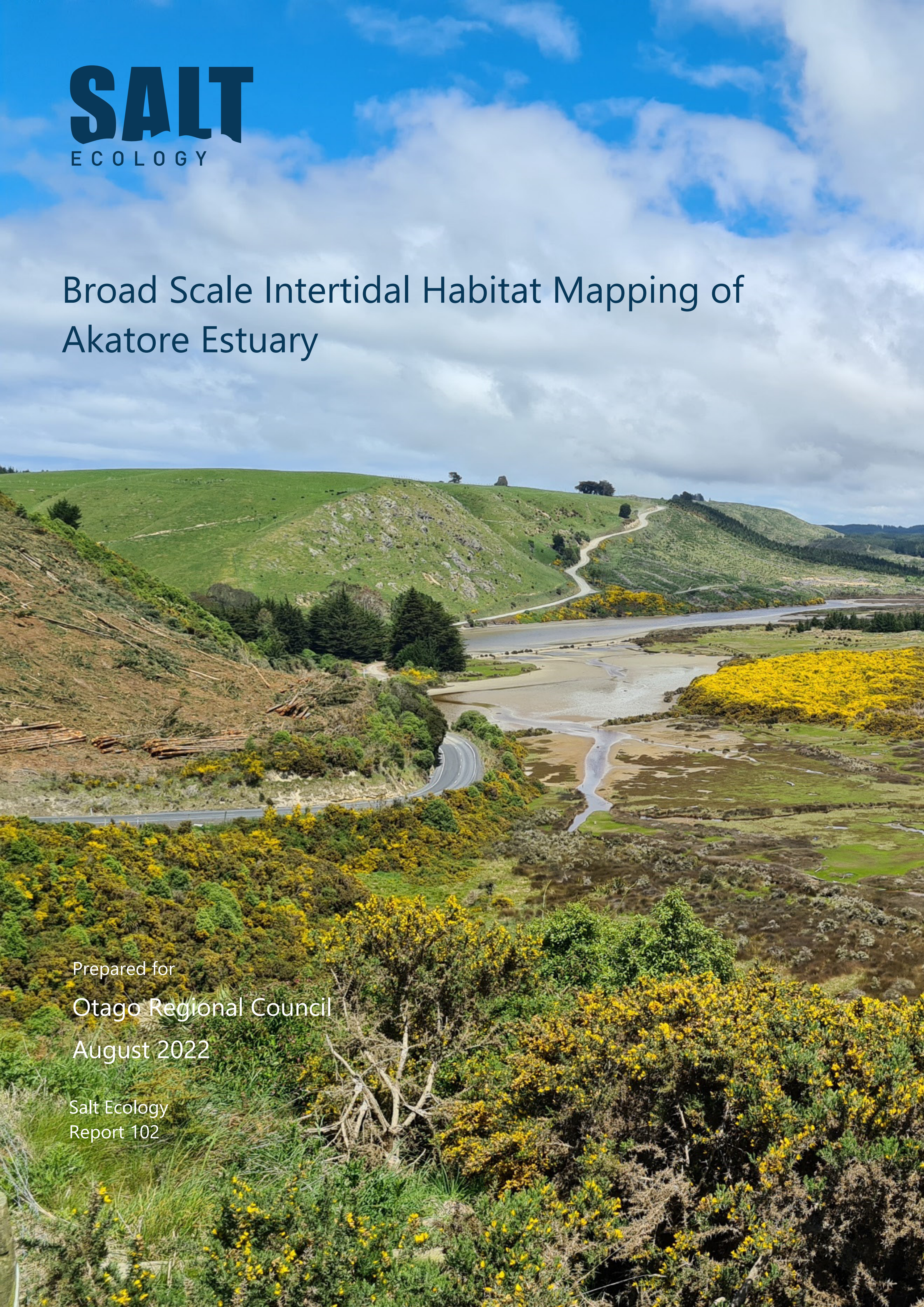
SALT ECOLOGY

Broad Scale Intertidal Habitat Mapping of Akatore Estuary



Prepared for

Otago Regional Council

August 2022

Salt Ecology Report 102

Cover photo: Akatore Estuary, November 2021, view to the southwest, over the northern arm

RECOMMENDED CITATION

Roberts KL, Stevens LM, Forrest BM. 2022. Broad Scale Intertidal Habitat Mapping of Akatore Estuary. Salt Ecology Report 102, prepared for Otago Regional Council, August 2022. 49p.

Broad Scale Intertidal Habitat Mapping of Akatore Estuary

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August 2022

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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

Many thanks to Sam Thomas (ORC) for reviewing the draft report. We are also grateful to Bryn Forrest and Thomas Scott-Simmonds for field assistance. The tools used to produce GIS summaries and maps were developed by Megan Southwick (Salt Ecology). ORC provided the rectified aerial imagery used in the mapping.

TABLE OF CONTENTS

FIGURES

TABLES

SUMMARY

Akatore Estuary is a medium sized (69ha) shallow, intertidally dominated, tidal lagoon type estuary located ~50km south of Dunedin on New Zealand's south coast. The estuary 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. This report describes a survey conducted in November 2021 which assessed the dominant substrate and vegetation features present including seagrass, salt marsh and macroalgae.

KEY FINDINGS

- Unvegetated intertidal flats were dominated by sandy mud (>50-90% mud) in the upper estuary, muddy sand (25-50% mud) in the mid estuary and sands (<10% mud) in the lower estuary. The substrate within most salt marsh areas comprised firm muddy sand (25-50% mud).
- Mud extent (13.7% of the intertidal area) was rated 'fair', and sedimentation rate 'poor', indicating fine sediments are a cause for concern.
- Nuisance macroalgae was a minor feature in the estuary (1.3ha or 3% of the available intertidal habitat) and localised to channel margins and within depositional areas of salt marsh. Subtidal growths were also evident.
- Salt marsh, mainly rushland, was the dominant vegetation type (26.9ha 44.3% of the intertidal area). Historic drainage and reclamation of salt marsh has been extensive. No intertidal seagrass was recorded.
- The 200m terrestrial margin was 42.5% densely vegetated and dominated by exotic forest and gorse/ broom.
- The catchment is highly modified with 77.2% exotic forest, and 12% high-producing grassland.
- The Estuary Trophic Index (ETI) score (0.523) indicated moderate nutrient enrichment (eutrophication).

The broad scale indicators, summarised in the table below, show Akatore Estuary was in 'good' to 'very good' condition with respect to salt marsh, macroalgae and high enrichment conditions. Mud extent and sedimentation rate were rated 'fair' to 'poor' indicating that fine sediment is the primary issue in the estuary.

Broad Scale Indicators	Unit	2021 Value	November 2021
Estuary Trophic Index (ETI) Score	No unit	0.523	Fair
Mud-dominated substrate	% of intertidal area >50% mud	13.7 (13.7)[1]	Fair
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.881	Very Good
Seagrass	% decrease from baseline	-	*baseline year*
Salt marsh extent (current)	% of intertidal area	44.3	Very Good
Historical salt marsh extent[2]	% of historical remaining	70[2]	Good
200m terrestrial margin	% densely vegetated	42.5	Fair
High Enrichment Conditions	ha	0.2	Very Good
High Enrichment Conditions	% of estuary	0.3	Very Good
Sedimentation rate[2]	CSR:NSR ratio[3]	2.2	Fair
Sedimentation rate[2]	mm/yr	3.2	Poor

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.
- Explore options to further protect and enhance existing salt marsh and wetland habitat
- Assess contemporary and historic sediment sources, and management options of major inputs.
- Establish sediment plate monitoring sites to measure temporal changes in sedimentation and mud content.
- Include Akatore 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

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 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.

The current report describes the methods and results of broad scale monitoring undertaken in Akatore Estuary on 28 November 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.

Akatore Estuary, salt marsh in the northern arm

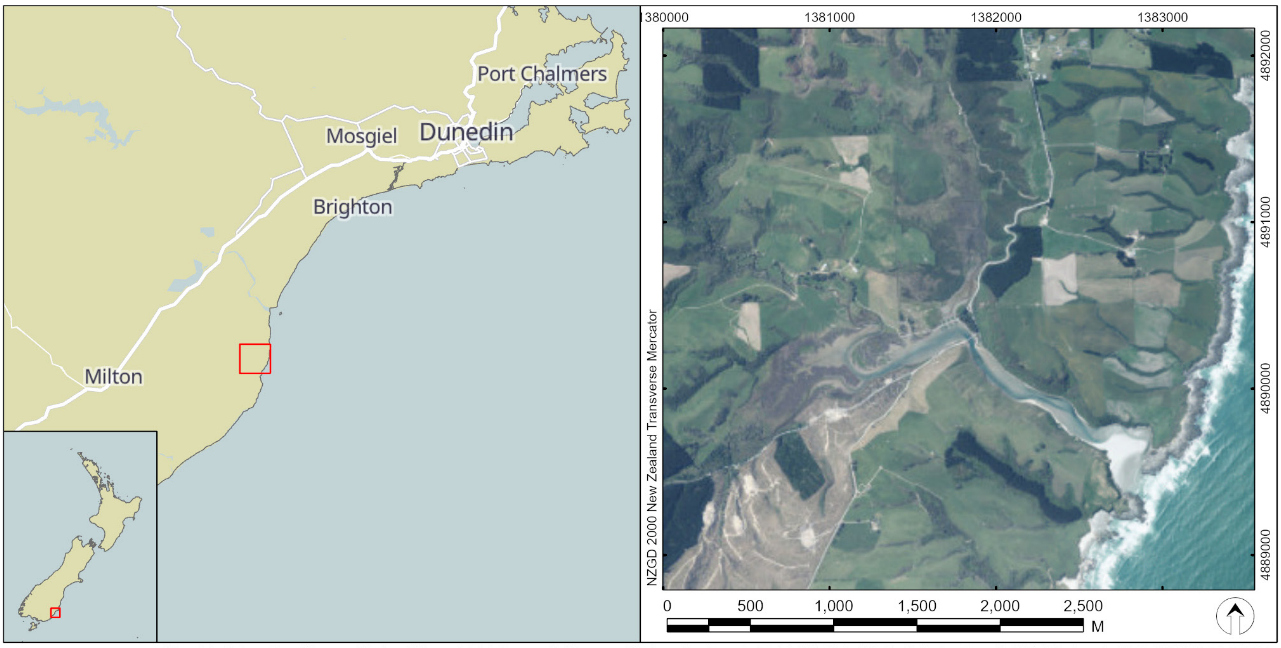

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Fig. 1. Location of Akatore Estuary, Otago.

2. BACKGROUND TO AKATORE ESTUARY

Akatore Estuary is a medium sized (69ha) estuarine system located ~50km south of Dunedin on New Zealand's south coast. The estuary is a shallow, intertidally dominated (~88%) estuary (SIDE) with a flushing time of ~5 days (Plew et al. 2018). The residence time, particularly in the upper tidal reaches, means the estuary is susceptible to nutrient driven water column problems on occasion (e.g. phytoplankton blooms; Plew et al. 2018). The estuary also has the capacity to retain fine sediments and sediment-bound nutrients in deposition areas making it susceptible to both nutrient enrichment and fine sediment impacts.

The main freshwater inflows are Akatore Creek (Whakatōrea) to the northwest and Stoneygrove Creek to the west, along with several other smaller streams. The mean freshwater inflow of $0.69m^3/s$ represents ~31% of the total estuary volume (Plew et al. 2018). Hydrology has been significantly modified with roads constructed through the estuary, culverts and a causeway in the northern arm, and drainage channels through wetland and salt marsh areas (see photos on following page).

The estuary drains a 6,945ha catchment that has been significantly modified with only small areas (6.7%) of indigenous vegetation remaining (Table 1; Fig. 2). While the catchment is 87.9% densely vegetated, this is dominated by 68.8% exotic forest, 8.4% harvested exotic forest and 3.9% gorse and/or broom (Table 1; Fig. 2). High producing exotic grassland comprises 12.0% of the catchment area, approximately half of it located in the upper catchment and half directly adjacent to the estuary.

While large areas of salt marsh and freshwater wetland have been lost due to historic burning, drainage and land-use change, extensive areas remain and are recognised as regionally significant in the ORC Regional Plan: Water for Otago. The area is an important habitat for the at risk (declining) South Island fernbird (mātātā) and the at risk (naturally uncommon) herbfield species *Thyridia (Mimulus) repens* - New Zealand musk (ORC Regional Plan: Water 2004).

Birdlife are abundant both on the intertidal flats and within salt marsh, with spur-winged plover, yellowhammer, redpoll, Australasian harrier, pied stilt, variable oystercatcher, and South Island fernbird (mātātā) recorded previously (Rate & Lloyd 2012). In 2016, a marine protected area with fishery restrictions was proposed for Akatore Estuary to prevent overfishing of shellfish and other fish species including flounder (pātiki) and eels (tuna) (SEMPF, 2016). Cockles (tuaki) in Akatore Estuary are a customary mahinga kai resource for Kāi Tahu and are also collected recreationally (SEMPF, 2016).

