukr(Caed) indicates that sea rush was dominant over ice plant (*Carpobrotus edulis*). A relative measure of vegetation height can be derived from its structural class (e.g. rushland is taller than herbfield).

The NEMP approach to estuary substrate classification has been extended to record substrate beneath vegetation (salt marsh, seagrass and macroalgae) to provide a continuous substrate layer for the estuary. Furthermore, the NEMP substrate classifications themselves have been revised to provide a more meaningful classification of sediment based on mud content (Table A1.2).

Under the original NEMP classification, mud/sand mixtures can have a mud content ranging from 1-100% within the same class, and classes are separated only by sediment firmness (how much a person sinks), with increasing softness being a proxy measure of increasing muddiness. Not only is sinking variable between individuals (heavier people sink more readily than lighter people), but also in many cases the relationship between muddiness and sediment firmness does not hold true. Very muddy sediments may be firm to walk on, e.g. sun-baked muds or muds deposited over gravel beds. In other instances, soft sediments may have low mud contents, e.g. coarse muddy sands. Further, many of the NEMP fine sediment classes have ambiguous definitions making classification subjective, or are inconsistent with commonly accepted geological criteria (e.g. the Wentworth scale).

To address these issues, mud and sand classifications have been revised to provide additional resolution based on the estimated mud content of fine-grained substrates, with sediment firmness used as an independent descriptor (Table A1).

Lower-case abbreviations are used to designate sediment firmness (f=firm, s=soft, vs=very soft). Mobile substrate (m) is classified separately. Upper-case abbreviations are used to designate four fine unconsolidated substrate classes consistent with existing geological terminology (S=Sand, MS=Muddy Sand, SM=Sandy Mud, M=Mud). These are based on sediment mud content (Table A1.2) and reflect both biologically meaningful thresholds where key changes in sediment macrofaunal communities occur, and categories that can be subjectively assessed in the field by experienced scientists and validated by laboratory analyses.

In developing the revised classifications, care has been taken to ensure that key metrics such as the area of mud dominated habitat can be assessed using both the NEMP and the revised classifications so that comparisons with existing work can be made.

Table A1.1 Modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes

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 grasslike, often hollow-stemmed plant. Iincludes 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. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and are mapped separately to the substrates they overlie.

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 cholorophyll, 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 sof**t 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: boulder, cobble, gravel, sand or substrates (seawalls, bunds etc).

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%.

Shell: Area that is dominated by dead shells.

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

Sand/Shell: Granular beach sand and shell with a low mud content (i.e. 0-10%) No conspicuous fines evident when sediment is disturbed.

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.

Table A1.2 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. ANALYTICAL METHODS AND RESULTS FOR SEDIMENTS

Hill Laboratories
TRIED, TESTED AND TRUSTED

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	2308541
Contact:	Leigh Stevens	**Date Received:**	22-Jan-2020
	C/- Salt Ecology Limited	**Date Reported:**	03-Mar-2020
	21 Mount Vernon Place	**Quote No:**	97111
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Waikawa Estuary - HRC
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		WAIK-MANA A 18-Jan-2020	WAIK-MANA B 18-Jan-2020	WAIK-MANA C 18-Jan-2020	WAIK-MANA D (T9) 18-Jan-2020	
Lab Number:		2308541.1	2308541.2	2308541.3	2308541.4	
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	79	73	65	43	-
Total Recoverable Phosphorus	mg/kg dry wt	300	420	530	640	-
Total Nitrogen*	g/100g dry wt	< 0.05	< 0.05	0.07	0.16	-
Total Organic Carbon*	g/100g dry wt	0.13	0.50	0.95	2.1	-
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	3.5	3.7	4.1	5.1	-
Total Recoverable Cadmium	mg/kg dry wt	< 0.010	0.020	0.019	0.042	-
Total Recoverable Chromium	mg/kg dry wt	8	10	11	16	-
Total Recoverable Copper	mg/kg dry wt	3	6	6	10	-
Total Recoverable Lead	mg/kg dry wt	3.6	6.0	7.7	11.3	-
Total Recoverable Mercury	mg/kg dry wt	< 0.02	0.03	0.09	0.08	-
Total Recoverable Nickel	mg/kg dry wt	7	8	9	13	-
Total Recoverable Zinc	mg/kg dry wt	26	33	43	54	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	0.9	< 0.1	< 0.1	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	91.6	82.4	65.7	38.3	-
Fraction < 63 µm*	g/100g dry wt	8.4	16.7	34.3	61.7	-

Summary of Methods

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

Sample Type: 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%.	-	1-4
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%.	-	1-4
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	1-4
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-4
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	1-4
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-4

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

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

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

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

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

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Algal Cell Count Report

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

Attention: Leigh Stevens

Sample Information

Client description:	Waikawa Estuary	Laboratory ID:	2020000105/AS11182
Client ID:	WAIK-MANA	Date received:	22/01/2020
Date sampled:	20/01/2020	Date analysed:	23/01/2020
Time sampled:	1700	Sample Type:	Not specified

Potentially Toxic Algal Counts

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

Algal Species Counts

Dominant species (inc non toxic)	Cells per mL	Phyla
Prymnesium parvum/Rhinomonas sp. sp.	2,828	Prymnesiaceae/Cryptophyceae
Flagellates/Unicells <5um	491	Flagellates/Unicells
Gymnodinium sp.	187	Dinoflagellates (Dinoflagellata)
Rhodomonas sp.	70	Cryptophyceae
unidentified pennate diatoms	70	Diatoms (Bacillariophyceae)
Asterionellopsis sp.	4	Diatoms (Bacillariophyceae)
Protoperidinium sp. sp.	1	Dinoflagellates (Dinoflagellata)

