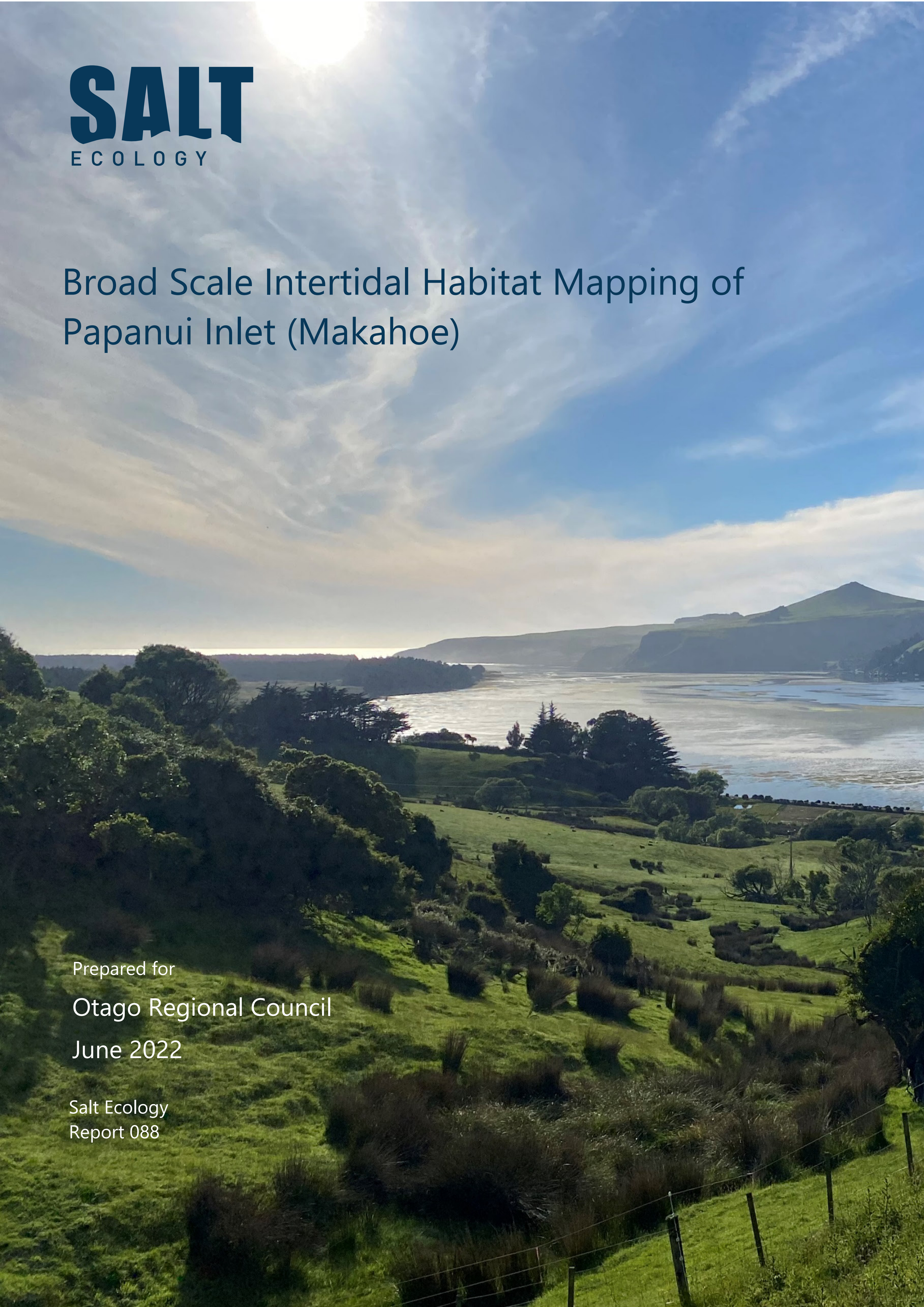

SALT ECOLOGY

Broad Scale Intertidal Habitat Mapping of Papanui Inlet (Makahoe)

Prepared for

Otago Regional Council

June 2022

Salt Ecology
Report 088

Cover photo: Looking down at Papanui Inlet (Makahoe) in the direction of the entrance showing extensive seagrass beds, November 2021.

RECOMMENDED CITATION

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For the People
Mō ngā tāngata

Broad Scale Intertidal Habitat Mapping of Papanui Inlet (Makahoe)

Prepared by

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for

Otago Regional Council

June 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. The tools used to produce GIS summaries and maps were developed by Megan Southwick (Salt Ecology). The macrofauna data analysis was carried out by Barrie Forrest (Salt Ecology). ORC provided the rectified aerial imagery used in the mapping. Thanks to Rebecca McGrouther (Port Otago) for providing consent monitoring reports.

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SUMMARY

Papanui Inlet (Makahoe) is a medium sized (378ha) shallow, intertidally dominated, tidal lagoon type estuary (SIDE) located on the Otago Peninsula on New Zealand's southeast coast. The estuary is a monitored by Otago Regional Council (ORC) as part of its State of the Environment programme using methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). This report describes a survey conducted in November 2021 which assessed the dominant substrate and vegetation features present including seagrass, salt marsh and macroalgae.

KEY FINDINGS

- Intertidal substrate was dominated by sand (263.7ha, 90.8% of the intertidal area), with virtually no mud-dominated (>50% mud) substrate (0.07ha, 0.02%).
- There was no evidence of nuisance macroalgae or excessive sedimentation indicating current nutrient and fine sediment inputs are below thresholds of concern.
- Intertidal seagrass beds were extensive (111.1ha, 38.3%) reflecting suitable growing conditions comprising low sediment mud content, high water clarity and low nutrient inputs. However, extensive grazing damage from waterfowl was evident.
- Salt marsh (12.9ha, 4.4% of the intertidal area) was dominated by herbfield (81.0%), estuarine shrub (8.4%), grassland (4.8%) and rushland (3.9%). It was most extensive on the northern margin of the Inlet. Localised grazing pressures were present.
- The estuary margin was heavily modified due to historic reclamation and drainage of salt marsh, and shoreline hardening to protect roading.
- The 200m terrestrial margin was 26.4% densely vegetated (mainly exotic forest) otherwise dominated by low producing grassland (66%).
- The dominant catchment land uses were high-producing (59%) and low-producing (18%) grassland, mixed exotic shrubland (9%), exotic forest (7%) and indigenous scrub/forest (6%).
- The Estuary Trophic Index (ETI) score (0.227) indicated nutrient enrichment (eutrophication) was very low.

Despite the grazing pressure on seagrass beds, Papanui Inlet (Makahoe) was in 'very good' condition, with expansive beds of high value seagrass, very little mud-dominated sediment and a diverse range of other habitat types including salt marsh, sandflats and cockle beds. The high ecological quality of the estuary can be attributed to small freshwater inflows, low nutrient and sediment inputs and well flushed tidal flats.

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) Score	No unit	0.227	Very Good
Mud-dominated substrate	% of intertidal area >50% mud	0.02	Very Good
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.945	Very Good
Seagrass	% decrease from baseline	nd	November 2021 - baseline
Salt marsh extent (current)	% of intertidal area	4.4	Poor
Historical salt marsh extent*	% of historical remaining	70%	Good
200m terrestrial margin	% densely vegetated	25.4	Fair
High Enrichment Conditions	ha	0	Very Good
High Enrichment Conditions	% of estuary	0	Very Good
Sedimentation rate*	CSR:NSR ratio**	1.7	Good
Sedimentation rate*	mm/yr	0.06	Very Good

Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. *Estimated. **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.
- Protect important habitats such as seagrass, cockle beds and salt marsh (e.g. vehicle exclusion, reconnect areas of remnant salt marsh to the estuary, reduce grazing pressures).
- Include Papanui Inlet (Makahoe) in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will maintain the high ecological quality of the estuary.

1. INTRODUCTION

1.1 BACKGROUND

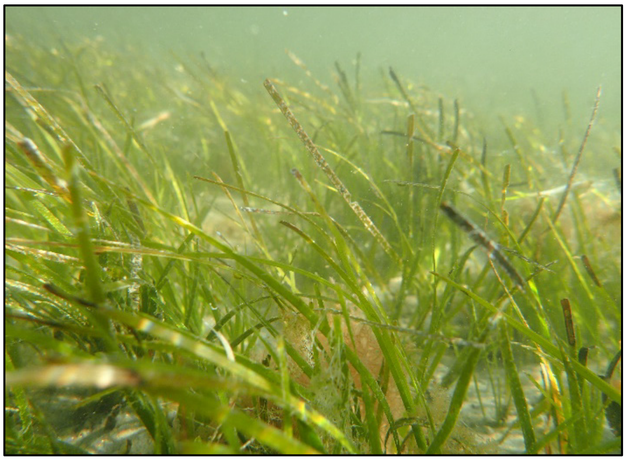
Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 based on the methods outlined in New Zealand's National Estuary Monitoring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

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

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

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

The current report describes the methods and results of broad scale monitoring undertaken in Papanui Inlet (Makahoe) on the 26 and 29 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.



Seagrass in Papanui Inlet (Makahoe)

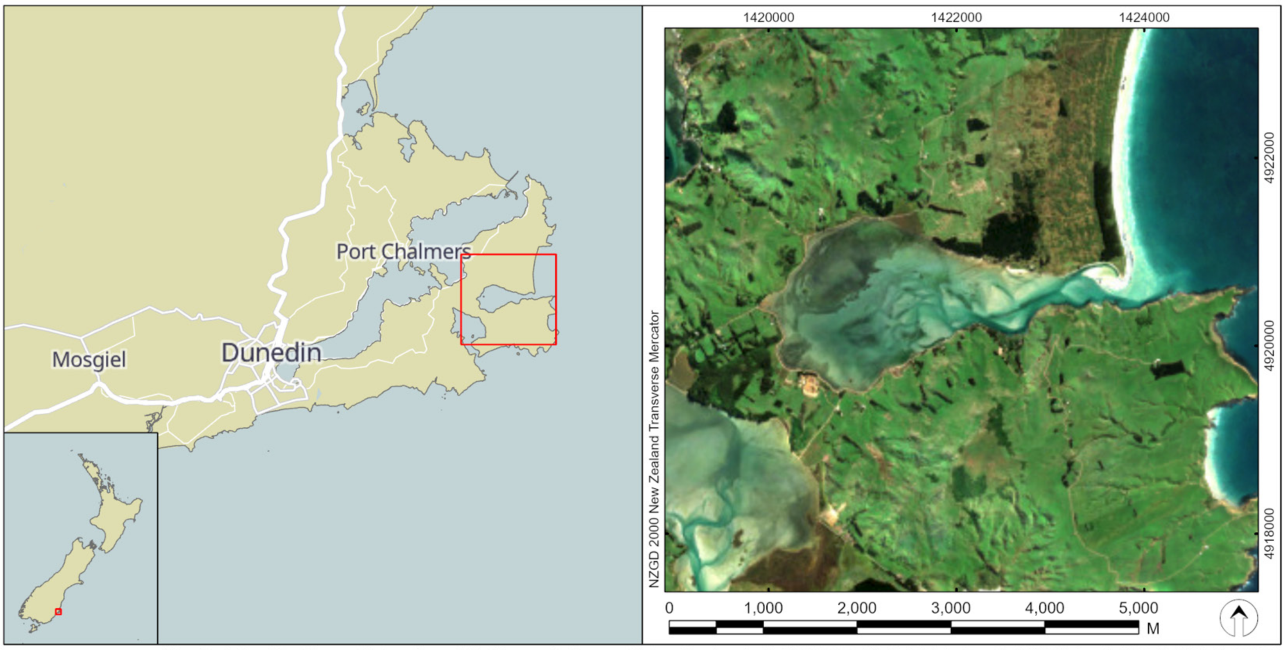


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Fig. 1. Location of Papanui Inlet (Makahoe), Otago.

1.2 OVERVIEW OF PAPANUI INLET (MAKAHOE)

Papanui Inlet (Makahoe) is a medium sized (378ha) estuarine system located on the Otago Peninsula on New Zealand's southeast coast. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary (SIDE) that is well flushed. Freshwater inputs represent ~1% of the total estuary volume (Plew et al. 2018). The combined flushing potential and low freshwater inputs mean the estuary is unlikely to experience nutrient driven water column problems, e.g. phytoplankton blooms. However, the estuary has the capacity to retain fine sediments and sediment-bound nutrients in deposition areas making it moderately susceptible to nutrient enrichment and fine sediment impacts.

The estuary drains almost completely at low tide exposing ~77% of the estuary area. The lower estuary is protected from the ocean by a sand spit dominated by lupin and marram grass dunes. The Okia Flats on the northern side of the estuary is classified as a regionally significant wetland in the Regional Plan: Water for Otago because it represents the best regional example of dune hollow vegetation and provides habitat for nationally or internationally rare or threatened species. The salt marsh present on the northern edge of the estuary is classified as a regionally significant wetland because it is habitat for the declining *Carex litorosa* (sea sedge) and the naturally uncommon *Stenostachys laevis* (wheatgrass; Regional Plan: Water for Otago).

Drained (top) and eroding (bottom) salt marsh on the northern estuary margin

Entrance of Papanui Inlet (Makahoe), looking over the Okia Flats

The estuary drains a 1,248ha catchment comprising ~58.8% intensive pasture, ~17.8% low producing pasture, 8.9% mixed exotic shrubland and 7.0% exotic forest. Only, 23.1% of the catchment is densely vegetated and mostly comprises exotic vegetation (Table 1; Fig. 2). The estuary margin is modified with a road around much of the estuary edge and a rock wall preventing landward migration of the estuary in response to sea level rise.

Road and artificial rock wall bordering the estuary

Table 1. Summary of catchment land cover (LCDB5 2017/18) Papanui Inlet (Makahoe).