Despite significant catchment modification the estuary retains high ecological, cultural and social values in addition to areas of protected salt marsh and wetland habitat.

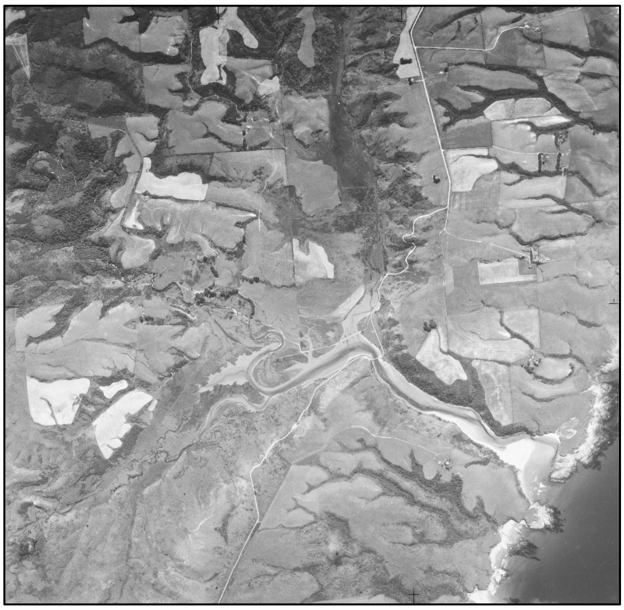
Table 1. Summary of catchment land cover (LCDB5 2017/18) Akatore Estuary.

LCDB5 (2017/2018) Catchment Land Cover	Ha	%
10 Sand or Gravel	4.6	0.1
21 River	1.7	0.02
40 High Producing Exotic Grassland	831.1	12.0
41 Low Producing Grassland	4.8	0.1
46 Herbaceous Saline Vegetation	79.0	1.1
51 Gorse and/or Broom	271.1	3.9
52 Manuka and/or Kanuka	103.1	1.5
54 Broadleaved Indigenous Hardwoods	251.5	3.6
64 Forest - Harvested	584.9	8.4
68 Deciduous Hardwoods	2.3	0.03
69 Indigenous Forest	33.0	0.5
71 Exotic Forest	4777.9	68.8
Grand Total	6944.8	100
Total densely vegetated area (LCDB classes 45-71)	6102.6	87.9

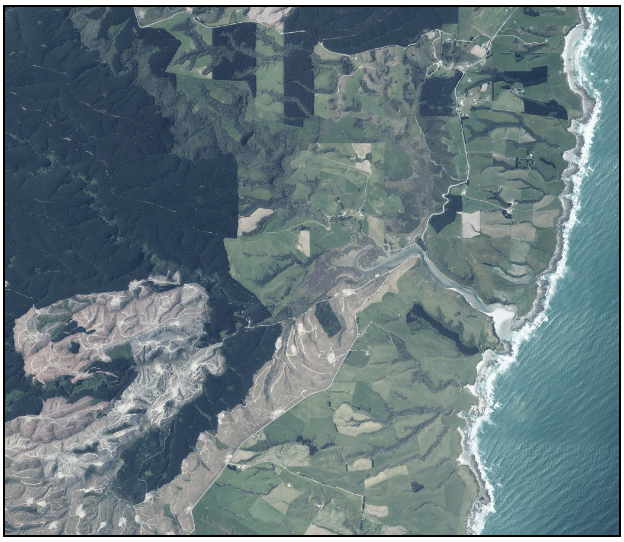
Akatore Estuary, pasture and wetland in the background and forestry (recently harvested and replanted) in the foreground

Aerial photo showing altered hydrology in the northern arm (top) and close up of road and culverts (bottom)

Drainage channel through salt marsh (top) and remnants of an old bridge causeway in the northern arm (bottom)



Akatore Estuary in 1946, hydrology was already modified and land mostly cleared



Aerial imagery showing dark green exotic forest along the east of the estuary in 2006 (top) and in 2019 (bottom) after harvesting

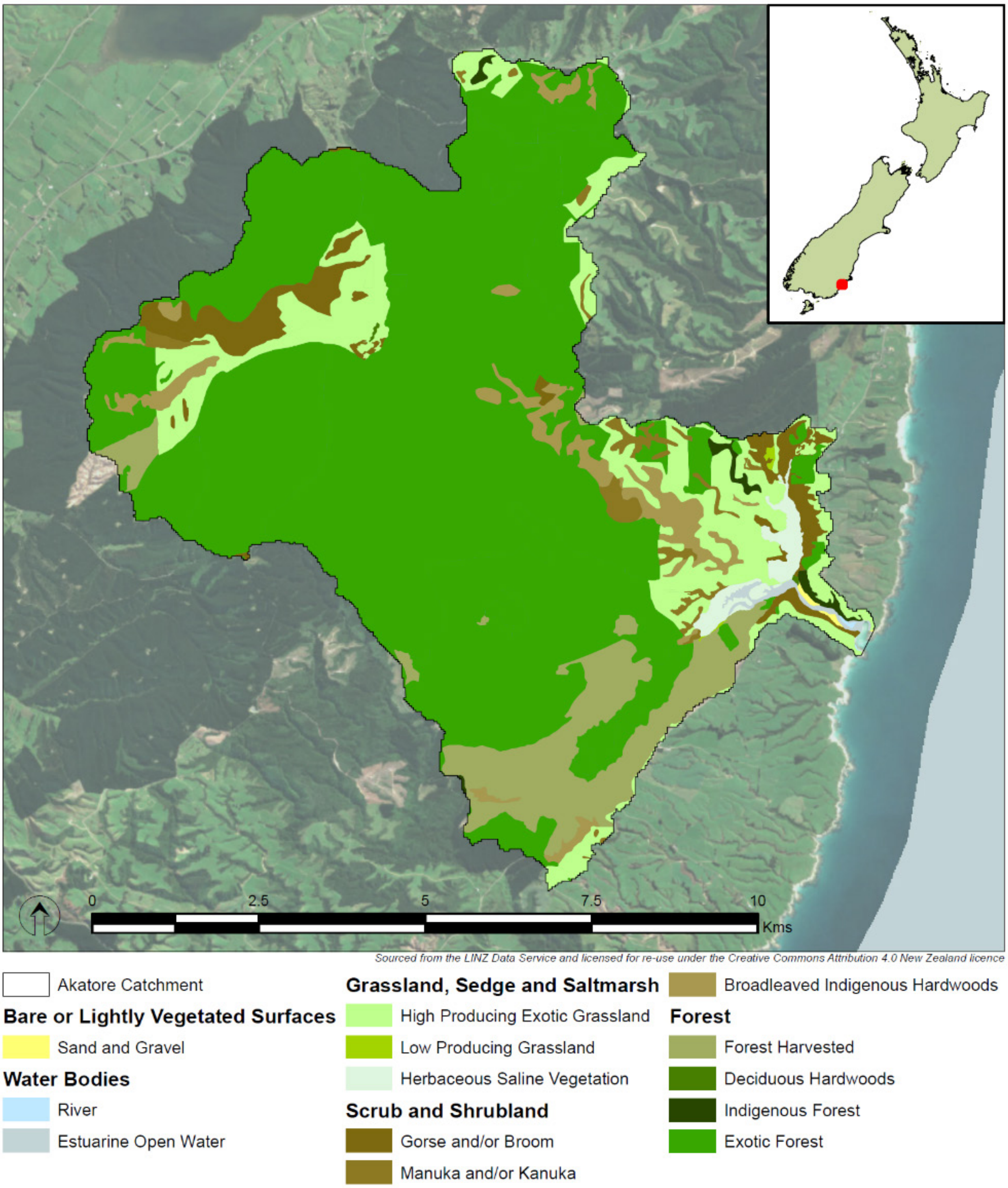


Fig. 2. Akatore Estuary catchment land use classifications from LCDB5 (2017/2018) database.

Salt marsh and gorse/broom on the margin of the northeast arm of Akatore Estuary

3. METHODS

3.1 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 (0.3m/pixel colour aerial imagery captured in the summer of 2018-2019). Ground-truthing was undertaken on 28 November 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 200m 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 1:3000 scale 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 3.2-3.7 and are summarised in Table 3.

Channel through rushland in Akatore Estuary

Gorse growing on the estuary margin of Akatore 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.

3.2 SUBSTRATE CLASSIFICATION AND MAPPING

Substrate classification in the NEMP is based on the dominant surface features present, e.g. rock, boulder, cobble, gravel, sand, mud. Salt Ecology has revised the NEMP substrate classifications for sand and mud (summarised in Appendix 1) by dividing previously merged categories of 'firmness' and 'muddiness' into independent categories. For 'muddiness', categories were defined relative to sediment mud content, which can be subjectively assessed in the field and validated using laboratory analyses. In 2021, 9 sediment grain size samples were collected to validate field classifications of substrate type (Appendix 2).

Salt Ecology has also extended the NEMP methodology to record the substrate present beneath vegetation. These extensions enable a continuous substrate layer for the estuary to be produced. Improved characterisation of sediment muddiness facilitates its assessment as a potential determinant of habitat condition and a driver of ecological change.

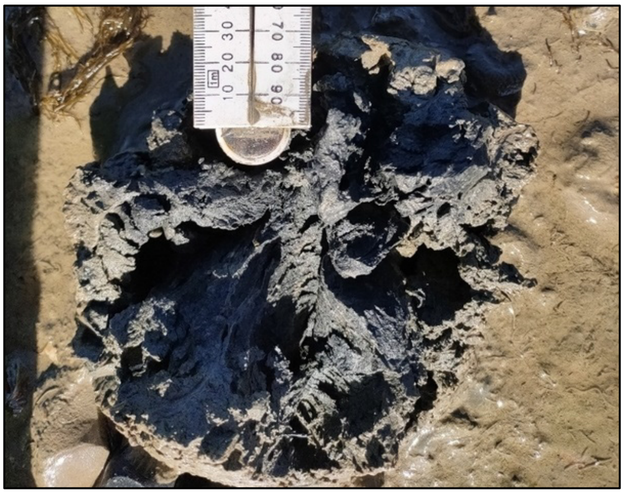
The area (horizontal extent) of mud-dominated sediment is used as a primary indicator of sediment mud impacts and in assessing susceptibility to nutrient enrichment impacts (trophic state).

Mobile sands near the estuary entrance

Soft muddy-sand in the mid estuary

3.3 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 depth 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 ~10mm

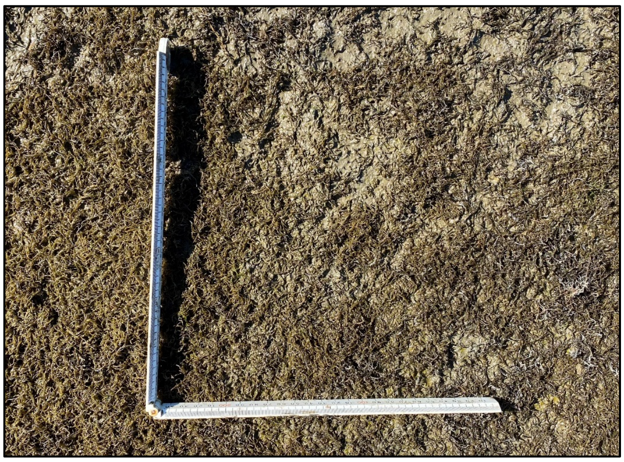
3.4 MACROALGAE ASSESSMENT

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

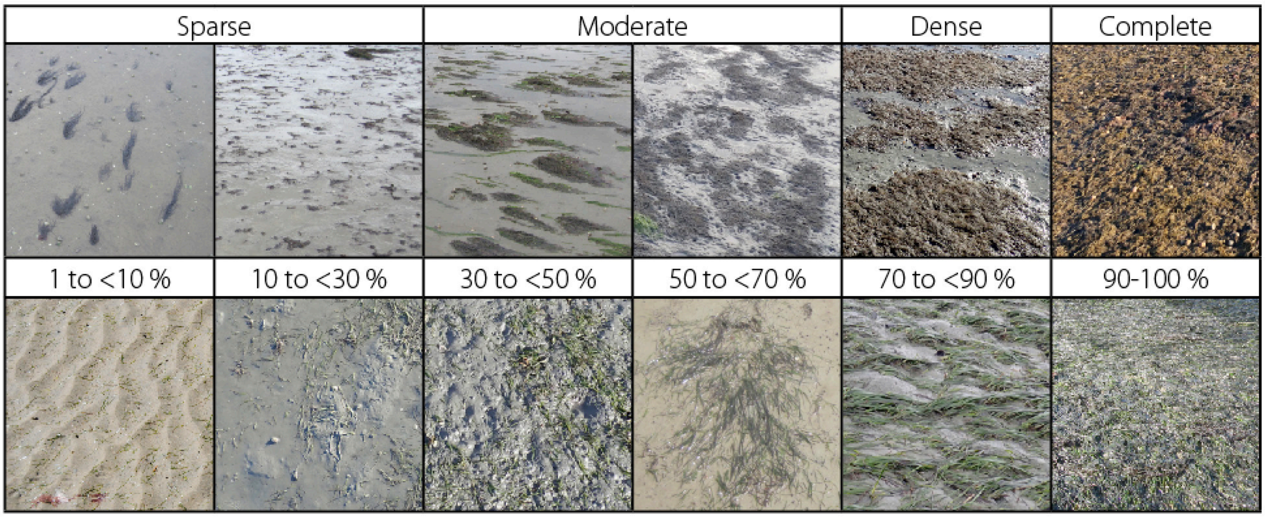


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

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.

