Broad Scale Intertidal Habitat Mapping of Tautuku Estuary

Prepared for

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Salt Ecology
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Cover photo: Tautuku Estuary, December 2021, rushland in the foreground and native bush catchment in the background.

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Prepared by

Keryn Roberts,

Thomas Scott-Simmonds,

Leigh Stevens

& Barrie Forrest

for

Otago Regional Council

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keryn@saltecology.co.nz, +64 (0)21 0294 8546

www.saltecology.co.nz

For the environment
Mō te taiao

GLOSSARY

AA	Affected Area (OMBT metric)
AIH	Available Intertidal Habitat (OMBT metric)
aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
HEC	High Enrichment Conditions
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

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SUMMARY

Tautuku Estuary is a medium sized (94ha) shallow, intertidally dominated, tidal lagoon type estuary (SIDE) located ~140km south of Dunedin on New Zealand's south coast. The estuary has high ecological quality attributed to the 'excellent' water quality of freshwater inputs and a high degree of naturalness in the catchment following recovery from past disturbances (e.g. logging). Tautuku Estuary therefore represents an important reference site in which comparisons can be made to other estuaries across the Otago region and is monitored by Otago Regional Council (ORC) as part of its State of the Environment programme using methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). This report describes a survey conducted in December 2021 which assessed the dominant substrate and vegetation features present including seagrass, salt marsh and macroalgae.

KEY FINDINGS

- Intertidal substrate was dominated by sand (0-10% mud) comprising 39.8ha (49.4% of the intertidal area), muddy-sand (>10-50% mud) 19.1ha (23.7%), and sandy-mud (>50-90% mud) 17.6ha (21.9%), the latter predominantly within salt marsh in the upper estuary.
- There was no evidence of widespread macroalgae problems in the estuary with only a small, localised area (1.2% of the available intertidal habitat) affected by opportunistic macroalgae.
- No intertidal seagrass was recorded, likely reflecting the dominance of mobile sands in the mid to lower estuary and other conditions limiting to seagrass growth, in particular, light limitation from the tannin rich waters of the Tautuku River.
- Salt marsh (34.3ha, 42.6% of the intertidal area) was extensive and comprised 94.1% rushland, 3.8% herbfield and 2.1% estuarine shrub.
- The 200m terrestrial margin of the estuary was 85.7% densely vegetated and dominated by indigenous forest.
- The catchment land cover was 91.5% indigenous forest, 3.3% manuka and/or kanuka, 1.2% freshwater wetlands and 1.1% dunes, reflecting a very high degree of naturalness.
- The Estuary Trophic Index (ETI) score (0.242) indicated very low nutrient enrichment (eutrophication).

The broad scale indicators, summarised in the table below, show Tautuku Estuary was in 'very good' condition overall, but was relatively muddy within upper estuary salt marsh areas.

Broad Scale Indicators	Unit	Value	December 2021
Estuary Trophic Index (ETI) Score	No unit	0.242	Very Good
Mud-dominated substrate	% of intertidal area >50% mud	25.7 (3.8[1])	Poor (area includes saltmarsh)
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.946	Very Good
Seagrass	% decrease from baseline	0.0	*baseline*
Salt marsh extent (current)	% of intertidal area	42.6	Very Good
Historical salt marsh extent*	% of historical remaining	>90[2]	Very Good
200m terrestrial margin	% densely vegetated	85.7	Very Good
High Enrichment Conditions	ha	0.3	Very Good
High Enrichment Conditions	% of estuary	0.3	Very Good
Sedimentation rate*	CSR:NSR ratio[3]	1.0	Very Good
Sedimentation rate*	mm/yr	1.8	Fair

Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. [1]In brackets mud dominated sediment outside salt marsh [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

RECOMMENDATIONS

- Repeat the broad scale habitat mapping at 5-10 yearly intervals to track long term changes in estuary condition.
- Include Tautuku Estuary in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will continue to protect the high ecological quality of the estuary and its catchment.

1. INTRODUCTION

1.1 BACKGROUND

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 based on the methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c), or extensions of that approach.

NEMP monitoring is primarily designed to detect and understand changes in estuaries over time and determine the effect of catchment influences, especially those contributing to the input of nutrients and muddy sediments. Excessive nutrient and fine sediment inputs are a primary driver of estuary eutrophication symptoms such as prolific macroalgal (seaweed) growth, and poor sediment condition.

The NEMP (Robertson et al. 2002a-c) is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results provide a valuable basis for establishing a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

Estuaries in a more natural state provide a point of comparison for modified estuaries and, overtime, an understanding of climate change effects in the absence of other stressors. Such systems are commonly referred to as reference estuaries, where the estuary and catchment as largely unmodified. Tautuku Estuary, the study site, represents one of the least impacted estuaries on the southeast coast and retains a high degree of naturalness in both the estuary and catchment.

The current report describes the methods and results of broad scale monitoring undertaken in Tautuku Estuary on 30 November and 1 December 2021 (Fig. 1). The primary purpose of the current work was to characterise substrate and the presence and extent of seagrass, macroalgae and salt marsh. Fine scale monitoring, undertaken at the time of sampling, is reported in Forrest et al. (2022).

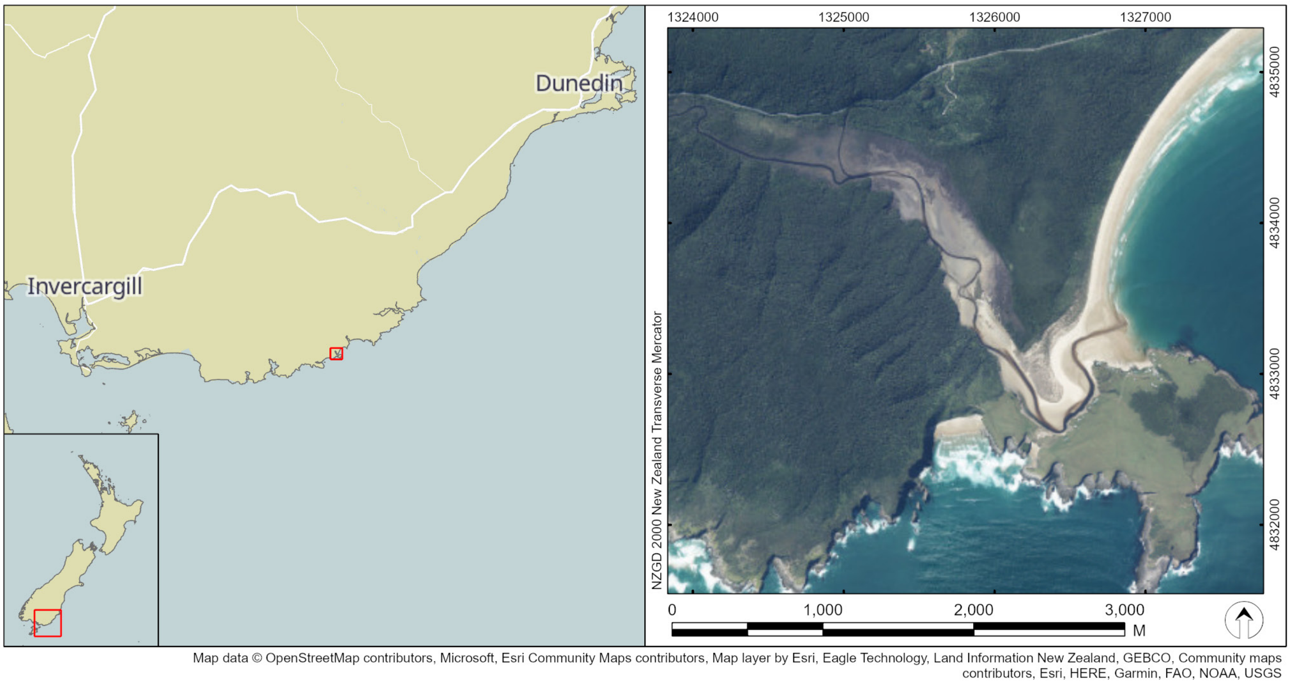


Fig. 1. Location of Tautuku Estuary, Otago.

1.2 OVERVIEW OF TAUTUKU ESTUARY

Tautuku Estuary is a medium sized (94ha) estuarine system located ~140km south of Dunedin on New Zealand's south coast. The estuary is a shallow, intertidally dominated (~86%), tidal lagoon type estuary (SIDE) with a flushing time of ~4 days (Plew et al. 2018). The short residence time means the estuary is unlikely to experience nutrient driven water column problems (e.g. phytoplankton blooms). However, the estuary has the capacity to retain fine sediments and sediment-bound nutrients in deposition areas making it moderately susceptible to nutrient enrichment and fine sediment impacts.

The estuary drains a 6,186ha catchment that is 97.9% densely vegetated comprising ~91.5% indigenous forest, 3.3% manuka and/or kanuka, and 1.2% herbaceous freshwater and 1.1% saline (dune) vegetation (Table 1; Fig. 2). In Tautuku Estuary the intact transition from native forest to wetland to estuarine salt marsh is uncommon in Otago and New Zealand. As such the wetlands and salt marsh are classified as regionally significant in the ORC Regional Plan: Water.

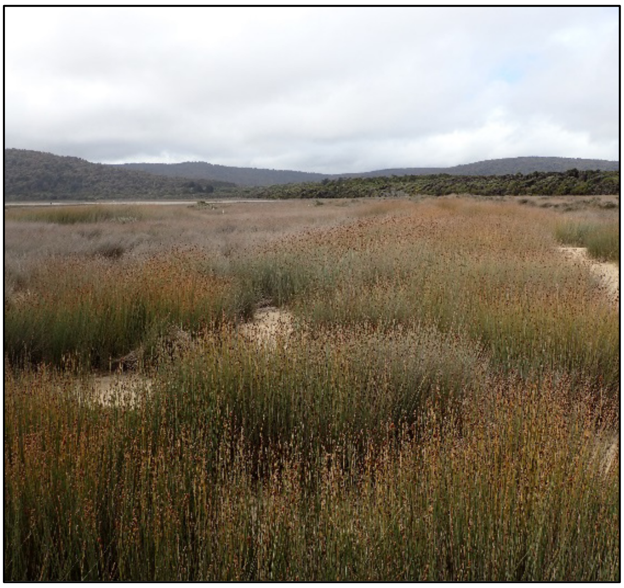
The main freshwater inflow to the estuary is Tautuku River which starts in the Maclennan Ranges (Kā Pukemāeroero) in the Catlins and meanders through a native bush catchment for almost its entire length (Fig. 2). Overall, the Tautuku River and smaller freshwater inputs represent ~30% of the total estuary volume (Plew et al. 2018). Water quality in the Tautuku River is 'excellent' and fish are abundant and in good condition (Ozanne 2011). The river and estuary support a number of diadromous species (i.e. fish that migrate between fresh and salt water) including redfin bully, longfin and shortfin eel (tuna), whitebait (inanga) and lamprey (kanakana). In 2016, a marine protected area with fishery restrictions was proposed for the Tautuku Estuary to protect black and yellow belly flounder (pātiki) and other wildlife (e.g. migratory birds such as spoonbills, pied oyster catchers and stilts; SEMPF, 2016). The estuary is also an important habitat for fernbird (mātātā) a threatened (nationally vulnerable) wetland bird on the South Island.

Indigenous forest margin of Tautuku Estuary

Looking up river toward the indigenous forest catchment

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

LCDB5 (2017/2018) Catchment Land Cover	Ha	%
1 Built-up Area (settlement)	1.0	0.02
10 Sand or Gravel	9.3	0.2
40 High Producing Exotic Grassland	122.6	2.0
45 Herbaceous Freshwater Vegetation	77.0	1.2
46 Herbaceous Saline Vegetation	67.5	1.1
51 Gorse and/or Broom	4.2	0.07
52 Manuka and/or Kanuka	201.3	3.3
54 Broadleaved Indigenous Hardwoods	42.0	0.7
69 Indigenous Forest	5658.9	91.5
71 Exotic Forest	2.0	0.03
Grand Total	6185.8	100
Total densely vegetated area (LCDB classes 45-71)	6052.9	97.9



Salt marsh habitat in the mid estuary

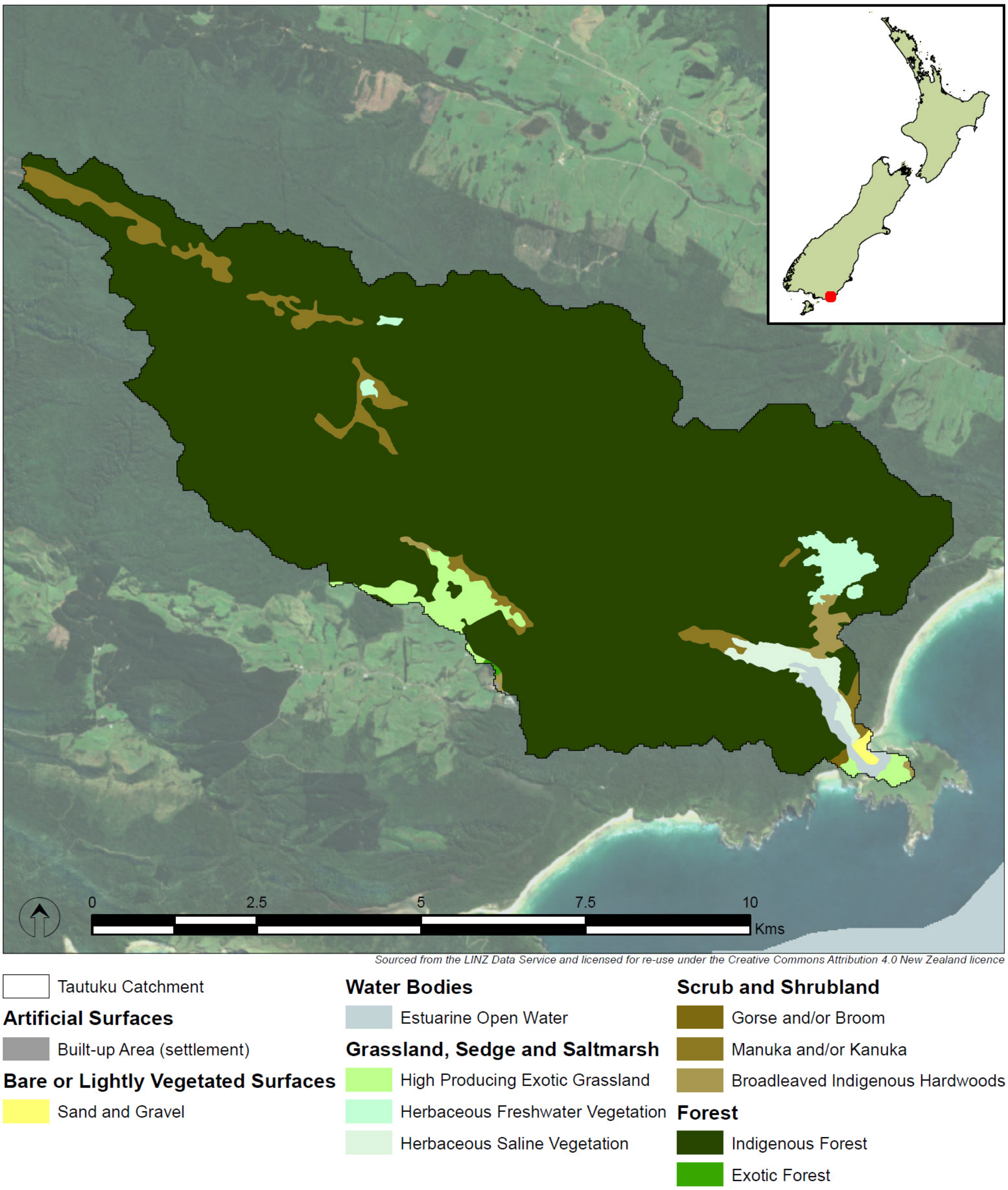


Fig. 2. Tautuku Estuary catchment land use classifications from LCDB5 (2017/2018) database.

