Synoptic Subtidal Monitoring of Waikawa Estuary, Manawatū

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Prepared for:

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GLOSSARY

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
Stratified	Fresh surface water overlying denser (heavier) seawater.
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
Zn	Zinc

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Background

Waikawa Estuary is a small-sized (~13ha) estuary that is a poorly flushed SSRTRE type estuary which discharges to the Manawatū coast. The mouth of the estuary is open to the sea; however, on occasion the estuary mouth closes or becomes constricted by a build-up of beach sand at the estuary entrance. The upper reaches are relatively narrow and confined within a well-defined river channel. Seawater intrusion extends approximately 4km inland from the coast and is commonly stratified with fresh surface water overlying denser (heavier) seawater.

Previous surveys have identified symptoms of high nutrient enrichment in the estuary including phytoplankton blooms, low oxygen bottom waters and with widespread fine sediment (i.e. mud) deposits throughout the subtidal reaches of the middle estuary. The spatial extent of eutrophic symptoms increased between February 2019 and a subsequent survey in January 2020, with areas expressing high enrichment conditions (i.e. low oxygen, elevated organic content, mud and nutrients) increasing from ~0.5ha (9%) to ~2.7ha (40%) of the subtidal area. In December 2020, the subtidal synoptic survey was repeated with the aim to assess trophic state, delineate the spatial extent of any salinity or temperature stratification, assess bottom water oxygen and phytoplankton concentration and reassess four subtidal sediment sites.

Key Findings

While there were some improvements in sediment condition and water quality in December 2020, the Waikawa estuary remains under pressure and is still expressing signs of eutrophication. The December 2020 sampling represents monitoring post-flood event, and as a result the estuary was mainly freshwater due to the dominance of the river flow over the seawater influence. The monitoring showed that the estuary has a high flushing potential and the capacity to remove excess sediments, nutrients, and low oxygen waters during high flow events. Given the estuary was well-flushed at the time of sampling no phytoplankton blooms or oxygen depletion were observed in the water column (Fig 5). These water quality results are reflective of the time of sampling, after a physical flushing event, rather than any improvements owing to nutrient and sediment reductions in the catchment.

Previous sampling dates (February 2019 and January 2020) identified severely low dissolved oxygen concentrations in the bottom waters and phytoplankton blooms at the halocline, in addition to poorly oxygenated soft sediments in the mid-estuary. It is apparent that under normal flow conditions the estuary is prone to stratification and oxygen depletion in the bottom waters, particularly during summer. Under these conditions, the estuary continues to express symptoms of eutrophication.

Recommendations

Considering eutrophication symptoms have been observed in previous surveys it is recommended that HRC consider the following:

1. Design and implement a long-term programme to assess estuary condition, ensuring it is linked to existing freshwater SOE monitoring. Include deployment of water quality loggers in eutrophic parts of the estuary.

2. Undertake a bathymetric survey of the estuary to enable accurate delineation of areas likely to stratify, and to underpin hydrodynamic models that will be used to estimate nutrient concentrations and predict ecological outcomes under changed nutrient and sediment management in the catchment.

3. 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.

4. From 2 and 3 above, establish limits for catchment sediment and nutrient inputs that will protect the estuary from degradation.

1. INTRODUCTION

1.1 BACKGROUND

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 the effect of 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. Manawatū and Whanganui, as well as smaller estuaries with developed catchments; e.g. Mowhanau, Kai iwi, Waikawa and Ōhau. These estuaries are shallow short-residence tidal river estuaries (SSRTREs). These systems are river-dominated with a high flushing potential meaning they are less susceptible to nutrients when compared to other estuary types. However, SSRTRE type estuaries can experience short periods (days to weeks) of restricted flushing when the estuary mouth undergoes partial or complete closure, increasing their susceptibility to nutrient loads during this time.

The National Estuary Monitoring Protocol (NEMP) 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 provide a valuable basis for establishing a benchmark of estuarine health 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.

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 for this estuary type.

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 & Robertson 2012, Stevens et al. 2016, Stevens 2019).

The current report describes the methods and results of synoptic monitoring undertaken at Waikawa Estuary in December 2020 (Fig. 1). The primary purpose of the work was to characterise the presence and extent of any subtidal stratification or phytoplankton blooms and assess the overall trophic state of the estuary. Previous surveys from 2016, 2018, 2019 and January 2020 are summarised in Stevens et al., (2020).

Waikawa Estuary; upper estuary (top) and lower estuary (bottom)

1.2 BACKGROUND ON WAIKAWA ESTUARY

Previous reports (e.g. Stevens et al. 2020; Robertson & Stevens, 2016; Robertson & Robertson, 2018) present background information on Waikawa Estuary, which is paraphrased (and expanded in places) below.

Waikawa Estuary is a small-sized (~13ha) poorly flushed SSRTRE type estuary which discharges to the Manawatū coast. The lower reaches are relatively shallow (mean depth ~0.5m) and comprise a low tide river channel dominated by marine sands. The mouth of the estuary is open to the sea; however, on occasion the estuary mouth closes or becomes constricted by a build-up of beach sand at the estuary entrance. Waikawa Stream flows into the estuary and has a moderate freshwater inflow (mean flow ~1.5 m^3/s).

The upper reaches are relatively narrow and confined within a well-defined river channel. Seawater intrusion extends approximately 4km inland from the coast. The estuary is commonly stratified with fresh surface water overlying denser (heavier) seawater. This denser seawater can become trapped in deep (2-4m) pools in the estuary allowing phytoplankton blooms to establish and oxygen to deplete after extended periods of poor flushing. This was observed in the mid and upper estuary during February 2019 and January 2020, where stratification led to oxygen depletion in the bottom waters in the saline bottom waters and a phytoplankton bloom at the halocline (Stevens 2019; Stevens et al. 2020). These findings indicate the estuary is expressing localised water column symptoms of nutrient enrichment (eutrophication).

No intertidal seagrass has been observed in the estuary and occasional nuisance macroalgal blooms (e.g. *Ulva* spp.) can be present in the lower estuary (see Robertson & Stevens, 2016). Horse's mane weed (*Ruppia megacarpa*) is widely distributed in the shallow subtidal reaches of the middle and upper estuary. Intertidal salt marsh is relatively sparse and restricted to narrow strips along the river margins. This reflects the limited extent of intertidal flats commonly associated with SSRTRE type estuaries. Historical areas of salt marsh have also been disconnected from tidal flows and modification of the estuary margin has reduced salt marsh extent. The landcover adjacent to the estuary is predominately grassland. The residential settlement of Waikawa is the dominant feature of the mid-estuary and the lower reaches are mostly unvegetated sands. The surrounding catchment is dominated by native forest (27%) and exotic forest (10%) in the upper catchment, and high and low production grassland (48%) in the lower catchment (see Fig 2 in Stevens et al. 2020).

The estuary has high cultural and spiritual values and is ecologically important because it is a feeding and roosting area for birds and an important habitat for fish. It is also frequented for recreational purposes.

Figure 1. Location map of Waikawa Estuary, Manawatū

2. METHODS

2.1 OVERVIEW

The primary focus of the current synoptic survey was to quantify the ecological condition of the subtidal reaches of the estuary by revisiting transect locations established in January 2020. Water quality, substrate type, sediment quality and the macroinvertebrate assemblage were assessed by wading, or grab sampling from a boat. Because the intertidal part of the estuary had previously been mapped and is summarised in Stevens et al. (2020) intertidal habitat mapping was not repeated in the current survey.

2.2 SUBTIDAL ASSESSMENT

2.2.1 Sites and sampling

Seventeen subtidal sites were distributed relatively evenly throughout representative parts of the estuary (Fig. 2). Sampling was conducted around high tide to enable the best delineation of saline extent in the upper estuary. The tidal range on the day of sampling was 0.5-2.2m, reflecting spring tides, and was approximately double the predicted neap tidal range of 0.8-1.8m (NIWA online tide forecaster).

At all sites in the deepest part of the channel cross-section the subtidal habitat was assessed by measuring the following variables:

- Channel width (approximate)
- Water depth
- Secchi disk clarity
- Surface and bottom water quality variables: temperature, salinity, pH, dissolved oxygen, chlorophyll-*a*
- Thermocline depth (if present)
- Halocline depth (if present)
- Substrate type
- Depth in the sediment of the apparent Redox Potential Discontinuity (aRPD)
- Sediment quality i.e., nutrients and organic content (at sites T3, T5, T8.2 and T10)
- Macroinvertebrate assemblage (at sites T3, T5, T8.2 and T10)

River cross-sections were assessed, and a decision made to not remeasure them in the current survey because there was no discernible change to the cross-sectional area recorded in January 2020.

Waikawa Estuary looking upstream from site T12

2.2.2 Water column indicators

At the deepest point in the channel, water quality measures were taken from ~20cm below the water the surface and ~20cm above the bottom sediment surface, and the depth of any salinity or temperature stratification recorded. Water column measures of pH, salinity, dissolved oxygen (DO), temperature and chlorophyll-*a* (as an indicator of phytoplankton presence) were made using a YSI Pro10 meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Care was taken not to disturb bottom sediments before sampling. A description of water column parameters is provided in Table 1.

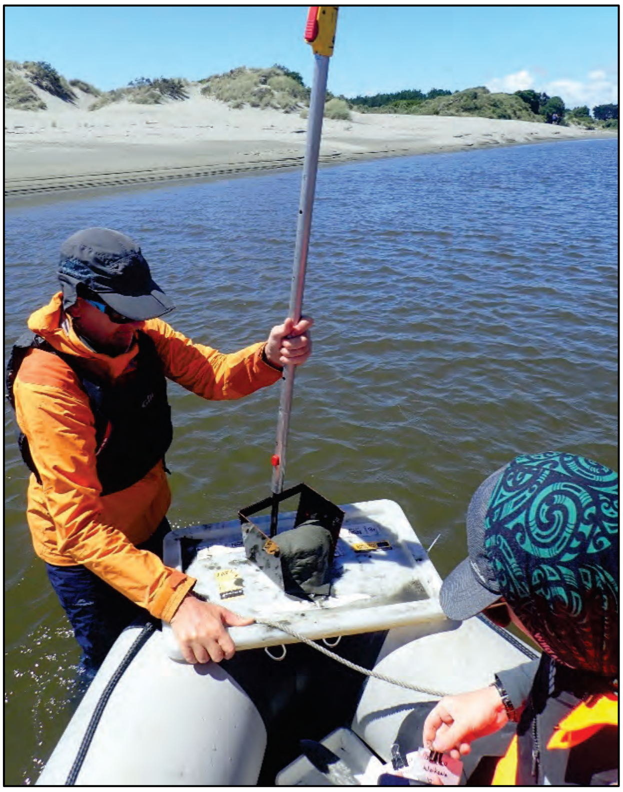
Water quality testing equipment

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

To assess whether potentially toxic phytoplankton were present in the estuary, a single grab sample was collected from site T5, the same location as the January 2020 survey. The sample was collected directly into a laboratory supplied sample container, preserved with lugols solution and stored in a dark environment, before being sent to NIWA, Hamilton for analysis.