3.5 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.

3.6 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.

Sampling biomass in Aaktore Estuary at ETI Site 1

Herbfield and rushland in Akatore Estuary

3.7 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.

Newly planted forestry on estuary margin, Akatore Estuary

Gorse and mixed exotic forest on the margin, Akatore Estuary

Pasture on the estuary margin, Akatore Estuary

3.8 WATER QUALITY

At three 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 in the mid estuary

3.9 SEDIMENT QUALITY & MACROFAUNA

Sediment quality and macrofauna samples were collected from three sites and used as supporting indicators to calculate an 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).

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 each site, 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. 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).

Eutrophic ETI Site 2 (top) and Site 3 (bottom)

3.10 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 November 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.

3.11 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 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.

Looking down on salt marsh in the southeast arm, forestry in the foreground

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).

Mudflats in 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)

4. RESULTS

A summary of the 28 November 2021 survey in Akatore Estuary is provided below, with additional information 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.

4.1 SUBSTRATE

Table 4 and Fig. 4 show the dominant substrates were firm muddy sand (>25-50% mud; 45% of the estuary), predominantly located among salt marsh in the upper tidal range, and mobile sand (8.8ha, 14.6%) and firm sand (6.9ha, 11.4%) in the lower estuary. Elsewhere, unvegetated intertidal flats in the upper estuary were dominated by soft sandy mud, with areas of very soft sandy mud localised to channel margins and around the fringes of salt marsh. Soft muddy sand (>25-50% mud) was the dominant substrate type In the mid estuary (5.3ha, 8.7%). Rock field was most prominent toward the estuary entrance (Fig. 4) along with small areas of gravel, while zootic habitat (shellbank) comprised only (0.02%) in the lower estuary intertidal area. There was very good agreement between the subjective assessment of substrate class and the laboratory analysed sediment validation samples (Appendix 2).

Table 4. Summary of dominant intertidal substrate, Akatore Estuary, November 2021.

Substrate Class	Features	Ha	%
Artificial	Boulder field	0.02	0.04
	Gravel field	0.01	0.01
Bedrock	Rock field	1.6	2.6
Boulder/Cobble/ Gravel	Boulder field	0.1	0.1
	Cobble field	0.1	0.2
	Gravel field	0.9	1.5
Sand (0-10% mud)	Mobile sand	8.8	14.6
	Firm sand	6.9	11.4
Muddy Sand (>10-25% mud)	Firm muddy sand	1.5	2.4
Muddy Sand (>25-50% mud)	Firm muddy sand	27.2	44.8
	Soft muddy sand	5.3	8.7
Sandy Mud (>50-90% mud)	Firm sandy mud	0.7	1.2
	Soft sandy mud	5.6	9.2
	Very soft sandy mud	2.0	3.4
Zootic	Shell bank	0.01	0.02
Total		**60.7**	**100**

Gravel in the lower estuary

Upper estuary intertidal flats (top) and near the channel margin (bottom) comprising sandy mud

Shellbank on firm sands in the lower estuary

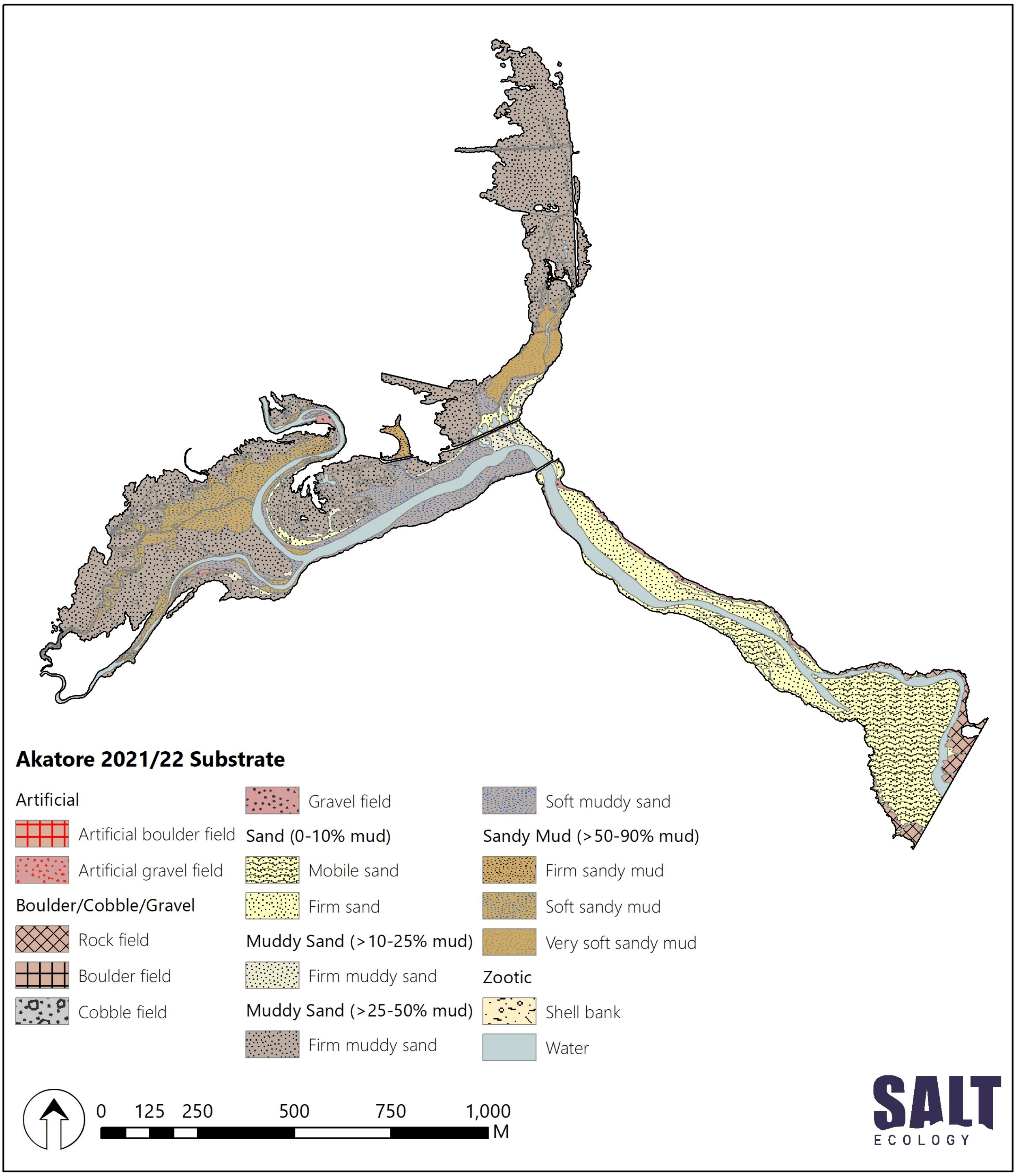


Fig. 4. Distribution of dominant surface substrate types recorded in Akatore Estuary, November 2021.

Rock field and mobile sands at the estuary entrance

4.2 SEDIMENT OXYGENATION

Sediment oxygenation was measured within representative substrate types to assess the trophic state of the sediment. In November 2021, spot measurements of aRPD showed that sand-dominated sediments were well oxygenated, while firm muddy sands in the mid to upper estuary generally had a relatively shallow aRPD (<10mm - see photo) indicating organic enrichment.

The shallowest aRPD depths occurred in sediments with elevated mud or organic content. For example, near stream inputs, deposition areas or in the presence of macroalgae. Areas of poor sediment oxygenation were most common in the upper estuary.

Shallow aRPD in firm muddy sand (10-25% mud)

Soft sandy mud (left) and mud (right) with shallow aRPD

4.3 MACROALGAE

4.3.1 Opportunistic macroalgae

Table 5 summarises macroalgae percentage cover and biomass classes, with the mapped cover and biomass shown in Figs 5 and 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), Akatore Estuary, November 2021.

A. Percent Cover

Percent cover category	Ha	%
Absent or trace (<1%)	59.4	97.8
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	0.1	0.2
Low-Moderate (30 to <50%)	0.0	0.0
High-Moderate (50 to <70%)	0.2	0.3
Dense (70 to >90%)	1.0	1.7
Complete (>90%)	0.03	0.1
Total	60.7*	100.0

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	59.4	97.8
Very low (1 - 100)	0.0	0.0
Low (101 - 200)	0.1	0.2
Moderate (201 - 500)	0.0	0.0
High (501 - 1450)	0.5	0.8
Very high (>1450)	0.8	1.3
Total	60.7*	100.0

* Total intertidal area including salt marsh

Shallow aRPD in soft sandy mud with complete macroalgae cover

Agarophtyon spp. growing on soft sandy muds in the mid estuary

Key macroalgae results were as follows:

- Very little macroalgae was present in the estuary. Cover was classified as absent or trace (<1%) across 97.8% of the intertidal area (Table 5A). Within the Available Intertidal Habitat (AIH) the Affected Area (AA), where macroalgae were growing, was small (1.3ha, 3.9%; Fig. 5; Table 6).
- When present, macroalgal patches generally exceeded 50% cover (1.2ha) and were located in the upper western arm of the estuary. They were dominated by the green seaweed *Ulva* spp. growing on soft and very soft sandy muds (see photos). Underlying sediments had a shallow aRPD indicating organic enrichment and sediment degradation.
- Mean wet weight biomass was low across the AIH (65.6g/m^2), but high in the very localised AA (1669g/m^2; Table 6), and at a level above which adverse ecological impacts are expected to occur.
- Subtidal macroalgae was common in the shallow channels in the upper estuary and near the estuary entrance and comprised both *Ulva* spp. and *Agarophyton* spp (see photos opposite).

Because the estuary had <5% opportunistic macroalgal cover across the AIH (3.0%; 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 (0.881), reflects that macroalgae was not a dominant feature in the estuary and was largely confined to the channels and channel margins of the upper estuary.

Ulva spp. growing on soft sandy mud, near the channel

Agarophtyon spp. growing in the channel and on the margin

Ulva spp. and filamentous green algae on soft sandy muds

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.

Nov-2021 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	3.0*	0.881	High
Average biomass (g/m^2) in AIH	65.6	0.869	High
Average biomass (g/m^2) in AA	1669.0	0.197	Bad
% entrained in AA	26.4	0.357	Poor
Worst of AA (ha) and AA (% of AIH)		0.843	High
AA (ha)	*1.3*	*0.973*	*High*
AA (% of AIH)	*3.9*	*0.843*	*High*
Survey EQR		0.881*	'Very Good'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating
*Because there was <5% cover in the AIH, EQR score calculated from % cover AIH sub-metric only using the method in Stevens et al. (2022).

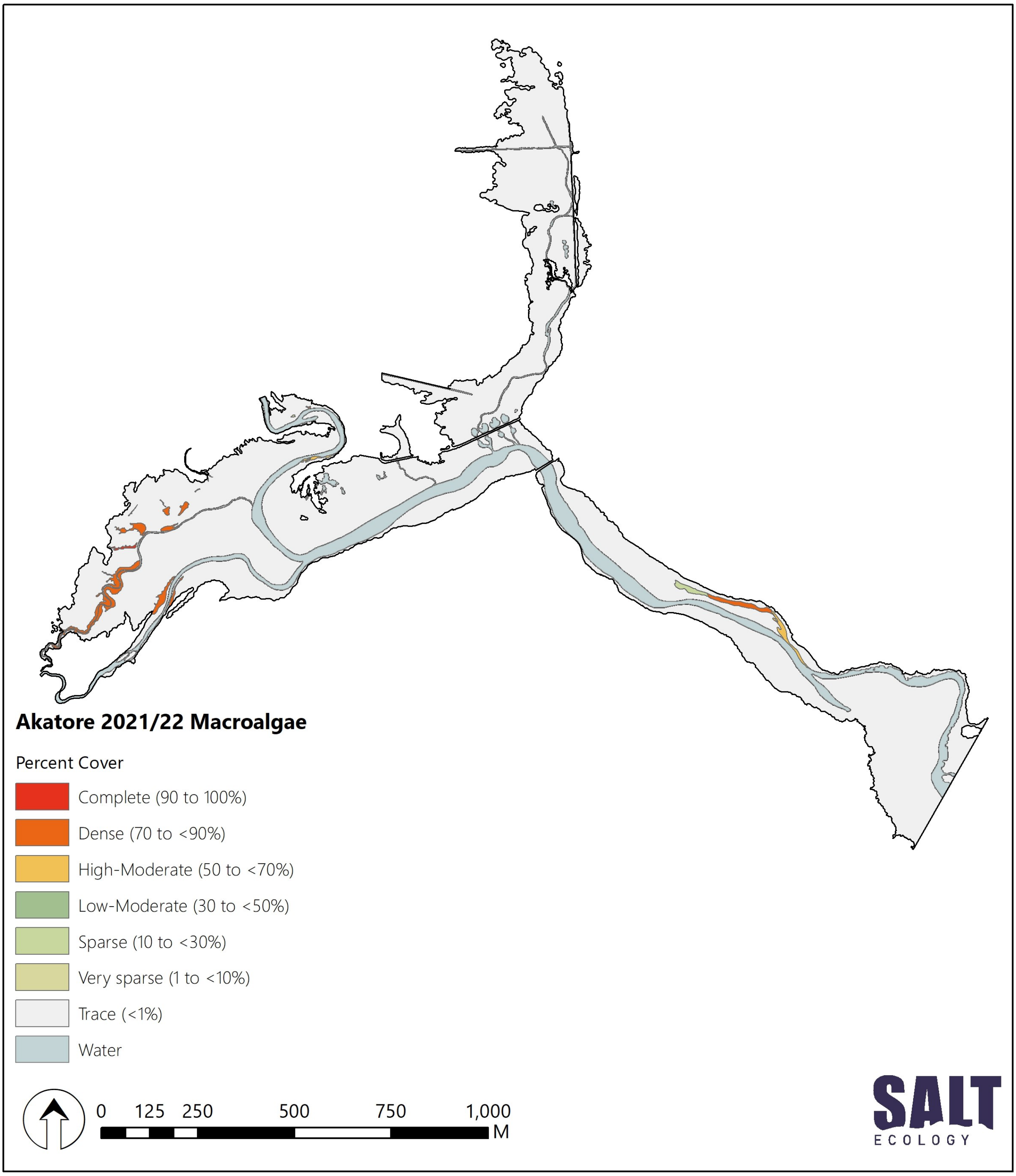


Fig. 5. Distribution and percent cover classes of macroalgae in Akatore Estuary, November 2021.