Tautuku Bay looking toward the estuary entrance at the end of the beach surrounded by indigenous forest

Tautuku was traditionally an important kāinga mahinga kai (food gathering settlement) for Māori. Archaeological sites on the Tautuku Peninsula have identified moa, smaller birds, seals and fish bones (Hamel 2001). Two large blocks of land on the southern margin extending to the peninsula were set aside as Māori freehold land under by the Native Land Court in 1868 and under the South Island Landless Native Act in 1906 (Ngāi Tahu Atlas). The land remains under the management of trustees with majority of the land remaining in native bush cover.

From 1839 to 1846, a whaling station was located on Tautuku Peninsula (Hamel 2001; Prickett 2002) and later a port that was used for fishing, flax, and timber. Sawmills near Tautuku processed rimu, maitai, miro, totara and kahikatea from 1901 through to 1950. Land was cleared on the northern side of the estuary to support the timber mills (see photo). In the 1920's eight fishing boats were operating out of Tautuku and Maclennan however they concluded by the 1930's because of 'silting up' in the rivers (Tyrrell, 2016).

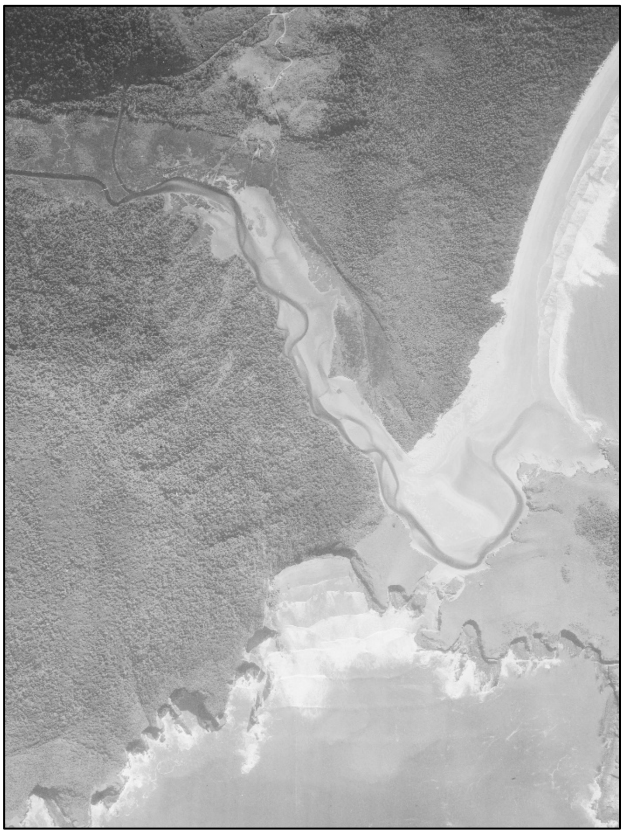
Present day, the Tautuku catchment is largely protected within the Catlins Conservation Park, Lenz Historic Reserve and Māori freehold land. Areas that have been previously modified are now regenerating indigenous forest, except for the Tautuku Peninsula where grassland dominates, and a small number of dwellings are present.

The Tautuku Estuary represents an example of a reference estuary surrounded by indigenous forest, wetland and salt marsh. Moore (2015) described the salt marsh and estuarine communities as 'pristine' from an ecological perspective. Because the estuary retains very high ecological, cultural, and social values it is classified as a coastal protection area in the Otago Regional Plan: Coast.

Board walk to Tautuku estuary within rushland

Tautuku Estuary in the early 1900's looking upstream from the peninsula (source: Owaka Museum Information Centre)

Historic location of sawmills close to the estuary margin



Areal imagery showing clearing of forest for logging toward the north, and mobile sands and active sand dunes near the estuary entrance

2. METHODS

2.1 BROAD SCALE MAPPING METHODS

Broad scale surveys involve describing and mapping estuaries according to dominant surface habitat features (substrate and vegetation). The type, presence and extent of substrate, salt marsh, macroalgae or seagrass reflects multiple factors, for example the combined influence of sediment deposition, nutrient availability, salinity, water quality, clarity and hydrology. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to small scale temporal variation associated with instantaneous water quality measures.

NEMP methods (Appendix 1) were used to map and categorise intertidal estuary substrate and vegetation. The mapping procedure combines aerial photography, detailed ground-truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats can be monitored by repeating the mapping exercise. Broad scale mapping is typically carried out during September to May when most plants are still visible and seasonal vegetation has not died back. Aerial photographs are ideally assessed at a scale of less than 1:5000, as at a broader scale it becomes difficult to accurately determine changes over time.

In 2021, imagery was supplied by ORC (1:3000 colour aerial imagery captured between 5 and 20 February 2021). Ground-truthing was undertaken between 30 November and 1 December 2021 by experienced scientists who assessed the estuary on foot to map the spatial extent of dominant vegetation and substrate. A particular focus was to characterise muddy sediment (as a key stressor), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats. The latter were estuarine seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the terrestrial margin bordering the estuary. Background information on the ecological significance of opportunistic macroalgae and the different vegetation features is provided in Table 2.

In the field, features were drawn directly onto laminated aerial photographs. The broad scale features were subsequently digitised into ArcMap 10.6 shapefiles using a Huion Kamvas 22 drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features, e.g. salt marsh, and its underlying substrate type.

For broad scale mapping purposes, an estuary is defined as a partly enclosed body of water, where freshwater inputs (i.e. rivers, streams) mix with seawater. The estuary entrance (i.e seaward boundary) was defined as a straight line between the seaward-most points of land that enclose the estuary, and the upper estuary boundary (i.e. riverine boundary) was based on the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For further detail see FGDC (2012).

Assessment criteria, developed largely from previous broad scale mapping assessments, apply thresholds for helping to assess estuary condition. Additional details on specific broad scale measures are provided in Sections 2.3-2.8.

Transition from salt marsh vegetation to native forest, Tautuku Estuary

Table 2. Overview of the ecological significance of various vegetation types.

Habitat	Description
Terrestrial margin vegetation	A densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important food source and habitat for a variety of species and, in waterway riparian zones, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity.
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, acts as a buffer that protects against introduced grasses and weeds and provides an important habitat for a variety of species including fish and birds.
Seagrass	Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

2.2 SUBSTRATE CLASSIFICATION AND MAPPING

Salt Ecology has extended the NEMP approach to include substrate beneath vegetation to create a continuous substrate layer for the estuary. Furthermore, a revision of the NEMP substrate classifications is summarised in Appendix 1.

Substrate classification is based on the dominant surface substrate features present, e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories based on sediment 'muddiness', assessed according to an expert field-based assessment of textural and firmness characteristics. In 2021, 12 sediment grainsize samples were collected to validate field classifications of substrate type (Appendix 2).

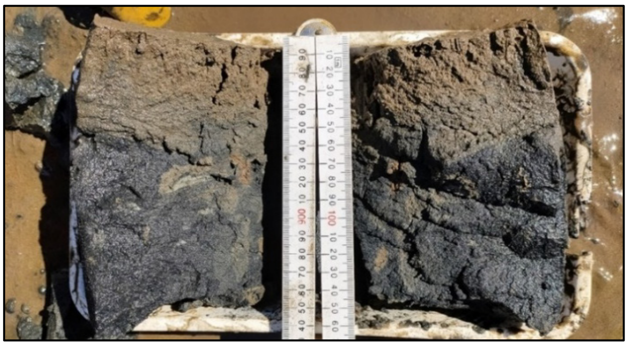
The area (horizontal extent) of mud-dominated sediment is used as a primary indicator of sediment mud impacts and in assessing susceptibility to nutrient enrichment impacts (trophic state).

Mobile sands near the estuary entrance

Soft muddy-sand on the estuary margin

2.3 SEDIMENT OXYGENATION

The apparent Redox Potential Discontinuity (aRPD) depth was 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). aRPD provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions. Sediments were considered to have poor oxygenation if the aRPD was consistently <10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. As significant sampling effort is required to map sub-surface conditions accurately, the approach is intended as a preliminary screening tool to determine the need for additional sampling effort. The aRPD depth was recorded at all grain size locations collected from representative substrate types (Appendix 2).



Example of distinct colour change with depth, brown oxygenated sediments are on the surface down to ~50mm

2.4 MACROALGAE ASSESSMENT

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature.

The ETI (Robertson et al. 2016b) adopted the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach. The OMBT, described in detail in Appendix 3, 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 in total 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. A numeric EQR score is calculated for the 'high' band using the approach described in Stevens et al. (2022).

Using the OMBT approach, opportunistic macroalgae patches were mapped during field ground-truthing using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (Fig. 3). Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the extent of macroalgal entrainment were measured.

Sampling macroalgal biomass in Tautuku Estuary

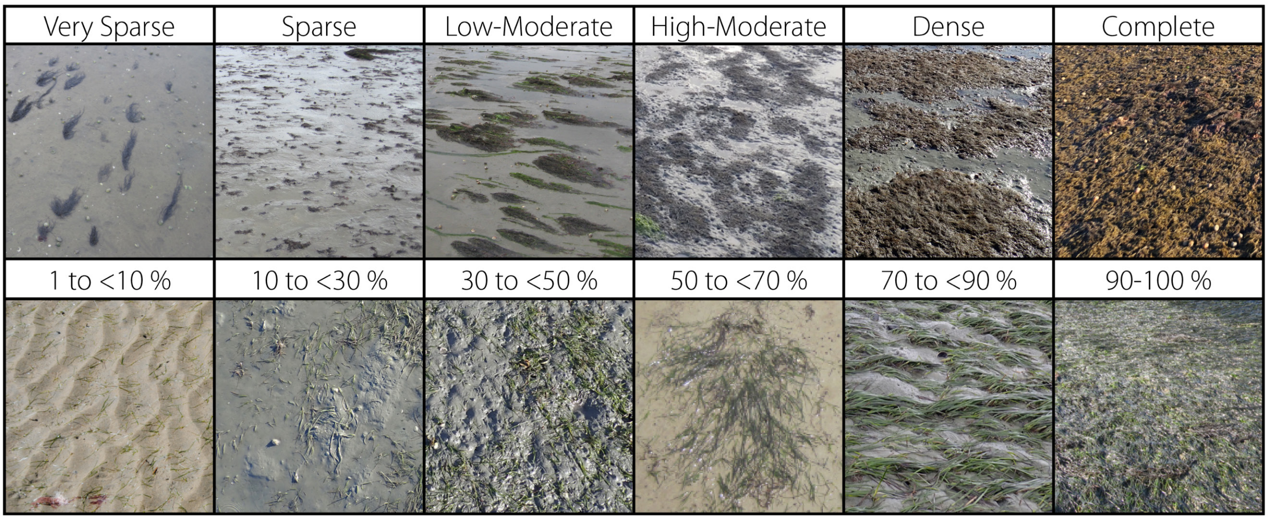


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

Biomass was 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 was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale. When sufficient representative patches had been measured to enable biomass to be reliably estimated, biomass estimates were made following the OMBT method. Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on the five-point scale adopted by the method as noted above.

2.5 SEAGRASS ASSESSMENT

As for macroalgae, the percent cover of seagrass patches was visually estimated through ground-truthing, based on the 6-category percent cover scale in Fig. 3.

2.6 SALT MARSH

NEMP methods were 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; Robertson et al. 2002a-c; Appendix 1). Two measures were used to assess salt marsh condition: i) intertidal extent (percent cover) and ii) current extent compared to estimated historical extent. Historic aerial imagery was used to estimate historical extent.

Rinsing macroalgae in Tautuku Estuary

Herbfield mounds in Tautuku Estuary

2.7 TERRESTRIAL MARGIN

Broad scale NEMP methods were used to map and categorise the 200m terrestrial margin using the dominant land cover classification codes described in the Landcare Research Land Cover Data Base (LCDB) detailed in Appendix 1.

Transition from salt marsh to native forest

Cleared forest at Tautuku pensinsula, and steep sedimentary cliffs

Marram dunes at the estuary entrance

2.8 WATER QUALITY

At two sampling locations, water quality measures were taken from ~20cm below the water surface and 5cm from the bottom to assess whether there was any salinity or temperature stratification. Water column measures of pH, salinity, dissolved oxygen (DO), temperature and chlorophyll-a (as an indicator of phytoplankton presence) were made using a YSI Pro10 meter and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. Care was taken not to disturb bottom sediments before sampling. Stratification, where present, was recorded along with water depth and clarity (Secchi depth).

Measuring water quality at the upstream site

2.9 SEDIMENT QUALITY & MACROFAUNA

Sediment quality and macrofauna samples were collected from three sites and used as supporting indicators to calculate an Estuary Trophic Index (ETI) score for the estuary (Robertson et al (2016b). The ETI requires supporting indicators represent the 10% of the estuary most susceptible to eutrophication (Zeldis et al. 2017).

Because eutrophication was not a major issue in Tautuku Estuary, three samples were collected from different substrate types. ETI 1 was collected from very soft sandy mud, ETI 2 from mobile sand and ETI 3 was collected from fine scale Site A, an area of firm muddy-sand (see map Appendix 2). ETI 3 was used to calculate an ETI Score.

At each of the three locations, a surface (~20mm) sediment sample was collected, stored on ice, and sent to RJ Hill Laboratories for analysis of the following: 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 total sulfur (TS). Details of laboratory methods and detection limits are provided in Appendix 2.