LCDB5 (2017/2018) Catchment Land Cover		Ha	%
6	Surface Mine or Dump	4.3	0.3
40	High Producing Exotic Grassland	733.4	58.8
41	Low Producing Grassland	222.4	17.8
45	Herbaceous Freshwater Vegetation	3.7	0.3
46	Herbaceous Saline Vegetation[1]	10.3	0.8
52	Manuka and/or Kanuka	5.4	0.4
54	Broadleaved Indigenous Hardwoods	33.0	2.6
56	Mixed Exotic Shrubland	111.3	8.9
64	Forest - Harvested	1.8	0.1
69	Indigenous Forest	34.4	2.8
71	Exotic Forest	87.8	7.0
Grand Total		1248	100
Total densely vegetated area (LCDB classes 45-71)		287.8	23.1

[1]Herbaceous Saline Vegetation includes dunes

Papanui Inlet (Makahoe) was an early Māori settlement, providing shelter, kaimoana, including shellfish, seals and penguins along the coast, and access to the fishery offshore. Several important archeological sites exist including middens and the second oldest waka (canoe) ever found in New Zealand.

Cockles (*Austrovenus stutchburyi*) remain abundant and an important source of kaimoana for Ngāi Tahu (James et al. 2010; Kainamu 2010). Southern Clams Ltd commercially harvest cockles in Papanui Inlet, although harvesting temporarily ceased between 2006 and 2017 because water quality did not meet shellfish quality assurance standards. Some water quality degradation has been attributed to nutrient run off from land and contamination by waterfowl (Moore et al. 2015). The estuary comprises both terrestrial and marine sediments, with terrestrial inputs likely enhanced during forest clearance (Moore et al. 2015).

Cockle beds in the mid estuary

The estuary is an important habitat for waders including the eastern bar-tailed godwit, white-faced heron, pied oystercatcher, variable oyster catcher, pied stilt and spur winged plover (ORC Regional Plan: Coast; 2016 Wader Count). Other habitats include extensive seagrass beds and sandflats that are an important nursery for pātiki (flatfish; ORC Regional Plan: Coast). The estuary retains high cultural and ecological values and is therefore classified as a coastal protection area in the Otago Regional Plan: Coast.

Seagrass beds in Papanui Inlet (Makahoe)

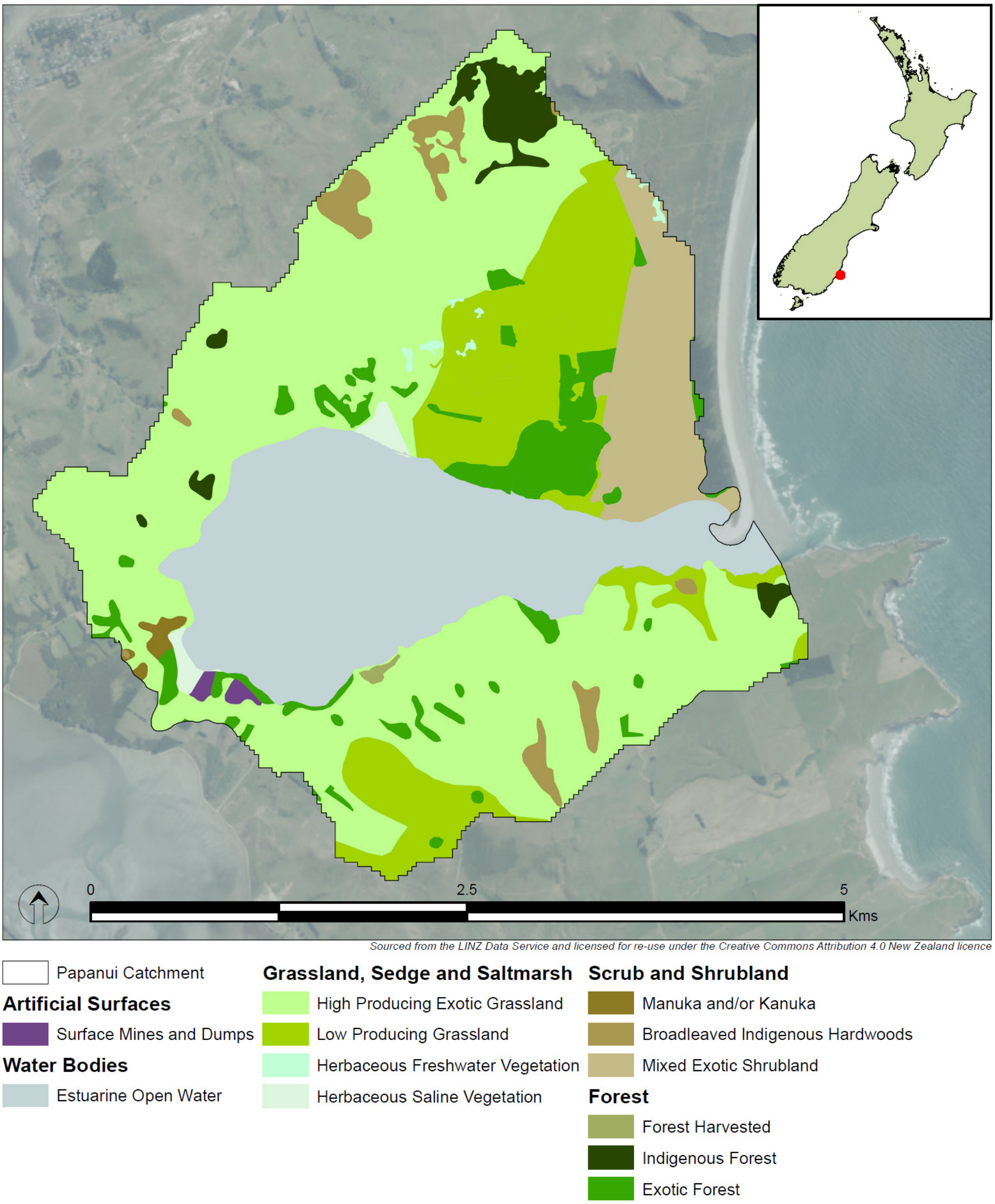


Fig. 2. Papanui Inlet (Makahoe) catchment land use classifications from LCDB5 (2017/2018) database.

2. METHODS

2.1 OVERVIEW

Broad scale habitat mapping of Papanui Inlet (Makahoe) was carried out on 26 and 29 November 2021. The focus of the study was to characterise substrate and the presence and extent of seagrass, macroalgae and salt marsh.

2.2 BROAD SCALE MAPPING METHODS

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

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

In 2021, imagery was supplied by ORC (1:3000 colour aerial imagery captured between January and April 2019). Ground-truthing was undertaken on 26 and 29 November 2021 by experienced scientists who assessed the estuary on foot to map spatial extent of dominant vegetation and substrate. A particular focus was to characterise the spatial extent of muddy sediment (as a key stressor), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats. The latter were estuarine seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the terrestrial margin bordering the estuary. Background information on the ecological significance of opportunistic macroalgae and the different vegetation features is provided in Table 2.

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

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

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

Seagrass in Papanui Inlet (Makahoe), looking toward the entrance

Salt marsh on the margin of Papanui Inlet (Makahoe)

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

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

2.3 SUBSTRATE CLASSIFICATION AND MAPPING

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

Substrate classification is based on the dominant surface substrate features present, e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories based on sediment 'muddiness', assessed according to an expert field-based assessment of textural and firmness characteristics. In November 2021, 6 sediment grainsize samples were collected to validate field classifications of substrate type, with 4 additional validation samples sourced from consent monitoring results (Appendix 2).

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

Mobile sands near the estuary entrance

Causeway and drain input to Papanui Inlet (Makahoe)

2.4 SEDIMENT OXYGENATION

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

Example of distinct colour change with depth, brown oxygenated sediments are on the surface down to ~30mm

2.5 MACROALGAE ASSESSMENT

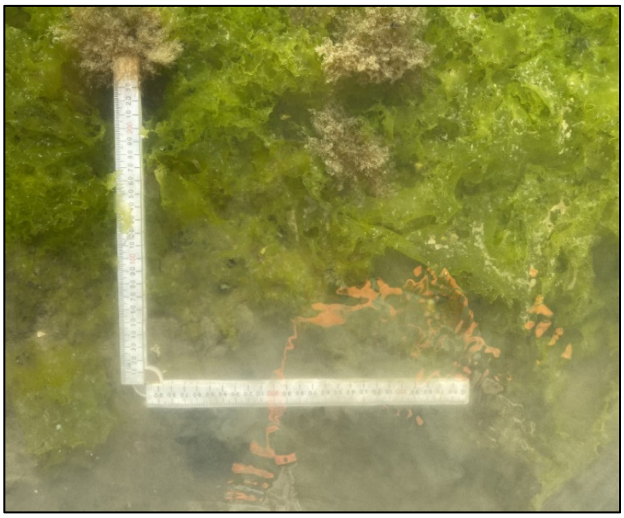
The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature.

The ETI (Robertson et al. 2016b) adopted the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach. The OMBT, described in detail in Appendix 3, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within five overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

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

If an estuary supports <5% opportunistic macroalgal cover in total within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' (EQR score ≥ 0.8 to 1.0) with no further sampling required. A numeric EQR score is calculated for the 'high' band using the approach described in Stevens et al. (2022).

Using this 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.



Assessing macroalgal cover in Papanui Inlet (Makahoe)

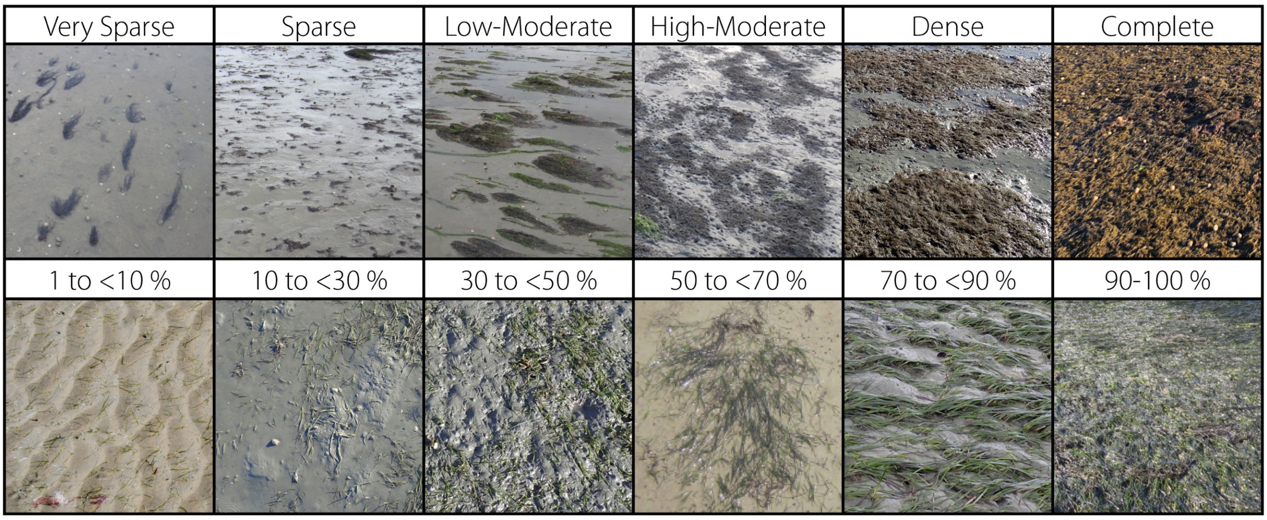


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

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.

Ulva spp. present on the southern side of the estuary

2.6 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.

To assess change in seagrass extent over time, aerial imagery from 1958, 1970, 1985 and 2000 (retrolens.co.nz) was georeferenced in ArcMap 10.6 and visible seagrass was digitised. Because it was difficult to distinguish boundaries between subtidal and intertidal areas on the historic imagery, the total area of seagrass (>50% cover) across the whole estuary has been compared across years. For comparison with November 2021, both intertidal and subtidal seagrass were mapped. Because the estuary nearly completely drained at low tide, and the remaining subtidal areas were shallow with high water clarity, subtidal areas were mapped based on the aerial imagery. As discussed in Section 2.10, it is difficult to reliably map seagrass areas of <50% cover solely from aerial imagery (i.e., no ground-truthing), therefore comparisons with November 2021 are made with the percent cover categories >50% cover.

2.7 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.

LiDAR and historic aerial imagery were used to estimate historic salt marsh extent. LiDAR data was supplied by ORC as a terrain dataset of the coastal margin. All LiDAR geoprocessing was performed using ArcGIS Pro 2.9.3. The terrain dataset was converted to raster using the Terrain to Raster (3D Analyst) tool. Contour lines were created using the Contour List (Spatial Analyst) tool. The 1.6m contour was selected to represent the upper estuary boundary elevation based on a comparison with existing estuary mapping and a visual assessment of aerial imagery.

2.8 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.

Terrestrial margin in the lower estuary, mix of exotic vegetation

Road and artifical rock wall on edge of estuary

Fenced and grazed salt marsh adjacent to estuary

2.9 SEDIMENT QUALITY & MACROFAUNA

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

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).

Sediment sampling on the incoming tide – note the high water clarity

2.10 DATA RECORDING AND QA/QC

Broad scale mapping provides a rapid overview of estuary substrate, macroalgae, seagrass and salt marsh condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial imagery, the extent of ground-truthing undertaken to validate features visible on photographs, and the experience of those undertaking the mapping. In most instances features with readily defined edges can be mapped at a scale of ~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse seagrass or macroalgal beds. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed, but when relying on photographs alone, accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

In 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 10.6.

2.11 ASSESSMENT OF ESTUARY CONDITION

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

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) have been recently revised for use in New Zealand (Plew et al. 2020a) and are included in Appendix 3.

