# Synoptic Subtidal Monitoring of Waikawa Estuary, Manawatū

June 2019

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# Synoptic Subtidal Monitoring of Waikawa Estuary, Manawatu

Prepared for
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June 2019

**Salt Ecology**
**Report 015**

Sediment sampling in the lower estuary, Feb 2019

## RECOMMENDED CITATION

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# Synoptic Subtidal Monitoring of Waikawa Estuary, Manawatu


**Prepared by**

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**for**

**Horizons Regional Council**

**June 2019**


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For the People
Mō ngā tāngata

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## 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 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.

In late 2018 Salt Ecology were commissioned by Horizons Regional Council (HRC) to undertake a targeted subtidal survey to broadly map estuary depth, benthic substrate, seagrass and nuisance macroalgae extent; and to collect *in situ* water quality measures (i.e. chlorophyll-a, salinity, temperature, dissolved oxygen). The aim was to assess trophic state, delineate the spatial extent of any salinity or temperature stratification, and reassess three subtidal sediment sites sampled in 2018.

## Results

Tables 3 and 4 in the main report assess fine scale and broad scale ecological indicators against condition rating criteria for estuary health. Those assigned a 'poor' status were the extent of depleted oxygenation of the water column (dissolved oxygen, DO) and sediments (apparent Redox Potential Discontinuity depth, aRPD), mud content, phytoplankton blooms (indicating nutrient enrichment), and estuary margin intactness.

The subtidal area of the estuary comprised 5.2ha (24%), of which 56% had sediments characterised by elevated mud concentrations (i.e. mud content >25%). These areas were most widespread in the upper and middle estuary, with the lower estuary dominated by marine sand.

Field measurements of water and sediment quality were collected from 11 sites, 3 in the lower, 2 in the middle and 6 in the upper estuary. Results showed salinity stratification extending for ~2km over much of the middle and upper estuary. Surface waters were freshwater dominated, with 20-26ppt salinity present in the deeper pools where phytoplankton (indicated by highly elevated chlorophyll-a levels) concentrations were also highest. Dissolved oxygen concentrations were severely depleted (<1mg/l) at the deeper sites in the estuary, with 0.5ha (9%) of the subtidal having very low oxygen levels in both water and sediment.

The salinity tolerant seagrass *Ruppia megacarpa* (Horse's mane weed) covered 0.3ha (7%) of the subtidal zone on both sides of the middle and upper estuary channel. Seagrass beds were 1-2m wide and extended to a depth of ~1.5m. Seagrass has high ecological value and, aside from its importance as aquatic habitat for many species, plays important functional roles in the uptake of nutrients, and trapping and stabilising fine sediments.

## Synthesis of key findings

Waikawa Estuary is currently expressing strong symptoms of eutrophication. Phytoplankton indicators were high, consistent with long-term HRC data that have recorded median concentrations of chlorophyll-a above the 'poor' indicator rating for the previous 5-year period.

In the middle and upper estuary, dissolved oxygen levels were severely low, and sediment oxygenation was poor. Such conditions, even for a few hours across a tidal cycle will cause severe adverse ecological effects, particularly to fish.

The extent of high enrichment conditions (HEC; an index that combines measures of oxygen status, organic carbon, mud and nutrients) encompassed 9% of the estuary. This is a significant area and highlights that large parts of the upper estuary are currently adversely impacted by elevated catchment inputs of nutrients and, to a lesser degree, sediments.

## Recommendations:

In light of the significant symptoms of high eutrophication identified it is recommended that:

1. Additional sampling be undertaken in the summer of 2020 to further define 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 repeat measures would be undertaken im-

mediately following a flood event to determine the capacity for the estuary to flush excessive sediments, nutrients and low oxygen waters from the estuary.

2. Design and implement a long-term programme for regular ongoing monitoring of estuary condition linked to existing freshwater SOE monitoring, including the deployment of water quality loggers in the eutrophic parts of the estuary, as well as more frequent field assessments to determine the nature and extent of the current problems.
3. Collect macrofaunal samples from representative sites inside and outside of the eutrophic upper estuary (e.g. sites T5, T7 and SED) as a pilot study to determine the potential biological impact of the current conditions on sediment animal and fish communities.
4. Combine all recently collected data on the estuary into a single comprehensive report. This will require resolution of uncertainty relating to the extent of salt marsh habitat in the estuary, and the mapping of terrestrial margin habitat. It is recommended that dominant freshwater plants along the upper estuary be identified as part of this work.
5. Because of the long-term presence of elevated phytoplankton concentrations in the estuary, identify the phytoplankton species present to determine if there is any risk from harmful (toxic) algal blooms or from benthic cyanobacteria.
6. 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.

# 1. INTRODUCTION

In 2016 Horizons Regional Council (HRC) commissioned a synoptic Ecological Vulnerability Assessment (EVA) of the estuaries on both coasts of the Horizons region to assess sediment and nutrient enrichment (eutrophication) risks (see Robertson and 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.

The EVA identified Waikawa Estuary (Fig. 1) as being a poorly flushed shallow short-residence tidal river estuary (SSRTRE) whose mouth is intermittently open/closed. Based on ETI criteria (Robertson et al. 2016b) it was rated as having a low/moderate vulnerability to catchment sediment impacts (predicted sediment load <5 times the predicted natural load), and a moderate/high vulnerability to nutrient enrichment (estimated catchment N areal loading (1195mgNm$^{-2}$.d$^{-1}$) above the tentative guideline for high susceptibility SSRTREs (250mgNm$^{-2}$.d$^{-1}$). Because sediment and nutrients concentrate in the subtidal reaches of SSRTREs under periods of restricted flushing, eutrophication issues are most commonly expressed in the subtidal parts of the estuary.

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 fine sediment deposits being widespread throughout the subtidal reaches of the middle estuary. The EVA consequently recommended targeted subtidal monitoring of eutrophication and sedimentation indicators to collect data to assess long-term trends in trophic state.

Monitoring of Waikawa Estuary commenced in March 2018 as part of long-term HRC estuary monitoring being implemented in a staged manner throughout the region. The 2018 monitoring repeated the intertidal broad scale habitat mapping undertaken in 2016, and collected one-off water and sediment quality samples at three locations in the lower, middle and upper estuary - see Robertson & Robertson (2018) for details. The study concluded, based primarily on independently collected HRC water quality data (chlorophyll-a), that the subtidal estuary had high eutrophic symptoms.

In late 2018, Salt Ecology was commissioned by HRC to undertake a targeted subtidal survey of Waikawa Estuary to broadly map estuary depth, benthic substrate, seagrass extent; and to collect *in situ* water quality measures to complement HRC's comprehensive long-term monthly water quality monitoring programme in the Waikawa River catchment. The aim was to assess trophic state, delineate the spatial extent of any salinity or temperature stratification, and reassess three subtidal sediment sites sampled in 2018.

The following report describes the methods and results of field sampling undertaken in February 2019, and makes recommendations for future monitoring and management.

# 2. BACKGROUND TO WAIKAWA ESTUARY

Waikawa Estuary is a moderate length (~3km), 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. When seawater is retained in the estuary it becomes brackish (very low salinity) and can stratify with denser seawater being trapped beneath freshwater surface flows.

The upper estuary is confined within channelised meandering river banks and has a strong freshwater influence. Margin vegetation comprises a narrow strip of freshwater species flanked by terrestrial grassland. 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*) are most common on the margins of the middle and lower estuary near the open coast.

Phytoplankton blooms (coffee-coloured cryptomonads) are common in the middle and upper estuary, particularly in the bottom waters, and nuisance opportunistic macroalgal blooms (*Ulva* spp.) can be present in the lower estuary (see Robertson and Stevens 2016). The seagrass *Ruppia megacarpa* (Horse's mane weed) grows extensively in the subtidal reaches of the middle and upper estuary.

The estuary has a moderate freshwater inflow (1.9m$^3$.s$^{-1}$) from a catchment dominated by lowland pastoral sheep and beef (26%) and dairy farming (23%), but with extensive native (35%) and exotic forest (13%) cover in the upper catchment.

Sediments are dominated by marine sands throughout the lower estuary, becoming progressively muddier in the middle and upper estuary, particularly in subtidal zones.

The middle and lower estuary is flanked by residential housing on the true left bank, and has high public use.


