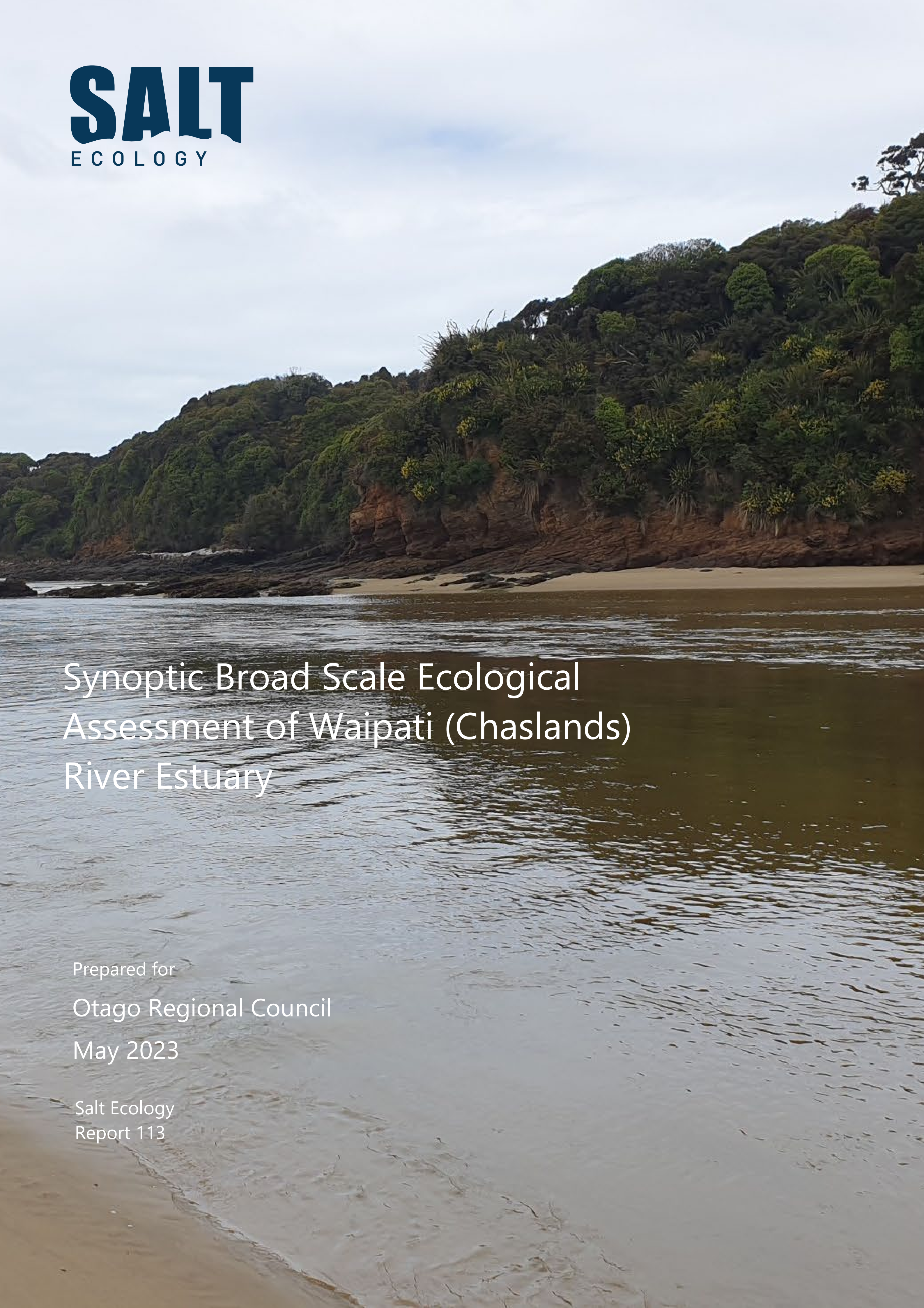

SALT
ECOLOGY

Synoptic Broad Scale Ecological Assessment of Waipati (Chaslands) River Estuary

Prepared for

Otago Regional Council

May 2023

Salt Ecology
Report 113

Cover and back photo: Waipati River Estuary entrance showing tannin-stained water, clean sands and rocky margin, December 2022.

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For the People
Mō ngā tāngata

Synoptic Broad Scale Ecological Assessment of Waipati (Chaslands) River Estuary

Prepared by

Barrie Forrest, Keryn Roberts, Leigh Stevens and Thomas Scott-Simmonds

for

Otago Regional Council

May 2023

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For the environment
Mō te taiao

GLOSSARY

AA	Affected Area (OMBT metric)
AIH	Available Intertidal Habitat (OMBT metric)
AMBI	AZTI Marine Biotic Index
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 (ANZG 2018)
EQR	Ecological Quality Rating (OMBT metric)
ETI	Estuary Trophic Index
HEC	High Enrichment Conditions
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TS	Total Sulfur
Zn	Zinc

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SUMMARY

Waipati (Chaslands) River Estuary (hereafter Waipati) is a medium-sized (68ha), shallow, intertidally dominated (83% of the 68ha), tidal lagoon type estuary located in the Catlins area of South Otago. It is an isolated estuary with no public road access, and is not well understood in terms of its habitats and ecological health. This report describes a survey conducted in December 2022, which mapped intertidal habitats according to the general approach described in New Zealand's National Estuary Monitoring Protocol (NEMP), supported by synoptic sampling of sediment quality, sediment-dwelling biota, and water quality.

KEY FINDINGS

The survey showed that Waipati River Estuary is in a healthy state overall. It is one of few remaining estuaries in the Otago region in which there is a relatively natural transition from estuary salt marsh to freshwater wetland habitat through to indigenous forest in its upper reaches. A summary of key monitoring indicators assessed against preliminary condition rating thresholds for estuary health are provided in the tables below and on the next page. The rating tables show that most indicators are rated 'good' or 'very good', with the most notable exceptions being predicted sediment rate, macrofauna 'AMBI' scores and, to a lesser degree, the extent of mud-elevated sediment. The features that contribute to favourable condition rating values include the following:

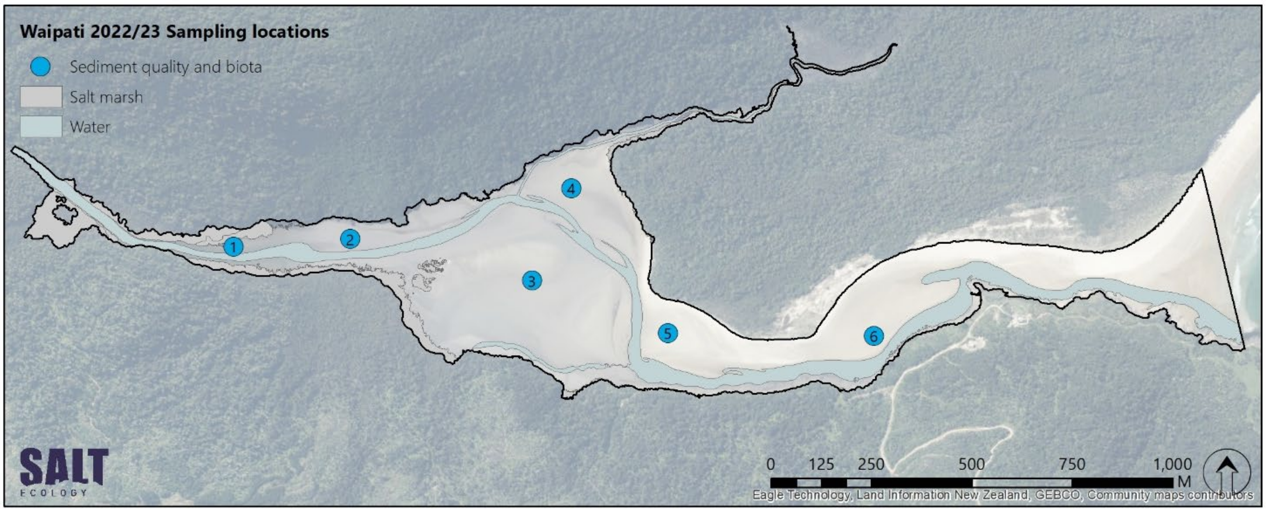
- A relatively intact and unmodified terrestrial margin, with ~75% of the wider catchment (7,269ha) being mainly intact indigenous forest (~66%) with smaller areas of scrub.
- Salt marsh (5ha or 8.9% of the intertidal area) that transitions to freshwater wetland. Historic imagery (earliest from 1948) shows a decline of ~25% near the river mouths and in the mid-estuary, likely due to erosion.
- Clean, sand-dominated sediment in most areas outside the western and northeast estuary side arms.
- Almost no growth of opportunistic macroalgal species that can become prolific under eutrophic conditions.
- An absence of High Enrichment Conditions (i.e., symptoms of an enriched and eutrophic sediment state).
- Very low trace metal contaminant concentrations, consistent with the low level of catchment development and absence of significant contaminant sources.
- High-value seagrass habitat is likely naturally absent from the estuary, for reasons described in the report.
- 'Very good' water quality (i.e., high dissolved oxygen, low chlorophyll-*a*) at the time of sampling, based on a small suite of field indicators measured (ratings shown in main report).

Summary of broad scale indicator condition ratings.

Broadscale Indicators	Unit	Value	Condition Rating
Mapped indicators			
200m terrestrial margin	% densely vegetated	92.1	Very Good
Mud-elevated substrate	% intertidal area >25% mud[1]	10.8	Fair
Macroalgae (OMBT[2])	Ecological Quality Rating (EQR)	0.996	Very Good
Seagrass	% decrease from baseline	no seagrass present	na
Salt marsh extent (current)	% of intertidal area	8.9	Fair
Historical salt marsh extent[3]	% of historical remaining	~75%	Good
High Enrichment Conditions	ha	0	Very Good
High Enrichment Conditions	% of estuary	0	Very Good
Estuary-wide sedimentation indicators			
Mean sedimentation ratio[4]	CSR:NSR ratio	1.1	Very Good
Sedimentation rate[4]	mm/yr	3.8	Poor

[1] Excludes salt marsh area; [2]OMBT = Opportunistic Macroalgal Blooming Tool; [3]Estimated from historic aerial imagery, [4]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling). na = not applicable.

Synoptic sampling sites (1-6) and indicator condition ratings for sediment quality and macrofauna AMBI.



Parameter	Unit	1	2	3	4	5	6
Mud	%	48.5	19.2	17.3	11.1	3.3	1.6
aRPD	mm	30	25	40	40	90	>150
TN	mg/kg	1200	< 500	< 500	< 500	< 1300	< 1300
TP	mg/kg	370	250	300	260	230	198
TOC	%	2.10	0.57	0.22	0.30	< 0.13	< 0.13
TS	%	0.15	0.65	0.03	0.03	0.02	0.01
Trace metals	mg/kg	All trace metals were rated 'Very good'					
AMBI	na	4.2	4.4	4.5	4.5	4.4	2.5

See Glossary for abbreviations. < Values below lab detection limit. Colour bandings in Table 3 of main report.

The macrofauna biotic index 'AMBI' rated 'poor' due to a sediment-dwelling faunal community that is adapted to naturally harsh environmental conditions (e.g., seafloor scouring, low salinity water). Based on its physical characteristics and estimated flushing time, Waipati River Estuary is not considered particularly vulnerable to catchment-derived inputs of nutrients. However, due to a predicted high sediment retention (81% trapping efficiency) and a modelled sedimentation rate of 3.8mm/yr, which is almost double the national guideline value, the estuary is considered vulnerable to increased inputs of catchment-derived muddy sediments. Currently, the area of mud-elevated substrate (>25% mud content) is relatively modest at 10.8% of the unvegetated intertidal area (rated 'fair'), with muddy sediment also naturally trapped in salt marsh. Changes in land-use, including future harvesting of ~9% of the catchment that is in exotic plantation forest, has the potential to increase the mass load of sediment to the estuary and create muddier more degraded habitats on the main intertidal flats. The opportunity exists to consider management options that could mitigate this risk.

RECOMMENDATIONS

Waipati River Estuary is in a healthy state overall; however, it is vulnerable to inputs of catchment-derived muddy sediment. To mitigate against such risks the following is recommended:

- Evaluate current and potential future sediment sources to the estuary, and investigate options for a reduction of inputs. This could be facilitated by including Waipati River Estuary in the ORC limit setting programme and establishing limits for catchment sediment (and nutrient) inputs that will maintain estuary health.
- Include Waipati River Estuary in a broader review of the Otago estuary SOE monitoring programme, in order to understand and prioritise long term monitoring needs.

1. INTRODUCTION

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). 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 establish a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuary biota and sediment quality. This type of detailed monitoring is typically conducted at 2-3 fixed sites in the dominant habitat of the estuary and is repeated at intervals of ~5 years after initially establishing a multi-year baseline.

The approaches are intended to detect and understand changes in estuaries over time, with a particular focus on changes in habitat type (e.g., salt marsh or mud extent), as well as changes within habitats from the input of nutrients, fine (muddy) sediments and contaminants, which are key drivers of degraded estuary sediment condition as well as of eutrophication symptoms such as prolific macroalgal (seaweed) growth.

Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 using NEMP methods (or extensions of that approach), with key locations being (from north to south) Kakanui, Shag River, Pleasant River, Waikouaiti, Blueskin Bay, Pūrākaunui, Hoopers Inlet, Kaikorai, Tokomairiro, Akatore, Catlins, Tahakopa (Papatowai), and Tautuku estuaries. The current report describes the methods and results of a broad scale assessment undertaken on 1 December 2022 in a new location, Waipati (Chaslands) River Estuary (hereafter Waipati) in the southern Catlins (Fig. 1).

The primary purpose of the work was to characterise substrate, salt marsh and the presence and extent of any seagrass or macroalgae, using NEMP broad scale mapping approaches. While NEMP fine scale monitoring focuses on the dominant habitat within an estuary, the protocol does not broadly characterise the ecology of other unvegetated habitats. To address this, a synoptic assessment was undertaken of sediment quality, biota and water quality at representative sites throughout the estuary, using some of the same indicators as are typically used for NEMP fine scale monitoring. The purpose of this additional work was two-fold; (1) provide additional information on the ecological condition of unvegetated habitats to support the broad scale assessment and, (2) inform decisions regarding the need for implementation of long-term fine scale SOE monitoring, and provide a basis for identifying potential monitoring sites.

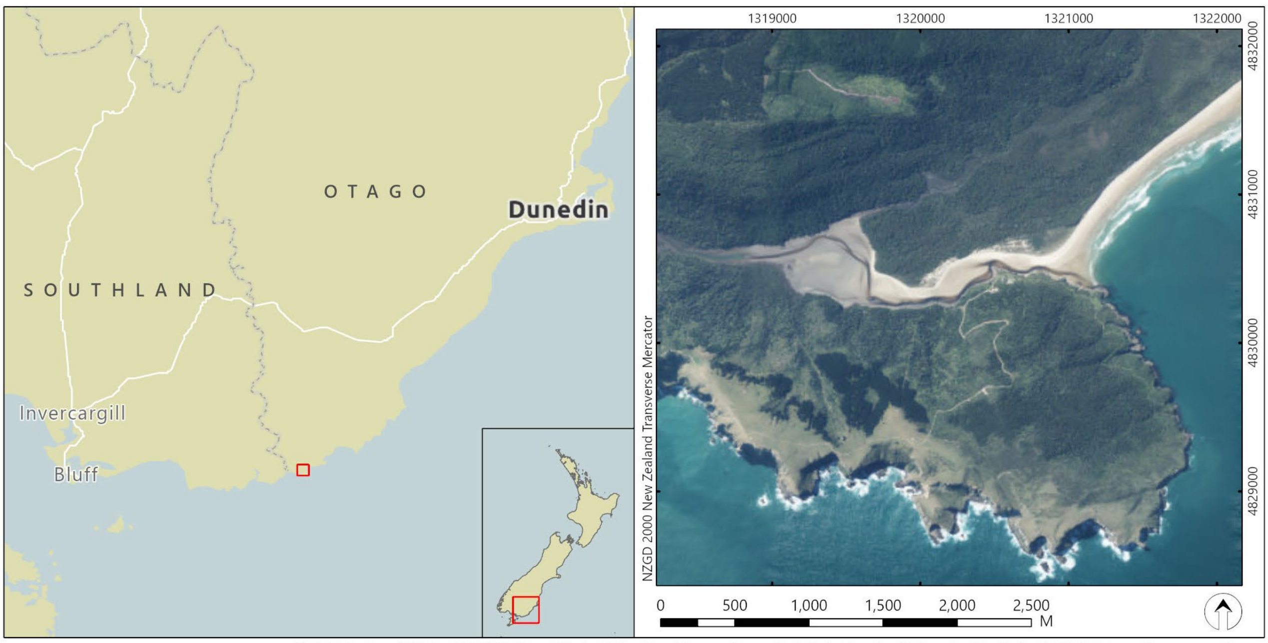


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Fig. 1. Location of Waipati (Chaslands) River Estuary, south Otago.

2. OVERVIEW OF WAIPATI RIVER ESTUARY

Waipati River Estuary in South Otago is close to the regional boundary with Southland. It is one of four estuarine systems in the Catlins (the others being Tautuku, Tahakopa, and Catlins Estuaries), and is the most isolated and least accessible. There is a single private dwelling (crib) and associated jetty on south side near the estuary entrance, which is accessed by a rough 4WD track. Public walking access is possible via a track on the south side of the estuary or at low tide from the Cathedral Caves tourist attraction more the 2km to the northeast along Waipati Beach.

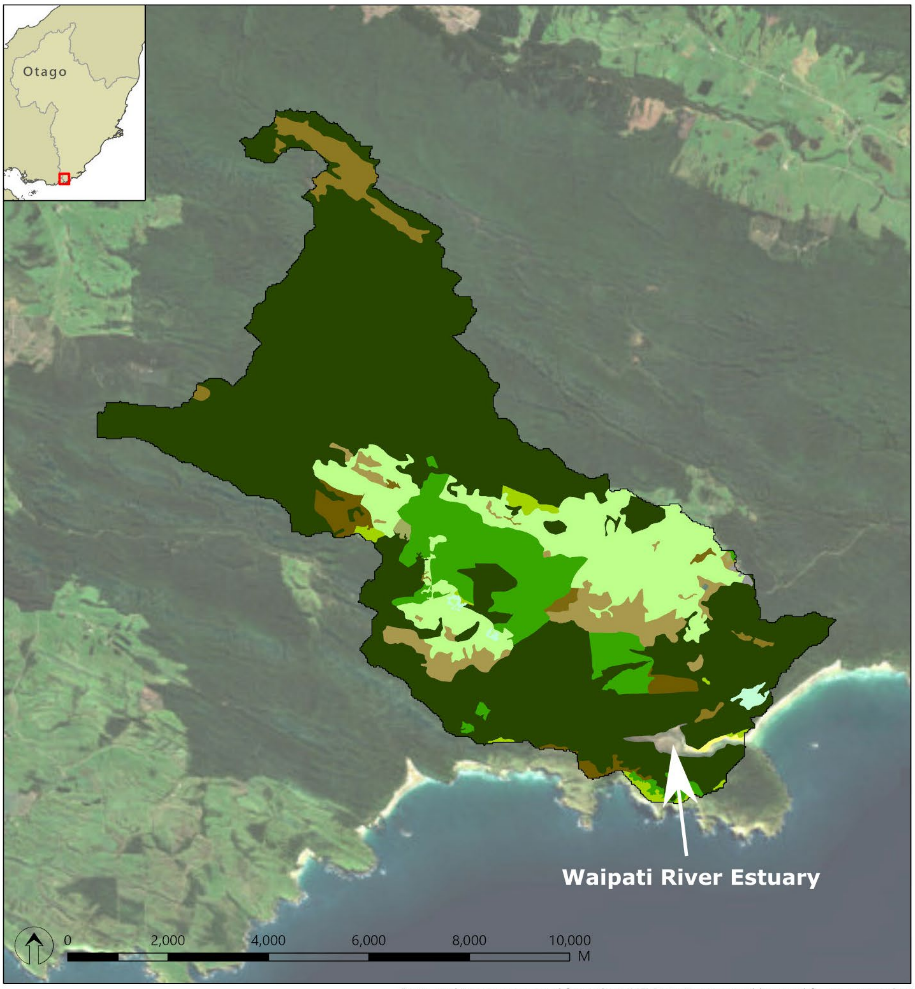
The estuary itself is elongate, with a narrow entrance, and tidal flats in the central reaches. By regional and national standards, Waipati River Estuary is of medium size (68ha). It is relatively well-protected from the ocean by a protruding headland on the south side of the entrance. The estuary typology is classified as a shallow, intertidally dominated, tidal lagoon-type estuary (SIDE), meaning that most of the area is intertidal. It receives a mean freshwater input from Waipati River of ~1.6m^3/sec, and has an estimated flushing time of 3.3 days (Plew et al. 2018).

We are unaware of any previous ecological studies of Waipati River Estuary, hence the broad scale survey described here appears to be one of the first efforts to characterise its main features and current condition. There appears to be no monitoring of estuary catchment waters by ORC, although water quality and stream ecology are monitored in four other rivers in the Catlins area (Catlins, Owaka, Maclennan and Tahakopa Rivers). However, there appears to have been a limited assessment of freshwater values, with Waipati River described in the Otago Regional Plan (Water) as having significant ecosystem values for trout and eels. In addition, Ozanne (2011) describes a range of native freshwater fish in the monitored catchments, which potentially also occur in the Waipati River.

Despite the absence of information on the state of Waipati River Estuary and of catchment freshwater inputs, we expect pressures on the system are likely to be low by comparison to many other estuaries in the region. For example, in addition to the difficult public access, the estuary itself is bordered mainly by indigenous forest, with a small narrow dune margin on the true left at the entrance (Fig. 2). According to Moore (2015) this is an area of "*previously active sand dunes…now largely stabilised with marram [grass]…*".

A strip of the estuary margin (~1-2km wide) on the north side forms the Waipati Beach Reserve while the southern margin is within the Māori freehold land administered by the Tautuku and Waikawa Trust (kahurumanu.co.nz/atlas). The wider catchment has experienced a small amount of development, starting with attempts by European settlers to develop farmland from the 1890s (Tyrrell 2016). Based on the LCDB5 (2017/2018) database, of a total catchment area of 7,269ha, some 14.4% is presently in farmland, with a 9.3% being exotic plantation forestry, of which 0.1% (10.6ha) was classified as being harvested based on 2018 data (Fig. 2). About two-thirds (66.4%) of the catchment remains as indigenous forest, with a further area of ~9% being a mix of indigenous and exotic scrub and shrubland. The estuary was described by Moore (2015) as having outstanding natural character.

