Synoptic Subtidal Monitoring of Ohau Estuary

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June 2020

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For the People
Mō ngā tāngata

SALT ECOLOGY

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
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
Zn	Zinc

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BACKGROUND

Ohau Estuary is a moderate-sized (~50ha) shallow short-residence tidal river estuary (SSRTRE) which discharges to the open coast at Ohau on the Manawatu coast. The upper reaches are relatively narrow and confined within a well-defined river channel. Seawater intrusion extends approximately 3.5km inland from the coast and is commonly stratified with fresh surface water overlying relatively dense (heavier) seawater.

Broad scale intertidal mapping in 2016 indicated a low potential for eutrophication and sedimentation issues and recommended low frequency screening level (synoptic) monitoring. A repeat broad scale intertidal mapping survey in 2018, and synoptic sampling at three subtidal sites, reported moderate eutrophic symptoms but no phytoplankton blooms.

In late 2019 Salt Ecology were commissioned by Horizons Regional Council (HRC) to undertake a targeted subtidal survey to broadly map estuary depth, substrate, seagrass and macroalgae extent; and to collect *in situ* water quality measures (i.e. chlorophyll-a, salinity, temperature, dissolved oxygen). The aim was to assess trophic state, delineate the spatial extent of any salinity or temperature stratification, reassess three subtidal sediment sites sampled in 2018, and resolve discrepancies in the 2016 and 2018 intertidal mapping results.

RESULTS

Within intertidal areas, the dominant substrates comprised 28.9ha (82%) clean or mobile sands, most common near the estuary entrance, and 5.1ha (15%) muddy sands in the middle estuary. Relatively small intertidal flats in the middle estuary were the only areas with mud-dominated (>50% mud) substrate. Salt marsh comprised mainly sedgeland and herbfield and small areas of rushland. When bench-marked against national criteria for assessing estuary health, the salt marsh extent (3.5ha, 10%) was rated 'fair', although the estimated reduction from historical extent was rated 'poor'.

Mapping showed that 15.1ha (30%) of the estuary was subtidal, comprising 4.0ha (26%) of gravel fields located primarily in the upper reaches, 6.0ha (40%) muddy sands in the middle estuary, and 5.1ha (34%) clean sands in the lower estuary. No subtidal sediments were mud-dominated (i.e. >50% mud content).

Subtidal sediment trace contaminant results were all rated 'good' or 'very good, indicating that the estuary is unlikely to have sediment contamination issues. In the worst affected area mud content was rated 'poor'. The absence of nuisance macroalgae was rated 'very good'. These results indicate the absence of excessive sediment enrichment. However, water quality indicators for dissolved oxygen and phytoplankton were both rated 'poor', and a non-toxic phytoplankton bloom was evident in the estuary between sites T4 and T8 at a depth of ~0.5-1.5m. The bloom covered ~2.25ha (15%) of the subtidal area. This indicates there are sufficient nutrients and suitable growing conditions to support phytoplankton blooms.

SYNTHESIS OF KEY FINDINGS

Ohau Estuary is currently expressing localised water column symptoms of nutrient enrichment (eutrophication). Phytoplankton indicators were high, consistent with long-term HRC data that have recorded 90th percentile concentrations of chlorophyll-a above the 'poor' indicator rating for the previous 5-year period.

The Estuary Trophic Index (ETI) score for the estuary (which integrates a range of indicators) was 0.73, and corresponds to a rating of 'moderate' and is on the cusp of 'poor'.

Dissolved oxygen levels were at severely low concentrations (i.e. 1.1mg/L) over an estimated 0.75ha (5%) of the estuary below a depth of 2.5m at the time of sampling, well below the ETI threshold for 'poor' (<4mg/L). The presence of such conditions, even for as few as several hours over a tidal cycle, can cause severe adverse ecological effects, particularly to fish.

The spatial extent of high enrichment conditions in the estuary water column, estimated at ~5%, highlights that part of the upper estuary is currently adversely impacted by elevated phytoplankton blooms likely fuelled by catchment inputs of nutrients.

RECOMMENDATIONS:

In light of the eutrophication symptoms identified it is recommended that the following work be undertaken:

1. Repeat synoptic sampling in the summer of 2021 to further define the spatial extent and nature of

eutrophication impacts. This work should include boat-based sampling of subtidal sediments and water quality throughout the subtidal reaches of the upper estuary. Ideally repeat measures would be undertaken immediately following a flood event to determine the capacity for the estuary to flush excessive sediments, nutrients and low oxygen waters from the estuary.

2. Design and implement a long-term programme for regular ongoing monitoring of estuary condition linked to existing freshwater SOE monitoring, including the deployment of water quality loggers in the eutrophic parts of the estuary (ideally to measure salinity, dissolved oxygen and chl-a), as well as more frequent field assessments to determine the nature and extent of the current problems.
3. Assess catchment sources of nutrients and sediments to the estuary to determine whether changes to current land management practices are likely to significantly improve ecological condition and to guide council management priorities.

1. INTRODUCTION

1.1 BACKGROUND

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

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

The NEMP is intended to provide resource managers nationally 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 in this type of estuary.

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

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

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

The current report describes the methods and results of synoptic monitoring undertaken at Ohau Estuary in January 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. In addition, HRC sought clarification regarding differences reported in the type and extent of intertidal salt marsh from two earlier surveys conducted in 2016 (Robertson & Stevens 2016) and 2018 (Robertson & Robertson 2018).

1.2 BACKGROUND TO OHAU ESTUARY

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

Ohau Estuary is a moderate-sized (~50ha) SSRTRE which discharges to the open coast at Ohau on the Manawatu coast. The lower reaches are relatively shallow (mean depth ~0.5m) and comprise a low tide river channel and 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 Ohau River (mean low flow ~6.8 cumecs).

The upper reaches are relatively narrow and confined within a well-defined river channel. Seawater intrusion extends approximately 3.5km inland from the coast and is commonly stratified with fresh surface water overlying more dense (heavier) seawater. This denser seawater can become trapped in deep (2-4m) pools in the estuary allowing phytoplankton blooms to establish.

No intertidal seagrass has been observed in the estuary, and macroalgal growth appears to be uncommon. Intertidal salt marsh is relatively sparse and limited to narrow strips along the river margins. This reflects the limited intertidal habitat commonly associated with SSRTREs, but in the case of the Ohau is exacerbated by extensive development of the surrounding land with virtually all of the naturally vegetated terrestrial margin of the estuary modified, including coastal sand dunes dominated by introduced marram grass (*Ammophila arenaria*).

The surrounding catchment (Fig 2) is dominated by native forest and scrub in the upper catchment (53%), and pasture (33%) in the lower catchment (Table 1). Exotic forest is also prominent (7%).

The estuary has high cultural and spiritual values, and is ecologically important as feeding and roosting areas for birds and habitat for fish.

Intertidal flats and sedgeland in the middle estuary

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

LCDB5 (2017/18) Catchment land cover	Ha	%
1 Built-up Area (settlement)	27	0.1
2 Urban Parkland/Open Space	23	0.1
5 Transport Infrastructure	2	0.0
6 Surface Mine or Dump	13	0.1
10 Sand or Gravel	85	0.5
12 Landslide	12	0.1
16 Gravel or Rock	98	0.5
20 Lake or Pond	5	0.03
21 River	52	0.3
22 Estuarine Open Water	18	0.1
30 Short-rotation Cropland	459	2.4
33 Orchard, Vineyard, Other Perennial Crop	94	0.5
40 High Producing Exotic Grassland	6190	32.9
41 Low Producing Grassland	290	1.5
45 Herbaceous Freshwater Vegetation	22	0.1
50 Fernland	72	0.4
51 Gorse and/or Broom	82	0.4
52 Manuka and/or Kanuka	105	0.6
54 Broadleaved Indigenous Hardwoods	1933	10.3
55 Sub Alpine Shrubland	88	0.5
56 Mixed Exotic Shrubland	16	0.1
64 Forest - Harvested	103	0.5
68 Deciduous Hardwoods	63	0.3
69 Indigenous Forest	7754	41.2
71 Exotic Forest	1210	6.4
Grand Total	18818	100