**Figure 1. Waikawa Estuary showing the location of sampling transects established in Feb. 2019, and sediment sampling sites.**

*At each transect a cross-section was surveyed, water quality 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, T5 and T10 replicating sites X, Y and Z in Robertson and Robertson (2018). An additional sample was collected from the upper estuary ("SED") where the most degraded sediment conditions were encountered.*

# 3. MONITORING PROTOCOLS USED

A standard approach for assessing the ecological health of estuaries has been produced with methods outlined in a National Estuary Monitoring Protocol (NEMP) originally developed in 2001 by Cawthron Institute (Robertson et al. 2002a; Robertson et al. 2002b; Robertson et al. 2002c).

The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective, easy to use, nationally applied standard protocol with which they can assess and monitor the ecological status of estuaries in their region. The results provide a valuable basis for establishing a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made.

The NEMP programme has three main elements. The first part is a coarse screening tool that is intended to enable councils to undertake a preliminary assessment of the condition of estuaries in their region in order to establish monitoring priorities (Robertson et al. 2002a). Once initial priorities are established, the NEMP monitoring approach itself consists of two protocols described in Robertson et al. (2002c), which are as follows:

- Broad-scale mapping of habitat characteristics
  The aim of broad scale habitat mapping is to describe and map an estuary according to the dominant substrate and vegetation features present. Once a baseline map has been constructed, changes in the position, extent or type of dominant features can then be monitored by repeating the mapping exercise. This procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographical Information System (GIS) technology. This approach requires modification when assessing subtidal areas, with additional ground truthing required to validate subtidal features.
- Fine-scale assessment of habitat condition
  Once an estuary has been classified according to its main distinguishing features, and the dominant broad scale habitats have been described and mapped, representative habitats can be selected and targeted for fine scale monitoring. The NEMP, with its focus primarily on shallow intertidally dominated estuaries, advocates monitoring intertidal soft sediment (sand/mud) habitat in the mid to low tidal range of priority estuaries. The NEMP provides no specific guidance for sampling subtidal features.

  The environmental characteristics assessed in NEMP fine scale surveys incorporate a suite of commonly used benthic indicators, including biological (e.g. macroinvertebrate infauna) and physico-chemical (e.g. sediment mud content, metals, nutrients) characteristics.

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 subtidally dominant estuaries) 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).

# 4. METHODS

## 4.1 ESTUARY EXTENT

To set the boundaries for the synoptic survey, estuary extent was based on the definition used in the ETI (Robertson et al. 2016a) which defines an estuary as the area between the 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°.

## 4.2 SYNOPTIC SUBTIDAL SAMPLING

### 4.2.1. General approach

Synoptic estuary sampling was conducted on 2 February 2019. For tidal river estuaries like Waikawa, where the most susceptible areas are subtidal, site-specific approaches beyond that described in the NEMP and ETI are needed.

The selected approach was based on sampling of a series of cross-sectional transects throughout the subtidal sections of the estuary, combined with assessment of broad and fine scale metrics (described below), which has previously been demonstrated to be an effective way to map broad scale ecological features and characterise estuary trophic status (e.g. Stevens and Robertson 2012, Stevens et al. 2016). The approach includes measuring a range of water and sediment quality indicators. Water quality measures are instantaneous and reflect ambient conditions and tide. They are supplemented here with HRC data collected as part of a comprehensive long-term monthly water quality monitoring programme in the Waikawa River catchment. Sediment indicators, such as sediment oxygenation, enrichment and mud content, provide integrated measures of prevailing environmental conditions. As such they are generally less prone to small scale temporal variation and are therefore used in conjunction with water quality measures. This meso-scale assessment approach can be repeated over time and scaled up or down to address specific issues as necessary.

Broad scale measures incorporate wider spatial indicators that commonly integrate a variety of factors, for example macroalgal or seagrass growth reflect the combined influence of nutrient availability, sediment deposition, water quality, and hydrology.

Because the estuary had previously been mapped, and the key broad scale and subtidal features were already broadly known, locations for undertaking cross-section surveys could largely be pre-determined. Eleven sites were distributed relatively evenly throughout representative parts of the lower, middle and upper estuary. Site locations are shown in Fig. 1 with coordinates for each given in Table 2. Sampling was conducted around low tide to enable the best delineation of stratified bottom waters retained in the estuary. The tidal range on the day of sampling (1.2m) was in the middle of the range predicted by LINZ (1.9-0.6m), hence represents a state intermediate between spring and neap tides.

At each transect, subtidal habitat was assessed by ei-

**Table 1. Summary of condition ratings referred to in the present report.**

| Indicator | Unit | Very Good | Good | Moderate | 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 |
| **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] | mg/l | ≥ 5.5 | ≥ 5.0 | ≥ 4.0 | < 4.0 |
| Phytoplankton (chl-a)[1] | ug/l | ≤ 5 | ≥ 5 to < 10 | ≥ 10 to < 16 | ≥ 16 |
| **Broad scale spatial indicators** | | | | | |
| Mud extent[1] | % of estuary | < 1% | 1-5% | > 5-15% | > 15% |
| Macroalgae (OMBT)[1] | 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[3] | % of intertidal area | > 20% | > 10-20% | > 5-10% | 0-5% |
| 200m terrestrial margin[3] | % densely vegetated | > 80-100% | > 50-80% | > 25-50% | < 25% |
| High Enrichment Conditions (HEC)[1] | ha or % of estuary | < 0.5ha or < 1% | 0.5-5ha or 1-5% | 6-20ha or > 5-10% | > 20ha or > 10% |
| Sedimentation rate[1*] | CSR:NSR ratio | CSR 1 to 1.1 x NSR | CSR 1.1 to 2 x NSR | CSR 2 to 5 x NSR | CSR > 5 x NSR |

*1. General indicator thresholds derived from a New Zealand Estuarine Tropic Index, with adjustments for aRPD 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 ANZECC (2000) as follows: Very good: < 0.5 x ISQG-low; Good: 0.5 x ISQG-low to < ISGQ-low; Moderate: ISQG-low to < ISQG-high; Poor: ≥ ISQG high.*

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

**CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)* ther wading or by sampling from a kayak, 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 macroalgal (percent cover)

Each channel cross-section was also surveyed at a 1-2m horizontal resolution to record the channel profile. On each transect, sediment quality was assessed by collecting sediment samples from across each profile using a remote grab sampler. At the surface they were assessed for substrate type, aRPD and seagrass or macroalgal cover. At the deepest point in the channel, water quality measures were taken as described below.

### 4.2.2 Water column indicators

Water quality measures were made *in situ* using a YSI Pro10 pH/Conductivity/DO/Temperature meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Water quality measurements were collected ~20cm below the water surface, and ~20cm above the sediment surface, with care taken not to disturb bottom sediments before sampling. 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. All data were recorded electronically in the field (see Section 4.3).

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. Waters that are high in phytoplankton typically reflect situations where nutrient supply is high 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.

The ETI provides criteria for assessing phytoplankton (an optional primary indicator of nutrient enrichment), and for 1-day instantaneous dissolved oxygen minima in the water column measured from representative areas (including likely worst-case conditions). Criteria for nutrient concentrations remain under development.

### 4.2.3 Sediment measures

#### Substrate classification

Appendix 1 summarises the key NEMP classes used to define estuarine habitats in the current report. 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 either through laboratory analysis of sediment mud content, or according to subjective field-based assessment of textural and firmness characteristics.

At the deepest point on transects T3, T5 and T10, which replicated the discrete sampling sites X, Y and Z in Robertson and Robertson (2018), and at station 'SED' located in the most degraded sediments in the estuary midway between T8 and T9 (see Fig. 1), a composite sediment sample from 3 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.

#### Sediment grain size

Sediment 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%.

#### Sediment oxygenation

The visual assessment of aRPD depth provides an easily measured, time integrated, and relatively stable measure of sediment oxygenation conditions. Sediment aRPD was assessed by splitting sediment cores or grabs vertically with a hand trowel to determine whether there were any significant areas where sediment oxygenation was depleted. Sediments were considered to have poor oxygenation if the aRPD was consistently <5mm deep and showed clear signs of organic enrichment indicated by a distinctive colour change in the sediments from brown/grey to black. Such sediments can also emanate a strong 'rotten egg' smell of hydrogen sulphide.

