Synoptic Subtidal Monitoring of Ōhau 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

ACKNOWLEDGEMENTS

Many thanks to Mark Mitchell (HRC) for reviewing the draft report. We also thank the Salt Ecology team for macrofauna sample processing, and Gary Stephenson (Coastal Marine Ecology Consultants) for taxonomic identifications of macrofauna specimens.

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BACKGROUND

Ōhau Estuary is a moderate-sized (~50ha) shallow short-residence tidal river estuary (SSRTRE) which discharges to the Manawatū coast. The upper reaches are relatively narrow and confined within a well-defined river channel. Seawater intrusion extends ~3km inland from the coast and is commonly stratified with fresh surface water overlying denser (heavier) seawater.

A preliminary assessment of the estuary in 2016 indicated a low potential for eutrophication and sedimentation issues. In January 2020, a subtidal synoptic survey was undertaken after a protracted period of fine weather to assess trophic state, delineate the spatial extent of any salinity or temperature stratification, measure bottom water oxygen and phytoplankton concentrations, and assess three subtidal sediment sites for nutrient enrichment. Results showed that symptoms of nutrient enrichment extended (conservatively) over ~0.75ha (5%) of the subtidal area, primarily where seawater was trapped in deeper pools. Eutrophication symptoms included phytoplankton blooms and depleted oxygen levels, exacerbated by subtidal fine sediment deposition.

KEY FINDINGS

In December 2020, the subtidal synoptic survey was repeated the week following a relatively large flood event. Results showed some improvements in sediment condition and water quality compared to the January 2020 results, although these changes are reflective of the timing of sampling rather than the outcome of any improvements in the catchment and estuary state. In December 2020, salt water remained localised to the lower estuary and extended only ~1km upstream from the mouth. No stratification or eutrophic symptoms (low oxygen and high phytoplankton) were observed in the water column, not unexpected given the estuary was sampled post-flood. Concentrations of sediment mud, organic content and nutrients decreased compared to results from previous years at three fixed sites. Flushing of excess sediments, nutrients, and low oxygen waters from the estuary to the open coast represents a period of short-term improvement in conditions that will quickly return to a more degraded state if catchment inputs remain elevated. Therefore, while Ōhau Estuary is currently in a moderate state, it remains under pressure and will continue to express eutrophic symptoms particularly over the summer period when flushing is reduced.

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 nutrient enrichment impacts 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; Robertson et al. 2002a-c) is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results 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 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 type of estuary.

A typical way of modifying the NEMP approach for the assessment of SSRTREs is to use a series of cross-sectional transects, combined with assessment of broad and fine scale metrics which can be repeated over time and scaled up or down to address specific issues, as necessary.

Broad scale measures include synoptic mapping of estuary depth, benthic substrate, seagrass, and macroalgae, as well as delineating the spatial extent of phytoplankton blooms and any salinity or temperature stratification. Fine scale measures include *in situ* water and sediment quality measurements and the collection of sediment samples for laboratory analyses.

This approach has been previously shown to be a robust way to quickly describe estuary habitat and characterise trophic status (e.g. Stevens & Robertson 2012; Stevens et al. 2016, 2020; Stevens 2019).

The current report describes the methods and results of synoptic monitoring undertaken at Ōhau 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.

Lower Ōhau Estuary, at low tide

1.2 BACKGROUND ON ŌHAU ESTUARY

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

Ōhau Estuary is a moderate-sized (~50ha) 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 and a relatively large high tide lagoon running parallel to the outer coast. This lagoon is variable in size depending on the state of mouth closure or restriction and can extend for 2-3km along the coast when the mouth is closed. The mouth however remains open most of the time and the estuary drains readily and is relatively well-flushed by the Ōhau River (mean flow ~6.8 m^3/s).

The upper reaches are relatively narrow and confined within a well-defined river channel. Seawater intrusion extends approximately 3km inland from the coast and 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-estuary during January 2020, where stratification led to oxygen depletion in the saline bottom waters and a phytoplankton bloom at the halocline. 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 macroalgal growth appears to be uncommon. 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, but in the case of the Ōhau is exacerbated by extensive development of the surrounding land. Almost all the naturally vegetated terrestrial margin is modified, including coastal sand dunes dominated by introduced marram grass (*Ammophila arenaria*). The surrounding catchment is dominated by native forest and scrub in the upper catchment (53%), and pasture (33%) in the lower catchment. Exotic forest is also prominent (7%) (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.

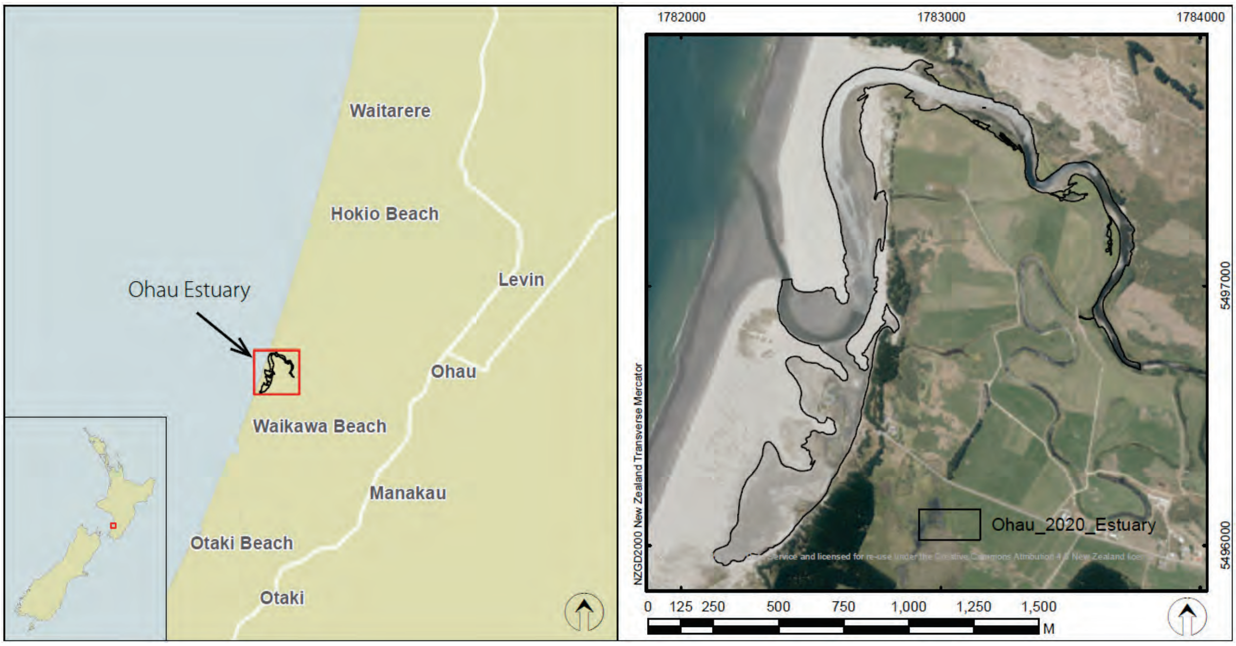


Figure 1. Location map of Ōhau Estuary, Manawatū

2. METHODS

2.1 OVERVIEW

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

2.2 SUBTIDAL ASSESSMENT

2.2.1 Sites and sampling

Eleven 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 0.4-2.2m, reflecting spring tides, and was approximately double the predicted neap tidal range of 0.9-1.7m (NIWA online tide forecaster).