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

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Algal Services
Gate 10, Silverdale Road, Hamilton
P O Box 11-115, Hamilton, New Zealand
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Algal Cell Count Report

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

Attention: Leigh Stevens

NIWA
Taihoro Nukurangi

Sample Information

Client description:	Waikawa Estuary	Laboratory ID:	2020000105/AS11182
Client ID:	WAIK-MANA	Date received:	22/01/2020
Date sampled:	20/01/2020	Date analysed:	23/01/2020
Time sampled:	1700	Sample Type:	Not specified

Comments:

Sample analysed as received by the laboratory in accordance with NIWA Algal services , SOP#1-6; Microscopic analysis of settled sample. This document may only be reproduced with permission from NIWA. Part reproduction or alteration of this document is prohibited.

Authorised by: Karl Safi
Key Tech Personnel, Algal Services

Signature:

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

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APPENDIX 3. SEDIMENT MACROFAUNA RESULTS, JAN. 2020

Main group	Taxa	Habitat	EG	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
Gastropoda	*Halopyrgus pupoides*	epibiota	III	0	0	0	0	0	0	1	0	0	0	0	0
Gastropoda	*Potamopyrgus antipodarum*	epibiota	III	0	0	0	0	0	0	0	1	0	3	0	0
Gastropoda	*Potamopyrgus estuarinus*	epibiota	III	15	9	0	700	1000	766	229	14	132	99	55	10
Gastropoda	*Zemelanopsis trifasciata*	epibiota	NA	0	0	0	1	4	2	1	0	0	0	0	0
Maxillopoda	*Austrominius modestus*	epibiota	II	0	1	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 1	infauna	II	0	0	0	16	5	4	0	0	5	0	0	0
Amphipoda	Amphipoda sp. A	infauna	II	0	3	16	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. B	infauna	II	0	1	0	0	0	0	0	0	0	0	0	0
Amphipoda	*Paracorophium* sp. 1	infauna	IV	500	500	85	200	550	149	350	2	51	0	30	0
Bivalvia	*Paphies australis*	infauna	II	4	3	0	0	4	0	0	0	0	0	0	0
Decapoda	*Halicarcinus whitei*	infauna	III	3	15	0	0	2	1	2	0	0	0	0	0
Isopoda	Isopoda Anthuroidea	infauna	NA	0	0	0	1	0	0	5	0	0	0	0	0
Isopoda	*Pseudaega* sp. 1	infauna	NA	0	26	2	0	0	0	0	0	0	0	0	0
Oligochaeta	Oligochaeta sp. 1	infauna	III	0	0	0	1	100	1	1	0	1	96	54	0
Polychaeta	*Capitella* sp. 1	infauna	IV	0	0	0	0	0	0	0	0	0	0	0	18
Polychaeta	*Scolecolepides benhami*	infauna	IV	0	0	0	3	7	14	1	0	0	3	10	0
Polychaeta	Spionidae sp. 1	infauna	III	0	0	0	0	0	0	1	0	0	0	0	0
Polychaeta	Spionidae sp. A	infauna	III	0	0	58	0	0	0	0	0	0	0	0	0
Diptera	Diptera sp. 1	larva	II	0	0	0	0	0	1	0	0	0	0	0	0

APPENDIX 4. HRC CHLOROPHYLL-A DATA

Chlorophyll-a data collected monthly from T5, 'Waikawa at footbridge'. by HRC. Sample depth 0.2m.

Year	90thpctl	Min	Max	Median	Mean	Count
2011*	6.9	0.30	15.0	1.5	3.4	10
2012	16.9	0.30	24.5	1.9	6.1	12
2013	48.3	1.90	176.4	2.1	21.6	12
2014	4.8	1.90	9.4	2.0	3.0	12
2015	3.2	0.90	5.8	0.95	1.6	18
2016	12.8	0.95	29.0	0.95	4.8	22
2017	55.0	0.95	140.0	0.95	14.9	21
2018	14.1	0.95	181.0	0.95	15.2	24
2019	2.7	0.95	8.2	0.95	1.6	19
2020	9.0	0.95	11.0	0.95	4.3	3
Summer 2020	20.6	0.95	46	3	8	40

Note: Where data were recorded as 'less than', 50% of the reported detection limit was applied.

*2011 HRC data appear to be 3 decimal places out and have been adjusted in this summary.

Summer 2020 data comprise 4 samples collected from Dec 2019 to March 2020 by HRC from 0.2m at site T5, and spot samples measured 0.2m from the surface and 0.2m from the bottom by Salt Ecology at 18 sites on 18 Jan 2020.

APPENDIX 5. NZ ESTUARY TROPHIC INDEX

The NZ ETI (Robertson et al. 2016a,b) is a preliminary tool designed to facilitate the consistent assessment of estuary state in relation to nutrient enrichment. It remains under development with data collected from estuaries throughout New Zealand being used to validate, update and improve the tool.

As part of this development process, integrated online calculators have been made available to predict estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary) [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/], as well as to assess trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/].

To date, the application of field data to the tools and calculators has revealed a need to re-evaluate several of the indicators and thresholds used to derive ETI scores. There is also a need to reduce the subjectivity regarding which data are included in scoring, as this has a strong bearing on the scores derived. Until these issues are addressed, it is recommended that the ETI scores be used as preliminary guidance only.

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