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

### Sediment nutrients and organic carbon

TN and 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). Organic carbon provides a measure of the organic material present in sediments. When this exceeds ~2%, 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.

### 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 necessary.

## 4.2.4 Broad scale spatial measures

### 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. 2 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

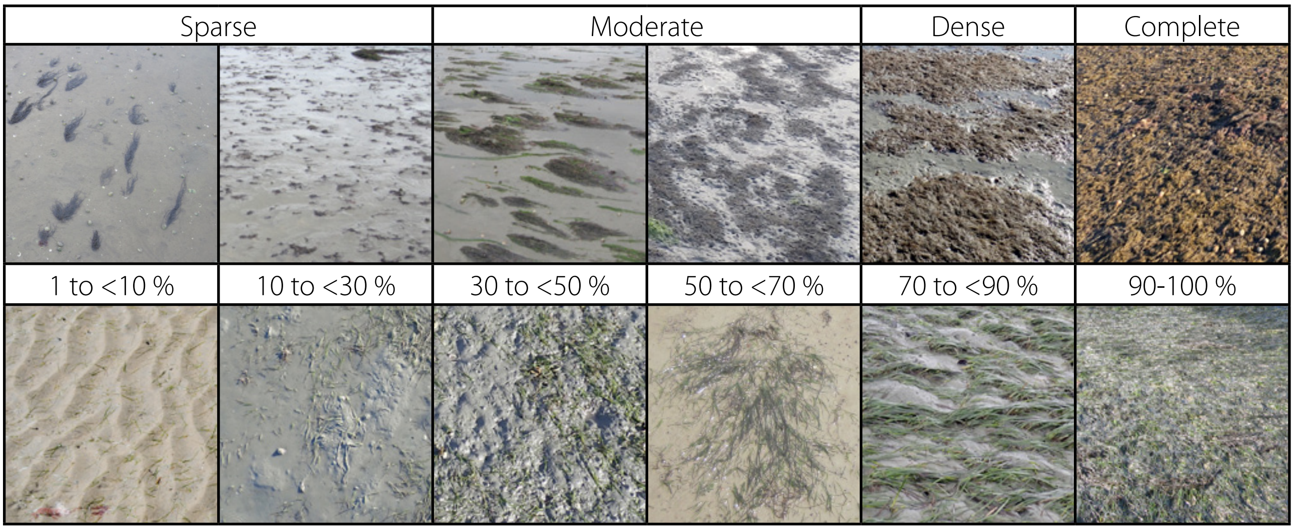



**Figure 2. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom).** Modified from FGDC (2012).

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. 2 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% TOC) and/or dense macroalgal cover (>50%), combined with an elevated mud content (≥25% mud) and low sediment oxygenation (<10mm) or water column oxygenation (<4mg/l). 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.

### 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.

## 4.3 DATA RECORDING, QA/QC AND ANALYSIS

Broad scale habitat features were recorded on a combination of laminated aerial photographs and waterproof paper. They were subsequently digitised into ArcMap 10.5 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs to produce habitat maps showing dominant estuary features (substrate, stratified bottom water, macroalgae, seagrass).

All sediment samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. All field measurements were recorded electronically in templates that were custom-built using Fulcrumapp software (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 and was exported to Excel for reporting purposes.

## 4.4 ASSESSMENT OF ESTUARY CONDITION

In addition to our 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 'health status' bands, colour-coded as shown in Table 1. The thresholds used in the current report, summarised in Table 1, 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 %mud, TOC, TN, aRPD, metals, dissolved oxygen, phytoplankton concentrations and the AMBI biotic index for macroinvertebrates. We adopt these thresholds for present purposes as relevant, but for aRPD, we have modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012) which provides a more comprehensive rating than that included in the ETI.

The ETI also contains metrics intended to be applied to the estuary as a whole (i.e. in a broad scale context). Spatial measures include the extent of mud, seagrass, macroalgae, the combined presence of factors contributing to high enrichment conditions (HECs), and sedimentation rate. 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 and Forrest 2019). These thresholds are also adopted. As many of the ETI scoring categories and supporting metrics are still provisional or undergoing further development or refinement, they should be regarded only as a general guide to assist with interpretation of estuary health status.

Unvegetated clean marine sands in the lower estuary

Raised sand bank and herbfield in the lower estuary

Discoloured waters indicating the presence of phytoplankton at T5

Fringing vegetation 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

# 5. RESULTS

## 5.1 BROAD SCALE SUBTIDAL MAPPING

A summary of the broad scale subtidal mapping undertaken in 2019 is presented in Fig. 3. It shows that the subtidal area of the estuary comprised 5.2ha, or 24% of the estuary extent as defined in Section 4.1. Within the subtidal zone, 56% of the estuary had sediments characterised by elevated mud concentrations (i.e. mud content >25%). These areas were most widespread in the upper and middle estuary, and decreased in the lower estuary where they became progressively confined to the deeper mid-channel areas. In many places a relatively thin layer of mud was evident on top of underlying sands e.g. sites T7 - T10 (see Fig. 7 for substrate photos). The lower estuary was dominated by marine sand.

Seagrass was relatively widespread in the estuary, beds starting to appear as isolated patches ~100m upstream of the footbridge in the middle estuary (T5), before becoming widespread on both sides of the upper channel between T7 and T10 (see Fig. 3 and photos below). Seagrass covered 0.3ha (7%) of the sub-tidal zone and extended to a depth of ~1.5m, with beds typically 1-2m wide. Seagrass was recorded previously in the estuary (Robertson & Stevens 2016) but was not mapped at that time. Seagrass was not recorded or mapped in the broad scale assessment of the estuary undertaken in 2018 (Robertson & Robertson 2018). As such, it is not possible to assess any change in seagrass extent.

Field measurements of water and sediment quality collected from each of the 10 cross-sections are presented in Table 2 and Figs 4 and 5. Fig. 4 presents a simplified cross-section of the estuary from the open coast to the upstream Waikawa River. Fig. 5 summarises the prevailing water quality conditions during sampling, showing halocline and thermocline depths, and surface and bottom water measurements of temperature, salinity, chlorophyll-a and dissolved oxygen. Additional detail of each cross-section, showing the channel shape and depth, presence of stratification, seagrass cover and aRPD depth is presented in Figs 6 and 7.

Fig. 4 highlights that salinity stratification was present over much of the middle and upper estuary (T3-T9), extending for ~2km upstream from the estuary's seaward extent. Salinity stratification closely matched temperature stratification at all sites except T9 (Fig. 5a).

Temperatures were warmer in the shallower parts of the lower estuary, and 2-3 °C cooler at the upstream sections where flow from the Waikawa River domi-

Seagrass (*Ruppia megacarpa*) grows throughout the middle and upper estuary, February 2019

| Subtidal Substrate | Ha | % of subtidal | % of total estuary |
|---|---|---|---|
| Firm sand | 1.5 | 28.9 | 7.0 |
| Firm muddy sand | 0.7 | 12.8 | 3.1 |
| Soft muddy sand | 0.1 | 2.1 | 0.5 |
| Soft mud | 2.9 | 56.2 | 13.5 |
| **Subtidal total** | **5.2** | **100** | **24.1** |
| Zone of low $O_2$ | 0.5 | 9.1 | 2.2 |
| Seagrass (*Ruppia*) cover | 0.3 | 6.6 | 1.6 |