Ulva spp. and filamentous green algae growing on soft sandy mud on the channel margin in the western arm

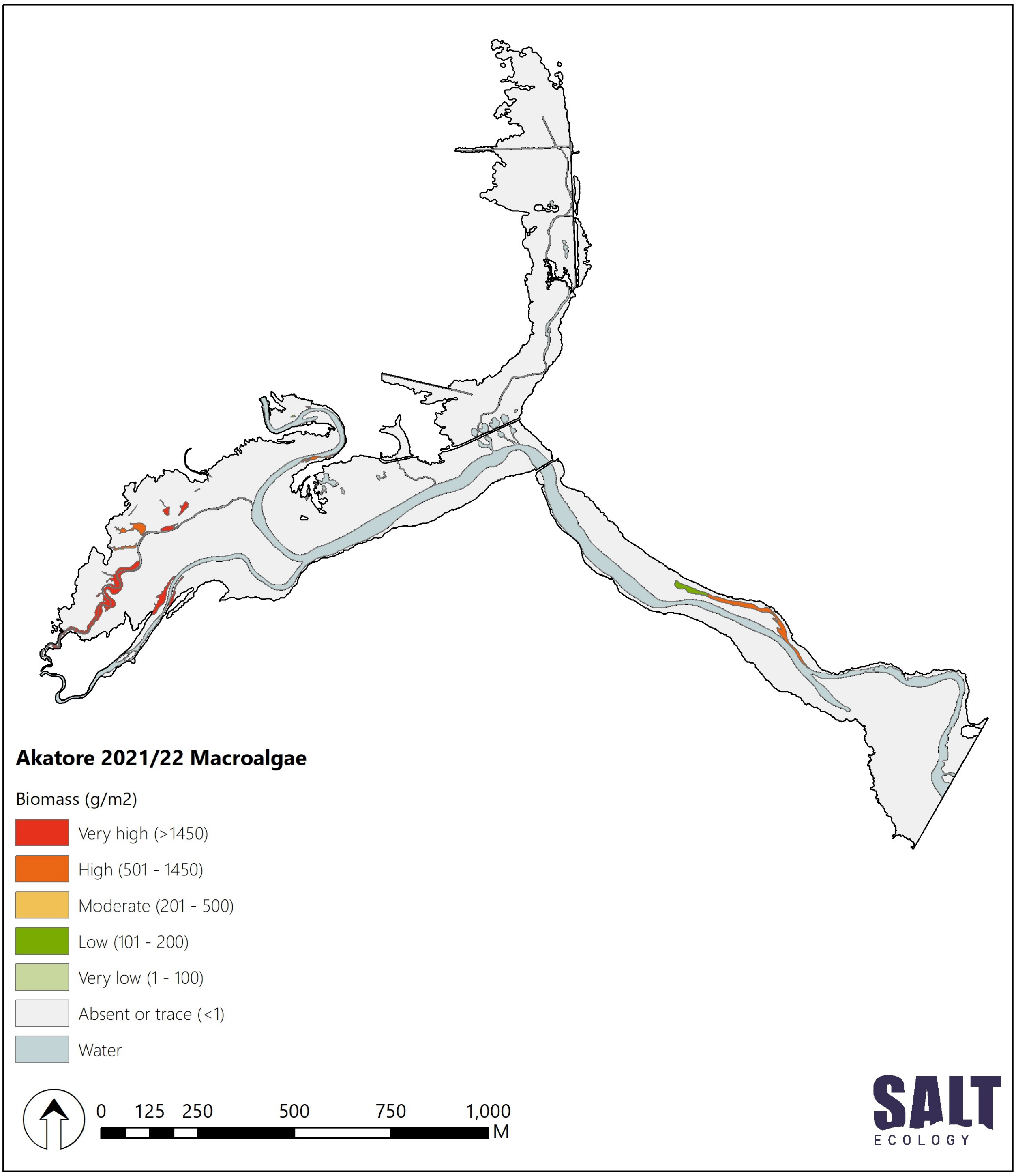


Fig. 6. Distribution and biomass classes of macroalgae in Akatore Estuary, November 2021.

Ulva spp. on the channel margin in the lower estuary associated with firm sands and gravel

4.3.2 Other macroalgae

In addition to opportunistic macroalgal species, a dark green filamentous mat-forming macroalga (identified by NIWA as *Vaucheria* sp.; Roberts et al. 2022) was growing in localised parts of the estuary. Because of the small extent present and overlap with opportunistic macroalgae, these growths were not mapped separately or characterised in detail.

Vaucheria sp. was present in the western arm on the channel margins and growing on eroding herbfield in the northern arm (see photos below). *Vaucheria* sp. was typically associated with soft sandy-mud growing as a smothering layer on the sediment surface. The underlying sediment was generally organically enriched and poorly oxygenated.

Mat of *Vaucheria* sp. growing in a bed of *Ulva* spp. on the channel margin in the western arm

Vaucheria sp. growing on eroding herbfield

4.3.3 High Enrichment Conditions

High Enrichment Condition (HEC) areas (mud-dominated sediments with >50% macroalgal cover entrained in stable beds) comprised 0.2ha (0.3% of the intertidal area). These areas were limited to small deposition zones in the upper estuary, particularly around channels and freshwater inputs (Appendix 6).

Areas of high enrichment conditions comrpising high macroalgal cover growing in very soft sandy mud

High enrichment conditions, thick macroalgal cover and anoxic muddy sediments above knee height

4.4 SEAGRASS

No intertidal seagrass was recorded in Akatore Estuary in November 2021.

4.5 SALT MARSH

Table 7 summarises intertidal salt marsh with the distribution mapped in November 2021 presented in Fig. 7. Dominant and subdominant species are recorded in Appendix 7. Salt marsh covered 26.9ha (44.3%) of the intertidal area and was most extensive in the upper estuary arms.

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

Class	Ha	%
Estuarine Shrub	2.2	8.2
Sedgeland	0.1	0.4
Rushland	19.3	71.6
Herbfield	5.3	19.9
Total	**26.9**	**100**

The dominant class was rushland comprising 19.3ha (71.6% of total salt marsh). The dominant species was *Apodasmia similis* (Jointed wirerush). Estuarine shrubs comprised 2.2ha (8.2% of total salt marsh) and the dominant species was *Plagianthus divaricatus* (Salt marsh ribbonwood). Herbfield was present across 5.3ha (19.9% of total salt marsh) and the dominant species were *Selliera radicans* (Remuremu) and *Samolus repens* (Primrose). Other salt marsh species included *Sarcocornia quinqueflora* (Glasswort), *Thyridia repens* (New Zealand musk), *Cyperus ustulatus* (Giant umbrella sedge), *Coprosma propinqua subsp. propinqua* (Mingi mingi) and the rush *Isolepis cernua* (Slender clubrush). Introduced weeds and the grass *Festuca arundinacea* (tall fescue) were present in some areas. Vehicle damage was evident in the northwest of the estuary (see top photo opposite) and natural erosion of the herbfield margin was relatively common along seaward or channel margins.

Large areas of salt marsh have been historically drained with long straight channels remaining today, particularly in the northern arm. This has compromised much of the remaining salt marsh by limiting tidal inundation and allowing terrestrial weeds to become widely established. Many of these drained areas are grazed resulting in additional impacts from pugging and trampling.

Vehicle tracks through herbfield in the western arm

Apodasmia similis (Jointed wirerush) and *Plagianthus divaricatus* (Salt marsh ribbonwood)

Selliera radicans (Remuremu)

Eroding edge of *Samolus repens* (Primrose) herbfield

Historic drainage channels carved through rushland

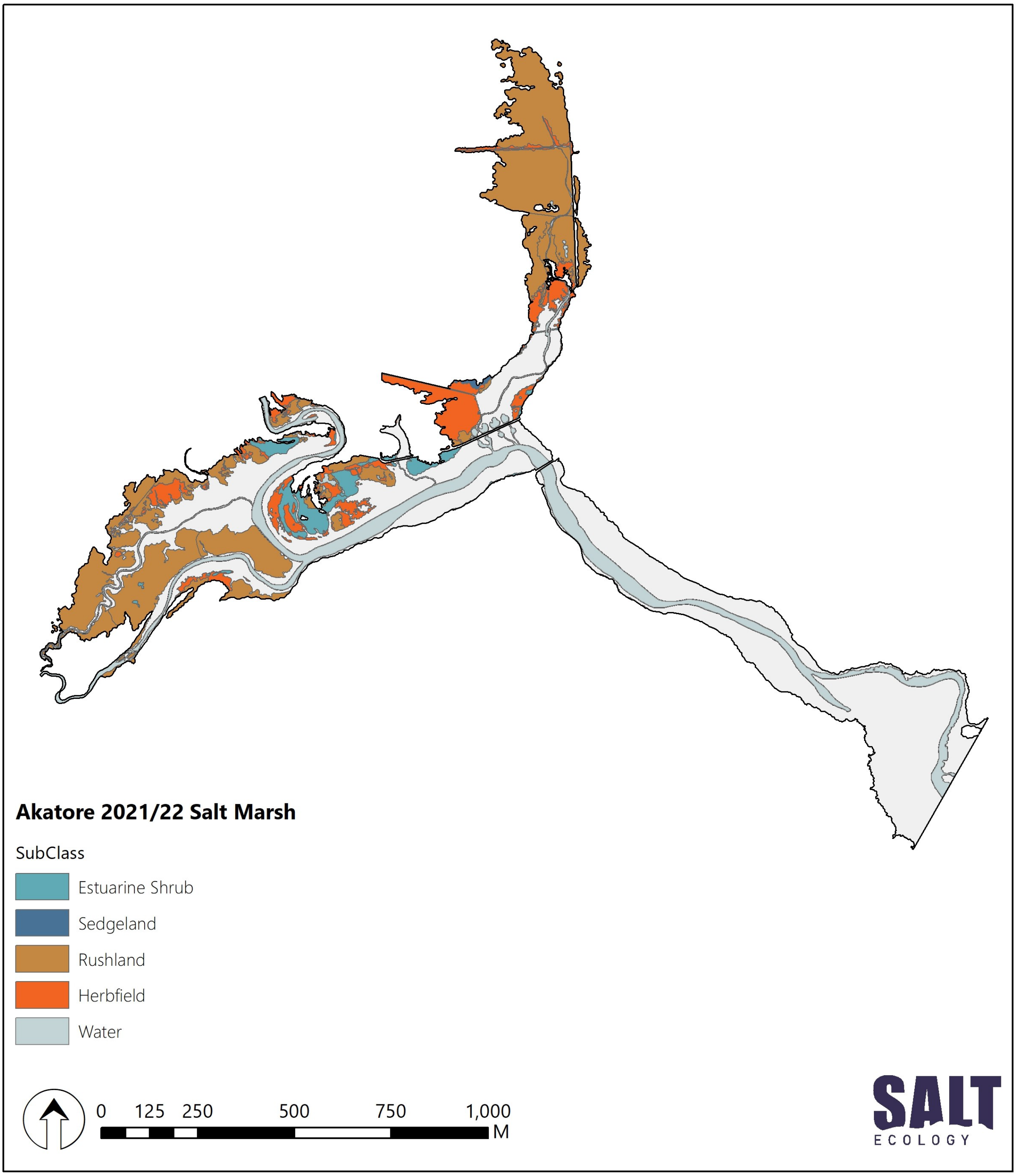


Fig. 7. Distribution of salt marsh in Akatore Estuary, November 2021.