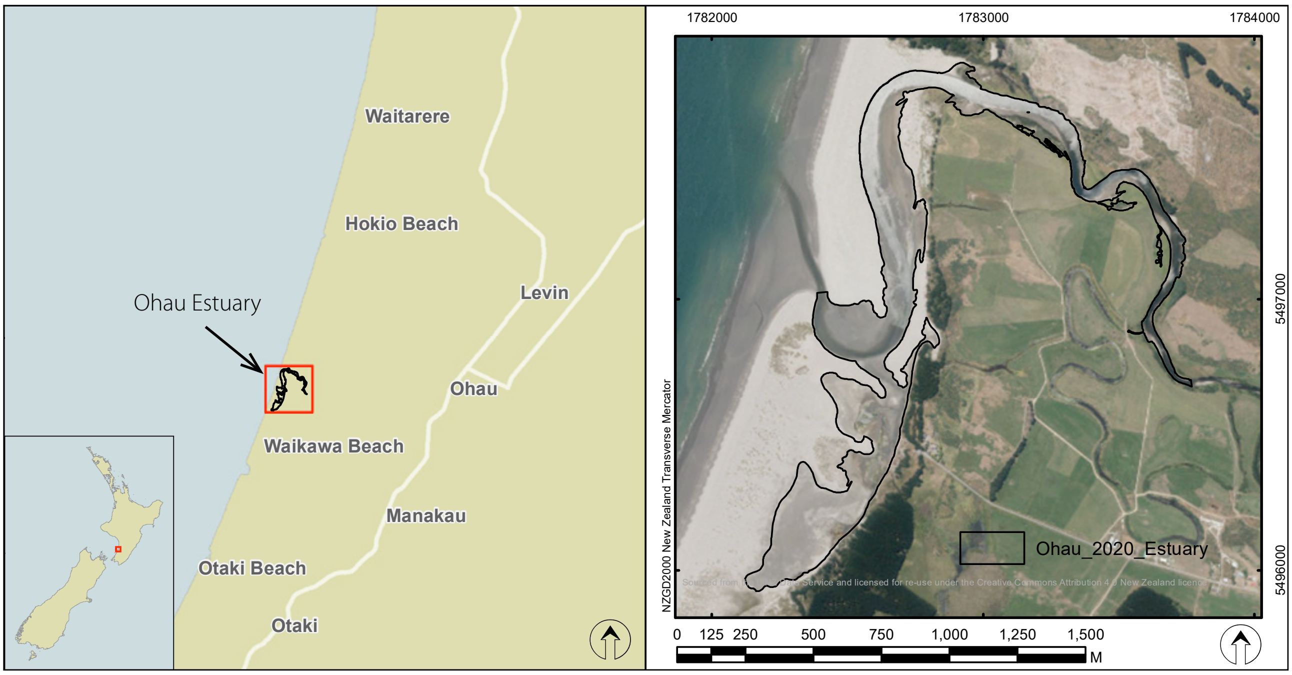


Fig. 1. Location map of Ohau Estuary.

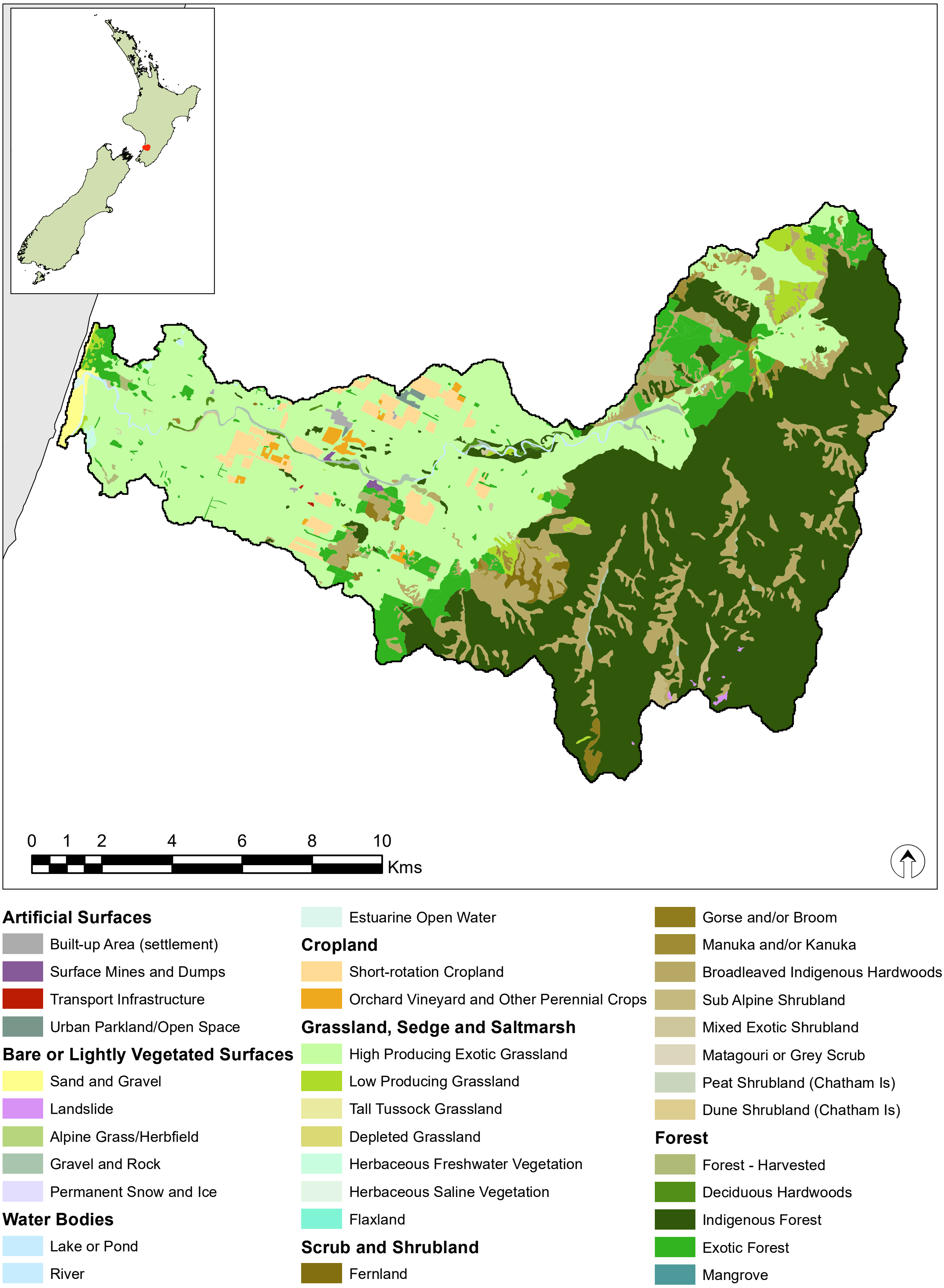


Fig. 2. Map of catchment land cover (LCDB5 2017/18), Ohau Estuary.

2. METHODS

2.1 OVERVIEW

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

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

2.2 BROAD SCALE METHODS

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

NEMP methods (Appendix 1) were used to map and categorise estuary substrate and vegetation. The mapping procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology. Broad scale mapping was undertaken using 0.3m/pixel rural aerial photos flown in the summer of 2016-2017 supplied by Greater Wellington Regional Council and sourced from ESRI online New Zealand imagery. Ground truthing was undertaken by experienced scientists who assessed the estuary on foot or by boat to map the spatial extent of dominant vegetation and substrate. When present, macroalgae and seagrass patches are mapped to the nearest 10% using a 6-category rating scale as a guide to describe percentage cover (see Fig. 4).

In the field features were drawn directly onto laminated aerial photographs. The broad scale

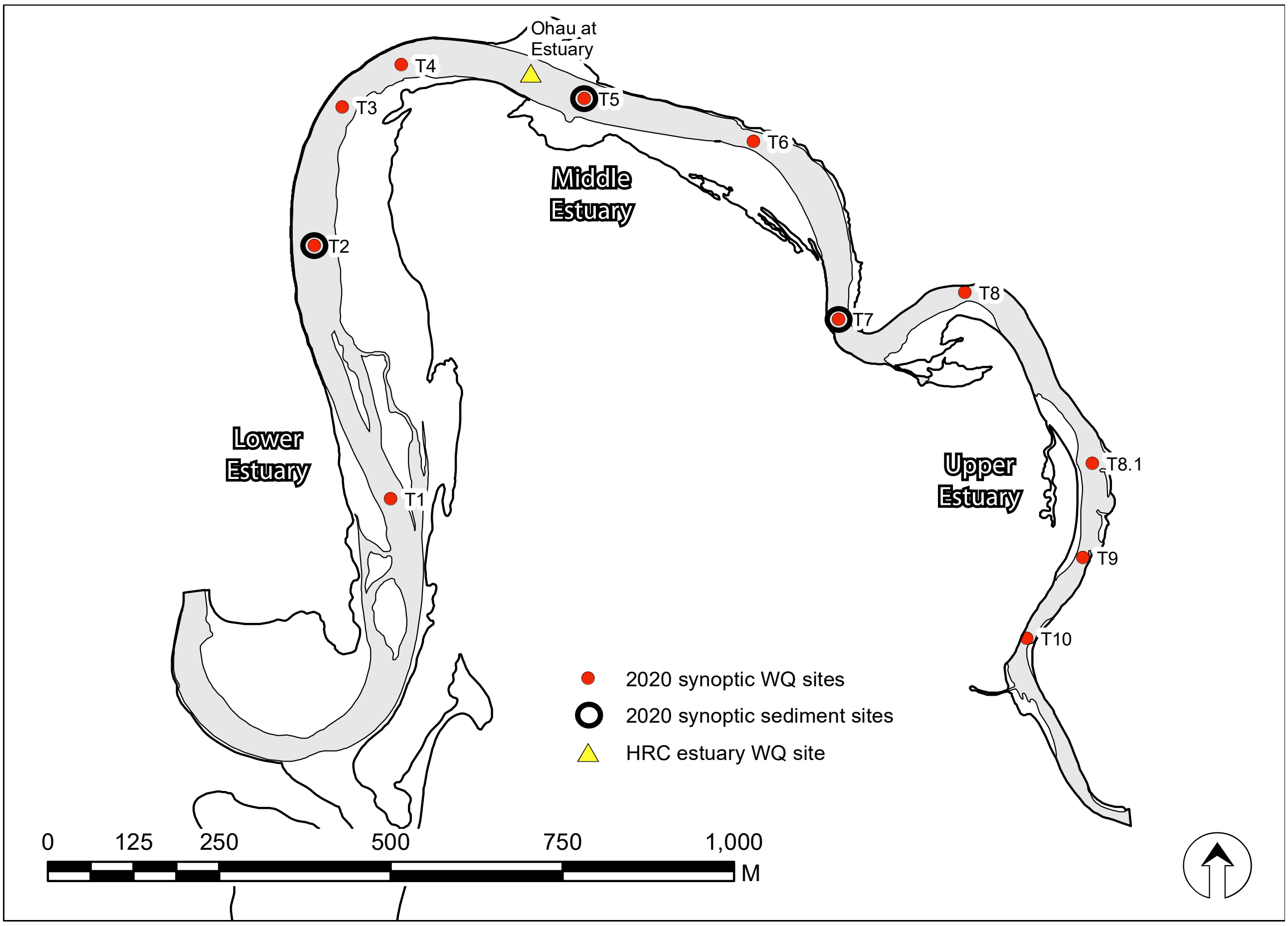


Fig. 3. Location of estuary cross-sections and synoptic water and sediment sampling sites