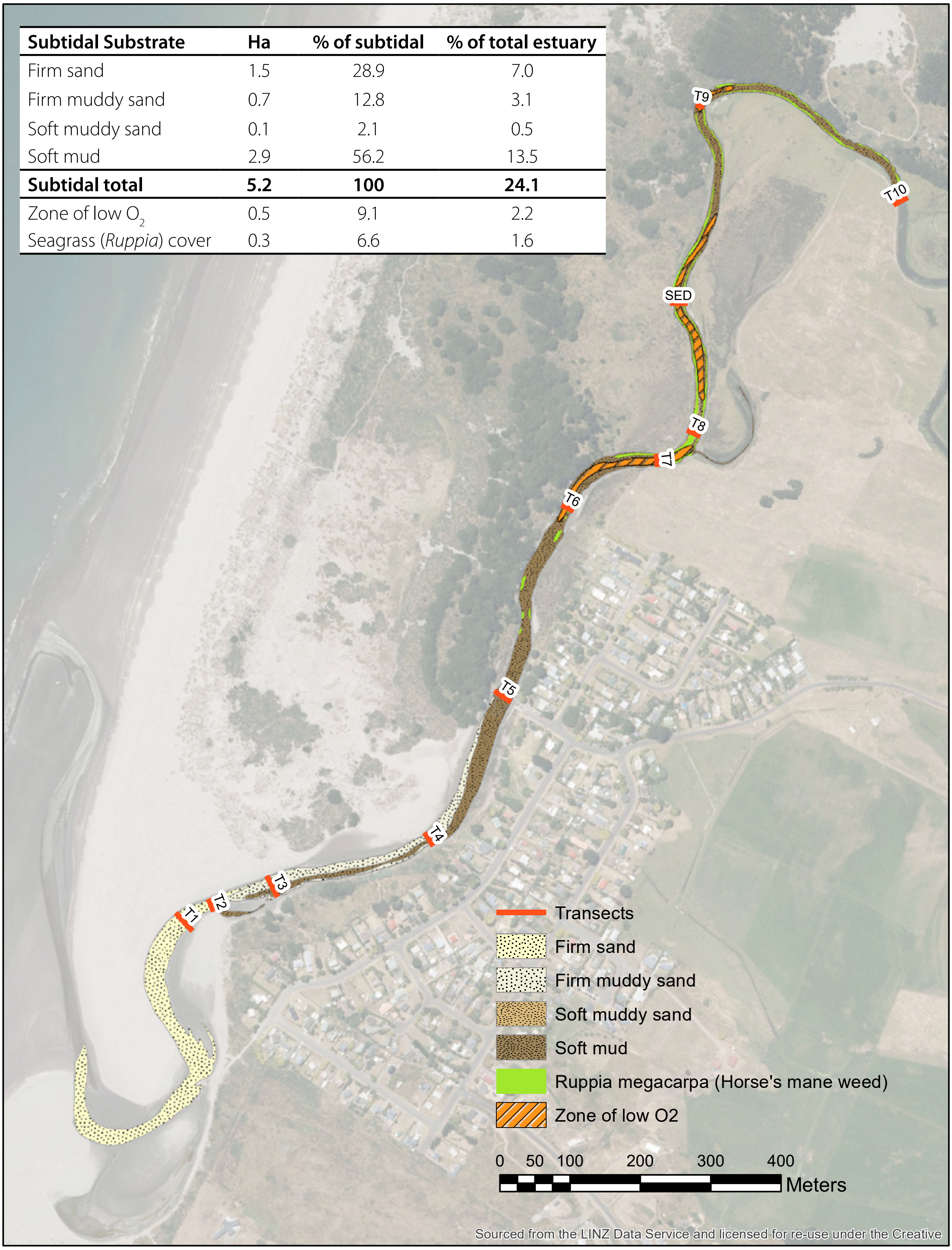



**Figure 3. Map showing broad scale sub-tidal results for substrate, seagrass and bottom water oxygenation.**

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

**Table 2. Summary of field measurements collected at each sampling site. Refer to Fig. 1 and Fig. 4 for site locations.**

| Station | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | Sed | T9 | T10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 ($^{o}$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 concentration (mg/l) | 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 |
| Chl-a (ug/l) | 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 | na |
| Thermocline depth (m) | na | na | 0.8 | 1.2 | 1.2 | 1.7 | na | 1.5 | 2.3 | 3.3 | na |
| Measurement depth 2 (m) | 0.2 | 0.5 | 0.9 | 1.3 | 1.25 | 2 | 1.4 | 1.35 | 2.2 | 2.2 | 1.7 |
| Temperature ($^{o}$C) | 23.3 | 23.2 | 22.6 | 22.6 | 22.5 | 20.3 | 21.7 | 20 | 20.2 | 20.2 | 20.1 |
| DO saturation (%) | 81 | 80 | 73 | 40 | 58 | 14 | 79 | 80 | 15 | 7 | 86 |
| DO concentration (mg/l) | 6.9 | 6.8 | 6.2 | 3.1 | 5.0 | 1.0 | 7.0 | 7.1 | 0.9 | 0.5 | 7.8 |
| Salinity (ppt) | 0.6 | 0.6 | 1.5 | 20.4 | 0.5 | 25.7 | 0.1 | 0.1 | 25.9 | 25.9 | 0.1 |
| pH | 8.1 | 8.1 | 7.6 | 7.4 | 7.8 | 7.4 | 8.0 | 7.9 | 7.3 | 7.1 | 8.2 |
| Chl-a (ug/l) | 1 | 1 | 2 | 5 | 1 | 17 | 0 | 0 | 20 | 7 | 0 |
| Secchi depth (m) | Bottom | Bottom | 0.9 | 0.9 | 0.9 | 1.2 | 1.1 | 1.0 | 1.2 | 1.5 | 1.4 |
| Maximum 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 type | FS | MS | SM | FMS | SM | VSM | VSM | SM | VSM | VSM | SM |
| aRPD depth (mm) | >50 | >50 | 23 | 15 | 15 | 5 | 2 | 20 | 0 | 1 | 10 |

FS=firm sand, FMS=firm mud/sand, MS=mobile sand, SM=soft mud, VSM=very soft mud

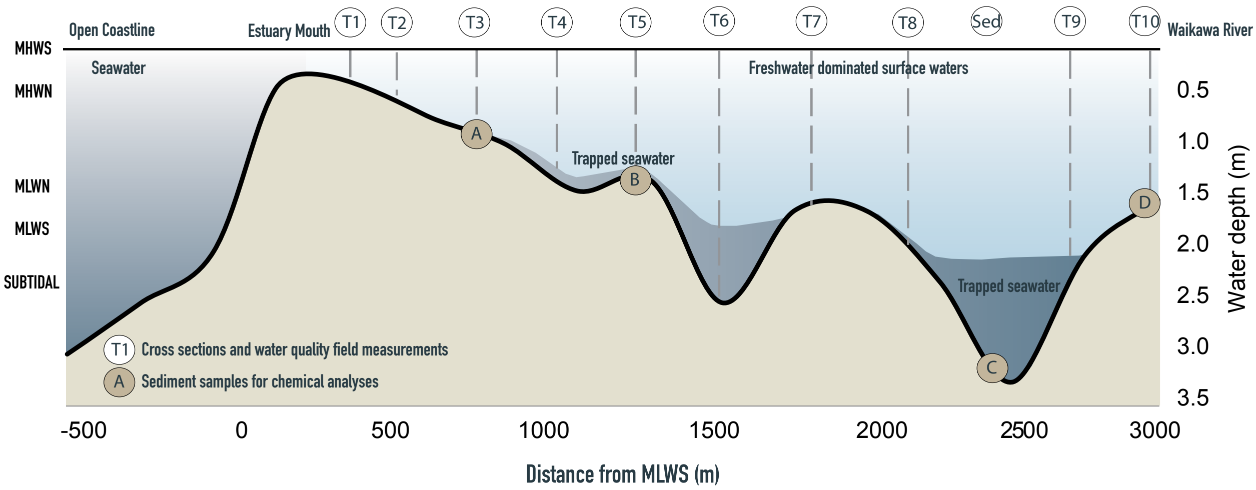



**Figure 4. Simplified longitudinal cross-section of Waikawa Estuary showing bed height, sediment sampling locations and location of channel cross-sections.**