Extensive areas of *Apodasmia similis* (Jointed wirerush) in the mid to upper estuary

Extensive areas of *Apodasmia similis* (Jointed wirerush) in the western arm, planted pine trees in the foreground

Salt marsh in the northern arm comprising herbfield, rushland and estuarine shrubs. Yellow flowers are gorse and broom.

4.6 TERRESTRIAL MARGIN

Table 8 and Fig. 8 summarise the land cover of the 200m terrestrial margin which was 42.5% densely vegetated, including extensive areas of gorse and/or broom (13.1%), exotic forest (13.5%) and small areas of native vegetation, i.e. broadleaved indigenous hardwoods (9.5%) and manuka and/or kanuka (2.6%). Both high-producing (27.3%) and low-producing (25.3%) grassland were a common feature in the terrestrial margin.

Gorse and pine near the estuary margin

Broadleaved indigenous hardwoods with small areas of exotic forest near the estuary entrance

Transition from herbfield, rushland, estuarine shrub through to native scrub

In areas of previously drained salt marsh, particularly in the northern arm, herbaceous freshwater vegetation (1.1%) was present. Both the salt marsh and freshwater wetland are classified as regionally significant in the Otago Regional Plan: Water for Otago (2004).

Upper boundary of the salt marsh habitat in the northern arm

Table 8. Summary of 200m terrestrial margin land cover, Akatore Estuary, November 2021.

LCDB5 Class		%
1	Built-up Area (settlement)	0.01
5	Transport Infrastructure	1.4
10	Sand and Gravel	0.4
16	Gravel and Rock	2.8
20	Lake or Pond	0.1
21	River	0.3
40	High Producing Exotic Grassland	27.3
41	Low Producing Grassland	25.2
45	Herbaceous Freshwater Vegetation	1.1
46	Herbaceous Saline Vegetation	0.5
47	Flaxland	1.1
50	Fernland	0.5
51	Gorse and/or Broom	13.1
52	Manuka and/or Kanuka	2.6
54	Broadleaved Indigenous Hardwoods	9.5
56	Mixed Exotic Shrubland	0.4
58	Matagouri or Grey Scrub	0.1
71	Exotic Forest	13.5
Total		**100**
Total dense vegetated margin (LCDB classes 45-71)		42.5

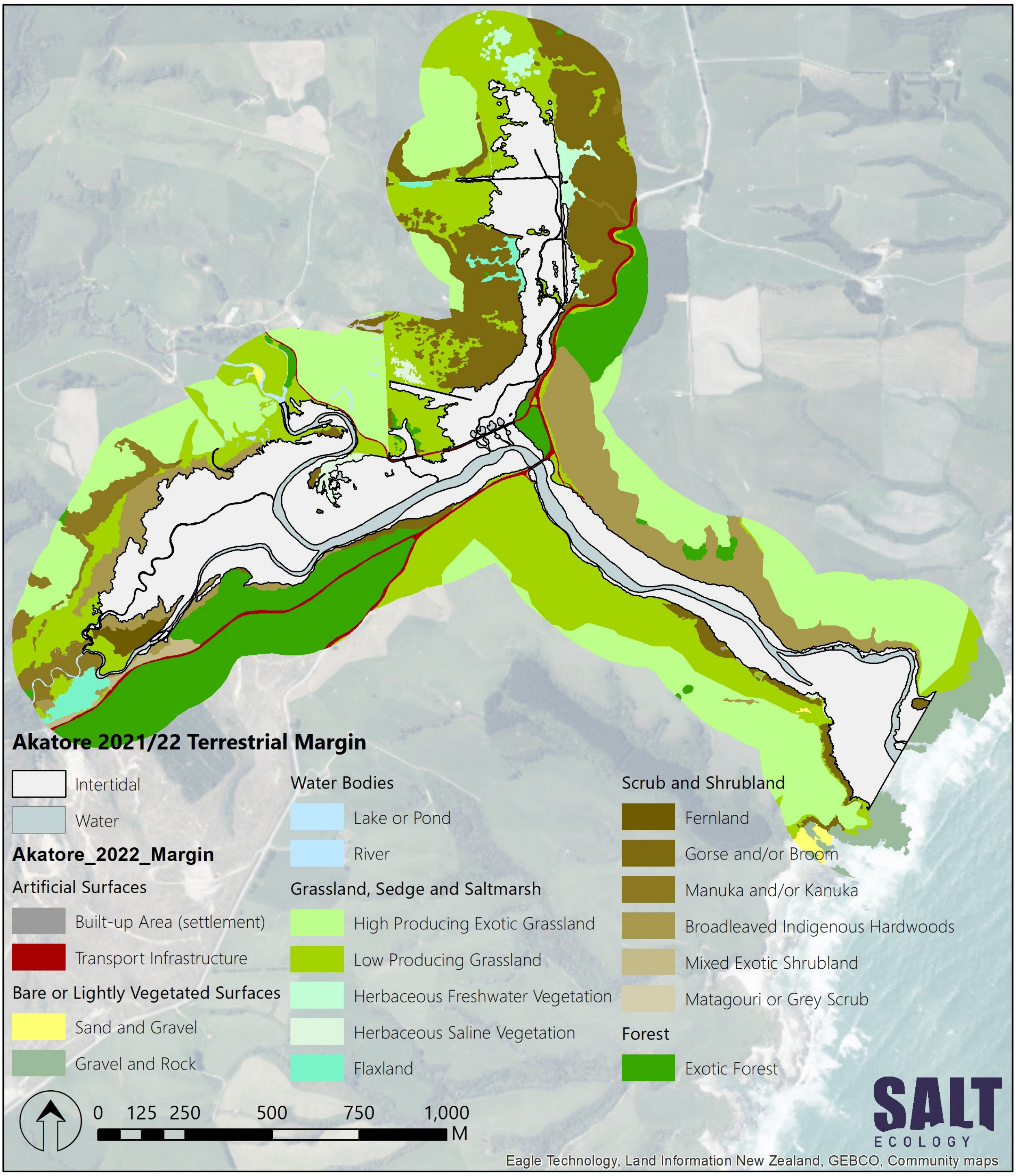


Fig. 8. Map of 200m terrestrial margin land cover, Akatore Estuary, November 2021.

Low producing pasture and exotic forest on the estuary margin

4.7 WATER QUALITY

Water quality data presented in Table 9 provides ancillary information to support the broad scale mapping survey. Three measurements were taken, one from Akatore bridge in the mid-lower estuary, and from two sites where water pools above the culverts under Akatore Creek Road (see map in Appendix 2).

Table 9. Water quality for Akatore Estuary, November 2021.

Station	Site 1 Pool	Site 2 Pool	Site 3 Bridge
NZTM East	1381661	1381714	1381844
NZTM North	4890390	4890412	4890305
Distance from mouth (m)	1500	1500	1350
Stratified	yes	no	yes
Surface measurements			
Measurement depth (m)	0.2	0.2	0.2
Temperature (°C)	24.8	16.3	20.5
DO saturation (%)	102.0	163.0	114.0
DO concentration (g/m³)	8.4	12.0	10.0
Salinity	2.7	12.0	3.8
pH	8.7	8.4	8.5
Chlorophyll-a (mg/m³)	9.4	2.2	4.5
Bottom measurements			
Measurement depth (m)	0.5	0.5	1.0
Temperature (°C)	16.2	16.3	16.1
DO saturation (%)	132.0	163.0	156.0
DO concentration (g/m³)	10.9	12.0	12.5
Salinity	32.3	12.0	34.3
pH	8.2	8.4	8.2
Chlorophyll-a (mg/m³)	4.5	2.2	11.5
Secchi depth (m)	>0.7	>0.7	>1.5
Max depth (m)	0.70	0.70	1.5
Channel width (m)[1]	15	15	40
Sediment texture	firm	firm	firm
Sediment type	sand	sand	sand

[1]Estimated at the time of sampling.

The poorly-flushed pool above the culvert at Site 1 was stratified and had high surface water temperatures and elevated chlorophyll-*a* relative to the other surface water sites. The pool at Site 2 was well mixed with no stratification observed. At all sites the water column was well oxygenated (>100% dissolved oxygen saturation) at the time of sampling.

As expected, the site closest to the estuary entrance (Site 3) exhibited higher salinity in the bottom water than the sites further upstream (Site 1 and 2). The main channel through the estuary was shallow (<1.5m) and stratified at the time of sampling with a freshwater layer overlying salt water (Site 3; Table 9). Chlorophyll-*a* was elevated in the bottom waters of the main channel, and appeared to reflect a marine source of phytoplankton.

While nutrients were not directly measured, observations of excess macroalgae growing in the subtidal channels throughout the estuary suggest there are sufficient nutrients to support excessive algal growths under suitable growing conditions.


Site 1, stratified water upstream of the road culvert near margin


Site 2, well mixed water upstream of the road culvert in centre


Site 3, Akatore bridge

4.8 ESTUARY TROPHIC INDEX (ETI)

Table 10 summarises the indicators used to calculate an overall ETI score for Akatore Estuary. Raw data for sediment metrics are presented in Appendix 8. The primary indicator of eutrophication response in SIDE type estuaries, like Akatore, is macroalgae (OMBT-EQR) with ETI supporting sediment indicators of macrofauna (AMBI), total nitrogen (TN), total organic carbon (TOC) and sediment oxygenation (aRPD) used to assess trophic state. The overall ETI score of 0.523 was rated 'fair' in terms of eutrophication, driven largely by sediment enrichment indicators. Areas of enrichment were localised to the upper estuary channels, channel margins and deposition areas within salt marsh habitat.

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

Indicator	Raw Value	Equivalent ETI Score
Primary indicator		
Macroalgae (EQR)	0.881	0.188
Supporting Indicator		
AMBI	4.79	0.875
TN (mg/kg)	2700	0.813
TOC (%)	2.62	0.813
aRPD (mm)	4	0.934
Final ETI Score		0.523 "Fair"

High macroalgae cover in very soft sandy muds with shallow aRPD

Salt marsh (rushland) and unvegetated mud flats

5. SYNTHESIS OF 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.

Akatore Estuary was intertidally dominated (60.7ha or 87.5% of the estuary area) with subtidal areas comprising low tide channels and pools behind the road causeway. The estuary supported a variety of habitats including salt marsh, mudflats, rock field and firm and mobile sands. Large parts of the western arm are protected within the Department of Conservation Akatore Wildlife Management Area and the estuary salt marsh and adjacent freshwater wetland are classified as regionally significant in the Otago Regional Plan: Water for Otago (2004). While the estuary retains high ecological values (e.g. extensive salt marsh habitat), the catchment is extensively modified, salt marsh has been historically reclaimed and/or drained, there are localised areas of excess macroalgal growth, and muddy sediments are common.

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

a. Area summary	Ha	% Estuary
Intertidal area	60.7	87.5
Subtidal area	8.7	12.5
Total estuary area	**69.4**	**100**

b. Key substrate features	Ha	% Intertidal
Mud-enriched (25 to <50%)	32.5	53.4
Mud-dominated (≥50%)	8.3	13.7

c. Key habitat features	Ha	% Intertidal
Salt marsh	26.9	44.3
Seagrass (≥50% cover)	0.0	0.0
Macroalgal beds (≥50% cover)	1.2	2.0

d. Terrestrial margin (200m)	% Margin
200m densely vegetated margin	82.2

Mud-dominated sediments, a common stressor in New Zealand estuaries, comprised 8.3ha or 13.7% of the intertidal area and were common in the upper estuary intertidal flats and on the channel margins within salt marsh habitat (see photos). Deposition of fine sediments is promoted in the upper estuary because of salinity driven flocculation, low wave energy, altered hydrology (i.e. low flushing in the northern arm) and their close proximity to freshwater inputs. While estuaries naturally accumulate sediments, catchment land uses and modification to the estuary (e.g. salt marsh drainage, altered hydrology) can accelerate fine sediment deposition.

Mud-dominated anoxic sediments in the upper estuary

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 ~3.2mm/yr of estuary infilling (Table 13), a condition rating of 'poor' (Table 12). Based on the relative difference in estimated yields from an undisturbed catchment, and assuming a further 50% attenuation from the historical presence of wetlands, the current sedimentation rate (CSR) based on land cover is estimated to be 2.2 times the natural sedimentation rate (NSR; Table 13). The condition rating for the CSR:NSR ratio is rated 'fair' (Table 12), but does not account for additional inputs expected from recent disturbance activities like forest harvesting.

