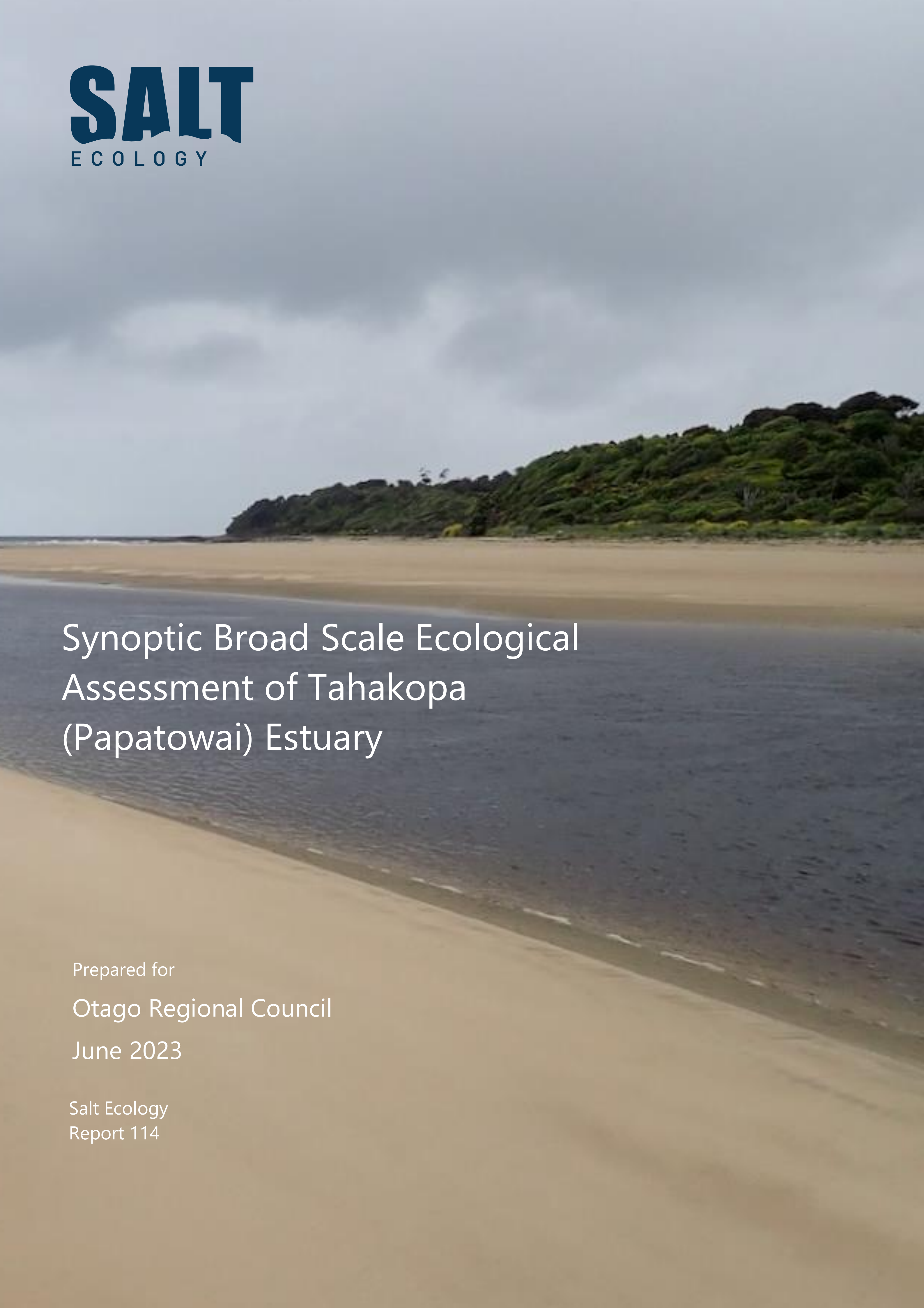

SALT ECOLOGY

Synoptic Broad Scale Ecological Assessment of Tahakopa (Papatowai) Estuary

Prepared for

Otago Regional Council

June 2023

Salt Ecology
Report 114

Cover and back photo: Tahakopa Estuary near entrance showing tannin-stained water, clean sands and bushy margin, November 2022.

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SALT ECOLOGY

For the People
Mō ngā tāngata

Synoptic Broad Scale Ecological Assessment of Tahakopa (Papatowai) Estuary

Prepared by

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

for

Otago Regional Council

June 2023

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SALT ECOLOGY

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

Tahakopa (Papatowai) Estuary (hereafter Tahakopa) is a medium-sized (~120ha), shallow, intertidally dominated (58% of the 118ha), tidal lagoon type estuary located in the Catlins area of South Otago. It is little-understood in terms of its habitats and ecological health. This report describes a survey conducted in November 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 Tahakopa Estuary is in a healthy state overall. It is one of few remaining estuaries in the Otago region with a catchment that still has a considerable area of indigenous forest, although farmland and exotic forestry are nonetheless well-developed in parts. A summary of key monitoring indicators assessed against condition rating thresholds for estuary health are provided in tables on the next page. The rating tables show that most indicators meet the classification of 'good' or 'very good'. Exceptions are predicted sedimentation, the macrofauna index AMBI 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 200m terrestrial margin and wider (31,173ha) catchment, with the catchment comprising mainly indigenous forest (~64%) and smaller areas of scrub (7%).
- An extensive salt marsh (17.7ha) that has suffered a small to moderate decline (~9%) since first available records in 1948. This decline reflects erosion of beds and losses due to reclamation and rock hardening of the margin.
- Clean, sand-dominated sediment in most areas outside the upper estuary margins.
- Opportunistic macroalgal growths in only a very small area of the upper estuary, with the area classified as representing High Enrichment Conditions (HECs; characterised by muddy sediments and entrained turfs of *Agarophyton* spp.) being only 0.1% of the intertidal area outside salt marsh.
- High-value seagrass habitat is likely naturally absent from the estuary, for reasons described in the report.
- A sediment-dwelling faunal community adapted to naturally harsh environmental conditions (e.g., seafloor scouring, low salinity water), reflected in 'fair' or 'poor' condition scores for the 'AMBI' macrofauna biotic index.
- Very low trace metal contaminant concentrations, consistent with the low to moderate level of catchment development and absence of significant contaminant sources.
- 'Very good' water quality at the time of sampling, based on the small suite of field indicators, including high dissolved oxygen and low chlorophyll-*a* (ratings shown in main report).

Summary of broad scale indicator condition ratings.

Broad Scale Indicators	Unit	Value	Condition Rating
200m terrestrial margin	% densely vegetated	66.4	Very Good
Mud-elevated substrate[1]	% of intertidal area >25% mud	5.8	Fair
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.884	Very Good
Seagrass	% decrease from baseline	no seagrass present	na
Salt marsh extent (current)	% of intertidal area	26.2	Very Good
Historical salt marsh extent[3]	% of historical remaining	>80%	Very Good
High Enrichment Conditions	ha	0.05	Very Good
High Enrichment Conditions	% of estuary	0.1	Very Good
Estuary-wide sedimentation indicators			
Sedimentation rate[4]	CSR:NSR ratio	1.1	Very Good
Sedimentation rate[4]	mm/yr	6.7	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 (see Fig. 3 of main report) and indicator condition ratings for sediment quality and macrofauna AMBI.

Parameter	Unit	1	2	3	4	5	6
Mud	%	19.9	7.4	21.9	4.8	16.6	2.9
aRPD	mm	35	45	35	50	65	na
TN	mg/kg	700	< 500	600	< 500	500	< 1300
TP	mg/kg	360	250	330	260	330	220
TOC	%	0.96	0.32	0.60	0.24	0.53	< 0.13
TS	%	0.09	0.06	0.07	0.03	0.05	0.02
As	mg/kg	4.6	5.7	5.2	5.1	6.2	6.5
Cd	mg/kg	0.028	0.013	0.024	0.010	0.016	0.012
Cr	mg/kg	9.1	6.8	9.1	6.8	7.7	5.8
Cu	mg/kg	5.4	3.2	5.2	2.7	3.6	2.1
Hg	mg/kg	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ni	mg/kg	6.2	4.5	6.4	4.2	5.0	3.3
Pb	mg/kg	3.7	2.5	4.0	1.9	2.7	1.4
Zn	mg/kg	32.0	22.0	33.0	14.7	21.0	11.3
AMBI	na	4.4	4.4	4.4	4.4	4.5	3.0

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

The extent to which Tahakopa Estuary is vulnerable to increased catchment-derived inputs of sediments (e.g. from plantation forest harvest) and nutrients (e.g. from farmland runoff) is uncertain. As well as a small HEC area, the area of mud-elevated substrate (>25% mud content) is relatively small at 5.8% of the unvegetated intertidal area (rated 'fair'). This situation may reflect factors such as a high estuary flushing rate, and retention and deposition of muddy sediment inputs within salt marsh. However, these low current impacts are contradictory to catchment models that predict a sedimentation rate of 6.7mm/yr, suggesting a potential impact far greater than evident at present. In addition, the synoptic water quality survey revealed salinity stratification in the water column, raising the possibility that the estuary will be susceptible to degraded bottom water conditions (e.g., depleted dissolved oxygen, phytoplankton blooms) during summer low flow periods. This is an important consideration given that ~42% of the estuary area is subtidal.

RECOMMENDATIONS

Tahakopa Estuary is in a healthy state overall; however, its vulnerability to ongoing and future inputs of catchment-derived muddy sediment and nutrients is uncertain, particularly in subtidal areas. To mitigate against potential risks the following is recommended:

- Undertake further investigation to assess risks of water quality degradation, focusing on the summer low flow period.
- Establish sediment plates to measure sediment accretion and mud content in representative parts of the central basin of the estuary.
- Evaluate current and potential future sediment sources to the estuary, and investigate options for a reduction of inputs. This could be facilitated by including Tahakopa Estuary in the ORC limit setting programme and establishing limits for catchment sediment (and nutrient) inputs that will maintain estuary health.
- Include Tahakopa Estuary in a broader review of the Otago estuary SOE monitoring programme, in order to understand and prioritise long term monitoring needs. This is likely to include a recommendation for ongoing broad scale mapping of estuarine intertidal habitats every 5 to 10 years, but the merit of more detailed fine scale monitoring needs to be considered further in a regional context.

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, Tautuku and Waipati (Chaslands) River estuaries. The current report describes the methods and results of a broad scale assessment undertaken on 30 November 2022 in a new location, Tahakopa Estuary in the southern Catlins at Papatowai (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 fine scale monitoring focuses on the dominant habitat with an estuary, the NEMP 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.

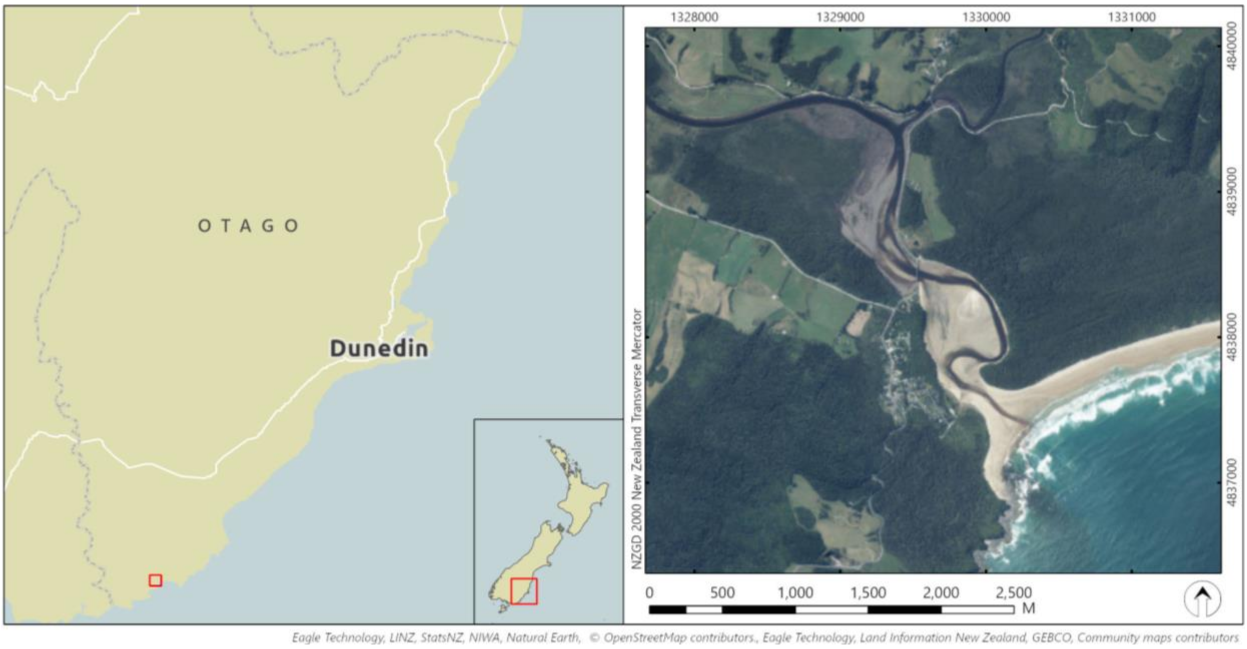


Fig. 1. Location of Tahakopa (Papatowai) Estuary, south Otago.

2. OVERVIEW OF TAHAKOPA ESTUARY

Tahakopa Estuary in South Otago is one of four estuarine systems in the Catlins (the others being Waipati-Chaslands, Tautuku, and Catlins Estuaries). It has a long history of human occupation, with historic Māori occupation sites in Tahakopa Valley, including numerous middens around the estuary margin at Papatowai (Hamel 1977, 2001).

The broad scale survey described here appears to be one of the first efforts to characterise the main features of Tahakopa Estuary and its ecological health. Limited earlier work has described cockle and pipi beds in the estuary, from surveys undertaken as part of archaeological investigations by Hamel (1977). Cockles, blue mussels, pipi, mud snails and paua are the most common shellfish found in the Papatowai middens.

European settlement began in the late 1800's, with land clearance for farming in the Tahakopa and Maclennan River Valleys, and logging of the forest for its timber resources, including rimu, totara and kahikatea (Hamel 1977; Tyrrell 2016). The first road bridge across the central estuary was completed in 1921.