At all sites in the deepest part of the channel cross-section the subtidal habitat was assessed by either wading or by sampling from a boat, to measure 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. heavy metals, nutrients, organic content (at sites T2, T5 and T7)
- Macroinvertebrate assemblage (at sites T2, T5 and T7)

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

Ōhau Estuary looking upstream from site T10

2.2.2 Water column indicators

At the deepest point at each sampling location, water quality measures were taken from ~20cm below the water 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 T7, the same location as the January 2020 survey. The sample was collected directly into 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 T2, T5, and T7 retained for laboratory analyses

Hoe sampler, collecting sediment by wading

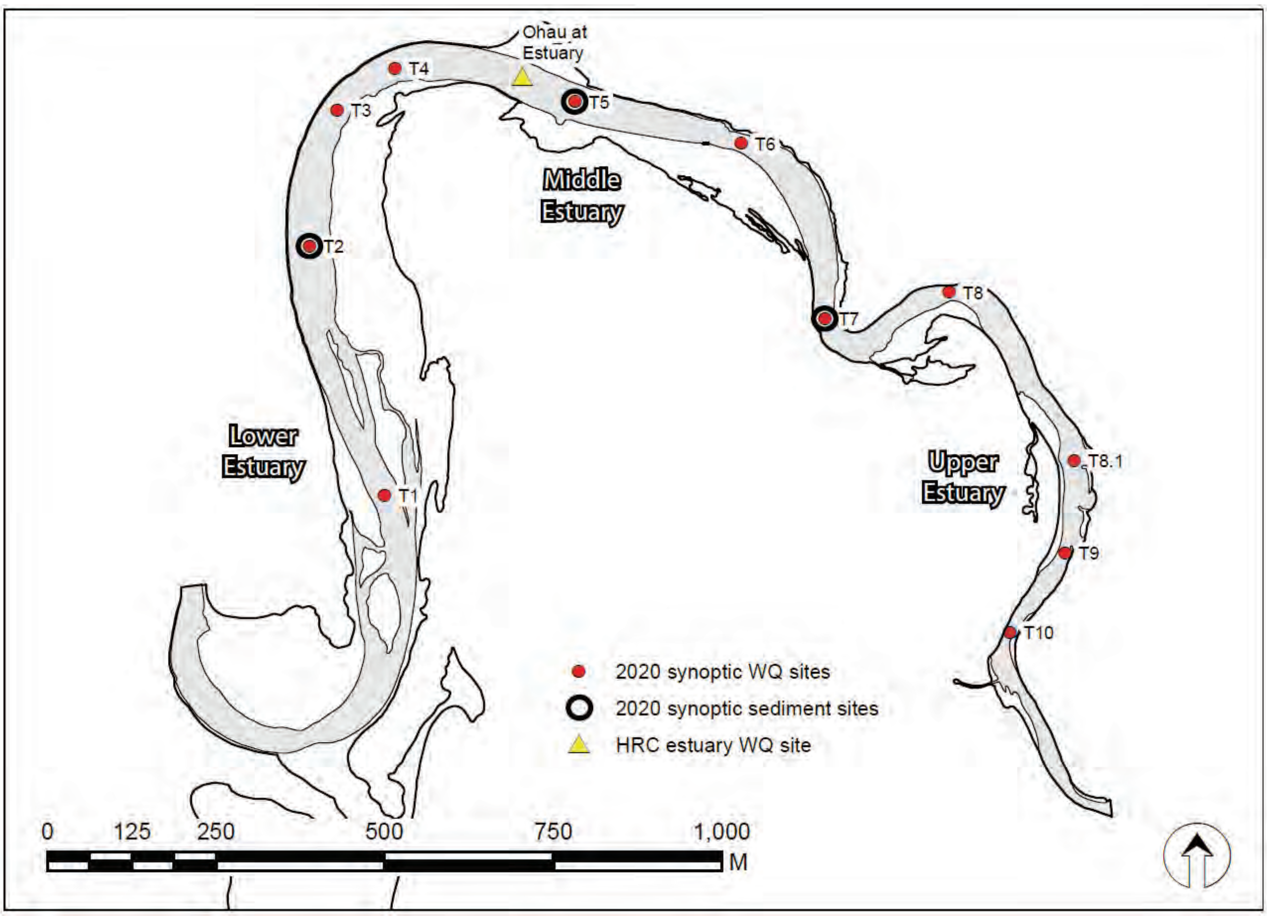


Figure 2. Locations of water quality and sediment sites in the Ōhau Estuary

Substrate classification

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

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 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.
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 T2, T5, and T7 (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 three sites (T2, T5 and T7) 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 sample 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).

Eroding banks middle estuary, site T7

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.

Channelised estuary in the upper estuary, site T9

Lower estuary tidal flats

Ōhau estuary site T8, eroding sand dune mid-estuary

Ōhau estuary site T6, mid-estuary

3. RESULTS

3.1 WATER QUALITY

Fig. 3 summarises the stratification conditions in the estuary in 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 on the surface (Fig. 3a). The upper extent of salt water was ~3km (Site T8.1) from the estuary mouth. In contrast, in December 2020 no stratification was observed in the middle estuary and salt water was not observed upstream of site T1, ~1km from the estuary entrance (Fig. 3b).

Fig. 3c summarises freshwater flow measured at a regional council water quality monitoring site ~20km upstream of the estuary mouth (Ōhau River at Rongomātāne). Results show there were low flow conditions prior to the January 2020 sampling, coinciding with below average rainfall recorded across most of New Zealand (NIWA climate summary). In contrast, the December 2020 sampling followed a recent rain event and high river flow (~64 m^3/s recorded 8/12/2020). The water column was well mixed and mainly freshwater following this flood event (Table 3 and Fig 5). No oxygen depletion in the bottom waters was observed.

Water quality data, summarised in Fig. 4 and Fig. 5 were used to illustrate extent of stratification in the Ōhau Estuary (Fig. 3). In December 2020, the water column was well mixed throughout the estuary with the surface and bottom waters showing similar patterns, deviating only at site T1 where salinity stratification was observed.

At the well-mixed sites (T2 – T10; no stratification observed) temperature ranged from 12.7 to 13.5°C in the surface waters, near identical to the bottom waters which ranged from 12.7 to 13.3°C (Table 3). At site T1, where stratification was observed, the bottom waters were 16.1°C which is consistent with warmer seawater intruding into the estuary.