features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features; e.g. salt marsh, and its underlying substrate type.

2.3 SUBTIDAL ASSESSMENT

2.3.1 Sites and sampling

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

At all sites except 8.1 a cross-sectional transect was established and subtidal habitat assessed by either wading or by sampling from a dinghy, to measure the following variables:

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

2.3.2 Cross-section profiling

At each transect site the channel cross-section was surveyed at a 1-2m horizontal resolution to record the cross-channel width, depth and the bottom profile. A tape measure or field estimate was used to measure horizontal distance and a depth sounder mounted on the stern of an inflatable dinghy, or graduated surveying pole was used to record depth and assess changes in the bottom profile. The depth sounder was also used to assess the longitudinal channel profile of the estuary and to aid in cross-section site selection.

2.3.3 Water column indicators

At the deepest point in the channel, water quality measures (described below) were taken from the surface and bottom, and the depth of any salinity or temperature stratification recorded. Water column measures of pH, salinity, dissolved oxygen (DO), temperature and chlorophyll-a (as a measure of phytoplankton presence) were made using a YSI Pro10 meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Water measurements were collected ~20cm below the water surface, and ~20cm above the sediment surface in the deepest part of the channel, with care taken not to disturb bottom sediments before sampling. At site T7, the deepest part of the estuary, higher resolution profiling was also undertaken.

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

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

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

2.3.4 Sediment indicators

On each transect, sediment quality was assessed by collecting samples from across each profile using a remote grab sampler. At the surface, samples were collected for laboratory analyses or assessed *in situ* for a range of parameters as outlined below.

Substrate classification

Appendix 1 summarises the key NEMP classes used to define estuarine habitats in the current report. Substrate classification is based on the dominant surface substrate features present; e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories based on sediment 'muddiness', assessed according to subjective field-based assessment of textural and firmness characteristics. In addition sediment samples (0-20mm) were collected from three transects (T2, T5 and T7) and analysed for grain size (percent mud/sand/gravel).

The primary indicator used to assess sediment mud impacts is the area (horizontal extent) of mud-dominated sediment.

Sediment sampling and analysis

At the deepest point on transects T2, T5, and T7 (see Fig. 3), a composite sediment sample from three separate grabs (~250g in total) was collected from the sediment surface (to 20mm depth). Sediment samples were placed directly into laboratory supplied sample containers, stored on ice, and sent to RJ Hill Laboratories for analysis of: particle grain size (% mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP) and metals and metalloids (arsenic, copper, chromium, cadmium, lead, mercury, nickel, zinc). Details of laboratory methods and detection limits are provided in Appendix 2.

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 nutrients and organic carbon

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

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

The apparent Redox Potential Discontinuity (aRPD) depth is a subjective measure of the enrichment state of sediments according to the depth of the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in

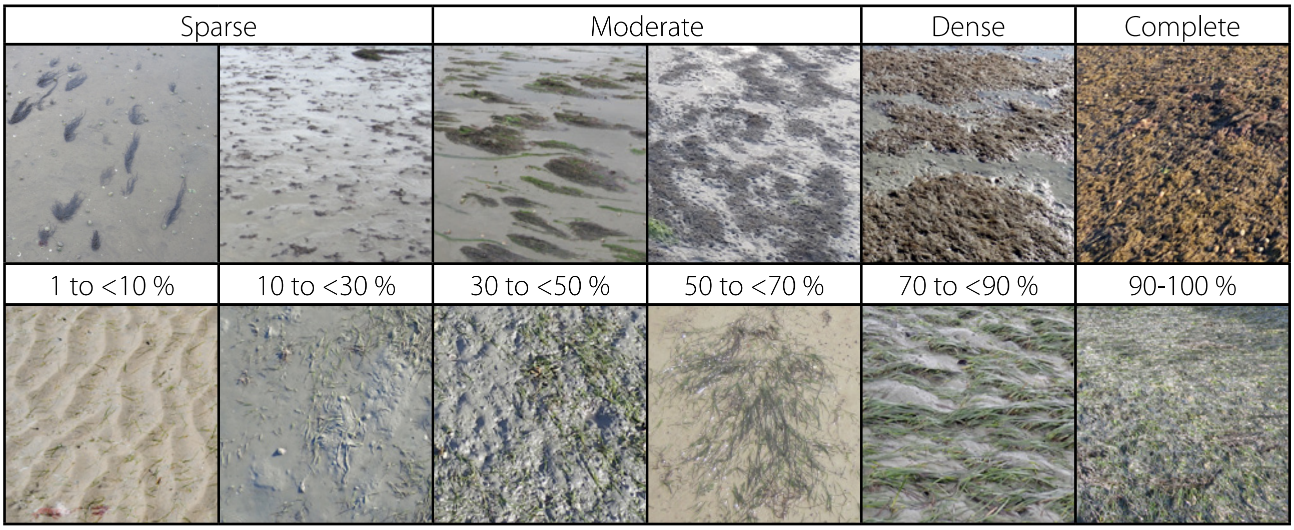


Fig. 4. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom).
Modified from FGDC (2012).

colour). 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.

As part of broad scale mapping in Ohau Estuary, sediment aRPD was assessed in representative samples collected with a hand trowel, hoe or grab sampler to determine whether there were any significant areas where sediment oxygenation was depleted close to the surface.

Firm muddy sand (10-25%mud), aRPD 70mm

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

2.4 DATA RECORDING, QA/QC AND ANALYSIS

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

Following digitising, in-house Salt Ecology scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes), and calculate areas and percentages used in summary tables. Using these same tools, the 2016 (Wriggle) and 2018 (Robertson Environmental) GIS layers were similarly checked for any errors in basic geometry (e.g. overlapping polygons), and updated to fix any identified issues. Where discrepancies were identified between GIS data and hard copy reports, the underpinning GIS data were re-analysed to produce revised summary statistics.

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

2.5 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 ETI (Robertson et al. 2016b) and subsequent revisions (Zeldis et al 2017). The ETI provides screening guidance for assessing where an estuary is positioned on a eutrophication gradient. It includes site-specific thresholds for percent mud, TOC, TN, aRPD, metals, dissolved oxygen, phytoplankton concentrations, generally using spot measures from within the most degraded 10% of the estuary. The ETI also contains metrics intended to be applied to the estuary as a whole (i.e. in a broad scale context), e.g. the extent of mud, macroalgae or sedimentation rates. We adopted those thresholds for present purposes, except: (i) for %mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016c); and (ii) for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012). Note that we did not use the ORP thresholds in the ETI as they are provisional and have been recognised as requiring further development.

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

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of areas with High Enrichment Conditions (HEC) was evaluated. HEC areas are defined as having sediments with elevated organic content (>1% TOC) and/or dense macroalgal cover (>50%) or phytoplankton concentrations >16 ug/l, combined with an elevated mud content (≥25% mud) and low sediment oxygenation (aRPD <10mm). HEC areas are referred to as 'Gross Eutrophic Zones' (GEZs) in the ETI (Zeldis et al. 2017).