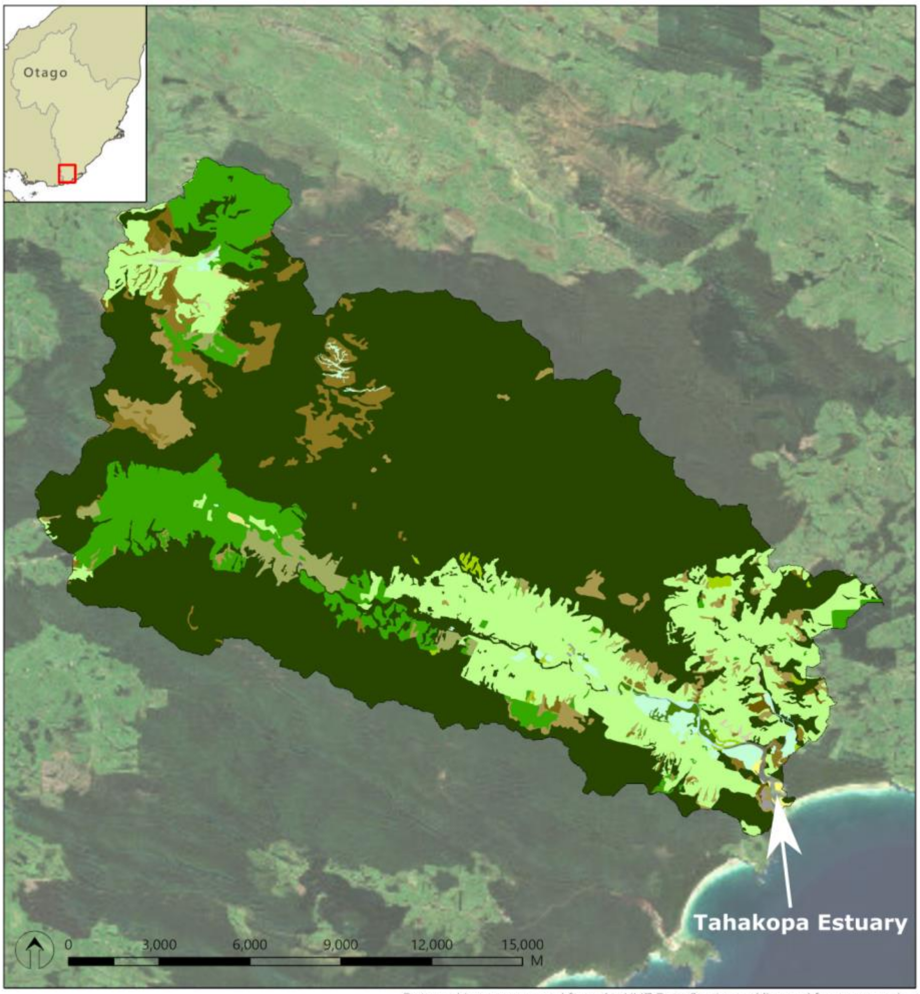
By regional and national standards, Tahakopa Estuary is of medium size (~118ha). Its typology was classified by Plew et al. (2018) as a shallow, short-residence time tidal river estuary (SSRTRE), which contrasts it's designation as a tidal lagoon-type estuary by Hume et al. (2016). The latter classification reflects that the estuary has reasonably extensive intertidal flats above and below the main road bridge. The estuary receives a mean freshwater inflow of ~7.2m^3/sec from the from Tahakopa and Maclennan Rivers, and has an estimated flushing time of 1.3 days (Plew et al. 2018). The Tahakopa River is the larger and longer of the two rivers, having a total length of 32km compared with 17.5km for Maclennan River.

The lower Tahakopa and Maclennan River catchments have been extensively developed for farmland; however, the upper catchments of both rivers remain in indigenous forest (Fig. 2). From Fig. 2, the land cover database (LCDB5; 2017/2018) shows that of a total catchment area of 31,173ha, 16.4% is presently in farmland ('High Producing Exotic Grassland'), used mainly for sheep and beef farming (Ozanne 2011). A further 10.7% is exotic plantation forestry, of which 1.4% (~423ha) was classified in 2018 as having been recently harvested. The exotic forestry is mainly in the upper Tahakopa catchment along the lower slopes. About two-thirds (~64%) of the catchment remains as indigenous forest, with a further 7% classified as a mix of indigenous and exotic scrub and shrubland.

ORC's regional programme for monitoring water quality and stream ecology has historically included three sites in the Tahakopa River catchment (upper, mid, lower) and one in the lower Maclennan. Monitored parameters include nutrients, suspended sediments, periphyton and macroinvertebrates. An unpublished ORC report '*State and Trends of River and Lake Water Quality in the Otago Region 2000-2020*' refers to high water quality in the upper Tahakopa catchment, but degraded water quality (high suspended sediments and *E. coli* bacteria) in the lower catchment. All monitoring sites were classified as having Macroinvertebrate Community Index (MCI) scores indicative of 'moderate organic pollution or nutrient enrichment', and were rated as 'fair' according to MCI criteria. However, in a separate study by Ozanne (2011), MCI scores for the upper and mid Tahakopa sites and the Maclennan site were rated as 'excellent'. Tahakopa River is described in the Otago Regional Plan (Water) as having significant ecosystem values, and various documents describe trout and a range of native freshwater fish in the catchment.

View looking north across the Tahakopa Estuary below the main road bridge (source: Moore 2015).

View upstream from main road bridge.



Catchment Land Use in 2018	ha	%
Artificial Surfaces	0	0
Built-up Area (settlement)	19.4	0.1
Surface Mines and Dumps	0.9	0.0
Transport Infrastructure	0	0
Urban Parkland/Open Space	2.1	0.0
Bare or Lightly Vegetated Surfaces	0	0
Sand and Gravel	23.4	0.1
Landslide	0	0
Alpine Grass/Herbfield	0	0
Gravel and Rock	0	0
Water Bodies	0	0
River, Lake or Pond	23.5	0.1
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	5,122.7	16.4
Low Producing Grassland	103.5	0.3
Tall Tussock Grassland	17.8	0.1
Depleted Grassland	0	0
Herbaceous Freshwater Vegetation	359.4	1.2
Herbaceous Saline Vegetation	0.9	0.0
Flaxland	0	0
Scrub and Shrubland	0	0
Fernland	33.3	0.1
Gorse and/or Broom	180.1	0.6
Manuka and/or Kanuka	1,072.2	3.4
Broadleaved Indigenous Hardwoods	886.1	2.8
Sub Alpine Shrubland	0	0
Mixed Exotic Shrubland	6.1	0.0
Matagouri or Grey Scrub	31.3	0.1
Forest	0	0
Forest Harvested	422.9	1.4
Deciduous Hardwoods	85.8	0.3
Indigenous Forest	19,816.1	63.6
Exotic Forest	2,903.3	9.3
	31,173.0	100

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

3. METHODS

3.1 OVERVIEW

The survey of Tahakopa Estuary was carried out on 30 November 2022. It consisted of broad scale habitat mapping of substrates and vegetation, sampling of sediment quality and macrofauna in representative areas, and a cursory water quality assessment. Fig. 3 shows the discrete sampling sites. Detail of the survey approach, sampling methods and analyses is provided in Appendix 1, and is summarised below and in Tables 1 and 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 Tahakopa 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.

Fig. 3. Location of sites for sediment quality and biota samples (1-6), sediment validation (1-10), and water quality (WQ1-WQ4) measurements.

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.

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).

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 in the estuary. 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.

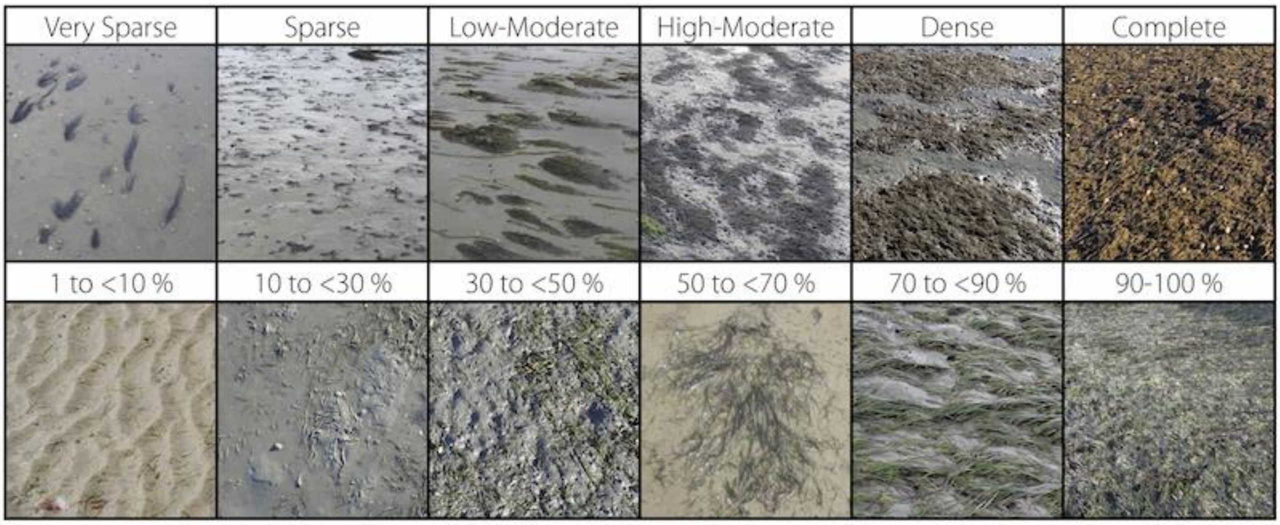


Fig. 4. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

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.

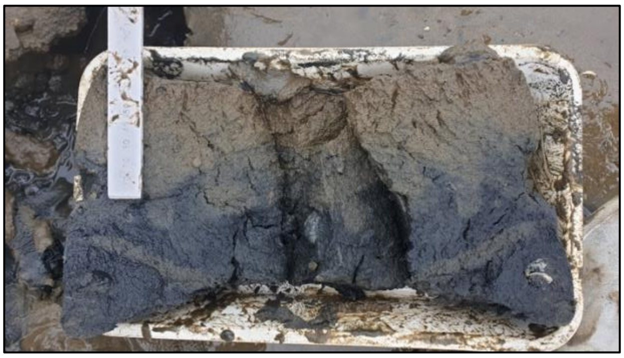
Lower Tahakopa Estuary.

- 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 described 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.



Measuring aRPD in the core profile (top), transferring the core to a mesh (0.5mm) sieve bag (middle) and assessing macroalgal biomass (bottom).

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 four sites (Fig. 3): the estuary channel at the main road bridge, a bridge near the confluence of Tahakopa and Maclennan Rivers, and an upper estuary site in each river channel, with probes lowered from a bridge in Maclennan River and a whitebait stand in Tahakopa River. Method detail is provided in Appendix 1.

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 characterisation, 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 column measurements were made around the high outgoing tide when stratification is likely to be most pronounced. An extra low tide sampling was undertaken at the main road bridge, to capture the 'worst-case' in terms of low salinity on the day of sampling.

Measuring water quality from an upstream whitebait stand.

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), geo-referenced it, and digitised the boundary to get an estimate of historic salt marsh extent.
- For seagrass % decrease from baseline, we assessed aerial imagery from 1948 (retrolens.co.nz), which showed no areas of distinguishable seagrass. This finding was confirmed by visually inspecting images captured in 1982, and 2019 (retrolens.co.nz; data.linz.govt.nz).

Salt marsh, rushland, in Tahakopa Estuary.

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. (2016a).
3. Mud-elevated substrate modified from Robertson et al. (2016a) 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	mg/kg	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. (2016a).
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 November 2022 mapping survey in Tahakopa 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. The mapped area was dominated by a mix of indigenous forest (29.6%), broadleaved indigenous hardwoods (23.7%) and rough pasture (Low Producing Exotic Grassland; 22.3% of area). Almost 10% was classified as mānuka/kānuka scrub. Overall, 66.4% of the margin was categorised as densely vegetated, which corresponds to a condition rating of 'good'.

Table 4. Summary of 200m terrestrial margin cover.

LCDB Class		Ha	%
1	Built-up Area (settlement)	10.8	2.5
2	Urban Parkland/Open Space	0.3	0.1
5	Transport Infrastructure	7.1	1.6
10	Sand or Gravel	6.0	1.4
16	Gravel and Rock	0.3	0.1
20	Lake or Pond	0.4	0.1
21	River	1.6	0.4
40	High Producing Exotic Grassland	22.8	5.2
41	Low Producing Grassland	97.6	22.3
45	Herbaceous Freshwater Vegetation	5.5	1.3
46	Herbaceous Saline Vegetation	0.2	0.0
47	Flaxland	1.3	0.3
52	Manuka and/or Kanuka	43.3	9.9
54	Broadleaved Indigenous Hardwoods	103.6	23.7
56	Mixed Exotic Shrubland	1.7	0.4
64	Forest - Harvested	0.4	0.1
69	Indigenous Forest	129.5	29.6
71	Exotic Forest	4.5	1.0
Grand Total		437	100
Total dense vegetated margin[1]		290	66

1. LCDB classes 45-71.

Maclennan River upstream margin.

Marram grass and tree lupin near the estuary entrance.

Indigenous forest margin in the lower estuary.

Farmland bordering the upper estuary.

Eroding banks of Tahakopa River channel.

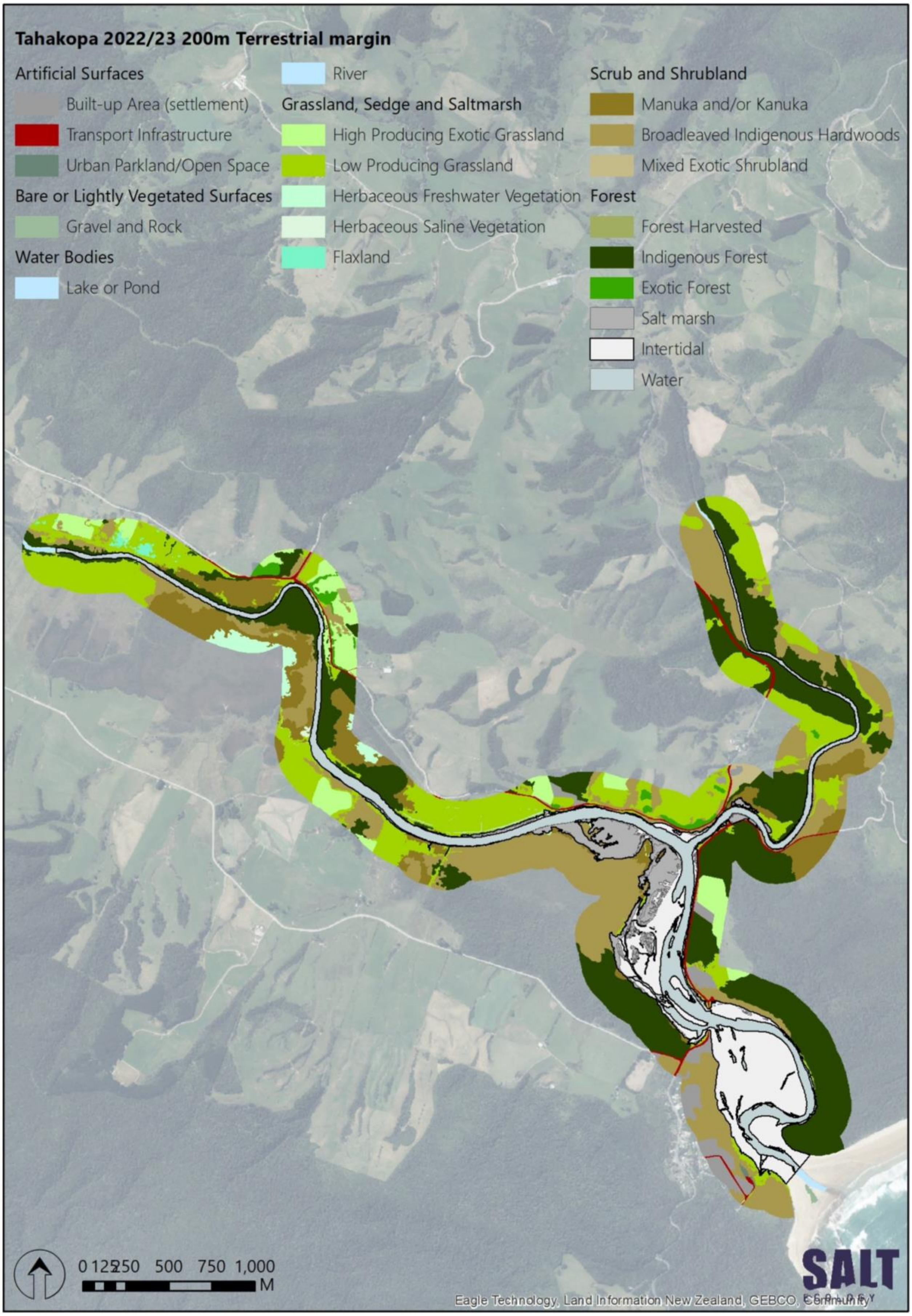
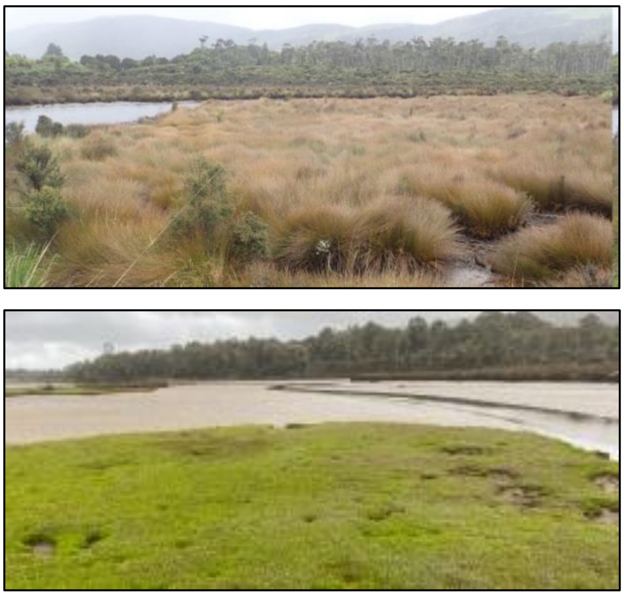


Fig. 5. Map of 200m terrestrial margin land cover.