View from sea looking up Waipati River Estuary (top); Lower Waipati River Estuary and Waipati Beach (bottom) (source: Moore 2015).



Catchment Land Use in 2018	ha	%
Artificial Surfaces	0	0
Built-up Area (settlement)	5.0	0.1
Surface Mines and Dumps	0	0
Transport Infrastructure	0	0
Urban Parkland/Open Space	1.2	0.0
Bare or Lightly Vegetated Surfaces	0	0
Sand and Gravel	7.8	0.1
Landslide	0	0
Alpine Grass/Herbfield	0	0
Gravel and Rock	0	0
Water Bodies	0	0
River, Lake or Pond	0	0
Cropland	0	0
Short-rotation Cropland	0	0
Orchard Vineyard and Other Perennial Crops	0	0
Grassland, Sedge and Saltmarsh	0	0
High Producing Exotic Grassland	981.0	13.5
Low Producing Grassland	67.6	0.9
Tall Tussock Grassland	0	0
Depleted Grassland	0	0
Herbaceous Freshwater Vegetation	27.1	0.4
Herbaceous Saline Vegetation	0	0
Flaxland	0	0
Scrub and Shrubland	0	0
Fernland	122.6	1.7
Gorse and/or Broom	24.3	0.3
Manuka and/or Kanuka	181.7	2.5
Broadleaved Indigenous Hardwoods	298.3	4.1
Sub Alpine Shrubland	0	0
Mixed Exotic Shrubland	0	0
Matagouri or Grey Scrub	0	0
Forest	0	0
Forest Harvested	10.6	0.1
Deciduous Hardwoods	0	0
Indigenous Forest	4,823.2	66.4
Exotic Forest	666.4	9.2
	7,269.2	100

Fig. 2. Waipati River Estuary catchment land use classifications from LCDB5 (2017/2018) database.

Waipati beach with lower estuary entrance on right.

Crib and jetty in low estuary.

3. METHODS

3.1 OVERVIEW

The survey of Waipati River Estuary was carried out on 1 December 2022. It consisted of broad scale habitat mapping of substrates and vegetation, targeted sampling of sediment quality and macrofauna in representative areas, and a cursory water quality assessment. Fig. 3 shows the estuary area surveyed, and indicates where the sampling described below was undertaken. Detail of the survey approach, sampling methods and analyses is provided in Appendix 1, and is summarised below and in Table 1 and Table 2.

3.2 BROAD SCALE HABITAT MAPPING

Broad scale mapping characterised the dominant intertidal substrates and vegetation types, with the spatial extent and location of different habitat types, and temporal changes in features, providing valuable indicators of estuary condition. Mapping was based on NEMP methods (Robertson et al. 2002), and included refinements by Salt Ecology that improve the utility and accuracy of the NEMP approach as detailed in Appendix 1 and summarised in Table 1.

The approach combined the use of aerial imagery, detailed field ground-truthing (e.g., annotation of laminated aerial photos, spot data on macroalgae and substrate type recorded in a web-based app, and field photos), and post-field digital mapping using Geographical Information System (GIS) technology. Aerial imagery for Waipati River Estuary was sourced from LINZ Data Service and consisted of 30cm/pixel colour aerial imagery captured between January and April 2019. QA/QC procedures, applied through the phases of field data collection, digitising, and GIS data collation processing, are described in Appendix 1.

The main broad scale survey elements were as follows.

- Substrate mapping subjectively classified sediments (e.g., mud, sand, gravel, cobble, bedrock) according to the scheme described in Table A2 of Appendix 1. As mud is a key stressor on estuary habitats, an important focus was to map the spatial extent of soft-sediment (mud and sand) habitats, with laboratory analyses of grain size collected from 10 representative locations (Fig. 3) used to validate field classifications.
- Vegetation mapping characterised high-value features, namely salt marsh (e.g., rushland, herbfield, sedgeland) and seagrass (*Zostera muelleri*), and also described the occurrence and extent of algae species that can be symptomatic of estuary degradation. Particularly important among the latter were nuisance 'opportunistic' macroalgae that can 'bloom' in response to conditions such as excess nutrient inputs, including the red seaweed *Agarophyton* spp. and green 'sea lettuce' *Ulva* spp.
- To assist with percent cover estimates of seagrass and opportunistic macroalgae, a visual rating scale was used based on photographs shown in Fig. 4. For macroalgae, field data collection also included wet-weighing of macroalgae biomass, to enable calculation of Opportunistic Macroalgal Blooming Tool (OMBT) scores. The OMBT is a multi-metric index that combines different measures of opportunistic macroalgal proliferation into an integrated measure of ecological condition (see Table 1; Appendix 1; WFD-UKTAG 2014; Stevens et al. 2022).

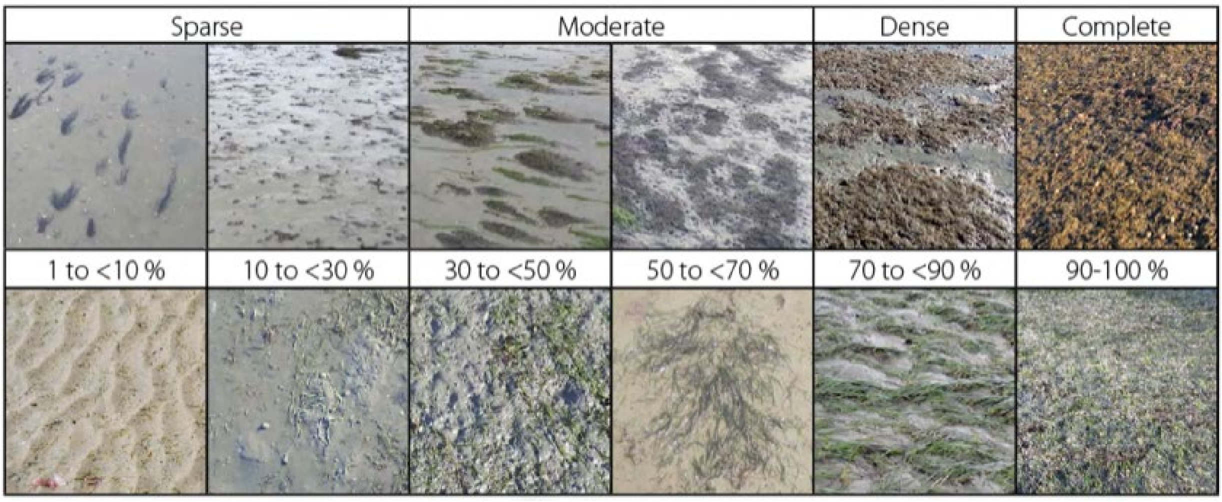


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

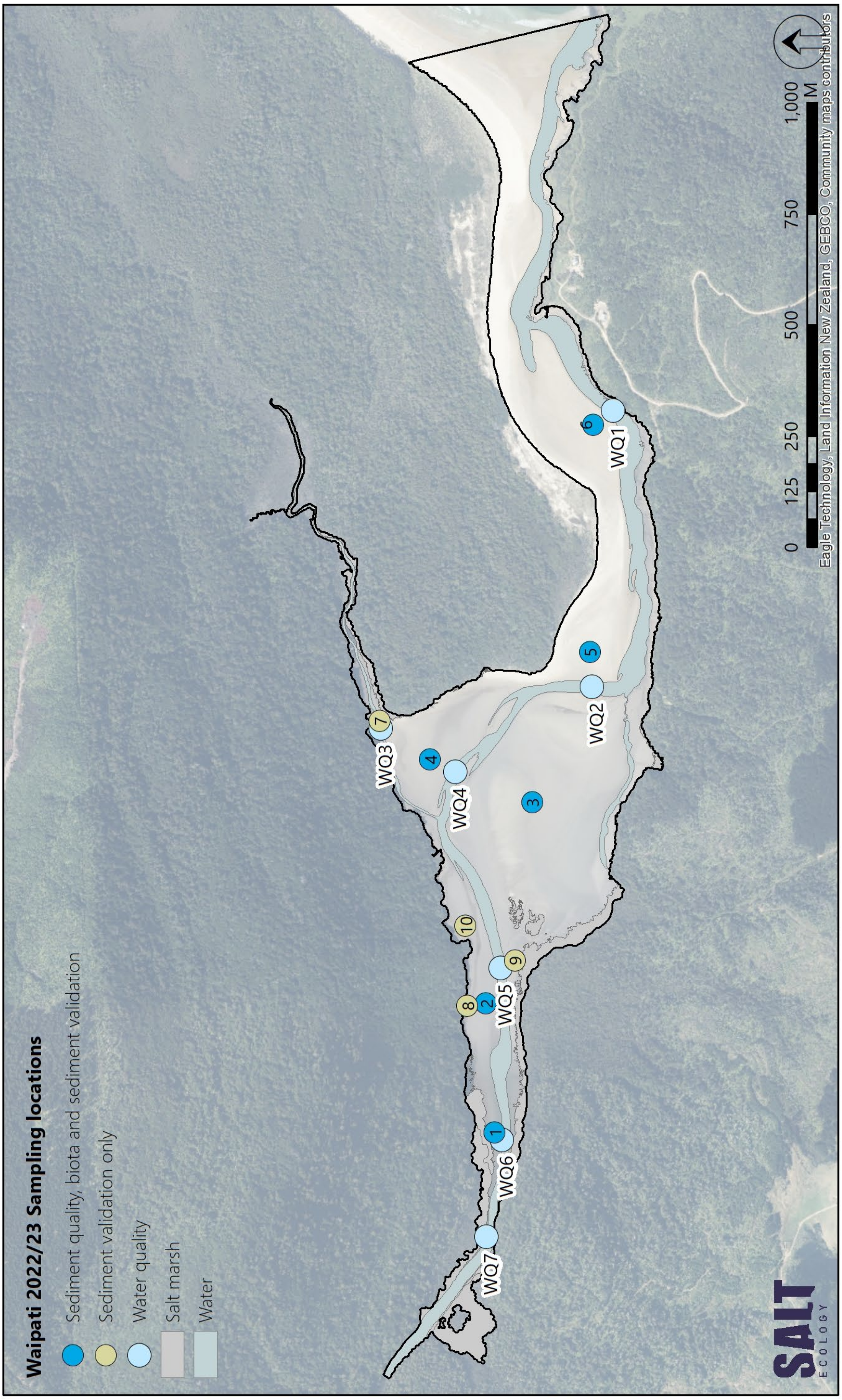


Fig. 4. Location of sites for sediment quality and biota samples (1-6), sediment validation (1-10), and water quality (WQ1-7).

Table 1. Broad scale indicators of estuary condition that are assessed by field mapping and related methods.

Indicator	General rationale	Method description
Terrestrial margin vegetation	A densely vegetated terrestrial margin filters and assimilates sediment and nutrients, is a buffer to introduced grasses and weeds, is an important food source and habitat for a variety of species and, in waterway riparian zones, provides shade that moderates stream temperature fluctuations, and improves estuary biodiversity.	Mapped based on aerial extent and classified using the LCDB5 classes, dominant species are also recorded as meta data where known.
Substrate type	High substrate heterogeneity generally supports high estuary biodiversity. Increases in fine sediment (i.e., mud <63µm) can reduce heterogeneity, concentrate contaminants, nutrients and organic matter, and lead to degradation of benthic communities by displacing sensitive species including shellfish. Enrichment of muddy sediments (i.e., high TOC and nutrients; Table 2) can additionally fuel algal growth and deplete sediment oxygen.	Mapped based on aerial extent and classified using a modified version of the NEMP system (see Table A2, Appendix 1). The improved classification frame-work, developed by Salt Ecology, characterises substrate type based on mud content and is supported by grain size validation samples. Substrate type is also recorded beneath vegetation.
Salt marsh	Salt marsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important in estuaries as it is highly productive, naturally filters and assimilates sediment and nutrients, mitigates shoreline erosion, and provides an important habitat for a variety of species including insects, fish and birds.	Mapped based on aerial extent. Dominant salt marsh species are recorded and categorised into sub-classes (e.g., rushland, herbfield). Pressures on salt marsh (e.g., drainage, grazing, erosion) are also recorded.
Seagrass	Seagrass (*Zostera muelleri*) beds enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for invertebrates and fish. Seagrass is vulnerable to muddy sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygenation).	Mapped based on aerial extent, and percent cover recorded within each seagrass patch. Pressures on seagrass beds (e.g., sediment or macroalgae smothering, leaf discolouration) are also recorded.
Opportunistic macroalgae	Opportunistic macroalgae (species of *Agarophyton* and *Ulva*) are a symptom of estuary eutrophication (nutrient enrichment). At nuisance levels, these algae can form mats on the estuary surface that can adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh. The Opportunistic Macroalgal Blooming Tool (OMBT) is a multi-metric index that combines different measures of macroalgae (see text) and is calculated as an indicator of ecological condition.	Mapped based on aerial extent. Species, percent cover, biomass and level of entrainment are recorded in each macroalgae patch to apply the OMBT (WFD-UKTAG 2014). The application of the OMBT incorporates New Zealand-based improvements described in Plew et al. (2020) and Stevens et al. (2022).
High Enrichment Conditions	HECs characterise substrates with extreme levels of organic or nutrient enrichment (i.e., eutrophication). HECs are sediments depleted in (or devoid of) oxygen, which have a very shallow aRPD (e.g., <10mm; Table 2), an intense black colour in the sediment profile, and typically have a strong hydrogen sulfide (i.e., rotten egg) smell. Sediment samples are likely to have a quantitatively high nutrient or organic content (e.g., TOC >2%; Table 2). In a broad scale context, the HEC metric is intended as an initial guide to highlight areas of enrichment that may require further investigation.	Mapped based on aerial extent where there are obvious low sediment oxygen conditions (e.g., black sediments with rotten egg smell), conspicuous surface growths of sulfur-oxidising bacteria, stable, entrained, dense (>50% cover) beds of opportunistic macroalgae, or the extensive presence of surface micro-algae or filamentous-algae.

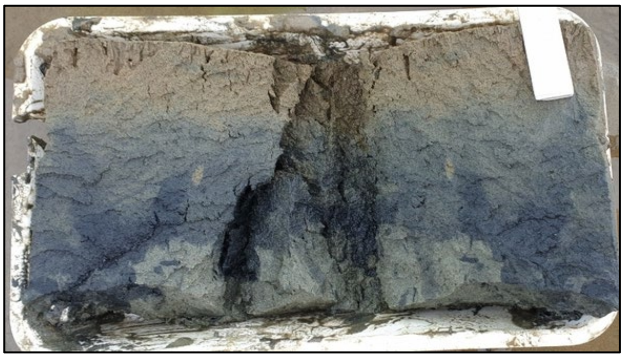
3.3 SEDIMENT QUALITY AND BIOTA

Sampling of sediment quality and associated biota was undertaken in representative soft-sediment habitats at six discrete sites (Fig. 3). Table 2 summarises sediment and biota indicators, field sampling methods, and the rationale for their use. These indicators, and the associated sampling methods, largely adhered to the NEMP protocol for 'fine scale' surveys of estuaries (except as noted in Table 2). However, whereas NEMP fine scale surveys involve intensive (high replication) sampling of 1-3 sites (typically) in the most common estuary habitat, the current survey had a less intensive, estuary-wide focus to provide a synoptic picture of ecological health across the range of soft-sediment habitat types present. The key sampling elements can be summarised as follows:

- Sediment quality: Indicators included sediment mud content, oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients and organic content, and chemical contaminants (selected trace elements). Sediment aRPD was measured in the field. For the other variables a single sample for sediment quality analyses at each site was composited from three sub-samples, and sent to RJ Hill Laboratories for analysis.
- Biota: The focus was on macrofauna, which are small organisms that live within or on the sediment matrix, which were sampled quantitatively using sediment cores (130mm diameter, 150mm deep). The composition of the core samples in terms of macrofauna species (or higher taxa) and their abundance, was determined by taxonomic experts at NIWA. We also used qualitative field methods to estimate the abundance or percent cover of conspicuous surface-dwelling estuary snails, macroalgae and microalgae.

In addition to the raw indicator data, three measures of macrofauna health were derived. Two of these (richness and abundance) are simple measures that describe the number of different species present in a sample (i.e., richness), and total organism abundance. A third derived variable ('AMBI') was also calculated. The AMBI is an international biotic health index (Borja et al. 2000) whose calculation is based on the proportion of macrofauna species falling into one of five eco-groups (EG) that reflect sensitivity to pollution, ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

The QA/QC procedures applied through the phases of field data collection, lab dispatch of samples, data transfer, macrofauna naming, EG standardisation, and other QA procedures, are described in Appendix 1.

Collection of sediment core (top), measuring aRPD in the core profile (upper middle), transferring the core to a mesh (0.5mm) sieve bag (lower middle) and rinsing the core sieve bags in the subtidal channel (bottom).

Table 2. NEMP sediment quality and biota indicators, rationale for their use, and sampling method. Any significant departures from the NEMP are described in footnotes.

Indicator	General rationale	Sampling method
Physical and chemical		
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated.	Composited surface scrape to 20mm sediment depth.
Nutrients (nitrogen and phosphorus), organic matter & total sulfur	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Surface scrape to 20mm sediment depth. Organic matter measured as Total Organic Carbon (TOC) (note 1).
Trace elements (arsenic copper, chromium, cadmium, lead, mercury, nickel, zinc)	Common toxic contaminants generally associated with human activities. High concentrations may indicate a need to investigate other anthropogenic inputs, e.g., pesticides, hydrocarbons.	Surface scrape to 20mm sediment depth (note 2).
Substrate oxygenation (apparent Redox Potential Discontinuity depth; aRPD)	Measures the enrichment/trophic state of sediments according to the depth of the apparent Redox Potential Discontinuity layer (aRPD). This is the visual transition between brown oxygenated surface sediments and deeper less oxygenated black sediments. The aRPD can occur closer to the sediment surface as organic matter loading or sediment mud content increase.	Sediment core, split vertically, with average depth of aRPD recorded in the field where visible.
Biological		
Macrofauna	Abundance, composition and diversity of infauna living with the sediment are commonly-used indicators of estuarine health.	130mm diameter sediment core to 150mm depth ($0.013m^2$ sample area, 2L core volume), sieved to 0.5mm to retain macrofauna.
Epibiota (epifauna)	Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health.	Abundance based on SACFOR in Appendix 1, Table B3 (note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR in Appendix 1, Table B3 (note 3).
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR in Appendix 1, Table B3 (notes 3, 4).

[1] Since the NEMP was published, Total Organic Carbon (TOC) has become available as a routine low-cost analysis which provides a more direct and reliable measure than the NEMP recommendation of converting Ash Free Dry Weight (AFDW) to TOC.

[2] Arsenic and mercury are not specified in the NEMP, but can be included in the trace element suite by the analytical laboratory.

[3] Assessment of epifauna, macroalgae and microalgae uses SACFOR instead of quadrat sampling outlined in the NEMP. Quadrat sampling is subject to considerable within-site variation for epibiota that have clumped or patchy distributions.

[4] NEMP recommends taxonomic composition assessment for microalgae but this is not typically undertaken due to clumped or patchy distributions and the lack of demonstrated utility of microalgae as a routine indicator.

Western side arm of Waipati River Estuary.

3.4 WATER QUALITY

To obtain synoptic information on easily-measured water quality parameters, portable meters were used to measure salinity, dissolved oxygen, temperature and chlorophyll-*a* (the latter is an indicator of phytoplankton abundance). Measurements were undertaken at 7 sites in the main estuary channel, from WQ1 near the estuary entrance to WQ7 in the upper western arm (Fig. 3). Method detail is provided in Appendix 1. Measurements were made around the low tide period. Unfortunately high tide measurements, which could be used to determine upper saline extent, were not possible in Waipati River Estuary due to access restrictions at high tide.

Clearly, one-off measurements of water quality provide limited ability to make inferences regarding estuary state. Hence in the current situation the primary purposes were to gather ancillary data to help interpret the broad scale information, and also to capture preliminary information to help assess whether the estuary may be vulnerable to water quality degradation. For the second purpose, vertical profiling was undertaken to assess the extent of salinity stratification in the water column. Stratification, whereby denser seawater can become trapped beneath overlying freshwater from river inputs, can make bottom waters vulnerable to degradation.

Water quality site WQ3, native forest on the estuary margin.

Tannin-rich waters of the subtidal channel near WQ2.

3.5 ASSESSMENT OF ESTUARY CONDITION

In addition to the authors' expert interpretation of the data and summaries, results are assessed against established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 3). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3.

In previous reports for ORC, we have also calculated scores for the New Zealand Estuary Trophic Index (ETI). The ETI is a multi-metric index developed in New Zealand to provide a single score for estuary health. However, as the ETI documentation provides no clear guidance on the estuary area (and associated data) that should be used for the calculation, ETI scores can vary according to the data choices made; for example, whether scores are calculated from the most degraded sections of an estuary, or for the estuary overall. As such, we have deferred the further application of the ETI approach until the methodology issues are resolved.

Note that there are two broad scale rating indicators (salt marsh and seagrass) that rely on assessment of differences between current state and historic or baseline state. For this purpose we undertook the following:

- For salt marsh, we looked at historic aerial imagery captured from 1948 (retrolens.co.nz). In ArcMap 10.8 the imagery was geo-referenced and then the area of salt marsh digitised to get an estimate of historic salt marsh extent. More recent losses evident since 2013, were only visually assessed, because it was outside of scope to create a time series of salt marsh loss.
- For seagrass % decrease from baseline, the same aerial imagery from 1948 showed no areas of distinguishable seagrass. This finding was confirmed by visually inspecting images captured in 1967, 1982, and 2019 (retrolens.co.nz; data.linz.govt.nz).