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

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

Cockles beds, Papanui Inlet (Makahoe)

Herbfield adjacent to dune vegetation in Papanui Inlet (Makahoe)

3. RESULTS

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

3.1 SUBSTRATE

Table 4 and Fig. 4 show intertidal substrate was dominated by firm sand (182.0ha, 62.7%) in the main body of the estuary, and mobile sand (81.6ha, 28.1%) in the lower estuary. Rockfield (1.8ha or 0.6%) was present on the southern margin of the estuary toward the entrance. Artificial boulder field (0.2%) was localised along the estuary margin to protect the road from erosion. Mud-dominated sediments were scarce (0.07ha, 0.02%) and associated with salt marsh habitat or localised stream inputs where fine sediments naturally accumulate. While large cockle (*Austrovenus stutchburyi)* beds exist, only a small area was dominated by shellbank (1.1ha), with cockles otherwise growing in the dominant substrate types (firm or mobile sand). There was good agreement between the subjective sediment classifications applied during mapping and the sediment grainsize validation measures (see Appendix 2).

Table 4. Summary of dominant intertidal substrate, Papanui Inlet (Makahoe), November 2021.

Substrate Class	Feature	Ha	%
Artificial	Boulder field	0.7	0.2
	Gravel field	0.8	0.3
Bedrock	Rock field	1.8	0.6
Boulder/ Cobble/ Gravel	Cobble field	0.2	0.1
	Gravel field	1.0	0.3
Sand (0-10% mud)	Mobile sand	81.6	28.1
	Firm sand	182.0	62.7
Muddy Sand (>10-25% mud)	Firm muddy sand	5.0	1.7
	Soft muddy sand	8.3	2.9
Muddy Sand (>25-50% mud)	Firm muddy sand	7.5	2.6
	Soft muddy sand	0.01	0.004
Sandy Mud (>50-90% mud)	Firm sandy mud	0.04	0.01
	Soft sandy mud	0.03	0.01
Zootic	Shell bank	1.1	0.4
Total		**290.2**	**100**

Shellbank on mobile sand (top) and sand with sparse cockles (bottom)

Artificial boulder field and gravel field on road margin (top) and eroding artificial boulder field (bottom)

Muddy sands associated with a freshwater input (top) and drainage channels through salt marsh (bottom)

Seagrass growing on firms sands

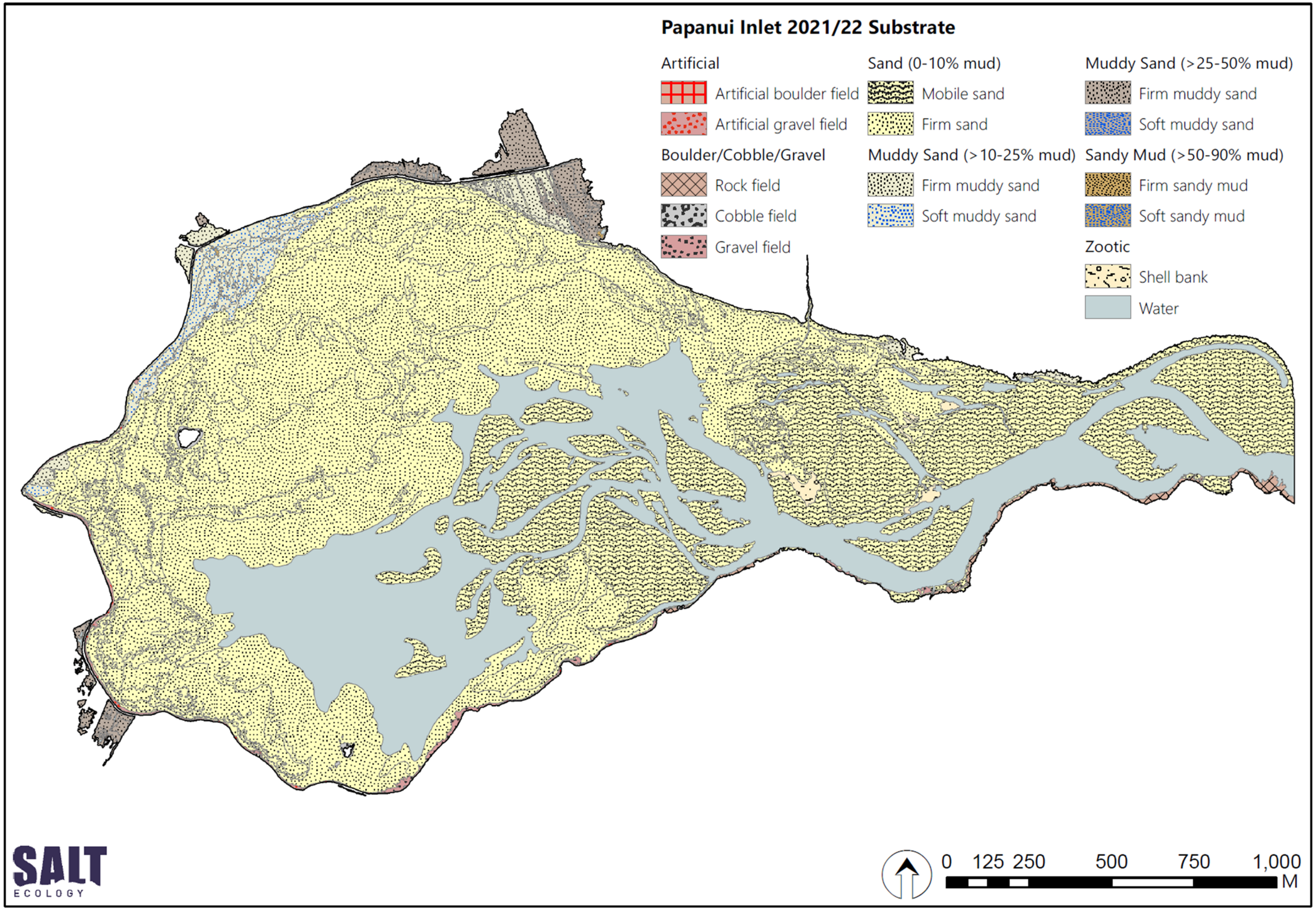


Fig. 4. Dominant substrate types in the intertidal zone, Papanui Inlet (Makahoe), November 2021.

3.2 SEDIMENT OXYGENATION

In November 2021, spot measurements of aRPD showed that sand-dominated sediments were well oxygenated (see photo). In areas of high macroalgal cover there were no visible signs of poor sediment oxygenation suggesting that intermittent blooms of macroalgae observed in the estuary are not significantly impacting the benthic habitat. Firm sands supporting seagrass were generally well oxygenated with seagrass roots extending deep into the sediment. In contrast, the aRPD was shallow (<10mm) in seagrass growing in soft muddy-sands on the northwest margin.

In general, the shallowest aRPD depths occurred in sediments with increasing mud content and/or organic material. For example, near stream inputs, soft muddy-sands or in areas where drift seagrass had accumulated and was decomposing. Areas of poor sediment oxygenation were uncommon in the estuary.

Firm sand (left) aRPD ~30mm and Ulva spp. (right) aRPD ~40mm

Low oxygen (black) sediments were present in crab burrowing deposits in soft muddy-sands (top), and beneath decaying seagrass washed ashore (bottom)

Low oxygen sediment directly below drain outlet

3.3 OPPORTUNISTIC MACROALGAE

Table 5 summarises macroalgae percentage cover and biomass classes for Papanui Inlet (Makahoe) in November 2021, with the mapped cover and biomass shown in Fig. 5 and Fig. 6 respectively. Macroalgal sampling stations and data are provided in Appendix 5. Marine species and drift macroalgae were not recorded as part of the nuisance macroalgae assessment.

Table 5. Summary of intertidal macroalgal cover (A) and biomass (B), Papanui Inlet (Makahoe), November 2021.

A. Cover

Percent cover category	Ha	%
Absent or trace (<1%)	275.4	94.9
Very sparse (1 to <10%)	6.8	2.3
Sparse (10 to <30%)	1.5	0.5
Low-Moderate (30 to <50%)	5.6	1.9
High-Moderate (50 to <70%)	0.6	0.2
Dense (70 to <90%)	0.4	0.1
Complete (≥90%)	0.02	0.01
Total	290.2	100.0

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	275.4	94.9
Very low (1 - 100)	8.3	2.8
Low (101 - 200)	0.0	0.0
Moderate (201 - 500)	0.0	0.0
High (501 - 1450)	6.2	2.1
Very high (>1450)	0.4	0.1
Total	290.2	100.0

Key macroalgae results were as follows:

- Macroalgae were scarce in the Available Intertidal Habitat (AIH). Cover was classified as trace (<1%) or very sparse (1 to <10%) across 97.2% of the intertidal area, and sparse (10 to <30%) or low-moderate (30 to <50%) across 2.4% (Table 5). Overall, the Affected Area (AA) where macroalgae were growing was small (14.8ha, 5.3%; Fig. 5; Table 6).
- Macroalgae cover >50% only comprised 1.0ha (0.3%) of the intertidal area, and were predominantly growing on firm sands or near channel margins.
- When present, the dominant macroalgae was the green seaweed *Ulva* spp. with the red seaweed *Agarophyton* spp. (previously known as *Gracilaria* spp.) and the red seaweed *Ceramium* spp. only present in small amounts (see photos).
- Mean wet weight biomass was low across the AIH (23.3 g/m^2), and moderate in the AA (436.5 g/m^2; Table 6).
- Areas of high *Ulva* spp. biomass (i.e., >501g/m^2) were recorded on the northern and southern flats (Fig. 6), although underlying sediments appeared healthy.
- No High Enrichment Condition (HEC) areas (mud-dominated sediments with >50% macroalgal cover entrained in stable beds) were recorded.

Because the estuary had <5% opportunistic macroalgal cover across the AIH (1.4%; Table 6), the OMBT method rates overall quality status as 'high', equivalent to the condition rating of 'very good' (Table 3). In order to provide a more nuanced assessment of state, a numeric OMBT EQR score was calculated using only the % cover AIH sub-metric as described in Stevens et al. (2022). The numeric EQR score (0.945) highlights that macroalgae were not a dominant vegetation type in the estuary, and did not appear to be causing any significant adverse effects on the benthic community or seagrass.

Ulva spp. northern Papanui Inlet

Localised macroalgal growths on stream margin

Mix of *Ulva* spp. and *Agarophyton* spp. on firm sands

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

2021 Metric	Face value	FEDS	Environmental Quality Class
%cover in AIH	1.4	0.945	High
Average biomass (g/m^2) in AIH	23.3	0.953	High
Average biomass (g/m^2) in AA	436.5	0.442	Moderate
%entrained in AA	0	1.0	High
Worst of AA (ha) and AA (% of AIH)		0.776	Good
AA (ha)	14.8	0.776	Good
AA (% of AIH)	5.3	0.793	Good
Survey EQR		0.945*	'Very Good'

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

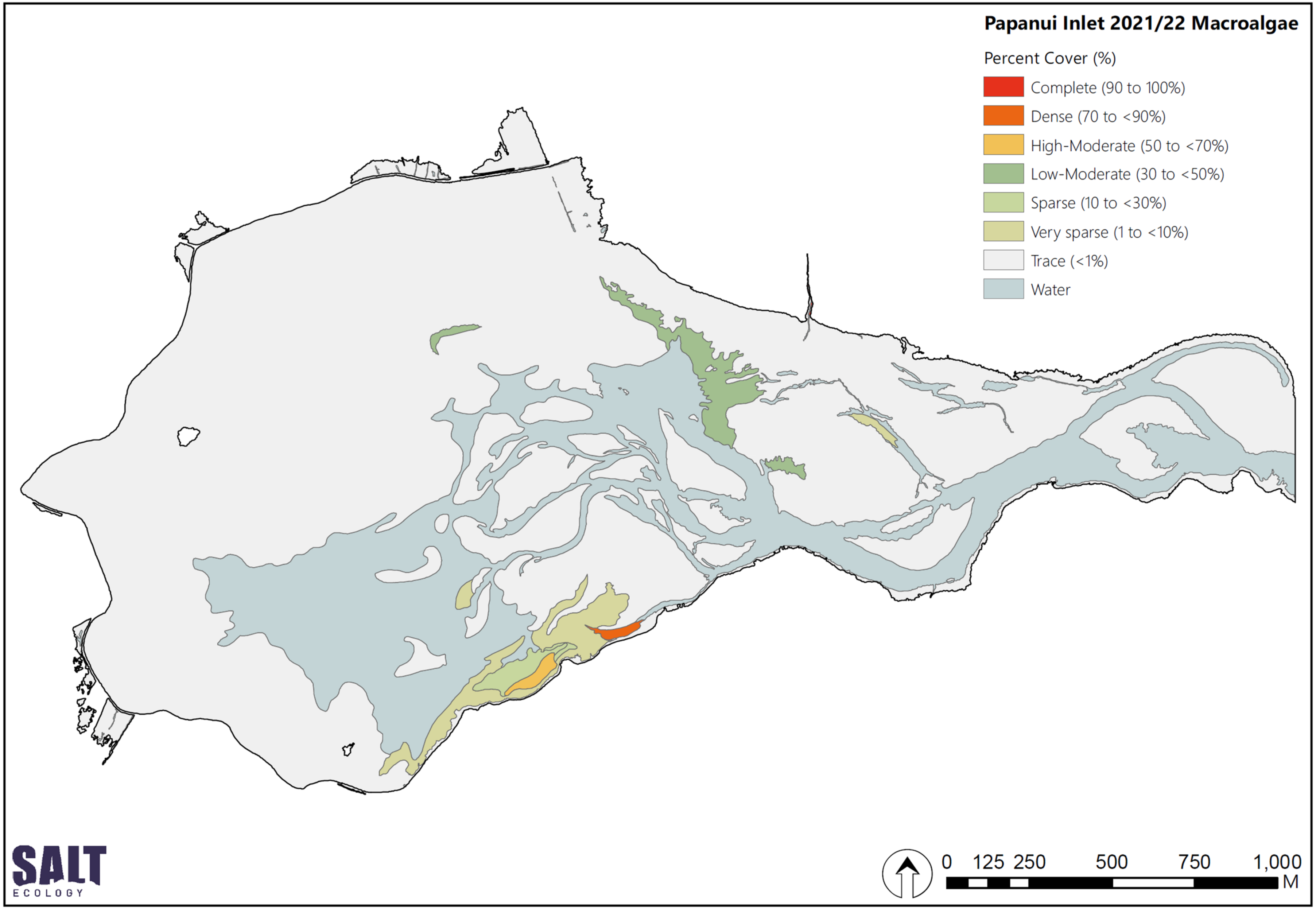


Fig. 5. Distribution and percent cover classes of macroalgae, Papanui Inlet (Makahoe), November 2021.