4.2 SALT MARSH

Of a total mapped intertidal zone of 67.9ha, there was almost 18ha of salt marsh (Table 5), which represented ~26% of the area. The majority was located in the northwest section of the estuary near the confluence of the Tahakopa and Maclennan Rivers (Fig. 6). The salt marsh consisted mainly of rushland (~89%) dominated by jointed wirerush (*Apodasmia similis*). There were smaller areas classified as estuarine shrub (~6% of intertidal), which were dominated by salt marsh ribbonwood (*Plagianthus divaricatus*), and herbfield (5% of intertidal) consisting of a mix of sea primrose (*Samolus repens*) and remuremu (*Selliera radicans*). The main species and sub-dominant species are further described in Appendix 3. Most (~99%) of the substrate in salt marsh areas had an elevated mud component (>25% mud), with 87% being classified as sandy mud (50-90% mud). Substrate details for salt marsh and other vegetated habitat are provided in Appendix 4.

Based on imagery from 1948, an historic salt marsh area of 19.4ha was digitised. Hence the present-day mapped extent represents a 9% loss from this available baseline, corresponding to a condition rating of 'very good' (i.e., ~91% of historic salt marsh remains). The areas of decline were attributed primarily to erosion of herbfield on the mid-estuary flats and below the bridge on the eastern side, and losses of rushland above the main road bridge on the eastern margin where the road margin has been hardened with rip-rap protection. It should be noted that reclamation for the road occurred prior to 1948 and is not accounted for in the calculation of percent loss, further assessment is required to determine potential natural salt marsh extent.



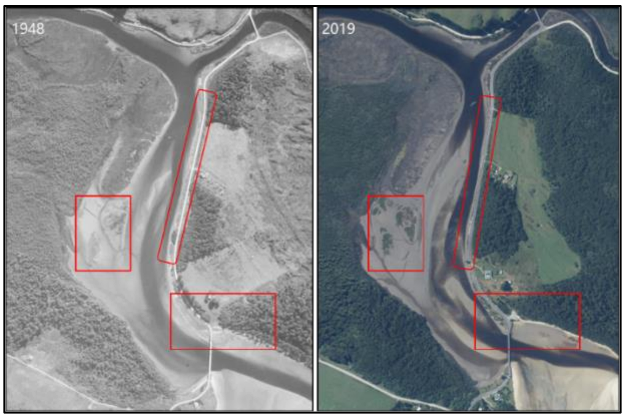
Rushland comprising jointed wirerush was the main salt marsh class (top). Mid-estuary herbfields (bottom).

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

Subclass	Dominant species	Ha	%
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	1.07	6.04
Tussockland	*Puccinella stricta* (Salt grass)	0.01	0.04
Rushland	*Apodasmia similis* (Jointed wirerush)	15.8	88.9
Herbfield	*Samolus repens* (Primrose) *Selliera radicans* (Remuremu)	0.9	5.0
Total		**17.7**	**100**

Salt grass, *Puccinella stricta*, in herbfield.

Erosion of rushland.



Salt marsh in 1948 compared with 2019.

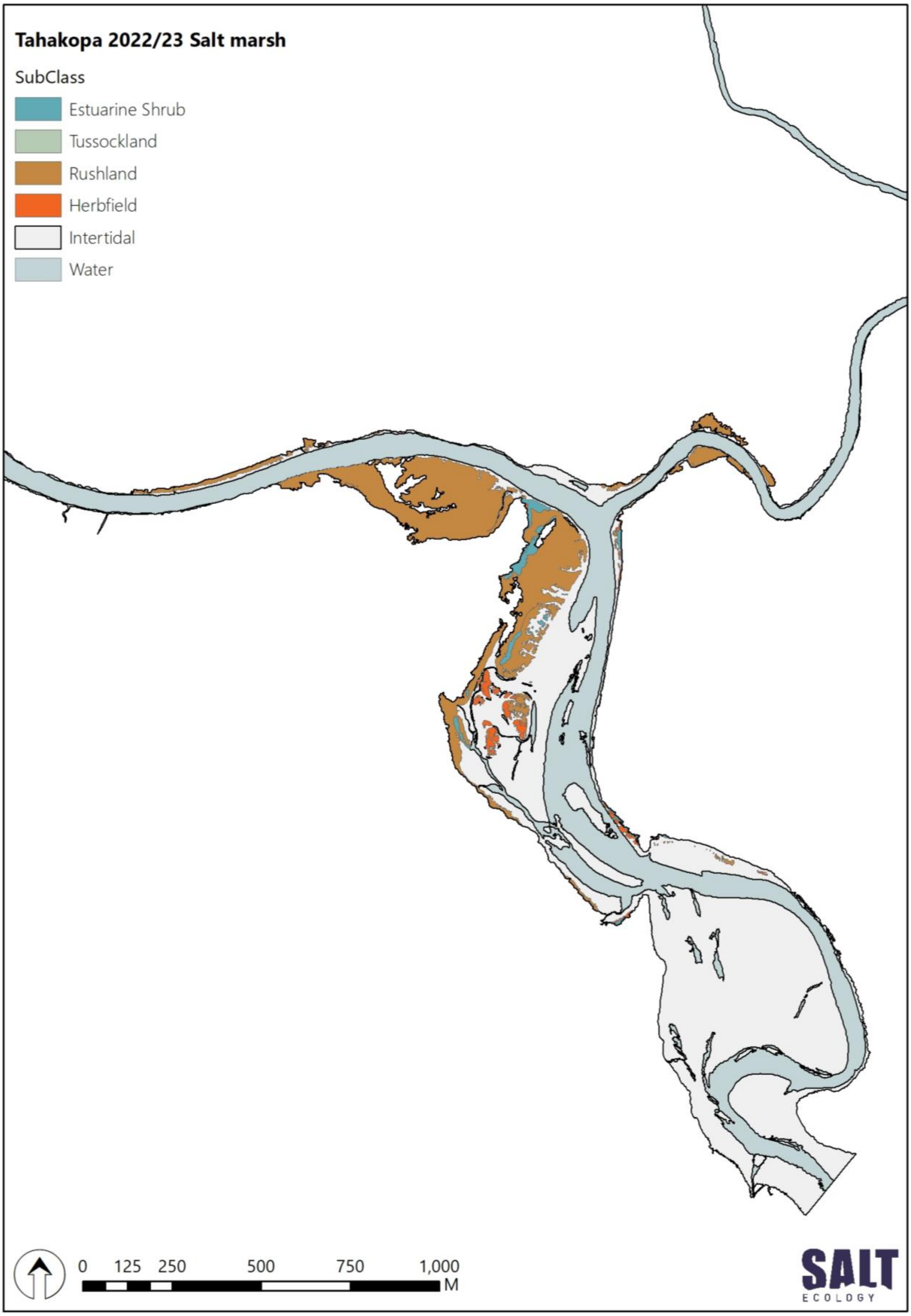


Fig. 6. Salt marsh sub-classes and their distribution.

4.3 SUBSTRATE

The mapped intertidal area outside the ~18ha of saltmarsh was 50.1ha, and had substrates dominated by sandy sediments (Table 6, Fig. 7). There was generally good agreement between the subjective classifications applied during mapping and the laboratory grainsize validation measures (Appendix 5). Two sediment validation samples (1 and 4) indicated field classifications needed adjusting with mapped substrate classifications updated to reflect the true grain size measures.

Table 6. Summary of dominant intertidal substrate outside areas of saltmarsh.

Substrate class	Features	Ha	%
Bedrock	Rock field	3.8	7.6
Unconsolidated coarse sediment (>2mm)	Artificial Boulder field	0.3	0.6
	Gravel field	2.3	4.6
	Cobble field	0.9	1.7
Sand (0-10% mud)	Firm sand	5.8	11.6
	Soft sand	1.0	1.9
	Mobile sand	23.7	47.4
Muddy Sand (>10-25% mud)	Firm muddy sand	2.3	4.6
	Soft muddy sand	7.1	14.2
Muddy Sand (>25-50% mud)	Firm muddy sand	0.0	0.0
	Soft muddy sand	2.2	4.3
Sandy Mud (>50-90% mud)	Firm sandy mud	0.0	0.0
	Soft sandy mud	0.7	1.3
	Very soft sandy mud	0.1	0.1
Zootic	Shell bank	0.04	0.09
Grand Total		**50.1**	**100**

Outside salt marsh, ~61% of the intertidal estuary area consisted of sand (<10% mud content). Much of this was represented by the intertidal flats of rippled mobile sand in the lower estuary. Sand mobility in this area predominantly reflects regular river and tidal flushing.

Whereas sediments inside salt marsh patches were largely mud-dominated, outside of the salt marsh only 5.8% of sediments had an elevated mud content (>25% mud), with the extent of mud-dominated sediment (>50% mud) being very low (0.8ha, 1.4% of area). The most extensive areas of mud-elevated (>25% mud) sediment occurred along parts of the western estuary margin between the main road bridge and the Tahakopa-Maclennan River confluence.

Natural rock habitat was reasonably extensive, and included areas of bedrock along the western side of the estuary down-channel from the main road bridge, as well as boulder, cobble and gravel habitat. In total, the combined area of these substrate types covered ~14% of the estuary area outside salt marsh, representing ~10% of the total mapped estuary area (Table 6, Fig. 7). By contrast, the only artificially hardened substrate (e.g., rip-rap walls, gabion baskets) occurred in a small area, including the mid-estuary eastern margin (upstream of the bridge), which has been armoured to protect roading infrastructure. Although artificial substates were small in area (0.4% of the total mapped area), there was an estimated 830m of hardened margin, which represents ~3.2% of the perimeter of the mapped area.

Rippled mobile sand flats in lower estuary.

Sand amongst bedrock down-channel from the main road bridge.

Muddy Tahakopa River margin in upper estuary.

Rock armouring of roadside margin.

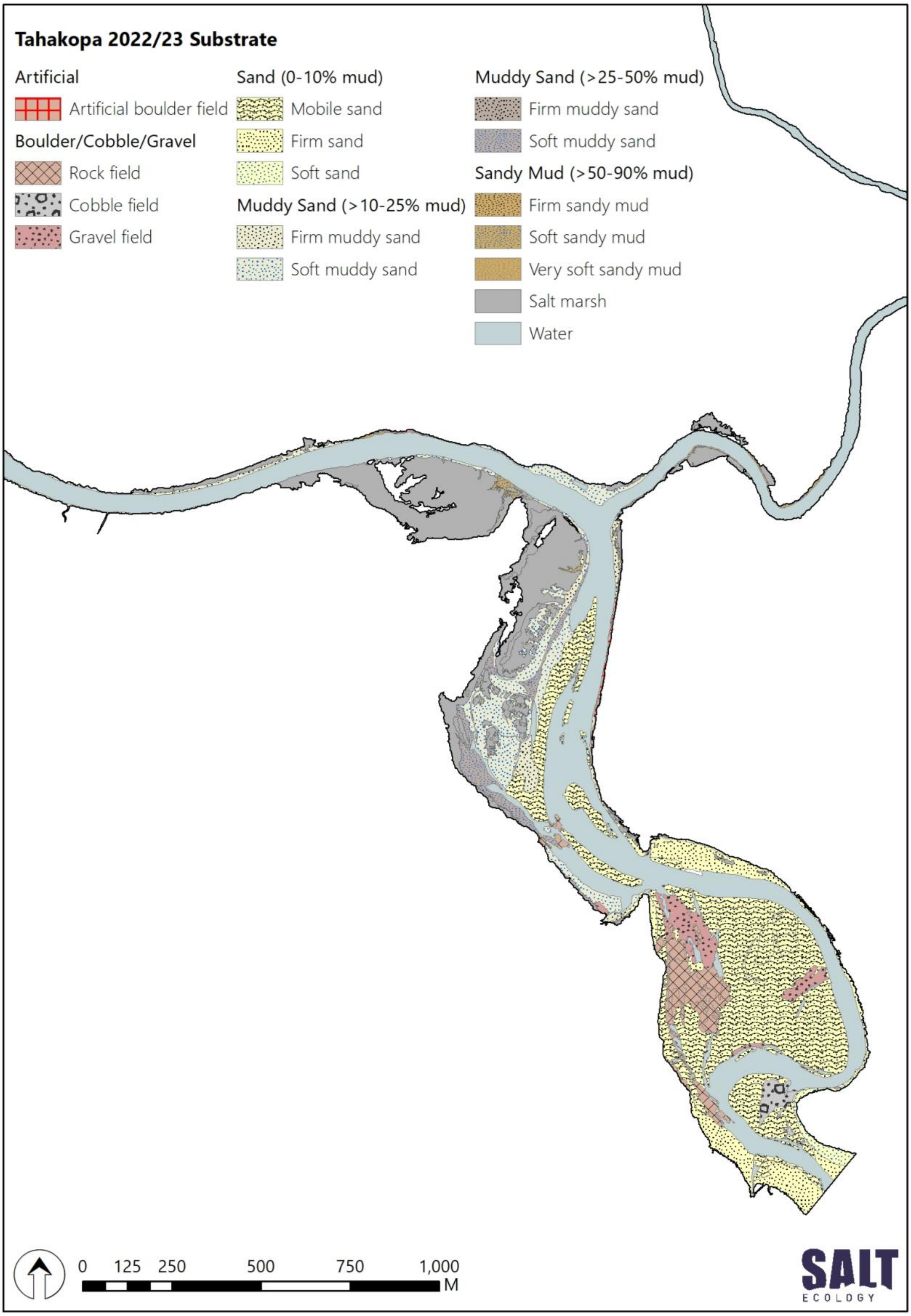


Fig. 7. Dominant intertidal substrate in areas outside salt marsh.