Table 3. Indicators used to assess results in the current report. See Glossary for definitions.

a. Broad scale

Indicator	Unit	Very good	Good	Fair	Poor
Mapped indicators					
200m terrestrial margin[1]	% densely vegetated	≥ 80 to 100	≥ 50 to 80	≥ 25 to 50	< 25
Mud-elevated substrate[2, 3]	% intertidal area >25% mud	< 1	1 to 5	> 5 to 15	> 15
Macroalgae (OMBT)[2,4]	Ecological Quality Rating	≥0.8 to 1.0	≥0.6 to <0.8	≥0.4 to <0.6	0.0 to <0.4
Seagrass[1]	% decrease from baseline	< 5	≥ 5 to 10	≥ 10 to 20	≥ 20
Salt marsh extent (current)[1]	% of intertidal area	> 20	> 10 to 20	> 5 to 10	0 to 5
Historical salt marsh extent[1,5]	% historical remaining	≥ 80 to 100	≥ 60 to 80	≥ 40 to 60	< 40
High Enrichment Conditions[1,6]	ha	< 0.5	≥ 0.5 to 5	≥ 5 to 20	≥ 20
High Enrichment Conditions[1,6]	% of estuary	< 1	≥ 1 to 5	≥ 5 to 10	≥ 10
Estuary-wide sedimentation indicators					
Mean sedimentation ratio[2,7]	CSR:NSR ratio	1 to 1.1 x NSR	>1.1 to 2	>2 to 5	> 5
Sedimentation rate[8]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2

1. General guidance as used in SOE reports for council(s) since 2007.
2. Ratings derived from Robertson et al. (2016).
3. Mud-elevated substrate modified from Robertson et al. (2016) to apply to the intertidal area excluding salt marsh, not the whole estuary area.
4. OMBT = Opportunistic Macroalgal Blooming Tool (WFD-UKTAG 2014).
5. Estimated from historic aerial imagery.
6. The final condition rating is based on the worst of the two High Enrichment Condition (HEC) scores.
7. Current Sedimentation Rate (CSR) to Natural Sedimentation Rate (NSR) ratio derived from catchment models (Hicks et al. 2019).
8. Condition rating adapted from Townsend and Lohrer (2015). Sedimentation rate derived from catchment models (Hicks et al. 2019).

b. Sediment quality and macrofauna

Indicator	Unit	Very good	Good	Fair	Poor
Sediment quality and macrofauna					
Mud content[1]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[2]	mm	≥ 50	20 to < 50	10 to < 20	< 10
TN[1]	mg/kg	< 250	250 to < 1000	1000 to < 2000	≥ 2000
TP			Requires development		
TOC[1]	%	< 0.5	0.5 to < 1	1 to < 2	≥ 2
TS			Requires development		
Macrofauna AMBI[1]	na	0 to 1.2	> 1.2 to 3.3	> 3.3 to 4.3	≥ 4.3
Sediment trace contaminants[3]					
As	mg/kg	< 10	10 to < 20	20 to < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 to <1.5	1.5 to < 10	≥ 10
Cr	mg/kg	< 40	40 to <80	80 to < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 to <65	65 to < 270	≥ 270
Hg	mg/kg	< 0.075	0.075 to <0.15	0.15 to < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 to <21	21 to < 52	≥ 52
Pb	mg/kg	< 25	25 to <50	50 to < 220	≥ 220
Zn	mg/kg	< 100	100 to <200	200 to < 410	≥ 410

1. Ratings from Robertson et al. (2016).
2. aRPD based on FGDC (2012).
3. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good <0.5 x DGV; Good 0.5 x DGV to <DGV; Fair DGV to <GV-high; Poor >GV-high. DGV = Default Guideline Value, GV-high = Guideline Value-high.

c. Water quality

Indicator	Unit	Very good	Good	Fair	Poor
Dissolved oxygen (DO)[1]	g/m^3	≥5.5	≥5.0 to <5.5	≥4.0 to <5.0	<4.0
Phytoplankton (chl-*a*)[2]	mg/m^3	<5	≥5 to <10	≥10 to <16	≥16

1. One-day minimum criterion in Robertson et al. (2016).
2. 90th percentile concentration in Robertson et al. (2016).

4. BROAD SCALE MAPPING

A summary of the December 2022 mapping survey in Waipati River Estuary is provided below. Supporting GIS files have been separately supplied to ORC, with ground-truthing tracks shown in Appendix 2.

4.1 TERRESTRIAL MARGIN

Table 4 and Fig. 5 summarise the land cover of the 200m terrestrial margin, which is primarily (~90%) native forest and mānuka/kānuka scrub. The dune areas near the entrance represent almost 4% of the margin area, and are dominated by exotic marram grass, tree lupin and flax. Deer tracks and browsing damage were conspicuous in most areas of the margin that were checked, with pig rooting in some places. A total of 92% of the margin was categorised as densely vegetated, which corresponds to a condition rating of 'very good'.

Table 4. Summary of 200m terrestrial margin land cover.

LCDB Class		Ha	%
1	Built-up Area (settlement)	0.05	0.03
10	Sand or Gravel	4.3	2.2
16	Gravel and Rock	1.1	0.6
20	Lake or Pond	0.01	0.003
21	River	0.6	0.3
41	Low Producing Grassland	1.8	0.9
410[1]	Duneland	7.4	3.8
45	Herbaceous Freshwater Vegetation	0.8	0.4
51	Gorse and/or Broom	2.8	1.4
52	Manuka and/or Kanuka	12.0	6.1
54	Broadleaved Indigenous Hardwoods	6.9	3.5
58	Matagouri or Grey Scrub	2.0	1.0
69	Indigenous Forest	154.7	79.5
71	Exotic Forest	0.03	0.01
Grand Total		194.6	100
Total dense vegetated margin[2]		186.6	92.1

1. Duneland is an additional category to the LCDB classes to help differentiate between "Low Producing Grassland" and "Duneland".
2. LCDB classes 45-71.

Sand dune at true left of estuary entrance dominated by tree lupin, flax and marram grass.

Conspicuous forest trees bordering the estuary edge included rimu, rata and kamahi.

Areas heavily tracked by deer were evident around the estuary margin.

The terrestial margin was dominated by native forest.

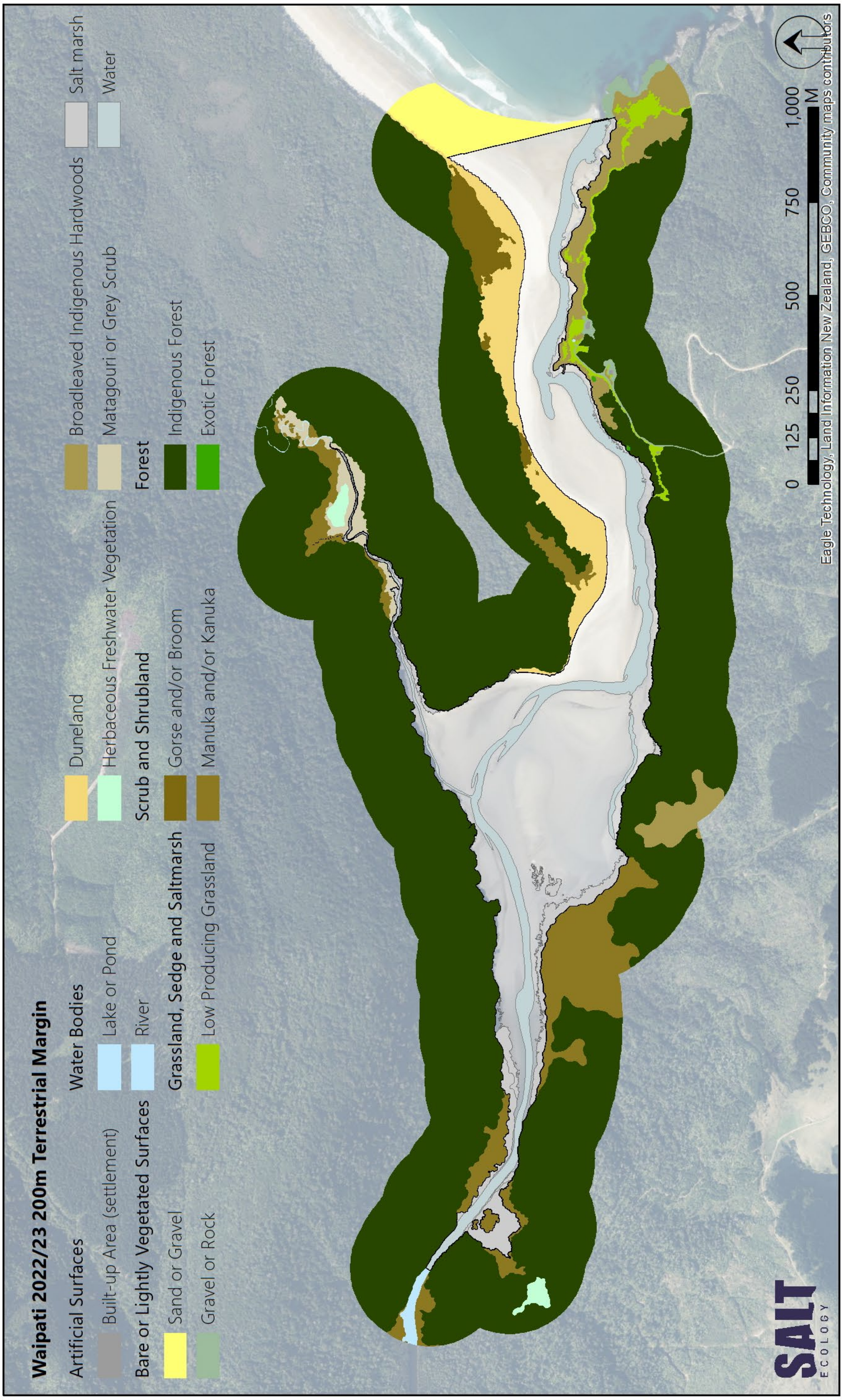


Fig. 5. Map of 200m terrestrial margin land cover.

4.2 SALT MARSH

The total mapped intertidal area of 56.3ha had 5ha of salt marsh (Table 4). The majority was located in the western arm of the estuary (Fig. 6), and consisted mainly (96.6%) of rushland, which consisted almost exclusively of jointed wirerush (*Apodasmia similis*) and a small amount of knobby clubrush (*Ficinia nodosa*). There were smaller areas of tussockland, sedgeland, and herbfield, with the main species noted in Table 5 and Appendix 3.

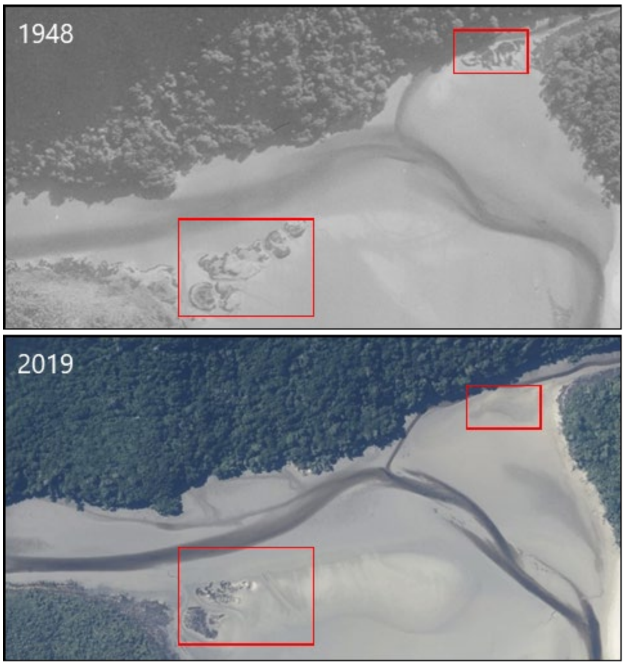
Table 5. Summary of salt marsh area (ha and %).

Subclass	Dominant species	Ha	%
Tussockland	*Carex litorosa* (Sea sedge)	0.01	0.2
Sedgeland	*Isolepis cernua* (Slender clubrush)	0.01	0.2
Rushland	*Apodasmia similis* (Jointed wirerush)	4.8	96.5
	Ficinia nodosa (Knobby clubrush)	0.003	0.1
Herbfield	*Leptinella dioica* (Shore cotula)	0.1	2.9
	Samolus repens (Primrose)	0.004	0.1
Total		**5.0**	**100**

Most (~97%) of the substrate in salt marsh had an elevated mud component (>25% mud), with 65% being muddy sand (25-50% mud) and 32% being sandy mud (50-90% mud). Substrate details for salt marsh and other vegetated habitats are provided in Appendix 4.

With increasing distance up-channel in the west and northeast arms, the salt marsh gradually transitioned to freshwater-dominated wetland habitat, which reflects a relatively pristine situation compared to most other estuaries in the region.

Based on imagery dating back to 1948, there appear to be changes on the seaward edge of salt marsh bordering the margins, and loss of isolated rushland patches near the river mouths, likely owing to erosion. The areal extent of salt marsh in 1948 was estimated to be 6.5ha, corresponding to a loss of ~25% since 1948 and a condition rating of 'good' (i.e., ~75% salt marsh remains). A cursory evaluation of historic imagery suggests that salt marsh islands on the mid-estuary flats have reduced significantly and the isolated patch near the Hukihuki Creek inflow was almost completely gone by the early 2000's. Further losses, due to erosion, have occurred at the mouth of the Waipati River on the true left bank.



Salt marsh islands in the mid-estuary and near Hukihuki Creek mouth in 1948 (top) and 2019 (bottom).

Uninterrupted transition from rushland to kānuka/mānuka (top) and transition into freshwater wetland in upper northeast arm (bottom).

Erosion of rushes on the true left bank in the western arm, Site 1.

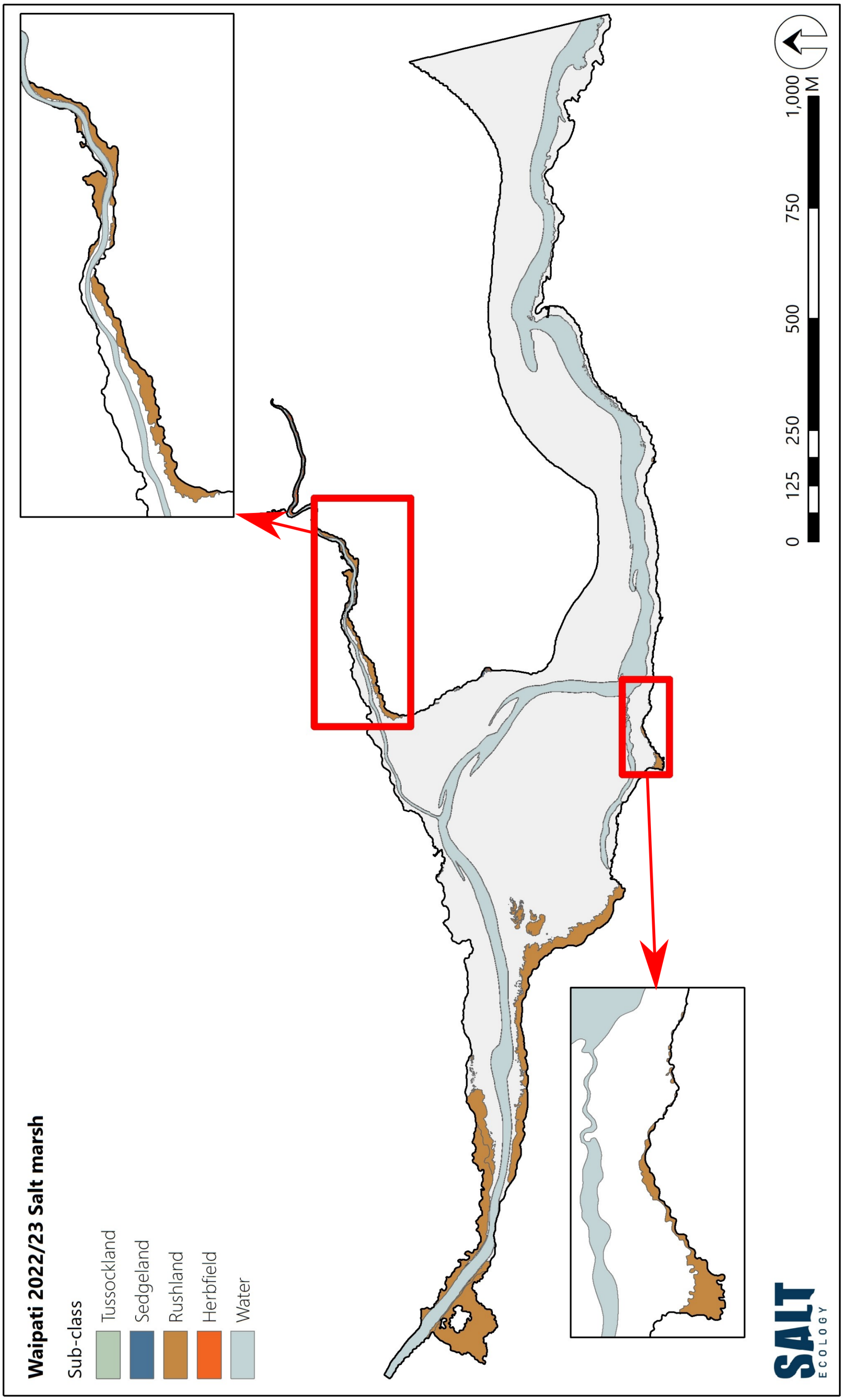


Fig. 6. Salt marsh sub-classes and their distribution.

4.3 SUBSTRATE

The mapped intertidal area outside the 5ha of saltmarsh was 51.2ha, and had substrates dominated by sandy sediments (Table 6, Fig. 7). There was generally a good agreement between the subjective sediment classifications applied during mapping and the sediment grain size validation measures (Appendix 5).

Table 6. Summary of dominant intertidal substrate outside areas of salt marsh.

Substrate Class	Features	Ha	%
Bedrock	Rock field	0.9	1.8
Unconsolidated coarse sediment (>2mm)	Boulder field	0.0	0.0
	Cobble field	0.2	0.3
	Gravel field	0.4	0.8
Sand (0-10% mud)	Mobile sand	11.6	22.7
	Soft sand	1.1	2.2
	Firm sand	15.5	30.3
Muddy Sand (>10-25% mud)	Soft muddy sand	13.4	26.1
	Firm muddy sand	2.5	4.9
Muddy Sand (>25-50% mud)	Soft muddy sand	3.8	7.4
	Firm muddy sand	1.0	1.9
Sandy Mud (>50-90% mud)	Firm sandy mud	0.0	0.0
	Soft sandy mud	0.1	0.2
	Very soft sandy mud	0.7	1.3
Zootic	Shell bank	0.01	0.01
Grand Total		**51.2**	**100**

Around 55% of the intertidal estuary area consisted of sand (<10% mud content), comprising rippled mobile sand towards the estuary entrance. As a general trend, the sediments became muddier with distance up-channel. The central estuary flats consisted mainly of muddy sand, ranging firm to soft-textured and having <25% mud content.

Mud-elevated sediments (>25% mud) were most prevalent along the channel margins of the west and northeast arms of the estuary (Fig. 7). They covered a total area of 5.6ha, representing 10.8% of estuary intertidal area (outside of salt marsh) and corresponded to a condition rating of 'fair'. The area of mud-dominated sediment (>50% mud) was relatively small (0.8ha), comprising only 1.5% of the intertidal area.

Hard substrates were limited in extent (<1ha) and were mainly represented by a bedrock margin on the south side of the estuary channel at the entrance. Cobble was mixed into soft sediment in some mid-estuary areas, mainly sourced from bank erosion.

Rippled mobile sand in lower estuary (top), and firm muddy sand on mid-estuary southern flats at Site 3 (bottom).

Lower estuary sand flats on north side of the channel, with rocky margin visible to the left of photo on south side.

Sandy northern flats at Site 4, many crab burrows visible on the sediment surface.

Soft, muddy sand sediments of the upper estuary near Site 9.

Soft muddy sand sediments of the upper estuary near Site 10.

Very soft mud-dominated sediments in deposition areas, near the area of rushland erosion, upper west arm channel.

Bank erosion on north side of estuary west arm.

Bedrock on the true right bank in the lower estuary.

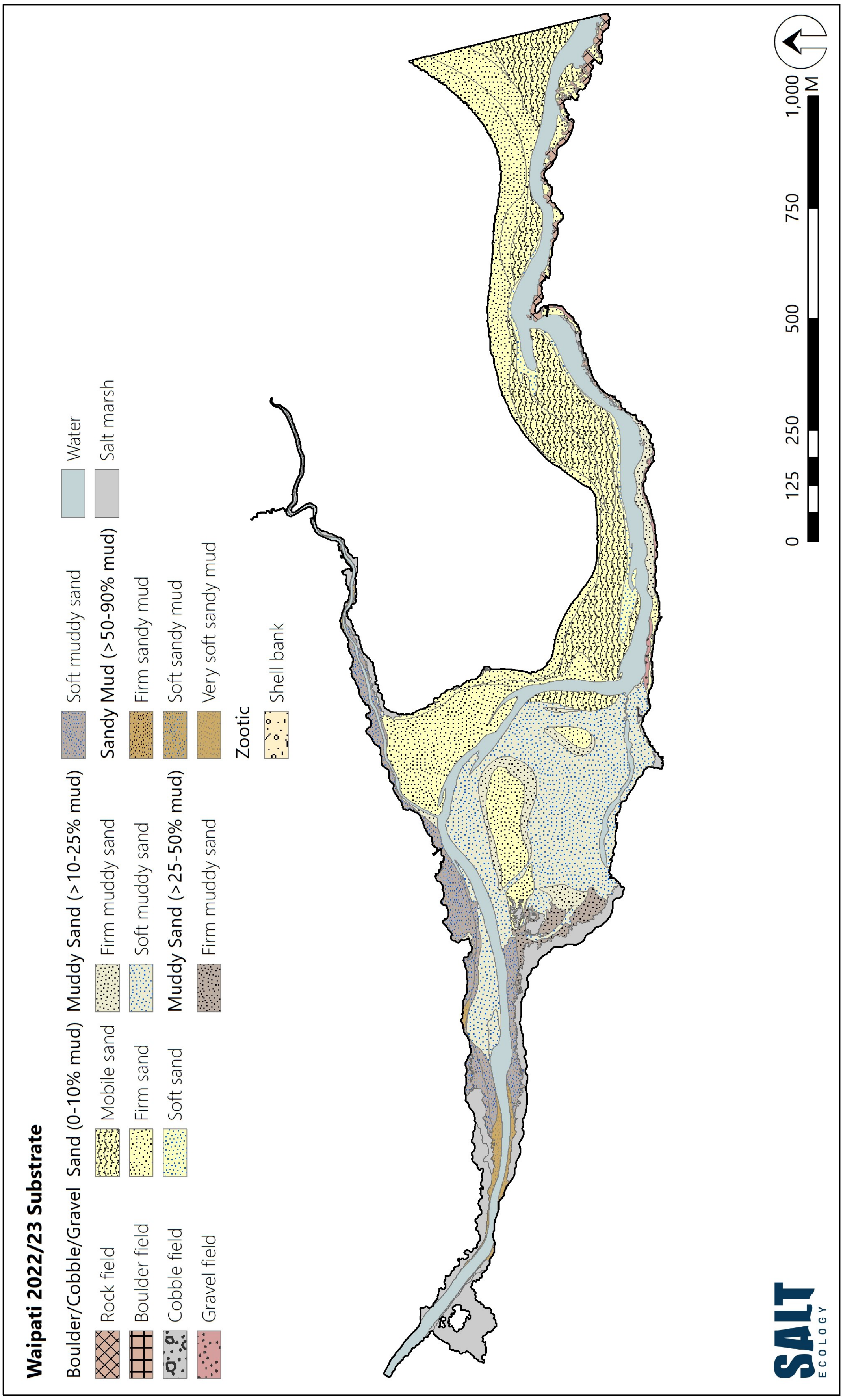


Fig. 7. Dominant intertidal substrate outside of salt marsh.