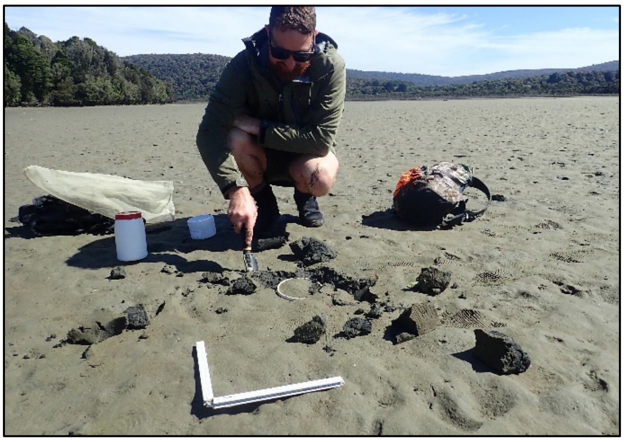
At sites ETI 1 and ETI 2, one sample for macrofauna was collected using a large sediment core (130mm diameter, 150mm deep). The core was extruded into a 0.5mm mesh sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a mixture of 75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification by NIWA. Macrofauna outputs for ETI-3 represent the average of the 9 fine scale cores reported in Forrest et al (2022). 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 (see Forrest et al. 2022).

2.10 DATA RECORDING AND QA/QC

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 photographs, 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 photographs alone, accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

In December 2021, following digitising of habitat features, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables.

As well as annotation of field information onto aerial photographs during the field ground-truthing, point estimate macroalgal data (i.e. biomass and cover measurements, entrainment), along with supporting measures of sediment aRPD, texture and sediment type were recorded in electronic templates 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) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP.



Sampling sediment and macrofauna

Looking upstream toward the native bush catchment

2.11 ASSESSMENT OF ESTUARY CONDITION

In addition to the authors' expert interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 3). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3. The condition ratings are primarily sourced from the NZ ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 4. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores (i.e. which range from 'high' to 'bad'). The thresholds used to place biomass into OMBT bands have been recently revised for use in New Zealand (Plew et al. 2020) and are included in Appendix 3.

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HECs) was evaluated. For our purposes, HECs are defined as mud-dominated sediments (≥50% mud content) with >50% macroalgal cover and with macroalgae entrained and growing as stable beds rooted within the sediment. These areas typically also have an aRPD depth shallower than 10mm due to sediment anoxia.

As many of the scoring categories in Table 3 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Mobile sand on the steep channel margin in the lower estuary

Table 3. Indicators used to assess results in the current report.

Indicator	Unit	Very good	Good	Fair	Poor
Broad scale Indicators					
ETI score[1]	No unit	≤ 0.25	>0.25 to 0.5	>0.5 to 0.75	>0.75 to 1.0
Mud-dominated substrate[2]	% of intertidal area >50% mud	< 1	1 to 5	> 5 to 15	> 15
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥0.8 to 1.0	≥0.6 to <0.8	≥0.4 to <0.6	0.0 to <0.4
Seagrass[2]	% decrease from baseline	< 5	≥ 5 to 10	≥ 10 to 20	≥ 20
Salt marsh extent (current)[2]	% of intertidal area	> 20	> 10 to 20	> 5 to 10	0 to 5
Historical salt marsh extent[2]	% of historical remaining	≥ 80 to 100	≥ 60 to 80	≥ 40 to 60	< 40
200m terrestrial margin[2]	% densely vegetated	≥ 80 to 100	≥ 50 to 80	≥ 25 to 50	< 25
High Enrichment Conditions[1]	ha	< 0.5	≥ 0.5 to 5	≥ 5 to 20	≥ 20
High Enrichment Conditions[1]	% of estuary	< 1	≥ 1 to 5	≥ 5 to 10	≥ 10
Sedimentation rate[1]*	CSR:NSR ratio	1 to 1.1 xNSR	1.1 to 2	2 to 5	> 5
Sedimentation rate[3]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Sediment quality					
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to ≤ 20	≤ 10

[1] General indicator thresholds derived from a New Zealand Estuary Tropic Index (Robertson et al. 2016b), with adjustments for aRPD (FGDC 2012). See text and Appendix 4 for further explanation of the origin or derivation of the different metrics.

[2] Subjective indicator thresholds derived from previous broad scale mapping assessments.

[3] Ratings derived or modified from Townsend and Lohrer (2015).

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

3. RESULTS

A summary of the December 2021 survey in Tautuku Estuary is provided below and in the appendices. Supporting GIS files (supplied to ORC as a separate electronic output) provide a more detailed dataset designed for easy interrogation and to address specific monitoring and management questions.

3.1 SUBSTRATE

Table 4 and Fig. 4 show intertidal substrate was dominated by mobile sand (27.6ha, 34.3%) and firm sand (12.2ha, 15.1%) in the mid to lower estuary. Salt marsh habitat in the upper estuary comprised firm sandy-mud (17.6ha, 21.9%), while areas of salt marsh in the mid-estuary comprised soft sandy-mud (8.8ha, 11.0%). Rock field was a prominent feature on the true right bank near the estuary entrance (see photo; Table 4). Mud-dominated sediments (>50% mud) were localised to salt marsh habitat in the upper estuary and a deposition area near the first large channel bend, areas that tend to naturally accumulate fine sediments (see photos). Zootic habitat (shellbank) was only a small feature of the estuary comprising 0.03% of the intertidal area. There was good agreement between the subjective assessment of substrate class and the laboratory analysed sediment validation samples (Appendix 4).

Mobile sands in the mid to lower estuary (top) and firm sand in the mid estuary (bottom)

Table 4. Summary of dominant intertidal substrate, Tautuku Estuary, December 2021.

Substrate Class	Features	Ha	%
Artificial	Artificial substrate	0.01	0.02
Bedrock	Rock field	0.9	1.1
Sand (0-10% mud)	Mobile sand	27.6	34.3
	Firm sand	12.2	15.1
Muddy Sand (>10-25% mud)	Firm muddy sand	5.8	7.2
	Soft muddy sand	0.8	1.0
Muddy Sand (>25-50% mud)	Firm muddy sand	3.7	4.5
	Soft muddy sand	8.8	11.0
Sandy Mud (>50-90% mud)	Firm sandy mud	17.6	21.9
	Soft sandy mud	2.7	3.3
	Very soft sandy mud	0.4	0.5
Zootic	Shell bank	0.03	0.04
Total		**80.5**	**100**

Rock field mid channel in the lower estuary and on the true right bank, Tautuku

Very soft sandy mud in the mid estuary deposition zone

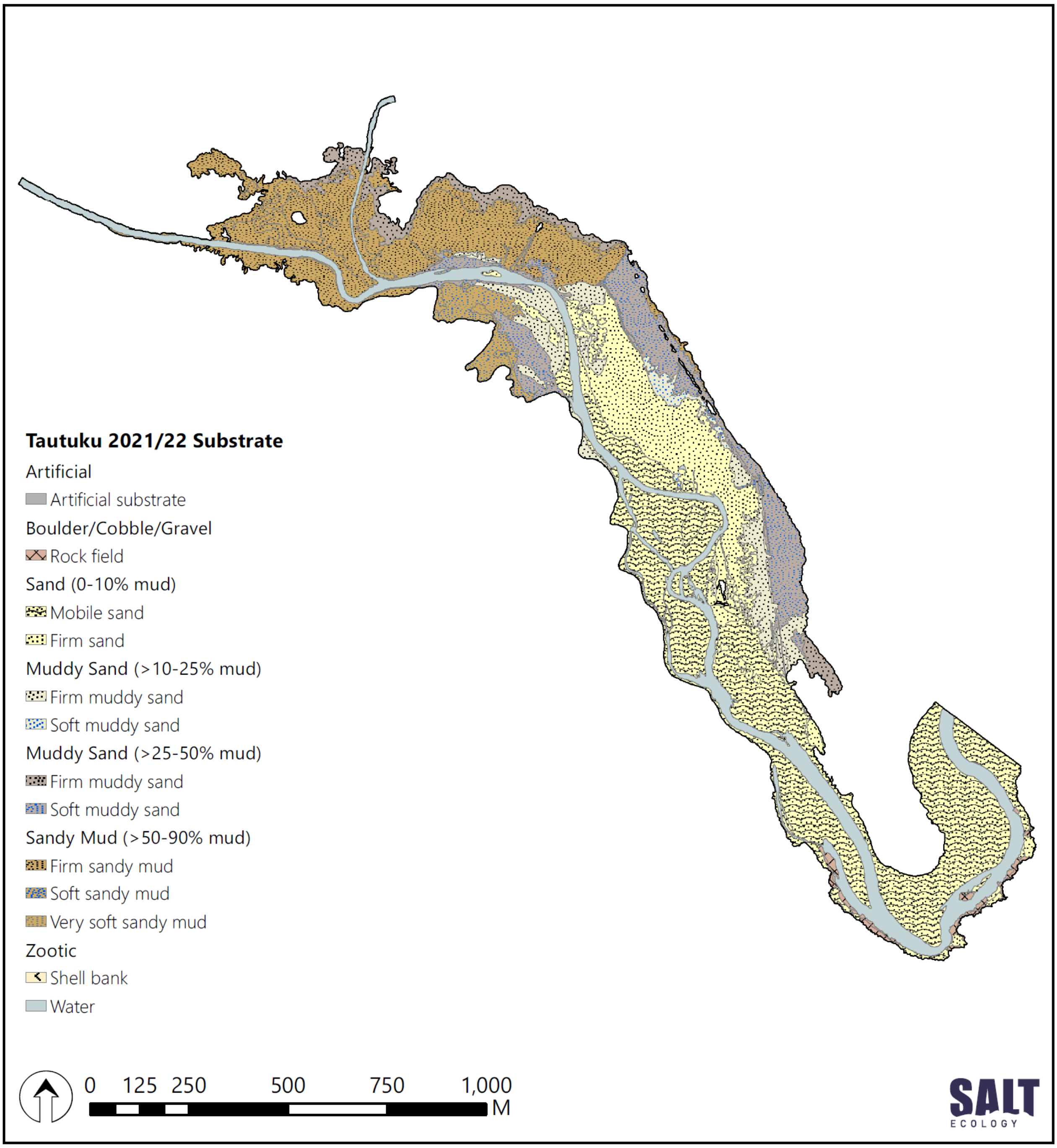


Fig. 4. Substrate types recorded in Tautuku Estuary, December 2021.

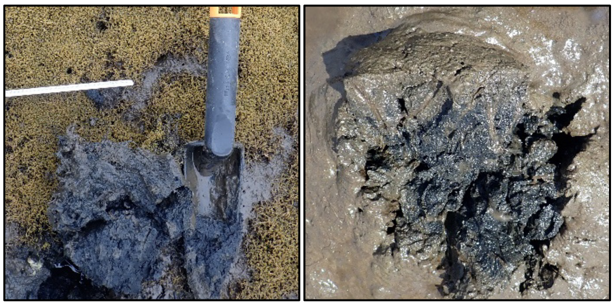
Photo taken looking upstream with mobile sands in the foreground, lower estuary

3.2 SEDIMENT OXYGENATION

Sediment oxygenation was measured within representative substrate types to assess the trophic state of the sediment. In December 2021, spot measurements of aRPD showed that sand dominated sediments were well oxygenated, particularly mobile sands (see photos). Firm muddy sands in the mid to upper estuary were also well oxygenated with an aRPD >30mm and visible faunal activity deeper in the sediment (see photo).

In general, the shallowest aRPD depths occurred in sediments with increasing mud content or organic content. For example, near stream inputs, deposition areas or in the presence of macroalgae. Areas of poor sediment oxygenation were uncommon in the estuary.

Mobile sands were well oxygenated aRPD >50mm



Shallower aRPD (~10mm) present in soft sandy muds

Fine scale site 'Taut-A' aRPD > 30mm in firm muddy sand

3.3 OPPORTUNISTIC MACROALGAE

Table 5 summarises macroalgae percentage cover and biomass classes, with the mapped cover and biomass shown in Fig. 5 and Fig. 6 respectively. Macroalgal sampling stations and data are provided in Appendix 5. Marine species and drift macroalgae were not recorded as part of the nuisance macroalgae assessment.

Table 5. Summary of intertidal macroalgal cover (A) and biomass (B), Tautuku Estuary, December 2021.

A. Percent Cover

Percent cover category	Ha	%
Absent or trace (<1%)	79.7	99.0
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	0.01	0.01
Low-Moderate (30 to <50%)	0.0	0.0
High-Moderate (50 to <70%)	0.3	0.4
Dense (70 to >90%)	0.07	0.1
Complete (>90%)	0.4	0.4
Total	80.5	100

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	79.7	99.0
Very low (1 - 100)	0.0	0.0
Low (101 - 200)	0.01	0.01
Moderate (201 - 500)	0.4	0.5
High (501 - 1450)	0.01	0.01
Very high (>1450)	0.3	0.4
Total	80.5	100

Measuring macroalgal biomass

Key macroalgae results were as follows:

- Macroalgae was scarce in the Available Intertidal Habitat (AIH). Cover was classified as absent or trace (<1% cover) across 99.0% of the intertidal area (Table 5A). Overall, the Affected Area (AA), where macroalgae were growing, was small (0.8ha, 1.7%; Fig. 5; Table 6)
- Macroalgal patches exceeding 90% cover (0.4ha) were recorded in the lower estuary and were dominated by the green seaweed *Ulva* spp. growing on hard substrate (see photo pg. 16).
- Localised areas of high to moderate cover (50 to <70%) of *Agarophyton* spp. were recorded in the mid estuary growing in soft and very soft sandy mud (see photo pg. 15). Underlying sediments had a shallow aRPD indicating organic enrichment.
- Mean wet weight biomass was low across the AIH (36.8g/m^2), and bad in the AA (2209g/m^2; Table 6).
- Subtidal macroalgae was common in the shallow channels near the estuary entrance and comprised *Ulva* spp. and unknown filamentous algae.
- High Enrichment Condition (HEC) areas (mud-dominated sediments with >50% macroalgal cover entrained in stable beds) comprised 0.3ha (0.4% of the intertidal area). These areas were localised to small deposition zones in the mid estuary (see Appendix 6).

Because the estuary had <5% opportunistic macroalgal cover across the AIH (1.2%; Table 6), the overall quality status using the OMBT method is reported as 'high' equivalent to the condition rating of 'very good' (Table 3). A numeric OMBT EQR score was calculated using only the % cover AIH sub-metric as described in Stevens et al (2022). The numeric OMBT EQR score (0.952), reflects that macroalgae was not a dominant feature in the estuary and, when present, was generally associated with hard substrates.

Agarophyton spp. growing on soft sand mud, mid estuary

Ulva spp. growing on rocky substrate near entrance

Ulva spp. and filamentous algae in subtidal channel near entrance

Table 6. Summary of OMBT input metrics, overall Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 3). ETI rating is based on criteria in Table 3.