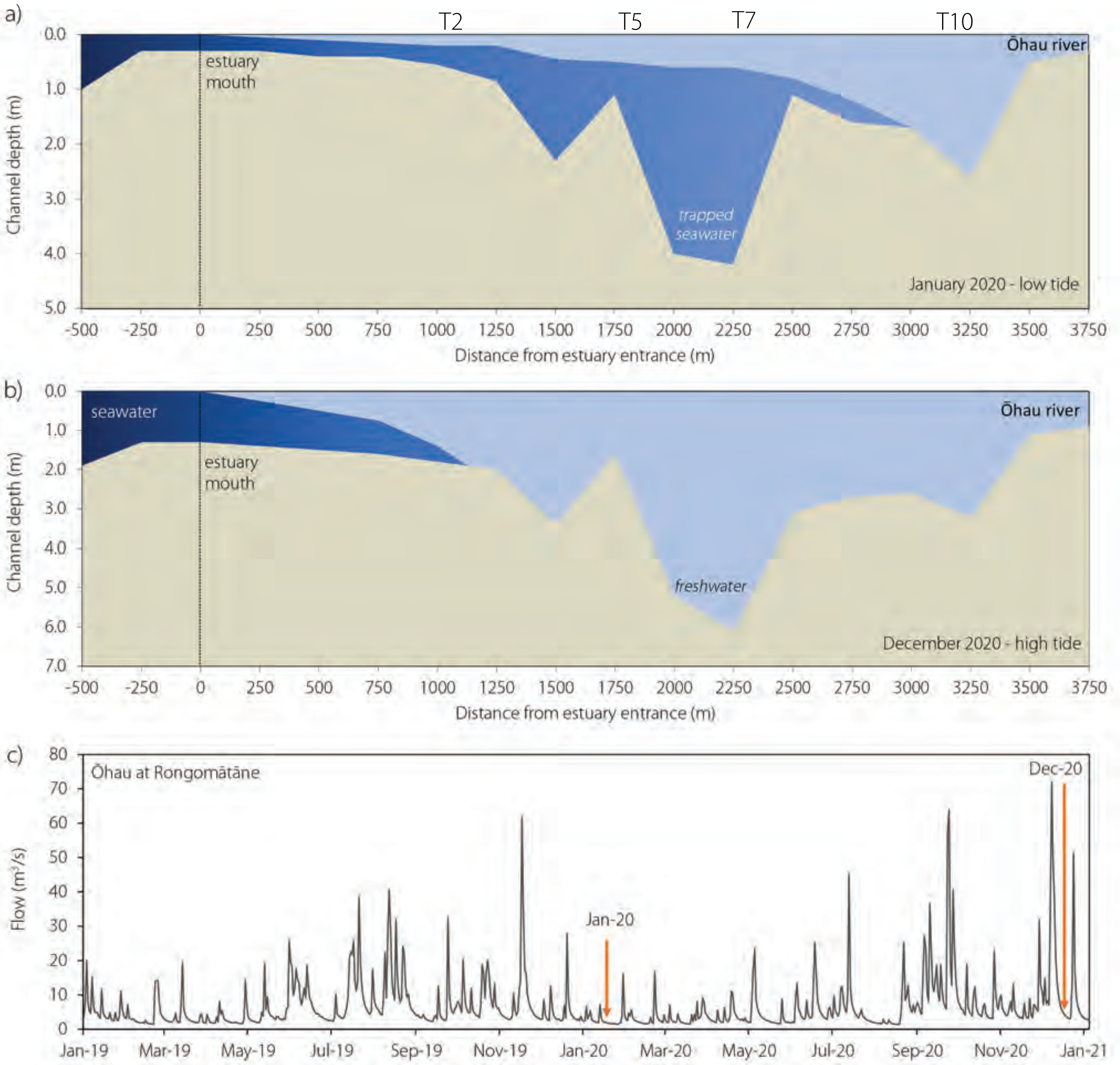


Figure 3. a) Ōhau Estuary showing extensive low tide stratification in January 2020; b) Ōhau Estuary showing no high tide stratification in Dec-2020 at high tide; c) Provisional flow data from HRC at Ōhau River at Rongomātāne upstream of the estuary over the two sampling dates.

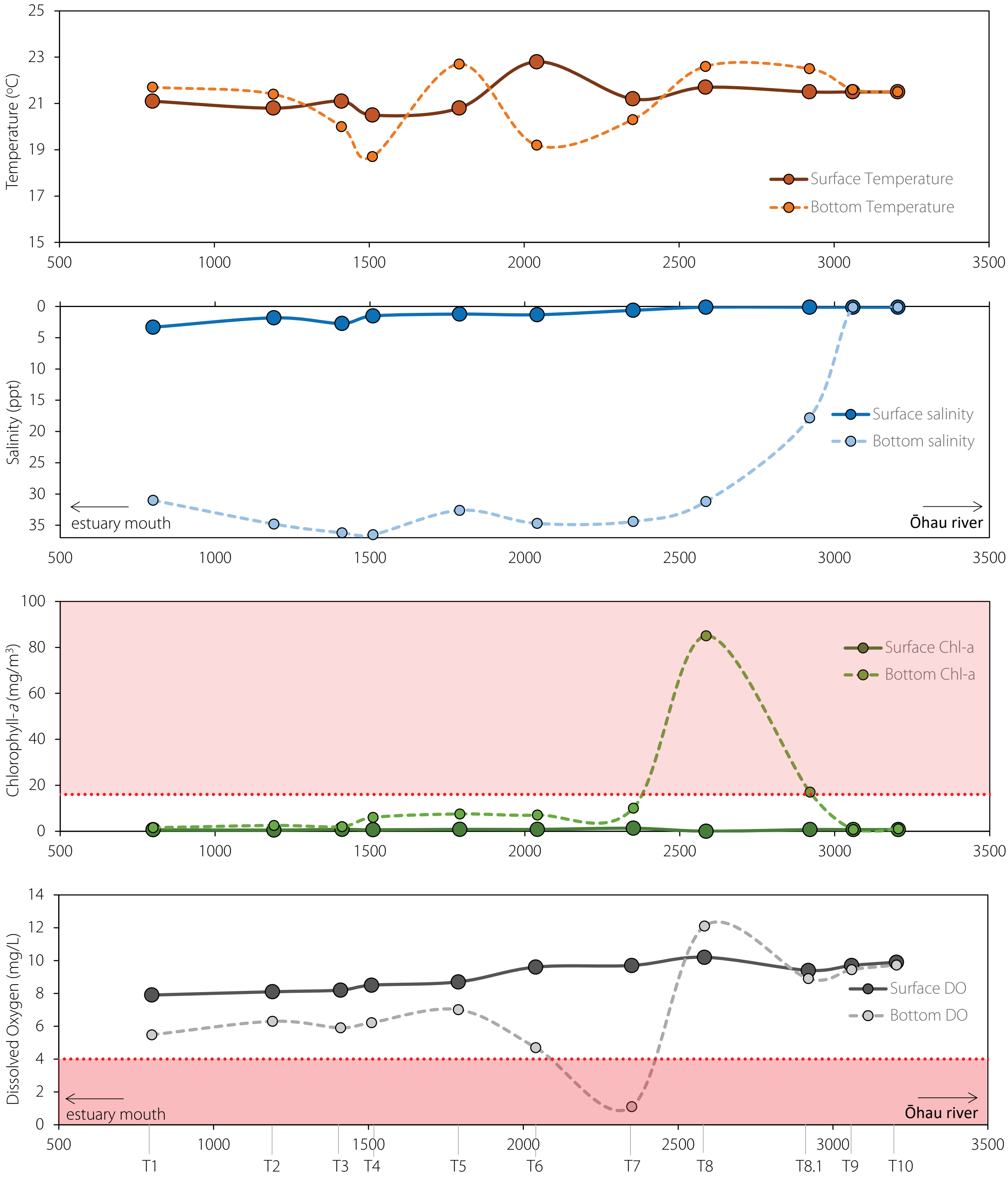


Figure 4. Ōhau Estuary water quality results, January 2020. a) Temperature (°C), b) Salinity (ppt), c) Chlorophyll-*a* (mg/m³) and d) Dissolved Oxygen (mg/L). Solid lines = surface water, dashed lines = bottom water. The red-dotted line and shading indicate the "poor" threshold and banding for chlorophyll-*a* and dissolved oxygen (Table 2). Raw data are presented in Appendix 4.