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

As many of the scoring categories in Table 2 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Table 2. 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
Sediment trace elements[2]					
As	mg/kg	< 10	10 - < 20	20 - < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 - < 1.5	1.5 - < 10	≥ 10
Cr	mg/kg	< 40	40 - < 80	80 - < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 - < 65	65 - < 270	≥ 270
Pb	mg/kg	< 25	25 - < 50	50 - < 220	≥ 220
Hg	mg/kg	< 0.075	0.075 - < 0.15	0.15 - < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 - < 21	21 - < 52	≥ 52
Zn	mg/kg	< 100	100 - < 200	200 - < 410	≥ 410
Water quality					
Dissolved oxygen (DO)[1]	mg/L	≥ 5.5	≥ 5.0	≥ 4.0	< 4.0
Phytoplankton (chl-a)[1]	mg/m³	≤ 5	≥ 5 to < 10	≥ 10 to < 16	≥ 16
Broad scale spatial indicators					
Mud-dominated substrate[3]	% of intertidal area >50% mud	< 1%	1-5%	> 5-15%	> 15%
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥ 0.8 - 1.0	≥ 0.6 - < 0.8	≥ 0.4 - < 0.6	0.0 - < 0.4
Seagrass[3]	% decrease from baseline	< 5%	5%-10%	> 10-20%	> 20%
Salt marsh extent (current)[3]	% of intertidal area	> 20%	> 10-20%	> 5-10%	0-5%
Historical salt marsh extent[3]	% of historical remaining	≥ 80-100	≥ 60-80	≥ 40-60	< 40
200m terrestrial margin[3]	% densely vegetated	≥ 80-100	≥ 50-80	≥ 25-50	< 25
High Enrichment Conditions[1]	ha	< 0.5ha	≥ 0.5-5ha	≥ 5-20ha	≥ 20ha
High Enrichment Conditions[1]	% of estuary	< 1%	≥ 1-5%	≥ 5-10%	≥ 10%
Sedimentation rate[1*]	CSR:NSR ratio	1 to 1.1	1.1 to 2	2 to 5	> 5

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

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

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

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

3. RESULTS

3.1 BROAD SCALE MAPPING

Summaries of the broad scale habitat mapping results for Jan 2020 are presented in Fig. 5 and Tables 3 and 4. Fig. 6 presents a simplified longitudinal cross-section profile of the estuary from the upstream Ohau River to the open coast, highlighting the presence of 2-4.5m deep pools in the estuary that trap seawater. Field measurements of water and sediment quality collected from each of the 10 cross-sections are presented in Table 5 and Figs 7 and 8. Estuary cross-sections are summarised in Figs 9 and 10.

Table 3. Summary of dominant substrate, Ohau Estuary, Jan 2020.

Intertidal Substrate	Ha	%
Artificial boulder field	0.0	0.1
Gravel field	0.6	1.8
Mobile Sand (0-10% mud)	4.6	13.2
Firm Sand (0-10% mud)	24.3	69.2
Firm Muddy Sand (>10-25% mud)	2.7	7.7
Firm Muddy Sand (>25-50% mud)	2.4	6.8
Firm Sandy Mud (>50-90% mud)	0.3	0.9
Soft Sandy Mud (>50-90% mud)	0.1	0.4
Grand Total	35.2	100

Subtidal Substrate	Ha	%
Gravel field	4.0	26.2
Firm Sand (0-10% mud)	5.1	33.9
Firm Muddy Sand (>10-25% mud)	4.6	30.6
Firm Muddy Sand (>25-50% mud)	1.4	9.3
Grand Total	15.1	100

Mapping showed that 15.1ha (30%) of the estuary was subtidal. Within the subtidal zone, 4.0ha (26%) of substrate comprised gravel fields, located primarily in the upper reaches. The middle estuary was dominated by muddy sands (6.0ha, 40%), while the lower estuary was dominated by clean sands (5.1ha, 34%). No subtidal sediments were mud-dominated (i.e. >50% mud content), although 1.4ha (9% of the middle estuary sediments were characterised by elevated mud concentrations (i.e. 25-50% mud).

Within intertidal areas, a similar pattern was evident with the dominant substrates comprising clean or mobile sands (28.9ha, 82%), most common near the estuary entrance, and muddy sands (5.1ha, 15%) in the middle estuary. The middle estuary, where relatively small intertidal flats are present, was the only part of the estuary that had mud-dominated (>50% mud) substrate. These intertidal flats appear to be the primary settling zones for river-borne sediments retained in the estuary which likely settle as the estuary widens and shallows near the coast and river velocities reduce.

Salt marsh was also most prominent in this part of the estuary and was dominated by large beds of three square sedgeland and low-growing herbfields. Rushland was relatively scarce. Although not assessed as part of the current work, it appears that large areas of salt marsh have been historically lost from the estuary as a result of drainage and conversion to pasture. The widespread presence of terrestrial grasses among the salt marsh indicates pressure on the remaining areas which will transition toward terrestrial vegetation as the influence of salinity decreases. This is a common result of drainage and infilling of estuary margins.

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

Class and Dominant Species	Ha	%
Sedgeland	1.8	52
Isolepis prolifera (Budding clubrush)	0.1	
Schoenoplectus pungens (Three square)	1.7	
Rushland	0.22	6
Juncus kraussii (Searush)	0.2	
Herbfield	1.48	42
Samolus repens (Primrose)	1.3	
Sarcocornia quinqueflora (Glasswort)	0.1	
Selliera radicans (Remuremu)	0.03	
Total	3.5	100

The current salt marsh results differed in the mapped extent and species composition to that reported by Robertson and Robertson (2018). GIS outputs of the 2018 mapping included 7.8ha of estuarine vegetation, although only 5.4ha of rushland-dominated salt marsh was included in the accompanying report. It appears that the primary reason for the larger area of salt marsh reported by Robertson and Robertson (2018) is the inclusion of several areas of terrestrial vegetation. When these terrestrial areas are excluded, a similar salt marsh extent to that recorded in 2020 is apparent. The main reason for the differences in reported salt marsh composition appear to be the misclassification of many vegetation types by Robertson and Robertson (2018), with sedge and rushland classified as herbfield, terrestrial grassland classified as rushland, and sedgeland classified as rushland.

However, consistent with the 2018 report, no seagrass or macroalgal beds were observed in the estuary in 2020.

Unvegetated clean marine sands in the lower estuary

Salt marsh and small intertidal flats near T6

Terrestrial grasses growing to the margin of the middle estuary

Dark phytoplankton bloom in the middle estuary near T7

Channelised banks and eroding sand dune in the middle estuary

Lush three-square growing in the middle estuary

Clear water and cobble substrate in the upper estuary

Ohau River near the upper extent of salinity intrusion

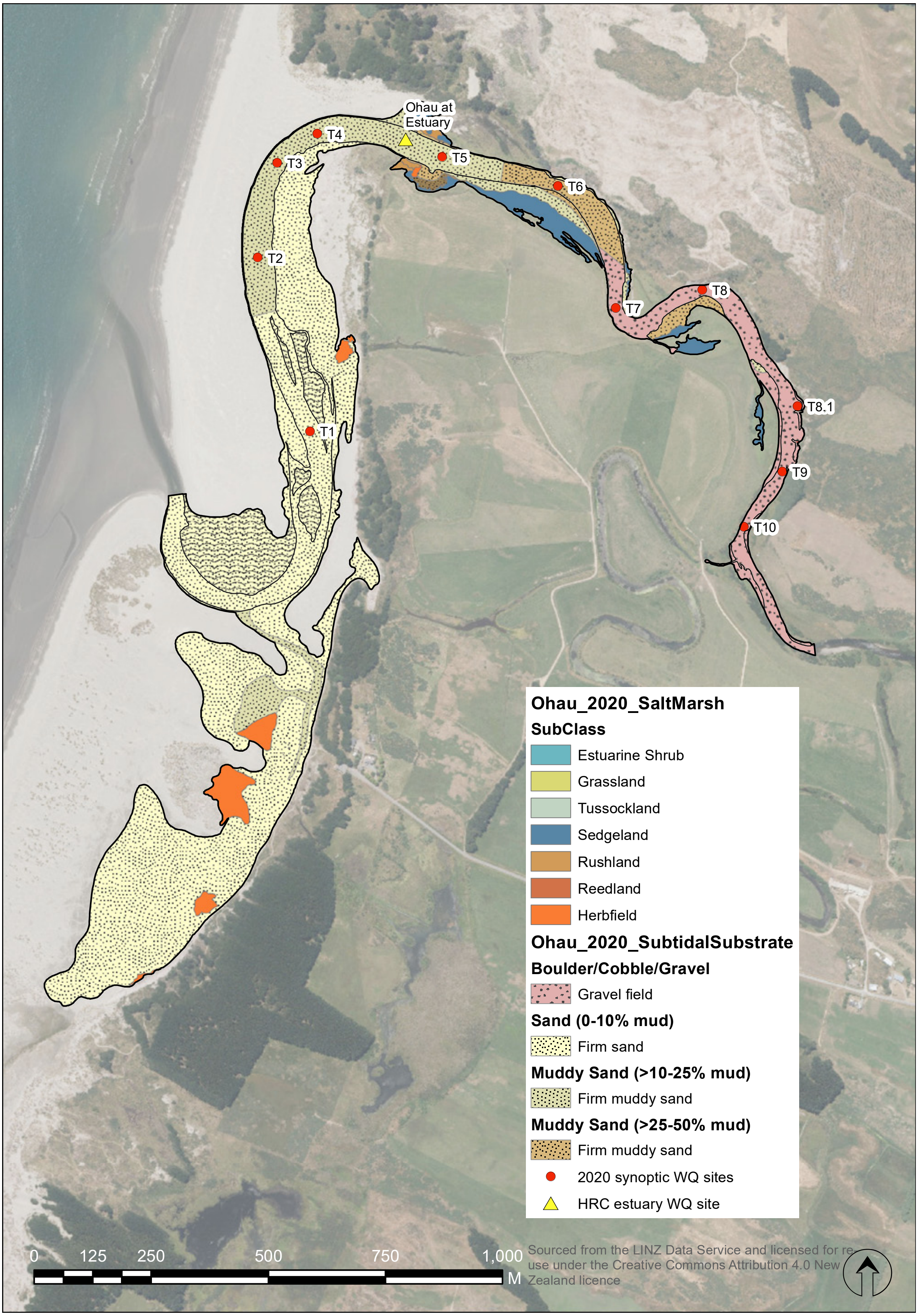


Fig. 5. Map showing dominant broad scale substrate and salt marsh features, Ohau Estuary, Jan 2020.