Dec-2021 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	1.21⁺	0.952	High
Biomass per m^2 AIH	36.82	0.926	High
Biomass per m^2 AA	2209.22	0.189	Bad
%entrained in AA	45.45	0.230	Poor
Worst of AA (ha) and AA (% of AIH)		0.933	High
AA (ha)	0.77	0.985	High
AA (% of AIH)	1.67	0.933	High
Survey EQR		0.952*	'Very Good'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating, *Table 2

⁺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).

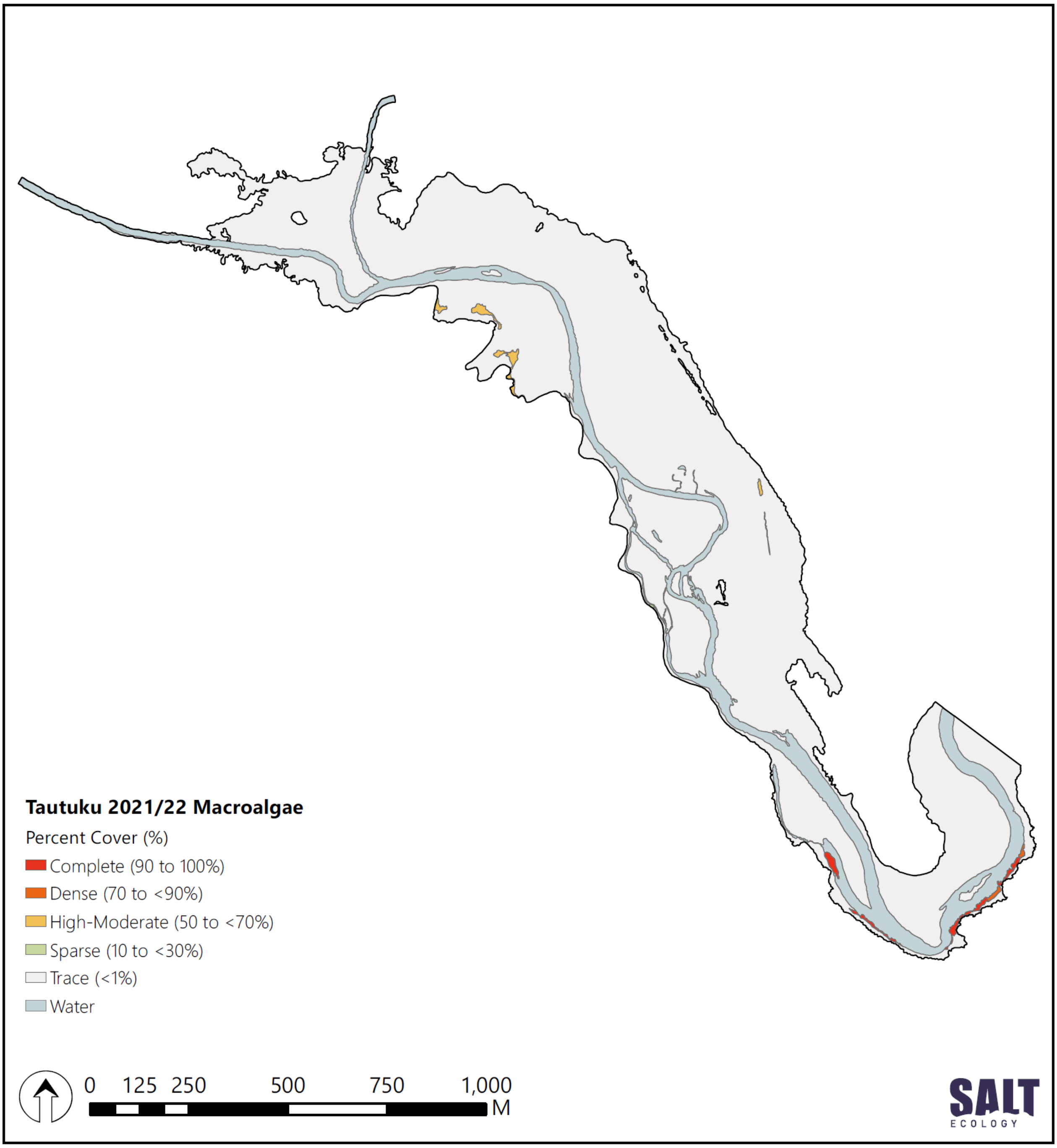


Fig. 5. Distribution and percent cover classes of macroalgae in Tautuku Estuary, December 2021.

Ulva spp. growing on rock substrate in the lower estuary

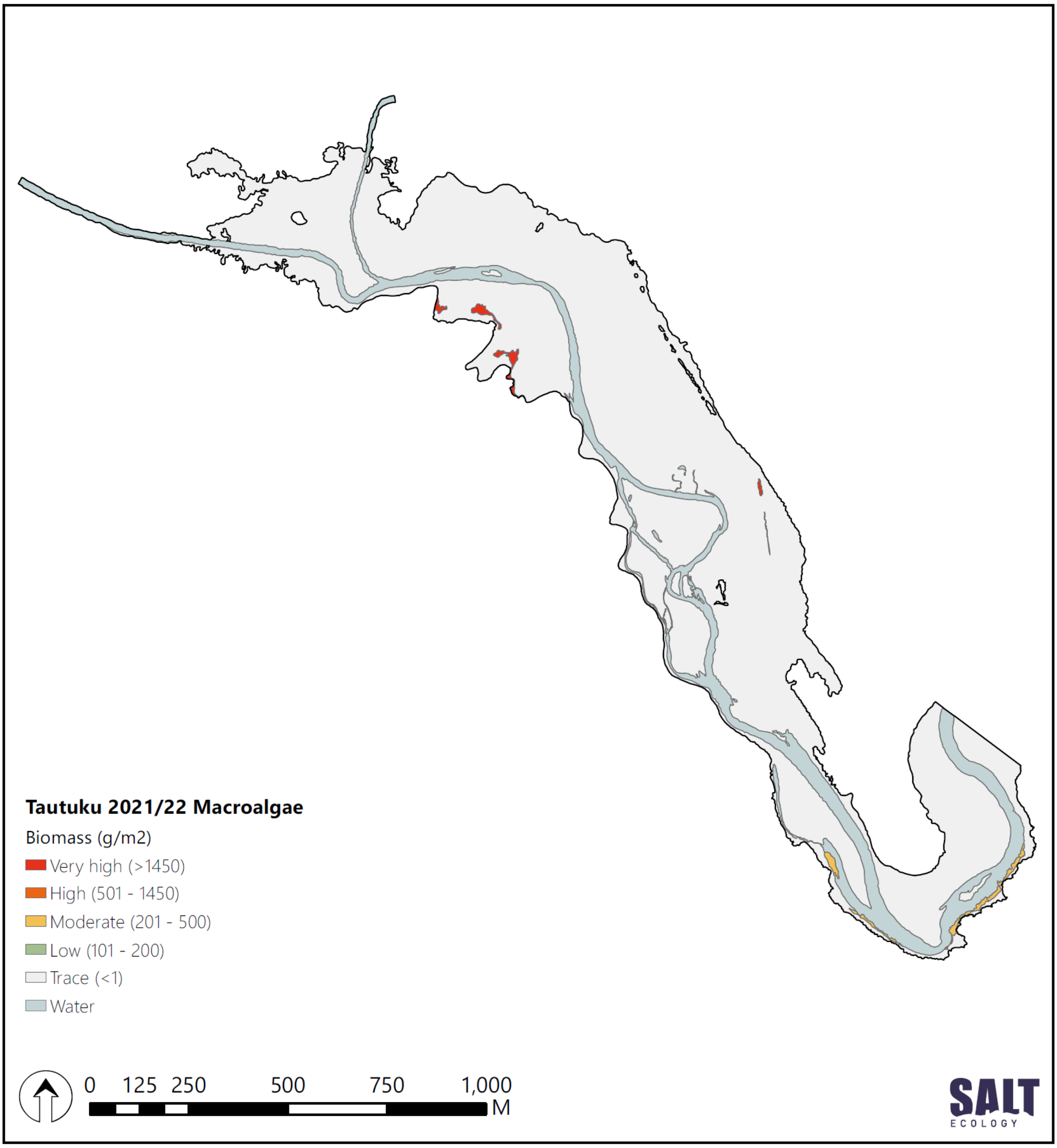


Fig. 6. Distribution and biomass classes of macroalgae in Tautuku Estuary, December 2021

Agarophyton spp. growing in soft sandy mud mid estuary

3.4 SEAGRASS

No seagrass was recorded in Tautuku Estuary in December 2021.

3.5 SALT MARSH

Table 7 summarises intertidal salt marsh with the distribution mapped in December 2021 presented in Fig. 7. Dominant and subdominant species are recorded in Appendix 7. Salt marsh covered 34.3ha (42.6%) of the intertidal area and was most extensive in the upper estuary and on the eastern margin (Fig. 7).

Intact transition from rushland through to native forest

Table 7. Summary of salt marsh area (ha and %) in Tautuku Estuary, December 2021.

Subclass	Ha	%
Estuarine Shrub	0.7	2.1
Grassland	0.0	0.0
Tussockland	0.0	0.0
Sedgeland	0.0	0.0
Rushland	32.3	94.1
Reedland	0.0	0.0
Herbfield	1.3	3.8
Total	34.3	100

Samolus repens (Primrose) transitioning to rushland

The dominant class was rushland comprising 32.3ha (94.1% of total salt marsh). The dominant species were *Apodasmia similis* (Jointed wirerush; see photo) and *Ficinia (Isolepis) nodosa* (Knobby clubrush). Estuarine shrubs comprised 0.7ha (2.1% of total salt marsh) and the dominant species was *Plagianthus divaricatus* (Salt marsh ribbonwood). Herbfield was present across 1.3ha (3.8% of total salt marsh) and the dominant species were *Samolus repens* (Primrose), *Sarcocornia quinqueflora* (Glasswort; see photo) and *Selliera radicans* (Remuremu; see photo). Other common salt marsh species included *Coprosma propinqua subsp. propinqua* (Mingi mingi), the rush *Isolepis cernua* (Slender clubrush) and the herb *Schoenoplectus pungens* (Three square). Introduced weeds and the grass *Festuca arundinacea* (tall fescue) were present in some areas. Vehicle damage and deer foraging were apparent in the salt marsh, and historic drainage channels carved through the rushland remain.

Vehicle damage in salt marsh habitat

In Tautuku Estuary there was an intact transition from salt marsh through to terrestrial forest or freshwater wetland. The intact transition is uncommon in the Otago region.

Historic drainage channels carved through rushland

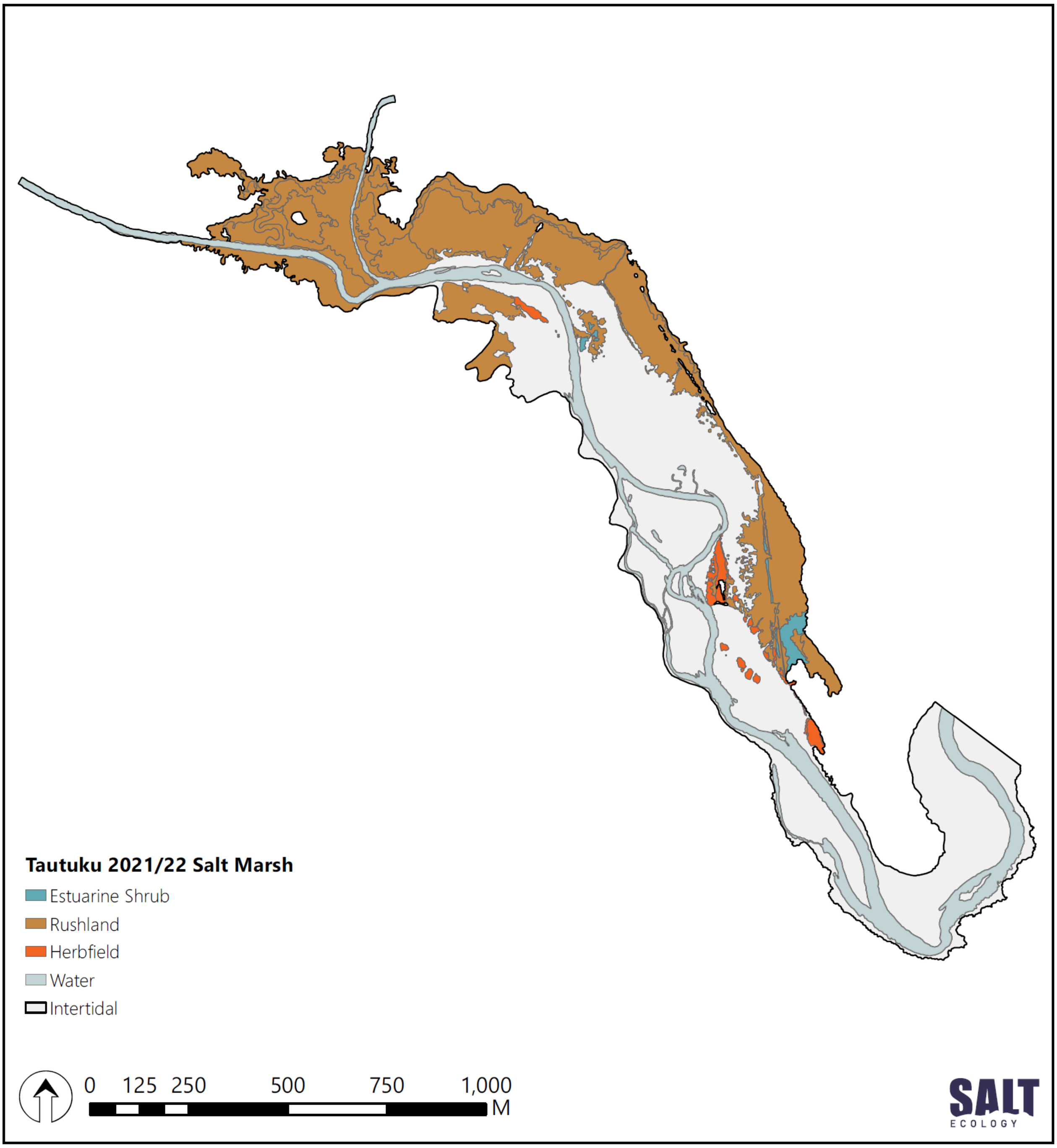


Fig. 7. Distribution of salt marsh in Tautuku Estuary, December 2021.

Extensive areas of *Apodasmia similis* (Jointed wirerush) in the upper estuary transition to a native forest terrestrial margin

3.6 TERRESTRIAL MARGIN

Table 8 and Fig. 8 summarise the land cover of the 200m terrestrial margin which was 85.7% densely vegetated (Table 8), including extensive areas of indigenous forest (58.6%), broad leaved indigenous hardwoods (13.4%) and manuka and/or kanuka (4.5%). The headland was dominated by low producing grassland (11.6%) and a small settlement (0.6%).