4.4 SEAGRASS

No seagrass was recorded in the estuary. For reasons discussed in Section 7.1, it is probably naturally absent.

4.5 OPPORTUNISTIC MACROALGAE

Macroalgae species and biomass information is included in Appendix 6, with key information summarised in Table 7 and Fig. 8. Opportunistic macroalgae was very sparse in the available habitat (i.e., intertidal flats outside of salt marsh), and was mapped as absent or trace (<1% cover) across 99.9% of the area (Table 7).

Table 7. Summary of intertidal macroalgal cover (A) and biomass (B), in areas outside salt marsh.

A. Percent Cover

Percent cover category	Ha	%
Absent or trace (<1%)	51.2	99.9
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	0.0	0.0
Low-Moderate (30 to <50%)	0.001	0.002
High-Moderate (50 to <70%)	0.0	0.0
Dense (70 to <90%)	0.01	0.02
Complete (≥90%)	0.05	0.1
Total	51.3	100

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	51.2	99.9
Very low (1 - 100)	0.0	0.0
Low (101 - 200)	0.0	0.0
Moderate (201 - 500)	0.0	0.0
High (501 - 1450)	0.01	0.02
Very high (>1450)	0.05	0.1
Total	51.3	100

The areas of macroalgae that were recorded are barely visible on Fig. 8, and included a small patch of the red seaweed *Agarophyton* spp. on the edge of salt marsh in the western arm, and two patches of the green seaweed *Ulva* spp. in the central estuary, with the most pronounced mid-intertidal patch also including ~5% *Agarophyton* spp. Maximum biomass in this patch was very high (8.8kg/m^2; Appendix 6). None of the macroalgal growth was entrained in soft sediment areas, but instead was attached to hard substrates such as cockles, shell and gravel.

Macroalgae was more conspicuous subtidally within the low tide channels. In these areas, patches of gravel or cockles enabled the attachment and growth of long filamentous strands of both *Ulva* and *Agarophyton* spp. Note that *Ulva* spp. was also present on the rocky habitat at the estuary mouth, but this is a typical feature of such habitats and is not related to a eutrophic response.

Due to the very low overall prevalence of macroalgae (<0.1 % of the available intertidal habitat outside salt marsh) the OMBT EQR score was 0.996, which equates to a condition rating of 'very good'.

Localised patch of *Agarophyton* spp. bordering salt marsh (top), main patch of mid-intertidal *Ulva* spp. (middle), and *Agarophyton* spp. attached to cockles (bottom).

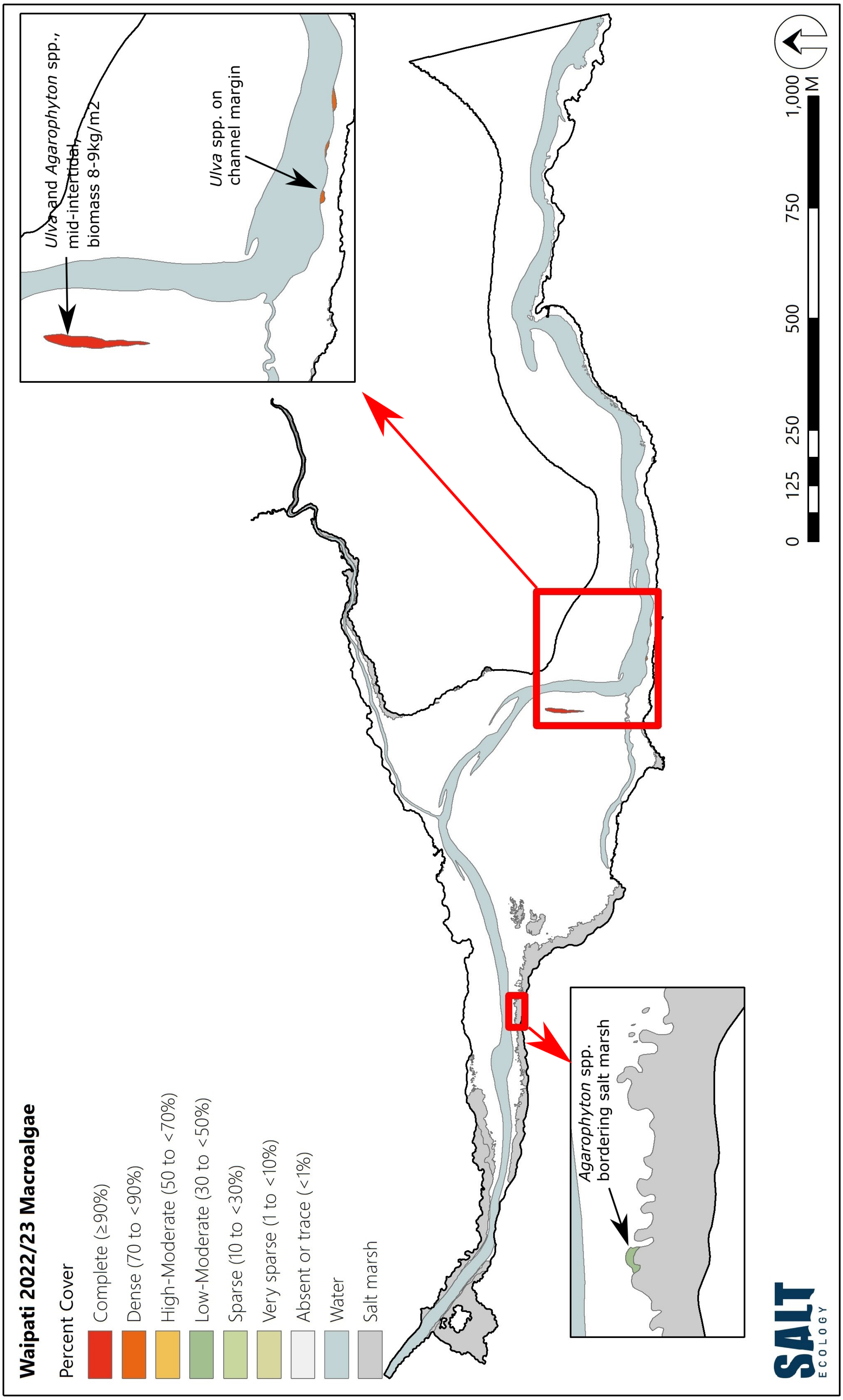


Fig. 8. Distribution and percent cover classes of macroalgae. Annotations indicate macroalgal species, and biomass in the most significant mid-estuary patch.

5. SEDIMENT QUALITY AND BIOTA

Illustrative photos of sediment quality and macrofauna sampling Sites 1-6 are provided on the next page, including examples of sediment core profiles. Photos of the four additional sites (Sites 7-10) from which sediment validation (i.e., grainsize only) samples were collected are presented in Appendix 5.

5.1 SEDIMENT QUALITY INDICATORS

Sampling confirmed the general broad scale mapping pattern of decreasing mud and increasing sand between Site 1 at the head of the upper west arm and Site 6 near the estuary entrance (Fig. 9). The sediment quality results generally show that the poorest sediment conditions were in the muddiest sediments at Site 1, but condition was relatively good elsewhere.

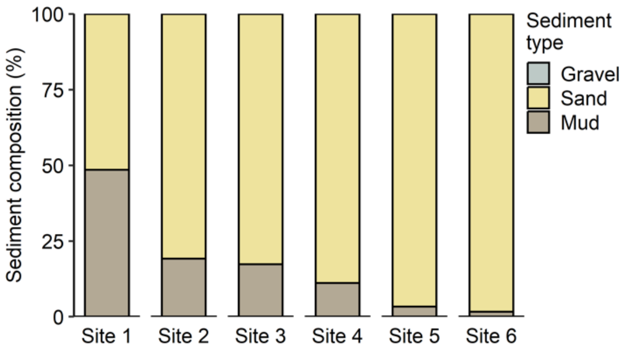


Fig. 9. Sediment grain size in composite samples. Size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

Sediment quality indicators are compared to condition rating thresholds in Fig. 10, with key points as follows:

- The high mud content (almost 50%) of upper estuary Site 1 was rated 'poor', as it exceeded the 25% threshold generally regarded as being biologically significant. The sandiest downstream sites were rated as 'very good'.
- The muddy sediment at Site 1 had elevated total organic carbon (TOC) and total nitrogen (TN). TOC generally decreased from the upper to lower estuary. TN likely mirrors this pattern, although values at Sites 2-6 were all less than method detection limits (which varied between sites) so values in Fig. 10 do not reflect a true trend.
- Sediment oxygenation was poorest (shallowest aRPD) in the muddier sites, as mud particles restrict the diffusion of oxygen into the sediment matrix. By contrast, at sandy sites the porous nature of the particles means the sediment is well-flushed and oxygenated. The aRPD was deeper than 20mm (rated 'good' or 'very good') at all sites, which was consistent with observations made during broad scale mapping.
- Two other trophic state indicators were measured (total phosphorus, TP; total sulfur, TS), but have no condition ratings. These parameters similarly showed a general trend of a decrease in values from the upper to lower estuary.
- Overall, despite the elevated values of trophic state indicators in the small area of muddy sediment around Site 1, there appear to be no symptoms of highly degraded sediments in the estuary associated with strong enrichment (e.g., intense black sediment profile, emission of a strong sulfide odour).

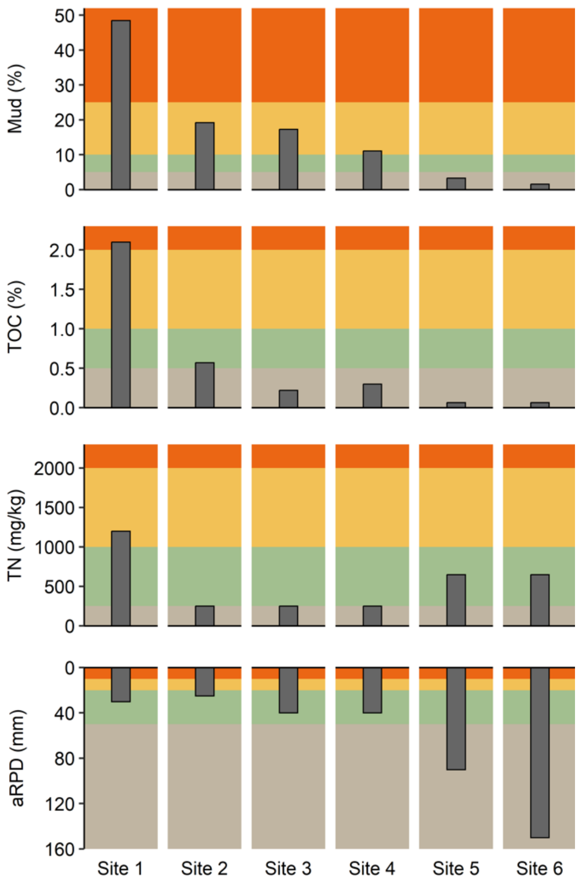


Fig. 10. Grey bars show sediment %mud, total organic carbon (TOC), and total nitrogen (TN) in composite samples, relative to condition ratings. TN at Sites 2-6 was less than method detection limits (MDL), hence half of the MDL value is shown.

Condition rating key:

Very Good	Good	Fair	Poor

Site 1

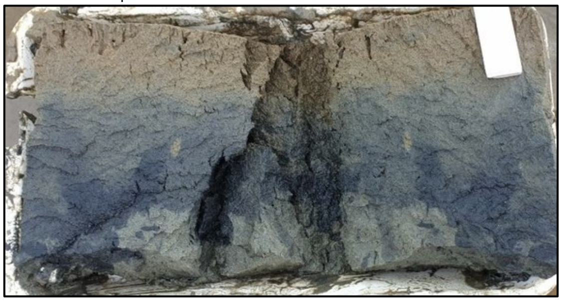
Site 1 – core photo

Site 2

Site 2 – core photo

Site 3

Site 3 – core photo



Site 4

Site 4 – core photo

Site 5

Site 5 – core photo

Site 6

Site 6 – core photo

Trace element concentrations were very low in all samples relative to ANZG (2018) Default Guideline Values and rated 'very good' (Table 8). These results are consistent with the relatively natural state of the catchment and the absence of significant sources of chemical contaminants.

Table 8. Trace element concentrations relative to ANZG (2018) Default Guideline Values (DGV). Shading corresponds to a 'very good' condition rating, which represents less than half of the DGV.

Site	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
1	3.8	0.038	10.1	7.1	0.03	6.8	4.5	44.0
2	4.2	0.018	7.9	4.0	<0.02	5.1	3.2	29.0
3	6.1	<0.01	6.9	2.8	<0.02	4.1	2.0	19.2
4	5.5	0.013	6.2	2.6	<0.02	3.6	1.9	15.6
5	7.2	0.012	5.7	1.9	<0.02	3.1	1.4	9.6
6	7.8	<0.01	5.5	1.5	<0.02	2.7	1.4	8.2
DGV	20	1.5	80	65	0.15	21	50	200

< Values below lab detection limit. The DGV indicates the concentrations below which there is a low risk of unacceptable effects.

5.2 BIOTA

No macroalgae or visible surface microalgae were noted at the sampling sites, and surface-dwelling epifauna were sparse. Mud snails (*Amphibola crenata*) were conspicuous at upper estuary Sites 1-4 (~1-10/m^2), with mud whelks (*Cominella glandiformis*) present but sparse at Site 5 (<1/m^2). No epibiota were noted on the mobile sands at Site 6.

By contrast, all sites had a suite of sediment-dwelling macrofauna in the core samples. A total of 19 species or higher taxa were recorded, representing eight main organism groups (Appendix 7). Fig. 11 shows the average species richness per site was reasonably low, but organism abundances were high in all locations except Site 6. From a summary of the most dominant species in Table 9, it can be seen that high abundances at Sites 1-5 were mainly due to the dominance of the tube-building amphipod *Paracorophium excavatum*. This is a hardy species often found in river-dominated estuaries with low salinity water or subject to regular disturbance (e.g., mobile substrate).

Small cockles (*Austrovenus stutchburyi*) up to 30mm shell width were present at Sites 2 and 5, with a few juvenile pipi (*Paphies australis*) of <5mm shell width at Sites 4-6 (Appendix 7). As well as pipi, the macrofauna community in the sandy sediment at Site 6 had a small number of other species in low densities that which were absent from the mid-upper estuary sites. Of these, the small cumacean *Colurostylis lemurum* was the most abundant.

Overall, from the descriptions of the dominant species in Table 9, it is evident that many are either disturbance-tolerant or tolerant of low salinity conditions. As a result, most are in eco-groups III-V, representing a relatively hardy suite of organisms, and resulting in AMBI scores (Fig. 12) suggesting 'fair' to 'poor' ecological conditions.

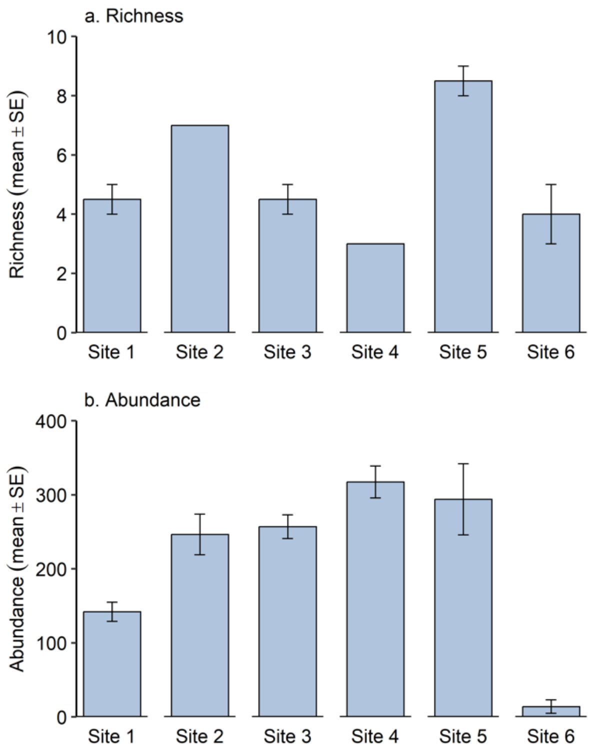


Fig. 11. Mean (± SE) taxon richness and abundance in duplicate core samples.

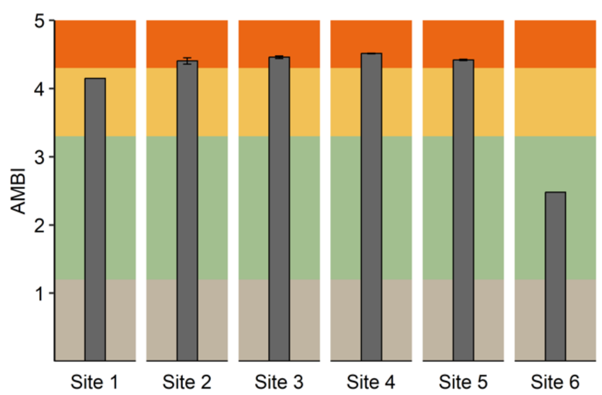


Fig. 12. Mean (± SE) macrofauna AMBI scores in duplicate cores, relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

Table 9. Dominant macrofauna at the six sites. Numbers are total abundances summed across duplicate cores. Examples of key species shown in images at bottom, courtesy of NIWA (pink colour due to a vital stain).

Main group	Taxa	EG	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Description
Amphipoda	*Paracorophium excavatum*	IV	159	452	490	610	466	8	Corophioid amphipod that is an opportunistic tube-dweller, and tolerant of muddy and low salinity conditions.
Anthozoa	*Edwardsia* sp.	II	-	-	-	-	10	-	A small elongate anemone adapted for burrowing. Fairly common throughout New Zealand in sandy sediments with low-moderate mud.
Bivalvia	*Arthritica* sp. 5	III	48	16	-	-	-	-	A small deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.
Bivalvia	*Legrandina turneri*	na	-	-	-	-	92	2	Small endemic bivalve that appears to be limited to southern NZ. Ecology unknown.
Bivalvia	*Paphies australis*	II	-	-	-	-	6	1	The endemic NZ pipi. Tolerant of moderate wave action, and commonly inhabits coarse sand in bays and at the mouths of estuaries.
Cumacea	*Colurostylis lemurum*	II	-	-	-	-	-	14	Small crustacean considered sensitive to enrichment. Some species can survive in brackish water.
Nemertea	Nemertea	III	-	-	-	-	-	1	Ribbon or proboscis worms, mostly solitary, predatory, free-living animals. Can tolerate moderate enrichment.
Polychaeta	*Nicon aestuariensis*	III	17	8	-	-	-	-	Omnivorous worm that is tolerant of freshwater.
Polychaeta	*Scolecolepides benhami*	IV	59	10	14	20	5	-	Spionid, surface deposit feeder. It is rarely absent in sandy/mud estuaries.

Paracorophium excavatum

Legrandina turneri

Scolecolepides benhami

A multivariate analysis of macrofauna community composition is summarised in Fig. 13. The top panel illustrates the magnitude of difference between sites in terms of their macrofauna composition. All sites had their distinct biota, but Site 6 was the most different, reflecting not only the presence of species that were not recorded at other sites, but also the absence of certain species that were common at some or all of the other sites; e.g., the polychaete worm *Scolecolepides benhami*.

Both panels in Fig. 13 illustrate the sediment quality attributes that were most closely correlated with the changes in macrofauna community composition, with the vector plot in the bottom panel highlighting their relative importance. From the upper to lower estuary, the most important attributes were a decrease in sediment mud content, an increase in aRPD depth (i.e., indicating increased sediment oxygenation), and an increase in total phosphorus (TP).

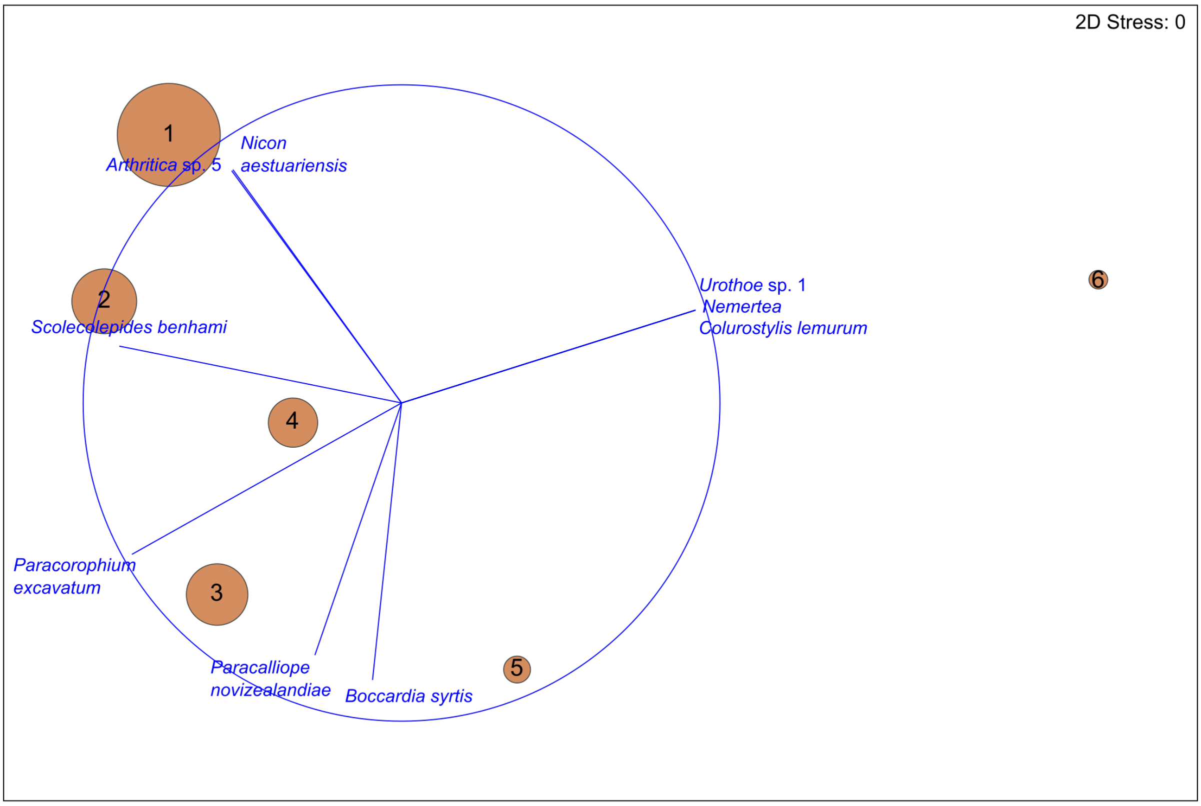
Note that TP may not itself be important, but is a proxy for total nitrogen (TN) with which it is typically highly correlated. Nitrogen rather than phosphorus is regarded as the nutrient that is most important for algal growth in estuaries. In this instance TN was not well-quantified, due to a laboratory issue with the method detection limit noted above. Other unmeasured factors are also likely to be important determinants of macrofauna composition differences, such as substrate stability and effects of wave action in the lower estuary, and the effects of pulses of low-salinity water during flood events, especially in the upper estuary.