3.2 WATER QUALITY

Fig. 7 summarises the prevailing water quality conditions during sampling, showing halocline depth, and surface and bottom water measurements of temperature, salinity, chlorophyll-a and dissolved oxygen. Halocline depth showed a steady change from freshwater dominated conditions with no stratification at upstream sites T9 and 10, to a small saltwater lens trapped near the bottom at sites T8 and T8.1, and extending downstream to the coast. These results indicate the saline wedge extends at least 3km inland from the coast.

Temperatures were all within 3°C and showed a variable pattern throughout the estuary. Temperatures tended to be cooler in deeper waters (e.g. T4, T6 and T7), but some mixing is apparent where the estuary bed shallows. This is likely the result of downstream flows moving over shallower sills, with increased velocities in the shallower sections facilitating mixing.

Surface salinity was relatively low throughout the estuary (0.1-3.3ppt) and lowest upstream. Bottom salinity was close to that of the sea (31-36ppt) extending from the estuary's seaward extent to T8. Upstream of T8, deeper pools (e.g. T8.1) were saline on the bottom but at reduced concentrations (18ppt), while T9 and T10 were freshwater.

Phytoplankton concentrations, assessed *in situ* by the fluorescence of chlorophyll present in the algae (i.e. chlorophyll-a measurement), were low near the surface (<2mg/m^3) but present at higher concentrations at all estuary bottom sites, particularly throughout the middle estuary (6 to 85mg/m^3). The highest near-bottom concentrations were at the relatively shallow T8 (measured at 1m). This depth coincided with the presence of a widespread dark brown bloom evident in the estuary between sites T4 and T8 at a depth of ~0.5-1.5m. The bloom covered ~2.25ha (15%) of the subtidal area).

The high chlorophyll-a concentrations at T8 mirror a peak in dissolved oxygen - a result of photosynthesis. There is also a significant trough in dissolved oxygen at T7 with near-anoxic conditions on the estuary bottom.

Clear surface waters over a dark phytoplankton bloom at 0.5-1.5m depth.

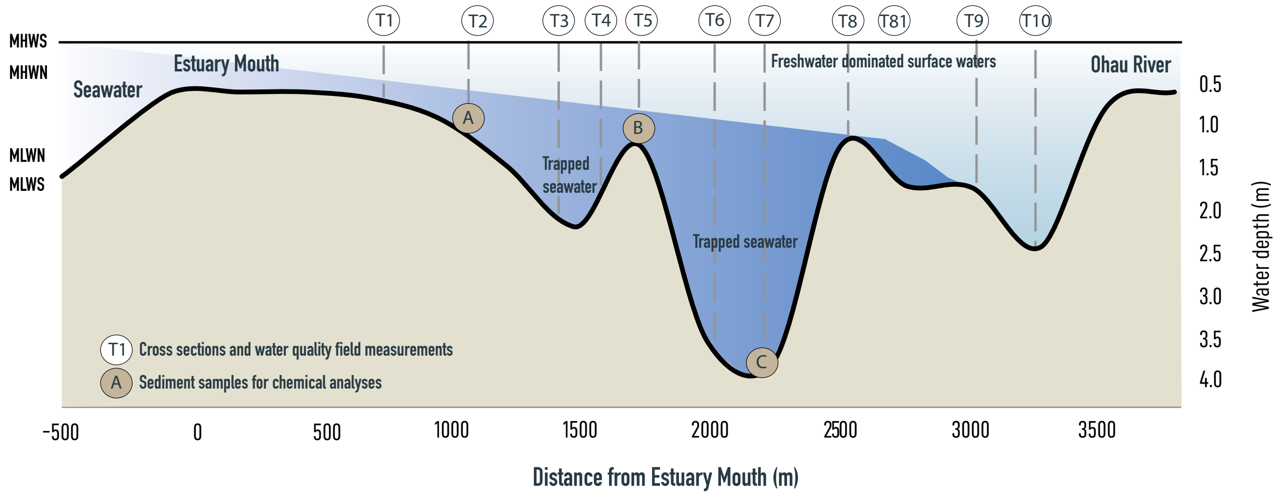


Fig. 6. Simplified longitudinal cross-section of Ohau Estuary showing bed height, sediment sampling locations and location of channel cross-sections.

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

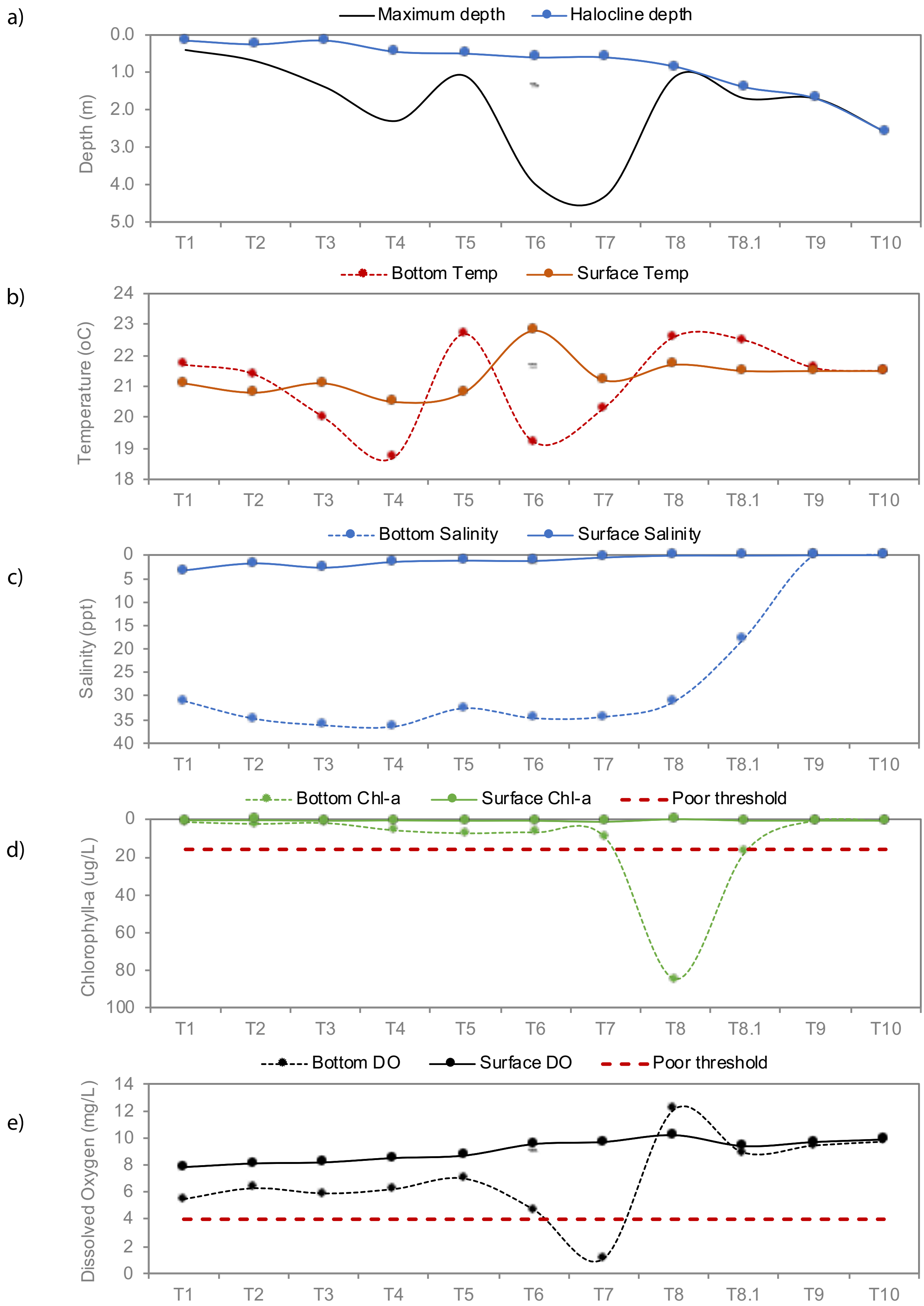


Fig. 7. Water quality measurements collected at transect sites showing a) halocline depth and estuary maximum depth; and surface and bottom water measurements of: b) temperature; c) salinity; d) chlorophyll-a; and e) dissolved oxygen. *Where no halocline was present, it was plotted as the maximum water depth. 'Poor' threshold as defined in Table 2.*