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

In the available intertidal habitat (i.e., outside salt marsh patches), opportunistic macroalgae was mapped as absent or trace (<1% cover) across 95.4% of the area (Table 7). Macroalgae was conspicuous in the lower estuary, where it consisted mainly of *Ulva* spp. attached to bedrock (Fig. 8), which formed patches classified as having a high or very-high biomass up to ~2kg/m^2 (Table 7, Appendix 6).

Macroalgae was also conspicuous subtidally within the low tide channel where it was attached to firm substrate (bedrock/cobble/gravel) enabling the attachment and growth of long filamentous strands of *Ulva* spp.

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%)	47.8	95.4
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	0.2	0.3
Low-Moderate (30 to <50%)	0.717	1.4
High-Moderate (50 to <70%)	0.0	0.1
Dense (70 to <90%)	1.36	2.7
Complete (≥90%)	0.05	0.1
Total	50.1	100

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	47.8	95.4
Very low (1 - 100)	0.0	0.1
Low (101 - 200)	0.0	0.0
Moderate (201 - 500)	0.1	0.2
High (501 - 1450)	0.78	1.5
Very high (>1450)	1.38	2.8
Total	50.1	100

In the lower estuary the red seaweed *Agarophyton* spp. was relatively sparse and was growing attached to firm substrate or cockles. By contrast, two upper western estuary areas had *Agarophyton* spp. beds that were growing as entrained turfs in mud-dominated sediments along the edge of the salt marsh. These patches are relatively small at present, but appear to be well-established beds that supported a reasonably high *Agarophyton* biomass (up to 6.5kg/m^2). These mud-dominated areas of entrained macroalgae were classified as HECs (Fig. 9), and showed symptoms that included relatively poor oxygenation (i.e., shallow aRPD; see photos). However, the total HEC area was small (0.05ha) and represented only 0.1% of the available intertidal habitat, a condition rating of 'very good'.

Due to the low overall spatial extent of macroalgae (<5% of the available intertidal habitat outside of salt marsh), the OMBT EQR score was 0.884, which equates to a condition rating of 'very good' (Appendix 6).

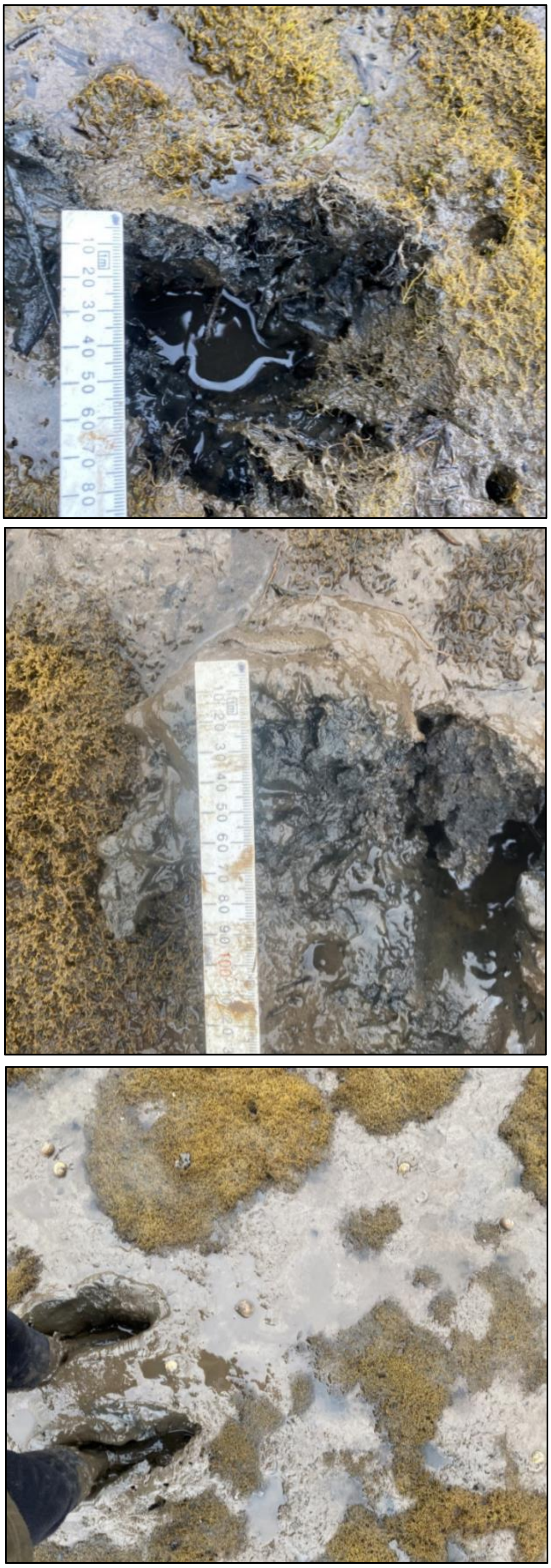
Ulva on bedrock substrate in lower estuary.

Long filamentous strand of *Ulva* spp. in low tide subtidal channel of lower estuary.

Relatively sparse cover of *Ulva* spp. east of Site 6 in lower estuary.

Tahakopa River channel with *Ulva* spp. on sand and cobble.

Agarophyton spp. in entrained turfs bordering salt marsh in mid-estuary (top) and Tahakopa arm upper estuary (bottom).



HECs evident as muddy, oxygen-depleted sediments among entrained turfs of *Agarophyton* spp., near sediment sampling Site 3 (top) and Site 8 (middle, bottom).

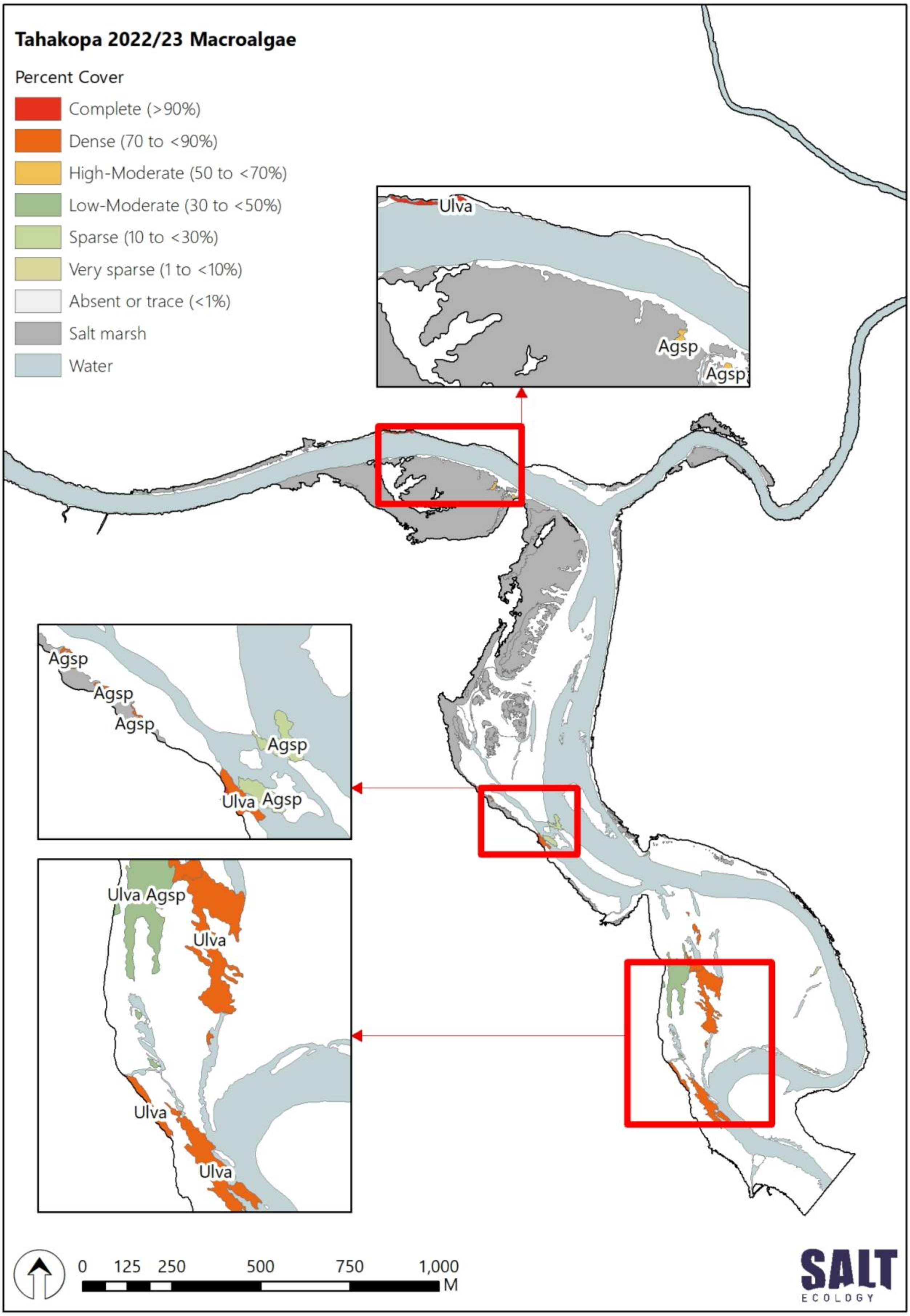


Fig. 8. Distribution and percent cover classes of macroalgae. Annotations indicate the macroalgal species as being: *Ulva* = *Ulva* spp., Agsp = *Agarophyton* spp.

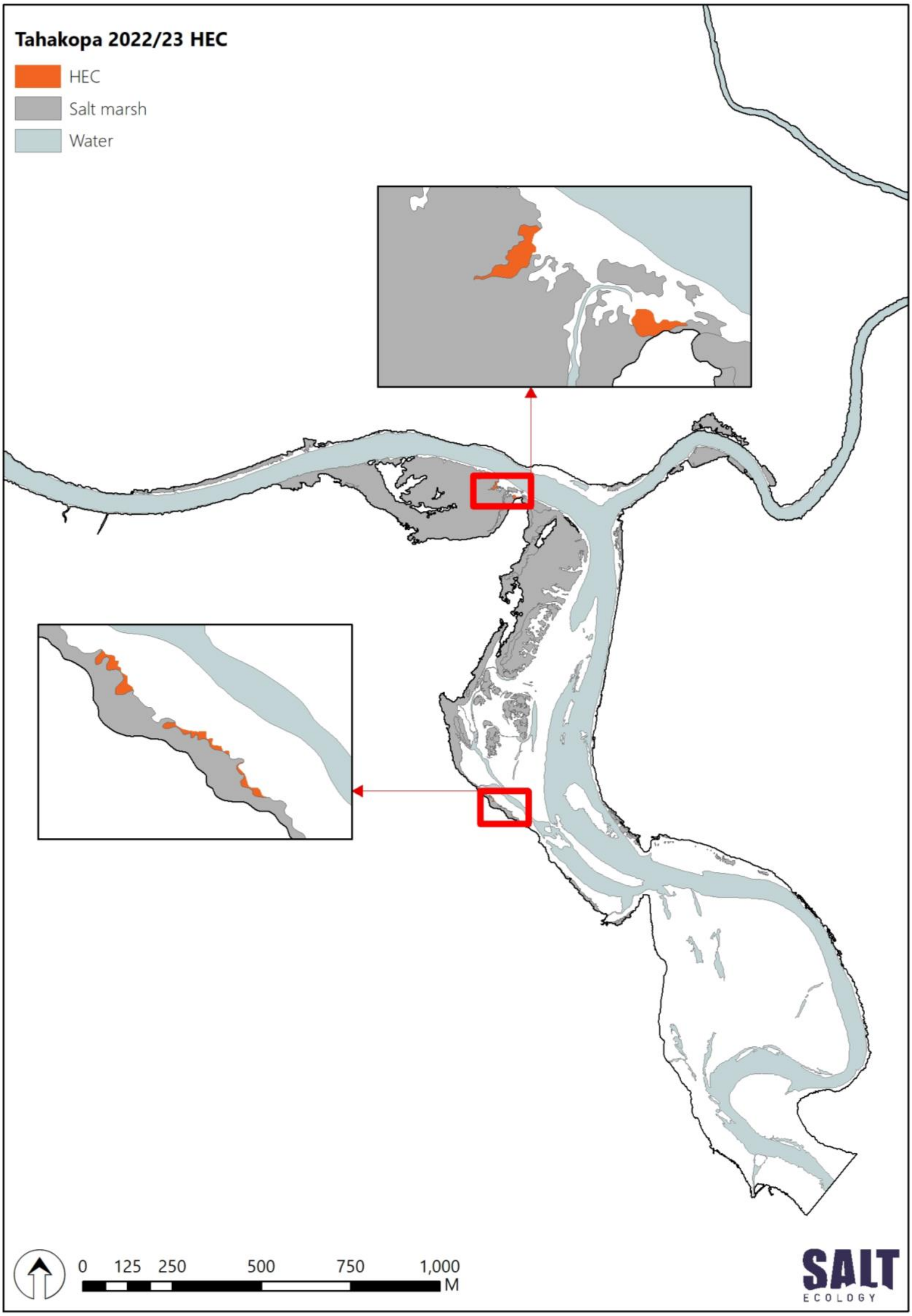


Fig. 9. Areas of High Enrichment Conditions (HEC), reflecting where stable beds of *Agarophyton* spp. were entrained into a mud-dominated sediment matrix with a shallow aRPD.

5. SEDIMENT QUALITY AND BIOTA

Illustrative photos of Sites 1-6, where sediment quality and biota sampling were undertaken, are provided on the next page. Note that sediment quality and biota sampling was not undertaken in the small areas of muddy upper estuary habitat, but these areas were sampled as part of the sediment validation described in Appendix 5.

5.1 SEDIMENT QUALITY INDICATORS

The results of the grain size analysis highlight the sand-dominated nature of the substrate (Fig. 10). Sediment mud content was generally higher upstream of the road bridge (Sites 1, 2, 3 & 5) and lowest near the estuary entrance at Site 6. However, there was not a strong mud gradient from the upper to lower estuary.