2.2.3 Sediment indicators

At each sampling location, a substrate sample was collected using either a hoe or an Ekman grab sampler. At the surface, sediment quality was assessed in situ for a range of parameters as outlined below, with sample material from sites T3, T5, T8.2 and T10 retained for laboratory analysis.



Hoe sampler, collecting sediment by wading

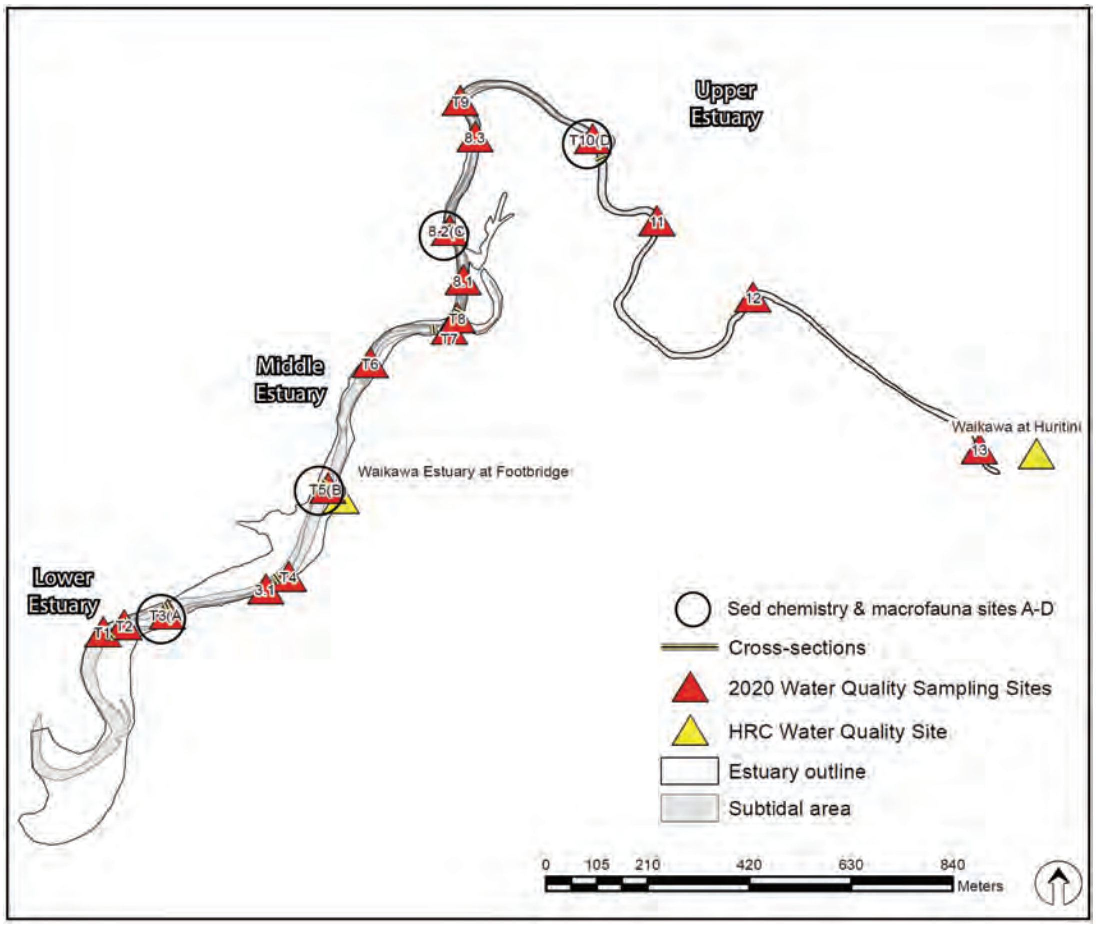


Figure 2. Locations of water quality and sediment sites in the Waikawa Estuary, Manawatū

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' and assessed by an experienced field observer considering the textural and firmness characteristics of the substrate. The field-based assessment was subsequently cross-checked against the results of grainsize (percent mud/ sand/ gravel) analyses at four locations (T3, T5, T8.2 and T10; Fig. 2).

Sediment oxygenation

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

Table 1. Description of water column and sediment indicators

INDICATOR	DESCRIPTION
Water column parameters	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 (algae) potentially able to grow and bloom in the retained water. Chlorophyll-*a* concentration is a proxy for phytoplankton which can be high in situations where nutrient supply is elevated and flushing is low. Elevated nutrients can 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.
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%.
Sediment organic matter	Total organic carbon (TOC) provides a measure of the organic material present in sediments. When this exceeds ~1%, sediment oxygen declines. Under anoxic (no oxygen) conditions bacteria can break down organic material producing sulphides which, as well having a strong odour, are toxic to most sediment dwelling animals.
Sediment nutrients	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 Estuary Trophic Index (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).
Sediment oxygenation (aRPD)	The apparent Redox Potential Discontinuity (aRPD) depth is a subjective measure of the enrichment state of sediments. The aRPD depth provides an easily measured, time integrated, and relatively stable measure of the sediment oxygenation conditions that infaunal communities are predominantly exposed to. An aRPD depth close to the sediment surface indicates oxygen is depleted, which can have a negative effect on infauna and alter nutrient cycling in the estuary (e.g. phosphorus release from sediments).

Sediment analysis

At the deepest point on transects T3, T5, T8.2 and T10 (Fig. 2), 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)

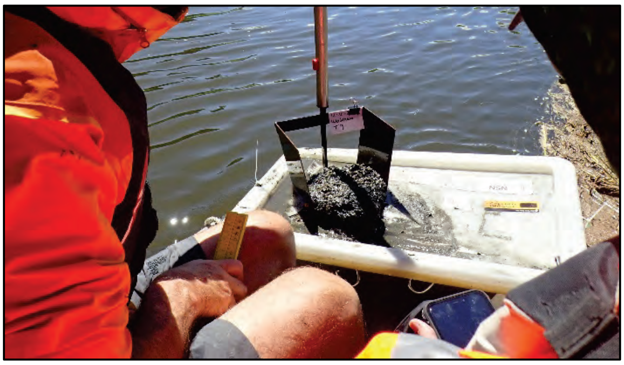
Details of laboratory methods and detection limits are provided in Appendix 2. A description of each sediment quality indicator is provided in Table 1.

2.2.4 Macrofauna

The abundance, composition and diversity of macrofauna, especially the infauna living within the sediment, are commonly used indicators of estuarine health. Three composite samples were collected from each of the four sites (T3, T5, T8.2 and T10) using a modified hoe or an Ekman grab sampler. A sub-sample (approx. down to 150mm deep) was taken from the hoe or grab sampler and placed within a 0.5mm sieve bag, which was gently washed in site water 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. Because of the sampling methodology (grab sample rather than core) the assessment is only intended as a qualitative measure to assess the health of the benthic community and prevailing sediment conditions.

The retained animals were 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.

Ekman grab sampler



Sediment collected with hoe sampler

Sediment sample in 0.5mm sieve bag prior to sieving

Sieving sediment samples in estuary water

2.3 DATA RECORDING AND QA/QC

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 sample).

2.4 ASSESSMENT OF ESTUARY CONDITION AND TEMPORAL CHANGE

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 Estuary Trophic Index (ETI; Robertson et al. 2016b) and subsequent revisions (Zeldis et al. 2017). The ETI provides screening guidance for assessing where an estuary is positioned on a eutrophication gradient. It includes site-specific thresholds for percent mud, TOC, TN, aRPD, metals, dissolved oxygen, and phytoplankton concentrations, generally using spot measures from within the most degraded 10% of the estuary. We adopted the ETI thresholds for present purposes, except for; (i) mud content (%); 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).

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).

Waikawa Estuary site T11

Table 2. Indicators used to assess results in the current 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
Water quality					
Dissolved oxygen (DO)[1]	mg/L	≥ 5.5	≥ 5.0	≥ 4.0	< 4.0
Phytoplankton (chl-*a*)[1]	mg/m^3	≤ 5	≥ 5 to < 10	≥ 10 to < 16	≥ 16

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.

Waikawa Estuary site T11

Waikawa Estuary site T8.3

Sand on the margin of middle estuary, site T7

Waikawa Estuary looking upstream site T5

3. RESULTS

3.1 WATER QUALITY

Fig. 3 summarises the stratification conditions in the estuary across two sampled dates January 2020 and December 2020. In January 2020 stratification was observed in the middle and upper estuary with denser (heavier) salt water trapped in the bottom waters and freshwater dominating the surface waters (Fig. 3a) The upper extent of salt water in January 2020 was ~4km (T13) from the estuary mouth. In contrast, no stratification was observed in December 2020, including the site closest to the estuary mouth (T1; Fig. 3b). Fig. 3c summarises freshwater flow measured at a site ~15km upstream of the estuary mouth, Waikawa Stream at Manakau Road. There were dry conditions prior ~2 months prior to the January 2020 sampling (Fig. 3), with below average rainfall recorded across most of New Zealand (NIWA climate summary). In contrast December 2020 sampling followed a recent rain event and high river flow (~12 m^3/s recorded 8/12/2020).

As shown in Fig. 3, the absence of stratification in the Waikawa Estuary in December 2020 is supported by the water quality data summarised in Table 3 and Fig. 5. The water column was well mixed throughout the estuary with no discernible difference between water quality parameters measured in the surface and bottom waters. In contrast in January 2020 stratification was observed in the water column (Fig. 4) and large changes in salinity, chlorophyll-*a* and dissolved oxygen were recorded between the surface and bottom waters.

In December 2020 the temperature ranged from 12.7 to 15.6°C in the surface waters. Similar observations were made in the bottom waters indicating the water column was well mixed (Fig. 5).

Salinity throughout the estuary ranged from 0.06 - 0.13 ppt in the surface and bottom waters at all sites (T1 to T13), indicating the estuary was comprised of freshwater at the time of sampling (Fig 3b).

In December 2020 phytoplankton (chl-*a*; mg/m^3) concentrations were consistently low (<2 mg/m^3) throughout the estuary in both the surface and bottom waters between sites T1 to T13 (Fig. 5). No toxic species of algae were detected at site T5.