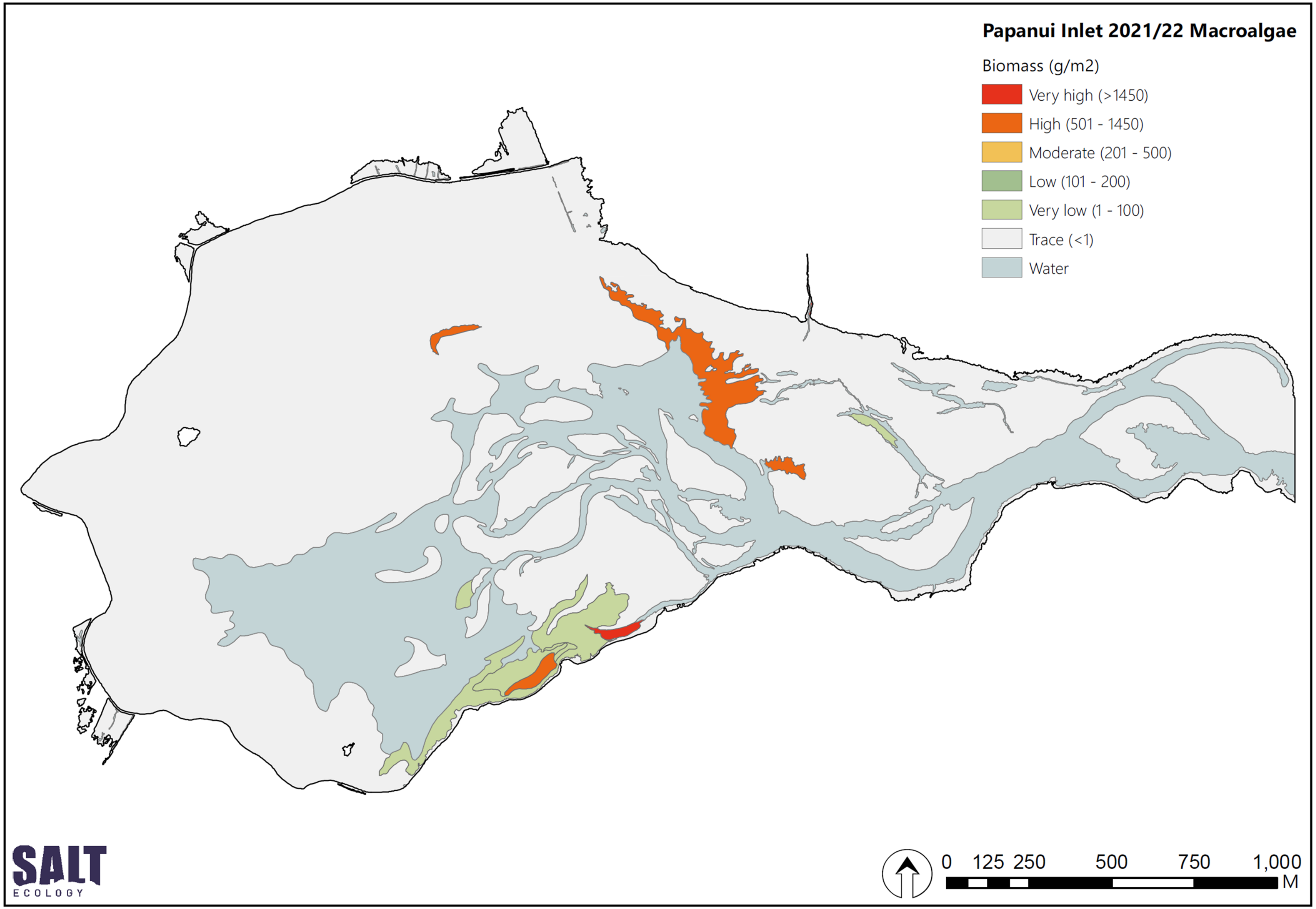


Fig. 6. Biomass (wet weight; g/m^2) classes of macroalgae, Papanui Inlet (Makahoe), November 2021.

3.4 SEAGRASS

Table 7 and Fig. 7 summarise seagrass (*Zostera muelleri*) percent cover. Seagrass was extensive, comprising 38.3% of the intertidal area with cover >50% across 84.0ha (28.9%). The largest expanse of seagrass was recorded in the northwest, with luxuriant beds of >70% cover common near the estuary margin. Overall seagrass appeared healthy, however there was extensive grazing damage by waterfowl (e.g. black swans and Canadian geese), and vehicle damage in the northern estuary (see photos). Dead seagrass was observed in beds and as accumulations on the southwest margin, however aside from grazing there were no other obvious stressors to explain the seagrass dieback.

Swan guano across the seagrass beds

Table 7. Summary of seagrass percent cover categories, Papanui Inlet (Makahoe), November 2021.

Percent cover category	Ha	%
Absent or trace (<1%)	179.0	61.7
Very sparse (1 to <10%)	0.1	0.0
Sparse (10 to <30%)	7.2	2.5
Low-Moderate (30 to <50%)	19.8	6.8
High-Moderate (50 to <70%)	60.6	20.9
Dense (70 to <90%)	21.2	7.3
Complete (≥90%)	2.1	0.7
Total	290.2	100

Dead seagrass (brown) in beds and washed ashore in background

Seagrass beds in Papanui Inlet (Makahoe)

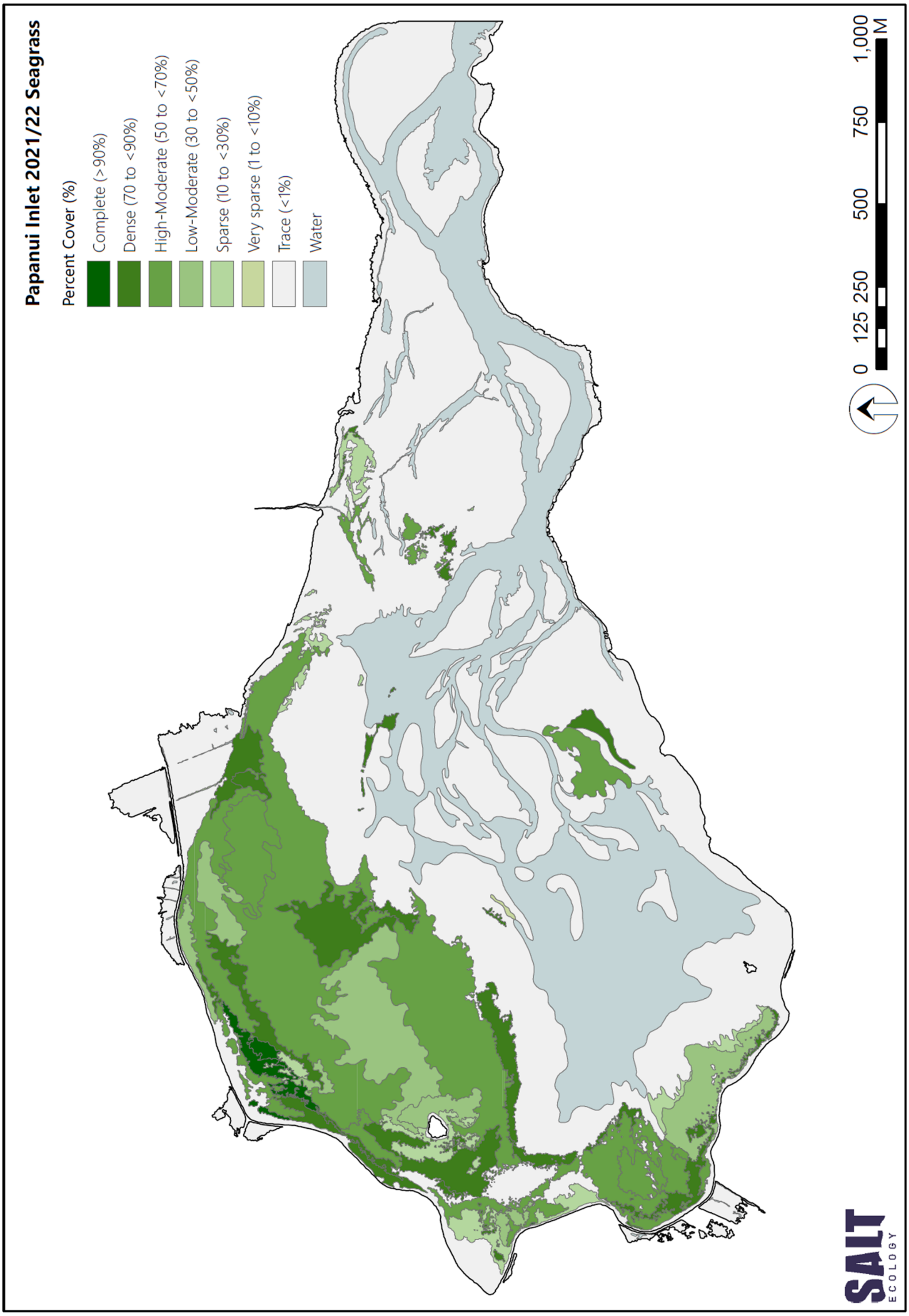


Fig. 7. Distribution and percent cover classes of seagrass, Papanui Inlet (Makahoe), November 2021.

Vehicle damage across seagrass beds, Papanui Inlet (Makahoe)

November 2021 represents the first baseline broad scale survey undertaken by ORC. Anecdotal reports from landowners in the area suggest areas of current seagrass extent in the northwest of the estuary were historically unvegetated sandflats. To explore this further, seagrass visible on aerial images taken in 1958, 1970, 1985, 2000 was digitised and compared to present day (see Section 2.6). For the purposes of comparison across years cover is assumed to be >50% and there is no distinction between intertidal and subtidal seagrass as the boundaries were difficult to distinguish from historic imagery. Table 8 and Fig. 8 represent seagrass extent between 1958 and present day. These should be treated as best estimates because image quality, time of image capture (i.e. month) and tide height varied between dates, and the images were not ground-truthed.

Table 8. Estimated historic seagrass extent for the whole estuary.

Year	ha	% Estuary
Feb-1958	62.0	16.4
Feb-1970	59.9	15.8
Feb-1985	70.6	18.7
Mar-2000	135.3	35.8
Nov-2021*	92.8	24.6

*Includes subtidal seagrass beds not included in Table 6 and Fig. 7.

In 1958 seagrass was localised in the central tidal flats and, over time, has migrated north (1985) and northwest (2000) with extent variable over time (Table 8; Fig. 8; Appendix 6). Seagrass has expanded over time and has remained the dominant vegetation type in the estuary ranging from 15.8% in 1970 to a peak of 35.8% in 2000 (Table 8).

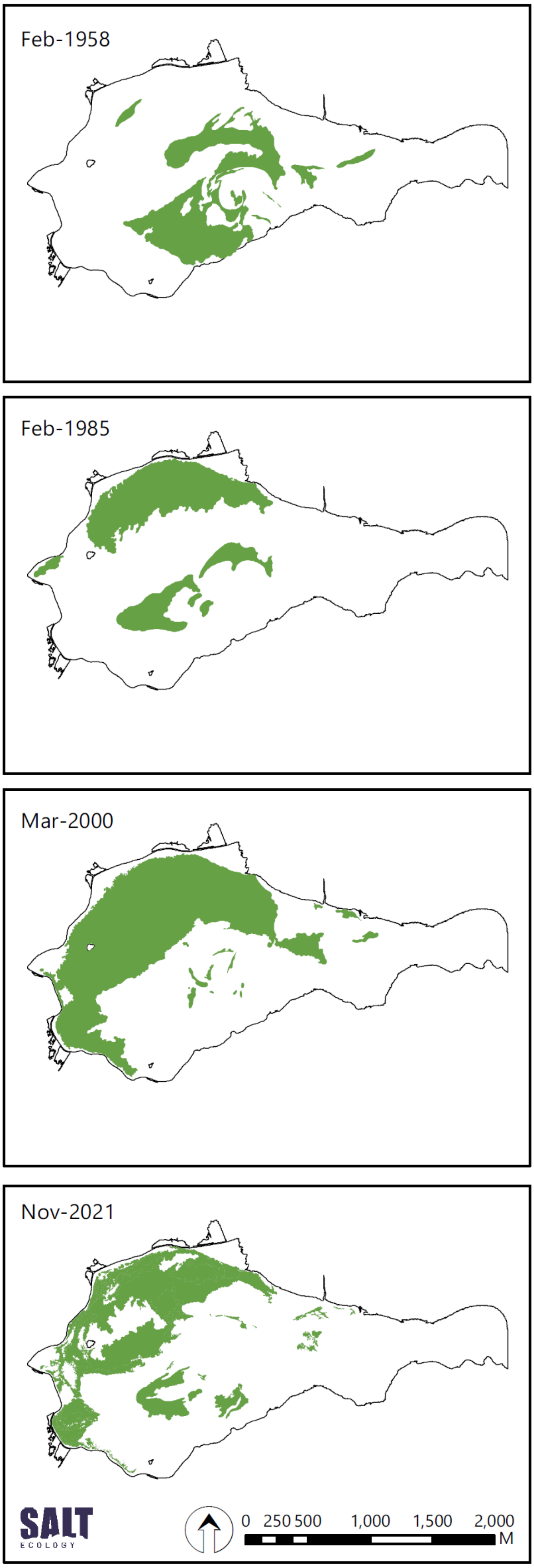


Fig. 8. Historic seagrass extent for the whole estuary. See Appendix 6 for larger images and 1970 map.