The fine sediment deposition evident in Akatore Estuary is likely attributable to a combination of historic land clearance and salt marsh drainage, and more contemporary inputs, particularly from exotic forestry, the dominant land use type in the catchment (77.2%, Fig. 2). In 2018, there was extensive harvesting in the lower catchment and on the estuary margin (see photos pg. 3). It is well known that land disturbance activities associated with exotic forestry can cause high sediment inputs, particularly during harvest and in the post-harvest period before replanted forest reaches a closed canopy state (Green et al. 2014; Gibbs & Swales 2019). Known catchment sediment sources coupled with the sedimentation results and the large area of mud-dominated sediments (13.7%), reinforce that fine sediment issues are a cause for concern and should be carefully managed.

Recently re-planted pine on the estuary margin and plantation forestry in the background

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

Broad Scale Indicators	Unit	2021 Value	November 2021
Estuary Trophic Index (ETI) Score	No unit	0.523	Fair
Mud-dominated substrate	% of intertidal area >50% mud	13.7 (13.7)[1]	Fair
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.881	Very Good
Seagrass	% decrease from baseline	-	*baseline year*
Salt marsh extent (current)	% of intertidal area	44.3	Very Good
Historical salt marsh extent[2]	% of historical remaining	70[2]	Good
200m terrestrial margin	% densely vegetated	42.5	Fair
High Enrichment Conditions	ha	0.2	Very Good
High Enrichment Conditions	% of estuary	0.3	Very Good
Sedimentation rate[2]	CSR:NSR ratio[3]	2.2	Fair
Sedimentation rate[2]	mm/yr	3.2	Poor

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)

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

Supporting Condition Measure	Akatore Estuary
Mean freshwater flow (m^3/s)[1]	0.44
Catchment Area (Ha)[1]	6945
Catchment nitrogen load (TN/yr)[2]	15.0
Catchment phosphorus load (TP/yr)[2]	1.5
Catchment sediment load (KT/yr)[1]	2.3
Estimated N areal load in estuary ($mg/m^2/d$)[2]	59.1
Estimated P areal load in estuary ($mg/m^2/d$)[2]	6.0
CSR:NSR ratio[1]	1.1
CSR:NSR ratio (50% natural wetland attenuation)	2.2
Trap efficiency (sediment retained in estuary; %)[1]	81.7
Estimated rate of sedimentation (mm/yr)[1]	3.2

[1] Hicks et al. 2019.

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

Ulva spp. and *Vaucheria* sp. on channel margin

Ulva spp. and *Agarophyton* spp. growing around salt marsh

The macroalgae OMBT-EQR score (0.881) was rated 'very good', with an ETI score of 0.523 (rated 'fair'), indicating that while macroalgae was a minor feature in the estuary, comprising only 3.9% of the available intertidal habitat, affected sediments were showing signs of enrichment (e.g. low sediment oxygen, impoverished macrofauna community). Macroalgae was dominated by the green seaweed *Ulva* spp. and to a lesser extent *Agarophyton* spp. (previously known as *Gracilaria* spp.). Localised areas of *Vaucheria* sp., also recorded in Pleasant River Estuary (Roberts et al. 2022), were associated with areas of very soft muds and low sediment oxygen. Dense areas of macroalgae with very high biomass (>1450g/m^2) were confined to channel margins or in deposition zones around salt marsh habitat (see photos). A small (0.3%) area of high enrichment conditions (i.e. high macroalgal cover, mud-dominated sediments with low sediment oxygen) was located in the western arm. The absence of widespread nuisance macroalgae is consistent with a modelled nitrogen load of 59mgN/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). However, localised areas of nuisance macroalgae, the presence of subtidal macroalgal growths particularly around freshwater inputs, and phytoplankton growths in pooled subtidal areas, all suggest nutrient loads should be managed to prevent any further expansion of macroalgae.

Salt marsh, mainly rushland, was the dominant vegetated 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. While the salt marsh is extensive (a condition rating of 'very good'), large areas of salt marsh and the adjacent freshwater wetland have been reclaimed and/or drained (see photos). In the northern arm, drained areas have become more terrestrially dominated with introduced species including gorse and tall fescue now the dominant vegetation type in parts. Elsewhere, salt marsh has been converted to pasture which is the dominant land use type in the 200m terrestrial margin of the estuary (Table 8). In addition to the relatively large losses from historical drainage, smaller recent losses were due to localised vehicle damage near the road edge and the erosion of herbfield near river channels.

Drainage channel through *Apodasmia similis* (Jointed wirerush)

Drainage channel through transitional saline and freshwater wetland

In terms of historical losses, the estuary is rated 'good' with an estimated >70% of the natural salt marsh cover remaining (Table 12). As discussed above, drainage, reclamation and altered estuary hydrology have contributed to the losses over time, and an increase in terrestrial freshwater vegetation in areas previously dominated by salt marsh. While the salt marsh and freshwater wetland areas are protected from development under the Otago Regional Plan: Water for Otago, there is still significant scope for salt marsh and wetland restoration in Akatore Estuary. The largest gains are likely achieved through stock exclusion and from restoring the natural connectivity (i.e. upgrading culverts in the northern arm to improve estuary flushing), and re-flooding areas of existing or previous estuary habitat, particularly in areas where herbfield vegetation persists.

Herbfield growing areas reclaimed for pasture

Eroding herbfield on the channel edge

Seagrass is a common feature in many of the larger lagoon type Otago estuaries (e.g. Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea). However, seagrass was not recorded from Akatore Estuary, a result consistent with findings from similar SIDE estuaries across the region that have extensive areas of salt marsh habitat (e.g. Tautuku and Pleasant River), but a strong freshwater influence. It is uncertain whether seagrass would have grown in the estuary prior to human modification because of naturally limiting conditions to seagrass growth, in particular, a strong freshwater influence (low salinity) and/or high wave fetch and substrate mobility in the mid to lower estuary. A review of aerial imagery indicates that there was no seagrass present in 1946. However, the estuary was already heavily modified at that time and the lack of seagrass may reflect modified hydrology and/or high sediment deposition in the estuary.

In conclusion, historic modification of hydrology and salt marsh habitat have substantially altered Akatore Estuary with the most significant current issue identified as fine sediment deposition. The sedimentation rate and mud extent, coupled with localised areas of nuisance macroalgae around stream inputs, suggest that both sediment loads, and to a lesser extent nutrient loads, need to be managed.

6. 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.
- Explore options to further protect and enhance existing salt marsh and wetland habitat, e.g. stock exclusion, tidal reconnection, weed control, management of fine sediment.
- Assess contemporary and historic sediment sources via a desktop review, and management options of major inputs.
- Establish sediment plate monitoring sites in the western arm to measure temporal changes in sedimentation and mud content.
- Include Akatore 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.

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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.

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

[1]*Additions to the NEMP classification.*

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 Parkland/Open 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

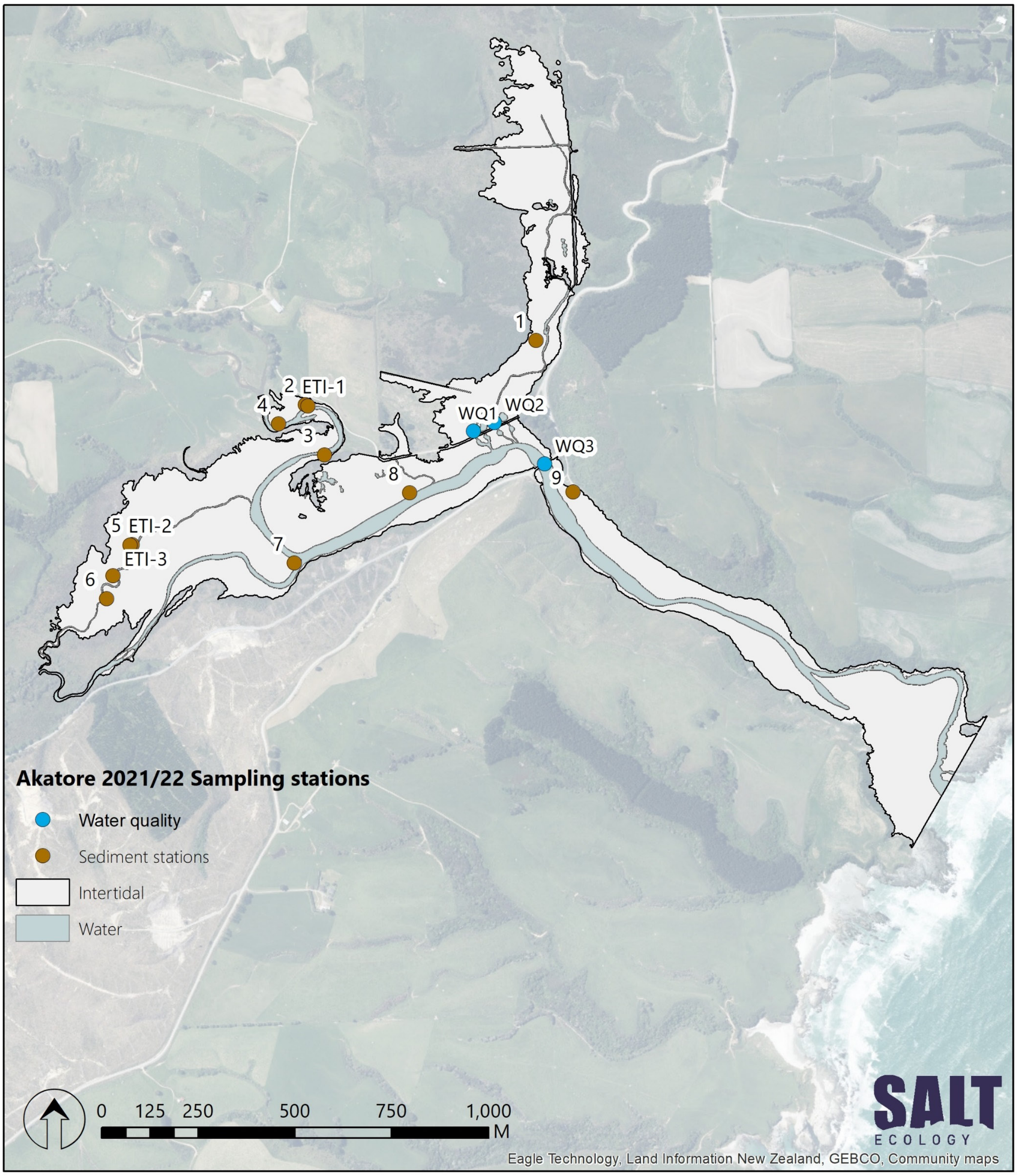
Grassland, Sedge and Saltmarsh
40 High Producing Exotic Grassland
41 Low Producing Grassland
45 Herbaceous Freshwater Vegetation
46 Herbaceous Saline Vegetation

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. SAMPLING STATIONS IN AKATORE ESTUARY, NOVEMBER 2021

Sampling stations for sediment validation and water quality



Site	NZTM_E	NZTM_N	Field code	Subjective % mud	Measured % mud	Measured % sand	Measured % gravel
Akat-Otag - 1			vsSM	50 - 90%	61.5	38.4	0.1
Akat-Otag - 2			vsSM	50 - 90%	53.9	45	1.1
Akat-Otag - 3			vsSM	50 - 90%	78.0	19.6	2.3
Akat-Otag - 4			fMS10	10 - 25%	21.3	78.5	0.2
Akat-Otag - 5			vsM90	90 - 100%	92.4	4.1	3.5
Akat-Otag - 6			vsSM	50 - 90%	95.4	4.5	< 0.1
Akat-Otag - 7			sMS25	25 - 50%	43.2	54.7	2.1
Akat-Otag – 8*			sMS25	25 - 50%	37.6	58.7	3.7
Akat-Otag – 9*			fS	0 - 10%	< 0.1	100.8	7.9
Akat-Otag - ETI-1			vsSM	50 - 90%	49.9	48.6	1.5
Akat-Otag - ETI-2			vsM90	90 - 100%	93.8	5.4	0.7
Akat-Otag - ETI-3			vsSM	50 - 90%	87.6	12.2	0.3

*Samples Akat-Otag-8 and Akat-Otag-9 were mis-labelled when sent to the lab. In the raw data sheet from Hills laboratories Akat-Otag-8 refers to Akat-Otag-9 (vice versa).

In general, there was very good agreement between the subjective %mud field estimates and the validation sample mud contents measured in the laboratory. Akat-Otag-6 showed the largest variation with a difference of ±5.4% mud when compared to the subjective assessment.