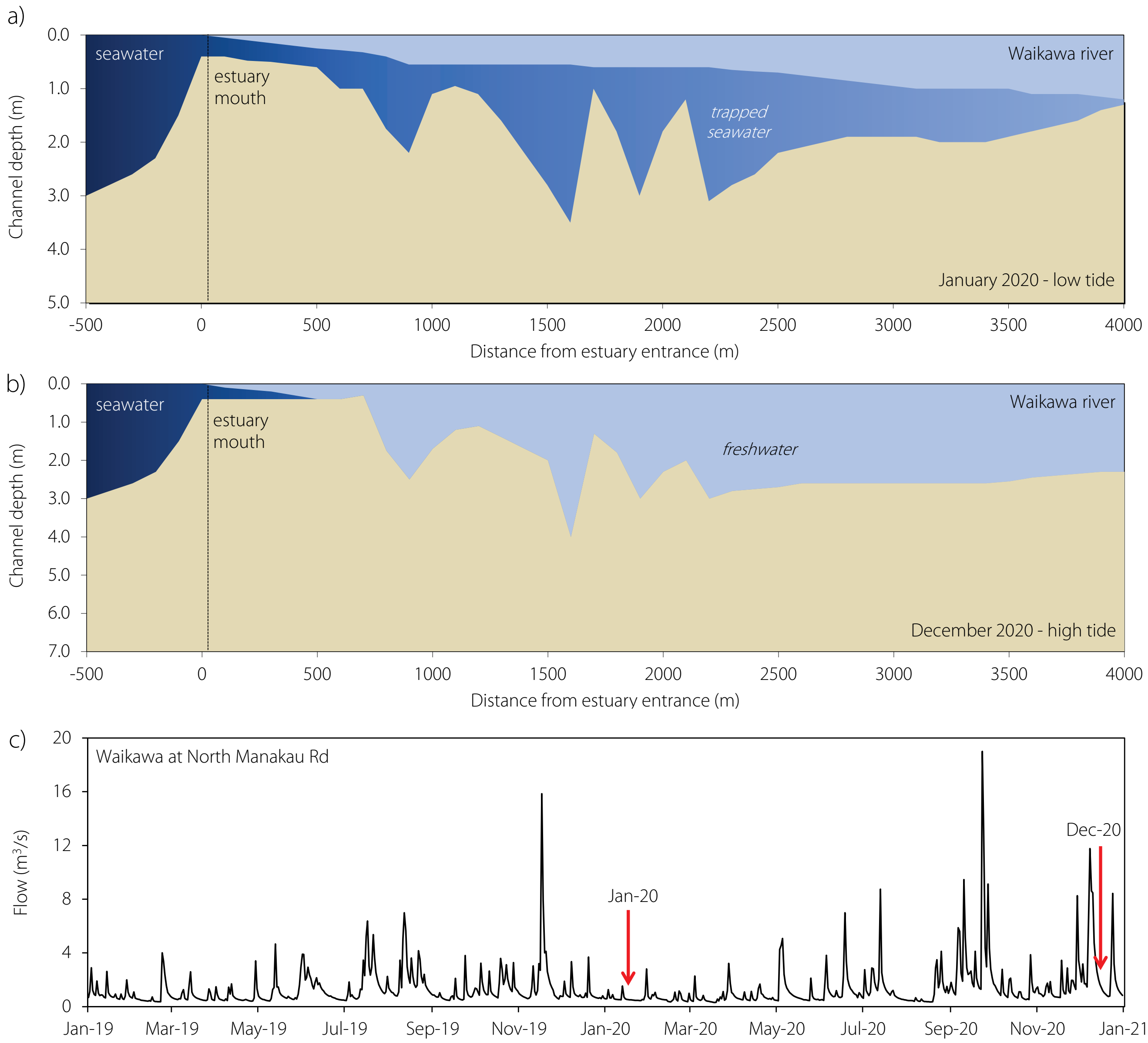


Figure 3. a) Waikawa Estuary showing extensive low tide stratification in Jan-2020; b) Waikawa Estuary showing no high tide stratification in Dec-2020; c) Provisional flow data from HRC at Waikawa Stream at North Manakau Road upstream of the estuary over the two sampling dates.

Lower Waikawa Estuary, near site T3

Birdlife in Waikawa Estuary

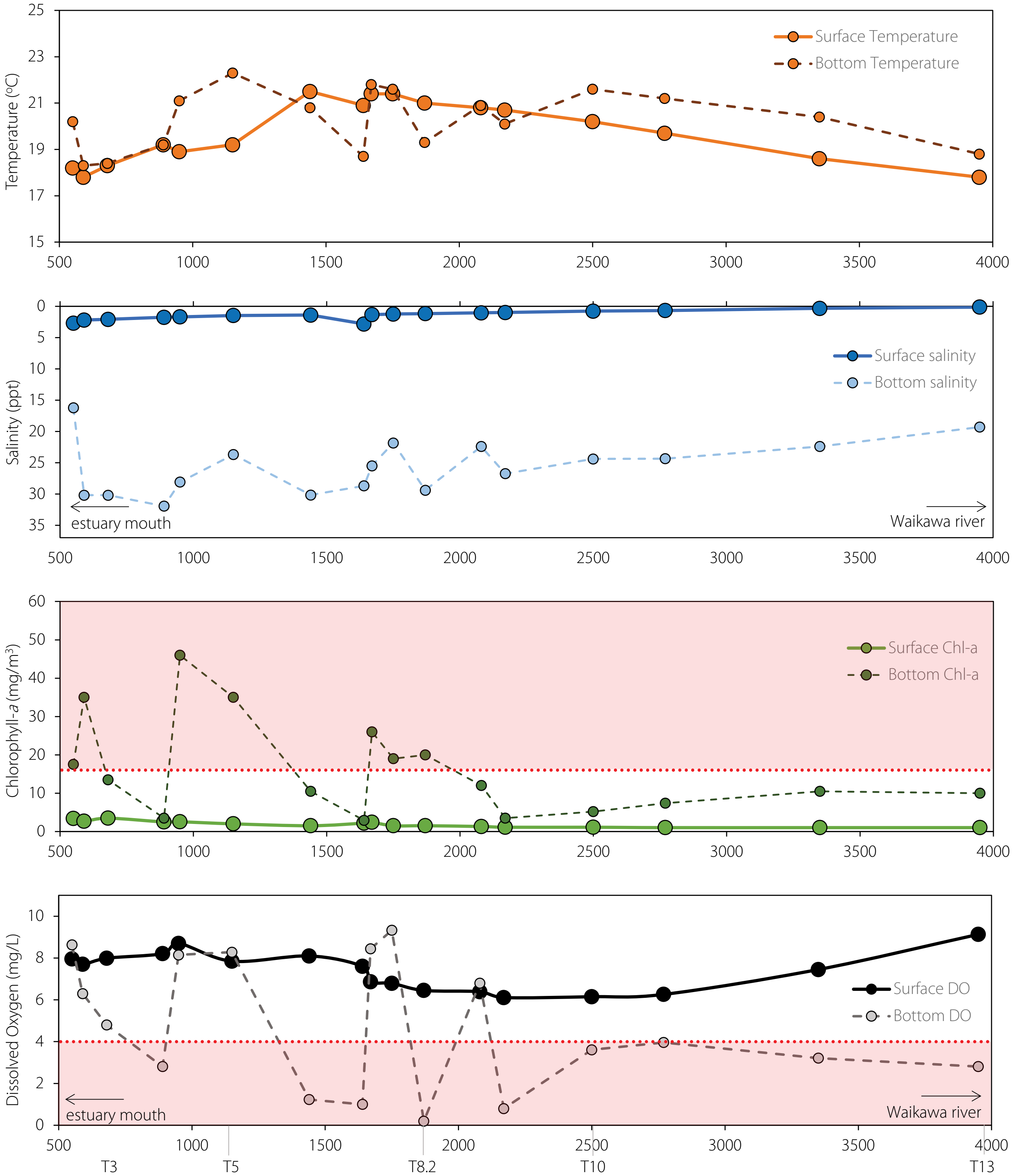


Figure 4. Water quality parameters in Jan-2020 a) Temperature (°C), b) Salinity (ppt), c) Chlorophyll-*a* (mg/m^3) and d) Dissolved Oxygen (mg/L) measured in the Waikawa Estuary for both surface and bottom waters. The red-dashed line and shading indicate the "poor" threshold and banding, respectively, for chlorophyll-*a* and dissolved oxygen (Table 2).

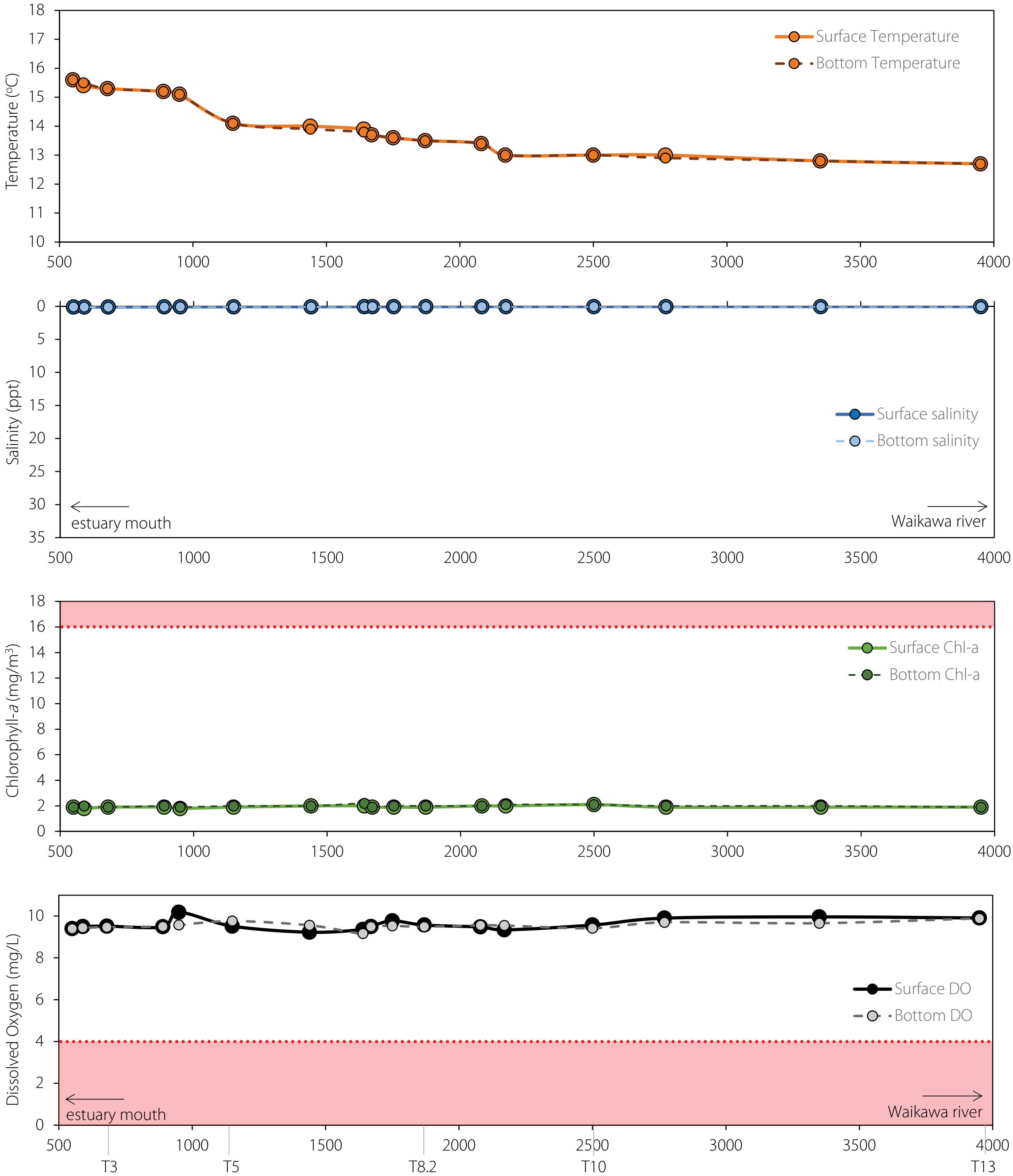


Figure 5. Water quality parameters in Dec-2020 a) Temperature (°C), b) Salinity (ppt), c) Chlorophyll-*a* (mg/m^3) and d) Dissolved Oxygen (mg/L) measured in the Waikawa Estuary for both surface and bottom waters. The red-dashed line and shading indicate the “poor” threshold and banding, respectively, for chlorophyll-*a* and dissolved oxygen (Table 2).