3.5 SALT MARSH

Table 9 summarises intertidal salt marsh with the distribution mapped in November 2021 presented in Fig. 9. Dominant and subdominant species are recorded in Appendix 7. The area of salt marsh recorded in November 2021 was 12.9ha (4.4% of the intertidal area) (Table 9), with the most extensive area on the northern margin.

Table 9. Summary of salt marsh area (ha and %) in Papanui Inlet (Makahoe), November 2021.

Subclass	Ha	%
Estuarine Shrub	1.1	8.4
Sedgeland	0.2	1.8
Tussockland	0.003	0.02
Grassland	0.6	4.8
Rushland	0.5	3.9
Herbfield	10.4	81.0
Total	**12.9**	**100**

Herbfield was the dominant class (10.4ha or 81% of total salt marsh). The dominant species were *Sarcocornia quinqueflora* (Glasswort; see photo), *Selliera radicans* (Remuremu), and *Samolus repens* (Primrose). Other common species included *Disphyma australe* (NZ ice plant) and *Cotula coronopifolia* (Bachelor's button). Estuarine shrub comprised 1.1ha or 8.4% of the salt marsh. The dominant species was *Plagianthus divaricatus* (Salt marsh ribbonwood). Rushland comprised only a small area (0.5ha) and was dominated by *Apodasmia similis* (Jointed wirerush) and *Ficinia (Isolepis) nodosa* (Knobby clubrush). Other common salt marsh species included *Puccinella pungens* (salt grass) and *Poa cita* (silver tussock). Introduced weeds and the grass *Festuca arundinacea* (tall fescue) were present in some areas, particularly on the margin near the road or adjacent grassland. Several patches of salt marsh are within fenced areas that are grazed by sheep.

In Papanui Inlet (Makahoe), salt marsh extent is limited by the steep topography of the adjacent land. Historical losses are evident with reclamation for roading on the margin, and drainage and conversion to pasture also common in the low-lying areas. The historic margin, estimated from LiDAR data (Fig. 9; Appendix 8), indicates there has been ~6ha or 30% loss of salt marsh when compared to the predicted historic extent (i.e., 70% of the natural cover remains), a condition rating of 'good' (Table 3). There is localised erosion of some herbfields at the seaward edge of the salt marsh (see photo).

Sarcocornia quinqueflora (Glasswort) eroding

Schoenoplectus pungens (Three square)

Rushland and sedgeland

Sheep grazing an area that contains herbfield species

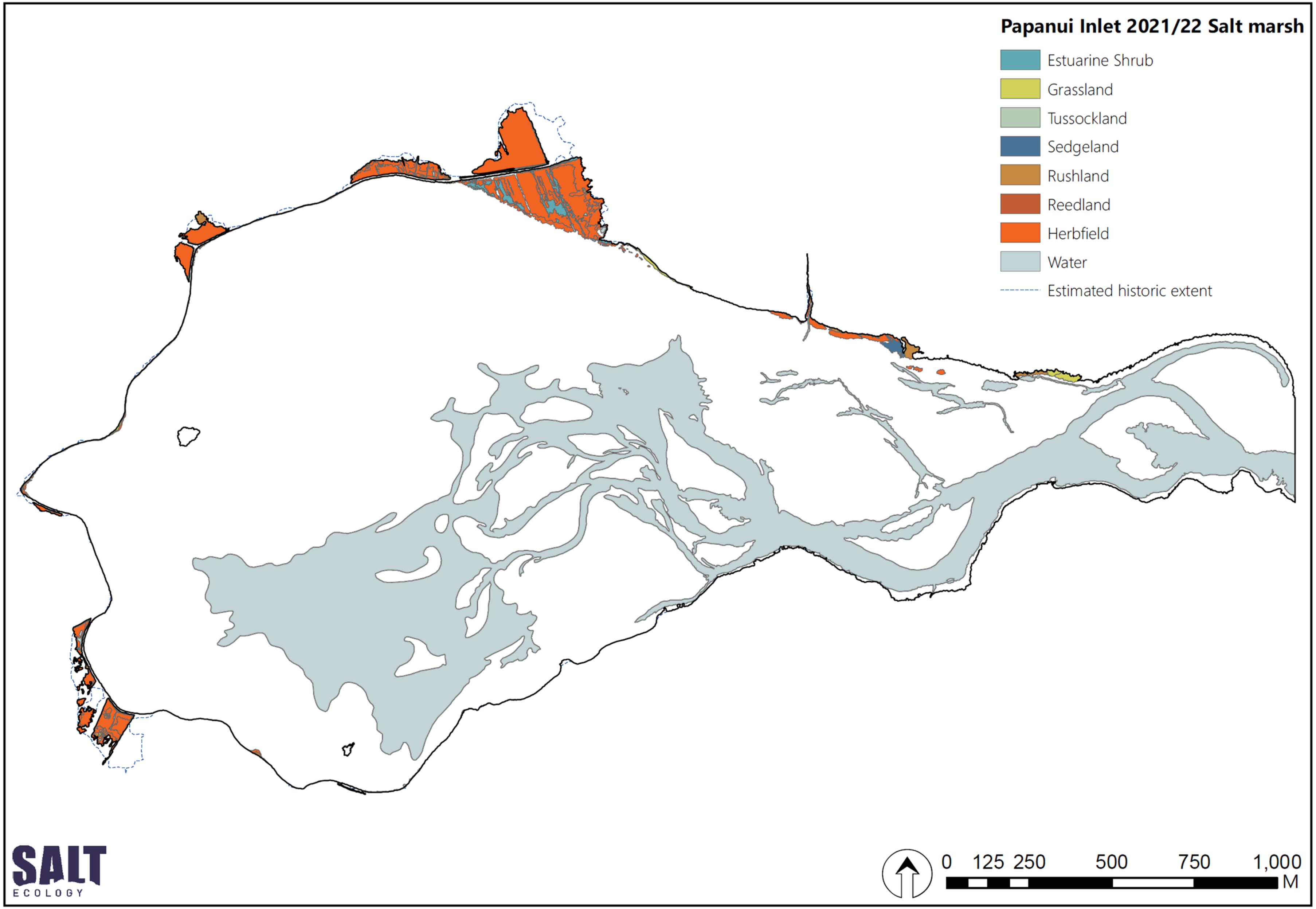


Fig. 9. Distribution and vegetation subclasses of salt marsh habitat, Papanui Inlet (Makahoe), November 2021.

3.6 TERRESTRIAL MARGIN

Table 10 and Fig. 10 summarise the land cover of the 200m terrestrial margin which has been extensively modified and is dominated by low producing grassland (66.0%) and exotic forest (17.1%). There are a few remnant patches of native vegetation scattered around the estuary (<7% of the margin). Gorse and/or broom comprised 0.9%.

Built-up areas comprised 5.4% and were mainly toward the south. While transport infrastructure comprises only a small portion (1.9%), its relative impact on the estuary is significant with most of the fringing margin modified for roading and protected from the sea by artificial rock wall which prevents any landward migration of the estuary in response to sea level rise (see photos on following page).

Of the terrestrial margin, 26.4% was densely vegetated (Table 10), including large areas of exotic forest (17.1%) and smaller areas of manuka and/or kanuka (2.3%) and broadleaved indigenous hardwoods (3.9%). Herbaceous saline vegetation (2.0%) represents the dune area near the entrance which was dominated by exotic species, namely *Lupinus arboreus* (tree lupin) and *Ammophilia arenaria* (marram grass).

As discussed in Section 1.1 the estuary drains a 1,248ha catchment comprising ~58.8% intensive pasture, ~17.8% low producing pasture, 8.9% mixed exotic shrubland and 7.0% exotic forest. Only, 23.1% of the catchment remains densely vegetated and mostly comprises exotic vegetation (Table 1; Fig. 2).

Table 10. Summary of 200m terrestrial margin land cover, Papanui Inlet (Makahoe), November 2021.

LCDB Class	Ha	%
1 Built-up Area (settlement)	12.4	5.4
5 Transport Infrastructure	4.4	1.9
16 Gravel and Rock	0.5	0.2
20 Lake or Pond	0.2	0.1
41 Low Producing Grassland	151.0	66.0
46 Herbaceous Saline Vegetation	4.6	2.0
47 Flaxland	0.1	0.0
51 Gorse and/or Broom	2.0	0.9
52 Manuka and/or Kanuka	5.3	2.3
54 Broadleaved Indigenous Hardwoods	9.0	3.9
56 Mixed Exotic Shrubland	0.3	0.1
71 Exotic Forest	39.2	17.1
Grand Total	228.8	100
Total dense vegetated margin (LCDB classes 45-71)	60.4	26.4

Low producing grassland and exotic forest on the northern margin of Papanui Inlet

Road and artificial rock wall on the estuary margin

Naturally steep topography on the estuary margin

Herbfield in paddock and exotic forest in background

Manuka and/or Kanuka and exotic eucalypt forest

Tree lupin and exotic forest on estuary margin

Gorse and grassland on the estuary margin

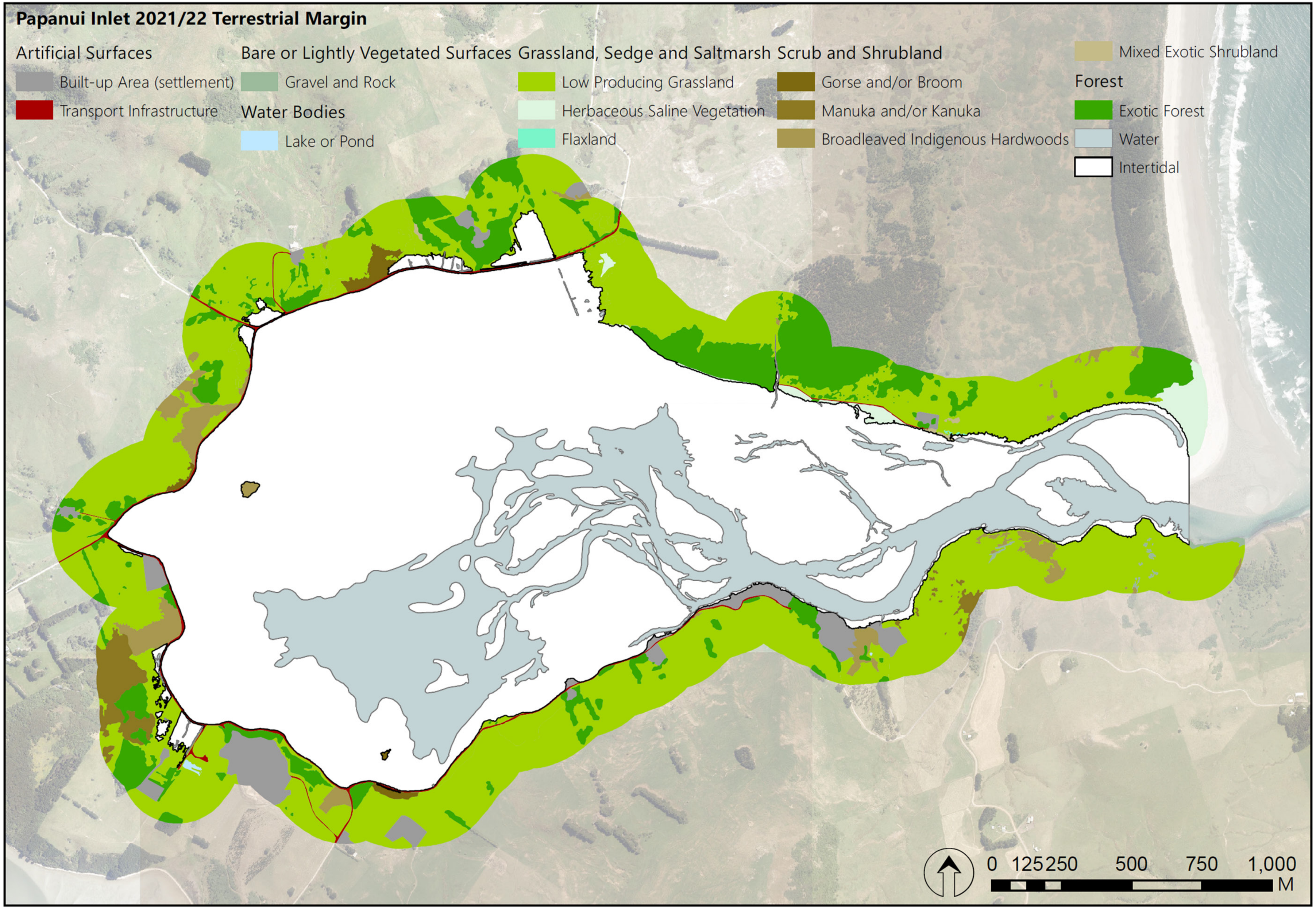


Fig. 10. Map of 200m terrestrial margin land cover, Papanui Inlet (Makahoe), November 2021.