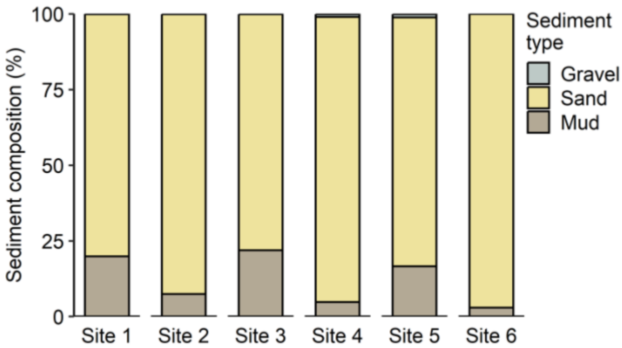


Fig. 10. Sediment grain size in composite samples. Size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

Key sediment quality indicators are compared to condition rating thresholds in Fig. 11, with key points being:

- The mud content of upper estuary Sites 1, 3 and 5 was rated 'fair', but was less than the 25% mud threshold where significant biological changes due to muddiness are expected. The mud contents from upper estuary sediment validation samples 7-9 were >25% (range 32-65%), which placed them in the 'poor' rating category (see Appendix 5).
- Other trophic state indicators were rated 'good' or 'very good', although the muddier sites tended to have higher trophic indicator values. Nonetheless, the sediments overall had low total nitrogen (TN) and low organic carbon (TOC) values, and were well-oxygenated (deep aRPD; see photos next page). The latter is in contrast to the poorly oxygenated sediments from HEC areas described above.

Overall, upstream areas were muddier but outside of the areas classified as HECs, there appear to be no symptoms of highly degraded sediments in the estuary. Even within the small areas classified as HECs, broad scale ground truthing did not reveal symptoms associated with extreme enrichment (e.g., intense black sediment at sediment surface, emission of a strong sulfide odour, surface growths of sulfur-oxidising bacteria).

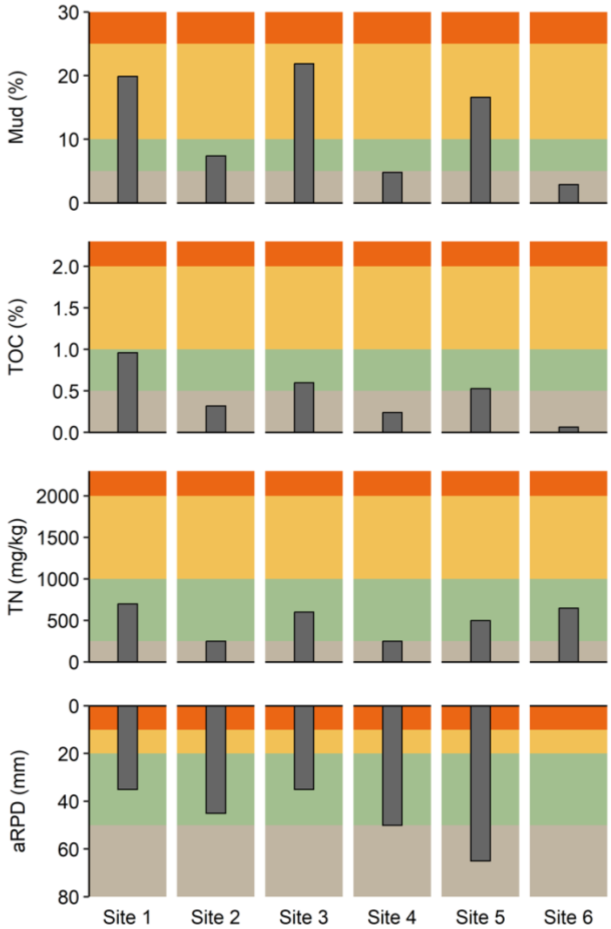


Fig. 11. Grey bars show sediment %mud, total organic carbon, and total nitrogen in composite samples, relative to condition ratings. Note that TN at Sites 2 & 4 was less than method detection limits (MDL), hence half of the MDL value is shown. The aRPD was indeterminate at Site 6.

Condition rating key:

Very Good	Good	Fair	Poor

Site 1

Site 1 - core

Site 2

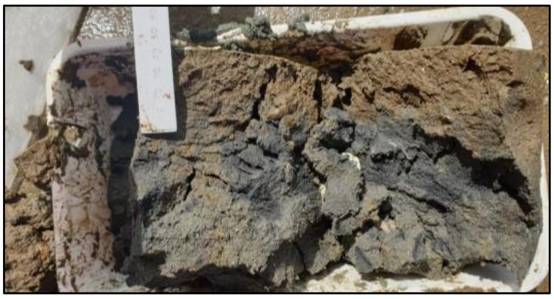
Site 2 - core

Site 3

Site 3 - core

Site 4

Site 4 - core



Site 5

Site 5 – core

Site 6

Site 6 – core

Trace metal concentrations were very low in all samples and rated 'very good' (Table 8). This rating means that metal concentrations were less than half of ANZG (2018) Default Guideline Values (DGV). These results are consistent with the relatively natural state of more than two thirds of the catchment, and the absence of significant sources of chemical contaminants.

Table 8. Trace metal concentrations (mg/kg) 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	4.6	0.028	9.1	5.4	< 0.02	6.2	3.7	32.0
2	5.7	0.013	6.8	3.2	< 0.02	4.5	2.5	22.0
3	5.2	0.024	9.1	5.2	< 0.02	6.4	4.0	33.0
4	5.1	0.010	6.8	2.7	< 0.02	4.2	1.9	14.7
5	6.2	0.016	7.7	3.6	< 0.02	5.0	2.7	21.0
6	6.5	0.012	5.8	2.1	< 0.02	3.3	1.4	11.3
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 occurring.

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 most abundant at Site 1 (3-4/m^2), and sparse at Sites 4 and 5 (0.1-0.5/m^2). Except for evidence of invertebrate burrows at the other sites, no surface epibiota were noted, although partially buried cockles were present at Site 6 in the lower estuary.

Mud snails were conspicuous on the sediment surface at Site 1.

By contrast, all sites had a suite of sediment-dwelling macrofauna in the core samples. A total of 26 species or higher taxa were recorded, representing 10 main organism groups (Appendix 7). Fig. 12 shows the average species richness per site was low-to-moderate, but organism abundances were high.

From a summary of the dominant macrofauna 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).

At Site 6, moderately-high abundances were due almost exclusively to the small bivalve *Legrandina turneri*. This is a poorly-understood endemic species that appears to be limited to southern New Zealand.

Despite cockle (*Austrovenus stutchburyi*) and pipi (*Paphies australis*) beds having been described from the estuary previously (see Section 2), core sampling revealed only very low cockle abundances at Sites 1, 4, 5 and 6 (shell widths up to 30mm), and four juvenile pipi (shell width <5mm) in one of the cores from Site 6 (Appendix 7).

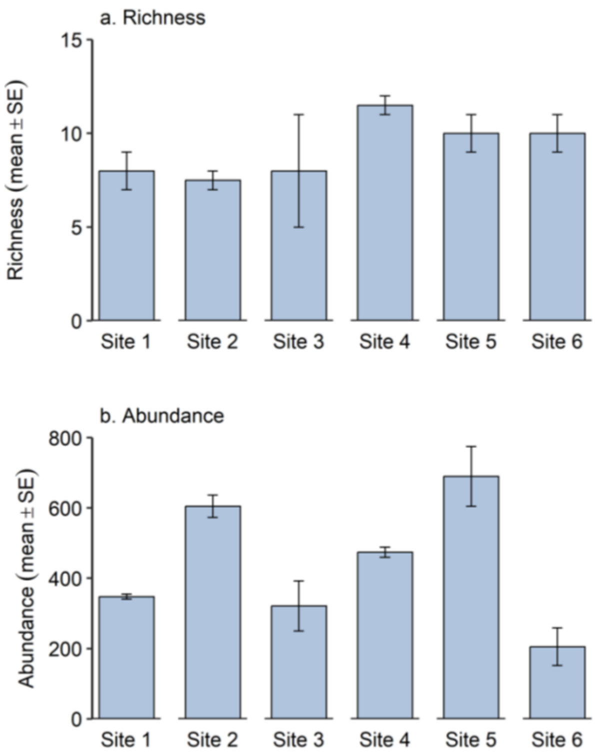


Fig. 12. Mean (± SE) taxon richness and abundance in duplicate core samples.

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	*Paracalliope novizealandiae*	I	-	9	2	3	7	5	Shrimp-like crustaceans common in NZ estuaries. Despite EG-I classification, it appears reasonably tolerant to muddy habitats.
Amphipoda	*Paracorophium excavatum*	IV	540	1143	605	816	1246	18	Corophioid amphipod that is an opportunistic tube-dweller, tolerant of muddy and low salinity conditions.
Bivalvia	*Arthritica* sp. 5	III	25	4	-	-	4	-	A small deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.
Bivalvia	*Legrandina turneri*	-	-	-	-	6	1	357	Small endemic bivalve that appears to be limited to southern NZ. Diet unknown.
Cumacea	*Colurostylis lemurum*	II	1	15	6	1	-	-	Small crustacean considered sensitive to enrichment. Some species can survive in brackish water.
Gastropoda	*Potamopyrgus estuarinus*	IV	21	-	-	-	-	-	Small endemic snail, requiring brackish conditions. Eats detritus, microbes & algae. Tolerant of muddy sediments and organic enrichment.
Oligochaeta	Naididae	V	3	2	1	20	55	1	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered pollution-tolerant.
Polychaeta	*Boccardia syrtis*	II	-	-	2	4	-	8	A small surface deposit-feeding spionid. Found in a wide range of sand/mud habitats. Considered sensitive to organic enrichment.
Polychaeta	*Capitella* cf. *capitata*	V	5	-	4	1	19	4	Subsurface deposit feeder, which can be abundant in disturbed on enriched conditions.
Polychaeta	*Nicon aestuariensis*	III	11	-	-	-	-	-	Omnivorous worm that is tolerant of freshwater.
Polychaeta	*Scolecolepides benhami*	IV	88	24	15	71	40	-	A spionid, surface deposit feeder that is rarely absent in sandy/mud estuaries.

Paracorophium excavatum

Arthritica sp. 5

Potamopyrgus estuarinus

Scolecolepides benhami

Overall, from the descriptions of the dominant species in Table 9, it is evident that many macrofauna 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 species, and resulting in elevated AMBI scores (Fig. 13) that suggest 'poor' ecological conditions at Site 1-5, and 'good' conditions at Site 6. However, the AMBI score at Site 6 was skewed by the fact that the dominant organism, *Legrandina turneri*, is not accounted for as it does not have an assigned EG.

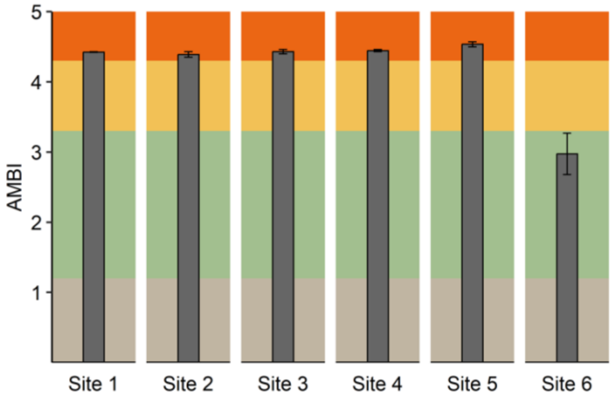


Fig. 13. Mean (± SE) macrofauna AMBI scores in duplicate cores, relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

A multivariate analysis of macrofauna community composition is summarised in Fig. 14. The top panel illustrates the magnitude of difference among sites in terms of their macrofauna taxa and abundances. All sites had their distinct biota, but Site 1 (upper estuary) and Site 6 (lower estuary) were 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.

For example, Site 1 was the only location having freshwater-tolerant species not sampled from the other sites, namely the estuarine snail *Potamopyrgus estuarinus* and 'ragworm' *Nicon aestuariensis*. On the other hand, Site 6 was missing the ubiquitous spionid worm, *Scolecolepides benhami*, which was common at the other sites.

Both panels in Fig. 14 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. Total organic carbon (and correlated variable total sulfur), and to a lesser extent %mud, most strongly explained the upper to lower (i.e., left-to-right in the Fig. 14 plot) estuary pattern of compositional change in the macrofauna. For example, sediment TOC was highest at Site 1, lowest at Site 6, and at intermediate levels at mid-estuary sites. Sediment aRPD was the only variable that had a reasonably strong association with the vertical site separation in Fig. 14, reflecting the upper to lower estuary transition from less oxygenated to well-oxygenated sediments. That said, none of Sites 1-6 had poor oxygenation, as this was a feature of the small muddy HEC areas only.

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.

Soft muddy sand at Site 1.

Firm sand at Site 4.

Mobile sand at Site 6.

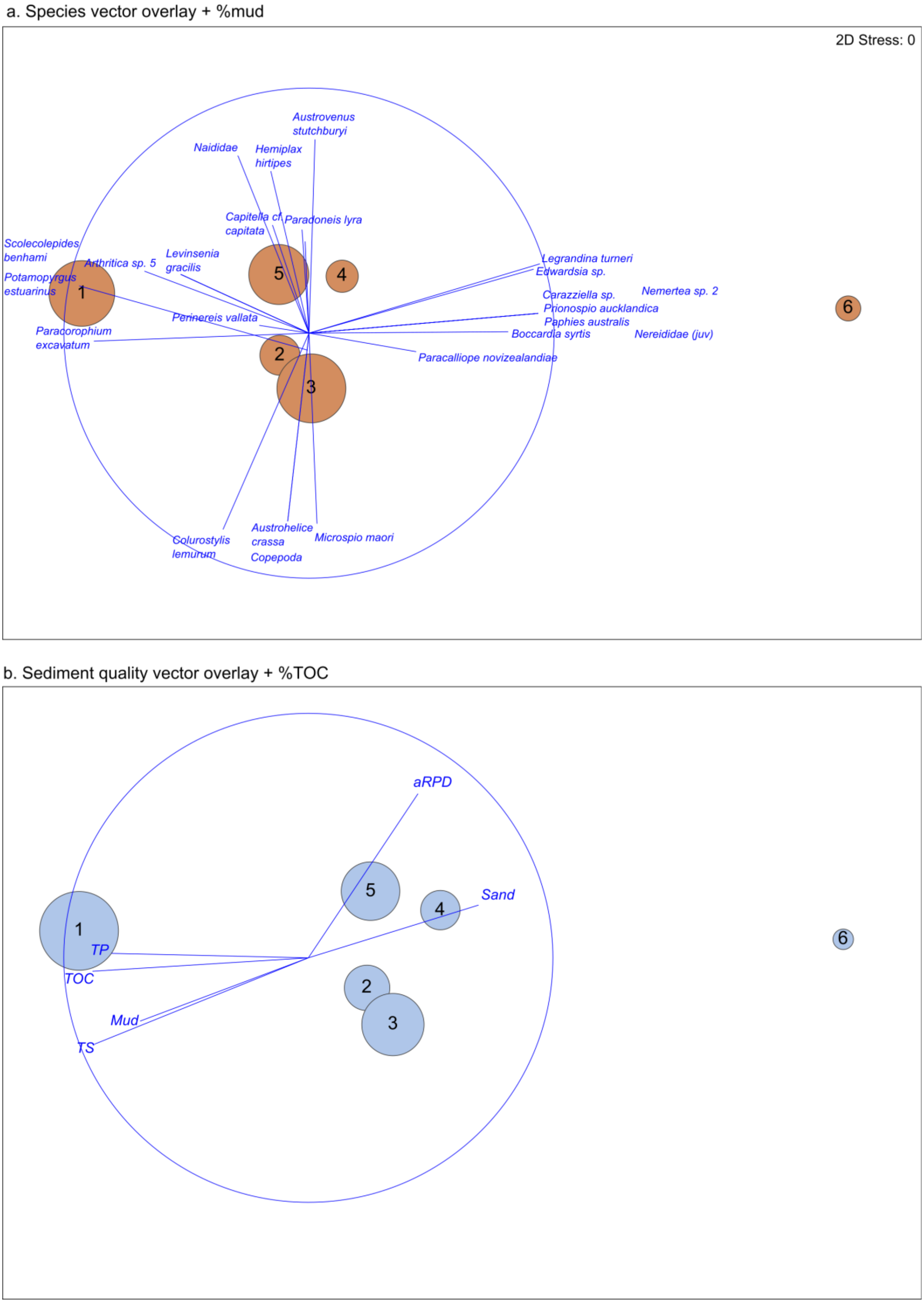


Fig. 14. Non-metric MDS ordination of macrofaunal core samples for each site.