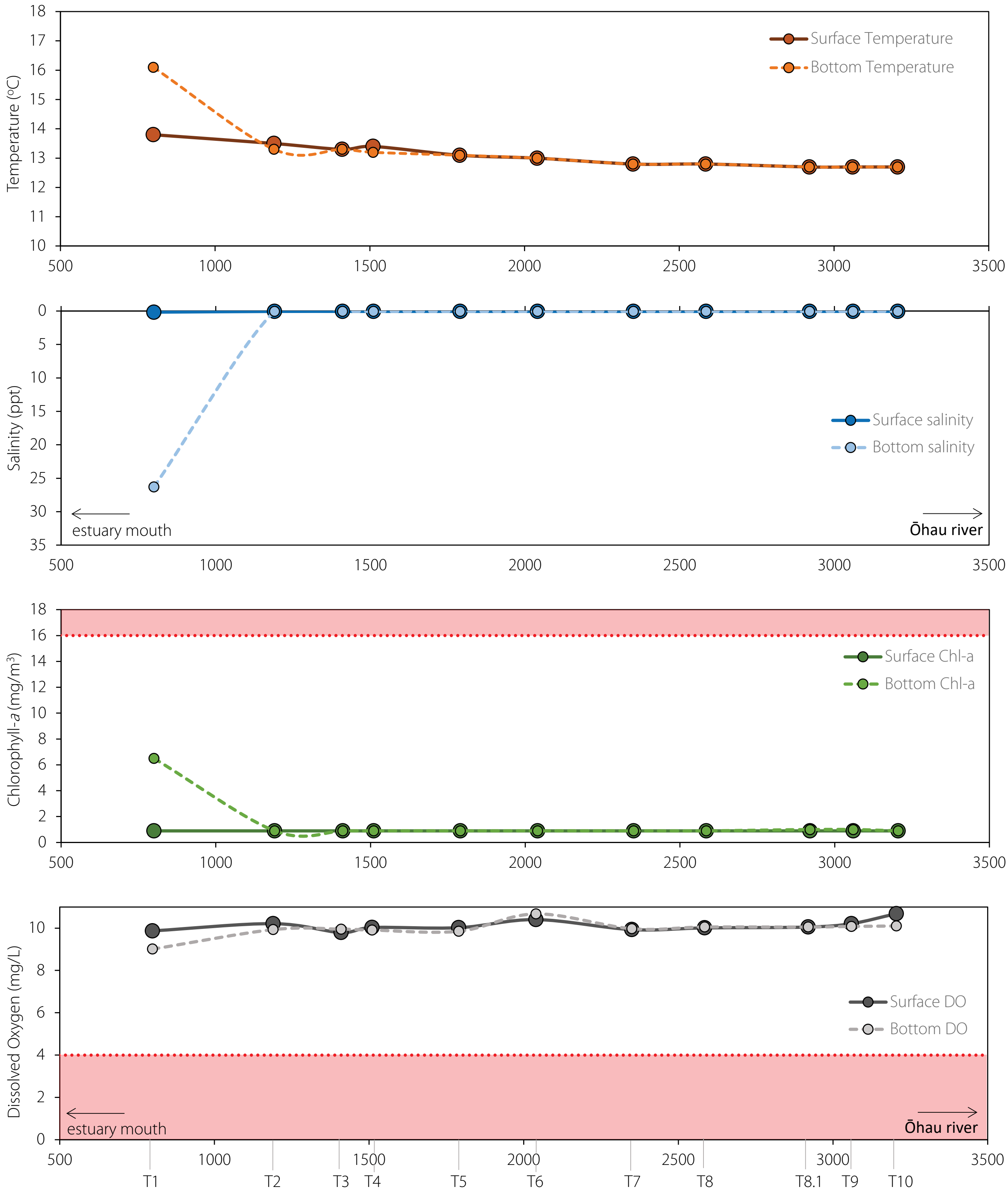


Figure 5. Ōhau Estuary water quality results, December 2020. a) Temperature (°C), b) Salinity (ppt), c) Chlorophyll-*a* (mg/m^3) and d) Dissolved Oxygen (mg/L). Solid lines = surface water, dashed lines = bottom water. The red-dotted line and shading indicate the "poor" threshold and banding for chlorophyll-*a* and dissolved oxygen (Table 2). Raw data are presented in Table 3.

The estuary was mostly freshwater at the time of sampling with salinity of 0.04 - 0.05ppt in the surface and bottom waters at all the well mixed sites (T2 – T10; Fig 3b; Table 3). High salinity was only observed in the bottom waters ~1km from the estuary entrance at site T1. Fig. 6 represents a depth profile at site T1 where salinity stratification was observed. The halocline was at ~0.8m depth with salinity reaching a maximum of 26.7ppt at 1.5m depth (Fig. 6).

Phytoplankton (chl-*a*; mg/m^3) concentrations were consistently low (<1mg/m^3) throughout the estuary in both the surface and bottom waters between sites T2 to T10 (Fig. 5), a condition rating of 'very good'. Phytoplankton increased marginally in the saline bottom waters at site T1 to a maximum concentration of 6.5mg/m^3, a condition rating of 'good'. Fig. 6 shows a marginal increase in phytoplankton concentration in the bottom waters and is consistent with increased salinity. The phytoplankton was likely marine in origin given it was evenly distributed in the bottom waters along with the sites proximity to the estuary entrance. No toxic species of algae were detected at site T7 (Appendix 3).

The depth profile for dissolved oxygen and temperature presented in Fig. 5 show there was no significant change in the oxygen concentration with depth at site T1.

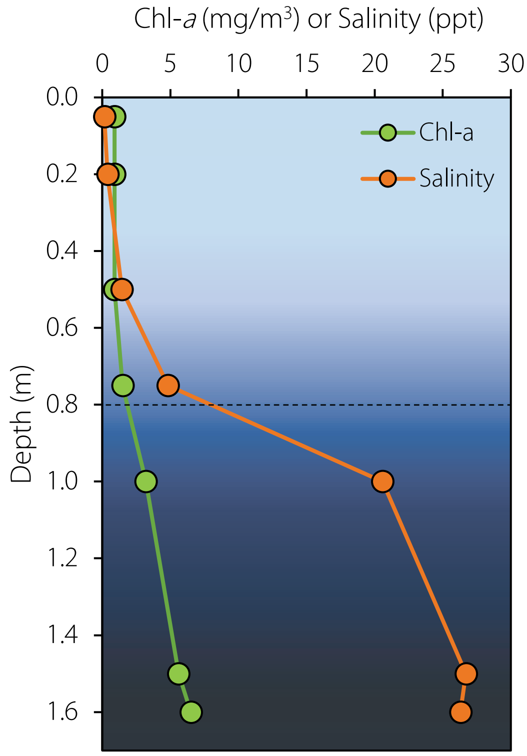


Figure 6. Phytoplankton (Chl-*a*; mg/m^3) and Salinity (ppt) at site T1; ~1km upstream from the estuary mouth. The dashed line represents the halocline.

Eroding banks at site T7

Lower Ōhau Estuary, site T2

Table 3. Summary of water quality measurements in the Ōhau Estuary, December 2020

Station	T1	T2	T3	T4	T5	T6	T7	T8	T8.1	T9	T10
NZTM East	1782626	1782631	1782658	1782710	1782977	1783221	1783340	1783526	1783726	1783703	1783611
NZTM North	5497155	5497538	5497720	5497789	5497762	5497692	5497426	5497482	5497214	5497071	5496958
Distance from mouth (m)	800	1190	1410	1510	1790	2040	2350	2585	2920	3060	3205
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)	13.8	13.5	13.3	13.4	13.1	13.0	12.8	12.8	12.7	12.7	12.7
DO saturation (%)	96	98.2	93.5	96.9	95.3	98.8	91.8	94.4	95.2	95	101.1
DO conc (g/m^3)	9.87	10.21	9.79	10.03	10.02	10.4	9.93	10.01	10.05	10.21	10.68
Salinity	0.18	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04
pH	7.93	6.55	6.6	6.84	6.8	6.83	6.92	7.03	7.06	7.28	7.45
Chlorophyll-*a* (mg/m^3)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Stratified	yes	no	no	no	no	no	no	no	no	no	no
Halocline depth (m)	0.8	-	-	-	-	-	-	-	-	-	-
Thermocline depth (m)	0.8	-	-	-	-	-	-	-	-	-	-
Bottom Measurement											
Depth (m)	1.6	1.9	2.0	3.0	1.5	4.7	6.0	3.2	2.4	2.6	3.2
Temperature (°C)	16.1	13.3	13.3	13.2	13.1	13.0	12.8	12.8	12.7	12.7	12.7
DO saturation (%)	108.8	95.1	95.1	94.2	93.7	103.3	92.7	94.8	94.9	95	96.7
DO conc (g/m^3)	9.01	9.93	9.95	9.91	9.85	10.67	9.97	10.05	10.05	10.08	10.1
Salinity	26.3	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.04	0.04
pH	6.96	6.57	6.57	6.76	6.79	6.9	6.85	6.95	7.04	7.22	7.36
Chlorophyll-*a* (mg/m^3)	6.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	0.9
Other measurements											
Secchi depth (m)	1.25	1.3	1.25	1.4	1.3	1.45	1.45	1.25	1.35	1.3	1.3
Max depth (m)	1.6	1.9	2.1	3.4	1.5	4.8	6.1	3.1	2.6	2.6	3.2
Channel width (m)[1]	40	45	35	30	50	24	28	45	50	25	20
Sediment texture	firm	firm	firm	firm	firm	firm	firm	firm	firm	firm	firm
Sediment type	S0_10	S0_10	SM50_90	S0_10	S0_10	MS10_25	S0_10	S0_10	GF	S0_10	GF
aRPD depth (mm)	>110	>100 (1)[2]	1 (>100)[2]	>100	>140	25	>60	>50	ind	ind	ind

*ind = indeterminate, [1]Recorded at low tide in January 2020.