*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.*

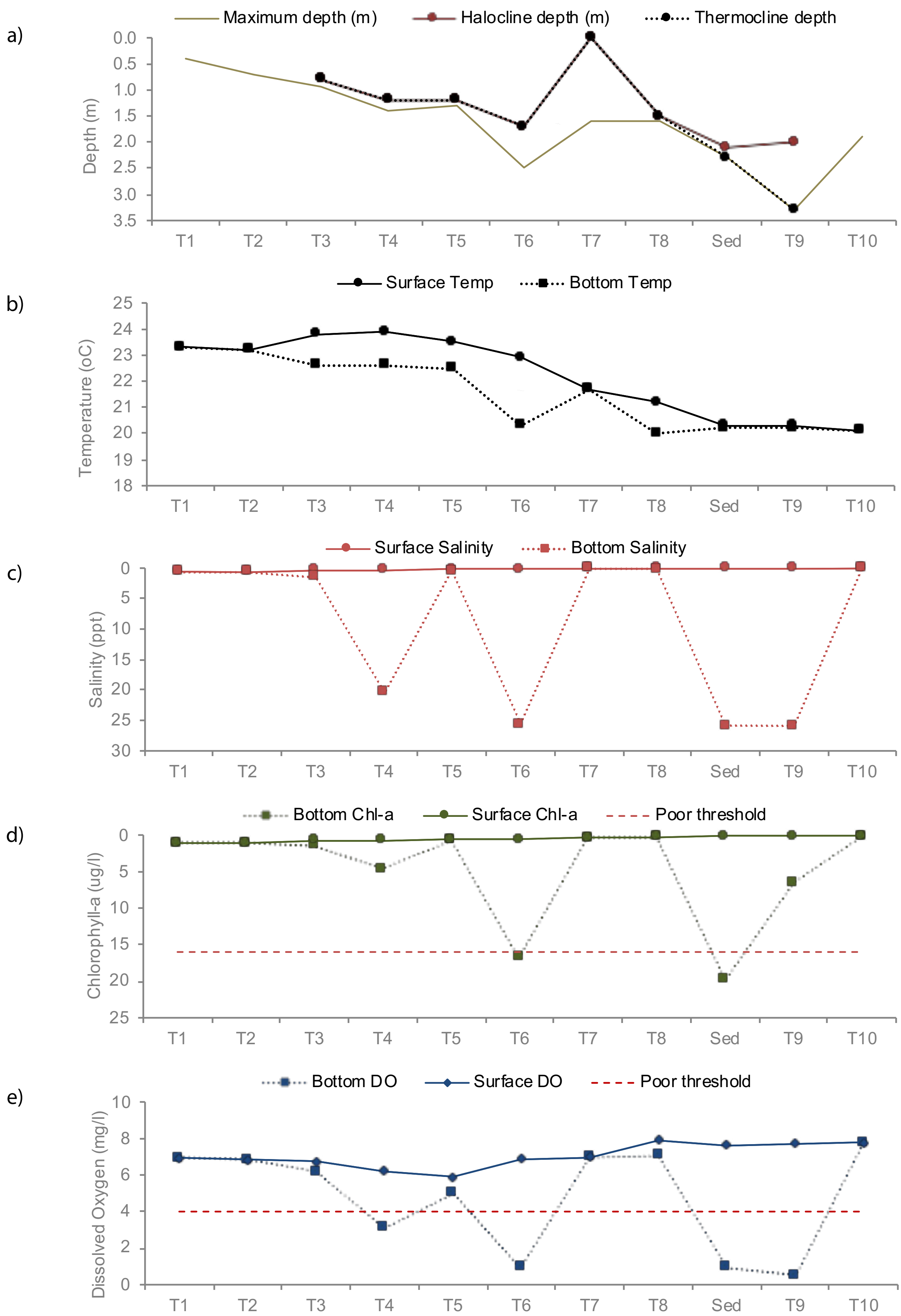



**Figure 5. Water quality measurements collected at transect sites showing a) halocline and thermocline depths, and surface and bottom water measurements of:b) temperature; c) salinity; d) chloropyll-a; and e) dissolved oxygen.** *Where no halocline or thermocline was present, it was plotted as the maximum water depth.*

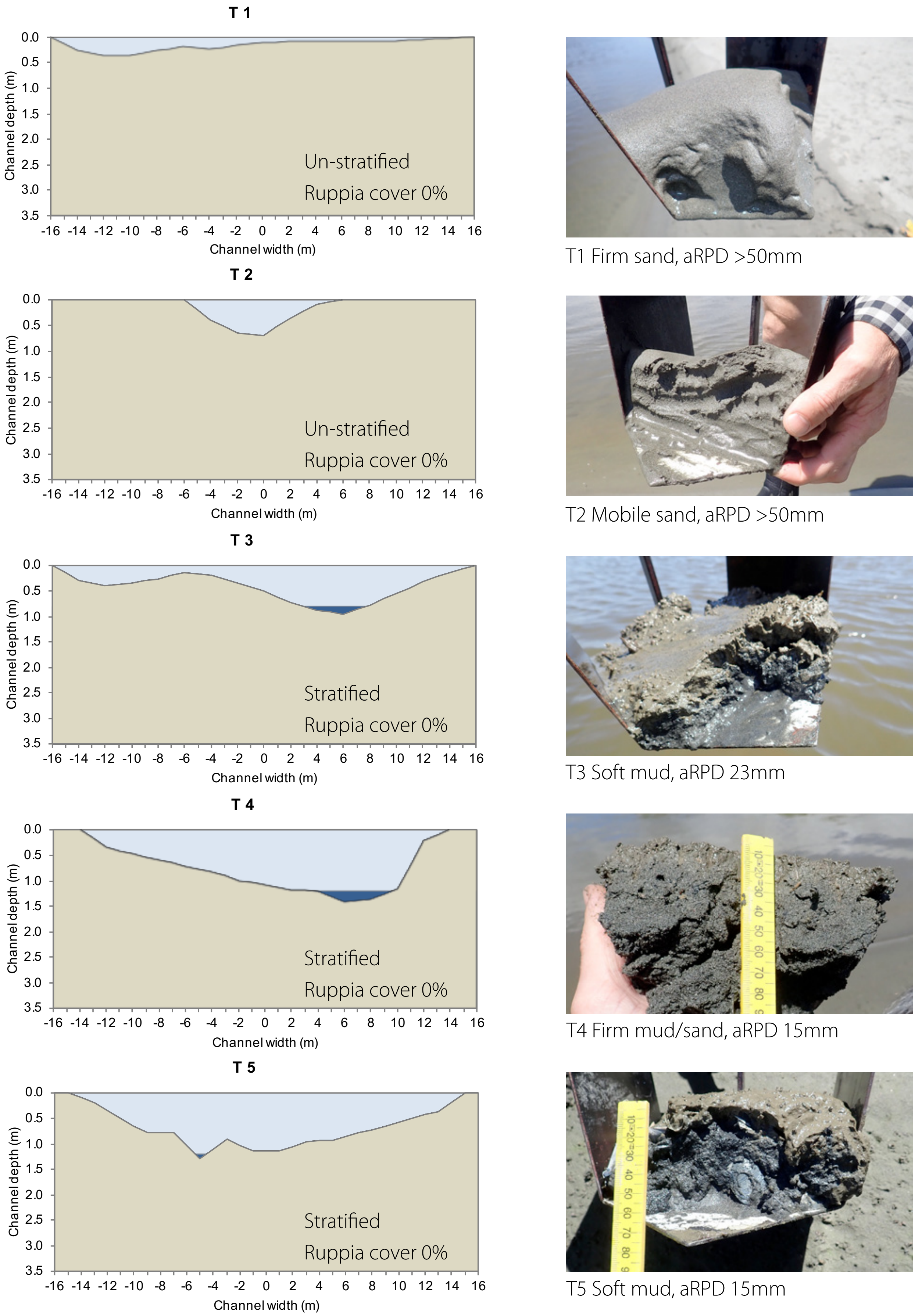
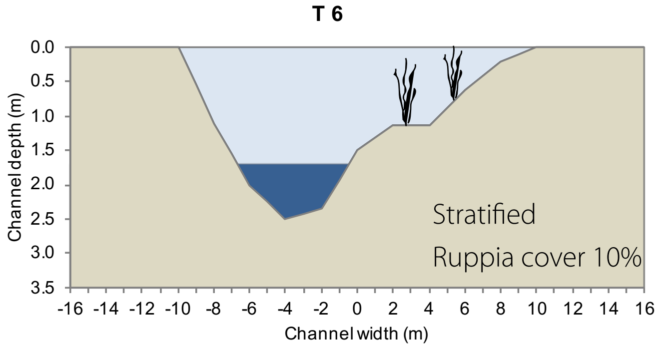
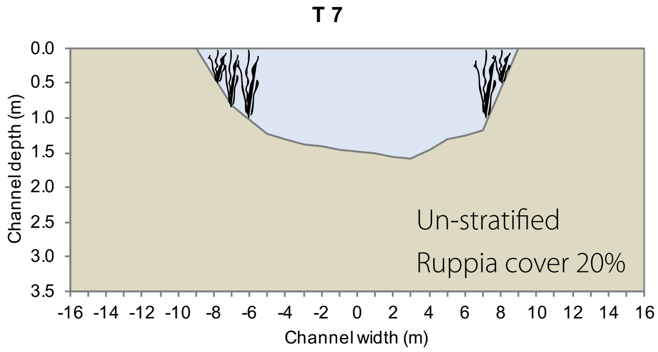