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 %TOC (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 the water column was stratified during high tide at measurement stations around the Tahakopa-Maclennan confluence and further up-channel. These areas had low salinity surface water (1.4-5.9ppt) overlying deeper, higher-salinity seawater (15.2-31.1ppt) that was pushed up-channel with the incoming tide. The marked transition between these layers is referred to in Table 10 as the halocline. There was no stratification at the main road bridge, although the high salinity water evident around high tide (30.1ppt) was flushed out and replaced by relatively low salinity water (8.7-9.3ppt) at low tide.

Despite the stratification of mid-upper estuary waters there was no evidence of water quality degradation, with the following noted:

- Dissolved oxygen was generally high, and above the 5.5g/m^3 'very good' condition rating for protection of aquatic ecosystems (see Table 3).
- Chlorophyll-*a* values, which are an indicator of phytoplankton abundance, ranged from 1.3-3.7mg/m^3. Concentrations of ≤5mg/m^3 correspond to a condition rating of 'very good'.

Although the synoptic survey provided no indication of degraded water column conditions in Tahakopa Estuary at the time of sampling, water column stratification potentially makes it susceptible to the development of degraded bottom water conditions during mid- to late-summer low flows. Stratification is a common indicator used to assess the vulnerability of the bottom waters to degradation (e.g., low dissolved oxygen), with the summer low-flows being a high-risk period for the manifestation of poor water quality in river-dominated systems. The implications for Tahakopa Estuary are discussed in the next section.

Tannin-stained upper estuary water.

Table 10. Water quality parameters measured on 30 November 2022. The WQ4 Main Road bridge site was measured on two tidal states. DO = dissolved oxygen, Chl-*a* = chlorophyll-*a*.

Site	Tidal state	Tidal stream	Depth (m)	Halocline depth (m)	Temp (°C)	DO (%)	DO g/m^3	Salinity (ppt)	pH	Chl-a (mg/m^3)
WQ1: Upstream	High	Outgoing	0.2	1.2	12.9	83.6	8.7	1.4	8	3.1
Tahakopa			2.6	1.2	13.5	68.3	6.4	15.2	7.8	3.4
WQ2: Upstream	High	Outgoing	0.2	1.2	12.0	82.2	8.8	4.1	7.6	3.3
MacLennan			1.6	1.2	13.7	67.8	5.8	27.6	8	2.2
WQ3: River	High	Outgoing	0.2	1.2	12.7	81.3	8.3	5.9	7.7	3.1
Confluence			1.6	1.2	14.0	84.0	7.1	31.1	6.3	1.4
WQ4: Main road	High	Outgoing	0.2	na	14.2	89.4	7.6	30.1	8.4	1.3
bridge				na	-	-	-	-	-	-
WQ4: Main road	Low	Outgoing	0.2	na	15.3	84.9	8.2	8.7	7.8	3.4
bridge			2.5	na	15.3	80.4	7.6	9.3	7.7	3.7

7. SYNTHESIS OF KEY FINDINGS

7.1 OVERVIEW

The 30 November 2022 survey showed that Tahakopa Estuary is in a healthy state overall. It is one of few remaining estuaries in the Otago region with a catchment that still has a considerable area of indigenous forest, although farmland and exotic forestry are nonetheless well-developed in some areas. 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, Tahakopa Estuary, November 2022.

a. Area summary	ha	% Estuary
Intertidal area	67.9	57.6
Subtidal area	50.0	42.4
Total estuary area	117.9	100
b. Key substrate features*	**ha**	**% Intertidal**
Mud-enriched (25 to <50%)	2.2	4.3
Mud-dominated (≥50%)	0.7	1.5
c. Key habitat features	**ha**	**% Intertidal**
Salt marsh	17.7	26.2
Seagrass (≥50% cover)*	0.0	0.0
Macroalgal beds (≥50% cover)*	1.4	2.9
HEC*	0.05	0.1
d. Terrestrial margin (200m)		**% Margin**
200m densely vegetated margin		66.4

*Note: Summary percentages for substrate, seagrass, macroalgae and HEC are for the 50.1ha of intertidal area that excludes salt marsh.

The rating tables show that most indicators meet the classification of 'good' or 'very good', with the 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 terrestrial margin and catchment with a low-to-moderate level of modification by comparison with areas outside the Catlins. More than two thirds of the margin and wider catchment has a dense vegetation cover.
- An extensive salt marsh (17.7ha) that has suffered a small to moderate decline (~9%) since first available records in 1948. This decline is attributed to erosion of beds and small losses due to reclamation and rock armouring of the road margin.
- Clean, sand-dominated sediment in most areas outside the upper estuary margins.
- Sparse growths of opportunistic macroalgae that have led to HEC formation (characterised by entrained turfs of *Agarophyton* spp.) in only a very small area (0.05ha) of the upper estuary.
- Very low trace metal contaminant concentrations, consistent with the moderate 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, including high dissolved oxygen and low chlorophyll-*a*.

Note that due to the absence of seagrass, this indicator was not rated. Based on a cursory assessment of features visible in historic aerial photographs (from 1948), we consider it likely that the estuary has never supported any/significant seagrass beds. 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 Waipati River and Tautuku Estuaries, whose catchments are even less modified that Tahakopa.

These findings likely reflect the presence of factors that limit seagrass growth, including light limitation from tannin-rich catchment waters (which could inhibit photosynthesis); a strong freshwater influence (low salinity water) up-channel from the main road bridge; and high substrate mobility in the lower estuary sand flats, which would prevent the establishment of beds.

The sediment-dwelling macrofaunal community was largely characterised by taxa that are resilient to most forms of disturbance. Accordingly, at five of the six sampling sites, macrofauna AMBI scores had a 'poor' condition rating (Table 13). A similar finding has been described for other southern Catlins' estuaries, namely Tautuku Estuary (Forrest et al. 2022a) and Waipati River Estuary (Forrest et al. 2023).

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 some of the least modified catchments of the Otago estuaries in the SOE programme, it is clear that their faunal state reflects the natural condition for these systems.

Although macrofauna composition changes among sites in Tahakopa Estuary were linked to gradients in variables such as sediment %mud and %TOC, the drivers of overall estuary condition that have been discussed for the other southern Catlins estuaries 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

Table 12. Summary of broad scale indicator condition ratings. See Table 3 for colour bands and definitions.

Broad Scale Indicators	Unit	Value	Condition Rating
200m terrestrial margin	% densely vegetated	66.4	Very Good
Mud-elevated substrate[1]	% of intertidal area >25% mud	5.8	Fair
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.884	Very Good
Seagrass	% decrease from baseline	not present	na
Salt marsh extent (current)	% of intertidal area	26.2	Very Good
Historical salt marsh extent	% of historical remaining	>80%	Very Good
High Enrichment Conditions	ha	0.05	Very Good
High Enrichment Conditions	% of estuary	0.1	Very Good
Sedimentation rate	CSR:NSR ratio	1.1	Very Good
Sedimentation rate	mm/yr	6.7	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. Colour bandings are provided in Table 3.

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

Site	Unit	1	2	3	4	5	6
Mud	%	19.9	7.4	21.9	4.8	16.6	2.9
aRPD	mm	35	45	35	50	65	na
TN	mg/kg	700	< 500	600	< 500	500	< 1300
TP	mg/kg	360	250	330	260	330	220
TOC	%	0.96	0.32	0.60	0.24	0.53	< 0.13
TS	%	0.09	0.06	0.07	0.03	0.05	0.02
As	mg/kg	4.6	5.7	5.2	5.1	6.2	6.5
Cd	mg/kg	0.028	0.013	0.024	0.010	0.016	0.012
Cr	mg/kg	9.1	6.8	9.1	6.8	7.7	5.8
Cu	mg/kg	5.4	3.2	5.2	2.7	3.6	2.1
Hg	mg/kg	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ni	mg/kg	6.2	4.5	6.4	4.2	5.0	3.3
Pb	mg/kg	3.7	2.5	4.0	1.9	2.7	1.4
Zn	mg/kg	32.0	22.0	33.0	14.7	21.0	11.3
AMBI	na	4.4	4.4	4.4	4.4	4.5	3.0

See Glossary for abbreviations. < Values below lab detection limit. Colour bandings are based on thresholds 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 (u/s)	WQ2	WQ3	WQ4 (d/s)
DO	g/m^3	6.4	5.8	7.1	7.6
Chl-*a*	mg/m^3	3.4	3.3	3.1	3.7

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

Tahakopa River, especially in the upper estuary. The Tahakopa 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 certain macrofauna. Under this range of conditions along the main estuary gradient, only the most resilient species can 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).

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

Supporting Condition Measure	Tahakopa Estuary
Mean freshwater flow (m^3/s)[1]	7.2
Catchment area (Ha)[1]	31173.0
Catchment nitrogen load (TN/yr)[2]	121.4
Catchment phosphorus load (TP/yr)[2]	18.0
Catchment sediment load (KT/yr)[1]	17.7
Estimated N areal load in estuary ($mg/m^2/d$)[2]	281.8
Estimated P areal load in estuary ($mg/m^2/d$)[2]	41.8
CSR:NSR ratio[1]	1.1
Trap efficiency (sediment retained in estuary)[1]	49%
Estimated rate of sedimentation (mm/yr)[1]	6.7

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

[2] CLUES version 10.8 (LCBD5); Run date: 31 May 2023

7.2 VULNERABILITY TO MUDDY SEDIMENTS

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

- Sediment validation sites 7-9 in the upper estuary had a sediment mud content >25% (range 32-65% - Appendix 5), and were rated as 'poor' according to the Table 3 criteria.
- 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 5.8% of the intertidal area outside salt marsh (Table 12). Most is likely to have entered the estuary from the catchment, with a minor contribution from erosion of salt marsh beds (releasing the sediment trapped within) or margin areas.

The spatial extent of mud-elevated sediment is low by comparison with other Otago estuaries, and appears lower than might be expected based on predictions from catchment models (Table 15). For example, although the ratio of predicted Current to Natural Sedimentation Rate was rated as 'very good' (ratio 1.1; Table 12), the annual sedimentation rate is estimated to be 6.7mm/yr, which is more than triple the Townsend and Lohrer (2015) guideline value for New Zealand estuaries of 2mm/yr (rated 'poor').

Even allowing for sediment trapping in the estuary's extensive salt marsh, these model predictions appear to overstate the risk to the wider estuary. The absence of significant muddy sediment deposition on the tidal flats outside saltmarsh areas suggest that physical flushing processes may act to mitigate the effects of catchment sediment inputs. On the other hand, the high proportion of mud-dominated sediment trapped within salt marsh reinforces the critical role for this habitat in mitigating catchment sediment inputs, and highlights the importance of avoiding further anthropogenic losses of salt marsh.

Consequently, it is uncertain whether future changes in catchment land-use that increase sediment loads will subsequently lead to estuary substrate changes. Around 27% of the catchment is in land-uses that are known to generate 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 Tahakopa Estuary catchment consisted of more than 10% exotic plantation forestry (including harvested area) based on 2018 data (see Fig. 2). Since then, recent aerial imagery suggests that the harvested area has increased compared to that indicated in Fig. 2. Furthermore, the Catlins has likely followed the national trend of conversion of farmland or scrub 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).

7.3 VULNERABILITY TO NUTRIENT ENRICHMENT AND EUTROPHICATION

From Table 15, the estimated areal nitrogen load to the estuary is ~282$mg/m^2/d$, which is almost triple the 100$mgN/m^2/d$ threshold at which nuisance macroalgae problems are predicted to occur in intertidally-dominated estuaries (Robertson et al. 2017). Hence, the current macroalgal status, with an OMBT score that meets a condition rating of 'very good', does not reflect this level of potential risk. For example, the area of HECs, with entrained turfs of *Agarophyton* spp., is small (0.05ha) and isolated to the mid-upper estuary margins. Furthermore, even though catchment-derived nitrogen may contribute to the growths of dense *Ulva* spp. in the mid-lower estuary, these beds are primarily enabled by the wide availability of rocky substrates to which *Ulva* spp. can attach and grow.

Hence, although the predicted areal nitrogen load is high, the current absence of widespread eutrophication symptoms in terms of macroalgal proliferation 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, *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 Tahakopa Estuary, the muddy habitats where *Agarophyton* spp. 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. In addition, Tahakopa Estuary is moderately intertidally-dominated (i.e., ~58% of the estuary area; Table 11) meaning it is well-flushed on every tide. In fact the modelled estimate of Plew et al. (2018) indicates a flushing time of 1.3 days, and this short duration 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) assessed phytoplankton susceptibility as a function of flushing time and potential TN concentration in estuaries with salinities <30ppt. From that work, it was estimated that estuaries with a flushing time of ~4 days or less would have a low susceptibility to eutrophication (chlorophyll-*a* <5mg/m^3) in response to increasing concentrations of nitrogen.

That said, the stratification of mid-upper estuary waters observed in the present survey is a risk factor for the development of degraded water quality. In river-dominated estuaries that we have assessed in other regions, stratification combined with seawater trapping in deeper areas upstream of shallow sills can be associated with the development of eutrophic symptoms (low dissolved oxygen, phytoplankton blooms) during summer low flows (e.g., Roberts et al. 2021; Forrest et al. 2022c). Understanding the susceptibility of Tahakopa Estuary would require a more comprehensive water quality assessment, which among other things would need to consider:

- The upper extent of seawater intrusion into the Tahakopa and Maclennan River channels during 'worst-case' conditions of summer low flows and spring tides.
- The bed morphology of the river channels, in particular the presence of any deeper pools where seawater could be trapped for an extended period.
- Whether there is evidence of degraded water quality during summer low flows.

For the latter purpose, ORC could consider further water column profiling (with field meters) of the upper estuarine reaches of Tahakopa and Maclennan Rivers under worst-case conditions. Sampling could be undertaken by lowering probes from bridges or whitebait stands in the upper estuary, making this a straightforward undertaking.

7.4 MANAGEMENT AND MONITORING CONSIDERATIONS

The absence of significant muddy sediment or HEC areas in Tahakopa Estuary is an indication of its overall healthy condition. The fact that this state persists despite catchment model predictions of high sedimentation and nutrient (nitrogen) loads, suggests that the intertidal estuary may be less vulnerable to these stressors than model estimates suggest. Nonetheless, this contradictory situation creates uncertainty regarding the estuary's response to catchment activities that could lead to increased loadings. As well as the potential for adverse effects in the intertidal, there is a significant subtidal area (i.e., ~42% of the estuary; Table 11) that should also be considered.