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

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
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	92	93	96	99	111	110	117	107	111	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)	1	1	1	1	1	1	1	0	1	1	1
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
Measurement depth 2 (m)	0.35	0.65	0.8	1.7	0.9	3.8	3.9	1	1.6	1.5	2.5
Temperature 2 (°C)	21.7	21.4	20	18.7	22.7	19.2	20.3	22.6	22.5	21.6	21.5
DO saturation 2 (%)	75	90	84	84	101	64	17	161	115	107	111
DO conc 2 (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 2	31.0	34.8	36.2	36.5	32.6	34.7	34.4	31.2	17.8	0.1	0.1
pH 2	7.8	7.5	7.9	7.8	7.8	7.7	7.8	7.8	7.5	7.8	7.6
Chlorophyll-a 2 (mg/m^3)	2	3	2	6	8	7	10	85	17	1	1
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

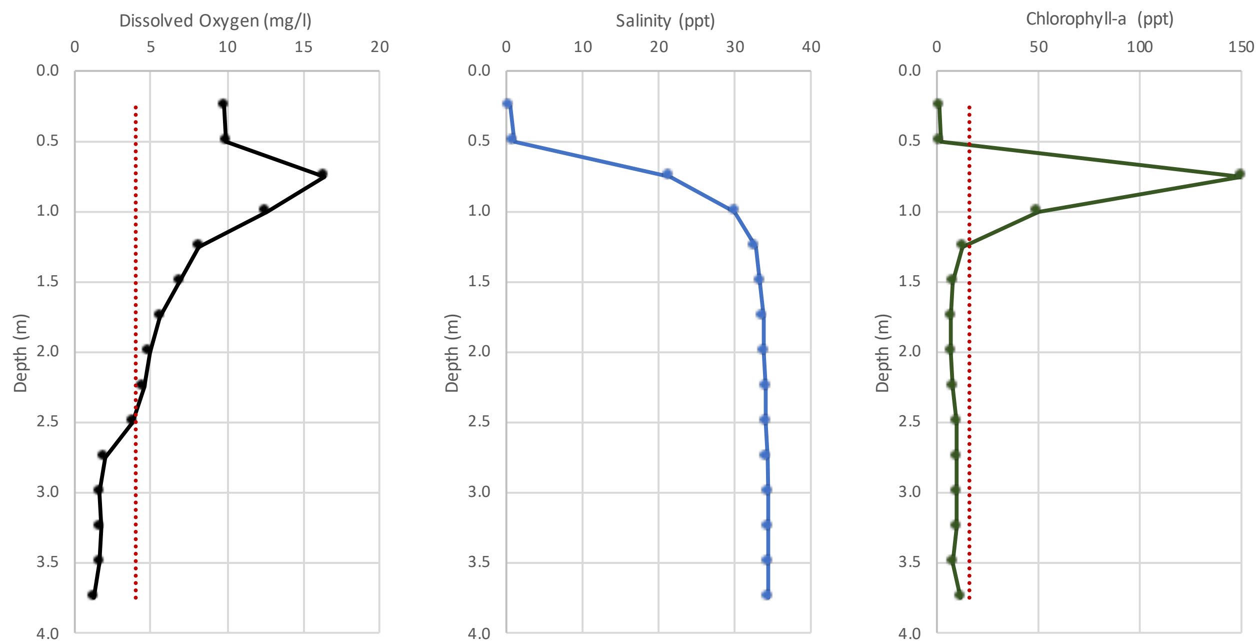


Fig. 8. Vertical profile of water quality measurements collected at transect site T7 showing a) dissolved oxygen b) salinity and c) chlorophyll-a; from the surface to the estuary bed.

To further explore this result a vertical profile was measured at 0.25m increments through the water column from the surface to the bottom. Data are presented in Fig. 8 for dissolved oxygen, salinity and chlorophyll-a.

Results highlight the strong correlation between near surface phytoplankton and high dissolved oxygen trapped just beneath the surface freshwater layer, with oxygen steadily declining with depth. Deeper than 2.5m, oxygen levels are below recommended 1 day instantaneous minimum thresholds. However depleted oxygen levels were not found to be widespread spatially and appeared restricted to the large deep pool present between sites T6 and T7. This comprised approximately 0.75ha (5%) of the subtidal estuary area at the time of sampling. A grab sample was collected from a depth of 0.75m to assess for the presence of toxic phytoplankton. Results, presented in Appendix 2, showed the dominant species were a relatively even mix of non-toxic *Prymnesium parvum/Rhinomonas* spp. and flagellates/unicells, and smaller numbers of various dinoflagellates and diatoms.

Detail of each cross-section, showing the channel shape and depth, and presence of stratification is presented in Figs 9 and 10. The results show the estuary is generally relatively wide and shallow in the lower reaches with well-oxygenated sandy sediments. Deeper and narrower sections develop mainly on the bends in the estuary channel where flows are concentrated. Shoreline erosion appears common and in places, e.g. adjacent to T7, rock reinforcing has been added to protect banks. Rock protection extended to the deeper sections of the estuary and compromised the sampling of bottom sediments at site T7 due to rocks and cobble preventing the jaws of the box corer from closing fully. However, sufficient fine material was able to be collected for laboratory analysis (see following section). Upstream sections of the estuary were dominated subtidally by gravels and cobbles, often with muddy sands deposited along the banks.

3.3 SEDIMENT PHYSICAL AND CHEMICAL CHARACTERISTICS

A summary of the 2020 composite sediment sample data collected from three sites is provided in Table 6 (see Appendix 2 for raw data from the laboratory). Data from 2018 are also presented for comparative purposes. Site C in 2020 was located in sediments representing the most impacted 10% of the estuary. Sediment measures summarised in Table 6 reflect the deepest point on each cross section.

3.3.1 Sediment grain size

Laboratory analyses revealed sediments in 2020 had a mud fraction between 16-25%, which is a 'moderate' or 'poor' rating according to the criteria in Table 2. The muddiest sediment was from the middle of the estuary at site B (T5), and the least muddy from the most upstream site C (T7). This pattern differed to 2018 where sediments got progressively muddier heading upstream. Compared to 2020 results, lower mud contents were recorded from sites A and B in 2018, and higher mud from site C.

3.3.2 Total organic carbon and nutrients

Total organic carbon (TOC) and nutrient (TN and TP) values were generally correlated with sediment grain size, being highest in the muddier sediments. Concentrations overall were relatively low at all sites and rated 'very good' or 'good'. This is consistent with the estimated catchment nitrogen areal load in the estuary derived from NIWA's CLUES model of 1213 mg/m^2/d, which is below the interim proposed threshold of 2000mg/m^2/d for low susceptibility SSRTREs below which eutrophic conditions are not expected (Robertson & Stevens 2016).

3.3.3 Trace contaminants

Trace metal and metalloid concentrations were low at all sites, and less than ANZG (2018) DGV values (Table 6), and rated 'very good' or 'good'.

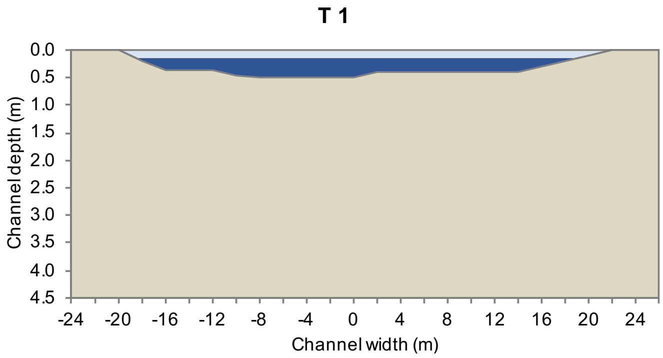
Table 6. Sediment grain size, nutrient, aRPD, trace metal and metalloid results for composite samples collected at three sites in 2020, and showing comparison with 2018 results.

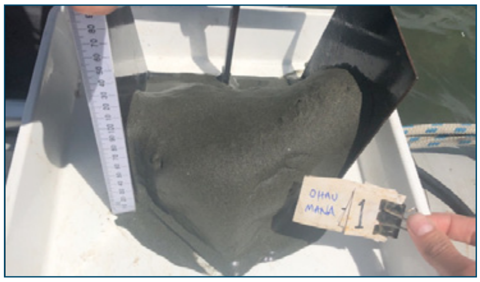
Site	Year	Mud %	TOC %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
A	2018	8.5	0.32	< 500	310	>30	3.1	0.012	8.0	4.7	0.02	7.9	5.5	28.0
	2020	16.3	0.26	< 500	310	100	3.0	0.014	9.0	3.0	< 0.02	7.0	4.1	30.0
B	2018	11.7	0.29	< 500	340	>30	2.5	0.016	7.9	5.2	0.03	7.9	5.9	31.0
	2020	25.0	0.57	500	390	70	4.6	0.024	14.0	7.0	0.05	11.0	9.3	50.0
C	2018	23.6	0.65	600	420	>30	2.8	0.034	10.0	6.6	0.05	10.0	8.5	41.0
	2020	12.2	0.45	< 500	400	*	3.4	0.022	13.9	7.1	0.05	11.0	9.3	49.0

< All values below lab detection limit

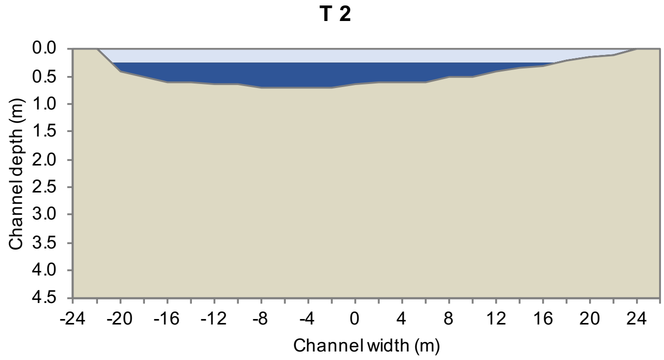
** aRPD indeterminate (cobble)*

Refer to Fig. 3 for site locations and Table 2 for condition rating colour codes and thresholds. There are no rating criteria for TP.