[2]Site T2 and T3 were mixed substrate across the channel ranging from sand (< 10% mud) to sandy mud (50-90% mud). At site T2 clean sand was overlying firm sandy mud. The aRPD for the dominant substrate, as described under sediment type, is recorded and the less dominant substrate is recorded in brackets for aRPD.

Ōhau Estuary site T3, roosting shags in the lower estuary

3.2 SEDIMENT PHYSICAL AND CHEMICAL CHARACTERISTICS

A summary of the December 2020 composite sediment sample data collected from three sites is provided in Table 4. For comparative purposes March 2018 and January 2020 data are also presented.

3.2.1 Sediment grainsize

Mud content decreased at all sites between January 2020 and December 2020 (Table 4). At site T2 the condition rating improved from 'fair' (16.3% mud) to 'very good' (4.5% mud) and at site T5 'poor' (25% mud) to 'very good' (1.6% mud). Site T7 remained in a condition rating of 'good'. At site T2 compacted mud was underlying a deep layer of clean sands (see photo). These results indicate that in the previous 11 months, mud has been scoured from the upper estuary, while there has been significant deposition of marine sands in the lower estuary.

3.2.2 Sediment Oxygenation (aRPD)

Sediment oxygenation was variable across the estuary. Sediment samples from each of the sampling locations are shown in the pictures above. The lower estuary (T1 to T5) was dominated by sands with aRPD depths generally >100mm. However, sites T2 and T3 had variable substrates and aRPD across the channel. In these two locations the substrate ranged from sand (<10% mud) to firm sandy mud (50-90%); aRPD was >100mm and 1mm respectively for each substrate type. In the mid-estuary the aRPD ranged from >50mm in sand substrate (sites T7 and T8) to 25mm in muddy sand at site T6. Sediment oxygenation was indeterminant in the upper estuary because the substrate type was gravel (Sites T8.1 to T10). Except for patches of shallow aRPD associated with firm muddy sands at sites T2 and T3 there were no other signs of poor sediment oxygen in the estuary.

Site T2 in Jan-2020 and Dec-2020, less fine sediment

Table 4. Sediment grainsize, nutrient, aRPD, trace metal and metalloid data for composite samples collected at three sites in December 2020, and showing comparison with March 2018 and January 2020 data.

Site	Year	Mud %	TOC %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
T2 (A)	Mar-18	8.5	0.32	< 500	310	>30	3.1	0.012	8.0	4.7	0.02	7.9	5.5	28.0
	Jan-20	16.3	0.26	< 500	310	100	3.0	0.014	9.0	3.0	< 0.02	7.0	4.1	30.0
	Dec-20	4.5	0.10	<500	260	>100	-	-	-	-	-	-	-	-
T5 (B)	Mar-18	11.7	0.29	< 500	340	>30	2.5	0.016	7.9	5.2	0.03	7.9	5.9	31.0
	Jan-20	25.0	0.57	500	390	70	4.6	0.024	14.0	7.0	0.05	11.0	9.3	50.0
	Dec-20	1.6	0.09	<500	220	>140	-	-	-	-	-	-	-	-
T7 (C)	Mar-18	23.6	0.65	600	420	>30	2.8	0.034	10.0	6.6	0.05	10.0	8.5	41.0
	Jan-20	12.2	0.45	< 500	400	*ind	3.4	0.022	13.9	7.1	0.05	11.0	9.3	49.0
	Dec-20	6.2	0.26	<500	310	>60	-	-	-	-	-	-	-	-

< All values below lab detection limit

Ind = indeterminate (cobble)

*Metals were not measured in Dec-2020 because they were all close to detection on previous sampling dates. Bandings for metals are presented in Stevens et al. (2020).


Ōhau Estuary site T1; sand <10% mud (aRPD >100 mm)

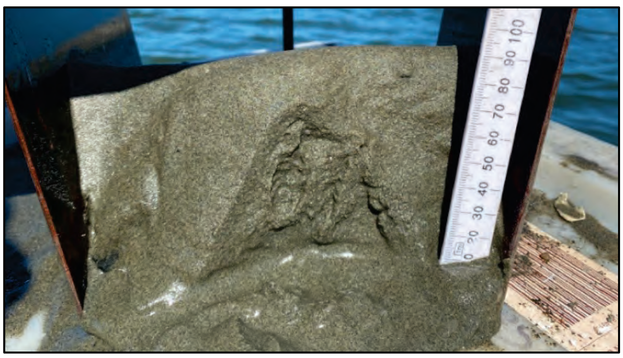

Ōhau Estuary site T5; sand <10% mud (aRPD >140 mm)

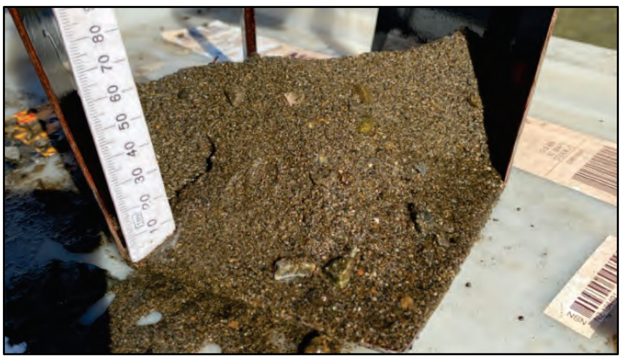

Ōhau Estuary site T2; sand <10% mud (aRPD >100 mm)

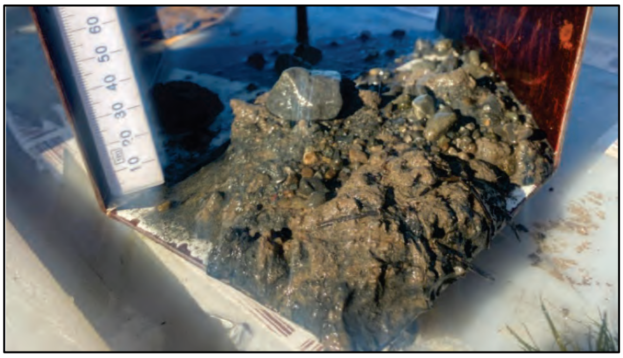
Ōhau Estuary site T6; muddy sand (10-25% mud) (aRPD 25 mm)


Mixed substrate across channel at site T3; firm sandy mud (50-90% mud) on margins (left; aRPD 1mm) and sand (<10% mud) toward middle of the channel (right; aRPD ind.)

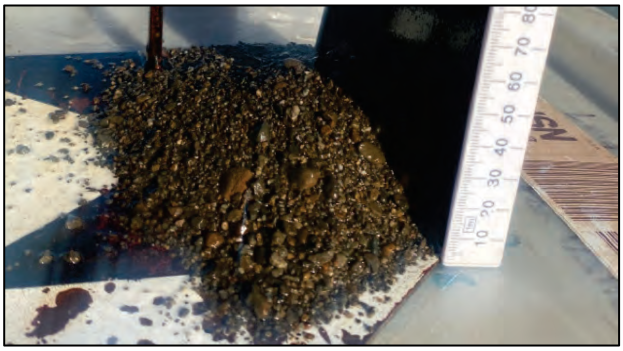

Ōhau Estuary site T7; sand <10% mud (aRPD >60 mm)


Ōhau Estuary site T4; sand <10% mud (aRPD >100 mm)


Ōhau Estuary site T8; sand <10% mud (aRPD >50 mm)



Ōhau Estuary T8.1; gravel with some sandy mud (aRPD ind.)