Table 3. Summary of water quality measurements taken in the Waikawa Estuary 12 December 2020. Locations shown on map in Fig. 2.

Station	T1	T2	T3	T3.1	T4	T5	T6	T7	T8	T8.1	T8.2	T8.3	T9	T10	T11	T12	T13
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 (^oC)	15.6	15.4	15.3	15.2	15.1	14.1	14.0	13.9	13.7	13.6	13.5	13.4	13.0	13.0	13.0	12.8	12.7
DO saturation (%)	94.5	96.0	94.4	94.6	101.6	93.2	90.3	90.7	92.1	94.2	91.7	91.1	90.6	91.0	94.4	93.2	93.4
DO conc (g/m^3)	9.40	9.50	9.52	9.49	10.18	9.52	9.23	9.36	9.50	9.77	9.57	9.48	9.34	9.57	9.90	9.96	9.91
Salinity	0.12	0.12	0.11	0.10	0.10	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
pH	6.70	6.65	6.65	6.67	6.98	6.67	6.62	6.57	6.68	6.75	6.62	6.57	6.77	6.87	7.00	7.02	7.50
Chlorophyll-a (mg/m^3)	1.9	1.8	1.9	1.9	1.8	1.9	2.0	2.0	1.9	1.9	1.9	2.0	2.0	2.1	1.9	1.9	1.9
Stratified	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Halocline depth (m)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thermocline depth (m)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Measurement depth 2 (m)	0.4	0.5	0.4	2.7	2.1	1.0	1.9	4.2	1.4	1.9	2.7	2.1	3.0	2.7	2.7	2.7	2.4
Temperature 2 (^oC)	15.6	15.5	15.3	15.2	15.1	14.1	13.9	13.8	13.7	13.6	13.5	13.4	13.0	13.0	12.9	12.8	12.7
DO saturation 2 (%)	94.3	94.6	94.2	94.8	95.8	94.9	93.0	89.9	91.5	92.1	91.3	91.5	91.4	89.6	92.0	91.9	93.4
DO conc 2 (g/m^3)	9.39	9.44	9.47	9.50	9.57	9.76	9.56	9.16	9.49	9.53	9.49	9.56	9.55	9.42	9.70	9.66	9.89
Salinity 2	0.12	0.12	0.13	0.11	0.10	0.08	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
pH 2	6.69	6.63	6.59	6.65	6.73	6.67	6.63	6.66	6.63	6.68	6.62	6.52	6.70	6.79	6.89	6.90	7.20
Chlorophyll-a 2 (mg/m^3)	1.9	2.0	1.9	2.0	1.9	2.0	2.0	2.2	1.9	2.0	2.0	2.0	2.1	2.1	2.0	2.0	1.9
Secchi depth (m)	>0.4	>0.5	>0.4	0.90	0.85	0.85	0.90	0.95	0.95	0.95	1.00	1.00	0.95	1.00	1.00	0.90	0.82
Max depth (m)	0.4	0.5	0.4	2.7	2.1	1.0	1.9	4.2	1.4	1.9	3.0	2.1	3.0	2.7	2.7	2.7	2.4
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	firm	soft	soft	soft	firm	firm	soft	firm	firm	soft	firm	firm	firm	firm
Sediment type	S0_10	S0_10	S0_10	CF	MS25_50	SM50_90	SM50_90	S0_10	S0_10	SM50_90	S0_10	S0_10	SM50_90	S0_10	S0_10	S0_10	MS25_50
aRPD depth (mm)	>60	>120	>120	ind	2	5 (>80)	30	>35	>90	2 (25)	>100	>60	1	>40	>35	>40	10

S_10 is sand (<10% mud), MS10_25 is muddy sand (10-25% mud), MS25_50 is muddy sand (25-50% mud), SM50_90 is sandy mud (50-90% mud); ind.=indeterminate, *recorded at low tide in January 2020.

[1]Mixed substrate across the channel; dominant substrate muddy sand (MS25_50) containing shell and organic material, closer to the bridge the substrate was sand (S0_10). The aRPD for the less dominant substrate, sand, is recorded in brackets.

[2]Mixed substrate across the channel; dominant substrate in the deeper parts of the channel sandy mud (SM50_90), in the shallower marginal areas the substrate was muddy sand (MS25_50). The aRPD for the less dominant substrate, muddy sand, is recorded in brackets.

3.2 SEDIMENT PHYSICAL AND CHEMICAL CHARACTERISTICS

A summary of the December 2020 composite sediment sample data collected from four sites is provided in Table 4. For comparative purposes earlier data are also presented (i.e., Robertson & Robertson 2018, Stevens 2019, Stevens et al., 2020)

3.2.1 Sediment grainsize

Mud content in the lower estuary (T3) has remained in the 'good' to 'very good' condition rating category since monitoring began in March 2018, reflecting the sites proximity to the estuary entrance and the dominance of marine sands (Table 4).

The mid-lower estuary site (T5) has shown improvement since monitoring began in 2018. Mud content decreased from 68.4% ('poor') to 5.8% ('good') between March 2018 and December 2020; at this site marine sands have been deposited over mud. Mud content decreased significantly in the mid to upper estuary (sites T8.2 and T10), improving from 'poor' in January 2020 to 'very good' in December 2020, indicating soft sediments have been scoured from the estuary in the preceding 11 months.

A decline in mud content has been observed at sites T5 and T8.2. Mud content in the upper estuary (site T10) is variable owing to its location in a straight stretch of the estuary making it prone to scouring and deposition under different flow regimes.

3.2.2 Sediment Oxygenation (aRPD)

Sediment oxygenation was variable across the estuary and correlated with substrate type (muddier sediments had lower aRPD). Sediment samples from each of the sampling locations are shown in the pictures above and aRPD is recorded in Tables 3 and 4. The lower estuary (T1 to T3) was dominated by sands with aRPD depths generally >60mm ('very good'). Sites T5 and T8.1 had variable substrates and aRPD across the channel. In these two locations the substrate ranged from sand to muddy sandy and aRPD ranged from >80mm ('very good') to 2 mm ('poor'; Table 3). In the mid-estuary the aRPD ranged from >35mm ('good') in sand substrate (sites T7 and T8) to 2mm ('poor) firm sandy mud (50-90%) at site T8.1. Shallow aRPD was generally recorded in sediments with >25% mud content, with the lowest aRPD (1mm; 'poor') recorded at site T9 in soft sandy mud (50-90% mud).

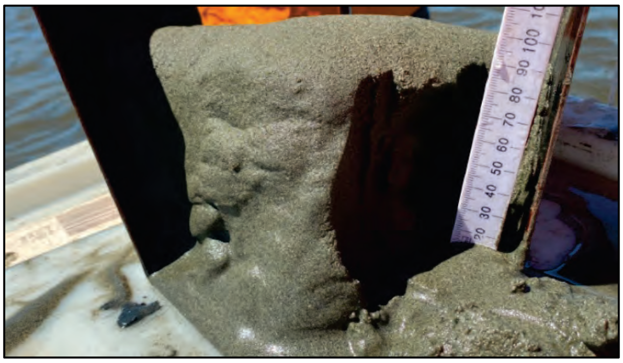
Table 4. Sediment grainsize, nutrient, aRPD, trace metal and metalloid data for composite samples collected at four sites in Dec-2020, and showing comparison with 2018 and Jan-2020 data.

Site	Year	Mud	TOC	TN	TP	aRPD	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
		%	%	mg/kg	mg/kg	mm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
T3 (A)	Mar-18	1.6	0.10	< 500	280	>30	3.4	< 0.010	7.4	2.6	< 0.02	7.2	3.2	23.0
	Feb-19	0.2	< 0.05	< 500	270	23	3.0	< 0.010	7.4	2.5	< 0.02	6.0	2.9	23.0
	Jan-20	8.4	0.13	< 500	300	>60	3.5	< 0.010	8.0	3.0	< 0.02	7.0	3.6	26.0
	Dec-20	0.2	0.07	<500	240	>120	-	-	-	-	-	-	-	-
T5 (B)	Mar-18	68.4	3.00	2100	760	10	6.4	0.072	14.2	10.6	0.12	14.0	14.0	59.0
	Feb-19	39.4	0.76	700	520	15	4.7	0.018	12.5	5.7	0.03	9.3	7.1	42.0
	Jan-20	16.7	0.50	< 500	420	55	3.7	0.020	10.0	6.0	0.03	8.0	6.0	33.0
	Dec-20	5.8	0.23	<500	280	5	-	-	-	-	-	-	-	-
T8.2 (C)	Mar-18	-	-	-	-	-	-	-	-	-	-	-	-	-
	Feb-19	59.7	1.36	1200	560	0	5.0	0.029	14.0	6.7	0.05	10.3	9.0	48.0
	Jan-20	34.3	0.95	700	530	10	4.1	0.019	11.0	6.0	0.09	9.0	7.7	43.0
	Dec-20	<0.1	0.12	<500	280	>100	-	-	-	-	-	-	-	-
T10 (D)	Mar-18	37.1	1.12	700	440	10	3.1	0.044	10.4	7.3	0.07	10.4	10.0	46.0
	Feb-19	16.5	0.69	600	530	10	3.9	0.027	11.7	5.5	0.05	9.8	9.8	49.0
	Jan-20	61.7	2.10	1600	640	ind.	5.1	0.042	16.0	10.0	0.08	13.0	11.3	54.0
	Dec-20	0.8	0.17	<500	420	>40	-	-	-	-	-	-	-	-

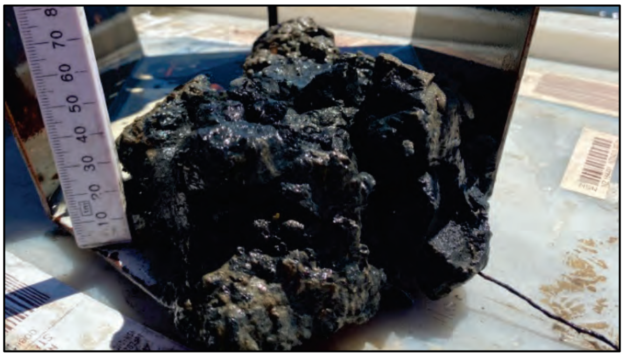
< All values below lab detection limit.
Ind.=indeterminate
*Metals were not measured in Dec-2020 because they were all close to detection and in the 'good' to 'very good' condition rating on the three previous samplings occasions. Condition bandings for metals are described in Stevens et al. (2020).