Mud snails on the surface of the sediment near Site 4.

Sampling biota on the intertidal flats.

Soft muddy sands in the western arm on the true left bank between patches of eroding rushland.

a. Species overlay + %mud



b. Sediment quality overlay + aRPD

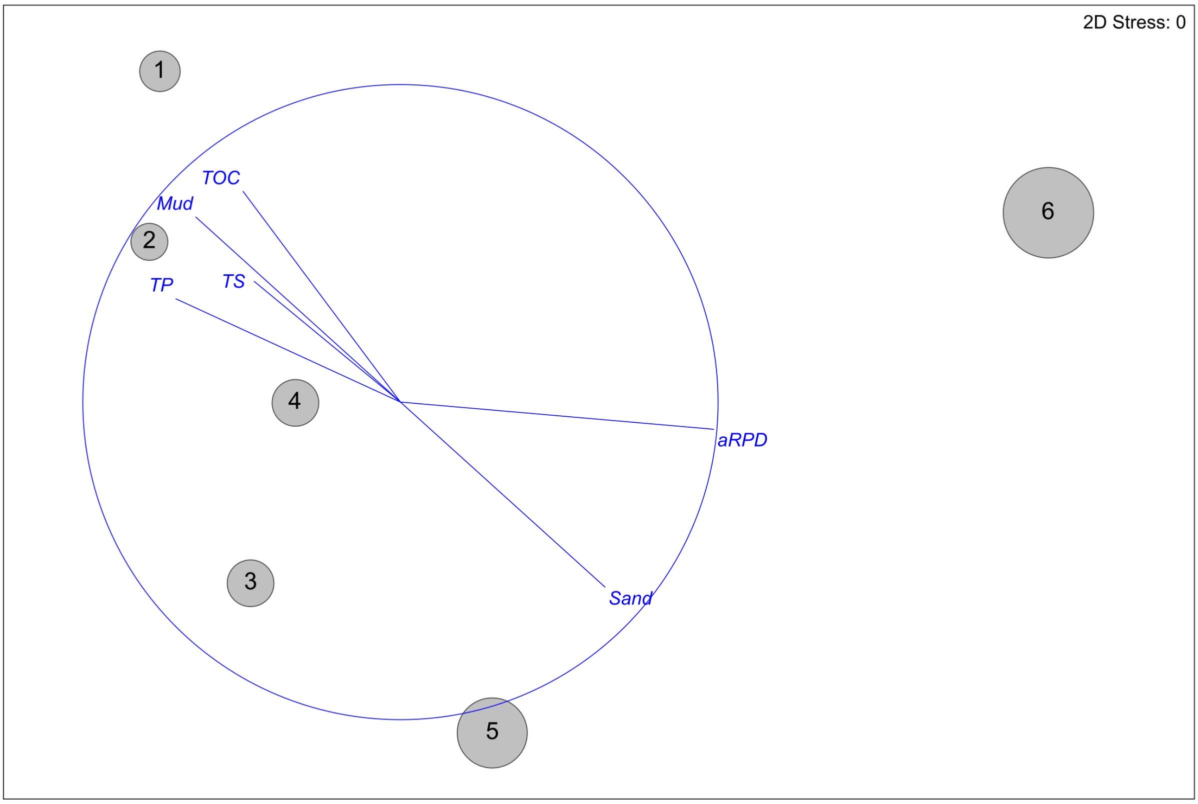


Fig. 13. Non-metric MDS ordination of macrofaunal core samples for each site.

Site groups are placed such that those closer to each other are more similar than distant groups in terms of macrofauna composition. A 'stress' value of zero indicates that a 2-dimensional plot provides a highly accurate representation of site differences. Vector overlays indicate the direction and strength of association (length of line relative to circle) of grouping patterns in terms of the most correlated macrofauna species (top) and sediment quality variables (bottom). Bubble sizes are scaled to sediment mud content (top) and aRPD (bottom), which were among the variables that were correlated with macrofauna composition differences.

6. WATER QUALITY

Synoptic water quality results in Table 10 show that:

- Dissolved oxygen was generally high, and well above the 5.5g/m^3 'very good' condition rating for protection of aquatic ecosystems (Table 3).
- Salinities ranged from ~10-22ppt at the time of sampling (outgoing low tide), which are ~29-63% of coastal salinity (~35ppt). Salinity would be higher during higher states of the tide when incoming seawater flooded the tidal flats; however, as noted in Section 3.4 it was not feasible to assess the estuary under these conditions.
- There was no water column stratification at the time of sampling (i.e., no abrupt change in parameter values with depth), but there was a gradual increase from lower salinity surface water to higher salinity bottom water, reflecting that these parts of the channel are partially mixed yet denser seawater remains on the bottom. The difference was most pronounced at upper estuary Site WQ7.
- Chlorophyll-*a* values, which are an indicator of phytoplankton abundance, were ≤4mg/m^3. Concentrations of ≤5mg/m^3 correspond to a condition rating of 'very good'.

Although only synoptic, the survey provided no indication of water quality degradation at the time of sampling. The vulnerability of the estuary to developed of degraded water quality (e.g. during summer low flows) is discussed in Section 7.

Hukihuki Creek, tannin-rich brackish (6.8ppt) water column.

Waipati Creek, tannin-rich water column brackish (11.9ppt) on the surface and saline in the bottom waters (>20ppt).

Table 10. Water quality parameters measured on the day of sampling on a low outgoing tide. Sites are distributed from the lower (WQ1) to upper (WQ7) estuary (see Fig. 3). DO = dissolved oxygen, Chl-*a* = chlorophyll-*a*.

Station	Depth (m)	Temperature (ºC)	DO (%)	DO (g/m^3)	Salinity (ppt)	pH	Chl-*a* (mg/m^3)
WQ1	0.2	13.8	91.5	8.40	19.7	8.33	2.4
	1	13.8	93.7	8.45	22.1	8.41	2.3
WQ2	0.2	13.4	89.3	8.39	16.9	8.27	2.6
	0.5	13.4	89.1	8.26	18.4	8.30	4.0
WQ3	0.2	11.5	84.3	8.76	6.8	7.65	3.8
	-	-	-	-	-	-	-
WQ4	0.2	13.3	87.6	8.25	16.6	8.22	2.8
	0.4	13.4	86.9	8.16	17.4	8.22	2.4
WQ5	0.2	12.9	88.6	8.62	12.1	8.14	2.1
	-	-	-	-	-	-	-
WQ6	0.2	13.1	87.4	8.36	9.7	7.99	2.5
	-	-	-	-	-	-	-
WQ7	0.2	12.8	82.9	8.12	11.9	8.06	2.7
	0.3	13.3	80.3	7.51	20.2	8.14	3.4

Dash (-) indicates no change from surface water measurement.

7. SYNTHESIS OF KEY FINDINGS

7.1 OVERVIEW

The 1 December 2022 survey showed that Waipati River Estuary is in a healthy state overall. It is one of few remaining estuaries in the Otago region in which there is a relatively natural transition from estuary salt marsh to freshwater wetland habitat in its upper reaches, with a relatively unmodified estuary margin and wider catchment dominated by indigenous forest.

A summary of key broad scale features is provided in Table 11, with condition ratings for broad scale, fine scale and water quality indicators summarised in Tables 12, 13 and 14, respectively. Supporting data used to assess and interpret estuary condition were derived from catchment-scale nutrient and sedimentation models (CLUES; Hicks et al. 2019) and are provided in Table 15.

Table 11. Summary of key broad scale features as a percentage of total estuary, intertidal or margin area, Waipati River Estuary, December 2022.

Component	Area (ha)	Percentage
a. Area summary		% Estuary
Intertidal area	56.3	82.8
Subtidal area	11.7	17.2
Total estuary area	68.0	100.0
b. Key substrate features		% Intertidal
Mud-enriched (25 to <50%)	4.8	9.3
Mud-dominated (≥50%)	0.8	1.5
c. Key habitat features		% Intertidal
Salt marsh	5.0	8.9
Seagrass (≥50% cover)	0.0	0.0
Macroalgal beds (≥50% cover)	0.06	0.1
d. Terrestrial margin (200m)		% Margin
200m densely vegetated margin		92.1

Note: Summary statistics for substrate, seagrass and macroalgae are for the 51.2ha of intertidal area that excludes salt marsh.

Rushland island in the mid-estuary.

The rating tables show that most indicators meet the classification of 'good' or 'very good', with the most notable exceptions being predicted sedimentation rate, macrofauna AMBI and, to a lesser degree, the extent of mud-elevated sediment.

The features that contribute to favourable rating values include the following:

- A relatively intact and unmodified terrestrial margin, with ~75% of the wider catchment (7,269ha) being mainly intact indigenous forest (~66%) with smaller areas of scrub.
- Salt marsh (5ha or 8.9% of the intertidal area) that transitions to freshwater wetland. Historic imagery (earliest from 1948) shows there has been a decline of ~25% in salt marsh extent near the river mouths and in the mid-estuary, likely due to erosion.
- Clean, sand-dominated sediment in most areas outside the western and northeast estuary side arms.
- Almost no growth of the opportunistic macroalgal species that can be prolific under eutrophic conditions.
- An absence of HEC areas displaying symptoms of an enriched and eutrophic sediment state.
- Very low trace metal contaminant concentrations, consistent with the low level of catchment development and absence of significant contaminant sources.
- Good water quality at the time of sampling, based on the small suite of field indicators measured, including high dissolved oxygen and low chlorophyll-*a*.

Note that due to the absence of seagrass, this indicator was not rated. A cursory assessment of features visible in historic aerial photographs (earliest 1948) suggests that the estuary has never supported any significant areas of seagrass. Although the absence of seagrass is in contrast to several other Otago estuaries (Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea), it is consistent with nearby Tautuku and Tahakopa Estuaries, whose catchments are even less modified than Waipati.

These findings likely reflect factors that limit seagrass growth, including light limitation from tannin-rich catchment waters (which could inhibit photosynthesis); a strong freshwater influence (low salinity water) in the likely locations where seagrass would grow in the mid-estuary; and high substrate mobility in the lower estuary, which would prevent the establishment of beds.

The sediment-dwelling macrofaunal community was relatively species-poor and largely characterised by taxa that are resilient to most forms of disturbance. Accordingly, at four of the six sampling sites macrofauna AMBI scores had a 'poor' condition rating (Table 13). A similar finding has been described from our other recent surveys in southern Catlins' estuaries, namely Tautuku (e.g., Forrest et al. 2022a) and Tahakopa Estuary (report in prep.)

The macrofauna characteristics of estuaries in the southern Catlins have similarities with river-dominated systems elsewhere in the region, such as the Tokomairiro and Shag River estuaries (e.g. Forrest et al. 2020). Given that the Catlins estuaries have catchments that are the least modified of the Otago estuaries in the SOE programme, it is clear that their faunal state reflects the natural condition for these systems.

Table 12. Summary of broad scale indicator condition ratings.

Broadscale Indicators	Unit	Value	Rating
Mapped indicators			
200m terrestrial margin	% densely vegetated	92.1	Very Good
Mud-elevated substrate	% intertidal area >25% mud[1]	10.8	Fair
Macroalgae (OMBT[2])	Ecological Quality Rating (EQR)	0.996	Very Good
Seagrass	% decrease from baseline	no seagrass present	na
Salt marsh extent (current)	% of intertidal area	8.9	Fair
Historical salt marsh extent[3]	% of historical remaining	~75%	Good
High Enrichment Conditions	ha	0	Very Good
High Enrichment Conditions	% of estuary	0	Very Good
Estuary-wide sedimentation indicators			
Mean sedimentation ratio[4]	CSR:NSR ratio	1.1	Very Good
Sedimentation rate[4]	mm/yr	3.8	Poor

[1]Excludes salt marsh area; [2]OMBT = Opportunistic Macroalgal Blooming Tool; [3]Estimated from historic aerial imagery, [4]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling). na = not applicable.

Table 13. Summary of fine scale indicator condition ratings for sediment quality and macrofauna AMBI.

Parameter	Unit	1	2	3	4	5	6
Mud	%	48.5	19.2	17.3	11.1	3.3	1.6
aRPD	mm	30	25	40	40	90	>150
TN	mg/kg	1200	< 500	< 500	< 500	< 1300	< 1300
TP	mg/kg	370	250	300	260	230	198
TOC	%	2.10	0.57	0.22	0.30	< 0.13	< 0.13
TS	%	0.15	0.65	0.03	0.03	0.02	0.01
As	mg/kg	3.8	4.2	6.1	5.5	7.2	7.8
Cd	mg/kg	0.038	0.018	< 0.010	0.013	0.012	< 0.010
Cr	mg/kg	10.1	7.9	6.9	6.2	5.7	5.5
Cu	mg/kg	7.1	4.0	2.8	2.6	1.9	1.5
Hg	mg/kg	0.03	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ni	mg/kg	6.8	5.1	4.1	3.6	3.1	2.7
Pb	mg/kg	4.5	3.2	2.0	1.9	1.4	1.4
Zn	mg/kg	44.0	29.0	19.2	15.6	9.6	8.2
AMBI	na	4.2	4.4	4.5	4.5	4.4	2.5

See Glossary for abbreviations.< Values below lab detection limit. Colour bandings are based on thresholds provided in Table 3.

Table 14. Summary of water quality indicator condition ratings. Values are shown that correspond to the 'worst-case' for each site.

Parameter	Unit	WQ1 (d/s)	WQ2	WQ3	WQ4	WQ5	WQ6	WQ7 (u/s)
DO	g/m^3	8.4	8.3	8.8	8.2	8.6	8.4	7.5
Chl-*a*	mg/m^3	2.4	4.0	3.8	2.8	2.1	2.5	3.4

One-off measurements do not meet the statistical requirement of the indicator condition ratings and should be treated with caution. d/s = downstream, u/s = upstream

Table 15. Supporting data used to assess estuary ecological condition in Waipati River Estuary.

Supporting Condition Measure	Waipati Estuary
Mean freshwater flow (m^3/s)[1]	1.6
Catchment Area (Ha)[1]	7269.2
Catchment nitrogen load (tonnes TN/yr)[2]	26.8
Catchment phosphorus load (tonnes TP/yr)[2]	3.9
Catchment sediment load (KT/yr)[1]	4.7
Estimated N areal load in estuary ($mg/m^2/d$)[2]	107.9
Estimated P areal load in estuary ($mg/m^2/d$)[2]	15.8
CSR:NSR ratio[1]	1.1
Trap efficiency (sediment retained in estuary)[1]	81%
Estimated rate of sedimentation (mm/yr)[1]	3.8

[1] Hicks et al. (2019) & Oldman (2022).

[2] CLUES version 10.8 (LCBD5); Run date: 23 May 2023 (CLUES).

Although macrofauna composition changes from the upper to lower estuary were linked to gradients in variables such as sediment %mud and aRPD depth, the drivers of overall estuary condition that were discussed by Forrest et al. (2022a) for Tautuku Estuary are equally relevant to the present situation. For example, the faunal community may be stressed by low salinity water, or physical scouring during flood flows in Waipati River, especially in the upper estuary. The Waipati River likely experiences a high frequency of flushing flows due to the generally high rainfall in catchments of the Catlins area (Ozanne 2011). Towards the estuary entrance it is more likely to be the presence of mobile sand habitats that limits the establishment of a diverse and abundant macrofauna community. Under this range of conditions along the main estuary gradient, only the most resilient species appear to be able to persist. By contrast, the regional estuaries with the most extensive and stable tidal flats (i.e., Blueskin Bay and Pleasant River) are also the most species-rich (e.g. Forrest et al. 2022b).

7.2 VULNERABILITY TO MUDDY SEDIMENTS

In terms of anthropogenic influences from catchment development, the most significant exceptions to the favourable condition ratings for Waipati River Estuary were:

- A 'poor' sediment quality rating at Site 1 in the upper western arm of the estuary, where sediment mud content was almost 50% (Table 13). This site is likely to be representative of the small area (0.8ha) of mud-dominated sediment (>50% mud) that occurs in the upper estuary.
- A 'fair' rating for the mapped extent of mud-elevated sediment (i.e., sediment that exceeds a 25% mud threshold regarded as being biologically important), which occurred across 10.8% of the intertidal area (Table 12). Based on historic aerials (see Section 4.2) some of this muddy sediment may have been derived from erosion of salt marsh beds or margin areas, but most is likely to have entered the estuary from the catchment.

The spatial extent of mud-elevated sediment, while low by comparison with most other Otago estuaries, is nonetheless significant, and likely reflects that almost a quarter of the catchment is in land-uses that are known to generate a high fine-sediment run-off to waterways, namely pastoral farming and exotic plantation forestry. The latter can be a particularly significant source of muddy sediment during forest harvest and for a few years after, when it can contribute a disproportionately high sediment load per catchment hectare (e.g. Gibbs & Woodward 2018).

As noted in Section 2, the Waipati Estuary catchment consisted of 9.3% exotic plantation forestry (including harvested area) based on 2018 data (see Fig. 2). Since then, recent aerial imagery suggests that the harvested area may be greater than indicated in Fig. 2. Furthermore, the Catlins has likely followed the national trend of conversion from some farmland areas to plantation forestry, in particular due to the high-value of pine forests for carbon sequestration. As such, it is timely for ORC to consider the current and future implications for the downstream receiving environment (see Section 7.4).

Muddy sediments in the upper western arm near Site 1.

The spatial extent of mud-elevated sediment in Waipati River Estuary is consistent with predictions from catchment models (Table 15). Although the ratio of predicted Current to Natural Sedimentation Rate was rated as 'very good' (Table 12), the estuary has an estimated 81% sediment trapping efficiency (Table 15), indicative of high potential sediment retention. Accordingly, the annual sedimentation rate is estimated to be 3.8mm/yr, which is almost double the Townsend and Lohrer (2015) guideline value for New Zealand estuaries of 2mm/yr (rated 'poor').

Based on these model predictions, and considering current sediment state, we suggest that the estuary may be particularly vulnerable to any future increase in muddy sediment loads from the catchment. Some of the current and historic muddy sediment inputs will have been trapped in salt marsh, or have accumulated along the upper estuary margins, with a lesser amount dispersed across the central intertidal flats. Given a predicted 81% retention efficiency, it is conceivable that an outcome of an increased sediment input may be an increase in sediment muddiness on these unvegetated central estuary flats. Due to the vulnerability of the estuary to increased sediment loads it is desirable to minimise activities in the catchment that result in high inputs.

7.3 VULNERABILITY TO NUTRIENT ENRICHMENT AND EUTROPHICATION

Associated with the elevated mud at Site 1 were relatively high levels of two eutrophication indicators (TOC & TN). The lack of any concomitant eutrophic response (e.g., low sediment oxygenation) to these high values suggests that the organic and nutrient sources comprise material that is relatively slow to break-down (e.g., leaf litter), hence does not exert a strong oxygen demand in the sediment.

Despite the lack of eutrophication symptoms in terms of sediment oxygenation and macroalgae, from Table 15 it can be seen that the estimated areal nitrogen load to the estuary is ~108mg/m^2/d, which is around the 100mgN/m^2/d threshold at which nuisance macroalgae problems are predicted to occur in intertidally-dominated estuaries (Robertson et al. 2017). Potential nutrient sources include fertiliser runoff from farmland; the dominant soil types in the catchment are brown soils and podzols, which have low natural fertility and require fertiliser for grassland farming.

However, despite the moderately high predicted areal nitrogen load, the current absence of macroalgal proliferation or other eutrophication symptoms suggests that the estuary may not be particularly vulnerable to adverse effects from nutrient enrichment, with some of the factors that are potentially limiting to seagrass also relevant to macroalgae. For example, the opportunistic species *Agarophyton* spp. can form extensive beds in muddy sediments in estuaries in Southland, which has been directly linked to catchment nitrogen loads (Stevens et al. 2020; Stevens et al. 2022). However, in Waipati River Estuary, the muddy habitats where *Agarophyton* could potentially flourish are in upper estuarine areas which are potentially subjected to light limitation from tannin-rich catchment waters (which could inhibit photosynthesis), and whose low salinity water may limit macroalgal growth. This area is also where salt marsh is concentrated and therefore nutrient availability may also be reduced by uptake in salt marsh plants. Further, as the estuary is intertidally-dominated (83%) it is well-flushed on every tide i.e., which may prevent nutrient-enriched conditions reaching a level that allows macroalgae to proliferate on the intertidal flats.

In relation to phytoplankton proliferation, Plew et al. (2018) estimated the estuary had a flushing time of 3.3 days, and assessed phytoplankton susceptibility as a function of flushing time and potential TN concentration in estuaries with salinities <30ppt. From that work, it was predicted that estuaries with a flushing time of ~4 days or less (as is the case for Waipati River Estuary) would have a low susceptibility to eutrophication (i.e., chlorophyll-*a* predicted to be <5mg/m^3) in response to increasing nitrogen concentrations.

A further factor minimising the risk of phytoplankton issues relates to the absence of deep pools along the estuary channel, and absence of water column stratification at the time of sampling (although there was a partially mixed water column, with more saline water on the bottom). While it is possible stratification occurs under low flow conditions, or at different tidal states, observations during the survey were that the bed morphology of the estuary channel is relatively uniform, with the absence of any obvious features that would result in seawater entrapment (e.g., deeper areas upstream of shallow sills).