Ōhau Estuary site T9; gravel mixed with sand (aRPD ind.)

Ōhau Estuary site T10; gravel (aRPD ind.)

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).

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

3.3 MACROFAUNA

In December 2020 a qualitative assessment of sediment dwelling organisms at three sites was made. The purpose was to assess community composition in response to prevailing sediment conditions. Results are summarised in Table 5, Figure 7 and Appendix 5.

The results show that the macrofaunal assemblage is relatively impoverished. In total only 18 benthic dwelling species or higher taxa were recorded, with a few species likely marine in origin rather than being resident estuary species.

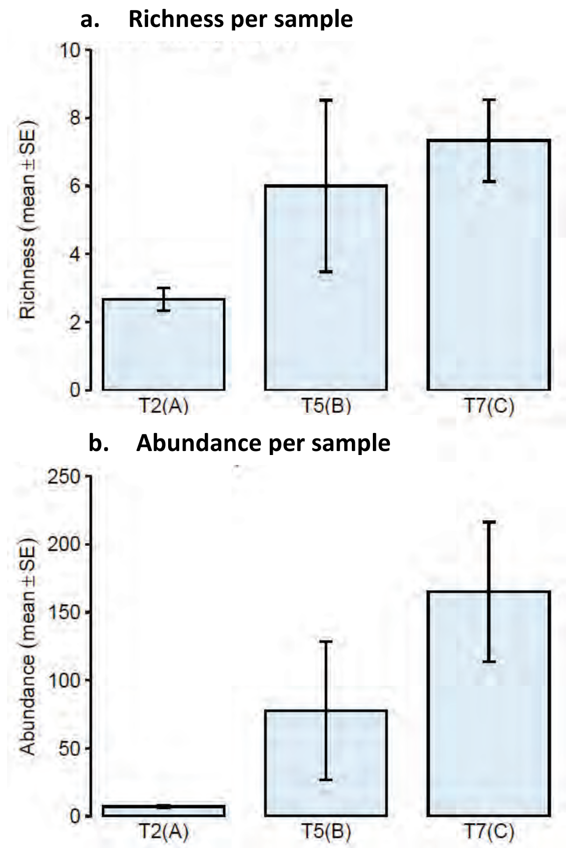


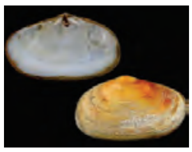
Figure 7. Sediment macrofauna taxon richness (mean ± SE) and abundance (mean ± SE) per site. Data are indicative only given the qualitative nature of sampling.

Mean species richness was low (2-7species/sample), and abundance was variable driven by the small estuarine snail *Potamopyrgus estuarinus* in the upper estuary and the amphipod *Paracorophium*, in the mid estuary (Table 5, Fig 7 and Appendix 3). Both species are tolerant to pollution and in particular, eutrophication, with ecological sensitivity groupings of EG-III and EG-IV, respectively.

The lowest richness was recorded in the lower estuary possibly due to the site's proximity to the entrance and the dynamic nature of combined tidal and river flows, and high salinity variance. One marine species Pseudaega sp. 1 was present at Site T2, likely washed into the estuary from the sea rather than being a resident species. Also present were low numbers of the disturbance-tolerant amphipod Paracorophium and the small estuarine snail Potamopyrgus estuarinus along with one individual of the more sensitive deposit-feeding spionid Microspio maori (Table 5, Appendix 3).

Further upstream both richness and abundance increased (Fig 7). Paracorophium was most abundant at mid estuary site T5, and P. estuarinus was the most abundant at the upper estuary sites (T7; Table 5). Pipi (Paphies australis) were recorded in one sample in the mid estuary (T5).

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. Images are illustrative and do not necessary show the exact species but are an example from the general group.

Main Group (Species name)	EG	T2 (A)	T5 (B)	T7 (C)	Description	
Polychaeta (*Scolecolepides benhami*)	IV	0	1	7	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	1	87	437	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.	
Crustacea (Paracorophium sp.)	IV	9	115	8	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	8	11	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.	
Crustacea (*Paracalliope novizealandiae*)	II	0	0	5	Amphipods are shrimp-like crustaceans. This species has a body usually tinged or speckled with orange and eyes moderately large and rectangular (almost square). The adjacent image is illustrative.	
Bilvalva (*Paphies australis*)	II	0	6	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

The results from December 2020 show some improvement in sediment condition and water quality in the Ōhau Estuary compared to January 2020, likely as a consequence of recent flushing following heavy rainfall in the week prior to the most recent sampling. However, the estuary remains under pressure from nutrient and sediment loads and continues to express signs of eutrophication.

Like other river-dominated estuaries in the region the Ōhau Estuary is a highly dynamic system that stratifies under low-flow conditions. To help illustrate the differences between each of the monitoring years a conceptual diagram that describes three scenarios will be referred to in the discussion (Fig. 8). Fig 8b represents January 2020 and Fig 8c represents December 2020.

During periods of base or low freshwater flow, seawater extends ~3km upstream from the Ōhau Estuary mouth (Fig 8a) 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, particularly in the deeper parts of the estuary, e.g. sites T6 and T7, where water stagnates (Fig 8b).