Waikawa Estuary site T1; sand <10% mud (aRPD >60 mm)

Waikawa Estuary site T2; sand <10% mud (aRPD >120 mm)



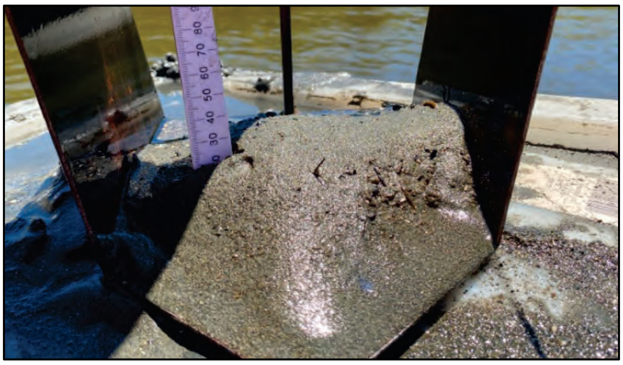
Waikawa Estuary site T3; sand <10% mud (aRPD >120 mm)



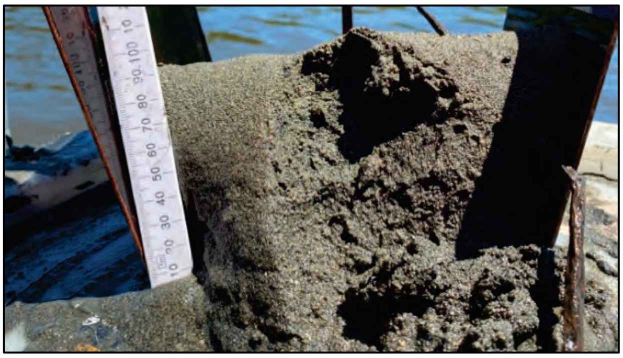
Waikawa Estuary site T4; muddy sand 25-50% mud (aRPD 2 mm)

Waikawa Estuary site T5; mixed substrate SM50_90 and S0_10 (aRPD 5 and >80 mm, respectively)

Waikawa Estuary site T6; sandy mud 50-90% mud (aRPD 30 mm)

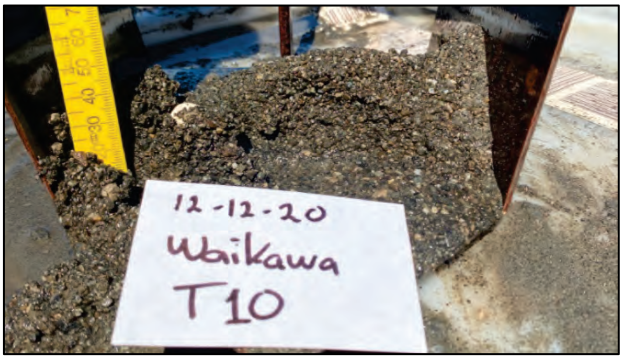


Waikawa Estuary site T7; sand <10% mud (aRPD >35 mm)



Waikawa Estuary site T8; sand <10% mud (aRPD >90 mm)

Waikawa Estuary site T8.1; sandy mud 50-90% mud (aRPD 2mm)



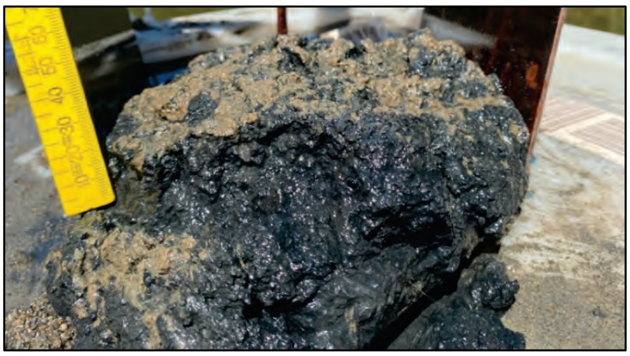
Waikawa Estuary site T10; sand <10% mud (aRPD >40mm)

Waikawa Estuary site T8.2; sand <10% mud (aRPD > 100mm)

Waikawa Estuary site T11; sand <10% mud (aRPD > 35mm)

Waikawa Estuary site T8.3; sand <10% mud (aRPD >60mm)

Waikawa Estuary site T12; sand <10% mud (aRPD >40mm)



Waikawa Estuary site T9; sandy mud 50-90% mud (aRPD 1mm)

Waikawa Estuary site T13; muddy sand 25-50% mud (aRPD 10 mm)

3.2.3 Total organic carbon and nutrients

In general, total organic carbon (TOC) and total nitrogen and phosphorus (TN and TP) are correlated with sediment grainsize, being highest in muddier sediments (Table 4).

In December 2020 mud content decreased coinciding with decrease in TOC and a rating of 'very good' at all sites sampled. Similarly, sediment TP decreased in December 2020, no condition rating has been developed for TP. TN was below detection (<500mg/kg) at all sites sampled, corresponding to a condition rating of 'good'.

3.3 MACROFAUNA

In December 2020 a qualitative assessment of sediment dwelling organisms at four sites was made. The purpose was to assess the community composition of sediment dwelling animals in response to prevailing sediment conditions. Results are summarised in Table 5, Figure 6 and Appendix 5.

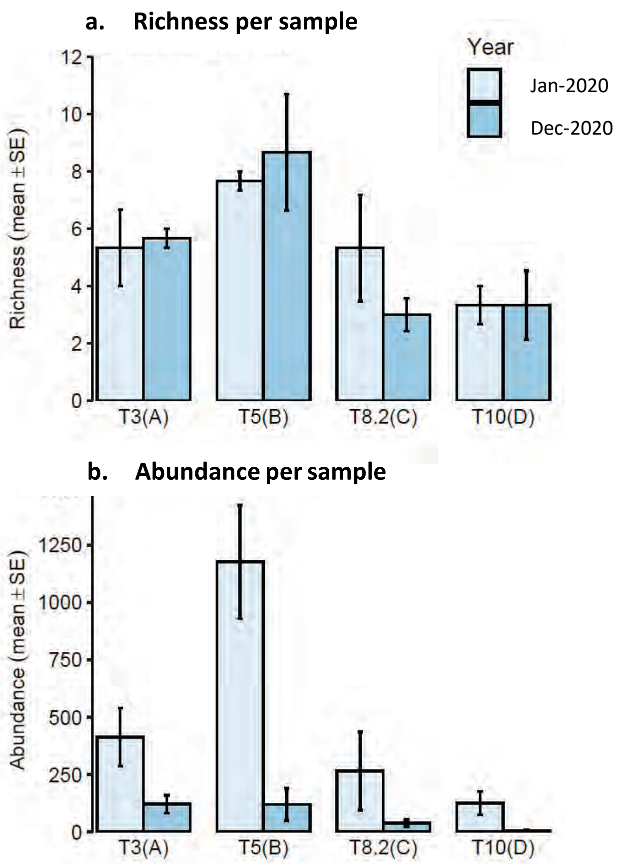


Figure 6. Taxon richness and abundance (mean ± SE) per site. Data are indicative only given the qualitative nature of sampling.

Results show that the macrofaunal assemblage is relatively impoverished. In total only 17 benthic dwelling species or higher taxa were recorded, with a few species likely marine in origin rather than being resident species in the estuary.

Similar to January 2020, mean species richness was low (3-9 species/sample), and abundance was variable driven primarily by the amphipod *Paracorophium,* in the lower estuary, and the small estuarine snail *Potamopyrgus estuarinus,* in the mid estuary (Table 5, Fig 6 and Appendix 3). Both species are tolerant to pollution and in particular, eutrophication, with ecological sensitivity groupings of EG-IV and EG-III, respectively.

Abundance decreased in December 2020 compared to January 2020 (Fig 6). While these data are qualitative given the sampling methodology, large changes likely indicate a shift in estuary condition. A plausible explanation for the decrease in abundance observed at all four sites in December 2020, is the significant scouring of fine sediments from the estuary caused by a disturbance event (e.g. flood flow), and the shift of the substrate to sand-dominated sediments.

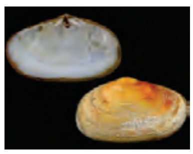
Species type varied between the four sites. At T3 (A), the site closest to the estuary entrance, marine species (e.g. *Pseudaega* sp. 1 a marine isopod) were present, likely washed into the estuary from the sea. High numbers of the disturbance tolerant amphipod *Paracorophium* and the more sensitive deposit feeding spionid *Microspio maori* were also present (Table 5).

Further upstream at the most diverse site (T5; B) pipi were present, appearing to be more abundant at the site (see photo) than what was recorded in the sample. Disturbance tolerant surface-dwelling animals such as the amphipod *Paracorophium* and estuarine snail *Potamopyrgus estuarinus* were also abundant.

Pipi present at site T5; the substrate mixed.

Abundance and richness decreased in the mid to upper estuary at sites T8.2 (C) and T10 (D). The lowest abundance was recorded at T10 (D) possibly due to the dynamic nature of this site with erosion and deposition events occurring frequently. At the two mid and upper estuary sites the amphipod *Paracorophium* and estuarine snail *Potamopyrgus estuarinus* were still the most abundant species present. However, the pollutant tolerant polychaete worm *Scolecolepides benhami* was present in the upper estuary and the estuarine snail *Potamopyrgus antipodarum* at site T10 (D), a species more tolerant to freshwater, was also present.

Table 5. Description of the sediment-dwelling species that were most abundant at one or more sites. EG refers to the ecological sensitivity grading, with EG-I describing sensitive species and EG-V species tolerant to pollution.

Main Group (Species name)	EG	T3 (A)	T5 (B)	T8.2 (C)	T10 (D)	Description	
Polychaeta (*Microspio maori*)	I	52	0	0	0	An endemic spionid commonly found in sandy intertidal and soft shore habitats. Surface and subsurface deposit feeding herbivore, can tolerate estuarine salinities.	
Polychaeta (*Scolecolepides benhami*)	IV	0	6	7	4	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.	
Gastropoda (*Potamopyrgus estuarinus*)	III	6	43	55	6	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.	
Gastropoda (*Potamopyrgus antipodarum*)	III	0	1	0	3	Small endemic snail that is prominent in freshwater ecosystems as well as brackish waters. Feeds on detritus, living plants and periphyton. Found in the upper estuary where freshwater is more common.	
Crustacea (Paracorophium sp.)	IV	234	277	52	4	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.	
Crustacea (Pseudaega sp. 1)	NA	19	8	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.	
Bilvalva (*Paphies australis*)	II	0	2	0	0	Endemic shellfish abundant at or below mid tide on flat sandy beaches and in soft-bottom estuaries where there is reasonable flushing. Filter feeder affected by changes in suspended sediment in the water column.	