Collectively, these observations suggest that salt water is easily flushed from the system. Consequently, the development of eutrophic symptoms during summer low flows, which occurs in stratified bottom waters of some estuary systems (e.g., Roberts et al. 2021; Forrest et al. 2022c), may not eventuate in Waipati River Estuary. More comprehensive water quality monitoring would be required to confirm this hypothesis, however.

7.4 MANAGEMENT AND MONITORING CONSIDERATIONS

Increases in the loading of fine, muddy sediment are considered in this report to be the greatest threat to Waipati River Estuary. At present the spatial extent of mud-elevated sediment is limited to 10.8% of the unvegetated intertidal area. However, this area is likely to expand under a scenario of increased sediment loading. Probably most at risk are the primarily sandy sediments of the central estuary flats. As such, the opportunity exists for ORC to assess potential changes in catchment land use that could lead to fine sediment load increases, and work with landowners to mitigate potential adverse effects. Land ownership in the catchment includes Catlins Conservation Park land administered by DOC, Māori freehold land on the south side of the estuary, and farm or forestry in private ownership.

Examples of management opportunities include addressing exotic plantation forest harvest which, if poorly managed, could exacerbate sediment deposition across the tidal flats. Understanding the current area of catchment land in growing or harvested forest, and future harvest schedules, are particularly important, especially given the possibility of land use conversion noted above. Other potential land use practices that could lead to an increase in sediment load to the estuary should also be considered; for example, use intensification of existing farmland (e.g., increased stock densities, intensive winter grazing).

Even with no change from existing land uses there may be some feasible measures that can be implemented to reduce current sediment loads and in fact improve estuary condition, for example fencing and riparian planting of waterways. Ozanne (2011) stated that most rivers in the Catlins are used to provide stock water, as there is no rural stock-water scheme, and that this practice has caused the erosion of riverbanks and the degradation of riparian vegetation. Ozanne's report noted that unfenced rivers and eroding banks are an issue in every Catlins estuary except Tautuku.

In light of the potential vulnerability of Waipati River Estuary to sedimentation, the merits of implementing an ongoing SOE programme are also worth considering, and in fact assessing this need was part of the rationale for the targeted sediment quality and biota monitoring that was undertaken. There is certainly merit in undertaking ongoing monitoring of key attributes that are easy to measure, such as broad scale mapping every 5-years, and measurements of sediment grain size and oxygenation. It is also worthwhile considering the installation of sediment plates for the direct measurement of annual sedimentation rates, bearing in mind that at least a 5-year annual dataset is needed for meaningful trends to be revealed.

A bigger question for ORC to consider is whether there is merit in implementing the full NEMP fine scale survey protocol, of which a significant cost component is the monitoring of macrofauna. Although the estuary macrofaunal assemblage is reasonably species poor, the richness and abundance values are nonetheless within the range of other SOE estuaries in the region that are monitored using the NEMP fine scale protocol. In many respects Waipati River Estuary is of more interest than some of the highly modified systems in the SOE programme (e.g., Tokomairiro and Shag River Estuary), as there is an opportunity to maintain it in a healthy state.

8. RECOMMENDATIONS

By regional and national standards, Waipati River Estuary is in a healthy state overall. However, it appears potentially vulnerable to ongoing and future inputs of catchment-derived muddy sediment. To mitigate against such risks the following is recommended:

- Establish sediment plates to measure sediment accretion and mud content in representative parts of the central estuary.
- Undertake broad scale habitat mapping every 5-years, in particular focusing on the change in mud extent.
- Evaluate current and future sediment sources to the estuary, and investigate options for a reduction of inputs. This could be facilitated by including Waipati River Estuary in the ORC limit setting programme and establishing limits for catchment sediment (and nutrient) inputs that will maintain the health of the estuary.
- Given that ORC has now undertaken ecological assessments of the main estuaries in Otago, it would be timely to consider the priority for fine scale monitoring in Waipati River Estuary alongside the monitoring priorities for other estuaries regionally.

9. REFERENCES

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian State and Territory Governments, Canberra ACT, Australia. Available at https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants.

CLUES Catchment Land Use for Environmental Sustainability model. NIWA. https://niwa.co.nz/freshwater/our-services/catchment-modelling/clues-catchment-land-use-for-environmental-sustainability-model.

FGDC 2012. Coastal and Marine Ecological Classification Standard. Standard FGDC-STD-018-2012, Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee, June, 2012.. 343p. Available at: https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf.

Forrest BM, Stevens LM, Rabel H 2020. Fine scale intertidal monitoring of Tokomairiro Estuary. Salt Ecology Report 043, prepared for Otago Regional Council, June 2020. 42p.

Forrest BM, Roberts KL, Stevens LM 2022a. Fine Scale Intertidal Monitoring of Tautuku Estuary. Salt Ecology Report 092, prepared for Otago Regional Council, June 2022. 27p.

Forrest BM, Roberts KL, Stevens LM 2022b. Fine scale intertidal monitoring of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 093, prepared for Otago Regional Council, June 2022. 29p.

Forrest BM, Roberts KL, Stevens LM 2022c. Synoptic broad scale survey of Ākitio Estuary. Salt Ecology Report 104, prepared for Horizons Regional Council, November 2022. 33p (Draft).

Gibbs M, Woodward B 2018. Waimea and Moutere sediment sources by land use. NIWA Client Report No: 2018026HN, Prepared for Tasman District Council, February 2018. 63p.

Hicks M, Semadeni-Davies A, Haddadchi A, Shankar U, Plew D 2019. Updated sediment load estimator for New Zealand. NIWA Client Report No: 2018341CH, prepared for Ministry for the Environment, March 2019. 190p.

Moore M 2015. Coastal Environment of Otago: Natural Character and Outstanding Natural Features and Landscapes Assessment, Clutha District Section Report. 77p.

Oldman J 2022. Coastal Sediment Source Portal: River Sediment Yield Data and User Manual. DHI report prepared for Department of Conservation. May 2022. 73p.

Ozanne R 2011. Water quality and ecological health for rivers in the Catlins area. Otago Regional Council, November 2011. 48p.

Plew D, Dudley B, Shankar U, Zeldis J 2018. Assessment of the eutrophication susceptibility of New Zealand estuaries. Prepared by NIWA for the Ministry for the Environment. 64p.

Plew DR, Zeldis JR, Dudley BD, Whitehead AL, Stevens LM, Robertson BM, Robertson BP 2020. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts 43(8): 2015-2033.

Roberts KL, Stevens LM, Forrest BM 2021. Synoptic subtidal monitoring of Waikawa Estuary, Manawatū. Salt Ecology Report 063, prepared for Horizons Regional Council, March 2021. 31p.

Robertson B, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A, Development; Part B, Appendices; and Part C, Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A, 93p; Part B, 159p; Part C, 40p plus field sheets.

Robertson BM, Stevens LM, Ward N, Robertson BP 2017. Condition of Southland's Shallow, Intertidal Dominated Estuaries in Relation to Eutrophication and Sedimentation: Output 1: Data Analysis and Technical Assessment - Habitat Mapping, Vulnerability Assessment and Monitoring Recommendations Related to Issues of Eutrophication and Sedimentation. Prepared for Environment Southland. 152p.

Stevens LM, Roberts K, Forrest BM 2020. Macroalgal and seagrass monitoring of Jacobs River Estuary. Salt Ecology Report 060, prepared for Environment Southland, May 2021. 41p.

Stevens LM, Forrest BM, Dudley BD, Plew DR, Zeldis JR, Shankar U, Haddadchi A, Roberts KL 2022. Use of a multi-metric macroalgal index to document severe eutrophication in a New Zealand estuary. New Zealand Journal of Marine and Freshwater Research: 1-20.

Townsend M, Lohrer D 2015. ANZECC Guidance for Estuary Sedimentation. NIWA client report number HAM2015-096, prepared for Ministry for the Environment. 45p.

Tyrrell AR 2016. Catlins Pioneering. Published by Catlins Historical Society, Owaka, New Zealand. 164p.

WFD-UKTAG 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Water Framework Directive – United Kingdom Technical Advisory Group. https://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/TraC%20Macroalgae%20OMBT%20UKTAG%20Method%20Statement.PDF.

APPENDIX 1. SURVEY METHODS, WAIPATI RIVER ESTUARY, DECEMBER 2022

This Appendix details the synoptic ecological assessment approach used by Salt Ecology for assessing intertidal estuary condition. It comprises estuary-wide broad scale habitat mapping, and assessment of sediment quality (including associated biota) and water quality at discrete sites. In relation to these components, note that:

- The broad scale habitat mapping methods largely follow the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002), with improvements to some of the assessment, analysis and QA/QC elements as described in Section A.
- Broad scale mapping seeks to characterise the spatial extent of dominant substrate types (with a particular focus on muddy sediments as a key indicator of catchment sediment inputs), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats vulnerable to human disturbance. The latter consist of intertidal seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the 200m terrestrial margin bordering the estuary.
- The synoptic assessments of sediment quality and biota largely use the NEMP fine scale indicators and analytical methods described in Section B, but vary from the NEMP by incorporating more sites with reduced within-site replication to provide a synoptic picture of ecological health across a range of soft-sediment habitat types throughout the estuary. In contrast, NEMP fine scale surveys are typically based on intensive (high replication) sampling of 1-3 sites in the dominant habitat type.
- The water quality methods are based on standard field measures that are an addition to NEMP methods. Comprehensive water quality sampling (e.g., numerous sites with high replication) is required characterise subtidal estuary condition. However one-off water quality parameters collected in synoptic surveys capture preliminary information to help assess whether an estuary may be vulnerable to water quality degradation (e.g., stratification, phytoplankton blooms and/or low dissolved oxygen).
- For the key components outlined above, the final section of this Appendix describes the metrics and associated threshold values that are used to rate estuary condition on a four-point colour-coded scale ranging from 'very good' to 'poor'.

A. BROAD SCALE METHODS

A1. MAPPING

A1.1 Overview

For broad scale mapping purposes, the estuary was defined as a partly enclosed body of water where freshwater inputs (i.e. rivers, streams) mix with seawater. The seaward boundary (estuary entrance) was defined as a straight line between the seaward-most points of land that enclose the estuary, with the upper estuary (i.e., riverine) boundary at the estimated upper extent of saline intrusion. For further discussion on estuary boundary definitions see FGDC (2012) and Hume et al. (2016).

Broad scale NEMP surveys involve mapping the intertidal zone of estuaries, and their terrestrial margin, according to dominant surface habitat (substrate and vegetation) features. The type, presence and extent of estuary 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 or direct human disturbance. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to the small scale spatial or temporal variation commonly associated with instantaneous measures of water quality or, to a lesser extent, sediment quality. Once a baseline map has been constructed, changes in the position and/or size or type of dominant features can be monitored by repeating the mapping exercise, and temporal changes due to the effects of anthropogenic inputs of sediment or nutrients, or activities such as vegetation clearance, margin hardening (e.g. rock walls), reclamation, or drainage of salt marsh, can be elucidated.

The mapping procedure follows NEMP methods and combines aerial photography or satellite imagery, detailed ground-truthing, and digital mapping using Geographic Information System (GIS) technology. Field surveys are typically carried out during September to May, when most plants are still visible and seasonal vegetation has not died back, with experienced scientists ground-truthing the estuary and margin on foot to directly map or validate the dominant vegetation and substrate visible on aerial imagery. Field maps are ideally >50cm/per pixel resolution at a scale of between 1:2000 and 1:5000, as at a coarser scale it becomes difficult to map features with sufficient resolution to reliably characterise features. The drawn or validated features, combined with field notes and georeferenced photographs, are later digitised into ArcMap (currently v10.8) shapefiles at a scale of at least 1:2000 using a drawing tablet to produce maps of the dominant estuary features.

A summary of the broad scale indicators and the rationale for their use is provided in the main body of the report, with methods for mapping and assessing each indicator also described.

A1.2 Catchment description and terrestrial margin mapping

Catchment land use maps are constructed from the most recent Landcare Research Land Cover Data Base (currently LCDB5 2017/2018) where dominant land cover has been classified based on the codes described in Table A1. Using the broad scale NEMP methods described in section A1.1, these same LCDB5 classes are used to categorise features within the 200m terrestrial margin of an estuary. The one exception is the addition of a new sub-class (410 – Duneland) to delineate coastal duneland from low producing grassland, due to the high value of duneland habitat type.

Table A1. Landcare Land Cover Database (LCDB5) classes used in the mapping of terrestrial features.

Artificial Surfaces		Grassland, Sedge and Saltmarsh	
1	Built-up Area (settlement)	40	High Producing Exotic Grassland
2	Urban Parkland/Open Space	41	Low Producing Grassland
5	Transport Infrastructure	410*	Duneland
6	Surface Mines and Dumps	43	Tussockland
Bare or Lightly Vegetated Surfaces		45	Herbaceous Freshwater Vegetation
10	Sand and Gravel	46	Herbaceous Saline Vegetation
12	Landslide	Scrub and Shrubland	
14	Permanent Snow and Ice	47	Flaxland
15	Alpine Grass/Herbfield	50	Fernland
16	Gravel and Rock	51	Gorse and/or Broom
Water Bodies		52	Manuka and/or Kanuka
20	Lake or Pond	54	Broadleaved Indigenous Hardwoods
21	River	55	Sub Alpine Shrubland
22	Estuarine water	56	Mixed Exotic Shrubland
Cropland		58	Matagouri or Grey Scrub Forest
30	Short-rotation Cropland	Forest	
33	Orchard Vineyard & Other Perennial Crops	64	Forest - Harvested
		68	Deciduous Hardwoods
		69	Indigenous Forest
		71	Exotic Forest

* Duneland is an additional category to the LCDB classes to help differentiate between "Low Producing Grassland" and "Duneland".

A1.3 Estuary substrate classification and mapping

NEMP substrate classification is based on the dominant surface features present, e.g., rock, boulder, cobble, gravel, sand, mud. However, many of the defined NEMP sediment classifications are inconsistent with commonly accepted geological criteria (e.g. the Wentworth scale), aggregate mud/sand mixtures into categories that can range in mud content from 10-100%, and use a subjective and variable measure of sediment 'firmness' (how much a person sinks) as a proxy for mud content. To address such issues, Salt Ecology has revised the NEMP classifications (summarised in Table A2) using terms consistent with commonly accepted geological criteria (e.g. Folk 1954) and, for fine unconsolidated substrate (<2mm), divided classes based on estimates of mud content where biologically meaningful changes in sediment macrofaunal communities commonly occur (e.g. Norkko et al. 2002, Thrush et al. 2003, Gibbs & Hewitt 2004, Hailes & Hewitt 2012, Rodil et al. 2013, Robertson et al. 2016c). Sediment 'firmness' is used as a descriptor independent of mud content. Salt Ecology also maps substrate beneath vegetation to create a continuous substrate layer for an estuary.

The Salt Ecology revisions (Table A2) use upper-case abbreviations to designate four fine unconsolidated substrate classes based on sediment mud content (S=Sand: 0-10%; MS=Muddy Sand: ≥10-50%; SM=Sandy Mud: ≥50-90%; M=Mud: ≥90%), with muddy sand further divided into two sub-classes of ≥10-25% or ≥25-50% mud content. These reflect categories that can be subjectively assessed in the field by experienced scientists, and validated by the laboratory analysis of particle grain size samples (wet sieving) collected from representative sites (typically ~10 per estuary) based on the methods described in Section B.

Lower-case abbreviations are used to designate sediment 'firmness' based on how much a person sinks (f=firm: 0-<2cm; s=soft: 2-5cm; vs=very soft: ≥5cm). Because this measure is highly variable between observers, it is only used as a supporting narrative descriptor of substrate type. Mobile substrate (m) is classified separately and, based on the NEMP, is considered to only apply to firm substrate.

Table A2 presents the revised classifications alongside the original NEMP equivalent classifications to facilitate consistent comparisons with previous work (by aggregating overlapping classes). The area (horizontal extent) of mud-elevated sediment (>25% mud content) is used as a primary indicator of sediment mud impacts, and in assessing susceptibility to nutrient enrichment impacts (trophic state).

A1.4 Estuary salt marsh

Salt marsh grows in the upper tidal extent of estuaries, usually bordering the terrestrial margin. NEMP methods are used to map and categorise salt marsh, with dominant estuarine plant species used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock; see Robertson et al. 2002). The following changes have been made to the original NEMP vegetation classifications:

- Forest (woody plants >10 cm density at breast height - dbh) and scrub (woody plants <10cm dbh) are considered terrestrial and mapped using LCDB codes as outlined in Table A1.
- Introduced weeds: Weeds are a common margin feature occasionally extending into upper intertidal areas and have been added to broad salt marsh structural classes.
- Estuarine shrubland: Woody plants <10 cm dbh growing in intertidal areas (e.g. mangroves, saltmarsh ribbonwood) have been added to broad salt marsh structural classes.

Two measures are used to assess salt marsh condition: i) intertidal extent (percent cover of total intertidal area) and ii) current extent compared to estimated historical extent.

LiDAR (where available) and historic aerial imagery are used to estimate historic salt marsh extent. All LiDAR geoprocessing is performed using ArcGIS Pro (currently v2.9.3). The terrain dataset is converted to raster using the Terrain to Raster (3D Analyst) tool. Contour lines are created using the Contour List (Spatial Analyst) tool. An elevation contour that represents the upper estuary boundary elevation is selected based on a comparison with existing estuary mapping and a visual assessment of aerial imagery. To estimate historic salt marsh extent, both the upper estuary boundary and historic aerial imagery (e.g. sourced from retrolens.co.nz or council archives) are used to approximate the margin of salt marsh which is digitised in ArcMap (currently v10.8) to determine areal extent.

In addition to mapping of the salt marsh itself, the substrate in which the salt marsh is growing is also mapped, based on the methods described in Section A1.3. As salt marsh can naturally trap and accrete muddy sediment, substrate mapping within salt marsh can provide an insight into ongoing or historic muddy sediment inputs.

Table A2. Modified NEMP substrate classes and field codes.

Consolidated substrate			Code	NEMP equivalent (depth of sinking)	
Bedrock		Rock field "solid bedrock"	RF	RF	Rockland
Coarse Unconsolidated Substrate (>2mm)					
Boulder	>256mm	Boulder field "bigger than your head"	BF	BF	Boulder field
Cobble	64 to <256mm	Cobble field "hand to head sized"	CF	CF	Cobble field
Gravel	2 to <64mm	Gravel field "smaller than palm of hand"	GF	GF	Gravel field
Shell	2 to <64mm	Shell "smaller than palm of hand"	Shel	Shell	Shell bank
Fine Unconsolidated Substrate (<2mm) – see footnotes					
Sand (S)	Low mud (0-10%)	Mobile sand	mS	MS	Mobile sand (<1cm)
		Firm shell/sand	fShS	FSS	Firm shell/sand (<1cm)
		Firm sand	fS	FS	Firm sand (<1cm)
		Soft sand	sS	SS	Soft sand (>2cm)
		Very soft sand	vsS	SS	Soft sand (>2cm)
Muddy Sand (MS)	Moderate mud (≥10-25%)	Mobile muddy sand	mMS10	MS	Mobile sand (<1cm)
		Firm muddy shell/sand	fMShS10	FSS	Firm shell/sand (<1cm)
		Firm muddy sand	fMS10	FMS	Firm mud/sand (<2cm)
		Soft muddy sand	sMS10	SM	Soft mud/sand (2-5cm)
		Very soft muddy sand	vsMS10	VSM	Very soft mud/sand (>5cm)
	High mud (≥25-50%)	Mobile muddy sand	mMS25	MS	Mobile sand (<1cm)
		Firm muddy shell/sand	fMShS25	FSS	Firm shell/sand (<1cm)
		Firm muddy sand	fMS25	FMS	Firm mud/sand (<2cm)
		Soft muddy sand	sMS25	SM	Soft mud/sand (2-5cm)
		Very soft muddy sand	vsMS25	VSM	Very soft mud/sand (>5cm)
Sandy Mud (SM)	Very high mud (≥50-90%)	Firm sandy mud	fSM	FMS	Firm mud/sand (<2cm)
		Soft sandy mud	sSM	SM	Soft mud/sand (2-5cm)
		Very soft sandy mud	vsSM	VSM	Very soft mud/sand (>5cm)
Mud (M)	Mud (≥90%)	Firm mud	fM90	FMS	Firm mud/sand (<2cm)
		Soft mud	sM90	SM	Soft mud/sand (2-5cm)
		Very soft mud	vsM90	VSM	Very soft mud/sand (>5cm)
Zoogenic (living)					
Area dominated by both live cockle, mussel, oyster, shellfish or tubeworm species respectively.		Cocklebed	CKLE		Cockle
		Mussel reef	MUSS		Mussel
		Oyster reef	OYST		Oyster
		Shellfish bed	SHFI		
		Tubeworm reef	TUBE		Sabellid
Artificial Substrate					
Introduced natural or human-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, groynes, flood control banks, stop gates.		Substrate (bund, ramp, wall, whf)	aS		
		Boulder field	aBF		Boulder field
		Cobble field	aCF		Cobble field
		Gravel field	aGF		Gravel field
		Sand field	aSF		Firm/Soft sand

Sediment firmness: Subjectively classified as firm if you sink 0-<2cm, soft if you sink 2-5cm, or very soft if you sink >5cm.
Mobile: Sediment is firm but routinely moved by tidal currents or waves. Commonly characterised by having a rippled surface layer.
Sand: Sandy sediment that is granular when rubbed between the fingers and releases no conspicuous fines when sediment is disturbed.
Shell/Sand: Mixed sand and shell hash. See muddy sand sub-classes below for field guidance on estimating mud content.
Muddy Sand: Sand-dominated sediment that is mostly granular when rubbed between the fingers but has a smoother consistency than sand. Subdivided into two sub-classes based on estimated mud content (commonly validated by laboratory analysis of representative substrate);

i. Moderate mud (≥10-25%) content: Muddy fines evident when sediment is disturbed. Sediments generally firm to walk on.
ii. High mud (≥25-50%) content): Muddy fines conspicuous when sediment is disturbed. Sediments generally soft to walk on.

Sandy Mud (≥50-90% mud content): Mud-dominated sediment primarily smooth/silken when rubbed between the fingers, but retains a granular component. Sediments generally soft or very soft and only firm if dried out, or another component (e.g. gravel) prevents sinking.
Mud (≥90% mud content): Mud-dominated sediment with no obvious sand component. Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out, or another component (e.g. gravel underneath mud) prevents sinking.

A1.5 Estuary seagrass assessment

The NEMP provides no guidance on the assessment of seagrass beyond recording its presence when it is a dominant surface feature. To improve on the NEMP, the mean percent cover of discrete seagrass patches is visually estimated through ground-truthing, based on the 6-category percent cover scale in Fig. A1.