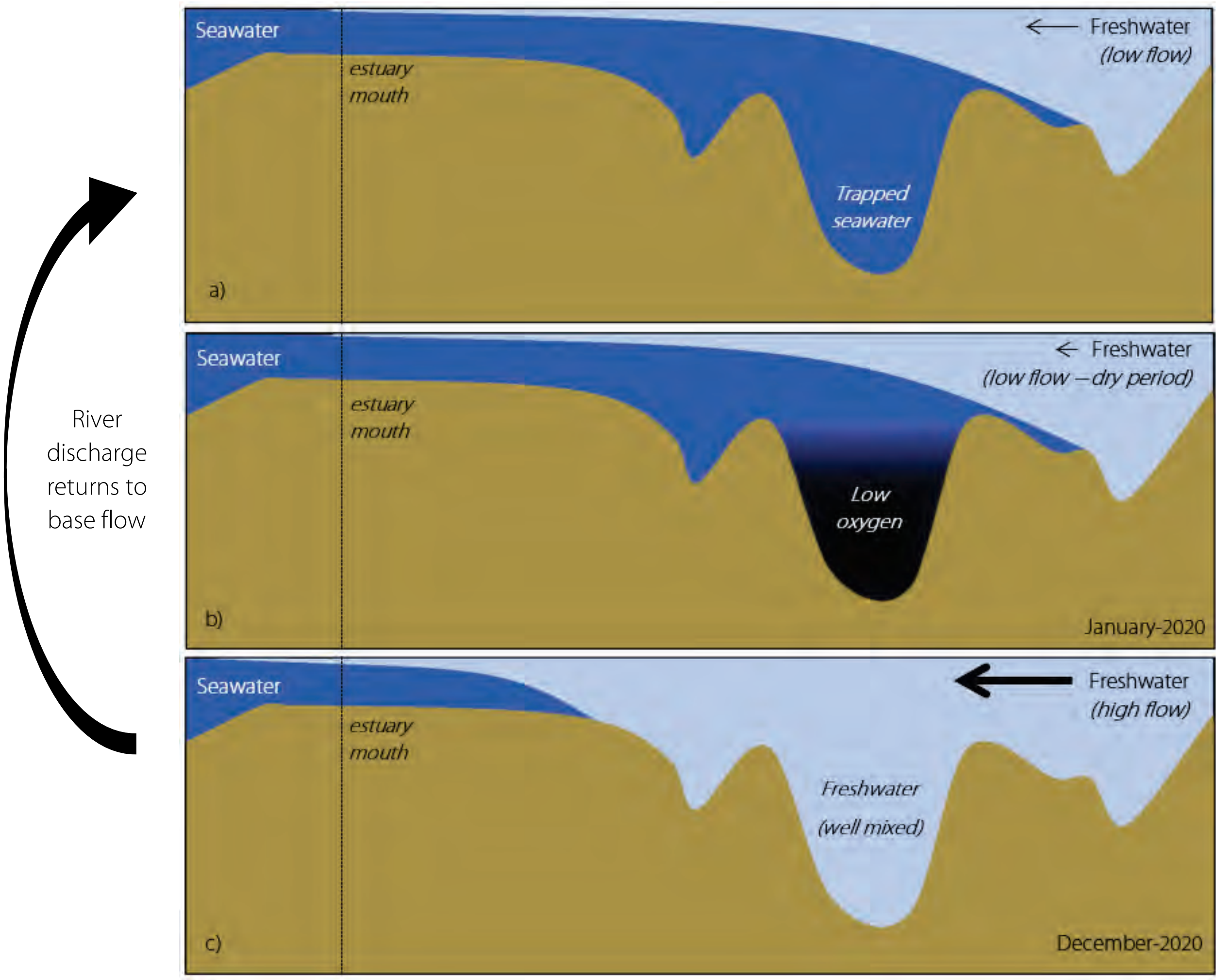


Figure 8. Conceptual diagram of the Ōhau Estuary under three scenarios. a) low freshwater flow with the extent of salt wedge ~3km upstream of the estuary mouth, b) extended dry period resulting in trapped seawater becoming depleted in oxygen (January 2020) and c) high freshwater inflow resulting in flushing of the deeper zones in the upper estuary with freshwater, salt wedge extent ~1km from estuary mouth (Dec-2020).

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 the breakdown of organic matter from phytoplankton blooms can lead to further decreases in oxygen concentration. Diurnal fluctuations in oxygen production (photosynthesis) and consumption (respiration) also have a very strong influence on bottom water oxygen concentration.

In January 2020, the scenario conceptually depicted in Fig 8b was observed, where a reasonably dry period ~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, redfin bully, lambrey, shortjaw kōkopu and banded kōkopu were recorded in the Waiti River, Ōhau River and Makorokio Stream (McArthur et al. 2007). These 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 during previous monitoring have the potential to inhibit or reduce the migration success of native fish species moving through the estuary.

Under a high-flow scenario (as present in December 2020), seawater trapped in the deeper parts of the estuary is washed out to sea and replaced with freshwater due to the river dominance over the seawater influence (Figs 3, 5 and 8c).

As the freshwater flow recedes, seawater begins to intrude into the estuary again (Fig 8a). In December 2020, Site T1 closest to the estuary entrance, was the only site where salinity stratification was recorded but there were no associated symptoms of eutrophication, likely owing to regular tidal flushing.

The December 2020 monitoring showed that the estuary has a high flushing potential and the capacity to remove excess sediments, nutrients, low oxygen waters and phytoplankton during high-flow events.

This was reflected in improvements in sediment condition with sites characterised by muddy sediments (e.g. T5) in January 2020 characterised by firms sands in December 2020, most likely due to flushing of muddy sediments during high flow events in the 11 months prior to sampling (Fig. 3c). The decrease in mud content coincided with an improvement in TOC (Table 4). The absence of phytoplankton blooms or oxygen depletion (Fig 5) are also likely reflective of sampling immediately after a flushing event, rather than any improvements owing to nutrient and sediment reductions in the catchment.

A consequence of variable salinity regimes, fluctuating water and sediment quality, and flushing events is that the benthic community in the estuary was relatively impoverished, with low species richness and abundance, the most common taxa being pollution or disturbance tolerant species e.g. the amphipod *Paracorophium* and estuarine snail *Potamopyrgus estuarinus*.

The available monitoring results show the dynamic nature of Ōhau Estuary under different flow conditions (e.g. Figs. 3 and 8). While predominantly in a good condition due to high flushing, the estuary is prone to stratification and oxygen depletion in the bottom waters, particularly during summer, and this is likely to result in localised eutrophication and degradation. While the December 2020 results provided insight into the effectiveness of the estuaries flushing potential that can mitigate against degradation, the results are likely to reflect a short-term change, with conditions quickly returning to a more degraded state.

5. RECOMMENDATIONS

As significant but localised 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 (e.g. Site T7), 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 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.

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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)

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:	OHAU-MANA-T7	Laboratory ID:	2020001286/AS12397
Client ID:	OHAU-MANA-T7	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
Eudorina sp.	2	Green algae (Chlorophyta)
Navicula sp.	2	Diatoms (Bacillariophyceae)
Flagellates/Unicells <5um	1	Flagellates/Unicells
Fragilaria sp.	1	Diatoms (Bacillariophyceae)
Cryptomonas sp.	<1	Golden-brown algae (Cryptophyceae)
Synura sp.	<1	Golden-brown algae (Chrysophyceae)
Euglena sp.	<1	Euglenoids (Euglenoidea)
Surirella sp.	<1	Diatoms (Bacillariophyceae)
Stauroneis sp.	<1	Diatoms (Bacillariophyceae)
Nitzschia sp.	<1	Diatoms (Bacillariophyceae)
Gomphonema sp.	<1	Diatoms (Bacillariophyceae)

ACCREDITED IANZ TESTING LABORATORY

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

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Algal Services
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Algal Cell Count Report

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

Attention: Leigh Stevens

Sample Information

Client description:	OHAU-MANA-T7	Laboratory ID:	2020001286/AS12397
Client ID:	OHAU-MANA-T7	Date received:	16/12/2020
Date sampled:	13/12/2020	Date analysed:	17/12/2020
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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APPENDIX 4. JANUARY 2020 WATER QUALITY DATA

Table A1: Summary of water quality measurements in the Ōhau estuary, January 2020