4. SYNTHESIS OF KEY FINDINGS

While there were some improvements in sediment condition and water quality in December 2020, Waikawa Estuary remains under pressure and is still expressing signs of eutrophication.

As seen in the monitoring to date, river-dominated estuaries, like Waikawa, can be highly dynamic systems. To further explore the differences between each of the monitoring years a conceptual diagram that describes three scenarios will be referred to in the discussion (Fig. 7). Fig 7b represents February 2019 and January 2020 whilst Fig 7c represents December 2020.

During periods of base or low freshwater flow, seawater extends ~4km upstream from the Waikawa Estuary mouth (Fig 7a) and the estuary becomes stratified, with lighter freshwater overlying denser (heavier) seawater. Under prolonged low flow conditions, the trapped seawater can become depleted in oxygen (Fig 7b).

Both physical and biological processes control the depletion of oxygen in the bottom waters. While physical processes such as stratification and isolation of the bottom waters promote oxygen depletion (i.e. through lack of mixing and re-aeration), biological processes such as high mineralisation rates during summer, increased oxygen demand as a result of high nutrient loading and breakdown of organic matter from phytoplankton blooms can lead to further decreases in oxygen concentration. Diurnal fluctuations in oxygen production (photosynthesis)

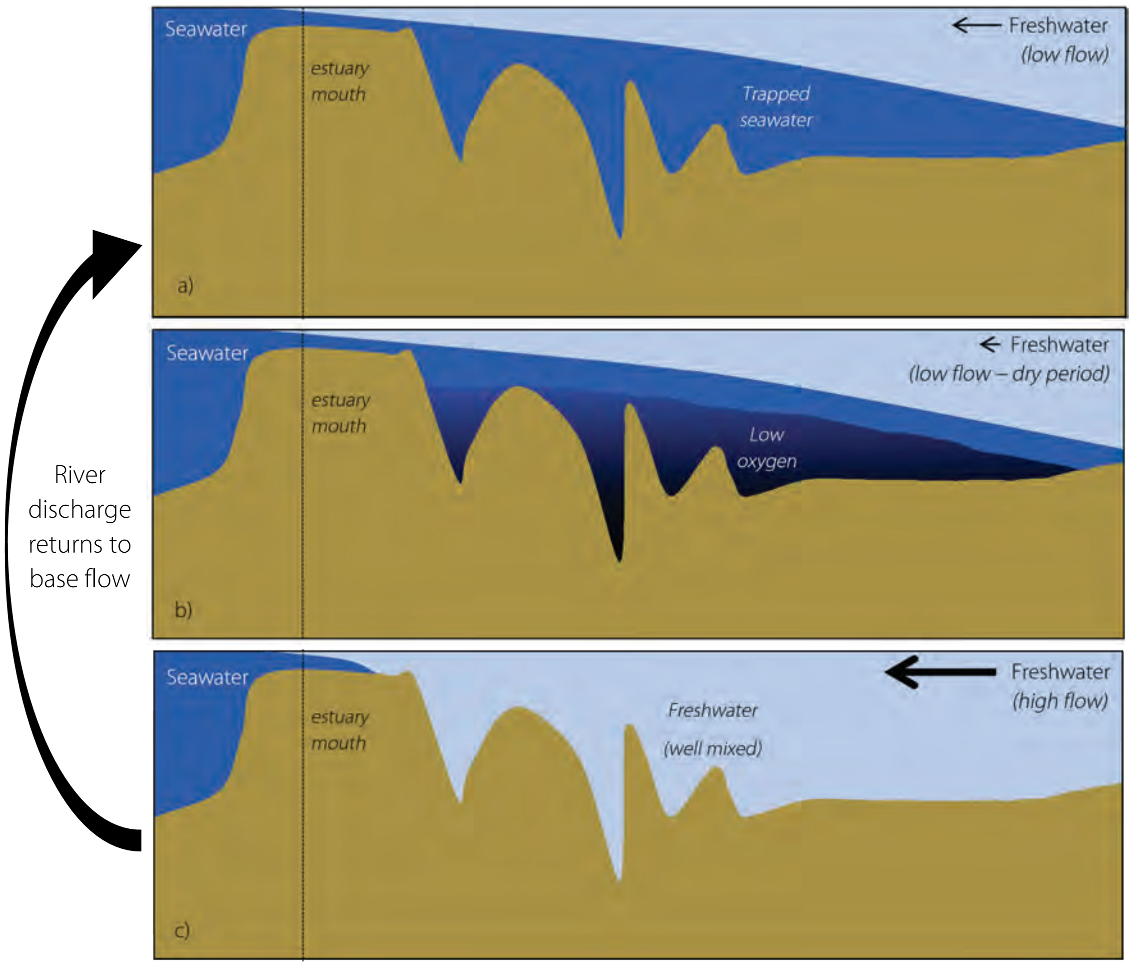


Figure 7. Conceptual diagram of the Waikawa Estuary under three scenarios. a) low freshwater flow with the extent of salt wedge ~4km upstream of the estuary mouth, b) extended dry period resulting in trapped seawater becoming depleted in oxygen (Jan-2020) and c) high freshwater inflow resulting in flushing of the deeper zones in the upper estuary with freshwater, no salt wedge extends into the estuary (Dec-2020).

and consumption (respiration) can also influence oxygen concentration in the bottom waters.

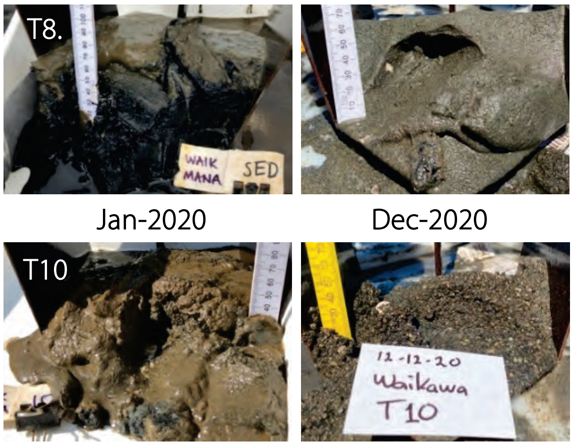
The scenario conceptually depicted in Fig 7b was observed in January 2020, where a dry period of ~2 months prior to sampling led to oxygen depletion in the deeper stratified parts of the estuary (Fig 3 and 4), coinciding with a phytoplankton bloom concentrated near the halocline. These observations confirmed that when conditions are suitable there are sufficient nutrients in the estuary to support nuisance-causing phytoplankton blooms.

Low oxygen events can also significantly alter biogeochemical processes. Including the cessation of nitrogen pathways (e.g. nitrification) and the release of sediment-bound phosphorus into the water column, further exacerbating nutrient related issues in the estuary (e.g. phytoplankton growth).

Moreover, severe ecological effects are observed, particularly in fish, below 4mg/L of dissolved oxygen (*see* Franklin 2014; Fig 3 and 4). In a study by Horizons Regional Council, shortjaw kōkopu and redfin bully were recorded in the Waikawa Stream (McArthur et al. 2007). Both species spend at least part of their life cycle at sea migrating through the estuary at different life stages. Redfin bully, for example, return to freshwater during the summer (from November) and are particularly sensitive to poor water quality. Low oxygen events observed on previous monitoring dates (February 2019 and January 2020) have the potential to inhibit or reduce the migration success of native fish species moving through the estuary.

In contrast, in December 2020 the sampling proceeded a high flow event in the Waikawa Stream. As a result, the estuary was mainly freshwater due to the river dominance over the seawater influence (Fig 3, 5 and 7c). Under a high-flow scenario, seawater trapped in the deeper parts of the estuary is washed out to sea and replaced with freshwater (Fig 7c). As the freshwater flow recedes, seawater begins to intrude into the estuary again (Fig 7a). The monitoring showed that the estuary has a high flushing potential and the capacity to remove excess sediments, nutrients, and low oxygen waters during high-flow events. Given the estuary was well-flushed at the time of sampling no phytoplankton blooms or oxygen depletion were observed in the water column (Fig 5). These water quality results are reflective of the time of sampling, after a physical flushing event, rather than any improvements owing to nutrient and sediment reductions in the catchment.

In December 2020 there were some obvious improvements in sediment condition. Sites that were characterised by muddy sediments (e.g. T8.2 and T10) in January 2020 were firms sands in December 2020 (see photo). It is probable that muddy sediments were flushed from the estuary during several high flow events recorded in the 11 months prior to sampling (Fig. 3). A decrease in mud content coincided with an improvement in TOC and TN (Table 4).



Comparison of Jan-2020 and Dec-2020 samples for sites T8.2 and T10. Muddy sediments in Jan-2020 cleared down to firm sands in Dec-2020.

While there was some improvement in sediment condition, likely the result of scouring, abundances of sediment dwelling organisms decreased in December 2020 and the benthic community remained relatively impoverished, with low richness and high abundances of pollution tolerant species such as the amphipod *Paracorophium* and estuarine snail *Potamopyrgus estuarinus.*

The available monitoring results show the dynamic nature of Waikawa Estuary under different flow conditions (Fig 7). Under normal flow conditions the estuary is prone to stratification and oxygen depletion in the bottom waters, particularly during summer with the estuary expressing significant symptoms of eutrophication. While December 2020 provided insight into the effective flushing potential of the estuary, such a change is likely to reflect a short-term change with conditions quickly returning to a more degraded state.

5. RECOMMENDATIONS

As significant eutrophication symptoms have been observed in previous surveys it is recommended that HRC consider the following:

1. 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, extent and persistence 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.

2. 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.

3. 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.

4. From 2 and 3 above, establish limits for catchment sediment and nutrient inputs that will protect the estuary from degradation.

Downstream site T5 Waikawa Estuary, turbid river flow after high flow event

Bank erosion in the upper estuary

Roosting shags and turbid water column, in the middle estuary.

Tidal flats of the lower estuary

Waikawa Estuary entrance

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APPENDICES

APPENDIX 1. BROADSCALE HABITAT CLASSIFICATION DEFINITIONS

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

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

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

Tussockland: Tussock cover is 20-100% and exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples occur in all species of *Cortaderia, Gahnia*, and *Phormium*, and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla*, and *Celmisia*.

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

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

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

Reedland: Reed cover is 20-100% and exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly- running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha, Bolboschoenus, Scirpus lacutris*, *Eleocharis sphacelata*, and *Baumea articulata*.

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

Cushionfield: Cushion plant cover is 20-100% and exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.