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	2783276 SPv1
Contact:	Keryn Roberts	**Date Received:**	30-Nov-2021
	C/- Salt Ecology Limited	**Date Reported:**	27-Jan-2022
	21 Mount Vernon Place	**Quote No:**	114524
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Broadscale - Akatore Estuary
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Akat-Otag-1 28-Nov-2021 2:00 pm	Akat-Otag-2 28-Nov-2021 2:30 pm	Akat-Otag-3 28-Nov-2021 3:00 pm	Akat-Otag-4 28-Nov-2021 3:30 pm	Akat-Otag-5 28-Nov-2021 4:00 pm
Lab Number:		2783276.1	2783276.2	2783276.3	2783276.4	2783276.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	62	57	47	73	30
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.1	1.1	2.3	0.2	3.5
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	38.4	45.0	19.6	78.5	4.1
Fraction < 63 µm*	g/100g dry wt	61.5	53.9	78.0	21.3	92.4

Sample Name:		Akat-Otag-6 28-Nov-2021 4:30 pm	Akat-Otag-7 28-Nov-2021 5:00 pm	Akat-Otag-8 28-Nov-2021 5:30 pm	Akat-Otag-9 28-Nov-2021 6:30 pm	Akat-Otag-ETI-1 28-Nov-2021 4:35 pm
Lab Number:		2783276.6	2783276.7	2783276.8	2783276.9	2783276.10
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	48	68	70	82	55
Total Recoverable Phosphorus	mg/kg dry wt	-	-	-	-	490
Total Sulphur*‡	g/100g dry wt	-	-	-	-	0.23
Total Nitrogen*	g/100g dry wt	-	-	-	-	0.18
Total Organic Carbon*	g/100g dry wt	-	-	-	-	1.97
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	2.1	7.9	3.7	1.5
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	4.5	54.7	100.8	58.7	48.6
Fraction < 63 µm*	g/100g dry wt	95.4	43.2	< 0.1	37.6	49.9

Sample Name:		Akat-Otag-ETI-2 28-Nov-2021 5:40 pm	Akat-Otag-ETI-3 28-Nov-2021 6:10 pm			
Lab Number:		2783276.11	2783276.12			
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	39	46	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	740	660	-	-	-
Total Sulphur*‡	g/100g dry wt	0.59	0.62	-	-	-
Total Nitrogen*	g/100g dry wt	0.36	0.27	-	-	-
Total Organic Carbon*	g/100g dry wt	3.2	2.7	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.7	0.3	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	5.4	12.2	-	-	-
Fraction < 63 µm*	g/100g dry wt	93.8	87.6	-	-	-

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked * or any comments and interpretations, which are not accredited.

Analyst's Comments

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

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 07-Dec-2021 and 27-Jan-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.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

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.

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

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.

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'.

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.

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.

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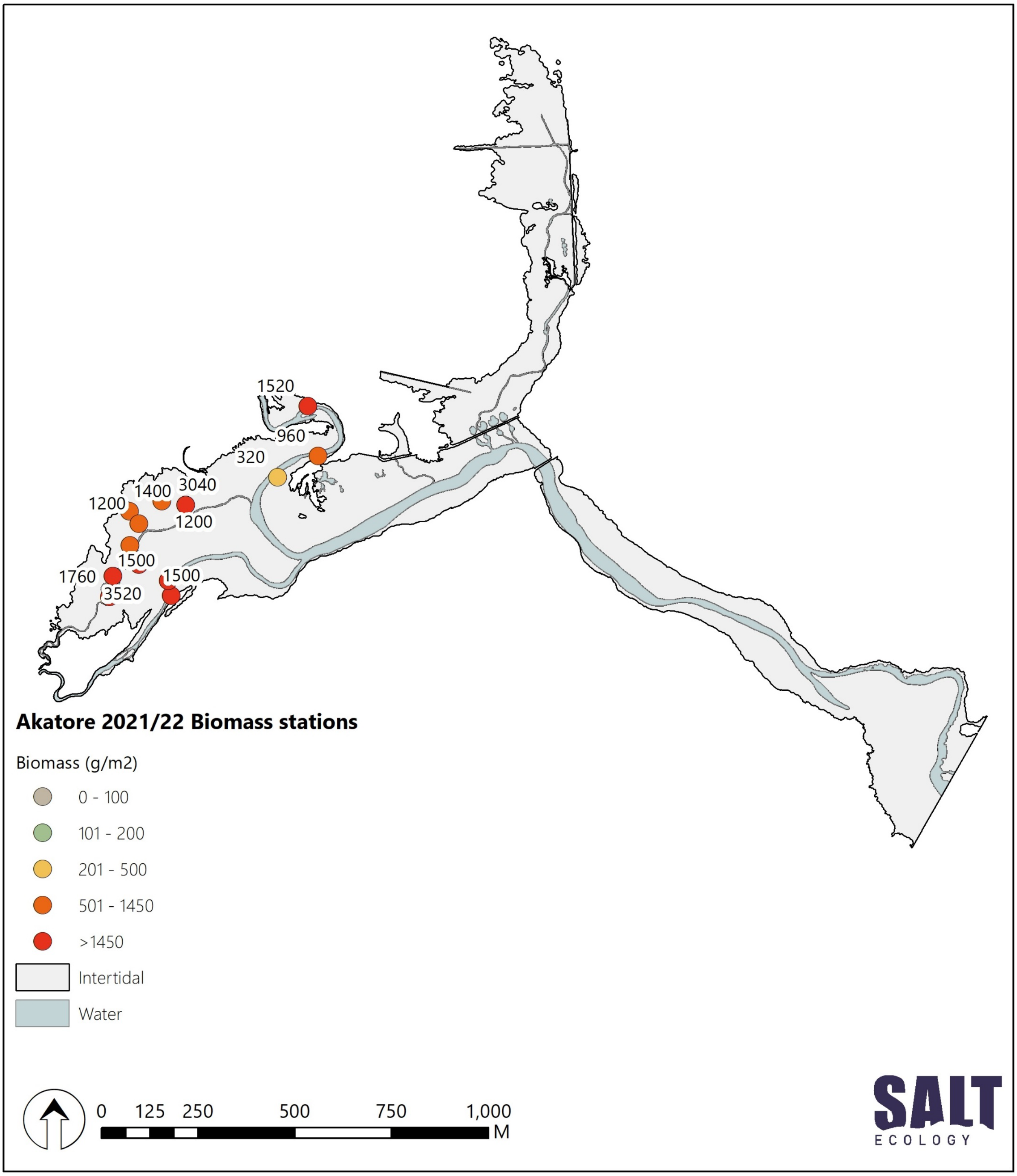
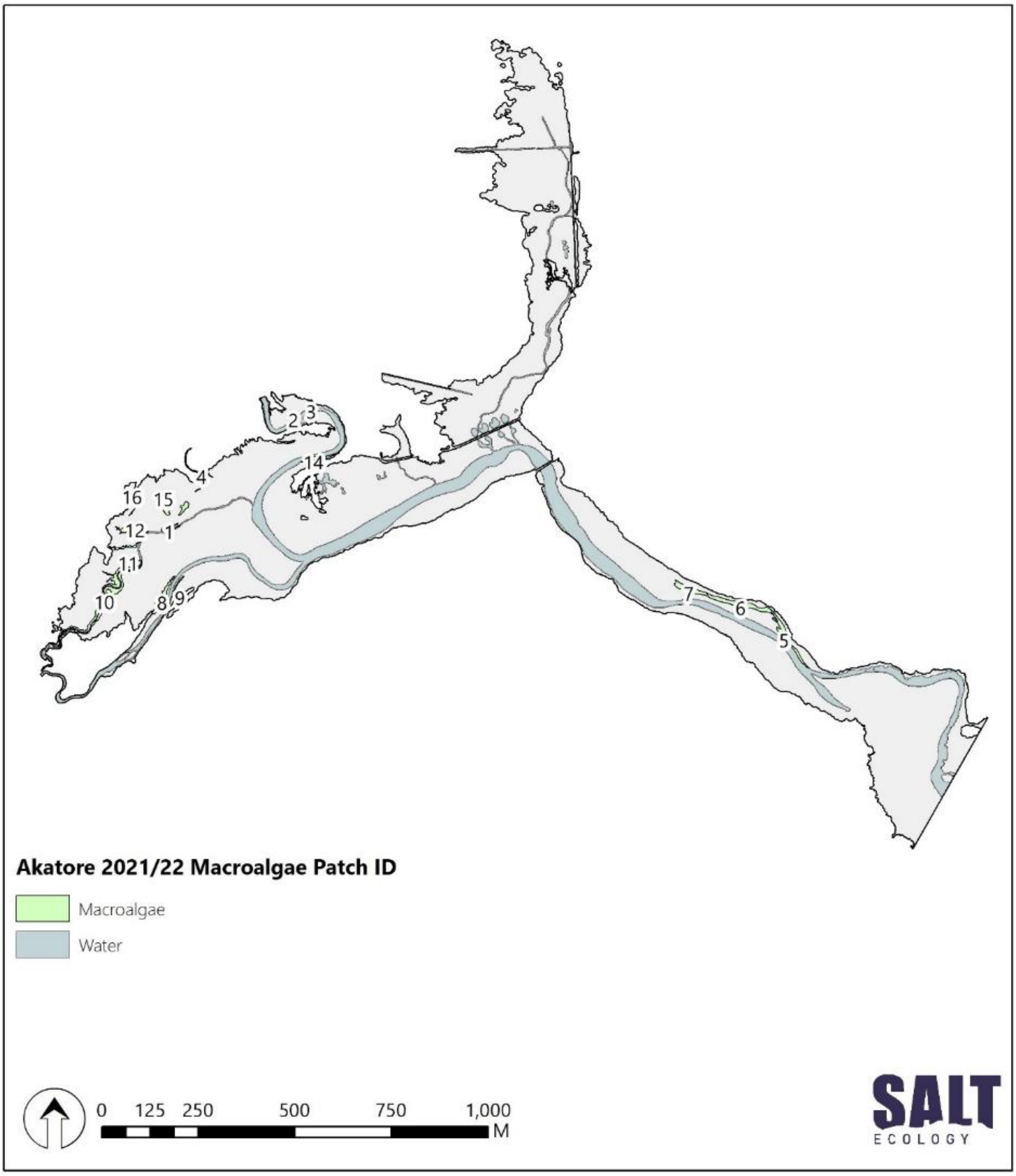
APPENDIX 5. MACROALGAL BIOMASS STATIONS & OMBT PATCH ID AND RAW DATA, AKATORE ESTUARY, NOVEMBER 2021



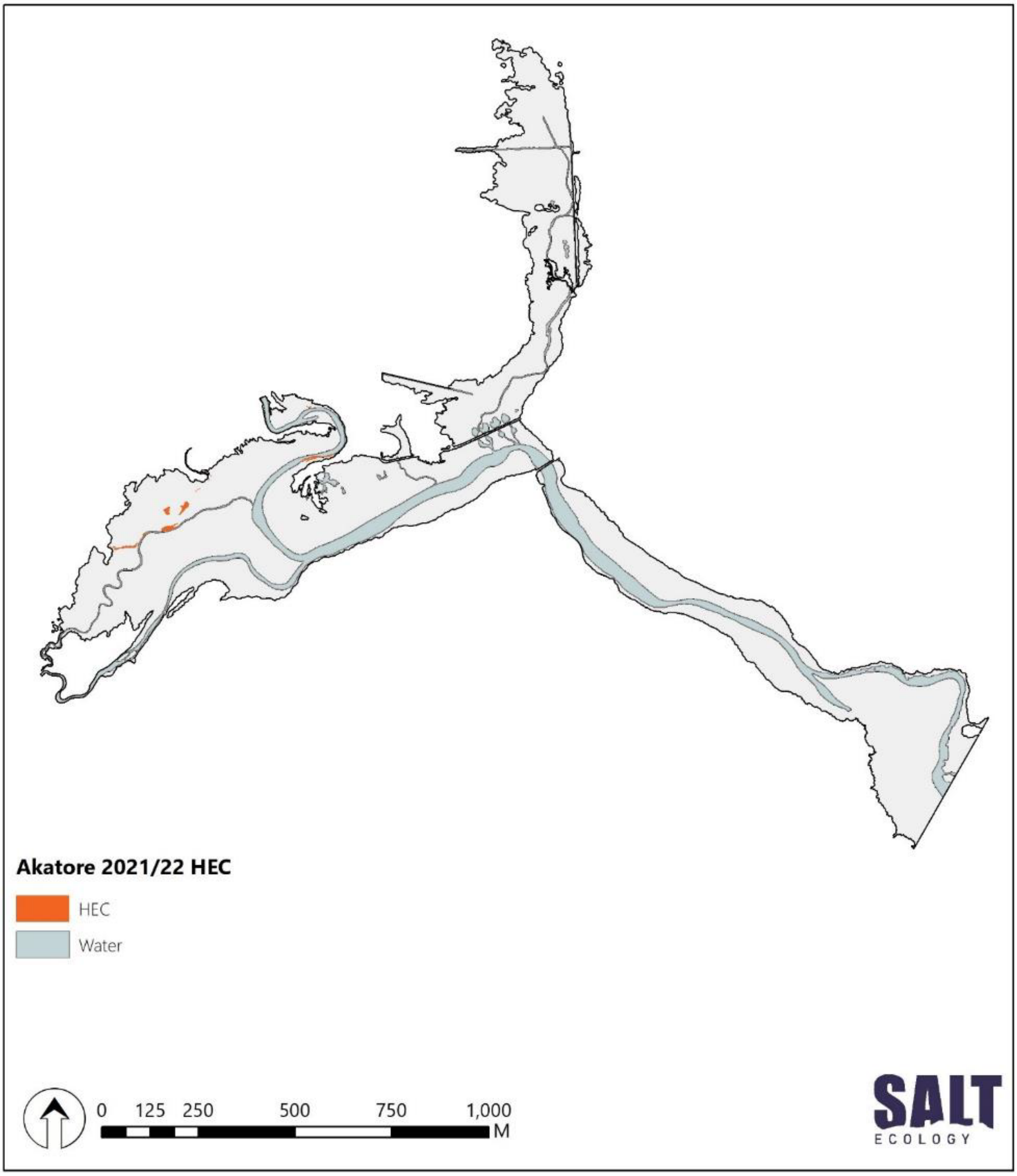
Macroalgal patch information used in the calculation of the OMBT-EQR