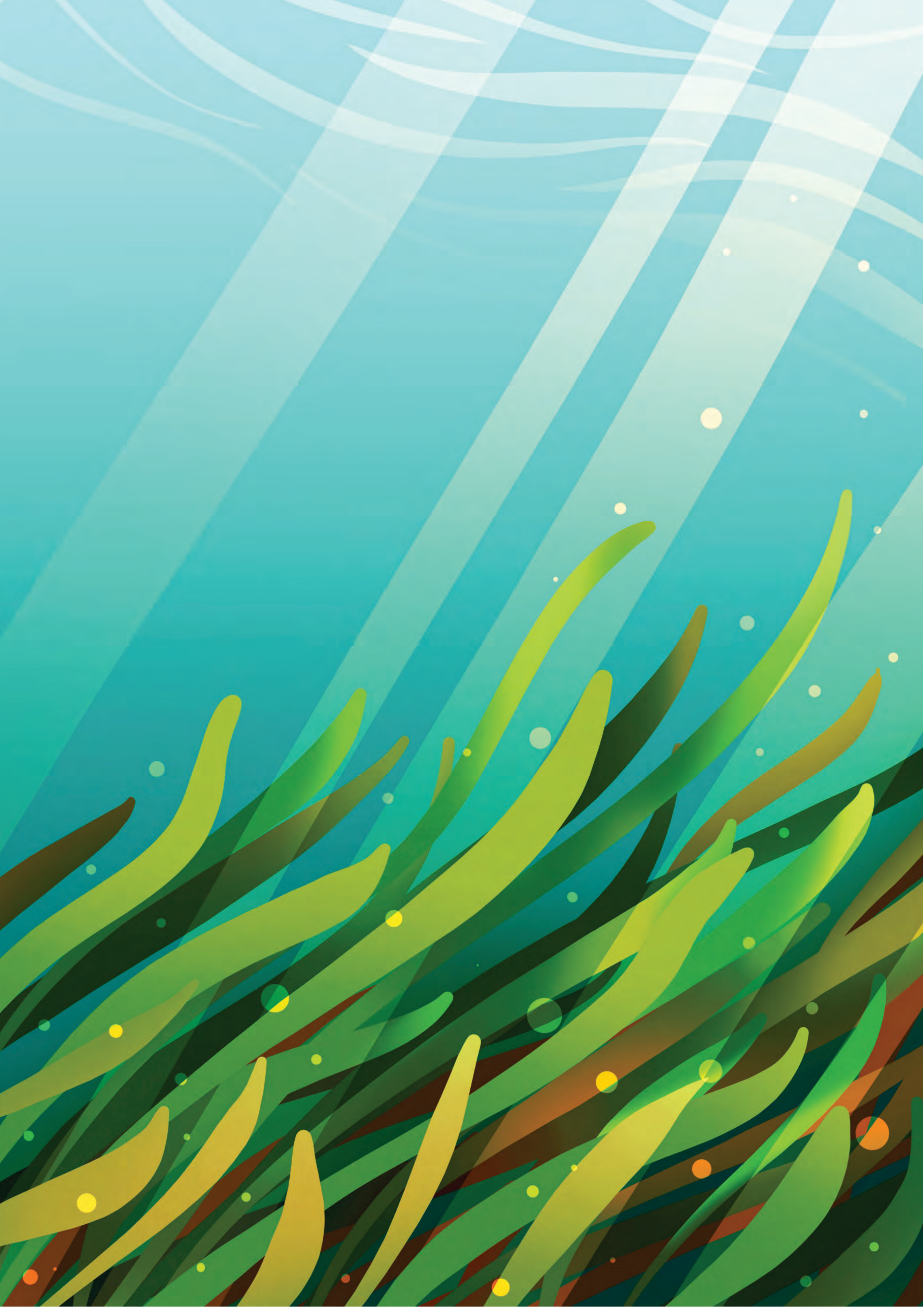
Station	T1	T2	T3	T4	T5	T6	T7	T8	T8.1	T9	T10
NZTM East	1782626	1782631	1782658	1782710	1782977	1783221	1783340	1783526	1783726	1783703	1783611
NZTM North	5497155	5497538	5497720	5497789	5497762	5497692	5497426	5497482	5497214	5497071	5496958
Distance from mouth (m)	800	1190	1410	1510	1790	2040	2350	2585	2920	3060	3205
Surface Measurement											
Depth (m)	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Temperature (°C)	21.1	20.8	21.1	20.5	20.8	22.8	21.2	21.7	21.5	21.5	21.5
DO saturation (%)	90	91.7	92.5	95.9	98.5	110.9	110.1	117	107.1	111.2	112
DO conc (g/m^3)	7.9	8.1	8.2	8.5	8.7	9.6	9.7	10.2	9.4	9.7	9.9
Salinity	3.3	1.8	2.7	1.5	1.2	1.3	0.6	0.1	0.1	0.1	0.1
pH	8.2	8.1	7.8	8.2	8.5	7.5	9.1	8.1	7.9	7.7	7.6
Chlorophyll-*a* (mg/m^3)	0.6	0.5	0.8	0.6	0.8	0.8	1.3	0	0.7	0.7	0.7
Stratified	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	no
Halocline depth (m)	0.15	0.25	0.15	0.45	0.5	0.6	0.6	0.85	1.4	1.7	2.6
Thermocline depth (m)	0.15	0.25	0.15	0.45	0.5	0.6	0.6	0.85	1.4	NA	NA
Bottom Measurement											
Depth (m)	0.35	0.65	0.8	1.7	0.9	3.8	3.9	1	1.6	1.5	2.5
Temperature (°C)	21.7	21.4	20	18.7	22.7	19.2	20.3	22.6	22.5	21.6	21.5
DO saturation (%)	75	90.1	84	83.6	101.1	64.2	17	160.9	114.7	107.1	111.1
DO conc (g/m^3)	5.48	6.3	5.9	6.22	7.01	4.7	1.1	12.1	8.9	9.45	9.73
Salinity	31	34.8	36.2	36.5	32.6	34.7	34.4	31.2	17.8	0.1	0.1
pH	7.8	7.5	7.9	7.8	7.75	7.7	7.8	7.8	7.53	7.8	7.6
Chlorophyll-*a* (mg/m^3)	1.5	2.5	2	6	7.5	7	10	85	17	0.7	1
Other measurements											
Secchi depth (m)	>0.4	>0.7	1.1	1.2	1.05	1.05	0.8	>1.1	>1.7	>1.7	>2.6
Max depth (m)	0.4	0.7	1.4	2.3	1.1	4	4.3	1.1	1.7	1.7	2.6
Channel width (m)	40	45	35	30	50	24	28	45	50	25	20
Sediment texture	firm	firm	soft	soft	firm	soft	firm	soft	soft	firm	firm
Sediment type	S0_10	MS10_25	MS10_25	MS10_25	MS10_25	MS25_50	CF GF	MS25_50	GF	GF	GF
aRPD depth (mm)	>100	>100	50	ind.	70	ind.	ind.	ind.	ind.	ind.	ind.

S0_10=Sand (<10% mud), MS10_25=muddy sand (10-25% mud), MS25-50=muddy sand (25-50% mud), CF=Cobblefield, GF=Gravelfield,

*ind = indeterminate, NA = not applicable

APPENDIX 5. RAW MACROFAUNA DATA DEC-2020

Main_group	Taxa	Habitat	EG	T2 (A)			T5 (B)			T7 (C)		
				1	2	3	1	2	3	1	2	3
Gastropoda	*Halopyrgus pupoides*	epibiota	III	0	0	0	0	0	2	0	0	0
Gastropoda	*Potamopyrgus antipodarum*	epibiota	III	0	0	0	0	0	0	0	2	2
Gastropoda	*Potamopyrgus estuarinus*	epibiota	III	0	1	0	35	2	50	228	163	46
Amphipoda	Amphipoda sp. 3	infauna	II	0	0	3	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 5	infauna	II	0	0	0	0	0	1	0	0	0
Amphipoda	Amphipoda sp. 6	infauna	II	0	0	0	0	0	0	1	0	0
Amphipoda	*Paracalliope novizealandiae*	infauna	II	0	0	0	0	0	0	4	0	1
Amphipoda	*Paracorophium spp.*	infauna	IV	7	2	0	8	0	107	7	1	0
Bivalvia	*Paphies australis*	infauna	II	0	0	0	6	0	0	0	0	0
Isopoda	Exosphaeroma sp. 1	infauna	V	0	0	0	1	0	0	0	0	0
Isopoda	Pseudaega sp. 1	infauna	NA	1	3	4	0	0	11	0	0	0
Oligochaeta	Oligochaeta sp. 1	infauna	III	0	0	0	1	0	0	1	0	3
Polychaeta	*Boccardia wellingtonensis*	infauna	II	0	0	0	0	0	0	0	0	2
Polychaeta	*Microspio maori*	infauna	I	1	0	0	0	0	0	0	0	0
Polychaeta	*Nicon aestuariensis*	infauna	III	0	0	0	1	0	0	0	0	0
Polychaeta	Sabellidae sp. 1	infauna	I	0	0	0	0	0	0	0	0	1
Polychaeta	*Scolecolepides benhami*	infauna	IV	0	0	0	0	0	1	0	0	7
Polychaeta	Nereididae (unidentified juveniles)	infauna juv	NA	0	0	0	1	0	0	0	0	0
Diptera	Diptera sp. 1	larva	II	0	0	0	2	0	1	0	0	0
Diptera	Diptera sp. 2	larva	II	0	0	0	0	0	0	2	0	0
Diptera	Diptera sp. 3	larva	II	0	0	0	0	0	0	3	8	9
Insecta	Coleoptera sp. 1	larva	NA	0	0	0	2	0	1	1	2	0
Insecta	Trichoptera sp. 1	larva	NA	0	0	0	0	0	0	1	0	0



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