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

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

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

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

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

[1]Additions to the NEMP classification.

SUBSTRATE (physical and zoogenic habitat)

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

Artificial substrate: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stop-gates. Commonly sub-grouped into artificial: substrates (seawalls, bunds etc), boulder, cobble, gravel, or sand.

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

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

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

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

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

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

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

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

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

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

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

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

Shell bank: Area that is dominated by dead shells

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

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

Artificial Surfaces
1 Built-up Area (settlement)
2 Urban ParklandOpen Space
5 Transport Infrastructure
6 Surface Mines and Dumps

Bare or Lightly Vegetated Surfaces
10 Sand and Gravel
12 Landslide
14 Permanent Snow and Ice
15 Alpine Grass/Herbfield
16 Gravel and Rock

Water Bodies
20 Lake or Pond
21 River

Cropland
30 Short-rotation Cropland
33 Orchard Vineyard & Other Perennial Crops

Grassland, Sedge and Saltmarsh
40 High Producing Exotic Grassland
41 Low Producing Grassland
43 Tall-Tussock Grassland
44 Depleted Grassland
45 Herbaceous Freshwater Vegetation
46 Herbaceous Saline Vegetation

Scrub and Shrubland
47 Flaxland
50 Fernland
51 Gorse and/or Broom
52 Manuka and/or Kanuka
54 Broadleaved Indigenous Hardwoods
55 Sub Alpine Shrubland
56 Mixed Exotic Shrubland
58 Matagouri or Grey Scrub

Forest
64 Forest - Harvested
68 Deciduous Hardwoods
69 Indigenous Forest
71 Exotic Forest

Field codes used in the report

Substrate Class	Feature	Code
Bedrock	Rock field	RF
Boulder/Cobble/Gravel	Boulder field	BF
	Cobble field	CF
Sand (0-10% mud)	Firm sand	fS
	Mobile sand	mS
Muddy Sand (>10-25% mud)	Firm muddy sand	fMS10
	Soft muddy sand	sMS10
Muddy Sand (>25-50% mud)	Firm muddy sand	fMS25
	Soft muddy sand	sMS25
Sandy Mud (>50-90% mud)	Soft sandy mud	sSM
	Very soft sandy mud	vsSM
Zootic	Cocklebed	CKLE
	Mussel reef	MUSS
	Shell bank	shel

Salt marsh Class	Feature	Code
Estuarine Shrub	*Plagianthus divaricatus (Salt marsh ribbonwood)*	Pldi
Tussockland	*Phormium tenax (New Zealand flax)*	Phte
	Carex spp. (Sedge)	Casp
	Cortaderia sp. (Toetoe)	Cosp
Grassland	*Festuca arundinacea (Tall fescue)*	Fear
Rushland	*Apodasmia similis (Jointed wirerush)*	Lesi
	Ficinia (Isolepis) nodosa (Knobby clubrush)	Isno
Herbfield	*Selliera radicans (Remuremu)*	Sera

APPENDIX 2. ANALYTICAL METHODS FOR SEDIMENT SAMPLES (RJ HILL LABORATORIES)

Only the grain size fraction methods are relevant to this report.

Sample Type: Sediment		
Test	**Method Description**	**Default Detection Limit**
Individual Tests		
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-
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
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-
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
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt
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
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
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
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
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt

APPENDIX 3. PHYTOPLANKTON DATA

Algal Cell Count Report

NIWA
Taihoro Nukurangi

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

Attention: Leigh Stevens

Sample Information

Client description:	WAIK-MANA-T5	Laboratory ID:	2020001286/AS12396
Client ID:	WAIK-MANA-T5	Date received:	16/12/2020
Date sampled:	13/12/2020	Date analysed:	17/12/2020
Time sampled:		Sample Type:	Not specified

Sample Results

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

Dominant species (inc non toxic)	Cells per mL	Phyla
Flagellates/Unicells <5um	3	Flagellates/Unicells
Trachelomonas sp.	2	Euglenoids (Euglenoidea)
Scenedesmus sp.	1	Green algae (Chlorophyta)
Synura sp.	1	Golden-brown algae (Chrysophyceae)
Pyramimonas sp.	<1	Green algae (Chlorophyta)
Cryptomonas sp.	<1	Golden-brown algae (Cryptophyceae)
Euglena sp.	<1	Euglenoids (Euglenoidea)
Stauroneis sp.	<1	Diatoms (Bacillariophyceae)
Pinnularia sp.	<1	Diatoms (Bacillariophyceae)
Nitzschia sp.	<1	Diatoms (Bacillariophyceae)
Navicula sp.	<1	Diatoms (Bacillariophyceae)
Frustulia sp.	<1	Diatoms (Bacillariophyceae)

ACCREDITED IANZ TESTING LABORATORY

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

National Institute of Water & Atmospheric Research Ltd
Algal Services
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Algal Cell Count Report

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Sample Information

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Time sampled:		Sample Type:	Not specified

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

Date of Issue: 17/12/2020

Authorised by: Karl Safi
Key Tech Personnel, Algal Services

Signature: KAS

www.niwa.co.nz

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

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Algal Services
Gate 10, Silverdale Road, Hamilton
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Phone +64-7-856 7026, Fax +64-7-856 0151

APPENDIX 4. DATA FROM PREVIOUS SURVEYS (2019 & 2020)

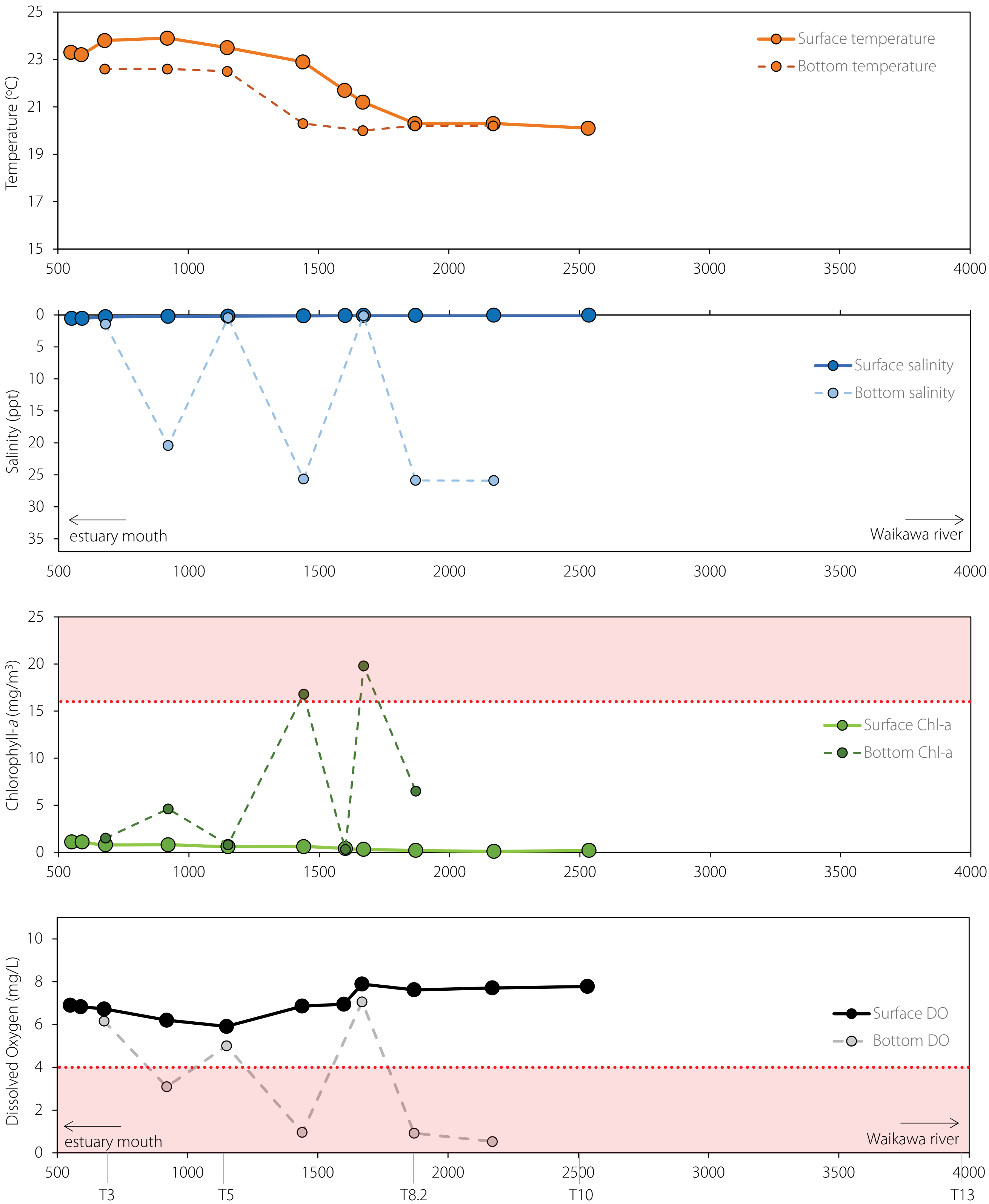


Figure A1: Water quality parameters for February 2019 a) Temperature (°C), b) Salinity (ppt), c) Chlorophyll-*a* (mg/m^3) and d) Dissolved Oxygen (mg/L) measured in the Waikawa Estuary for both surface and bottom waters. The red-dashed line and shading indicate the "poor" threshold and banding, respectively, for chlorophyll-*a* and dissolved oxygen (Table 2).