Indigeneous forest on the terrestrial margin

Indigeneous forest on true right bank

Settlement at the estuary entrance

Dunelands (i.e. classified as herbaceous saline vegetation in LCDB5) comprised 6.8% of the margin toward the estuary entrance on the true left bank. The dominant species recorded were marram grass (*Ammophila arenaria*) and tree lupin (*Lupinus arboreus*).

Marram dominated dunes at the estuary entrance (classified as herbaceous saline vegetation in LCDB5)

The freshwater wetland (i.e. classified as herbaceous freshwater vegetation in LCDB5) in the upper estuary comprised 1.7% of the margin and is classified as regionally significant in the Otago Regional Plan: Water 2013.

Table 8. Summary of 200m terrestrial margin land cover, Tautuku Estuary, December 2021.

LCDB5 Class		Ha	%
1	Built-up Area (settlement)	1.1	0.6
5	Transport Infrastructure	1.5	0.8
10	Sand and Gravel	0.8	0.4
16	Gravel and Rock	0.9	0.5
21	River	0.7	0.4
41	Low Producing Grassland	21.0	11.6
45	Herbaceous Freshwater Vegetation	3.1	1.7
46	Herbaceous Saline Vegetation	12.4	6.8
51	Gorse and/or Broom	0.8	0.5
52	Manuka and/or Kanuka	8.1	4.5
54	Broadleaved Indigenous Hardwoods	24.3	13.4
56	Mixed Exotic Shrubland	0.3	0.2
69	Indigenous Forest	106.0	58.6
Grand Total		180.9	100
Total dense vegetated margin (LCDB5 classes 45-71)		155.1	85.7

As discussed in Section 1.1 the estuary drains a 6,186ha catchment comprising ~91.5% indigenous forest, 3.3% manuka and/or kanuka and 1.2% herbaceous freshwater and 1.1% saline vegetation. Of the catchment, 97.9% is densely vegetated (Table 1; Fig. 2). Previously cleared areas in the north of the estuary are now regenerating indigenous forest (see historic photo pg. 2).

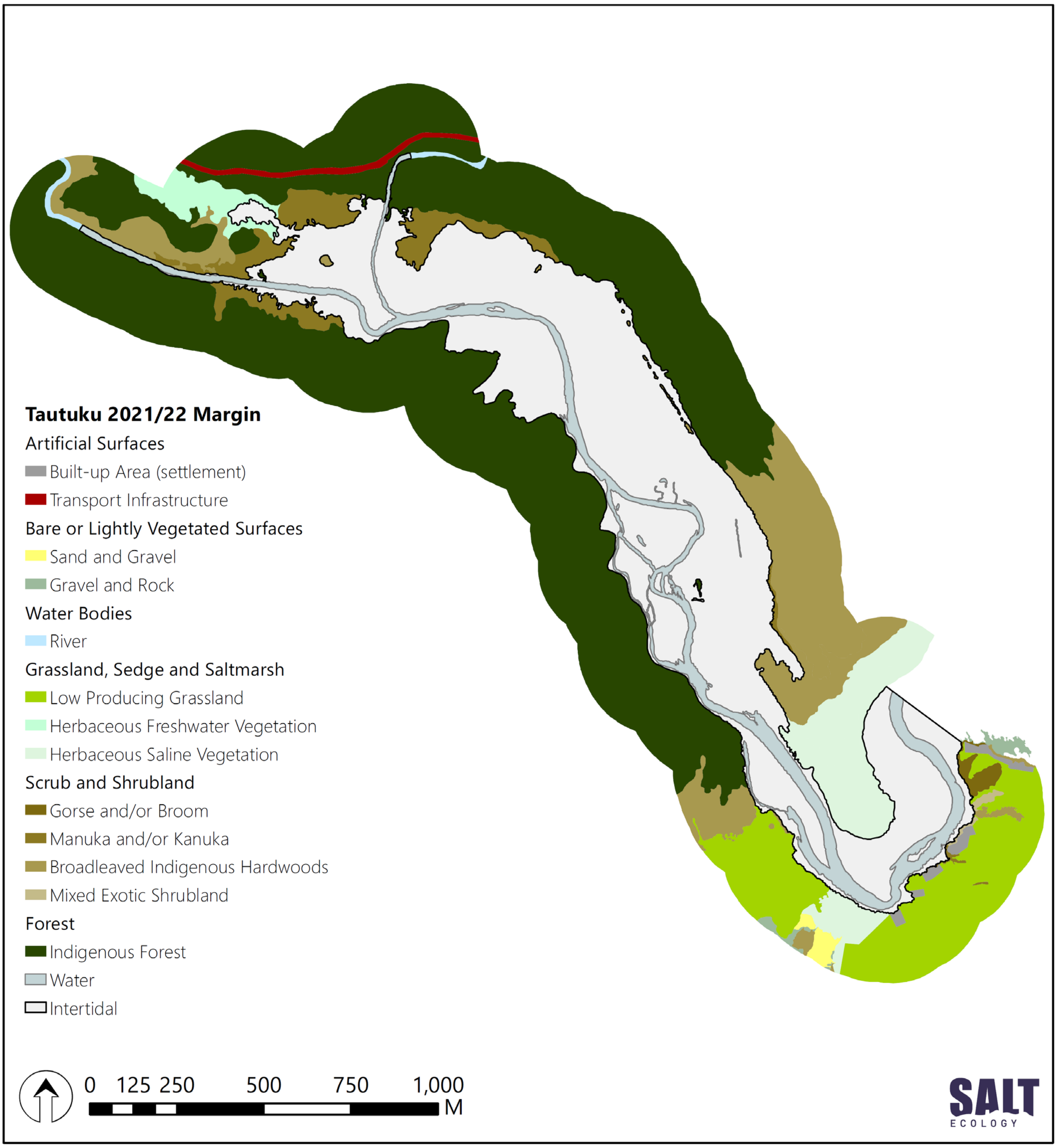


Fig. 8. Map of 200m terrestrial margin land cover, Tautuku Estuary, December 2021. Dunes, near the entrance, were categorised as 'herbaceous saline vegetation' to maintain consistency with LCDB5.

Looking upstream toward the native forest catchment

3.7 WATER QUALITY

Water quality data presented in Table 9 provides ancillary information to support the broad scale mapping survey. The main channel through the estuary was shallow (<1m) and not stratified at the time of sampling with dissolved oxygen, temperature and salinity remaining relatively consistent with depth.

Table 9. Water quality for Tautuku Estuary, December 2021.

Station	Site 1	Site 2
NZTM East	1325521	1325176
NZTM North	4834323	4834502
Distance from mouth (m)	2800	3200
Stratified	no	no
Surface measurements		
Measurement depth (m)	0.2	0.2
Temperature (°C)	16.0	14.4
DO saturation (%)	118.5	110.7
DO concentration (g/m^3)	11.0	11.0
Salinity	9.8	5.8
pH	7.8	7.6
Chlorophyll-a (mg/m^3)	~~50.0~~[1]	~~39.0~~[1]
Bottom measurements		
Measurement depth (m)	0.6	0.75
Temperature (°C)	15.9	14.1
DO saturation (%)	116.8	106.6
DO concentration (g/m^3)	10.7	10.5
Salinity	11.8	6.8
pH	7.8	7.6
Chlorophyll-a (mg/m^3)	~~18.0~~[1]	~~47.5~~[1]
Secchi depth (m)	>0.4	>0.4
Max depth (m)	0.7	0.8
Channel width (m)[2]	30	35
Sediment texture	firm	firm
Sediment type	MS10	S

[1] Erroneous chlorophyll concentration due to optical interference from tannins. [2] Estimated at the time of sampling.

As expected, the site closest to the estuary entrance (Site 1) exhibited higher salinity, temperature and pH than the site further upstream (Site 2). The water column was well oxygenated (>100% dissolved oxygen saturation) at the time of sampling.

The Tautuku River is rich in tannins (i.e. naturally brown in colour) owing to its native forest catchment. The coloured dissolved organic matter that make up tannins can absorb light and reduce water clarity. Furthermore, tannins can lead to optical interferences in the measurement of chlorophyll leading to erroneously high chlorophyll concentrations. As such chlorophyll concentrations presented in Table 9 do not reflect a phytoplankton issue in the estuary but rather instrument interference. No obvious water quality issues were identified at the time of sampling.

3.8 ESTUARY TROPHIC INDEX (ETI)

Table 10 summarises the indicators used to calculate an overall ETI score for Tautuku Estuary. Raw data are presented in Appendix 8. The primary indicator of eutrophication response in SIDE type estuaries, like Tautuku, is macroalgae (OMBT-EQR) with ETI supporting sediment indicators of macrofauna (AMBI), total nitrogen (TN), total organic carbon (TOC) and oxygenation (aRPD) used to assess trophic state. The overall ETI score of 0.242 was rated 'very good' in terms of eutrophication which is reflected in other metrics such as the high EQR, good sediment oxygenation and only a small, localised area of high enrichment conditions.

Table 10. Primary and supporting indicators used to calculate the ETI for Tautuku Estuary.

Indicator	Raw Value	Equivalent ETI Score
Primary indicator		
Macroalgae (EQR)	0.952	0.063
Supporting Indicator		
AMBI	4.45	0.813
TN (mg/kg)	<500	0.375
TOC (%)	0.33	0.188
aRPD (mm)	45	0.313
Final ETI Score		0.242 "Very Good"

Tannin rich waters in Tautuku Estuary

4. KEY FINDINGS

Key broad scale indicator results and ratings are summarised in Table 11 and Table 12 and additional supporting data used to assess estuary condition are presented in Table 13.

Table 11. Summary of key broad scale features as a percentage of total estuary, intertidal or margin area, Tautuku Estuary, December 2021.

a. Area summary	ha	% Estuary
Intertidal area	80.5	86.0
Subtidal area	13.1	14.0
Total estuary area	**93.6**	**100**

b. Key substrate features	ha	% Intertidal
Mud-enriched (25 to <50%)	12.5	15.5
Mud-dominated (≥50%)	20.7	25.7

c. Key habitat features	ha	% Intertidal
Salt marsh	34.3	42.6
Seagrass (≥50% cover)	0.0	0.0
Macroalgal beds (≥50% cover)	0.8	0.9

d. Terrestrial margin (200m)	% Margin
200m densely vegetated margin	85.7

Tautuku Estuary was intertidally dominated (80.5ha or 86% of the estuary area; Table 10) with the subtidal areas restricted to the river channel. Overall, the estuary was in 'very good' condition and supported a variety of habitats (salt marsh, mudflats, mobile sands and rocky shores) and associated biological communities. The high ecological quality of the estuary can, to a large part, be attributed to its native forested catchment (Table 1) and resulting high water quality in the Tautuku River (Ozanne 2011; Table 9), and to the low level of modification to the estuary itself.

Although the estuary was in 'very good' condition, mud-dominated sediments were a common feature with a rating of 'poor' (Table 12). However, over 85% of the mud-dominated sediments were associated with salt marsh habitat which naturally traps fine sediments. Mud-dominated sediments outside of salt marsh areas were relatively uncommon (3.8% of the intertidal area) and localised to the margins of rushland or in sheltered deposition zones. The extensive sandflats in the mid and lower estuary were comprised of clean firm or mobile sands that were in a healthy condition, but were naturally impoverished in terms of the biota living in the sediment (Forrest et al. 2022). Zootic habitat, as a dominant cover, was a minor feature in the estuary with only a small area of shellbank on the channel margin in the mid estuary. The mobility of the substrate in the mid and lower estuary likely limits the establishment of biota in the sediment.

Cockle shell debris in the mid estuary

Table 12. Summary of key broad scale indicator results and ratings.

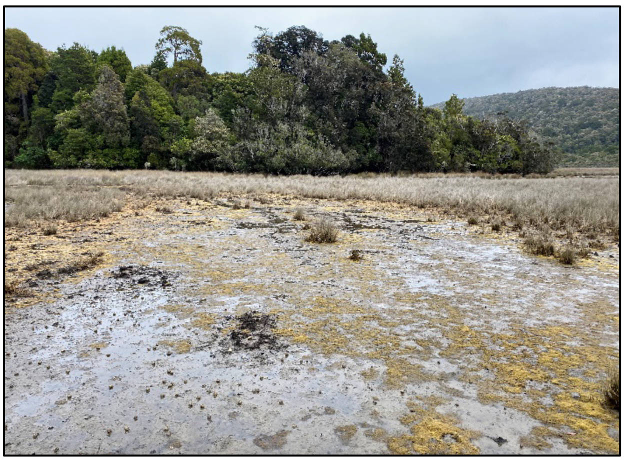
Broad Scale Indicators	Unit	2021 Value	December 2021
Estuary Trophic Index (ETI) Score	No unit	0.242	Very Good
Mud-dominated substrate	% of intertidal area >50% mud	25.7 (3.8[1])	Poor (area includes saltmarsh)
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.946	Very Good
Seagrass	% decrease from baseline	0.0	*baseline*
Salt marsh extent (current)	% of intertidal area	42.6	Very Good
Historical salt marsh extent*	% of historical remaining	>90[2]	Very Good
200m terrestrial margin	% densely vegetated	85.7	Very Good
High Enrichment Conditions	ha	0.3	Very Good
High Enrichment Conditions	% of estuary	0.3	Very Good
Sedimentation rate*	CSR:NSR ratio[3]	1.0	Very Good
Sedimentation rate*	mm/yr	1.8	Fair

Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. [1]In brackets mud-dominated sediment outside salt marsh [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

Epifauna *Amphibola crenata* visible on firms sands, mid estuary

Macroalgae was a minor feature in the estuary, comprising only 0.9% (>50% cover; Table 5A) of the intertidal area. *Ulva* spp. present in the lower estuary was associated with sand or rocky substrate with growth most likely marine influenced. In a sheltered deposition zone in the mid estuary, a localised area of nuisance macroalgae, *Agarophyton* spp., was growing and comprised a small area of high enrichment condition (0.4% of the intertidal area). In other areas, nuisance macroalgae was absent which is consistent with the OMBT EQR of 0.952, a condition rating of 'very good' (Table 12).

Localised area of *Agarophyton* spp. growing in mud-dominated sediments



Sheltered area of fine sediment deposition and *Agarophyton* spp.

Seagrass is a key feature in estuaries because it is a food source and habitat for fish, birds and macroinvertebrates. Seagrass can also influence water quality by trapping fine sediments, stabilising substrate, and assimilating nutrients. Unlike other Otago estuaries (Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea) where seagrass is the dominant vegetation type, no seagrass was recorded in Tautuku Estuary. This potentially reflects conditions limiting to seagrass growth, in particular, light limitation from the the tannin rich waters of the Tautuku River, a strong freshwater influence (low salinity) in the likely areas seagrass would grow in the mid estuary, and the high mobility of the substrate in the mid to lower estuary that would prevent establishment.