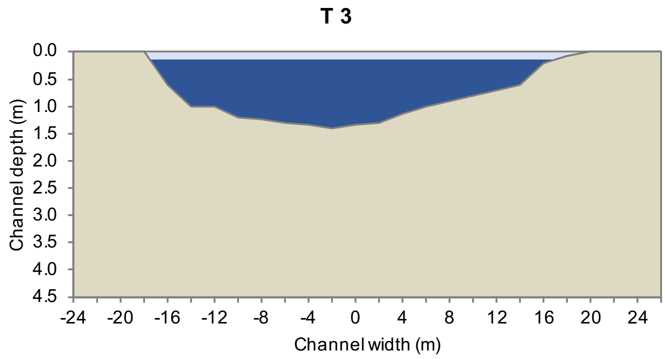




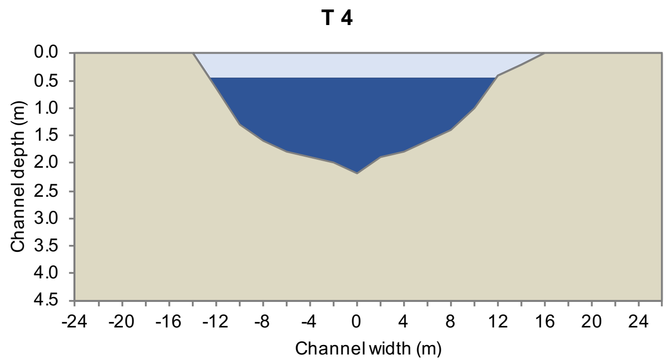
T1 Firm sand <10%mud),
aRPD >100mm

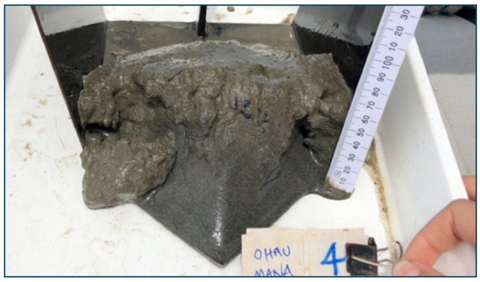


T2 Firm muddy sand (10-25%mud),
aRPD >100mm

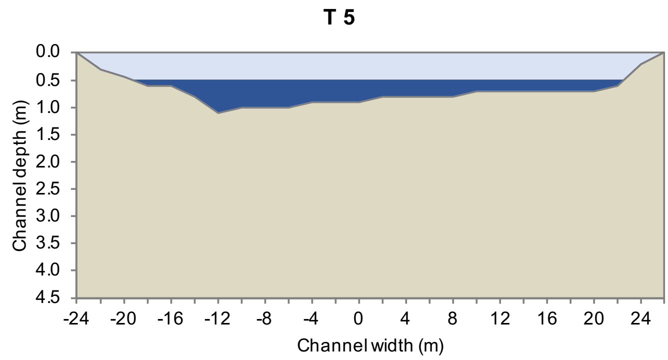


T3 Soft muddy sand (10-25%mud),
aRPD 50mm



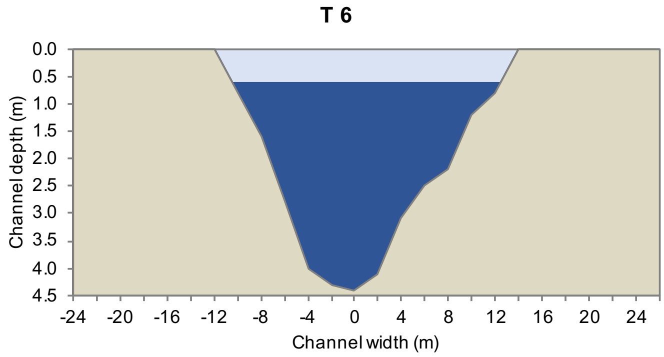


T4 Soft muddy sand (10-25%mud),
aRPD indeterminate

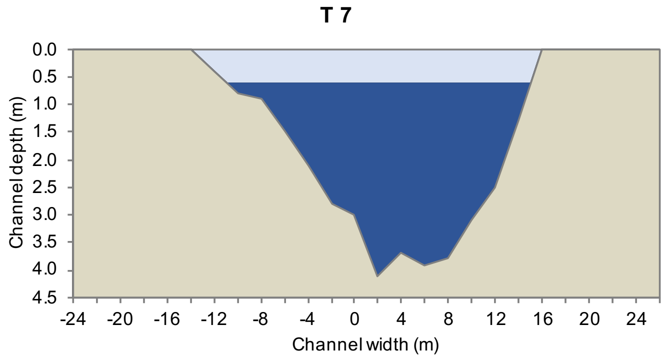


T5 Firm muddy sand (10-25%mud),
aRPD 70mm

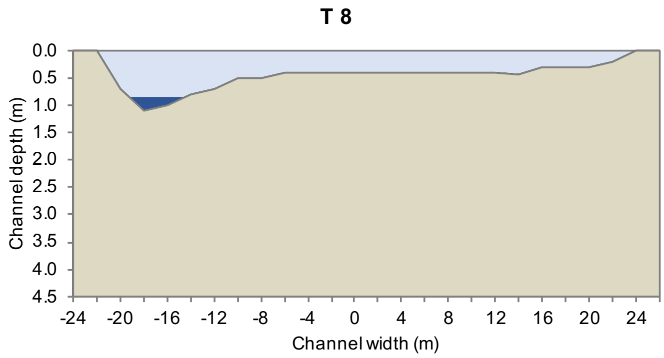
Fig. 9. Cross-section of the lower to middle Ohau Estuary (T1-T5) showing bed height, salinity stratification, substrate type and aRPD depth.



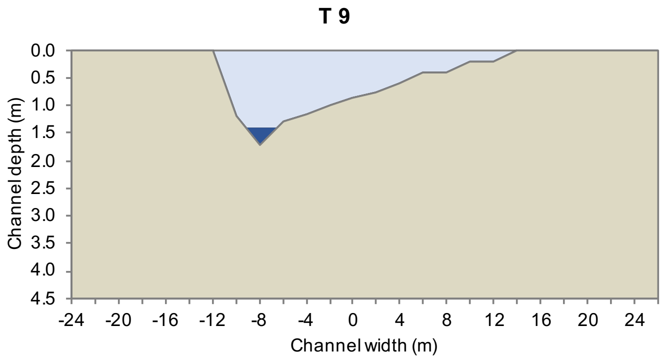
T6 Firm muddy sand (10-25%mud), aRPD indeterminate



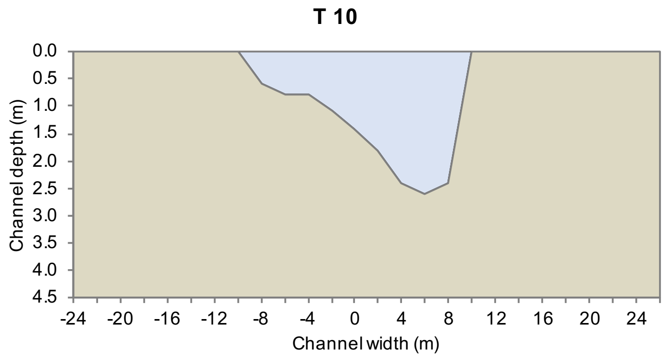
T7 Cobble field/gravel field (sample fines shown). aRPD indeterminate



T8 Soft muddy sand (25-50 %mud), aRPD indeterminate



T9 Gravel field
aRPD indeterminate (>150mm)



T10 Gravel field
aRPD indeterminate (>150mm)

Fig. 10. Cross-section of the middle to upper Ohau Estuary (T6-T10) showing bed height, salinity stratification, substrate type and aRPD depth.

3.3.4 High Enrichment Conditions

The spatial extent of high enrichment conditions is difficult to accurately estimate without far more extensive sampling than was undertaken. However, based primarily on the extent of low oxygenated bottom water, we estimate the HEC area at the time of sampling to be ~0.75ha (5%). In reality the low dissolved oxygen bottom waters will vary diurnally due to a decrease in photosynthesis at night, reflecting worse conditions than encountered at the time of sampling.

3.4 ASSESSMENT AGAINST CONDITION RATINGS AND CALCULATION OF THE ETI

Broad scale indicators are assessed on an estuary-wide basis, whereas many metrics within the ETI incorporate spot measures from within the most degraded 10% of the estuary.

Table 7 summarises the 2020 ecological condition scores for key indicators of sediment quality, water quality and broad scale spatial indicators used to calculate an ETI score. Criteria and ratings are summarised in Table 2.