3.7 ESTUARY TROPHIC INDEX (ETI)

Table 11 summarises the indicators used to calculate an overall ETI score for Papanui Inlet (Makahoe). Raw data are presented in Appendix 9. The primary indicator of eutrophication response in SIDE type estuaries, like Papanui/Makahoe, is macroalgae (OMBT EQR), with supporting sediment indicators of macrofauna (AMBI), total nitrogen (TN), total organic carbon (TOC) and oxygenation (aRPD). The overall ETI score of 0.227 was rated 'very good' in terms of eutrophication which is reflected in other metrics such as the high EQR, good sediment oxygenation and the absence of high enrichment conditions.

Table 11. Primary and supporting indicators used to calculate the ETI for Papanui Inlet (Makahoe).

Indicator	Raw Value	Equivalent ETI Score
Primary indicator		
Macroalgae (EQR)	0.945	0.125
Supporting Indicator		
AMBI	1.56	0.313
TN (mg/kg)	<500	0.375
TOC (%)	0.12	0.125
aRPD (mm)	20	0.500
Final ETI Score		0.227 "Very Good"

Seagrass on firm sand

Expansive intertidal flats with segarass beds on firms sands in Papanui Inlet (Makahoe)

4. KEY FINDINGS

Key broad scale indicator results and ratings are summarised in Tables 12 and 13, with additional supporting data used to assess estuary condition presented in Table 14.

Overall, Papanui Inlet (Makahoe) was in 'very good' condition with well flushed tidal flats dominated by clean firm sands or mobile sands supporting a variety of high value features including seagrass, cockle beds and salt marsh. Of the most common stressors evident in New Zealand estuaries, mud-dominated (>50% mud) sediments comprised just 0.02% of the intertidal area and were confined to areas near stream and drain inputs where localised deterioration in water quality was also evident. There was no evidence of nuisance macroalgae or excessive sedimentation indicating current nutrient and fine sediment inputs are below thresholds of concern. The high overall ecological quality of the estuary likely reflects low freshwater inputs (~1% of the estuary volume; Plew et al. 2018) and well-flushed intertidal flats (77% intertidal; Table 12).

The extensive sandflats in the well-flushed central basin supported large cockle beds. Cockles (*Austrovenus stutchburyi)* are an important food source for birds and smaller infauna, they also oxygenate sediments, and filter phytoplankton and sediment from the water column. Cockles are also an important source of kaimoana (seafood), although as filter feeders they are susceptible to contaminants in the water, with poor water quality causing the closure of the commercial cockle fishery between 2006 and 2017, likely due to run-off from the heavily developed catchment (77% pastoral farming).

Table 13. Summary of key broad scale features as a percentage of total estuary, intertidal or margin area, Papanui Inlet (Makahoe), November 2021.

a. Area summary	ha	% Estuary
Intertidal area	290.2	76.8
Subtidal area	87.8	23.2
Total estuary area	**378.0**	**100**

b. Key fine sediment features	ha	% Intertidal
Mud-enriched (25 to <50%)	7.5	2.6
Mud-dominated (≥50%)	0.1	0.02

c. Key vegetation features	ha	% Intertidal
Salt marsh	12.9	4.4
Seagrass (≥50% cover)	83.1	28.6
Macroalgal beds (≥50% cover)	1.0	0.3

d. Terrestrial margin (200m)	ha	% Margin
200m densely vegetated margin	60.4	26.4

Localised freshwater input from an under-road culvert

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

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) score	No unit	0.227	Very Good
Mud-dominated substrate	% of intertidal area >50% mud	0.02	Very Good
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.945	Very Good
Seagrass	% decrease from baseline	nd	November 2021 - baseline
Salt marsh extent (current)	% of intertidal area	4.4	Poor
Historical salt marsh extent*	% of historical remaining	70%	Good
200m terrestrial margin	% densely vegetated	25.4	Fair
High Enrichment Conditions	ha	0	Very Good
High Enrichment Conditions	% of estuary	0	Very Good
Sedimentation rate*	CSR:NSR ratio**	1.7	Good
Sedimentation rate*	mm/yr	0.06	Very Good

Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. *Estimated. **CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

The dominant vegetation type in the estuary was extensive beds of seagrass (*Zostera muelleri*) growing in in firm sands and a small area of soft muddy-sand on the northwest margin. Seagrass is a key feature in estuaries because it is a food source and habitat for fish, birds and macroinvertebrates. Seagrass can also influence water quality by trapping fine sediments, stabilising substrate, and assimilating nutrients. Seagrass is common in other Otago estuaries with large well-flushed intertidal areas and low freshwater inputs, for example, Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea.

The review of historic imagery highlights that seagrass has been an important habitat in Papanui Inlet since at least the 1950s, but has been variable over time and appears to be migrating from the centre of the estuary toward the north and west. This change is supported by anecdotal reports from landowners in the catchment, and consent monitoring which has shown seagrass cover and extent is variable at both the annual and seasonal temporal scales, with an overall reduction in seagrass extent observed between 2013 and 2021 (e3 scientific, 2022).

While seagrass remained extensive, stressors were present in November 2021 including grazing from waterfowl (e.g. black swans and Canadian geese) and vehicle tracks traversing the northern seagrass beds. In 2017, a large decrease in seagrass cover was attributed to drift algae deposited in the estuary over the summer period (Ryder Consulting 2017), however, there were no signs of excess drift algae in the estuary during the November 2021 sampling. Other common catchment driven stressors known to impact seagrass (i.e. fine sediment deposition, poor water clarity, excess nutrient inputs causing nuisance macroalgae blooms) were not evident in November 2021.

Shellbank and mobile sands

Seagrass on firm sands

Large cockle in Papanui Inlet

Salt marsh is an important feature of estuaries because it traps sediments and assimilates nutrients in addition to providing habitat for birds and insects. Salt marsh (12.9ha, 4.4% of the intertidal area) was a relatively small portion of the estuary, but is naturally limited in extent due to the steep topography of the margin. An estimated ~70% of the historic salt marsh extent remains in the estuary (a condition rating of 'good'), with losses primarily due to historical drainage and reclamation.

The largest remaining area of salt marsh on the northern margin of Papanui Inlet is classified as a regionally significant wetland in the Regional Plan: Water for Otago. While this area is largely protected, smaller remnant patches of salt marsh are under ongoing pressure due to drainage and grazing. Salt marsh is also under pressure from the extensively modified margin with shoreline hardening greatly limiting the scope for managed retreat in response to sea level rise.

Channel through salt marsh adjacent to the road, Papanui Inlet

Salt marsh and freshwater input in the southwest corner

Rock wall armoured road and adjacent grazed salt marsh

The ETI score was 0.227, a condition rating of 'very good' indicating few eutrophication impacts in the estuary. This is supported by the absence of High Enrichment Conditions (HEC) and low macroalgae cover. These results are consistent with modelled nitrogen loads of just 2.1mgN/m^2/d, well below the ~100mgN/m^2/d threshold at which nuisance macroalgae problems are predicted occur (Robertson et al. 2017; Table 14).

Table 14. Supporting data used to assess estuary ecological condition in Papanui Inlet (Makahoe).

Supporting Condition Measure	Papanui Inlet
Mean freshwater flow (m^3/s)[1]	0.9
Catchment Area (Ha)[1]	1248
Catchment nitrogen load (TN/yr)[2]	3.1
Catchment phosphorus load (TP/yr)[2]	0.2
Catchment sediment load (KT/yr)[1]	0.3
Estimated N areal load in estuary (mg/m^2/d)[2]	2.1
Estimated P areal load in estuary (mg/m^2/d)[2]	0.1
CSR:NSR ratio[1]	1.7
Trap efficiency (sediment retained in estuary)[1]	98%
Estimated rate of sed. trapped in estuary (mm/yr)[1]	0.06

[1]Hicks et al. 2019.

[2]CLUES version 10.3, Run date: March 2021

Furthermore, NIWA's national estuary sediment load estimator (Hicks et al., 2019) predicts sediment input and retention, and was used to calculate a net deposition rate for the estuary. The estuary is predicted to be highly efficient at trapping sediment (98% retention). Spreading all of the retained sediment evenly throughout the estuary would result in average estuary infilling of ~0.06mm/yr (Table 14), a condition rating of 'very good' (Table 13).

Based on the relative difference in estimated yields from an undisturbed catchment, the current sedimentation rate (CSR) is estimated to be 1.7 times the natural sedimentation rate (NSR; Table 14). The condition rating for the CSR:NSR ratio is rated 'good' (Table 12). These sedimentation rate results, the very small extent of mud-dominated sediments (0.02%), and the widespread dominance (90.8%) of sandy sediments with <10% mud content in the estuary, indicate fine sediment issues are not currently a concern.

The most significant current issues identified were extensive waterfowl grazing of seagrass beds, localised water quality issues at point source discharges (e.g. drains, culverts), grazing of salt marsh, and shoreline hardening. The latter has disrupted the natural connectivity between the land and estuary and greatly limits the capacity of the estuary to adapt to predicted sea level rise.

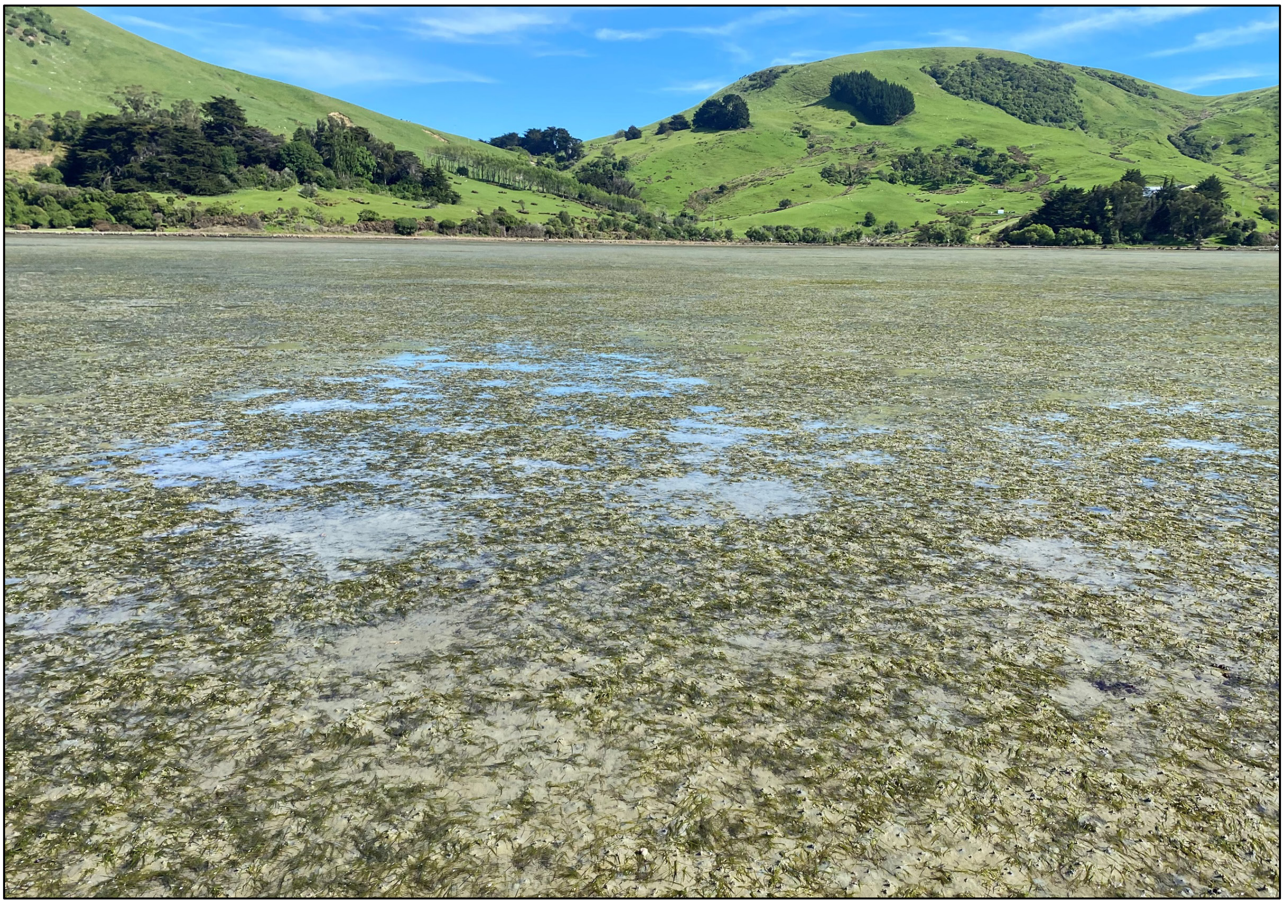
5. RECOMMENDATIONS

Despite the grazing pressure on seagrass beds, Papanui Inlet (Makahoe) was in 'very good' condition, with expansive beds of high value seagrass, very little mud-dominated sediment and a diverse range of other habitat types including salt marsh, sandflats and cockle beds. The high ecological quality of the estuary can be attributed to small freshwater inflows, low sediment and nutrient inputs and well flushed tidal flats.

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.
- Protect important habitats such as seagrass, cockle beds and salt marsh (e.g. vehicle exclusion, reconnect areas of remnant salt marsh to the estuary, reduce grazing pressures).
- Include Papanui Inlet (Makahoe) in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will maintain the high ecological quality of the estuary.