Tannin rich waters in Tautuku River

Salt marsh, mainly rushland, was the dominant intertidal habitat (Table 11). Salt marsh is an important feature of estuaries because it traps sediments and filters nutrients and also provides an important habitat for birds (e.g. South Island fernbird) and insects. Drainage channels, cut through the salt marsh (see photos on next page) to support early industries (i.e. whaling, port, sawmills, fishing) in Tautuku, remain visible today. In the upper estuary, salt marsh transitions abruptly to freshwater wetland, largely owing to the historic channelisation of waterways. However, the transition from salt marsh to freshwater wetland to indigenous forest remains rare in the Otago region and across New Zealand.

Herbfield transitioning to rushland and then indigenous forest

While the salt marsh is extensive (a condition rating of 'very good'), localised vehicle damage, erosion of rushland near river channels and deer foraging were evident. In terms of historical losses, the estuary is rated 'very good' with an estimated >95% of the natural salt marsh cover remaining (Table 12). The wetlands and salt marsh are classified as regionally significant in the ORC Regional Plan: Water and should continue to be protected for their high ecological values.

Historic channels through salt marsh in 1947 (top) and present day (bottom), Tautuku Estuary

The ETI score was 0.242, a condition rating of 'very good', indicating few eutrophication (nutrient enrichment) impacts in the estuary. This is supported by the small area (<0.4%) of high enrichment condition and low macroalgae cover (1.2% cover AIH). These results are consistent with a modelled nitrogen load of 56mgN/m^2/d, which is below the ~100mgN/m^2/d threshold at which nuisance macroalgae problems are predicted occur (Robertson et al. 2017; Table 13).

The Tautuku catchment and 200m estuary margin are densely vegetated (97.9% and 85.7%, respectively) and dominated by indigenous forest (Table 1; Table 8), meaning human activities that generally cause increased sediment inputs (e.g. agriculture, forestry) are uncommon. NIWA's national estuary sediment load estimator (Hicks et al. 2019) estimates sediment inputs and retention. This information can be used to calculate a net deposition rate in the estuary. The estuary is predicted to be highly efficient at trapping sediment (82% retention) and, if all of the retained sediment was spread evenly throughout the estuary, it would result in an overall average of ~1.8mm/yr of estuary infilling (Table 13), a condition rating of 'fair' (Table 12). Importantly the estimated current sedimentation rate (CSR) and natural sedimentation rate (NSR) were the same (CSR:NSR = 1.0; Table 13), indicating current sediment inputs from the catchment closely reflect natural rates.

The elevated muddiness of the upper estuary is therefore most likely a legacy of historic catchment land use (e.g. logging and drainage). For example, Tyrell (2016) attributed the end of the Tautuku fishing industry to the 'silting up' of the rivers, coincident with the period of logging in the catchment. As present-day sediment sources appear low, and fine sediments are largely confined to salt marsh in the upper estuary, there is little evidence to suggest active management of sediment to the estuary is needed.

Table 13. Supporting data used to assess estuary ecological condition in Tautuku Estuary.

Supporting Condition Measure	Tautuku Estuary
Mean freshwater flow (m^3/s)[1]	1.3
Catchment Area (Ha)[1]	6235
Catchment nitrogen load (TN/yr)[2]	19.0
Catchment phosphorus load (TP/yr)[2]	2.0
Catchment sediment load (KT/yr)[1]	3.1
Estimated N areal load in estuary (mg/m^2/d)[2]	56
Estimated P areal load in estuary (mg/m^2/d)[2]	6
CSR:NSR ratio[1]	1.0
Trap efficiency (sediment retained in estuary)[1]	82%
Estimated rate of sedimentation (mm/yr)[1]	1.8

[1] Hicks et al. 2019.

[2] CLUES version 10.6 (LCBD5), Run date: March 2022

Overall, condition ratings for broad scale mapping indicators suggest the estuary is in 'very good' condition, with large areas of salt marsh and a wide range of other habitat types (i.e. mobile sands, mud flats and rock field). However, the upper estuary salt marsh is relatively muddy. The catchment appears to have recovered from past disturbances (e.g. logging) and the estuary retains high ecological quality largely attributed to the 'excellent' water quality of freshwater inputs and high degree of naturalness remaining in the catchment (Ozanne 2011; Moore 2015). Tautuku Estuary represents an important reference site in which comparisons can be made to other estuaries across the Otago region.

5. RECOMMENDATIONS

Based on the findings of the current survey it is recommended that ORC consider the following:

- Repeat the broad scale habitat mapping at 5-10 yearly intervals to track long term changes in estuary condition.
- Include Tautuku Estuary in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will continue to protect the high ecological quality of the estuary and its catchment.

Tautuku Estuary entrance

Boardwalk entrance to estuary (top) and rinsing macrofauna samples in the main channel (bottom)

Mid estuary flats and abundant epifauna visible on the surface

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[1]*Additions to the NEMP classification.*

SUBSTRATE (physical and zoogenic habitat)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Shell bank: Area that is dominated by dead shells

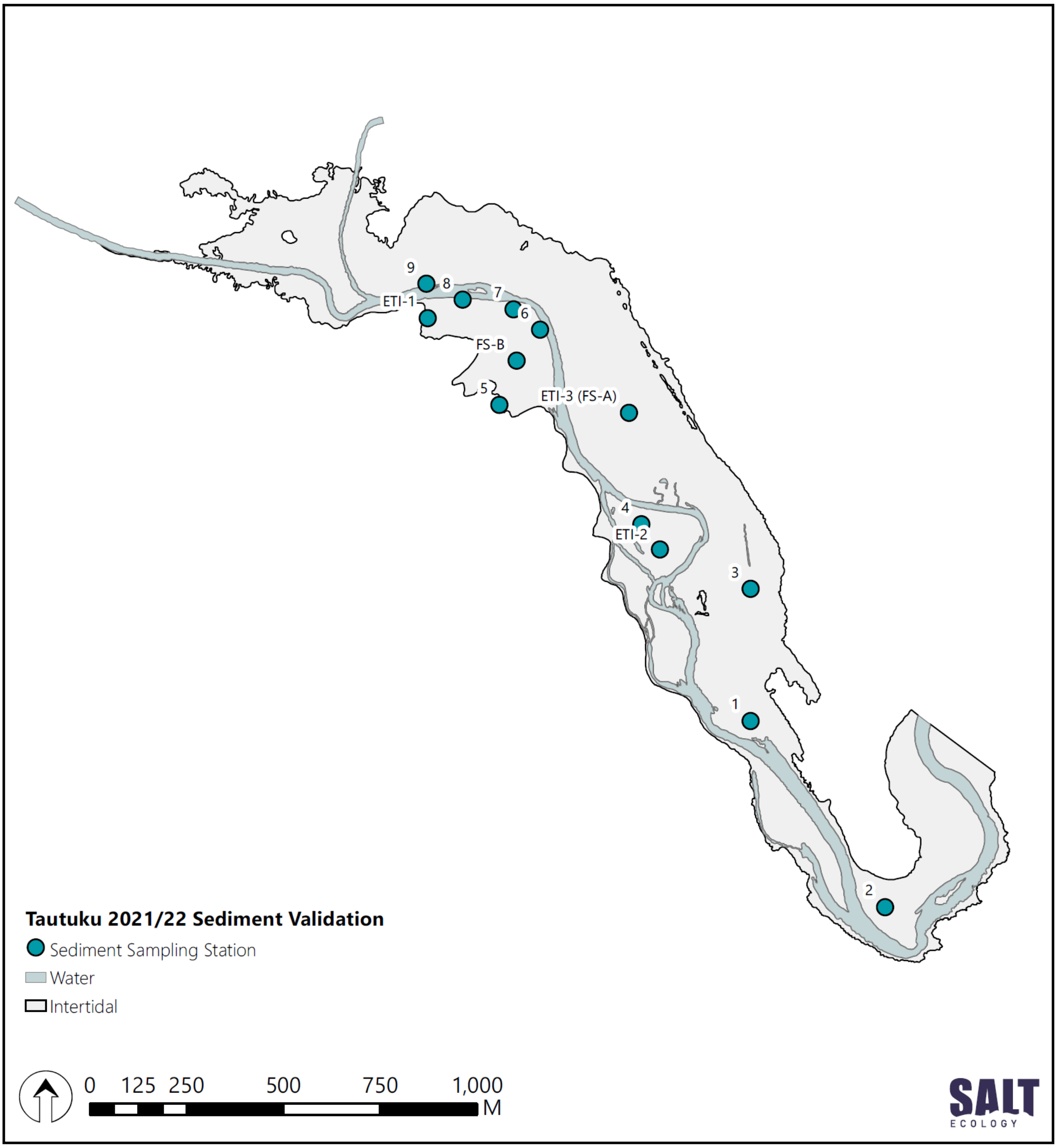
Table of modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.1m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Mobile sand	mS
		Firm shell/sand	fSS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Mobile muddy sand	mMS10
		Firm muddy shell/sand	fSS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Mobile muddy sand	mMS25
		Firm muddy shell/sand	fMSS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Mud (M)	Very high mud (>90%)	Firm mud	fM90
		Soft mud	sM90
		Very soft mud	vsM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Tubeworm reef	TUBE
Artificial Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aS BF
		Cobble field	aS CF
		Gravel field	aS GF
		Sand field	aS SF

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

APPENDIX 2. SEDIMENT SAMPLING STATIONS IN TAUTUKU ESTUARY, DECEMBER 2021

Sampling stations for sediment validation



Site	NZTM_E	NZTM_N	Field code	Subjective % mud	Measured % mud	Measured % sand	Measured % gravel
Taut-Otag - 1	1326022	4833220	mS	<10%	1.0	98.9	<0.1
Taut-Otag - 2	1326369	4832738	mS	<10%	1.6	98.4	<0.1
Taut-Otag - 3	1326022	4833561	sMS25	25 to 50%	40.9	57.1	2.0
Taut-Otag - 4	1325739	4833729	fS	<10%	18.7	81.3	<0.1
Taut-Otag - 5	1325372	4834037	vsSM	50 to 90%	41.1	58.8	<0.1
Taut-Otag - 6	1325478	4834231	fMS10	10 to 25%	10.3	88.9	0.8
Taut-Otag - 7	1325409	4834284	fMS10	10 to 25%	17.3	82.3	0.4
Taut-Otag - 8	1325277	4834309	sMS25	25 to 50%	26.4	73.4	0.3
Taut-Otag - 9	1325184	4834350	vsSM	50 to 90%	44.7	55.3	<0.1
Taut-Otag - ETI-1	1325187	4834261	vsSM	50 to 90%	63.2	36.3	0.5
Taut-Otag - ETI-2	1325787	4833663	fS	<10%	6.6	93.5	<0.1
Taut-Otag - ETI-3	1325707	4834017	fMS10	10 to 25%	13.8	86.2	<0.1
Taut-Otag - FS-A	1325707	4834017	fMS10	10 to 25%	16.1	83.9	<0.1
Taut-Otag - FS-B	1325417	4834151	sMS25	25 to 50%	53.5	46.4	0.1

There was good agreement between the measured mud content and the subjective mud classification for >70% of the samples collected. However, four sites were outside of the subjective mud classification. Sites 9 and FS-B were estimated within 5.3 and 3.5% mud. Sites Taut-Otag 4 and 5 were within ±10% mud of the estimated range.

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28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand

T 0508 HILL LAB (44 555 22)
T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	2789787
Contact:	Keryn Roberts C/- Salt Ecology Limited 21 Mount Vernon Place Washington Valley Nelson 7010	**Date Received:**	04-Dec-2021
		Date Reported:	15-Feb-2022
		Quote No:	114523
		Order No:	
		Client Reference:	Broadscale – Tautuku Estuary
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Taut-Otag-1 30-Nov-2021 6:00 pm	Taut-Otag-2 30-Nov-2021 5:30 pm	Taut-Otag-3 30-Nov-2021 5:00 pm	Taut-Otag-4 30-Nov-2021 4:30 pm	Taut-Otag-5 30-Nov-2021 4:45 pm
Lab Number:		2789787.1	2789787.2	2789787.3	2789787.4	2789787.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	76	82	45	74	68
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	< 0.1	2.0	< 0.1	< 0.1
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	98.9	98.4	57.1	81.3	58.8
Fraction < 63 µm*	g/100g dry wt	1.0	1.6	40.9	18.7	41.1

Sample Name:		Taut-Otag-6 02-Dec-2021 10:30 am	Taut-Otag-7 02-Dec-2021 10:40 am	Taut-Otag-8 02-Dec-2021 10:50 am	Taut-Otag-9 02-Dec-2021 11:15 am	Taut-Otag-ETI-1 02-Dec-2021 11:00 am
Lab Number:		2789787.6	2789787.7	2789787.8	2789787.9	2789787.10
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	73	73	65	57	56
Total Recoverable Phosphorus	mg/kg dry wt	-	-	-	-	610
Total Sulphur*‡	g/100g dry wt	-	-	-	-	0.30
Total Nitrogen*	g/100g dry wt	-	-	-	-	0.19
Total Organic Carbon*	g/100g dry wt	-	-	-	-	3.4
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.8	0.4	0.3	< 0.1	0.5
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	88.9	82.3	73.4	55.3	36.3
Fraction < 63 µm*	g/100g dry wt	10.3	17.3	26.4	44.7	63.2

Sample Name:		Taut-Otag-ETI-2 02-Dec-2021 11:30 am	Taut-Otag-ETI-3 02-Dec-2021 10:45 am			
Lab Number:		2789787.11	2789787.12			
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	77 #1	80	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	300	370	-	-	-
Total Sulphur*‡	g/100g dry wt	0.063	0.039	-	-	-
Total Nitrogen*	g/100g dry wt	< 0.05	< 0.05	-	-	-
Total Organic Carbon*	g/100g dry wt	0.29	0.33	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1 #1	< 0.1	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	93.5 #1	86.2	-	-	-
Fraction < 63 µm*	g/100g dry wt	6.6 #1	13.8	-	-	-

Analyst's Comments

‡ Analysis subcontracted to an external provider. Refer to the Summary of Methods section for more details.

#1 It should be noted that there was insufficient sample to complete the Grainsize_3_as analysis at the default quantity required of 100g. The analysis proceeded using approximately 50g of sample. should be kept in mind when interpreting these results.

Appendix No.1 - SGS Report

Summary of Methods

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

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	10-12
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%.	-	10-12
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-12
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	10-12
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	10-12
Total Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g dry wt	10-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	10-12
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	10-12
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-12
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12

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

Testing was completed between 13-Dec-2021 and 15-Feb-2022. For completion dates of individual analyses please contact the laboratory.