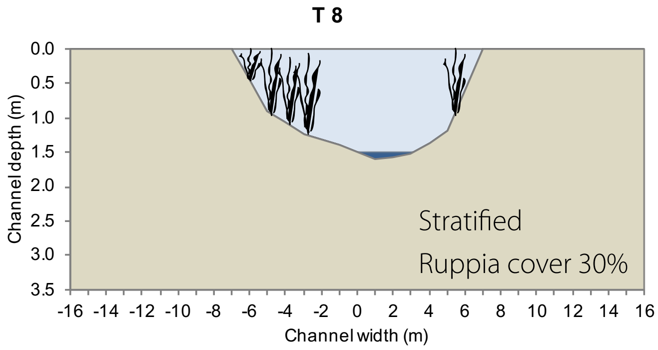

**Figure 6. Cross-section of the lower to middle Waikawa Estuary showing bed height, presence of salinity stratification, extent of seagrass (*Ruppia*) cover, substrate type and aRPD depth.**



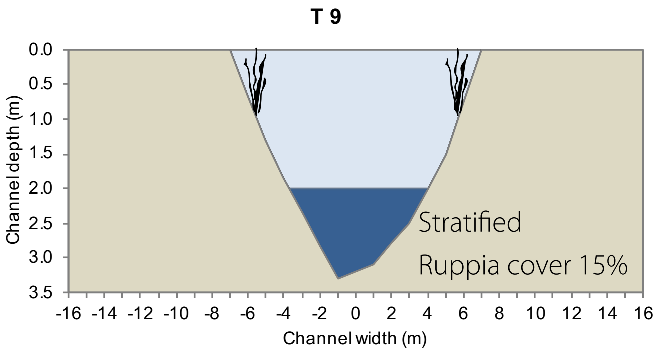

T6 Very soft mud, aRPD 5mm



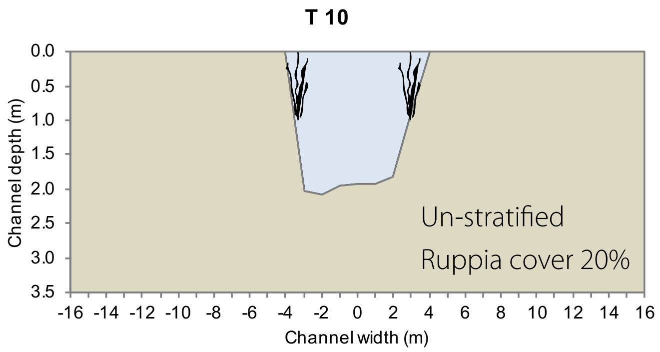

T7 Soft mud, aRPD 2mm




T8 Soft mud, aRPD 20mm




T9 Very soft mud, aRPD 1mm




T10 Soft mud, aRPD 10mm

**Figure 7. 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.**

nates (Fig 5b).

Surface waters (<0.2m deep) were freshwater dominated throughout the estuary, with the greatest salinity (20-26ppt) recorded in the deeper pools (Fig. 4, Fig. 5c).

Phytoplankton concentrations, assessed *in situ* by the fluorescence of chlorophyll present in the algae (i.e. chl-a measurement), were highest in the deepest stratified bottom waters (T6 and SED, Fig 5d). The waters throughout the estuary had an olive green-brown tinge at the time of sampling indicating the widespread and abundant growth of phytoplankton.

Dissolved oxygen concentrations (Fig. 5e) were severely depleted at the deeper sites in the estuary (T4, T6, SED and T9), with the latter three sites having DO concentrations of <1mg/l.

Bottom water dissolved oxygen (DO) and sediment oxygenation (aRPD depth) data were used to map areas subject to depleted oxygen levels (shown in Fig. 3). The results indicated that 0.5ha (9%) of the subtidal had very low (< 1mg/l) oxygen levels at the time of sampling. These sites were associated with stratified bottom waters where dense seawater was present beneath surface freshwater, and trapped due to the profile of the estuary bed (see Fig. 4).

The spatial extent of high enrichment conditions (HEC; low oxygen, elevated TOC, mud and nutrients) present in the estuary was significant (9%). This integrated metric highlights that there are widespread impacts from catchment derived sediment and nutrient inputs throughout much of the upper estuary.

## 5.2 SEDIMENT PHYSICAL AND CHEMICAL CHARACTERISTICS

A summary of the 2019 composite sediment sample data collected from four sites is provided in Table 3 (see Appendix 2 for raw data from the laboratory). Data from 2018 are also presented for comparative purposes. Site 'SED' in 2019 was located in sediments representing the most impacted 10% of the estuary. Sediment measures summarised in Table 2 reflect the deepest point on each cross section.

### 5.2.1 Sediment grain size

Laboratory analyses revealed that the mud fraction was very low in the lower estuary (T3) in both years (<2%), with sediments muddier in the middle and upper estuary (17-68%).

### 5.2.2 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, and lowest in the clean sands near the estuary entrance.

The highest values were present at sites T5 and SED. These deeper sites in the middle estuary appear to be where fine sediments and organic matter preferentially accumulate.

### 5.2.3 Trace contaminants

Trace metal and metalloid concentrations were low at all sites, and less than ANZECC (2000) ISQG-low values (Table 3).

## 5.3 INTERPRETATION OF ECOLOGICAL HEALTH AGAINST CONDITION RATINGS

Tables 3 summarises the ecological condition scores for key indicators of sediment chemistry comparing 2018 and 2019 results. Broad scale indicators and those used to calculate an ETI score are summarised in Table 4. Criteria and ratings are summarised in Table 1, with 2016 broad scale habitat mapping and synoptic data (Robertson & Stevens 2016) used to compliment the data in the current study.

Data show that the estuary condition ratings in relation to mud extent and catchment sediment inputs were 'moderate', although in the most impacted 10% of the estuary represented by site 'SED', sediment mud content was high, and given a rating of 'poor'. Broad scale mapping results show mud habitat extended across 2.9 ha (13% of the total estuary area (intertidal and subtidal), and 56% of the subtidal zone), with rat-

**Table 3. Sediment grain size, nutrient, aRPD, trace metal and metalloid results for composite samples collected at four sites in 2019, and showing comparison with 2018 results.**

| Year | Site | Gravel % | Sand % | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | T3 (X) | < 0.1 | 98 | 2 | 0.1 | < 500 | 280 | >30 | 3.4 | < 0.010 | 7.4 | 2.6 | < 0.02 | 7.2 | 3.2 | 23 |
| | T5 (Y) | 2.0 | 30 | 68 | 3.0 | 2100 | 760 | 10 | 6.4 | 0.072 | 14.2 | 10.6 | 0.12 | 14.0 | 14.0 | 59 |
| | T10 (Y) | < 0.1 | 63 | 37 | 1.1 | 700 | 440 | 10 | 3.1 | 0.044 | 10.4 | 7.3 | 0.07 | 10.4 | 10.0 | 46 |
| 2019 | T3 (A) | < 0.1 | 100 | 0 | < 0.05 | < 500 | 270 | 23 | 3.0 | < 0.010 | 7.4 | 2.5 | < 0.02 | 6.0 | 2.9 | 23 |
| | T5 (B) | 2.6 | 58 | 39 | 0.8 | 700 | 520 | 15 | 4.7 | 0.018 | 12.5 | 5.7 | 0.03 | 9.3 | 7.1 | 42 |
| | Sed (C) | 0.1 | 40 | 60 | 1.4 | 1200 | 560 | 0 | 5.0 | 0.029 | 14 | 6.7 | 0.05 | 10.3 | 9.0 | 48 |
| | T10 (D) | 0.5 | 83 | 17 | 0.7 | 600 | 530 | 10 | 3.9 | 0.027 | 11.7 | 5.5 | 0.05 | 9.8 | 9.8 | 49 |