Table A1: Summary of water quality measurements in the Waikawa Estuary, February 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
Surface 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 (%)	81.4	80.2	80.1	74.7	69.7	83.8	79.0	87.0	85.0	85.0	85.6
DO conc (g/m^3)	6.90	6.83	6.73	6.20	5.91	6.86	6.95	7.89	7.62	7.71	7.78
Salinity	0.57	0.55	0.30	0.26	0.22	0.16	0.11	0.08	0.08	0.07	0.06
pH	8.13	8.13	8.07	7.76	8.13	8.36	8.04	8.08	8.90	7.94	8.15
Chlorophyll-*a* (mg/m^3)	1.1	1.1	0.8	0.8	0.6	0.6	0.4	0.3	0.2	0.1	0.2
Stratified	no	no	yes	yes	yes	yes	no	yes	yes	yes	no
Halocline depth (m)	-	-	0.8	1.2	1.2	1.7	-	1.5	2.1	2	-
Thermocline depth (m)	-	-	0.8	1.2	1.2	1.7	-	1.5	0	0	-
Bottom Measurement											
Depth (m)	-	-	0.9	1.3	1.3	2.0	-	1.4	2.2	2.2	-
Temperature (°C)	-	-	22.6	22.6	22.5	20.3	-	20.0	20.2	20.2	-
DO saturation (%)	-	-	72.5	40.1	58.1	14.3	-	79.8	14.5	7.2	-
DO conc (g/m^3)	-	-	6.16	3.09	5.00	0.96	-	7.06	0.92	0.53	-
Salinity	-	-	1.46	20.41	0.45	25.66	-	0.14	25.87	25.90	-
pH	-	-	7.64	7.37	7.76	7.44	-	7.85	7.29	7.10	-
Chlorophyll-*a* (mg/m^3)	-	-	1.5	4.6	0.8	16.8	-	0.3	19.8	6.5	-
Other measurements											
Secchi depth (m)	>0.4	>0.7	0.9	0.85	0.90	1.20	1.10	1.00	1.20	1.50	1.40
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)[1]	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

S_10 is sand (<10% mud), MS10_25 is muddy sand (10-25% mud), MS25_50 is muddy sand (25-50% mud), SM50_90 is sandy mud (50-90% mud)

Table A2: Summary of water quality measurements in the Waikawa Estuary, Jan-2020

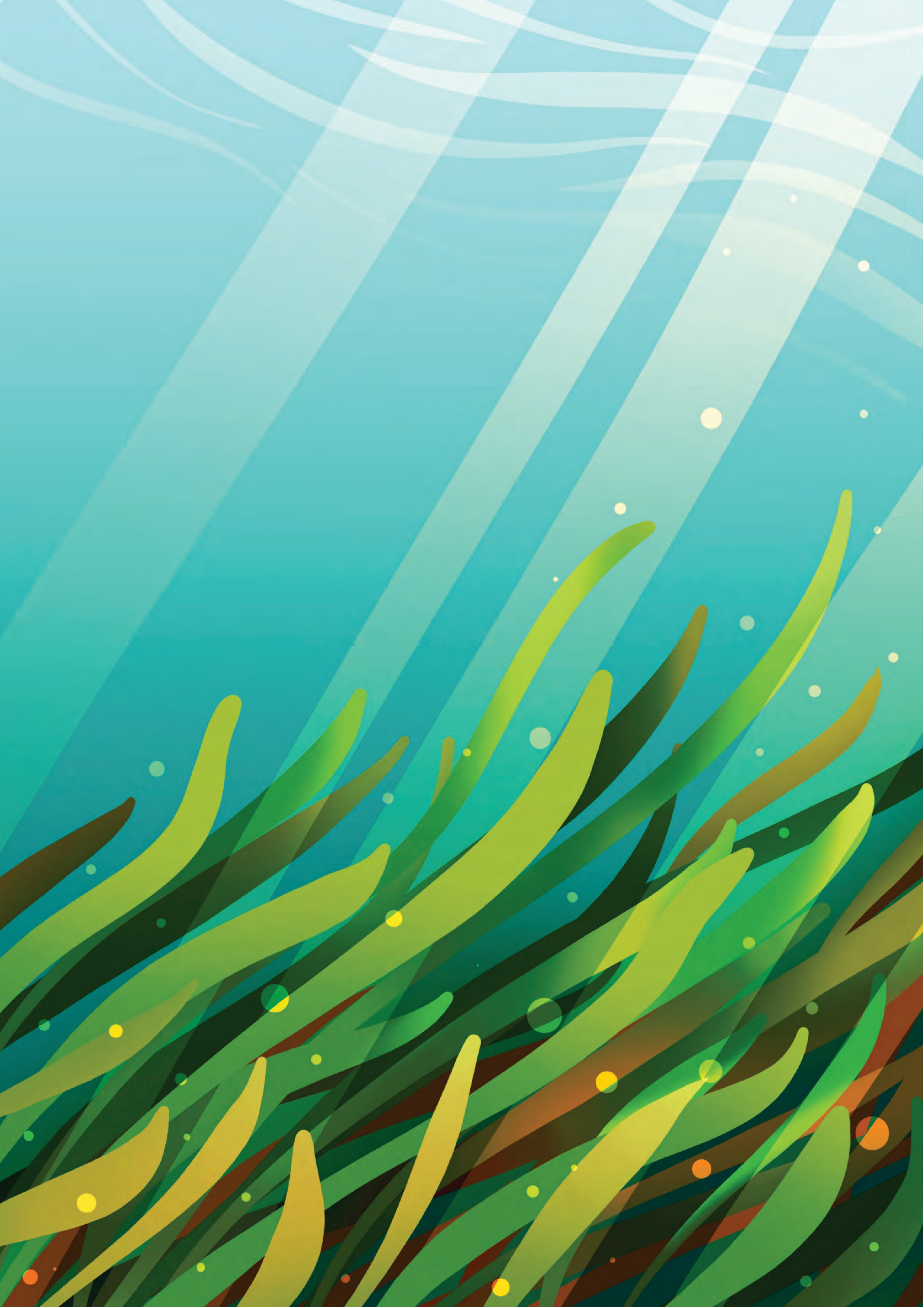
Station	T1	T2	T3(A)	3.1	T4	T5(B)	T6	T7	T8	8.1	8.2(C)	8.3	T9	T10(D)	11	12	13
NZTM East	1781056	1781098	1781189	1781392	1781437	1781519	1781606	1781770	1781786	1781799	1781770	1781823	1781792	1782065	1782198	1782397	1782864
NZTM North	5493401	5493416	5493439	5493495	5493521	5493712	5493984	5494056	5494080	5494163	5494270 .228	5494473	5494550	5494468	5494290	5494126	5493797
Distance from mouth (m)	550	590	680	890	950	1150	1440	1640	1670	1750	1870	2080	2170	2500	2770	3350	3950
Surface 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	21.0	20.8	20.7	20.2	19.7	18.6	17.8
DO saturation (%)	87.0	82.2	87.0	91.2	95.5	87.1	92.7	90.3	78.6	77.3	73.1	72.1	63.3	69.0	70.1	79.7	96.7
DO conc (g/m^3)	7.96	7.70	7.99	8.21	8.70	7.85	8.10	7.60	6.86	6.79	6.45	6.39	6.11	6.15	6.26	7.45	9.13
Salinity	2.69	2.20	2.09	1.75	1.69	1.47	1.40	2.83	1.33	1.23	1.17	1.04	0.98	0.76	0.67	0.33	0.12
pH	7.91	7.66	8.01	8.50	7.98	8.30	8.10	8.56	8.45	8.14	8.20	8.23	8.09	7.77	8.10	8.26	7.66
Chlorophyll-*a* (mg/m^3)	3.4	2.7	3.5	2.5	2.5	2.0	1.5	2.2	2.4	1.5	1.5	1.3	1.1	1.1	1.0	1.0	1.0
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	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	1.2
Bottom Measurement																	
Depth (m)	0.5	0.8	1.0	2.0	1.0	0.8	2.2	3.0	1.4	0.9	3.1	1.2	2.8	2.0	1.8	1.7	1.3
Temperature (°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 (%)	105.2	85.0	62.9	38.7	108.3	102.9	15.9	13.5	119.6	121.3	3.0	75.3	15.8	48.8	54.5	43.2	34.5
DO conc (g/m^3)	8.63	6.30	4.80	2.81	8.15	8.28	1.23	1.00	8.44	9.33	0.20	6.80	0.80	3.61	3.96	3.21	2.81
Salinity	16.21	30.20	30.20	31.94	28.10	23.70	30.17	28.70	25.50	21.84	29.40	22.40	26.75	24.40	24.36	22.40	19.30
pH	7.82	7.63	7.47	7.46	7.82	7.70	7.37	7.50	7.70	7.54	7.30	7.17	7.14	6.99	7.25	6.99	6.70
Chlorophyll-*a* (mg/m^3)	17.5	35.0	13.5	3.5	46.0	35.0	10.5	2.9	26.0	19.0	20.0	12.0	3.5	5.2	7.4	10.5	10.0
Other measurements																	
Secchi depth (m)	>0.6	0.85	0.95	0.85	0.95	>0.9	1.10	1.10	1.00	0.99	1.05	1.15	1.05	1.20	1.15	1.10	1.20
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)[1]	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	ind	>70	10	10	10	1	ind	ind	ind	ind

S_10 is sand (<10% mud), MS10_25 is muddy sand (10-25% mud), MS25_50 is muddy sand (25-50% mud), SM50_90 is sandy mud (50-90% mud)

APPENDIX 5. RAW DATA MACROINVERTEBRATES

Main group	Taxa	Habitat	EG	T3 - A (Jan-2020)	T3 - A2 (Dec-2020)	T5 - B1 (Jan-2020)	T5 - B1 (Dec 2020)	T8.2 - C1 (Jan2020)	T8.2 - C1 (Dec 2020)	T10 - D1 (Jan 2020)	T10 - D1 (Dec 2020)
Gastropoda	*Halopyrgus pupoides*	epibiota	III	0	0	0	0	1	0	0	0
Gastropoda	*Potamopyrgus antipodarum*	epibiota	III	0	0	0	1	1	0	3	3
Gastropoda	*Potamopyrgus estuarinus*	epibiota	III	24	6	2466	43	375	55	164	6
Gastropoda	*Zemelanopsis trifasciata*	epibiota	NA	0	0	7	2	1	0	0	0
Maxillopoda	*Austrominius modestus*	epibiota	II	1	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 1	infauna	II	0	0	25	2	5	0	0	0
Amphipoda	Amphipoda sp. 3	infauna	II	19	49	0	9	0	0	0	0
Amphipoda	Amphipoda sp. 4	infauna	II	0	0	0	2	0	0	0	0
Amphipoda	Amphipoda sp. 5	infauna	II	1	0	0	0	0	0	0	0
Amphipoda	Paracorophium spp.	infauna	IV	1085	234	899	277	403	52	30	4
Bivalvia	*Paphies australis*	infauna	II	7	0	4	2	0	0	0	0
Decapoda	*Halicarcinus whitei*	infauna	III	18	0	3	1	2	0	0	0
Isopoda	*Isopoda Anthuroidea*	infauna	NA	0	0	1	3	5	1	0	0
Isopoda	Pseudaega sp. 1	infauna	NA	28	19	0	8	0	0	0	0
Isopoda	Exosphaeroma sp. 1	infauna	NA	0	3	0	0	0	0	0	0
Oligochaeta	Oligochaeta sp. 1	infauna	III	0	0	102	1	2	0	150	0
Polychaeta	Capitella sp. 1	infauna	IV	0	0	0	0	0	0	18	0
Polychaeta	*Scolecolepides benhami*	infauna	IV	0	0	24	6	1	7	13	4
Polychaeta	*Boccardia wellingtonensis*	infauna	III	0	0	0	0	1	0	0	0
Polychaeta	*Microspio maori*	infauna	III	58	52	0	0	0	0	0	0
Mysidacea	Tenagomysis sp. 1	infauna	NA	0	0	0	1	0	0	0	0
Insecta	Diptera sp.1	larva	II	0	0	1	1	0	0	0	0
Insecta	Diptera sp.3	larva	II	0	0	0	0	0	1	0	1
Insecta	Megaloptera sp.1	larva	NA	0	1	0	0	0	0	0	0

*Note these abundances represent the combined raw data from three replicate samples taken at each site.



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