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

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 3. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multi-metric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5-part multi-metric OMBT, modified for NZ estuary types, is presented in the WFD-UKTAG (2014) with additions described in Plew et al. (2020), and is paraphrased below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of *mud*, *muddy sand*, *sandy mud*, *sand*, *stony mud and mussel beds*. Areas which are judged unsuitable for algal blooms, e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. PERCENTAGE COVER OF THE AVAILABLE INTERTIDAL HABITAT (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. TOTAL EXTENT OF AREA COVERED BY ALGAL MATS (AFFECTED AREA (AA)) OR AFFECTED AREA AS A PERCENTAGE OF THE AIH (AA/AIH, %).

The affected area represents the total area of macroalgal cover in hectares. In large water bodies, small patches of macroalgal coverage relative to the estuary size would result in the total percent cover across the AIH remaining within the 'high' or 'good' status. While the affected area may be relatively small when compared to estuary size the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities (WFD-UKTAG 2014). In order to account for this, the OMBT included an additional metric; the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse-case scenario.

3. BIOMASS OF AIH (G.M^{-2}).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within ±5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. BIOMASS OF AA (G.M^{-2}).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. PRESENCE OF ENTRAINED ALGAE (% OF QUADRATS).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool. All the metrics are equally weighted and combined within the multi-metric, in order to best describe the changes in the nature and degree of opportunistic macroalgae growth on sedimentary shores due to nutrient pressure.

TIMING

The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March). However, peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification, e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

SUITABLE LOCATIONS

The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing intermittently closed and open estuaries (ICOEs) due to the particular challenges in setting suitable reference conditions for these water bodies.

DERIVATION OF THRESHOLD VALUES

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

REFERENCE THRESHOLDS

A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g/m^2 wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

CLASS THRESHOLDS FOR PERCENT COVER

High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

Table A1. The final face value thresholds and metrics for levels of the ecological quality status. These thresholds have been recently revised for New Zealand (see Table A3).

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 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).
Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

CLASS THRESHOLDS FOR BIOMASS

Class boundaries for biomass values were derived from DETR (2001) recommendations that <500g.m^{-2} wet weight was an acceptable level above the reference level of <100g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500g.m^{-2} represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500gm^{-2} but less than 1,000g.m^{-2} would lead to a classification of Moderate quality status at best but would depend on the percentage of the AIH covered. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003). **Thresholds applied in the current study are described and presented in Table A3.**

THRESHOLDS FOR ENTRAINED ALGAE

Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently, the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

EQR CALCULATION

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Rating** score (EQR).
The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the categories in Table A1. The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 - where Total % cover = Sum of [(patch size) / 100] x average % cover for patch
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH (g.m^{-2}) = Total biomass / AIH - where Total biomass = Sum of (patch size x average biomass for the patch)
- Biomass of Affected Area (g.m^{-2}) = Total biomass / AA - where Total biomass = Sum of (patch size x average biomass for the patch)
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A2).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

*Final Equidistant Index score = Upper Equidistant range value – ([Face Value - Upper Face value range] * (Equidistant class range / Face Value Class Range)).*

Table A2 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range. Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.

Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

Metric	Quality status	Face value ranges			Equidistant class range values		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g.m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g.m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

The final EQR score is calculated as the average of equidistant metric scores.

A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

Biomass thresholds included in the OMBT were lowered for use in NZ by Plew et al. (2020) based on unpublished data from >25 shallow well-flushed intertidal NZ estuaries (Robertson et al. 2016b) and the results from similar estuaries in California. Sutula et al. (2014) reported that in eight Californian estuaries, macroalgal biomass of 1450g.m^{-2} wet weight, total organic carbon of 1.1% and sediment total nitrogen of 0.1% were thresholds associated with anoxic conditions near the surface (aRPD < 10 mm). Green et al. (2014) reported significant and rapid negative effects on benthic invertebrate abundance and species richness at macroalgal abundances as low as 840–930g.m^{-2} wet weight in two Californian estuaries. McLaughlin et al. (2014) reviewed Californian biomass thresholds and found the elimination of surface deposit feeders in the range of 700–800g.m^{-2}. As the Californian results were consistent with NZ findings, the latter thresholds were used to lower the OMBT good/moderate threshold from ≤500 to ≤200g.m^{-2}, the moderate/poor threshold from ≤1000 to ≤500gm^{-2} and the poor/bad threshold from >3000 to >1450g.m^{-2}. These thresholds are considered to provide an early warning of nutrient related impacts in NZ prior to the establishment of adverse enrichment conditions that are likely difficult to reverse.

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Table A3. Revised final face value thresholds and metrics for levels of the ecological quality status used in the current assessment.

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

*Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

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APPENDIX 4. INFORMATION SUPPORTING RATINGS IN THE REPORT

SEDIMENT MUD CONTENT

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more sticky and cohesive, and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon, and sediment-bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations and, on intertidal flats of estuaries, can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

APPARENT REDOX POTENTIAL DISCONTINUITY (ARPD)

aRPD depth, the visually apparent transition between oxygenated sediments near the surface and deeper more anoxic sediments, is a primary estuary condition indicator as it is a direct measure of time integrated sediment oxygenation. Knowing if the aRPD is close to the surface is important for three main reasons:

The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species. The tendency for sediments to become anoxic is much greater if the sediments are muddy. Anoxic sediments contain toxic sulphides and support very little aquatic life. As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, become released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (i.e. >3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

OPPORTUNISTIC MACROALGAE

The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with high mud and low oxygen conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014; Robertson et al 2016a,b; Zeldis et al. 2017), with results combined with those of other indicators to determine overall condition.

SEAGRASS

Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column. It is also susceptible to degraded sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent are likely to indicate an increase in these types of pressures. The assessment metric used is the percent change from baseline measurements.

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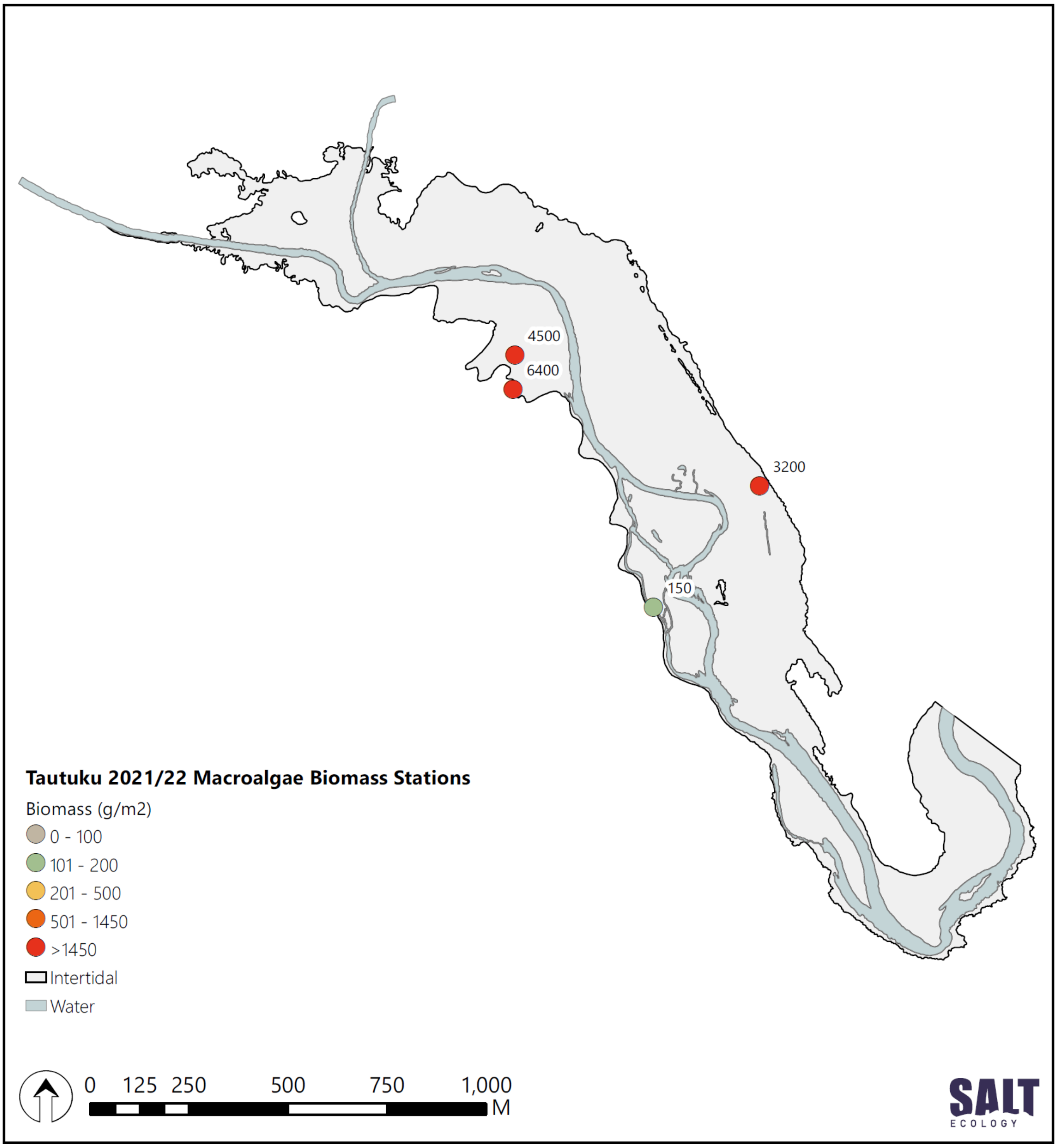
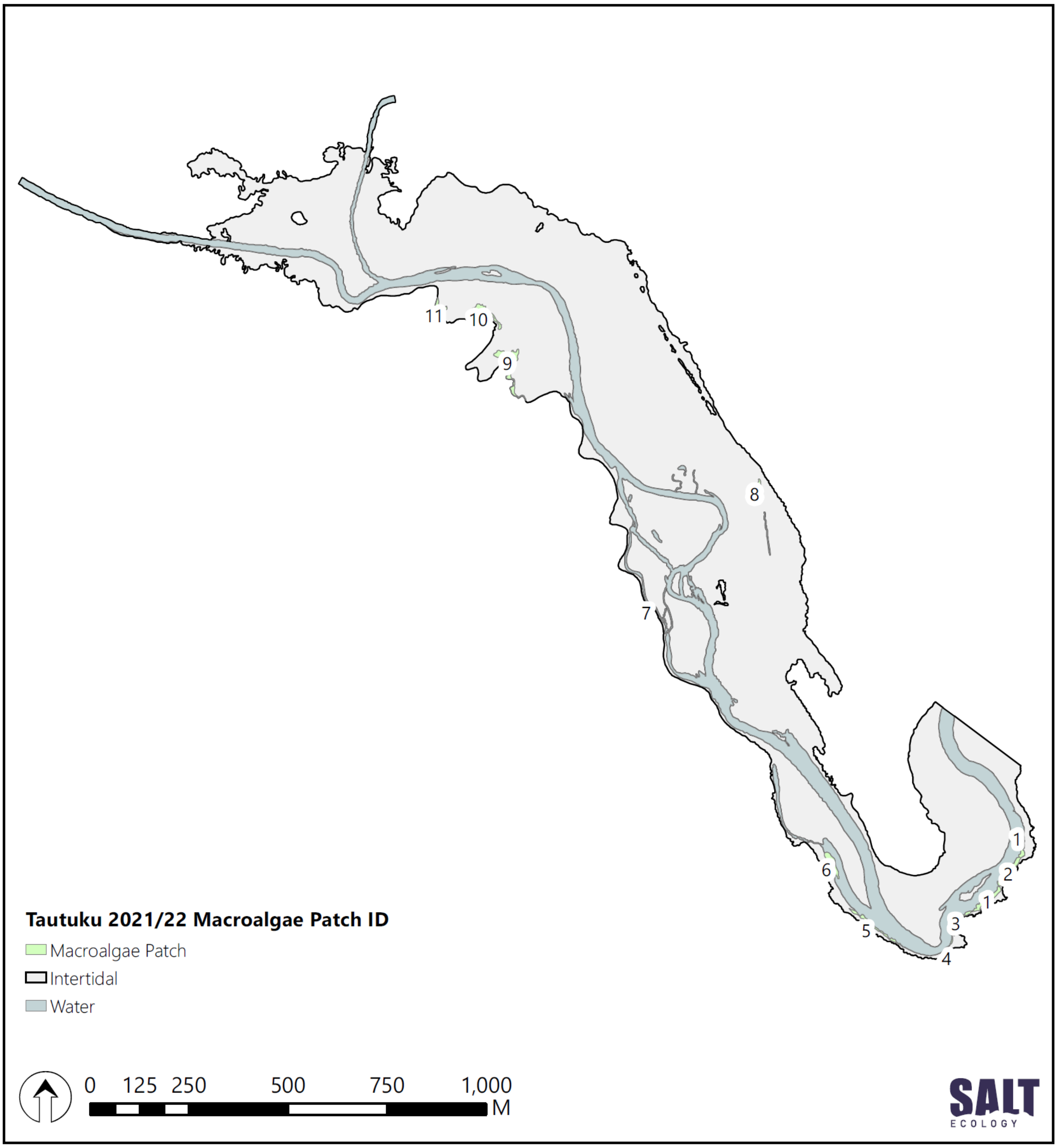
APPENDIX 5. MACROALGAL BIOMASS STATIONS & OMBT PATCH ID AND RAW DATA, TAUTUKU ESTUARY, DECEMBER 2021