Broad scale mapping seagrass beds on incoming tide



Seagrass growing on firm sands, Papanui Inlet (Makahoe)

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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
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Tubeworm reef	TUBE
Artificial Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aS BF
		Cobble field	aS CF
		Gravel field	aS GF
		Sand field	aS SF

Artificial Surfaces
1 Built-up Area (settlement)
2 Urban ParklandOpen Space
5 Transport Infrastructure
6 Surface Mines and Dumps

Bare or Lightly Vegetated Surfaces
10 Sand and Gravel
12 Landslide
16 Gravel and Rock

Water Bodies
20 Lake or Pond
21 River

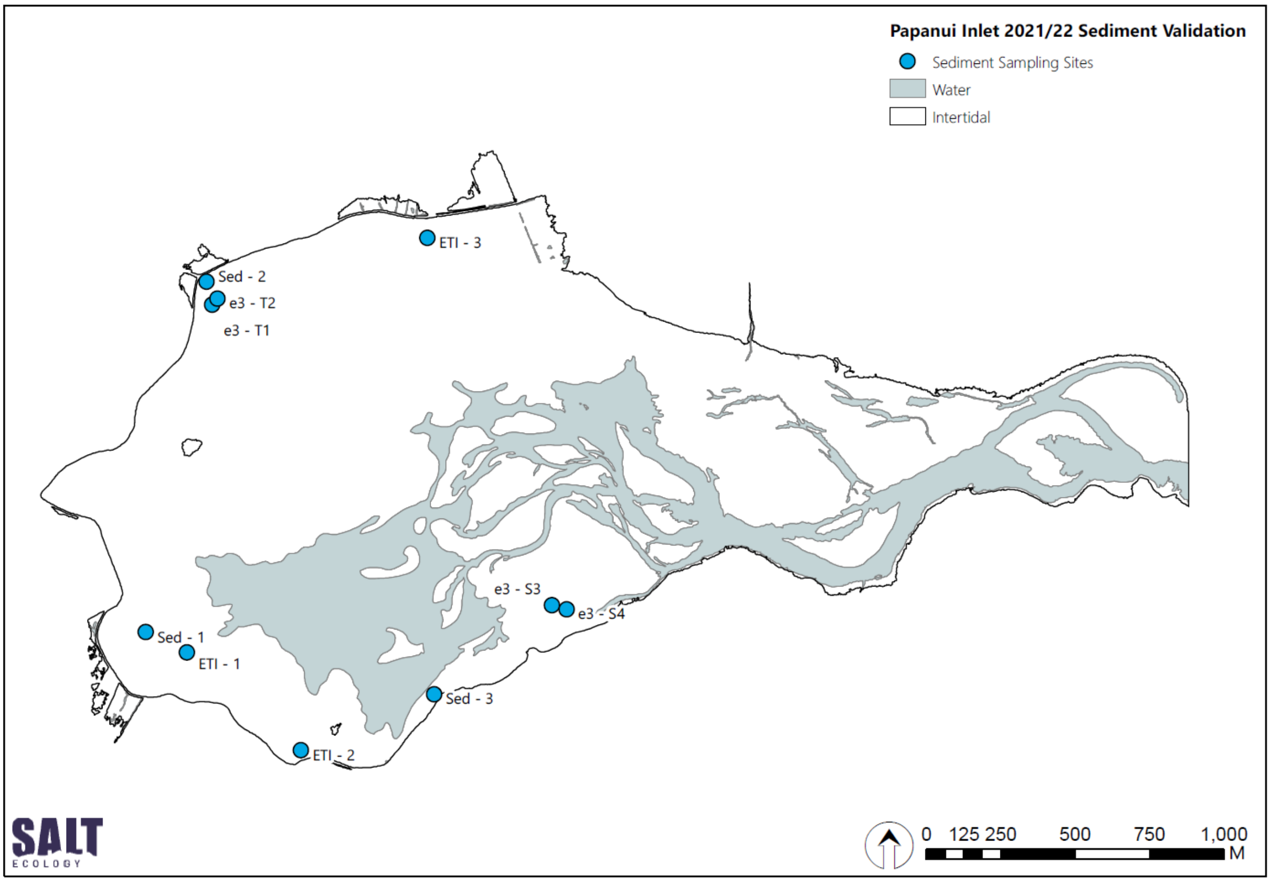
Cropland
30 Short-rotation Cropland
33 Orchard Vineyard & Other Perennial Crops

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

Scrub and Shrubland
47 Flaxland
50 Fernland
51 Gorse and/or Broom
52 Manuka and/or Kanuka
54 Broadleaved Indigenous Hardwoods
56 Mixed Exotic Shrubland
58 Matagouri or Grey Scrub

Forest
64 Forest - Harvested
68 Deciduous Hardwoods
69 Indigenous Forest
71 Exotic Forest

APPENDIX 2. SEDIMENT SAMPLING STATIONS PAPANUI INLET (MAKAHOE), NOVEMBER 2021



Sediment validation samples matched 6 of 6 % mud content bands assessed in the field. Additional data for 4 composite sediment samples collected on 26 Nov 2021 were obtained from an e3 Scientific report (e3 Scientific, 2022) and are also included in the table below. The % mud content bands were accurate for fs0-10 and ±2% mud content for the sms10_25 bands assessed in the field.

Source	NZTM_E	NZTM_N	Field code	Subjective % mud	% mud	% sand	% gravel
ETI - 1	1420377	4919891	fs0_10	<10%	5.8	94.2	< 0.1
ETI - 2	1420760	4919562	fs0_10	<10%	2.4	97.4	0.2
ETI - 3	1421185	4921285	fs0_10	<10%	2.8	97.2	< 0.1
Sediment - 1	1420238	4919959	fs0_10	<10%	2.8	97.1	< 0.1
Sediment - 2	1420443	4921137	sms10_25	10 to 25%	14.8	85.2	< 0.1
Sediment - 3	1421208	4919750	fs0_10	<10%	7.2	90.1	2.7
e3 Scientific data collected 26 November 2021 (e3 Scientific, 2022)							
Transect 1 (T1)	1420462	4921060	sms10_25	10 to 25%	26	nd.	nd.
Transect 2 (T2)	1420480	4921080	sms10_25	10 to 25%	27	nd.	nd.
Site 3 (S3)	1421604	4920050	fs0_10	<10%	4.2	nd.	nd.
Site 4 (S4)	1421653	4920036	fs0_10	<10%	5.2	nd.	nd.

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	2783394
Contact:	Keryn Roberts C/- Salt Ecology Limited 21 Mount Vernon Place Washington Valley Nelson 7010	**Date Received:**	30-Nov-2021
		Date Reported:	25-Jan-2022
		Quote No:	114525
		Order No:	
		Client Reference:	Broadscale- Papanui Inlet
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Papa-Otag-1 26-Nov-2021 2:30 pm	Papa-Otag-2 26-Nov-2021 5:00 pm	Papa-Otag-3 29-Nov-2021 9:00 am	Papa-Otag-ETI-1 29-Nov-2021 11:00 am	Papa-Otag-ETI-2 29-Nov-2021 11:30 am
Lab Number:		2783394.1	2783394.2	2783394.3	2783394.4	2783394.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	80	75	75	79	78
Total Recoverable Phosphorus	mg/kg dry wt	-	-	-	198	280
Total Sulphur*‡	g/100g dry wt	-	-	-	0.040	0.040
Total Nitrogen*	g/100g dry wt	-	-	-	< 0.05	< 0.05
Total Organic Carbon*	g/100g dry wt	-	-	-	0.12	0.10
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	< 0.1	2.7	< 0.1	0.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	97.1	85.2	90.1	94.2	97.4
Fraction < 63 µm*	g/100g dry wt	2.8	14.8	7.2	5.8	2.4

Sample Name:		Papa-Otag-ETI-3 29-Nov-2021 12:00 pm				
Lab Number:		2783394.6				
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	76	-	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	133	-	-	-	-
Total Sulphur*‡	g/100g dry wt	0.030	-	-	-	-
Total Nitrogen*	g/100g dry wt	< 0.05	-	-	-	-
Total Organic Carbon*	g/100g dry wt	0.13	-	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	-	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	97.2	-	-	-	-
Fraction < 63 µm*	g/100g dry wt	2.8	-	-	-	-

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			

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	4-6
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%.	-	4-6
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	1-6
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	4-6
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	4-6
Total Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g dry wt	4-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	4-6
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	4-6
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	1-6
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	1-6
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

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

Testing was completed between 07-Dec-2021 and 25-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.

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

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)[2]	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^{-2}) of AIH[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).

Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

CLASS THRESHOLDS FOR BIOMASS

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

THRESHOLDS FOR ENTRAINED ALGAE

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

EQR CALCULATION

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Rating** score (EQR).

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

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

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

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

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

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

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

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

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

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

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

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

CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

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

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

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

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

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APPENDIX 4. INFORMATION SUPPORTING RATINGS IN THE REPORT

SEDIMENT MUD CONTENT

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

APPARENT REDOX POTENTIAL DISCONTINUITY (ARPD)

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

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

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

OPPORTUNISTIC MACROALGAE

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

SEAGRASS

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

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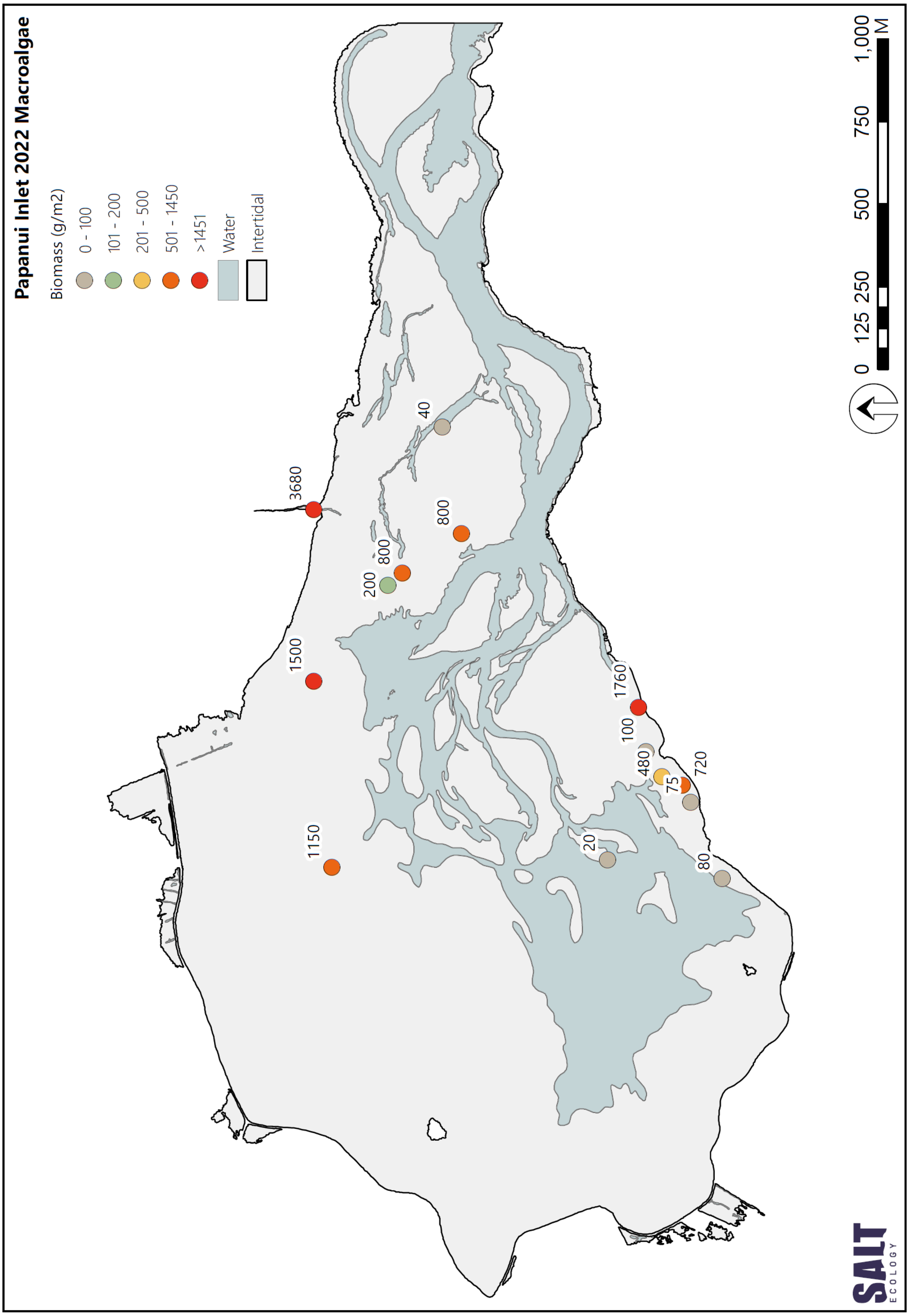
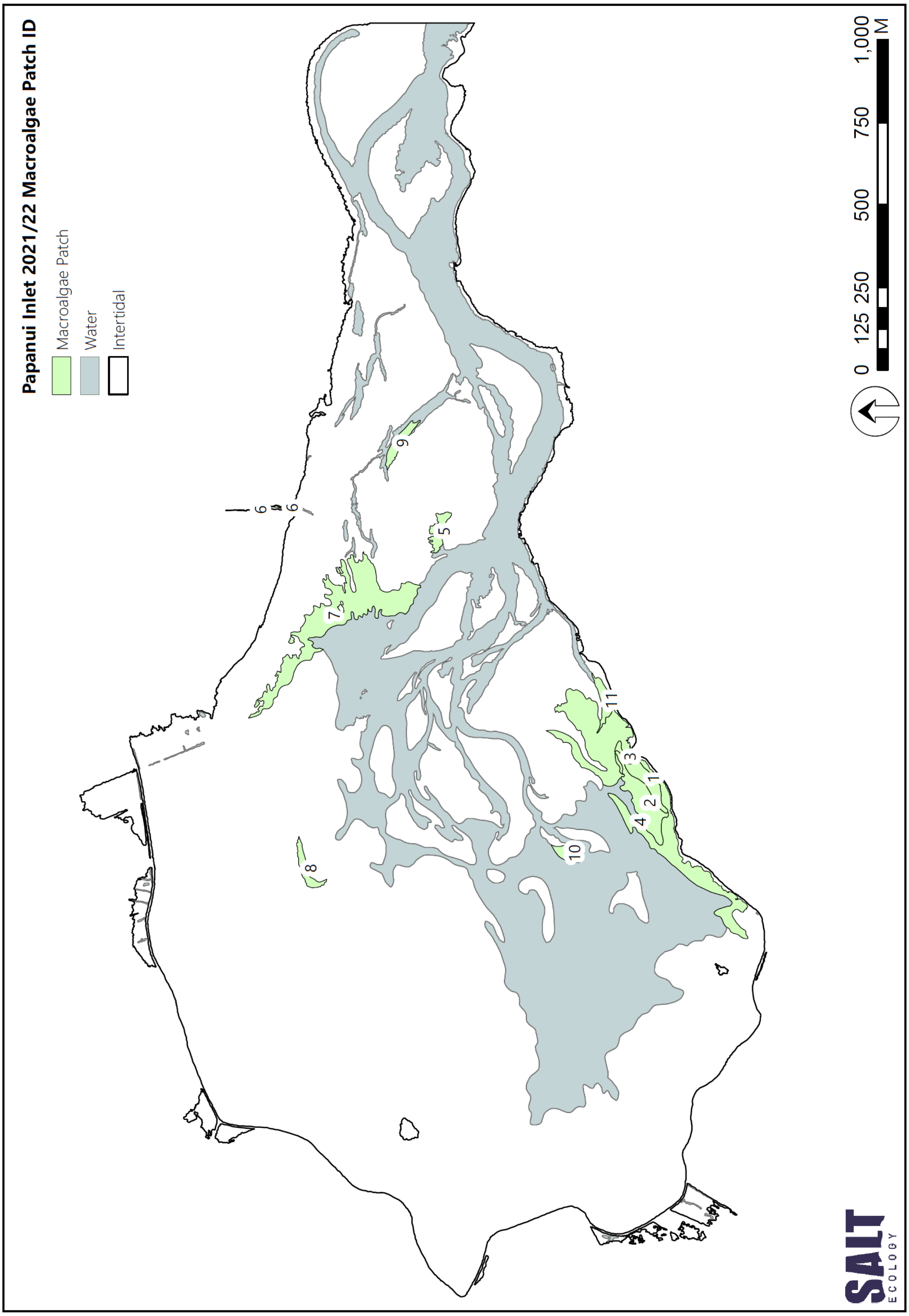
APPENDIX 5: MACROALGAL BIOMASS STATIONS & OMBT, PAPANUI INLET (MAKAHOE)