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 to understand, 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, intensification of existing farmland (e.g., increased stock densities, intensive winter grazing).

Even with no change from existing land uses there may be 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 uncertain vulnerability of Tahakopa Estuary to sedimentation and nutrient enrichment, the merits of implementing an ongoing SOE programme are 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 sediment attributes that are easy to measure, such as 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. Macrofauna richness and abundance values are within the range of other SOE estuaries in the region that are monitored using the NEMP fine scale protocol. In many respects Tahakopa 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, Tahakopa Estuary is in a healthy state overall. However, its vulnerability to ongoing and future inputs of catchment-derived muddy sediment and nutrients is uncertain. To mitigate against potential risks the following is recommended:

- Undertake further investigation to assess risks of water quality degradation, focusing on the summer low flow period.
- Undertake broad scale habitat mapping every 5-years, with a particular focus on mud-extent. Repeat grainsize measurements to assess changes over time. Due to river dominance and potential scouring effects, sediment plates are unsuitable for monitoring sediment impacts in Tahakopa.
- Evaluate current and potential future sediment sources to the estuary, and investigate options for a reduction of inputs. This could be facilitated by including Tahakopa Estuary in the ORC limit setting programme and establishing limits for catchment sediment (and nutrient) inputs that will maintain estuary health.
- 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 Tahakopa 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).

Forrest BM, Roberts KL, Stevens LM, Scott-Simmonds T 2023. Synoptic Broad Scale Ecological Assessment of Waipati (Chaslands) River Estuary. Salt Ecology Report 113, prepared for Otago Regional Council, May 2023. 53p.

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.

Hamel JE 1977. Prehistoric man and his environment in the Catlins, New Zealand. PhD. Thesis, University of Otago, Dunedin. 347 p. plus Tables and Figures.

Hamel JE 2001.

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.

Hume T, Gerbeaux P, Hart D, Kettles H, Neale D 2016. A classification of New Zealand's coastal hydrosystems. NIWA Client Report HAM2016-062, prepared for Ministry of the Environment, October 2016. 120p.

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.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016. 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.

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, TAHAKOPA ESTUARY, NOVEMBER 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).

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.

A1.4 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.

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

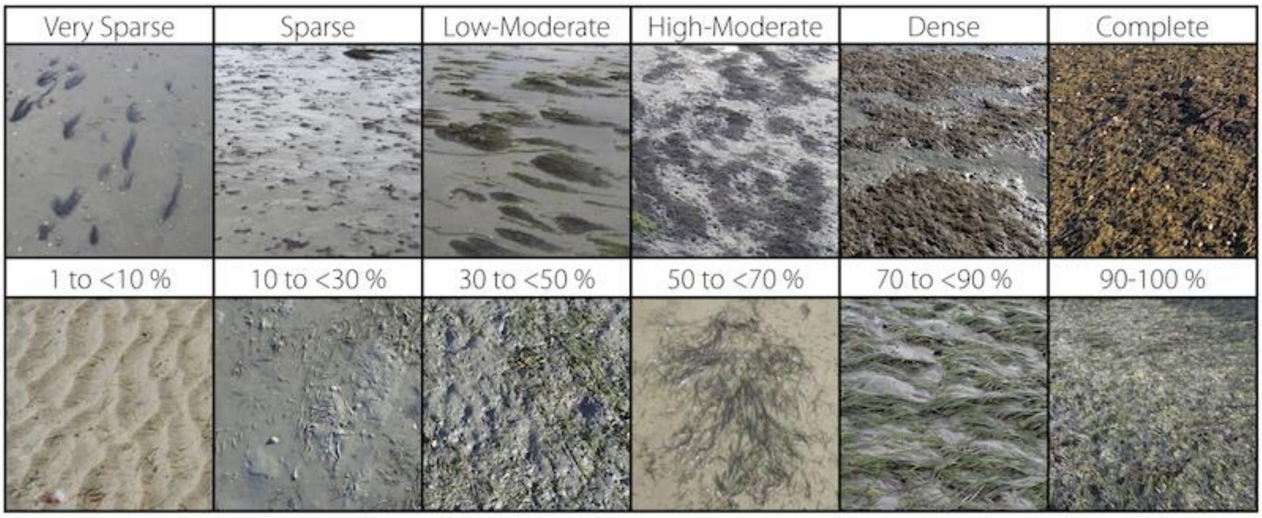


Fig. A1. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

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.

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.

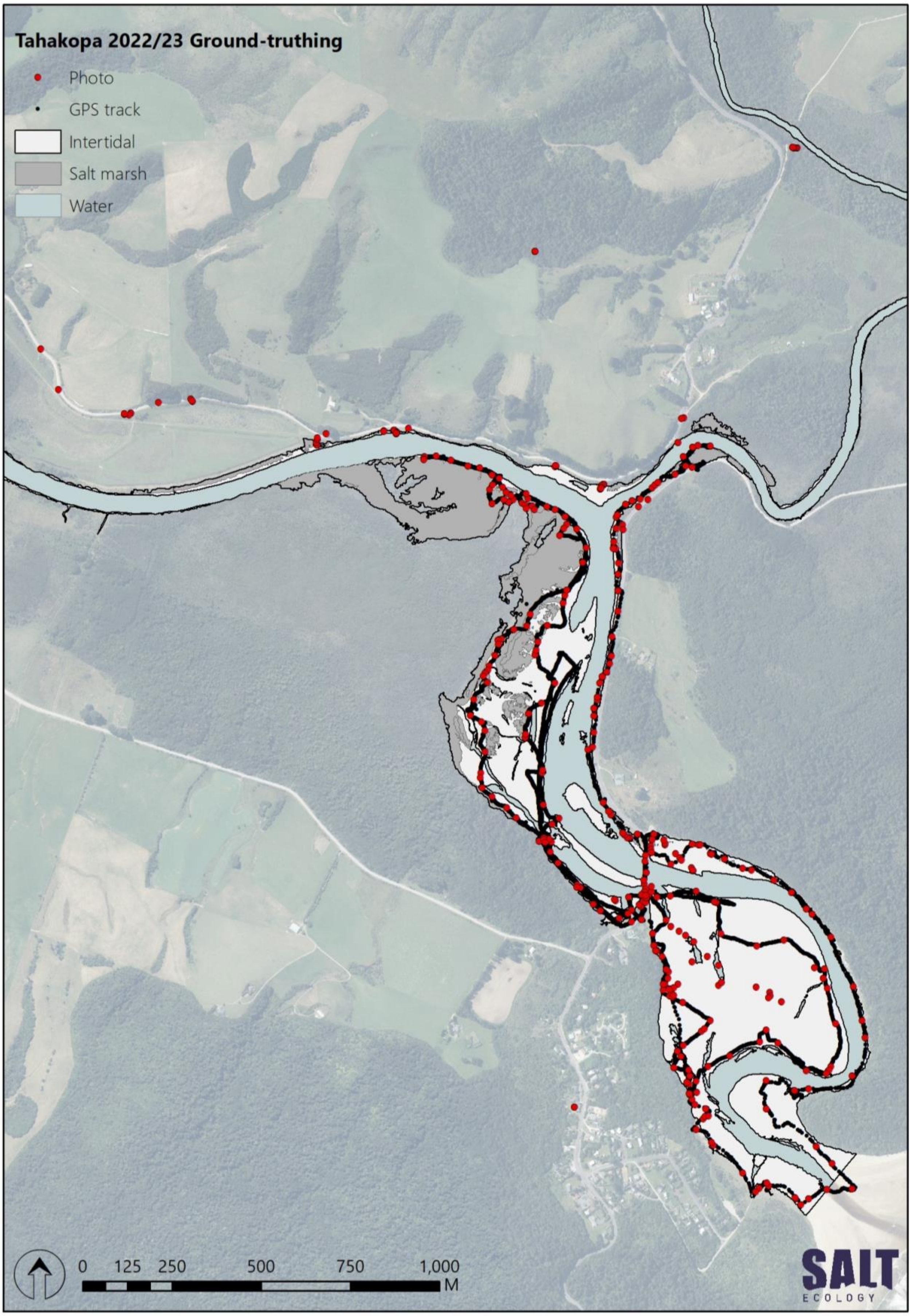
Stevens LM, Robertson BM 2014. Havelock Estuary 2014: Broad scale habitat mapping. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

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

Sub-class	Dominant species	Sub-dominant species 1	Sub-dominant species 2	Ha	%
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Coprosma propinqua subsp. Propinqua* (Mingimingi)	0.1	0.7
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)		0.1	0.7
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Coprosma propinqua subsp. Propinqua* (Mingimingi)	*Apodasmia similis* (Jointed wirerush)	0.6	3.5
	Plagianthus divaricatus (Salt marsh ribbonwood)			0.2	1.1
Tussockland	*Puccinella stricta* (Salt grass)			0.0	0.0
Rushland	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)		0.1	0.7
	Apodasmia similis (Jointed wirerush)			10.2	57.3
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Coprosma propinqua subsp. Propinqua* (Mingimingi)	3.9	21.7
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		1.5	8.7
	Apodasmia similis (Jointed wirerush)	*Samolus repens* (Primrose)		0.0	0.3
	Apodasmia similis (Jointed wirerush)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	0.0	0.2
Herbfield	*Samolus repens* (Primrose)			0.0	0.1
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)		0.0	0.1
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	0.1	0.6
	Selliera radicans (Remuremu)			0.0	0.1
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)		0.0	0.2
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	0.2	1.2
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	0.5	2.7
Grand Total				17.7	100

APPENDIX 4. RAW DATA ON SUBSTRATE

Total estuary substrate, substrate within salt marsh, and substrate within other vegetated habitats. AIH refers to 'Available Intertidal Habitat' (i.e., substrate area outside salt marsh).

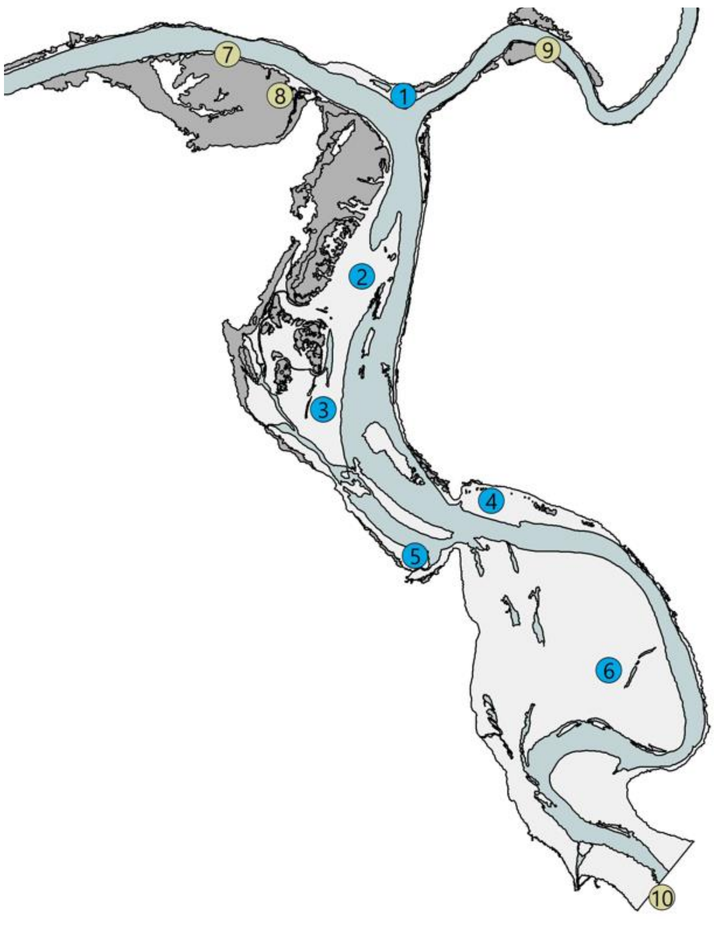
Substrate Class	Features	Intertidal area		AIH		Salt marsh		Seagrass		Macroalgae	
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Bedrock	Rock field	3.8	5.6	3.8	7.6	0.0	0.0	0.0	0.0	2.0	11.2
Unconsolidated coarse substrate (>2mm)	Artificial Boulder field	0.3	0.4	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0
	Gravel field	2.3	3.4	2.3	4.6	0.01	0.06	0.0	0.0	0.0	0.21
	Cobble field	0.9	1.3	0.9	1.7	0.0	0.0	0.0	0.0	0.0	0.1
Sand (0-10% mud)	Firm sand	5.9	8.7	5.8	11.6	0.1	0.6	0.0	0.0	0.1	0.8
	Soft sand	1.0	1.4	1.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0
	Mobile sand	23.7	35.0	23.7	47.4	0.0	0.0	0.00	0.0	0.00	0.0
Muddy Sand (>10-25% mud)	Firm muddy sand	2.4	3.5	2.3	4.6	0.1	0.5	0.0	0.0	0.0	0.0
	Soft muddy sand	7.1	10.5	7.1	14.2	0.0	0.0	0.0	0.0	0.0	0.0
Muddy Sand (>25-50% mud)	Firm muddy sand	0.6	0.9	0.0	0.0	0.6	3.3	0.0	0.0	0.0	0.0
	Soft muddy sand	3.7	5.5	2.2	4.3	1.6	8.8	0.0	0.0	0.1	0.3
Sandy Mud (>50-90% mud)	Firm sandy mud	5.7	8.4	0.0	0.0	5.7	32.3	0.0	0.0	0.0	0.0
	Soft sandy mud	10.3	15.2	0.7	1.3	9.7	54.5	0.0	0.0	0.0	0.2
	Very soft sandy mud	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Zootic	Shell bank	0.04	0.06	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Grand Total		67.9	100.0	50.1	100.0	17.7	100.0	0.0	0.0	2.3	100.0

APPENDIX 5. SEDIMENT VALIDATION

Sampling was undertaken at 10 sites (see map below and Fig. 4 of main report) to validate subjective field estimates of sediment type (with respect to mud content) against laboratory grainsize analysis of mud content. There was a good match for 8 of the 10 samples. The two differences are shown in red in the Table below. Variance of this type is generally the result of surface covers of sediment not being reflected within the underlying matrix sent for laboratory analysis. For example, a veneer of mud or sand on the surface can mask the true state of the underlying sediment. In these cases, the broad scale GIS polygons were adjusted to reflect the true mud content, as the differences were greater than the 5% tolerance adopted for this method.

Site	NZTM_E	NZTM_N	Sed firmness	Field code	Subjective % mud	Mud (%)	Sand (%)	Gravel (%)
1	1329398	4839494	soft	MS25_50	25 to <50%	19.9*	80	0.1
2	1329293	4839047	firm	S0_10	<10%	7.4	92.5	<0.1
3	1329199	4838716	firm	S0_10	<10%	21.9*	78	<0.1
4	1329616	4838490	firm	S0_10	<10%	4.8	94.2	0.9
5	1329427	4838353	soft	MS10_25	10 to <25%	16.6	82.3	1
6	1329907	4838069	mobile	S0_10	<10%	2.9	97.1	<0.1
7	1328961	4839597	soft	MS25_50	25 to <50%	31.8	68.2	<0.1
8	1329091	4839495	soft	SM50_90	50 to <90%	64.5	33.7	1.8
9	1329755	4839609	soft	SM50_90	50 to <90%	51.5	48	0.5
10	1330039	4837505	firm	S0_10	<10%	0.8	98	1.2

* Sites 1 and 3 polygons adjusted to MS10-25 to reflect true % mud.