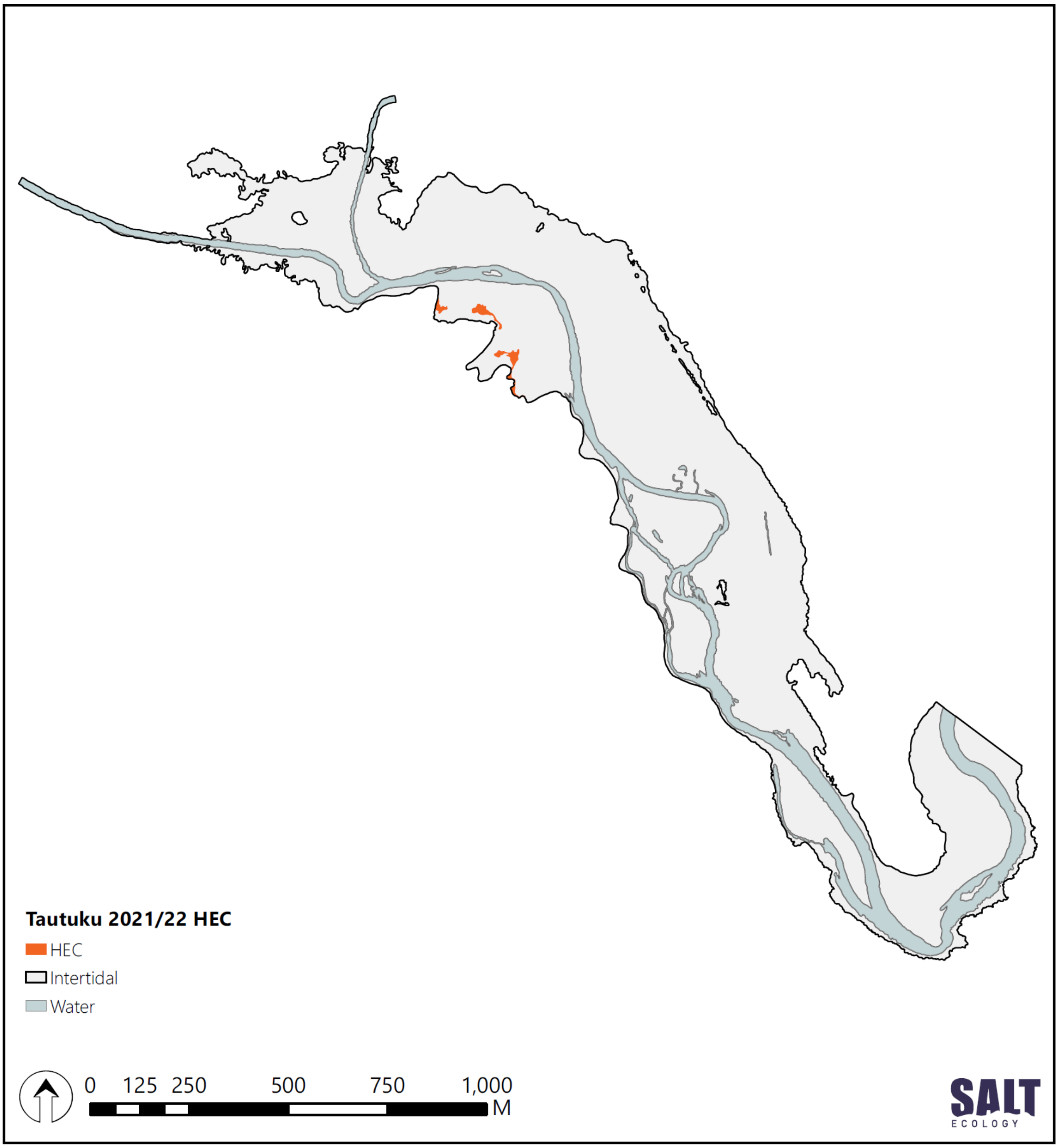
Macroalgal patch information used in the calculation of the OMBT-EQR

Estuary	Year	PatchID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (g/m	Biomass Category	Entrained*	Dominant Species	Sub.Dom sp.1	Area (ha)
Tautuku	2021	1	Ulva	80	80	Dense (70 to <90%)	300	Moderate (201 - 500)	0	*Ulva* spp. (Sea lettuce)		0.07
Tautuku	2021	3	Ulva	90	90	Complete (>90%)	300	Moderate (201 - 500)	0	*Ulva* spp. (Sea lettuce)		0.11
Tautuku	2021	4	Ulva	100	100	Complete (>90%)	900	High (501 - 1450)	0	*Ulva* spp. (Sea lettuce)		0.01
Tautuku	2021	5	Ulva	90	90	Complete (>90%)	300	Moderate (201 - 500)	0	*Ulva* spp. (Sea lettuce)		0.07
Tautuku	2021	11	Grch	50	50	High-Moderate (50 to <70%)	3200	Very high (>1450)	1	*Agarophyton* spp.		0.05
Tautuku	2021	10	Grch	50	50	High-Moderate (50 to <70%)	4500	Very high (>1450)	1	*Agarophyton* spp.		0.11
Tautuku	2021	9	Grch	60	60	High-Moderate (50 to <70%)	5450	Very high (>1450)	1	*Agarophyton* spp.		0.15
Tautuku	2021	8	Grch	50	50	High-Moderate (50 to <70%)	3200	Very high (>1450)	1	*Agarophyton* spp.		0.03
Tautuku	2021	7	Grch	15	15	Sparse (10 to <30%)	150	Low (101 - 200)	1	*Agarophyton* spp.		0.01
Tautuku	2021	6	Ulva Grch	80 10	90	Complete (>90%)	290	Moderate (201 - 500)	0	*Ulva* spp. (Sea lettuce)	*Agarophyton* spp.	0.09
Tautuku	2021	2	Ulva	90	90	Complete (>90%)	300	Moderate (201 - 500)	0	*Ulva* spp. (Sea lettuce)		0.07

*0=not entrained, 1=100% entrained



APPENDIX 6. AREAS OF HEC IN TAUTUKU ESTUARY, DECEMBER 2021



APPENDIX 7. DOMINANT SALT MARSH SPECIES IN TAUTUKU ESTUARY, DECEMBER 2021

SubClass	Dominant species	Subdominant species 1	Subdominant species 2	Ha	%
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Apodasmia similis (Jointed wirerush)	Ficinia (Isolepis) nodosa (Knobby clubrush)	0.1	0.2
	Plagianthus divaricatus (Salt marsh ribbonwood)	Apodasmia similis (Jointed wirerush)		0.1	0.2
	Plagianthus divaricatus (Salt marsh ribbonwood)	Ficinia (Isolepis) nodosa (Knobby clubrush)	Apodasmia similis (Jointed wirerush)	0.5	1.5
	Plagianthus divaricatus (Salt marsh ribbonwood)			0.1	0.2
Rushland	Apodasmia similis (Jointed wirerush)	Calystegia sepium (Pink bindweed)	Plagianthus divaricatus (Salt marsh ribbonwood)	0.6	1.8
	Apodasmia similis (Jointed wirerush)			12.2	35.7
	Apodasmia similis (Jointed wirerush)	Plagianthus divaricatus (Salt marsh ribbonwood)	Coprosma propinqua subsp. Propinqua (Mingimingi)	7.3	21.2
	Apodasmia similis (Jointed wirerush)	Plagianthus divaricatus (Salt marsh ribbonwood)	Festuca arundinacea (Tall fescue)	0.5	1.3
	Apodasmia similis (Jointed wirerush)	Plagianthus divaricatus (Salt marsh ribbonwood)	Ficinia (Isolepis) nodosa (Knobby clubrush)	0.3	0.8
	Apodasmia similis (Jointed wirerush)	Plagianthus divaricatus (Salt marsh ribbonwood)		11.3	33.0
	Apodasmia similis (Jointed wirerush)	Selliera radicans (Remuremu)		0.1	0.2
	Apodasmia similis (Jointed wirerush)	Selliera radicans (Remuremu)	Samolus repens (Primrose)	0.0	0.1
	Ficinia (Isolepis) nodosa (Knobby clubrush)			0.0	0.0
Herbfield	Samolus repens (Primrose)	Isolepis cernua (Slender clubrush)	Sarcocornia quinqueflora (Glasswort)	0.1	0.2
	Samolus repens (Primrose)			0.1	0.3
	Samolus repens (Primrose)	Sarcocornia quinqueflora (Glasswort)	Schoenoplectus pungens (Three square)	0.0	0.0
	Samolus repens (Primrose)	Schoenoplectus pungens (Three square)		0.0	0.0
	Samolus repens (Primrose)	Selliera radicans (Remuremu)	Apodasmia similis (Jointed wirerush)	0.2	0.6
	Samolus repens (Primrose)	Selliera radicans (Remuremu)	Isolepis cernua (Slender clubrush)	0.0	0.1
	Samolus repens (Primrose)	Selliera radicans (Remuremu)		0.3	0.8
	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	Schoenoplectus pungens (Three square)	0.0	0.1
	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	Selliera radicans (Remuremu)	0.2	0.6
	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	Schoenoplectus pungens (Three square)	0.0	0.1
	Selliera radicans (Remuremu)	Samolus repens (Primrose)	Ficinia (Isolepis) nodosa (Knobby clubrush)	0.1	0.2
	Selliera radicans (Remuremu)	Samolus repens (Primrose)	Sarcocornia quinqueflora (Glasswort)	0.3	0.9
			Total	34.3	100.0

APPENDIX 8. RAW SEDIMENT AND MACROFAUNA DATA IN TAUTUKU ESTUARY, DECEMBER 2021

Sediment data and macrofauna indices

Parameter	Unit	TAUT-OTAG ETI-1	TAUT-OTAG ETI-2	TAUT-OTAG ETI–3 (FS-A)
Sediment Chemistry				
Total Phosphorus (TP)	mg/kg dry wt	610	300	370
Total Sulfur (TS)	g/100g dry wt	0.30	0.063	0.039
Total Nitrogen (TN)	g/100g dry wt	0.19	< 0.05	< 0.05
Total Organic Carbon (TOC)	g/100g dry wt	3.4	0.29	0.33
Gravel (≥2mm)	g/100g dry wt	0.5	< 0.1	< 0.1
Sand (≥63mm to <2mm)	g/100g dry wt	36.3	93.5	86.2
Mud (≤63mm)	g/100g dry wt	63.2	6.6	13.8
aRPD	mm	20	30	45.2
Macrofauna indices				
AMBI	no unit	3.83	5.40	4.45[1]
Abundance	no unit	80	63	453[1]
Diversity	no unit	7	6	6[1]

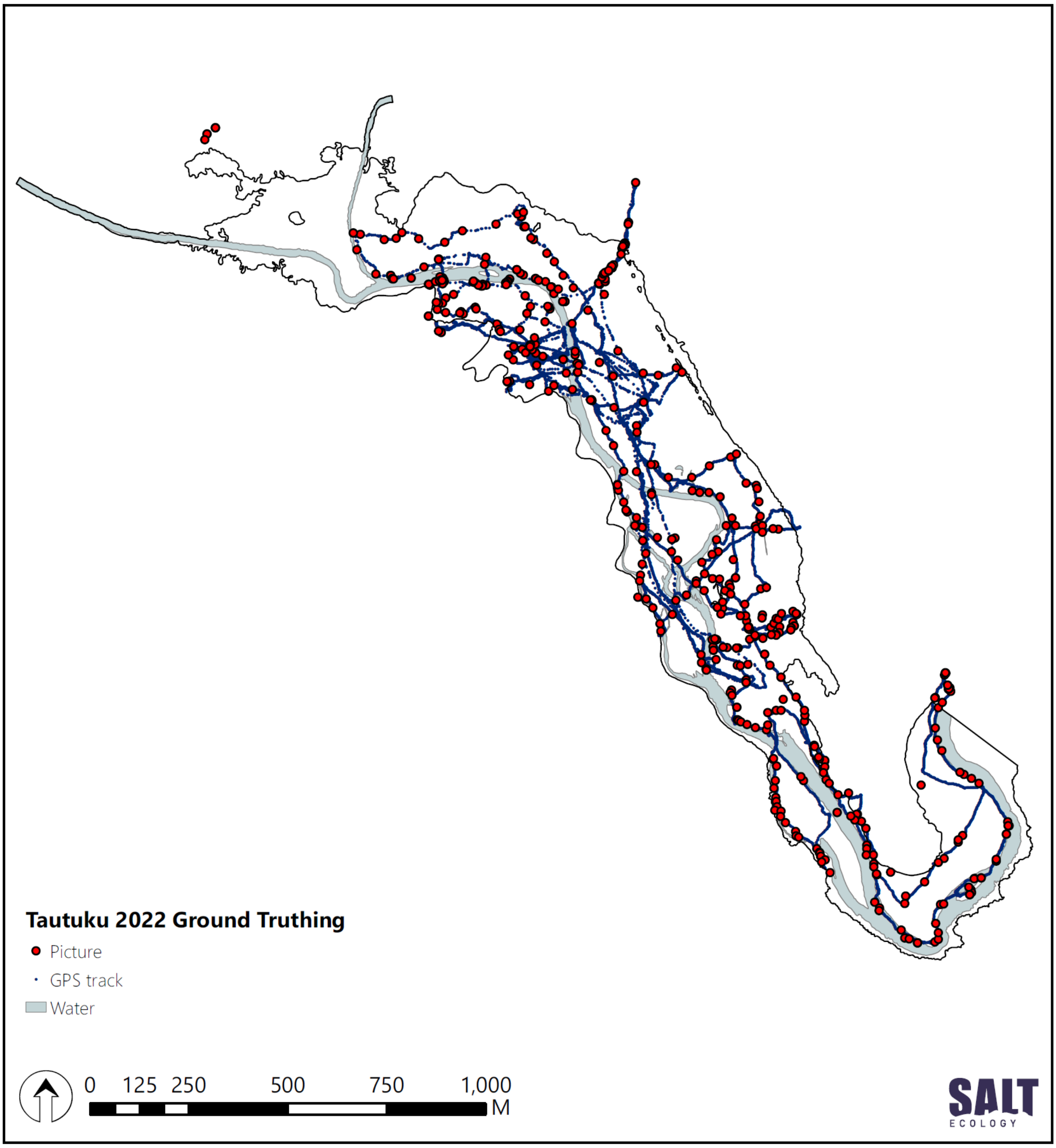
[1]The data from ETI-3 (fine scale Site A) represents the average of 9 samples (see Forrest et al. 2022) and was used to calculate the ETI score. Macrofauna data from ETI-1 and ETI-2 are based on a single sample and used solely as exploratory data.

Raw macrofauna data for ET-1 and ETI-2. See Forrest et al. (2022) for site ETI-3 (i.e. fine scale Site A) data.

Main group	Taxa	Habitat	EG	TAUT-OTAG ETI-1	TAUT_OTAG ETI-2
Amphipoda	*Paracorophium excavatum*	Infauna	IV	6	
Anthozoa	*Edwardsia* sp.	Epibiota	II		1
Bivalvia	*Arthritica* sp. 5	Infauna	III	26	3
Bivalvia	*Austrovenus stutchburyi*	Infauna	II		5
Bivalvia	*Paphies australis*	Infauna	II		1
Decapoda	*Hemiplax hirtipes*	Infauna	III	1	
Gastropoda	*Potamopyrgus estuarinus*	Epibiota	IV	11	
Polychaeta	*Capitella cf. capitata*	Infauna	V	12	52
Polychaeta	*Nicon aestuariensis*	Infauna	III	16	
Polychaeta	*Scolecolepides benhami*	Infauna	IV	8	1

EG=Eco-Group, ranging from sensitive (EG-I) to tolerant (EG-V) to enrichment and other types of environmental pollution

APPENDIX 9. GROUND-TRUTHING IN TAUTUKU ESTUARY, DECEMBER 2021

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