*Refer to Fig. 1 for site locations and Table 1 for condition rating colour codes and thresholds.*

**Table 4. Summary of broad scale spatial indicators and general indicators reflecting the most impacted 10% of the estuary.**

| Indicator | Unit | State | Rating | Data source |
|---|---|---|---|---|
| **Sediment Quality** | | | | |
| Mud content | % | 60 | Poor | current report |
| aRPD depth | mm | 0 | Poor | current report |
| Total nitrogen | mg/kg | 1200 | Moderate | current report |
| Total organic carbon | % | 1.4 | Moderate | current report |
| Trace elements | mg/kg | low | Very Good | current report |
| **Water Quality** | | | | |
| Dissolved oxygen | mg/l | 0.9 | Poor | current report |
| Phytoplankton (chl-a) | ug/l | 20 | Poor | HRC data 2012-2017 |
| **Broad scale spatial indicators** | | | | |
| Mud extent | % of estuary | 2.9ha 13% | Moderate | current report |
| Macroalgae (OMBT) | EQR | 1 | Very Good | default score as no macroalgae |
| Seagrass | % decrease from baseline | undetermined | - | insufficient data to assess |
| Salt marsh extent | % of intertidal area | 25 | Very Good | Robertson and Stevens (2016) |
| 200m terrestrial margin | % densely vegetated | <25 | Poor | Robertson and Stevens (2016) |
| High Enrichment Conditions | ha or % of estuary | 0.5ha 9% | Moderate | current report |
| Sedimentation rate | CSR:NSR ratio | 4.8 | Moderate | Robertson and Stevens (2016) |

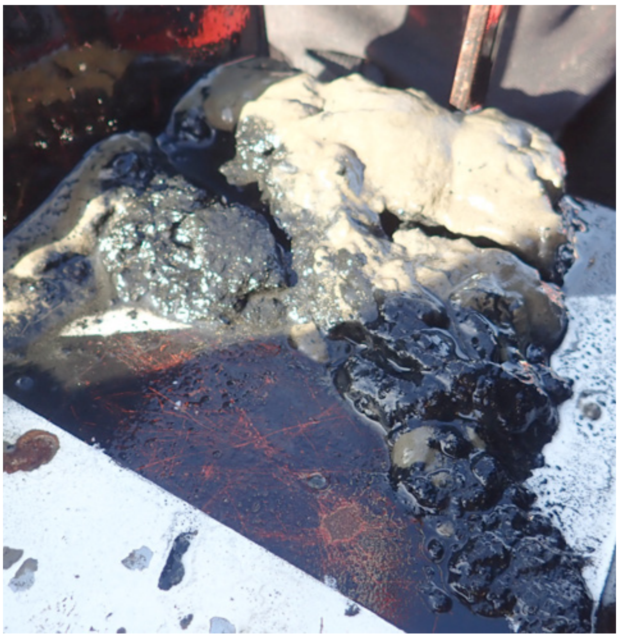
*Refer to Fig. 1 for site locations and Table 1 for condition rating colour codes and thresholds. Sediment and water quality indicators use site 'SED' data unless noted otherwise.*

ings of 'moderate' and 'poor' respectively.

The absence of nuisance macroalgae in 2019, and relatively extensive salt marsh were both rated 'very good'. For salt marsh, data from Robertson & Stevens (2016) were used in preference to that of Robertson & Robertson (2018). The latter data indicated salt marsh had reduced by nearly half (from 3.1 to 1.6ha) over 2 years, although this reduction was not evident in field observations in 2019.

Trace contaminant results were all low and indicate that the estuary is unlikely to have any significant sediment contamination issues, hence trace con-

High densities of shellfish among muddy sediments at T5 downstream of the eutrophic upper estuary



Highly sulphide-rich, anoxic and azoic sediments from site 'SED' in the eutrophic upper estuary taminants were assigned a rating of 'very good'.

TOC and sediment nutrients were moderately elevated in the most affected part of the middle estuary. However, nutrient indicators alone can be misleading, particularly under bloom conditions, as nutrients may have been utilised by algal growth rather than being present as available nutrients. In combination with high phytoplankton, and based on previous sampling data from the estuary (Robertson and Robertson 2018), nutrient status is rated 'poor'.

Water column dissolved oxygen and sediment aRPD were both rated 'poor' and indicate significant issues exist within the estuary.

Overall, the ETI score for the estuary, calculated using Table 4 data and NIWAs online Tool 2 calculator (https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/) was 0.85, which corresponds to a rating of 'poor'

In comparison with data provided in Robertson & Robertson (2018), there appears to have been no substantive change in estuary condition since 2018, with the exception of the aberration in the record of salt marsh extent, which is currently similar to that described by Robertson & Stevens (2016).

# 6. SYNTHESIS AND RECOMMENDATIONS

## 6.1 SYNTHESIS OF KEY FINDINGS

Waikawa Estuary is currently expressing strong symptoms of eutrophication. Phytoplankton indicators were high, consistent with long-term HRC data that have recorded median concentrations of chl-a above the 'poor' indicator rating for the previous 5-year period.

Dissolved oxygen levels were at severely low concentrations (0.5-1.0mg/l) at sites T6, SED and T9. These levels are well below the ETI threshold for 'poor' (<4mg/l), and the presence of such conditions, 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.

The spatial extent of high enrichment conditions (HEC; low oxygen, elevated TOC, mud and nutrients) present in the estuary (9%) is significant and highlights that large parts of the upper estuary are currently adversely impacted by elevated catchment inputs of nutrients and, to a lesser degree, sediments.

## 6.2 RECOMMENDATIONS

In terms of SOE estuary monitoring, Waikawa Estuary has now been monitored on three occasions in the last four years. The first two surveys focused on intertidal areas, while the latter (current report) has focused on subtidal areas. In light of the significant symptoms of high eutrophication identified it is recommended that:

1. Additional sampling be undertaken in the summer of 2020 to further define the spatial extent and nature of eutrophication impacts. This should include boat-based sampling of subtidal sediments and water quality throughout the subidal reaches of the upper estuary. Ideally repeat measures would be undertaken immediately following a flood event to determine the capacity for the estuary to flush excessive sediments, nutrients and low oxygen waters from the estuary.
2. Design and implement a long-term programme for regular ongoing monitoring of estuary condition linked to existing freshwater SOE monitoring, including the deployment of water quality loggers in the eutrophic parts of the estuary, as well as more frequent field assessments to determine the nature and extent of the current problems.
3. Collect macrofaunal samples from representative sites inside and outside of the eutrophic upper estuary (e.g. sites T5, T7 and Sed) as a pilot study to determine the potential biological impact of the current conditions on sediment animal and fish communities.
4. Combine all recently collected data on the estuary into a single comprehensive report. This will require resolution of uncertainty relating to the extent of salt marsh habitat in the estuary, and the mapping of terrestrial margin habitat. It is recommended that dominant freshwater plants along the upper estuary be identified as part of this work.
5. Because of the long-term presence of elevated phytoplankton concentrations in the estuary, identify the phytoplankton species present to determine if there is any risk from harmful (toxic) algal blooms or from benthic cyanobacteria.
6. 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.

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# APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Vegetation was classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the two first letters of their Latin genus and species names e.g. marram grass, *Ammophila arenaria*, was coded as Amar. An indication of dominance is provided by the use of ( ) to distinguish subdominant species e.g. Amar(Caed) indicates that marram grass was dominant over ice plant (*Carpobrotus edulis*). The use of ( ) is not always based on percentage cover, but the subjective observation of which vegetation is the dominant or subdominant species within the patch. A measure of vegetation height can be derived from its structural class (e.g. rushland, scrub, forest).

**VEGETATION (mapped separately to the substrates they overlie).**

**Forest:** Tree and shrub cover in the canopy is >80% and tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.

**Treeland:** Trees cover in the canopy is 20-80%. Trees are woody plants >10cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.

**Scrub:** Shrub and tree cover in the canopy is >80% and shrub cover exceeds that of trees (cf. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.

**Shrubland:** Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.

**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*.

**Duneland:** Sand dune vegetation (commonly Spinifex, Pingao or Marram grass) is 20-100% and the dune vegetation cover exceeds that of any other growth form or bare ground.

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

**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*.

**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 *Leptocarpus*.

**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*.

**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.

**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.

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

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

**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 separately to the substrates they overlie.

**SUBSTRATE (physical and zoogenic habitat)**

**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 barriers (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%.