Site 1

Site 2

Site 3

Site 4

Site 5

Site 6

Site 7

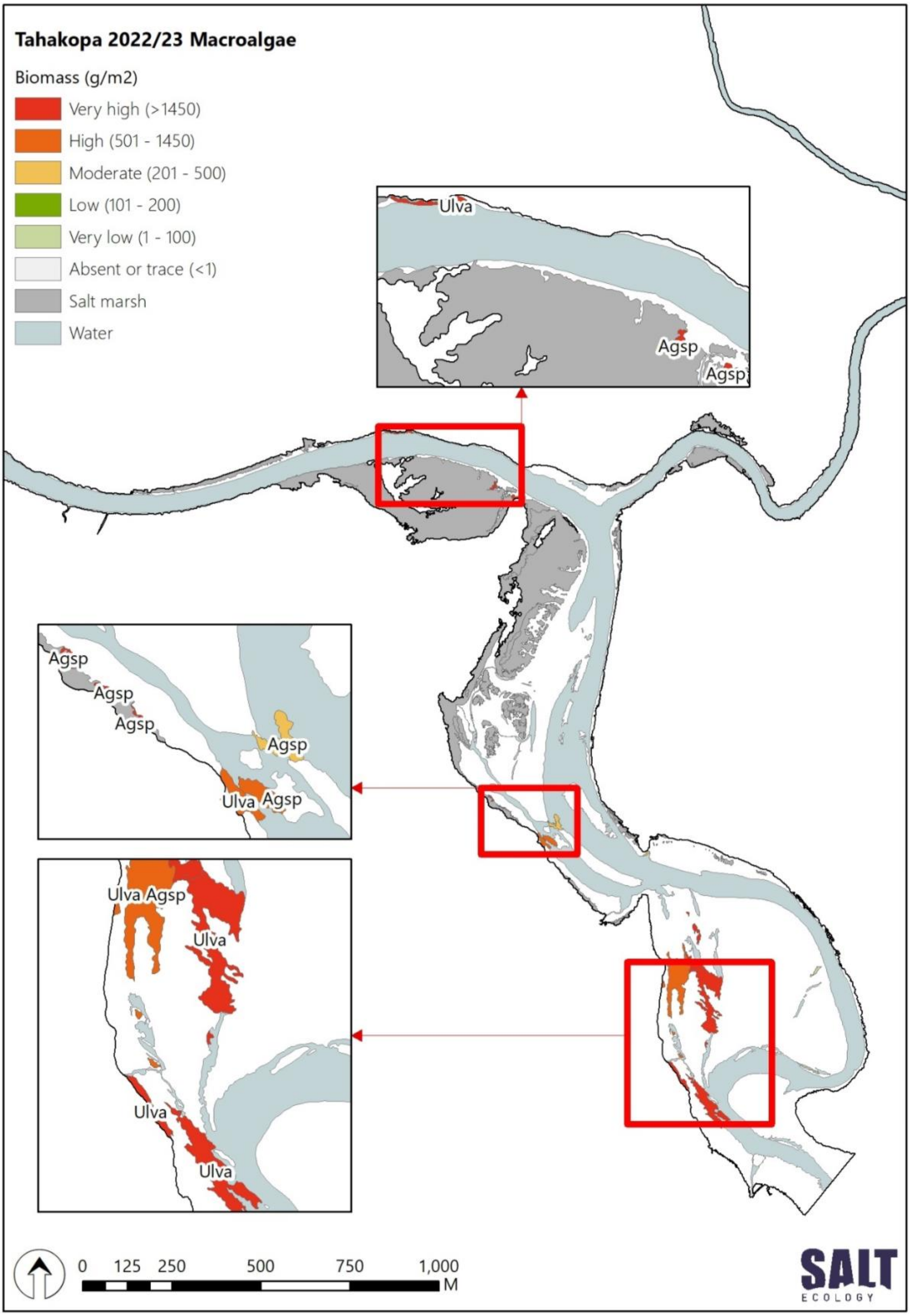
Site 8

Site 9

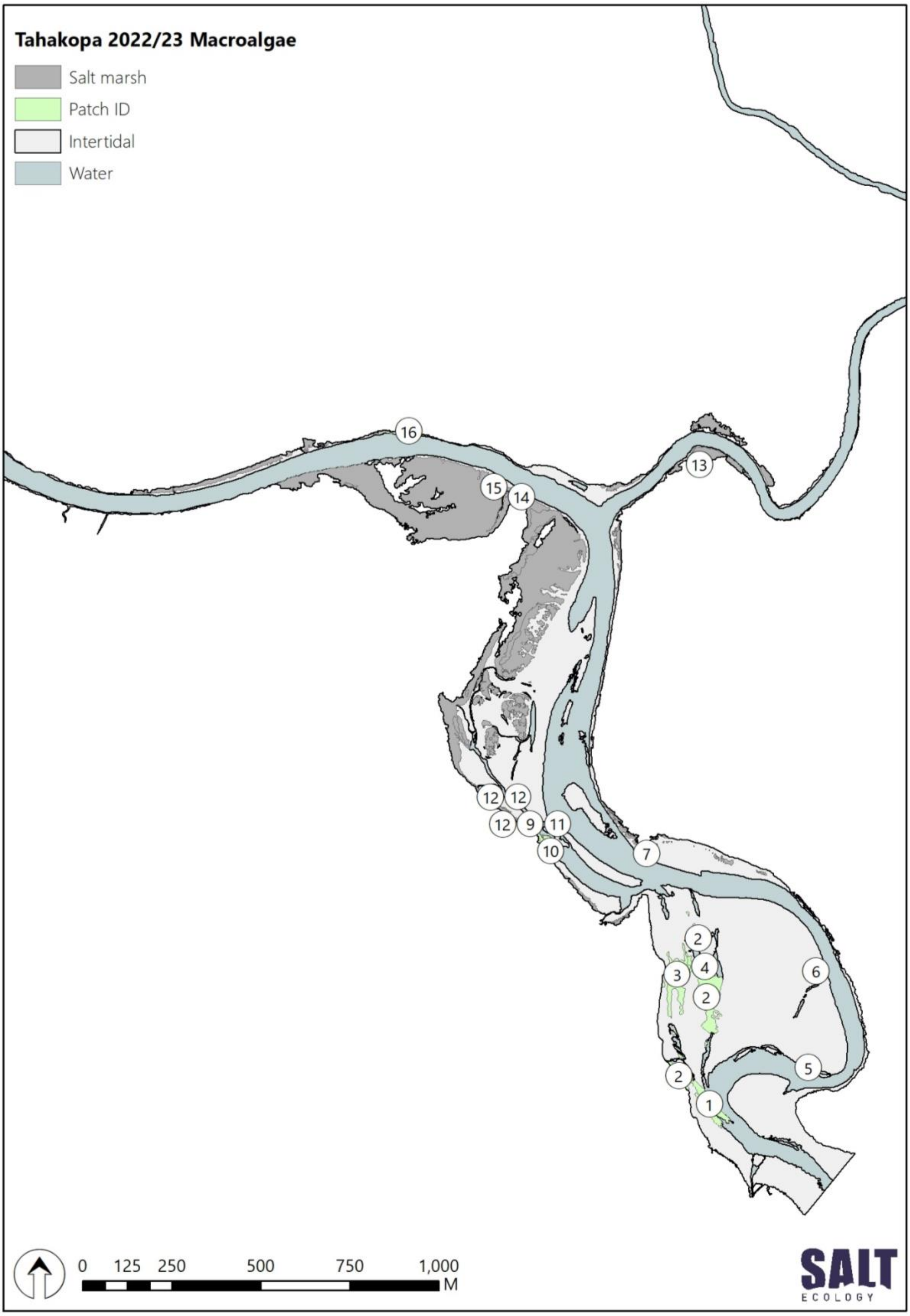
Site 10

APPENDIX 6. MACROALGAE BIOMASS AND PATCH INFORMATION

A. Biomass.



B. Macroalgae Patch ID numbers (for Table on next page).



C. Macroalgae Patch data.

Patch ID	ValidCode	Pct_Cover	TotPctCov	% Cover Category	Biomass (g/m^2)	Biomass category	Entrained	Dominant species	SubstrCode	Area (ha)
1	Ulva	87	87	Dense (70 to <90%)	3680	Very high (>1450)	0	*Ulva* spp. (Sea lettuce)	RF	0.38
2	Ulva	80	80	Dense (70 to <90%)	2160	Very high (>1450)	0	*Ulva* spp. (Sea lettuce)	RF	0.80
3	Ulva Agsp	27 12	39	Low-Moderate (30 to <50%)	640	High (501 - 1450)	0	*Ulva* spp. (Sea lettuce)*	RF	0.67
4	Ulva	70	70	Dense (70 to <90%)	1920	Very high (>1450)	0	*Ulva* spp. (Sea lettuce)	fS GF	0.11
5	Ulva	10	10	Sparse (10 to <30%)	40	Very low (1 - 100)	0	*Ulva* spp. (Sea lettuce)	fS	0.02
6	Ulva	20	20	Sparse (10 to <30%)	80	Very low (1 - 100)	0	*Ulva* spp. (Sea lettuce)	fS GF	0.02
7	Ulsp	40	40	Low-Moderate (30 to <50%)	400	Moderate (201 - 500)	0	*Ulva* spp. (Sea lettuce)	CF GF	0.01
8	Ulsp	100	100	Complete (>90%)	0	Absent or trace (<1)	0	*Ulva* spp. (Sea lettuce)	RF	0.01
9	Ulva	80	80	Dense (70 to <90%)	1120	High (501 - 1450)	0	*Ulva* spp. (Sea lettuce)	RF	0.05
10	Agsp	15	15	Sparse (10 to <30%)	640	High (501 - 1450)	0	*Agarophyton* spp. (Agar weed)	sMS25 RF	0.06
11	Agsp	10	10	Sparse (10 to <30%)	400	Moderate (201 - 500)	0	*Agarophyton* spp. (Agar weed)	RF	0.07
12	Agsp	75	75	Dense (70 to <90%)	6500	Very high (>1450)	1	*Agarophyton* spp. (Agar weed)	vsSM	0.02
13	Agsp	20	20	Sparse (10 to <30%)	2000	Very high (>1450)	1	*Agarophyton* spp. (Agar weed)	sSM	0.00
14	Agsp	60	60	High-Moderate (50 to <70%)	5920	Very high (>1450)	1	*Agarophyton* spp. (Agar weed)	sSM	0.01
15	Agsp	60	60	High-Moderate (50 to <70%)	5920	Very high (>1450)	1	*Agarophyton* spp. (Agar weed)	sSM	0.02
16	Ulva	95	95	Complete (>90%)	1840	Very high (>1450)	0	*Ulva* spp. (Sea lettuce)	GF	0.04

* In Patch ID 3, *Agarophyton* spp. (Agar weed) was sub-dominant

D. Macroalgal OMBT input data and EQR score.

Tahakopa Estuary	Face value	FEDS	Environmental Quality Class
% cover in AIH	2.90*	0.884	High
Average biomass (g/m^2) in AIH	85.72	0.829	High
Average biomass (g/m^2) in AA	1876	0.194	Bad
%entrained in AA	2.55	0.722	High
Worst of AA (ha) and AA (% of AIH)		0.817	High
AA (ha)	2.29	0.954	High
AA (% of AIH)	4.57	0.817	High
Survey EQR		0.884	'Very Good'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating.

*Because there was <5% cover in the AIH, EQR score calculated from % cover AIH sub-metric only using the method in Stevens et al. (2022).

APPENDIX 7. MACROFAUNA RAW DATA

Main group	Taxa	Habitat	EG	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b
Amphipoda	Josephosella awa	Infauna	II	-	-	-	-	-	-	-	-	-	2	-	-
Amphipoda	Paracalliope novizealandiae	Infauna	I	-	-	1	8	1	1	1	2	1	6	3	2
Amphipoda	Paracorophium excavatum	Infauna	IV	268	272	543	600	235	370	444	372	698	548	3	15
Anthozoa	Edwardsia sp.	Epibiota	II	-	-	-	-	-	-	-	1	-	-	1	3
Bivalvia	Arthritica sp. 5	Infauna	III	10	15	-	4	-	-	-	-	3	1	-	-
Bivalvia	Austrovenus stutchburyi	Infauna	II	1	-	-	-	-	-	2	8	1	1	-	1
Bivalvia	Legrandina turneri	Infauna	-	-	-	-	-	-	-	5	1	-	1	241	116
Bivalvia	Paphies australis	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	4
Copepoda	Copepoda	Infauna	II	-	-	-	-	1	1	-	-	-	-	-	-
Cumacea	Colurostylis lemurum	Infauna	II	-	1	6	9	1	5	1	-	-	-	-	-
Decapoda	Austrohelice crassa	Infauna	V	-	-	-	-	-	1	-	-	-	-	-	-
Decapoda	Hemiplax hirtipes	Infauna	III	-	-	-	-	-	-	-	1	1	1	-	-
Gastropoda	Potamopyrgus estuarinus	Epibiota	IV	9	12	-	-	-	-	-	-	-	-	-	-
Nemertea	Nemertea sp. 2	Infauna	III	-	-	-	-	-	-	-	-	-	-	-	2
Oligochaeta	Naididae	Infauna	V	-	3	1	1	-	1	4	16	36	19	1	-
Polychaeta	Boccardia syrtis	Infauna	II	-	-	-	-	-	2	1	3	-	-	2	6
Polychaeta	Capitella cf. capitata	Infauna	V	2	3	-	-	-	4	1	-	11	8	1	3
Polychaeta	Carazziella sp.	Infauna	III	-	-	-	-	-	-	-	-	-	-	1	-
Polychaeta	Levinsenia gracilis	Infauna	III	-	1	-	-	-	-	-	-	-	-	-	-
Polychaeta	Microspio maori	Infauna	I	-	-	3	5	-	4	1	-	-	1	1	-
Polychaeta	Nereididae (juv)	Infauna (Juvenile)	-	-	-	-	-	-	-	-	-	-	-	3	-
Polychaeta	Nicon aestuariensis	Infauna	III	5	6	-	-	-	-	-	-	-	-	-	-
Polychaeta	Paradoneis lyra	Infauna	III	-	-	-	-	-	-	1	2	-	-	-	-
Polychaeta	Perinereis vallata	Infauna	III	-	-	3	2	-	1	4	7	1	-	-	-
Polychaeta	Prionospio aucklandica	Infauna	III	-	-	-	-	-	-	-	-	-	-	2	-
Polychaeta	Scolecolepides benhami	Infauna	IV	46	42	16	8	12	3	24	47	23	17	-	-
			Richness	7	9	7	8	5	11	12	11	9	11	11	9
			Abundance	341	355	573	637	250	393	489	460	775	605	259	152


SALT
ECOLOGY