The state of seagrass is assessed by the change in spatial cover as a percentage of the measured 'baseline'. which generally represents the earliest available ground-truthed broad scale survey. In the absence of ground-truthed broad scale surveys historic imagery, supported by anecdotal reports of seagrass presence, can be georeferenced in ArcMap (v10.8) and visible seagrass digitised. It is difficult to reliably map seagrass areas of <50% cover, and to distinguish boundaries between subtidal and intertidal areas, solely from historic imagery (i.e., no ground-truthing). Therefore, comparisons of broad scale data captured from aerial imagery alone can generally only be reliably made for percent cover categories >50%, with the estuary-wide area of seagrass >50% cover typically compared across years. Notwithstanding that seagrass extent derived from historic imagery may be less reliable than that derived from ground-truthed surveys, it remains a useful metric to understanding the narrative of seagrass change, including its natural variability.

A1.6 Estuary macroalgae assessment

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature, hence, improved methods are used by Salt Ecology. These are based on the New Zealand Estuary Trophic Index (Robertson et al. 2016a), which adopts the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT). The OMBT, described in detail in previous reports (e.g. Stevens et al. 2022; Roberts et al. 2022), is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed), and rates estuarine condition in relation to macroalgal status within five overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- *Percentage cover of opportunistic macroalgae:* The spatial extent and surface cover of algae present in intertidal soft sediment habitat in an estuary provides an early warning of potential eutrophication issues.
- *Macroalgal biomass:* Biomass provides a direct measure of macroalgal growth (wet weight biomass). Measurements and estimates of mean biomass are made within areas affected by macroalgal growth, as well as across the total estuary intertidal area.
- *Extent of algal entrainment into the sediment matrix:* Macroalgae is defined as entrained when growing in stable beds or with roots deep (e.g., >30mm) within the sediments, which indicates that persistent macroalgal growths have established.

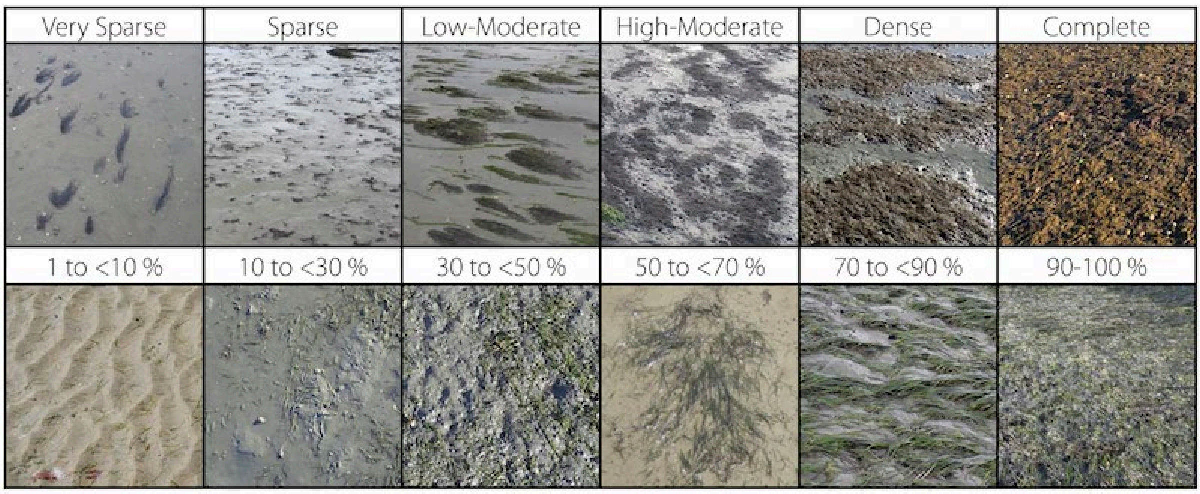


Fig. A1. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

If an estuary supports <5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' (EQR score ≥ 0.8 to 1.0) with no further sampling required. In this situation a numeric EQR score, which is based directly on the measured opportunistic macroalgal percent cover in the AIH, is calculated for the 'high' band using the approach described in Stevens et al. (2022). Using the OMBT, opportunistic macroalgae patches are mapped during field ground-truthing using a 6-category rating scale (modified from FGDC 2012) as a percentage cover guide (Fig. A1). Within these percent cover categories, representative patches of comparable macroalgal growth are identified and the biomass and the extent of macroalgal entrainment in sediment is measured. Biomass is measured by collecting algae growing on the surface of the sediment from within a defined area (e.g., 25x25cm quadrat) and placing it in a sieve bag. The algal material is then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g., crabs, shellfish) are also removed. Remaining algae are then hand squeezed or spun until water stops running, and the wet weight is recorded to the nearest 10g using 1kg Pesola light-line spring scales. When sufficient representative patches have been measured to enable biomass to be reliably estimated, biomass estimates are then made following the OMBT method.

Macroalgae patches are digitised in ArcMAP (v10.8) as described in Section 1.1 with each patch containing data on the species present, percent cover, biomass and entrainment status. Each macroalgal patch is given a unique 'Patch ID' up to a maximum of 100 patches per estuary (i.e. the maximum the OMBT excel calculator can calculate). If more than 100 patches are present, comparable patches are grouped (i.e. patches with the same species, percent cover, biomass and entrainment). The raw data is exported from ArcMap (v10.8) into excel using a scripting tool. The OMBT Microsoft Excel template (i.e. WFD-UKTAG Excel template) is used to calculate an OMBT EQR, with OMBT biomass thresholds (Table A3) updated to reflect conditions in New Zealand estuaries as described in Plew et al. (2020). The scores are then categorised on the five-point scale adopted by the method as outlined in Table A3.

Table A3. Thresholds used to calculate the OMBT-EQR in the current report.

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g/m^2) of AIH[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g/m^2) of AA[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

[1] Where ≤5%,cover AIH EQR was calculated as described in Section A1.6.

[2] Only the lower EQR of the 2 metrics, AA or AA/AIH, should be used in the final EQR calculation (WFD-UKTAG (2014).

[3] Updated thresholds for New Zealand estuaries described in Plew et al. (2020).

A1.7 Broad scale data recording, QA/QC and analysis

Broad scale mapping provides a rapid overview of estuary substrate, macroalgae, seagrass and salt marsh condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial imagery, the extent of ground-truthing undertaken to validate features visible on photographs, and the experience of those undertaking the mapping. In most instances features with readily defined edges 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 imagery, e.g. sparse seagrass or macroalgal beds. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed, but when relying on imagery alone (i.e. no ground-truthing), accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

There are many potential sources of error that can occur during the digitising and GIS data collation process that may affect the accuracy of the metrics derived from broad scale mapping, and undermine the assessment of temporal change. To minimise this risk, Salt Ecology has developed in-house scripting tools in Phyton to create a customised

GIS toolbox for broad scale mapping outputs. The scripting tools sequentially run through a QA/QC checklist to check for duplicated or overlapping GIS polygons and to identify gaps or slivers and validate typology (field codes). Following rectification of any errors, the customised toolbox is used to create maps with consistent symbology, generate standardised summary tables for reporting, and to add metadata to final GIS packages.

Additional to the annotation of field information onto aerial imagery during ground-truthing, electronic templates (custom-built using Fulcrum app software - www.fulcrumapp.com) are used to record substrate validation locations and measurements of sediment aRPD, texture and sediment type, as well as macroalgal data (i.e. biomass and cover measurements, entrainment). Each sampling record created in Fulcrum generates a GPS position, which is exported to ArcMap, with pre-specified data entry constraints (e.g., with minimum or maximum values for each data type) minimising the risk of erroneous data recording. Scripting tools are then used within ArcMap to upload data.

B. SEDIMENT QUALITY AND BIOTA METHODS

B1.1 Overview

Mapping the main habitats in an estuary using the NEMP broad scale approach provides a basis for identifying representative areas to sample sediment quality and associated biota. Samples are typically collected from sufficient sites to characterise the range of conditions in estuary soft sediments, from the seaward extent to upper estuary areas, including areas in the vicinity of any potentially strong catchment influences (e.g. river mouths, stormwater point sources). A summary of sediment and biota indicators, the rationale for their use, and field sampling methods, is provided in the main body of the report (i.e., Table 2). The sampling methods generally adhere to the NEMP 'fine scale' sampling protocol, except where noted.

B1.2 Sediment quality sampling and laboratory analyses

At each site, a composite sediment sample (~500g) is pooled from three sub-samples (to 20mm depth). Samples are stored on ice and sent to RJ Hill Laboratories for analysis of: particle grain size in three categories (%mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP); and trace contaminants (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; nickel, Ni; zinc, Zn). Details of laboratory methods and detection limits are provided in Table B1.

Table B1. RJ Hill Laboratories methods and detection limits.

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 Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g 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 - 0.8 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

B1.3 Field sediment oxygenation assessment

The apparent Redox Potential Discontinuity (aRPD) depth is used to assess the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment. The aRPD depth is the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). The aRPD provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions (Rosenberg et al. 2001; Gerwing et al. 2013). Sediments are considered to have poor oxygenation if the aRPD is consistently <10mm deep and shows clear signs of organic enrichment, indicated by a distinct colour change to grey or black in the sediments.

Example of distinct aRPD colour change with brown oxygenated sediments from the surface down to ~40mm

B1.4 Biological sampling: sediment-dwelling macrofauna

To sample sediment-dwelling macrofauna, duplicate large (130mm diameter) sediment cores (see Table 2 in main body of the report) are collected, and placed in separate 0.5mm mesh sieve bags, which are gently washed in seawater to remove fine sediment. The retained animals are preserved in a mixture of ~75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification by a skilled taxonomic laboratory (e.g. NIWA). The types of animals 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.

B1.5 Biological sampling: surface-dwelling epibiota

In addition to macrofaunal core sampling, epibiota (macroalgae and conspicuous surface-dwelling animals nominally >5mm body size) visible on the sediment surface at each site are semi-quantitatively categorised using 'SACFOR' abundance (animals) or percentage cover (macroalgae) ratings shown in Table B2. These ratings represent a scoring scheme simplified from established monitoring methods (MNCR 1990; Blyth-Skyrme et al. 2008).

The SACFOR method is ideally suited to characterise intertidal epibiota with patchy or clumped distributions. It was conducted as an alternative to the quantitative quadrat sampling specified in the NEMP, which is known to poorly characterise scarce or clumped species. Note that our epibiota assessment does not include infaunal species that may be visible on the sediment surface, but whose abundance cannot be reliably determined from surface observation (e.g. cockles). Nor does it include very small organisms such as the estuarine snail *Potamopyrgus* spp.

Table B2. SACFOR ratings for site-scale abundance, and percent cover of epibiota and algae, respectively.

SACFOR category	Code	Density per m^2	Percent cover
Super abundant	S	> 1000	> 50
Abundant	A	100 - 999	20 - 50
Common	C	10 - 99	10 - 19
Frequent	F	2 - 9	5 - 9
Occasional	O	0.1 - 1	1 - 4
Rare	R	< 0.1	< 1

B1.6 Sediment quality and biota data recording, QA/QC and analysis

All sediment and macrofaunal samples sent to analytical laboratories were tracked using standard Chain of Custody forms, and results were transferred electronically from the laboratory to avoid transcription errors. Field measurements (e.g. aRPD) and site metadata were recorded electronically in templates (custom-built using Fulcrum app software - www.fulcrumapp.com), with pre-specified data entry constraints (e.g. with minimum or maximum values for each data type) minimising the risk of erroneous data recording.

Excel sheets were imported into the software R 4.2.3 (R Core Team 2023) and assigned sample identification codes. All summaries of univariate responses (e.g. sediment analyte concentrations, macrofauna abundances) were produced in R, including tabulated or graphical representations of the data. Where results for sediment quality parameters were below analytical detection limits, half of the detection limit value was used, according to convention.

Before sediment-dwelling macrofaunal analyses, the data were screened to remove species that were not regarded as a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g. freshwater drift). To facilitate comparisons with any future surveys, and other estuaries, cross-checks were made to ensure consistent naming of species and higher taxa. For this purpose, the adopted name was that accepted by the World Register of Marine Species (WoRMS, www.marinespecies.org/).

Macrofaunal response variables included richness and abundance by species and higher taxonomic groupings. In addition, scores for the biotic health index AMBI (Borja et al. 2000; Borja et al. 2019) were derived. AMBI scores reflect the proportion of taxa falling into one of five eco-groups (EG) that reflect sensitivity to pollution, ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

To meet the criteria for AMBI calculation, macrofauna data were reduced to a subset that included only adult 'infauna' (those organisms living within the sediment matrix), which involved removing surface dwelling epibiota and any juvenile organisms. AMBI scores were calculated based on standard international eco-group classifications where possible (http://ambi.azti.es). However, to reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand (Keeley et al. 2012; Robertson et al. 2015; Robertson et al. 2016c; Robertson 2018). Note that AMBI scores were not calculated for macrofaunal cores that did not meet operational limits defined by Borja et al. (2012), in terms of the percentage of unassigned taxa (>20%), or low sample richness (<3 taxa) or abundances (<6 individuals).

Where helpful in understanding estuary health, multivariate analyses of macrofaunal community data are undertaken, mainly using the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in site similarity as a function of macrofaunal composition and abundance are assessed using an 'unconstrained' non-metric multidimensional scaling (nMDS) ordination plot, based on pairwise Bray-Curtis similarity index scores among samples.

Prior to the multivariate analysis, macrofaunal abundance data are transformed (e.g. square root) to down-weight the influence on the ordination pattern of the dominant species or higher taxa. The procedure PERMANOVA may be used to test for compositional differences among samples. Overlay vectors and bubble plots on the nMDS are used to visualise relationships between multivariate biological patterns and sediment quality data (the latter may need to be transformed (e.g. log x+1) and normalised to a standard scale. The Primer procedure Bio-Env is typically used to evaluate the suite of sediment quality variables that best explain the macrofauna ordination pattern.

C. WATER QUALITY METHODS

Although subject to high spatial and temporal variation, water column measures provide a useful tool for the synoptic appraisal of ecological condition. At the deepest point at each sampling site, water quality measures are taken from ~20cm below the water surface and ~20cm above the bottom sediment, and the depth of any halocline or thermocline stratification is recorded as the average depth of abrupt changes in salinity and temperature, respectively. Water column indicators and a rationale for their measurement is provided in Table C1. The parameters pH, salinity, dissolved oxygen (DO), and temperature are measured using a calibrated YSI Pro10 meter. Chlorophyll-*a* is measured using a calibrated Delrin Cyclops-7F fluorometer with chlorophyll optics. Care is taken not to disturb bottom sediments before sampling. A modified (pole-mounted) Secchi disk is used to measure vertical water clarity to the nearest centimetre.

Sampling data and metadata are recorded in an electronic template custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g., with respect to data type, minimum or maximum values) ensure that the risk of erroneous data recording is minimised. Each sampling record created in Fulcrum generates a GPS position and sampling time. Other metadata recorded include tidal state, water depth, channel width and bottom sediment type.

Table C1. Summary of water quality indicators, rationale for their use, and sampling method.

Indicator	Description
Salinity	Provides a simple measure to determine 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. Salinity also influences the macrofaunal community. The boundary of any abrupt salinity change with increasing water depth (i.e., halocline) is used as an indicator of water column stratification.
Temperature	Temperature is an important indicator of habitat quality as many aquatic animals and plants can only live within a defined temperature range. Temperature also regulates biogeochemical processes such as decomposition and oxygen consumption. In the context of synoptic water quality measurements temperature is used to assess thermal stratification or temperature stresses. Thermal stratification is assessed as the boundary of any abrupt temperature change with increasing water depth (i.e. thermocline).
Secchi depth	A field indicator of water clarity and potential for light penetration into the water column, the latter critical for plant photosynthesis.
Chlorophyll-a	A proxy indicator of phytoplankton abundance, 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.
Dissolved oxygen	An indicator of the suitability of a water body for aquatic life. Depleted water column oxygen can adversely impact sediment-dwelling and water column communities, and is a primary cause of most fish kills.

D. METHODS REFERENCES

Atkinson IAE 1985. Derivation of vegetation mapping units for an ecological survey of Tongariro National North Island, New Zealand. New Zealand Journal of Botany 23(3): 361-378.

Borja A, Franco J, Pérez V 2000. A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments. Marine Pollution Bulletin 40(12): 1100-1114.

Borja A, Chust G, Muxika I 2019. Forever young: The successful story of a marine biotic index. Advances in marine biology 82: 93-127.

Borja Á, Mader J, Muxika I 2012. Instructions for the use of the AMBI index software (Version 5.0). Revista de Investigación Marina, AZTI-Tecnalia 19(3): 71-82.

Clarke KR, Gorley RN, Somerfield PJ, Warwick RM 2014. Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, UK. 260p.

FGDC 2012. Coastal and Marine Ecological Classification Standard. Standard FGDC-STD-018-2012, Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee, June, 2012.. 343p. Available at: https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf.

Folk, R.L. 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology 62 (4), 344-359.

Gerwing TG, Gerwing AMA, Drolet D, Hamilton DJ, Barbeau MA 2013. Comparison of two methods of measuring the depth of the redox potential discontinuity in intertidal mudflat sediments. Marine Ecology Progress Series 487: 7-13.

Gibbs M, Hewitt JE. 2004. Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC. Auckland Regional Council, Auckland.

Hailes SF, Hewitt JE. 2012. Manukau Harbour Ecological Programme: Report on data collected up until February 2011. Prepared by The National Institute of Water and Atmospheric Research for Auckland Council. Auckland Council Technical Report 2012/004.

Keeley NB, Macleod CK, Forrest BM 2012. Combining best professional judgement and quantile regression splines to improve characterisation of macrofaunal responses to enrichment. Ecological Indicators 12: 154-166.

Norkko A, Talman S, Ellis J, Nicholls P, Thrush S. 2002. Macrofaunal Sensitivity to Fine Sediments in the Whitford Embayment. Auckland Regional Council, Technical Publication, 158: 1-30.

NPSFM 2020. National Policy Statement for Freshwater Management 2020. Minstry for the Environment, August 2020. 70p.

Plew DR, Zeldis JR, Dudley BD, Whitehead AL, Stevens LM, Robertson BM, Robertson BP 2020. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts 43(8): 2015-2033.

R Core Team 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Roberts KL, Stevens LM, Forrest BM 2021. Macroalgal and Seagrass monitoring of New River Estuary. Salt Ecology Report 080, prepared for Environment Southland, September 2021. 34p.

Roberts KL, Stevens LM, Forrest BM 2022. Broadscale Intertidal Habitat Mapping of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 086, prepared for Otago Regional Council, July 2022. 56p.

Robertson B, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A, Development; Part B, Appendices; and Part C, Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A, 93p; Part B, 159p; Part C, 40p plus field sheets.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016a. NZ Estuary Trophic Index Screening Tool 2: determining monitoring indicators and assessing estuary trophic state. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016b. NZ Estuary Trophic Index Screening Tool 1: Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420. 47p.

Robertson BP 2018. Optimising indicators of ecological condition in shallow tidal estuaries as function of nitrogen loading. A thesis submitted for the degree of Doctor of Philosophy at the University of Otago, Dunedin, New Zealand. 125p.

Robertson BP, Gardner JPA, Savage C 2015. Macrobenthic–mud relations strengthen the foundation for benthic index development: A case study from shallow, temperate New Zealand estuaries. Ecological Indicators 58: 161-174.

Robertson BP, Savage C, Gardner JPA, Robertson BM, Stevens LM 2016c. Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. Ecological Indicators 69: 595-605.

Rodil IF, Lohrer AM, Hewitt JE, Townsend M, Thrush SF, Carbines M. 2013. Tracking environmental stress gradients using three biotic integrity indices: Advantages of a locally-developed traits-based approach. Ecological Indicators34, 560-570.

Rosenberg R, Nilsson HC, Diaz RJ 2001. Response of Benthic Fauna and Changing Sediment Redox Profiles over a Hypoxic Gradient. Estuarine, Coastal and Shelf Science 53(3): 343-350.

Skilton J, Thompson N 2017. Mahakipawa Estuary fine scale monitoring and broad scale habitat mapping 2017. Report prepared by SLR Consulting for Marlborough District Council. SLR Report Number 740.10043. 58p.

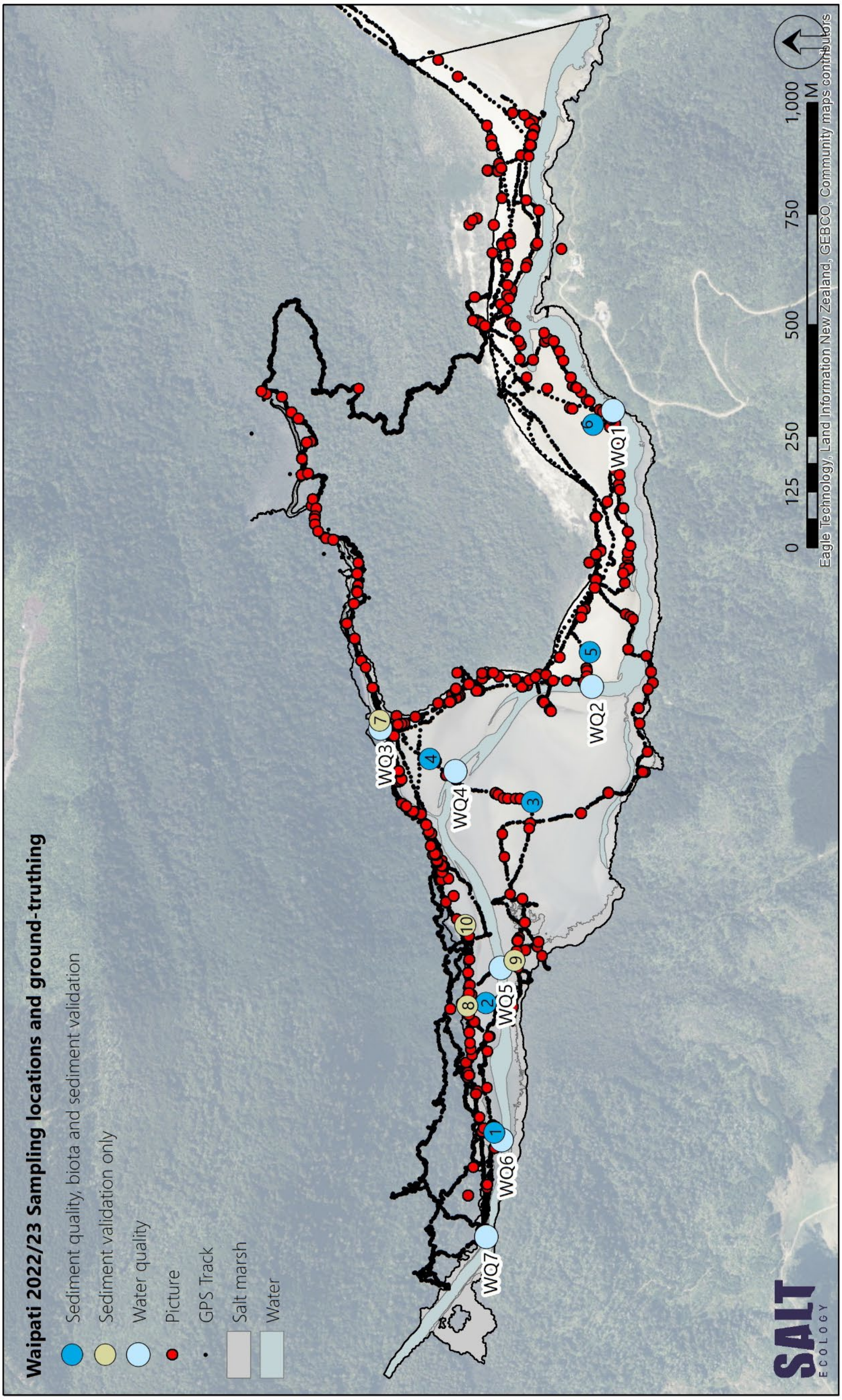
Stevens LM, Robertson BM 2014. Havelock Estuary 2014: Broad scale habitat mapping. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

Stevens LM, Forrest BM, Dudley BD, Plew DR, Zeldis JR, Shankar U, Haddadchi A, Roberts KL 2022. Use of a multi-metric macroalgal index to document severe eutrophication in a New Zealand estuary. New Zealand Journal of Marine and Freshwater Research: 1-20.