**Mobile sand:** Granular beach sand characterised by a rippled surface layer from strong tidal or wind-generated currents. Often forms bars and beaches.

**Sand:** Sand flats may be mud-like in appearance but are granular when rubbed between the fingers and no conspicuous fines are evident when sediment is disturbed e.g. a mud content <1%. Classified as firm sand if an adult sinks <2 cm or soft sand if an adult sinks >2 cm.

**Firm mud/sand (Low mud content):** A sand/mud mixture dominated by sand with a low mud fraction (e.g. 1-10%), the mud fraction conspicuous only when sediment is mixed in water. The sediment appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers.

**Firm mud/sand (Moderate mud content)**
A subjective division may be applied where the sand/mud mixture remains dominated by sand, but with an elevated mud fraction (e.g. 10-25%), the mud fraction visually conspicuous when walking on it. The surface appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm mud/sand with a low mud content, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers, but with a smoother consistency than firm muddy sand with a low mud fraction.

**Firm or soft mud/sand (High mud content):** A mixture of mud and sand where mud is a major component (e.g. >25%-50%mud). Sediment rubbed between the fingers retains a granular component but is primarily smooth/silken. The surface appears grey or brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm sandy mud, and very soft mud. Classified as firm mud if an adult sinks <2 cm (usually if sediments are dried out or another component e.g. gravel prevents sinking) or soft mud if an adult sinks 2-5 cm.

**Very soft mud/sand (Very high mud content):** A mixture of mud and sand where mud is the major component (e.g. >50% mud), the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink >5 cm unless another component e.g. gravel prevents sinking. From a distance appears visually similar to firm muddy sand, and firm or soft mud. Sediment rubbed between the fingers may retain a slight granular component but is primarily smooth/silken. From a distance appears visually similar to firm muddy sand, and firm or soft mud.

**Mud (Very high mud content):** A >90% mud dominated substrate with sand a minor component. Smooth/silken when rubbed between the fingers. When walking you'll sink >5 cm unless another component e.g. gravel or sediment drying prevents sinking.

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

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

**Shell bank:** Area that is dominated by dead shells.

# APPENDIX 2. ANALYTICAL METHODS AND RESULTS FOR SEDIMENTS.

**Hill Laboratories**
TRIED, TESTED **AND TRUSTED**

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## Certificate of Analysis



| | | | | |
|---|---|---|---|---|
| **Client:** | Salt Ecology Limited | **Lab No:** | 2119220 | SPv1 |
| **Contact:** | Leigh Stevens<br>C/- Salt Ecology Limited<br>21 Mount Vernon Place<br>Washington Valley<br>Nelson 7010 | **Date Received:** | 05-Feb-2019 | |
| | | **Date Reported:** | 27-Mar-2019 | |
| | | **Quote No:** | 97111 | |
| | | **Order No:** | | |
| | | **Client Reference:** | Waikawa, Kai Iwa and Mowhanau Estuaries | |
| | | **Submitted By:** | Leigh Stevens | |

**Sample Type: Sediment**

| **Sample Name:** | | WAIKAWA A 02-Feb-2019 |
|---|---|---|
| **Lab Number:** | | 2119220.5 |
| Individual Tests | | |
| Dry Matter of Sieved Sample | g/100g as rcvd | 78 |
| Total Recoverable Phosphorus | mg/kg dry wt | 270 |
| Total Nitrogen* | g/100g dry wt | < 0.05 |
| Total Organic Carbon* | g/100g dry wt | < 0.05 |
| Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg | | |
| Total Recoverable Arsenic | mg/kg dry wt | 3.0 |
| Total Recoverable Cadmium | mg/kg dry wt | < 0.010 |
| Total Recoverable Chromium | mg/kg dry wt | 7.4 |
| Total Recoverable Copper | mg/kg dry wt | 2.5 |
| Total Recoverable Lead | mg/kg dry wt | 2.9 |
| Total Recoverable Mercury | mg/kg dry wt | < 0.02 |
| Total Recoverable Nickel | mg/kg dry wt | 6.0 |
| Total Recoverable Zinc | mg/kg dry wt | 23 |
| 3 Grain Sizes Profile | | |
| Fraction >/= 2 mm* | g/100g dry wt | < 0.1 |
| Fraction < 2 mm, >/= 63 µm* | g/100g dry wt | 99.7 |
| Fraction < 63 µm* | g/100g dry wt | 0.2 |

| **Sample Name:** | | WAIKAWA B 02-Feb-2019 | WAIKAWA C 02-Feb-2019 | WAIKAWA D 02-Feb-2019 | | |
|---|---|---|---|---|---|---|
| **Lab Number:** | | 2119220.6 | 2119220.7 | 2119220.8 | | |
| Individual Tests | | | | | | |
| Dry Matter of Sieved Sample | g/100g as rcvd | 70 | 50 | 75 | - | - |
| Total Recoverable Phosphorus | mg/kg dry wt | 520 | 560 | 530 | - | - |
| Total Nitrogen* | g/100g dry wt | 0.07 | 0.12 | 0.06 | - | - |
| Total Organic Carbon* | g/100g dry wt | 0.76 | 1.36 | 0.69 | - | - |
| Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg | | | | | | |
| Total Recoverable Arsenic | mg/kg dry wt | 4.7 | 5.0 | 3.9 | - | - |
| Total Recoverable Cadmium | mg/kg dry wt | 0.018 | 0.029 | 0.027 | - | - |
| Total Recoverable Chromium | mg/kg dry wt | 12.5 | 14.0 | 11.7 | - | - |
| Total Recoverable Copper | mg/kg dry wt | 5.7 | 6.7 | 5.5 | - | - |
| Total Recoverable Lead | mg/kg dry wt | 7.1 | 9.0 | 9.8 | - | - |
| Total Recoverable Mercury | mg/kg dry wt | 0.03 | 0.05 | 0.05 | - | - |
| Total Recoverable Nickel | mg/kg dry wt | 9.3 | 10.3 | 9.8 | - | - |
| Total Recoverable Zinc | mg/kg dry wt | 42 | 48 | 49 | - | - |

| Sample Type: Sediment | | | | | | |
|---|---|---|---|---|---|---|
| | **Sample Name:** | WAIKAWA B 02-Feb-2019 | WAIKAWA C 02-Feb-2019 | WAIKAWA D 02-Feb-2019 | | |
| | **Lab Number:** | 2119220.6 | 2119220.7 | 2119220.8 | | |
| 3 Grain Sizes Profile | | | | | | |
| Fraction >/= 2 mm* | g/100g dry wt | 2.6 | 0.1 | 0.5 | - | - |
| Fraction < 2 mm, >/= 63 µm* | g/100g dry wt | 58.0 | 40.1 | 83.1 | - | - |
| Fraction < 63 µm* | g/100g dry wt | 39.4 | 59.7 | 16.5 | - | - |

# Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.
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<br>Used for sample preparation.<br>May contain a residual moisture content of 2-5%. | - | 1-8 |
| Environmental Solids Sample Preparation | Air dried at 35°C and sieved, <2mm fraction.<br>Used for sample preparation.<br>May contain a residual moisture content of 2-5%. | - | 1-8 |
| Dry Matter for Grainsize samples | Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis). | 0.10 g/100g as rcvd | 1-8 |
| Total Recoverable digestion | Nitric / hydrochloric acid digestion. US EPA 200.2. | - | 1-8 |
| Total Recoverable Phosphorus | Dried sample, sieved as specified (if required).<br>Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2. | 40 mg/kg dry wt | 1-8 |
| Total Nitrogen* | Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]. | 0.05 g/100g dry wt | 1-8 |
| 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 | 1-8 |
| 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 | 1-8 |
| 3 Grain Sizes Profile | | | |
| Fraction >/= 2 mm* | Wet sieving with dispersant, 2.00 mm sieve, gravimetry. | 0.1 g/100g dry wt | 1-8 |
| Fraction < 2 mm, >/= 63 µm* | Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference). | 0.1 g/100g dry wt | 1-8 |
| Fraction < 63 µm* | Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference). | 0.1 g/100g dry wt | 1-8 |

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

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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

Graham Corban MSc Tech (Hons)
Client Services Manager - Environmental

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