As indicated in Table 6, sediment quality was generally 'good' or 'very good, although mud content rated 'poor'. Trace contaminant results were all low and indicate that the estuary is unlikely to have any significant sediment contamination issues, hence trace contaminants were assigned a rating of 'very good'. This suggests the estuary substrate is in a relatively good condition with little indication of excessive enrichment. The absence of nuisance macroalgae in 2020 was rated 'very good'.

However, water quality indicators for dissolved oxygen and phytoplankton were both rated 'poor' indicating there are sufficient nutrients and suitable growing conditions in the estuary to support phytoplankton blooms.

Broad scale ratings in relation to mud extent and catchment sediment inputs were 'very good', likely to be facilitated by regular flushing of the estuary by freshwater. The salt marsh extent (3.5ha, 10%) was rated 'fair', and the estimated reduction from historical extent was rated 'poor'. After accounting for the misclassification of salt marsh species in 2018, there appears to have been no substantive change in estuary condition from that recently reported (see Section 3.1).

Overall, the ETI score for the estuary, calculated using Table 7 data and NIWAs online Tool 2 calculator (https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/) was 0.73, which corresponds to a rating of 'moderate', and is on the cusp of 'poor'.

Table 7. Summary of broad scale spatial indicators and general indicators reflecting the most impacted 10% of the estuary.

Indicator	Unit	State	Rating	Data source
Sediment Quality				
Mud content	%	25	Poor	Current report (site B)
aRPD depth	mm	70	Very Good	Current report (site B)
Total nitrogen	mg/kg	500	Good	Current report (site B)
Total organic carbon	%	0.57	Good	Current report (site B)
Trace elements	mg/kg	low	Very Good	Current report (site B)
Water Quality				
Dissolved oxygen	mg/L	1.1	Poor	Current report (site C)
Phytoplankton (chl-a)	90th percentile, mg/m^3	19 (n=75)	Poor	HRC data Sept 2015-Mar 2020
Broad scale spatial indicators				
Mud-dominated substrate	% of estuary >50% mud	0ha 0%	Very Good	Current report
Macroalgae (OMBT)	EQR	1	Very Good	Default score as no macroalgae
Seagrass	% decrease from baseline	NA	-	No seagrass present
Salt marsh extent (current)	% of intertidal area	10	Fair	Current report
Historical salt marsh extent	% of historical remaining	<25	Poor	Estimated from 2020 survey
High Enrichment Conditions	ha or % of estuary	0.75ha (5%)	Good	Current report
200m terrestrial margin	% densely vegetated	<25	Poor	Estimated from 2020 survey
Sedimentation rate	CSR:NSR ratio	1.1	Very Good	Hicks et al (2019)

4. SYNTHESIS OF KEY FINDINGS

Ohau Estuary is currently expressing localised symptoms of water column eutrophication. Phytoplankton indicators were high, consistent with long-term HRC data that have recorded 90th percentile concentrations of chl-a above the 'poor' indicator rating for the previous 5-year period at site T5.

Dissolved oxygen levels were at severely low concentrations (1.1mg/L) at site T7. These levels are well below the ETI threshold for 'poor' (<4mg/L), and the presence of such conditions, even for as few as several hours over a tidal cycle, can cause severe adverse ecological effects, particularly to fish (see Franklin (2014) for further background).

The spatial extent of high enrichment conditions in the estuary water column, estimated at ~5%, highlights that part of the upper estuary is currently adversely impacted by elevated phytoplankton blooms likely fuelled by catchment inputs of nutrients.

5. RECOMMENDATIONS

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

1. Repeat synoptic sampling in the summer of 2021 to further define the spatial extent and nature of eutrophication impacts. This work should include boat-based sampling of subtidal sediments and water quality throughout the subtidal reaches of the upper estuary. Ideally repeat measures would be undertaken immediately following a flood event to determine the capacity for the estuary to flush excessive sediments, nutrients and low oxygen waters from the estuary.
2. Design and implement a long-term programme for regular ongoing monitoring of estuary condition linked to existing freshwater SOE monitoring, including the deployment of water quality loggers in the eutrophic parts of the estuary (ideally to measure salinity, dissolved oxygen and chl-a), as well as more frequent field assessments to determine the nature and extent of the current problems.
3. Assess catchment sources of nutrients and sediments to the estuary to determine whether changes to current land management practices are likely to significantly improve ecological condition and to guide council management priorities.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP with minor modifications as listed below.

Revised substrate classes were developed by Salt Ecology to more accurately classify fine unconsolidated substrate see Table A1.2.

Terrestrial margin vegetation was classified using the field codes included in the Landcare Research Land Cover Database (LCDB5) - see Table A1.2.

Habitat classification and mapping

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

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

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

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

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

Lower-case abbreviations are used to designate sediment firmness (f=firm, s=soft, vs=very soft). Mobile substrate (m) is classified separately. Upper-case abbreviations are used to designate four fine unconsolidated substrate classes consistent with existing geological terminology (S=Sand, MS=Muddy Sand, SM=Sandy Mud, M=Mud). These are based on sediment mud content (Table 3) and reflect both biologically meaningful thresholds where key changes in sediment macrofaunal communities occur, and categories that can be subjectively assessed in the field by experienced scientists and validated by laboratory analyses.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[1]Additions to the NEMP classification.

SUBSTRATE (physical and zoogenic habitat)

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

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

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

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

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

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

Shell: Area that is dominated by dead shells.

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

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

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

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

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

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

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

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

Table A1.2 Modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes

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

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

APPENDIX 2. ANALYTICAL METHODS AND RESULTS

Hill Laboratories
TRIED, TESTED AND TRUSTED

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28 Duke Street Frankton 3204
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Hamilton 3240 New Zealand

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	2308445
Contact:	Leigh Stevens	**Date Received:**	22-Jan-2020
	C/- Salt Ecology Limited	**Date Reported:**	03-Mar-2020
	21 Mount Vernon Place	**Quote No:**	103368
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Ohau Estuary - HRC
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		Ohau-Mana A 20-Jan-2020	Ohau-Mana B 20-Jan-2020	Ohau-Mana C 20-Jan-2020		
Lab Number:		2308445.1	2308445.2	2308445.3		
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	80	77	80	-	-
Total Recoverable Phosphorus	mg/kg dry wt	310	390	400	-	-
Total Nitrogen*	g/100g dry wt	< 0.05	0.05	< 0.05	-	-
Total Organic Carbon*	g/100g dry wt	0.26	0.57	0.45	-	-
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	3.0	4.6	3.4	-	-
Total Recoverable Cadmium	mg/kg dry wt	0.014	0.024	0.022	-	-
Total Recoverable Chromium	mg/kg dry wt	9	14	13.9	-	-
Total Recoverable Copper	mg/kg dry wt	3	7	7.1	-	-
Total Recoverable Lead	mg/kg dry wt	4.1	9.3	9.3	-	-
Total Recoverable Mercury	mg/kg dry wt	< 0.02	0.05	0.05	-	-
Total Recoverable Nickel	mg/kg dry wt	7	11	11.0	-	-
Total Recoverable Zinc	mg/kg dry wt	30	50	49	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.2	0.6	0.2	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	83.5	74.4	87.6	-	-
Fraction < 63 µm*	g/100g dry wt	16.3	25.0	12.2	-	-

Summary of Methods

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

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-3
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-3
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-3
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-3
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-3
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-3

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

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

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

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

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Algal Cell Count Report

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

Attention: Leigh Stevens

Sample Information

Client description:	Ohau Estuary	Laboratory ID:	2020000105/AS11183
Client ID:	OHAU-MANA	Date received:	22/01/2020
Date sampled:	20/01/2020	Date analysed:	23/01/2020
Time sampled:	1500	Sample Type:	Not specified

Potentially Toxic Algal Counts

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

Algal Species Counts

Dominant species (inc non toxic)	Cells per mL	Phyla
Prymnesium parvum/Rhinomonas sp. sp.	3,645	Prymnesiaceae/Cryptophyceae
Flagellates/Unicells <5um	2,400	Flagellates/Unicells
Gymnodinium sp.	515	Dinoflagellates (Dinoflagellata)
Rhodomonas sp.	8	Cryptophyceae
unidentified pennate diatoms	2	Diatoms (Bacillariophyceae)
Mallomonas sp.	1	Golden-brown algae (Chrysophyceae)
Nitzschia sp.	1	Diatoms (Bacillariophyceae)
Skeletonema sp. sp.	1	Diatoms (Bacillariophyceae)
Rhizosolenia imbricata	1	Diatoms (Bacillariophyceae)
Asterionellopsis sp.	1	Diatoms (Bacillariophyceae)
Gomphonema sp.	<1	Diatoms (Bacillariophyceae)

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

National Institute of Water & Atmospheric Research Ltd
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P O Box 11-115, Hamilton, New Zealand
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Algal Cell Count Report

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

Attention: Leigh Stevens

Sample Information

Client description:	Ohau Estuary	Laboratory ID:	2020000105/AS11183
Client ID:	OHAU-MANA	Date received:	22/01/2020
Date sampled:	20/01/2020	Date analysed:	23/01/2020
Time sampled:	1500	Sample Type:	Not specified

Comments:

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

Authorised by: Karl Safi
Key Tech Personnel, Algal Services

Signature:

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

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