Thrush S, Hewitt, J, Norkko A, Nicholls P, Funnell G, Ellis J. 2003. Habitat change in estuaries: predicting broad scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progress Series, 263: 101-112.

WFD-UKTAG 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Water Framework Directive – United Kingdom Technical Advisory Group. https://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/TraC%20Macroalgae%20OMBT%20UKTAG%20Method%20Statement.PDF

APPENDIX 2. GROUND-TRUTHING



APPENDIX 3. RAW DATA ON DOMINANT SALT MARSH SPECIES

SubClass	Dominant species	SubDom1	SubDom2	Ha	%SaltMarsh
Tussockland	*Carex litorosa* (Sea sedge)	*Leptinella dioica*	*Coprosma propinqua* subsp. Propinqua (Mingimingi)	0.008	0.2
Sedgeland	*Isolepis cernua* (Slender clubrush)	*Leptinella dioica*		0.000	0.0
	Isolepis cernua (Slender clubrush)			0.004	0.1
	Isolepis cernua (Slender clubrush)	*Selliera radicans* (Remuremu)	*Apodasmia similis* (Jointed wirerush)	0.006	0.1
Rushland	*Apodasmia similis* (Jointed wirerush)	*Coprosma propinqua* subsp. Propinqua (Mingimingi)		0.2	3.7
	Apodasmia similis (Jointed wirerush)	*Leptinella dioica*	*Isolepis cernua* (Slender clubrush)	0.008	0.2
	Apodasmia similis (Jointed wirerush)			2.0	40.7
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Leptospermum scoparium* (Manuka)	1.2	23.9
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		1.4	28.0
	Ficinia nodosa (Knobby clubrush)	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.003	0.1
Herbfield	*Leptinella dioica*	*Phormium tenax* (New Zealand flax)	*Apodasmia similis* (Jointed wirerush)	0.1	2.8
	Leptinella dioica	*Phormium tenax* (New Zealand flax)		0.005	0.1
	Samolus repens (Primrose)	*Leptinella dioica*	*Isolepis cernua* (Slender clubrush)	0.006	0.1
	Samolus repens (Primrose)			0.001	0.02
Grand Total				5.0	100

APPENDIX 4. RAW DATA ON SUBSTRATE

Total estuary substrate, substrate within salt marsh, and substrate within other vegetated habitats.

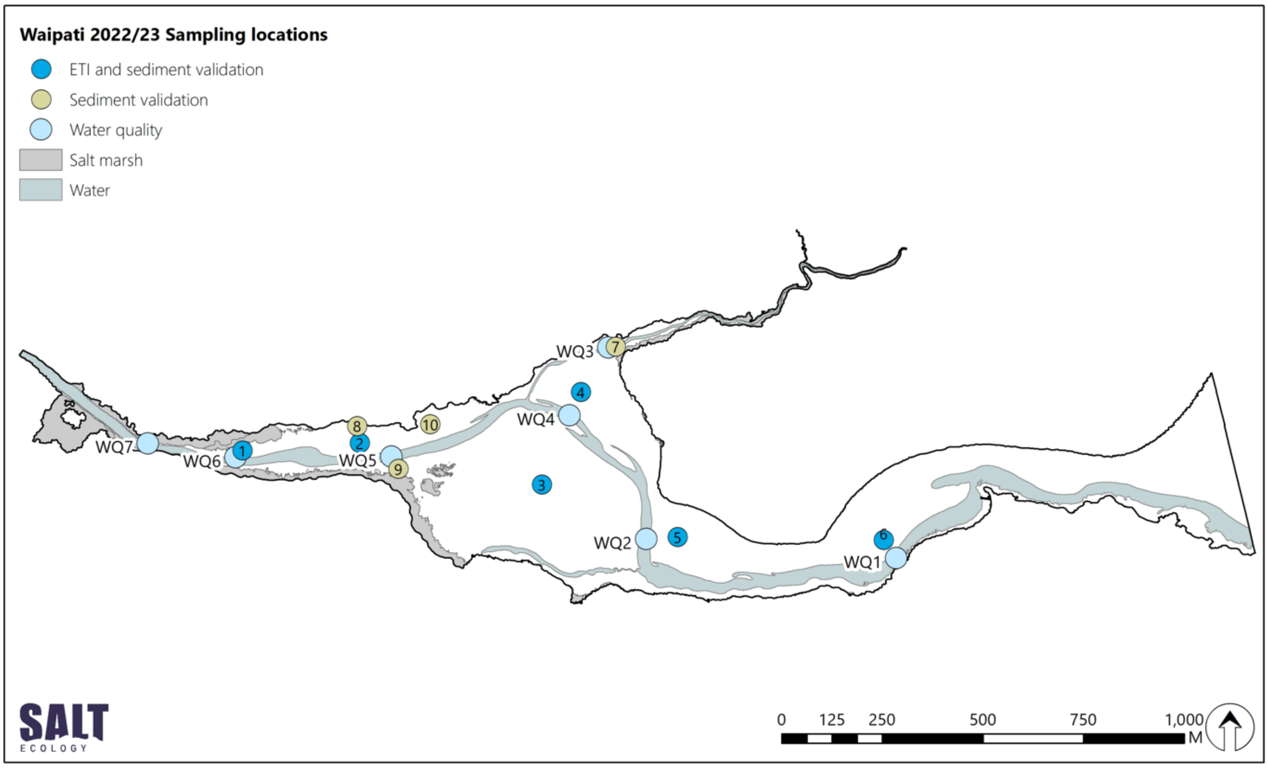
		Estuary intertidal area		Available intertidal habitat[1]		Salt marsh		Seagrass		Macroalgae	
Substrate Class	Features	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Boulder/Cobble/ Gravel	Boulder field	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0
	Cobble field	0.2	0.3	0.2	0.3	0.01	0.2	0.0	-	0.0	0.0
	Gravel field	0.4	0.7	0.4	0.8	0.02	0.3	0.0	-	0.01	15.1
Bedrock	Rock field	0.9	1.6	0.9	1.8	0.0	0.0	0.0	-	0.0	0.0
Sand (0-10% mud)	Mobile sand	11.6	20.7	11.6	22.7	0.0	0.0	0.0	-	0.0	0.0
	Soft sand	1.1	2.0	1.1	2.2	0.0	0.0	0.0	-	0.0	0.0
	Firm sand	15.6	27.7	15.5	30.3	0.02	0.4	0.0	-	0.0	0.0
Muddy Sand (>10-25% mud)	Soft muddy sand	13.4	23.8	13.4	26.1	0.0	0.0	0.0	-	0.0	0.0
	Firm muddy sand	2.6	4.7	2.5	4.9	0.1	1.8	0.0	-	0.1	83.5
Muddy Sand (>25-50% mud)	Soft muddy sand	7.1	12.6	3.8	7.4	3.3	65.0	0.0	-	0.001	1.3
	Firm muddy sand	1.0	1.7	1.0	1.9	0.0	0.0	0.0	-	0.0	0.0
Sandy Mud (>50-90% mud)	Firm sandy mud	1.2	2.1	0.0	0.0	1.2	23.5	0.0	-	0.0	0.0
	Soft sandy mud	0.5	0.9	0.1	0.2	0.4	8.8	0.0	-	0.0	0.0
	Very soft sandy mud	0.7	1.2	0.7	1.3	0.0	0.0	0.0	-	0.0	0.0
Zootic	Shell bank	0.01	0.01	0.01	0.01	0.0	0.0	0.0	-	0.0	0.0
Grand Total		**56.3**	**100.0**	**51.2**	**100.0**	**5.0**	**100.0**	**0.0**	**-**	**0.1**	**100.0**

1. Excludes salt marsh

APPENDIX 5. SEDIMENT VALIDATION

Sampling was undertaken at 10 sites (see map below) to validate subjective field estimates of sediment type (with respect to mud content) against laboratory grain size analysis of mud content. There was a match for 8 of the 10 samples. The two differences are shown in red in the Table below. In these cases, the laboratory result was within 1.5% mud content of the subjective threshold boundary, which was within the 5% tolerance adopted for this method. As such, no adjustments to field classifications were made.

Site	NZTM_E	NZTM_N	Sed firmness	Field code	Subjective % mud	Mud (%)	Sand (%)	Gravel (%)
1	1318651	4830602	very soft	vsSM50_90	50 to 90%	48.5	51.5	<0.1
2	1318942	4830621	soft	sMS10-25	10 to <25%	19.2	80.8	<0.1
3	1319395	4830517	firm	fMS10_25	10 to <25%	17.3	82.7	<0.1
4	1319491	4830747	firm	fS0_10	<10%	11.1	88.9	<0.1
5	1319732	4830387	mobile	mS0_10	<10%	3.3	96.7	<0.1
6	1320244	4830379	mobile	mS0_10	<10%	1.6	98.4	<0.1
7	1319578	4830860	soft	sMS25_50	25 to <50%	29.7	70.2	<0.1
8	1318936	4830663	very soft	vsSM50_90	50 to 90%	61.6	38.4	<0.1
9	1319038	4830556	soft	sMS25_50	25 to <50%	41.7	58.2	<0.1
10	1319117	4830667	soft	sMS25_50	25 to <50%	38.5	61.4	0.1



Site 1

Site 2

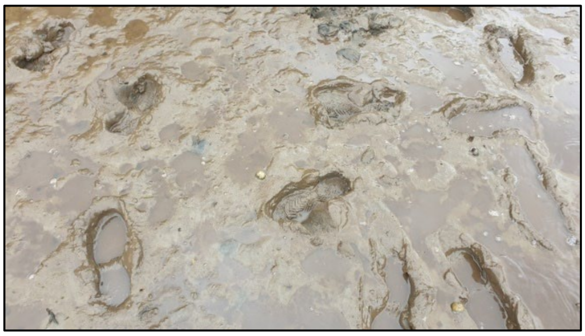
Site 3

Site 4

Site 5

Site 6

Site 7



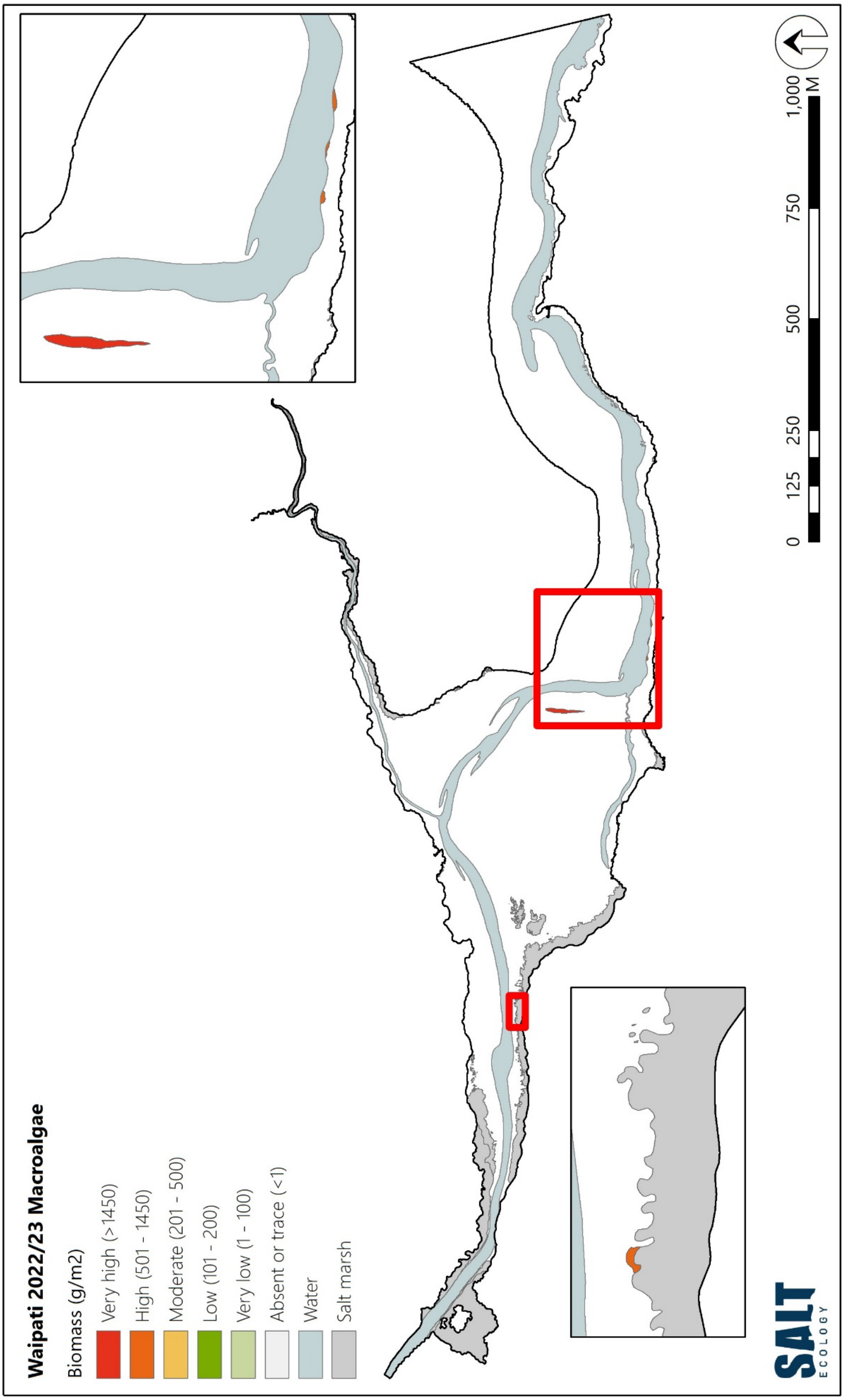
Site 8

Site 9

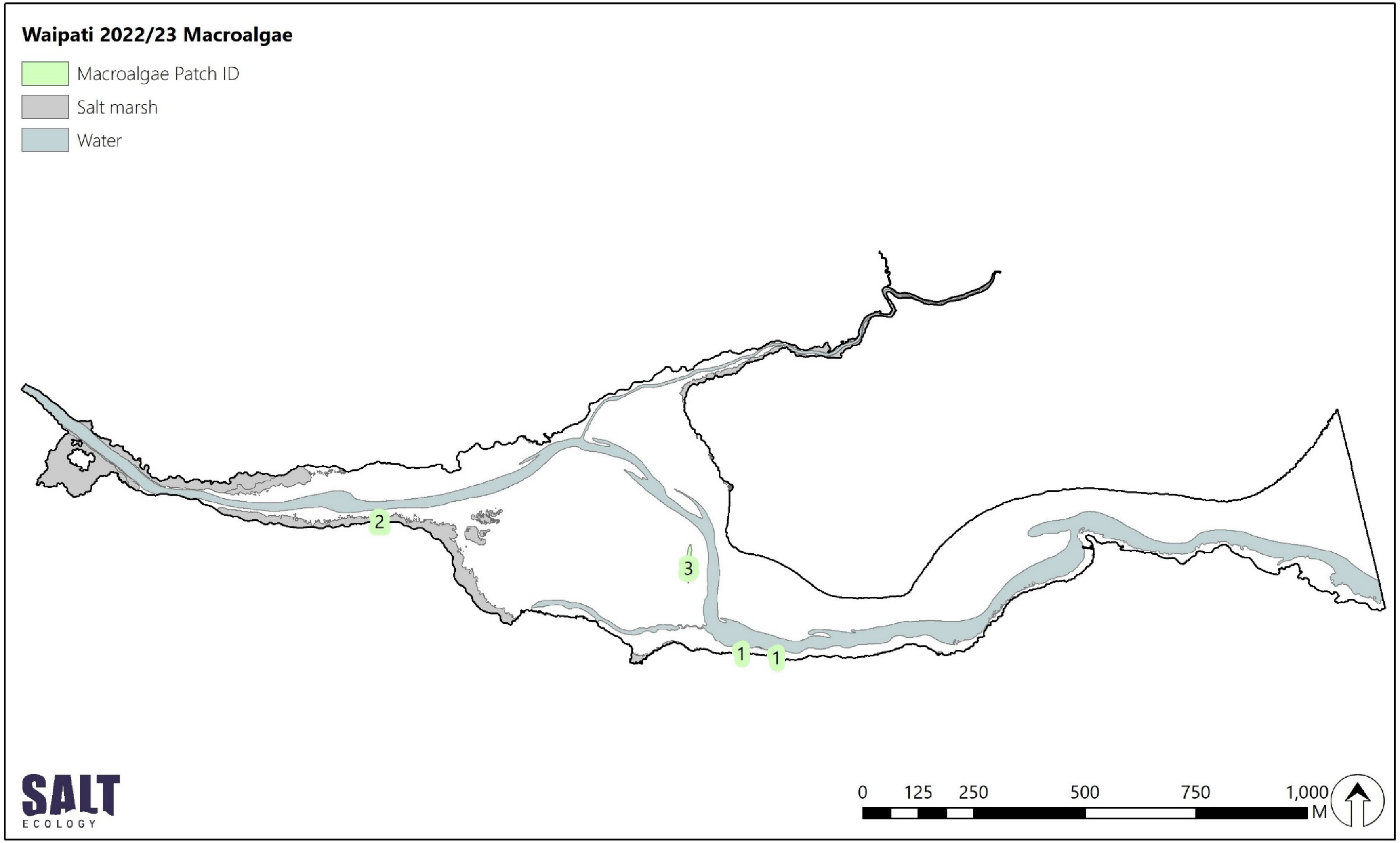
Site 10

APPENDIX 6. MACROALGAE BIOMASS AND PATCH INFORMATION

A. Biomass



B. Macroalgae patch information



Patch ID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (g/m^2)	Biomass Category	Entrained	DomHab	SubDom1	SubstrCode	Area_ha
1	Ulva	70	70	Dense (70 to <90%)	1200	High (501 - 1450)	0	Ulva sp (Sea lettuce)		GF	0.00938
2	Agsp	40	40	Low-Moderate (30 to <50%)	800	High (501 - 1450)	1	Agarophyton spp. (Agar weed)		sMS25	0.00083
3	Ulva Agsp	95 5	100	Complete (>=90%)	8800	Very high (>1450)	0	Ulva sp (Sea lettuce)	Agarophyton spp. (Agar weed)	fMS10	0.05173

APPENDIX 7. MACROFAUNA RAW DATA

Main group	Taxa	Habitat	EG	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
Amphipoda	Paracalliope novizealandiae	Infauna	I	-	-	1	-	2	-	-	-	1	1	-	-
Amphipoda	Paracorophium excavatum	Infauna	IV	91	68	195	257	260	230	327	283	187	279	1	7
Amphipoda	Urothoe sp. 1	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	2
Anthozoa	Edwardsia sp.	Epibiota	II	-	-	-	-	-	-	-	-	7	3	-	-
Bivalvia	Arthritica sp. 5	Infauna	III	27	21	11	5	-	-	-	-	-	-	-	-
Bivalvia	Austrovenus stutchburyi	Infauna	II	-	-	2	1	-	-	-	-	1	1	-	-
Bivalvia	Legrandina turneri	Infauna	-	-	-	-	-	-	-	-	-	43	49	-	2
Bivalvia	Paphies australis	Infauna	II	-	-	-	-	-	-	-	-	1	5	1	-
Cumacea	Colurostylis lemurum	Infauna	II	-	-	-	-	-	-	-	-	-	-	3	11
Decapoda	Austrohelice crassa	Infauna	V	-	-	1	1	-	-	-	-	-	-	-	-
Decapoda	Hemiplax hirtipes	Infauna	III	1	-	-	-	-	-	-	-	-	-	-	-
Nemertea	Nemertea	Infauna	III	-	-	-	-	-	-	-	-	-	-	-	1
Oligochaeta	Naididae	Infauna	V	-	-	-	-	-	-	2	3	1	1	-	-
Polychaeta	Boccardia syrtis	Infauna	II	-	-	-	-	1	3	-	-	3	-	-	-
Polychaeta	Capitella cf. capitata	Infauna	V	-	-	-	-	-	3	-	-	-	-	-	-
Polychaeta	Heteromastus filiformis	Infauna	IV	-	-	-	1	-	-	-	-	-	-	-	-
Polychaeta	Nicon aestuariensis	Infauna	III	8	9	4	4	-	-	-	-	-	-	-	-
Polychaeta	Scolecolepides benhami	Infauna	IV	28	31	5	5	9	5	10	10	2	3	-	-
Polychaeta	Scoloplos cylindrifer	Infauna	I	-	-	-	-	1	-	-	-	-	-	-	-
			Richness	5	4	7	7	5	4	3	3	9	8	3	5
			Abundance	155	129	219	274	273	241	339	296	246	342	5	23


SALT
ECOLOGY