Estuary	Year	PatchID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (g/m^2)	Biomass Category	Entrained	Dominant Species	Sub-Dominant Species	Substrate	Area (ha)
Akatore	2021	1	Grch Ulva	80 1	81	Dense (70 to <90%)	3040	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	vsSM	0.10
Akatore	2021	2	Grch	10	10	Sparse (10 to <30%)	200	Low (101 - 200)	0	*Agarophyton* spp.		vsSM	0.004
Akatore	2021	3	Grch Ulva	70 10	80	Dense (70 to <90%)	1520	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	vsSM	0.004
Akatore	2021	4	Grch Ulva	60 20	80	Dense (70 to <90%)	1500	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	sSM	0.01
Akatore	2021	5	Grch Ulva	30 30	60	High-Moderate (50 to <70%)	750	High (501 - 1450)	0	*Agarophyton* spp.	*Ulva* spp.	fS	0.14
Akatore	2021	6	Ulva Grch	70 5	75	Dense (70 to <90%)	750	High (501 - 1450)	0	*Ulva* spp.	*Agarophyton* spp.	fS	0.17
Akatore	2021	7	Ulva	20	20	Sparse (10 to <30%)	200	Low (101 - 200)	0	*Ulva* spp.		fS	0.10
Akatore	2021	8	Ulva	80	80	Dense (70 to <90%)	1500	Very high (>1450)	0	*Ulva* spp.		sSM	0.11
Akatore	2021	9	Ulva Grch	80 5	85	Dense (70 to <90%)	1500	Very high (>1450)	0	*Ulva* spp.	*Agarophyton* spp.	sSM	0.04
Akatore	2021	10	Ulva Grch	46 43	89	Dense (70 to <90%)	2507	Very high (>1450)	0.3	*Ulva* spp.	*Agarophyton* spp.	sSM	0.49
Akatore	2021	11	Grch Other Ulva	70 25 5	100	Complete (>90%)	1120	High (501 - 1450)	1	*Agarophyton* spp.	Unspecified Macroalgae	sSM	0.03
Akatore	2021	12	Ulva	75	75	Dense (70 to <90%)	1200	High (501 - 1450)	0	*Ulva* spp.		sSM	0.09
Akatore	2021	13	Grch Ulva	70 10	80	Dense (70 to <90%)	1500	Very high (>1450)	1	*Agarophyton* spp.	*Ulva* spp.	sSM	0.01
Akatore	2021	14	Grch Ulva	55 5	60	High-Moderate (50 to <70%)	960	High (501 - 1450)	1	*Agarophyton* spp.	*Ulva* spp.	vsSM	0.04
Akatore	2021	15	Ulva	70	70	Dense (70 to <90%)	1200	High (501 - 1450)	0	*Ulva* spp.		sSM	0.002
Akatore	2021	16	Ulva	80	80	Dense (70 to <90%)	1400	High (501 - 1450)	0	*Ulva* spp.		sSM	0.003

*0=not entrained, 1=100% entrained



APPENDIX 6. AREAS OF HEC IN AKATORE ESTUARY, NOVEMBER 2021



APPENDIX 7. DOMINANT SALT MARSH SPECIES IN AKATORE ESTUARY, NOVEMBER 2021

Sub Class	Dominant species	Sub-dominant species 1	Sub-dominant species 2	Ha	%Salt Marsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	0.4	1.4
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Leptospermum scoparium* (Manuka)	0.3	1.1
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)		1.1	4.1
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Selliera radicans* (Remuremu)	0.3	1.2
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)		0.01	0.1
	Plagianthus divaricatus (Salt marsh ribbonwood)			0.1	0.2
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)		0.01	0.02
Sedgeland	*Cyperus ustulatus* (Giant umbrella sedge)			0.1	0.4
Rushland	*Apodasmia similis* (Jointed wirerush)	*Coprosma propinqua subsp. Propinqua* (Mingimingi)		0.03	0.1
	Apodasmia similis (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	*Phormium tenax* (New Zealand flax)	3.2	12.0
	Apodasmia similis (Jointed wirerush)			1.1	3.9
	Apodasmia similis (Jointed wirerush)	*Phormium tenax* (New Zealand flax)		0.4	1.6
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	2.5	9.4
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Muehlenbeckia complexa* (Wire vine)	2.0	7.6
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		4.6	17.1
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Phormium tenax* (New Zealand flax)	3.8	14.1
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Selliera radicans* (Remuremu)	0.5	2.0
	Apodasmia similis (Jointed wirerush)	*Selliera radicans* (Remuremu)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	1.0	3.7
	Apodasmia similis (Jointed wirerush)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	0.04	0.2
Herbfield	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	*Samolus repens* (Primrose)	0.001	0.004
	Samolus repens (Primrose)			0.01	0.05
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	0.3	1.0
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)		0.2	0.9
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	0.00	0.00
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	0.3	1.2
	Sarcocornia quinqueflora (Glasswort)			0.00	0.00
	Selliera radicans (Remuremu)	*Agrostis stolonifera* (Creeping bent)		0.1	0.2
	Selliera radicans (Remuremu)	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.2	0.6
	Selliera radicans (Remuremu)	*Atriplex prostrata* (Orache, Creeping saltbush)	*Sarcocornia quinqueflora* (Glasswort)	0.01	0.05
	Selliera radicans (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	*Thyridia repens* (New Zealand musk)	0.02	0.1
	Selliera radicans (Remuremu)	*Isolepis cernua* (Slender clubrush)		0.3	1.0
	Selliera radicans (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Samolus repens* (Primrose)	0.2	0.7
	Selliera radicans (Remuremu)			0.2	0.7
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.03	0.1
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	0.1	0.3
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)		1.7	6.5
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	0.01	0.03
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	0.9	3.2
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	0.7	2.6
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)		0.1	0.3
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.1	0.2
	Selliera radicans (Remuremu)	*Thyridia repens* (New Zealand musk)		0.01	0.05
	Selliera radicans (Remuremu)	*Thyridia repens* (New Zealand musk)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.01	0.02
Grand Total				26.9	100

APPENDIX 8. RAW SEDIMENT AND MACROFAUNA DATA IN AKATORE ESTUARY, NOVEMBER 2021

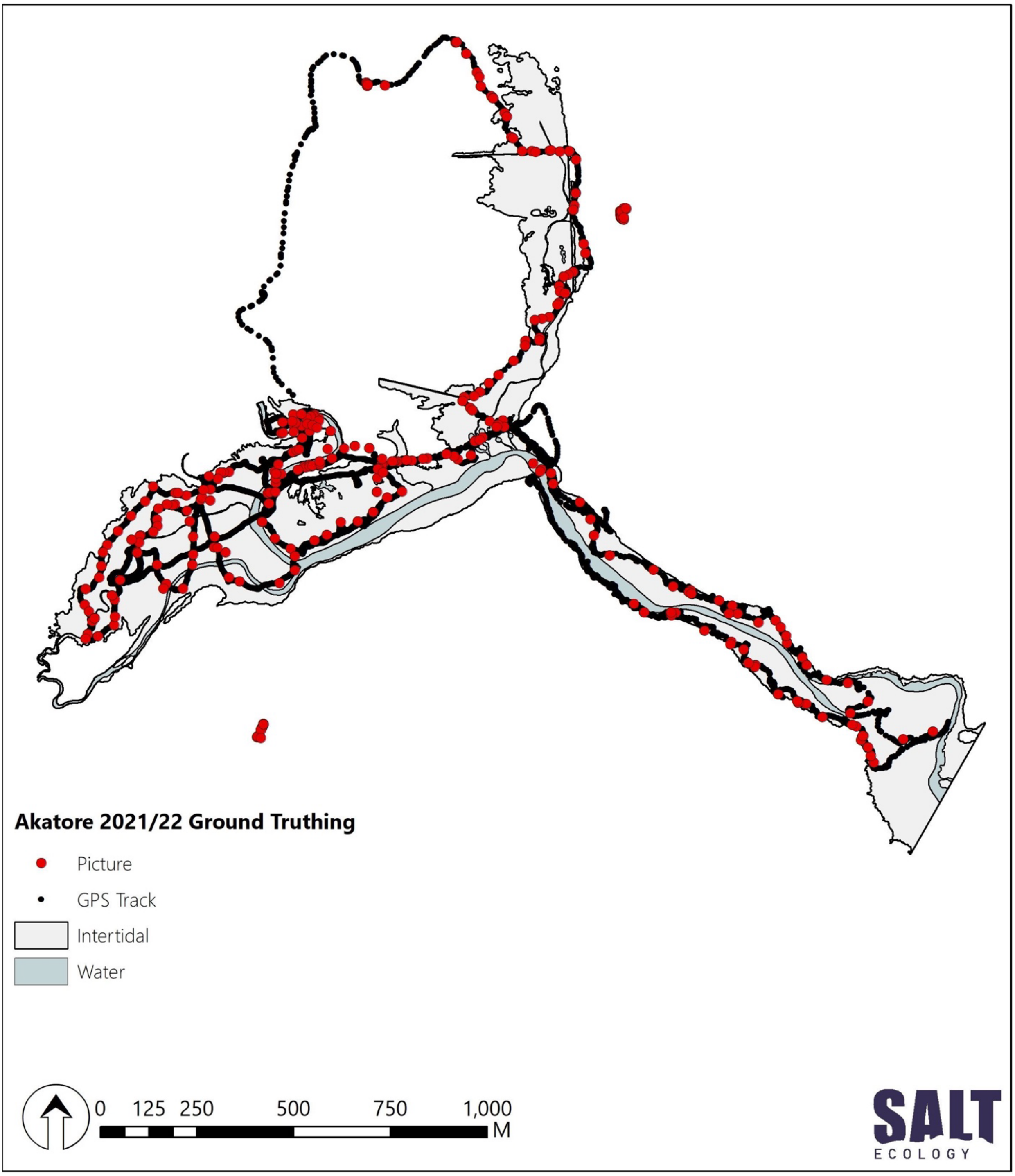
Sediment data and macrofauna indices

Parameter	Unit	AKAT-OTAG ETI-1	AKAT-OTAG ETI-2	AKAT-OTAG ETI–3
Sediment Chemistry				
Total Phosphorus (TP)	mg/kg dry wt	490	740	660
Total Sulfur (TS)	g/100g dry wt	0.23	0.59	0.62
Total Nitrogen (TN)	g/100g dry wt	0.18	0.36	0.27
Total Organic Carbon (TOC)	g/100g dry wt	1.97	3.2	2.7
Gravel (≥2mm)	g/100g dry wt	1.5	0.7	0.3
Sand (≥63mm to <2mm)	g/100g dry wt	48.6	5.4	12.2
Mud (≤63mm)	g/100g dry wt	49.9	93.8	87.6
aRPD	mm	10	1	2
Macrofauna indices				
AMBI	no unit	3.96	5.15	5.26
Abundance	Number of individuals	624	999	121
Diversity	Number of taxa	12	11	9

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

Main group	Taxa	Habitat	EG	AKAT-OTAG ETI-1	AKAT-OTAG ETI-2	AKAT-OTAG ETI-3
Amphipoda	*Aoridae*	Infauna	I	1		
Amphipoda	*Eusiridae*	Infauna (juvenile)	II			1
Amphipoda	*Josephosella awa*	Infauna	II	92	6	4
Amphipoda	*Paracalliope novizealandiae*	Infauna	I		4	
Amphipoda	*Paracorophium excavatum*	Infauna	IV	410	517	32
Anthozoa	*Edwardsia* sp.	Epibiota	II	1		
Bivalvia	*Arthritica* sp. 5	Infauna	III	67		5
Bivalvia	*Lasaea parengaensis*	Infauna	II	1		
Gastropoda	*Amphibola crenata*	Epibiota	III	1	1	
Gastropoda	*Dotidae*	Epibiota	NA		1	
Isopoda	*Exosphaeroma planulum*	Infauna	V	19		15
Mysidacea	*Mysida*	Infauna	II		1	
Oligochaeta	*Naididae*	Infauna	V		350	57
Polychaeta	*Capitella cf. capitata*	Infauna	V	17	112	3
Polychaeta	*Nicon aestuariensis*	Infauna	III	1	1	
Polychaeta	*Perinereis vallata*	Infauna	III	2	2	
Polychaeta	*Platynereis* sp.	Infauna	III			1
Polychaeta	*Scolecolepides benhami*	Infauna	IV	12	4	3

APPENDIX 9. GROUND-TRUTHING IN AKATORE ESTUARY, NOVEMBER 2021

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