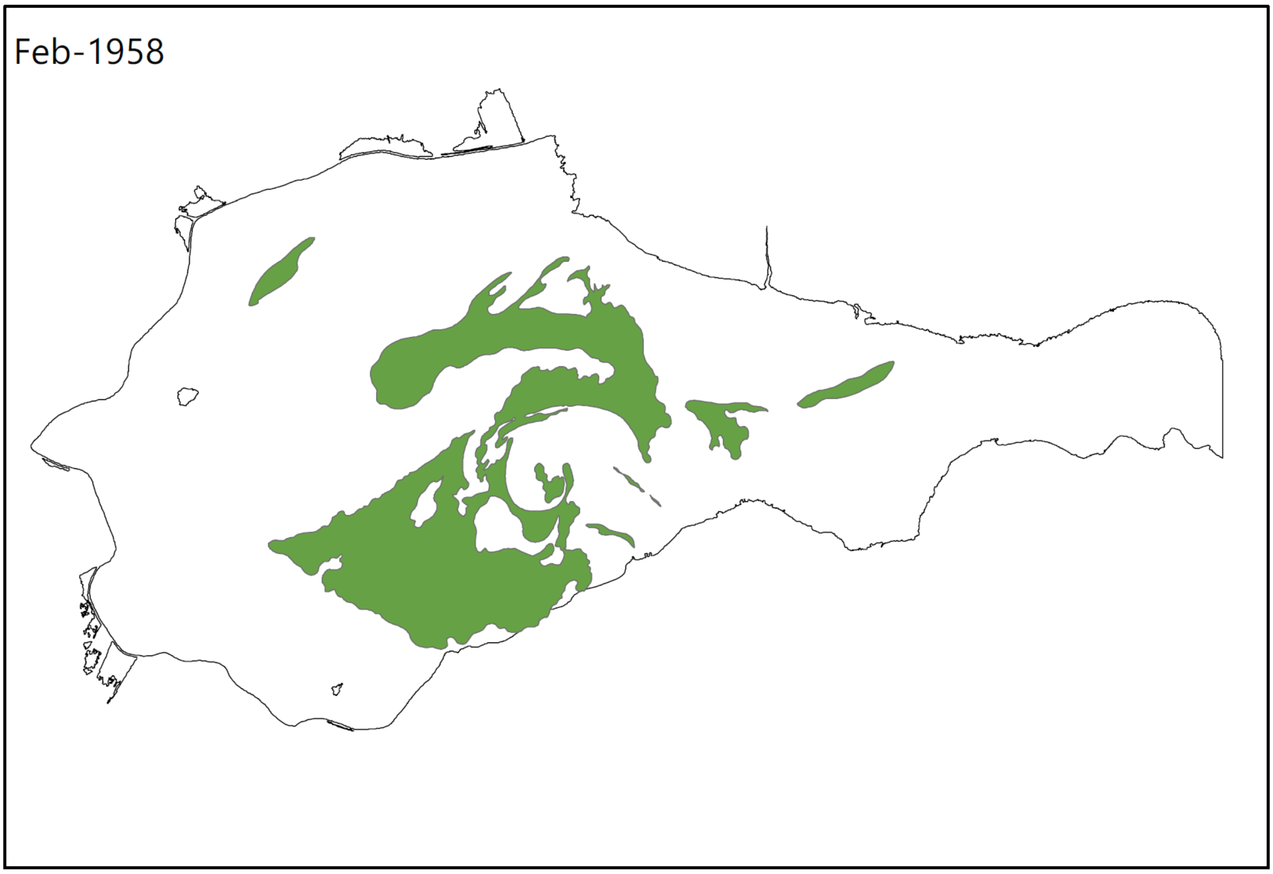
Macroalgal patch ID used in the OMBT-EQR

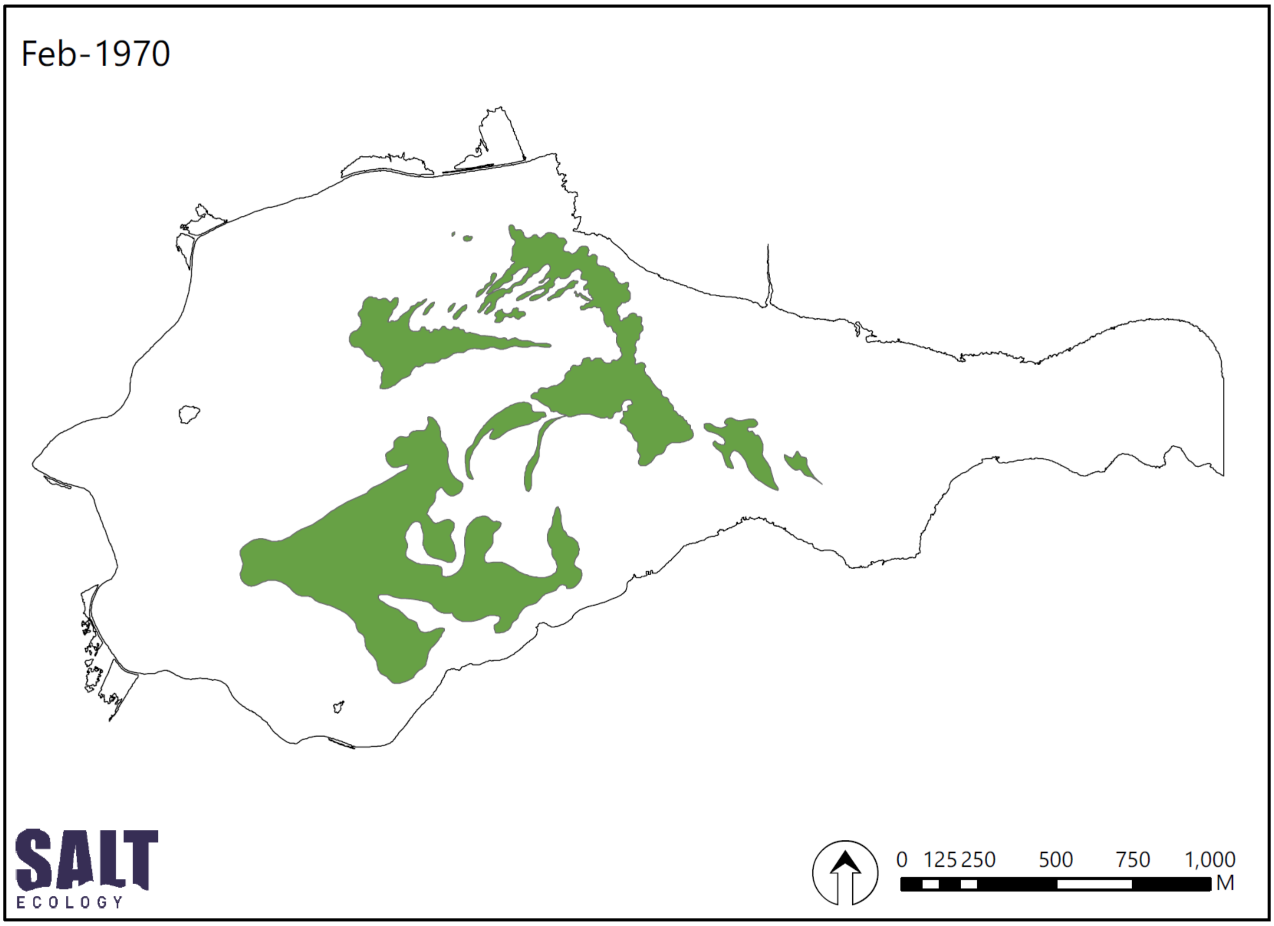


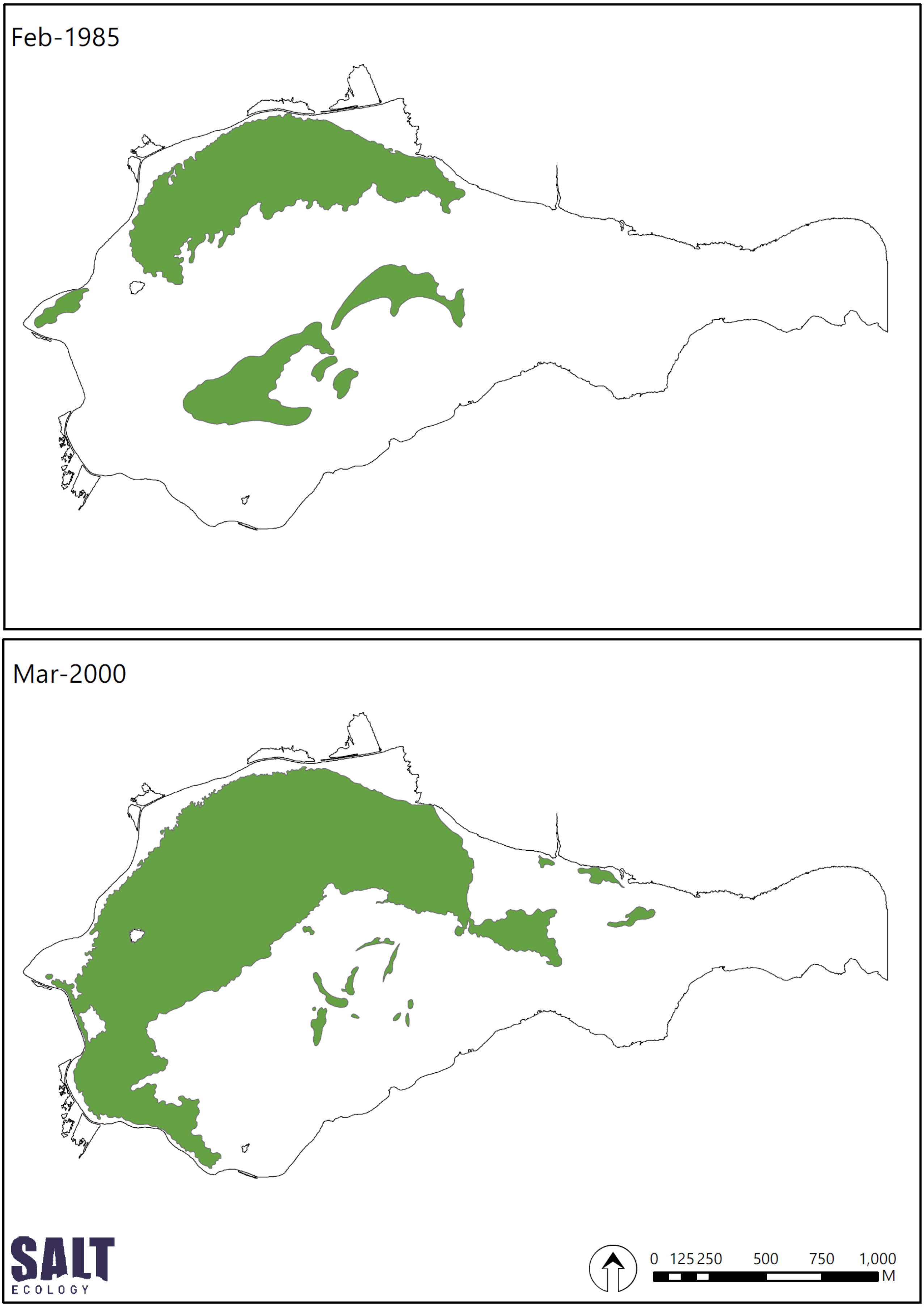
Macroalgal patch information used in the calculation of the OMBT-EQR

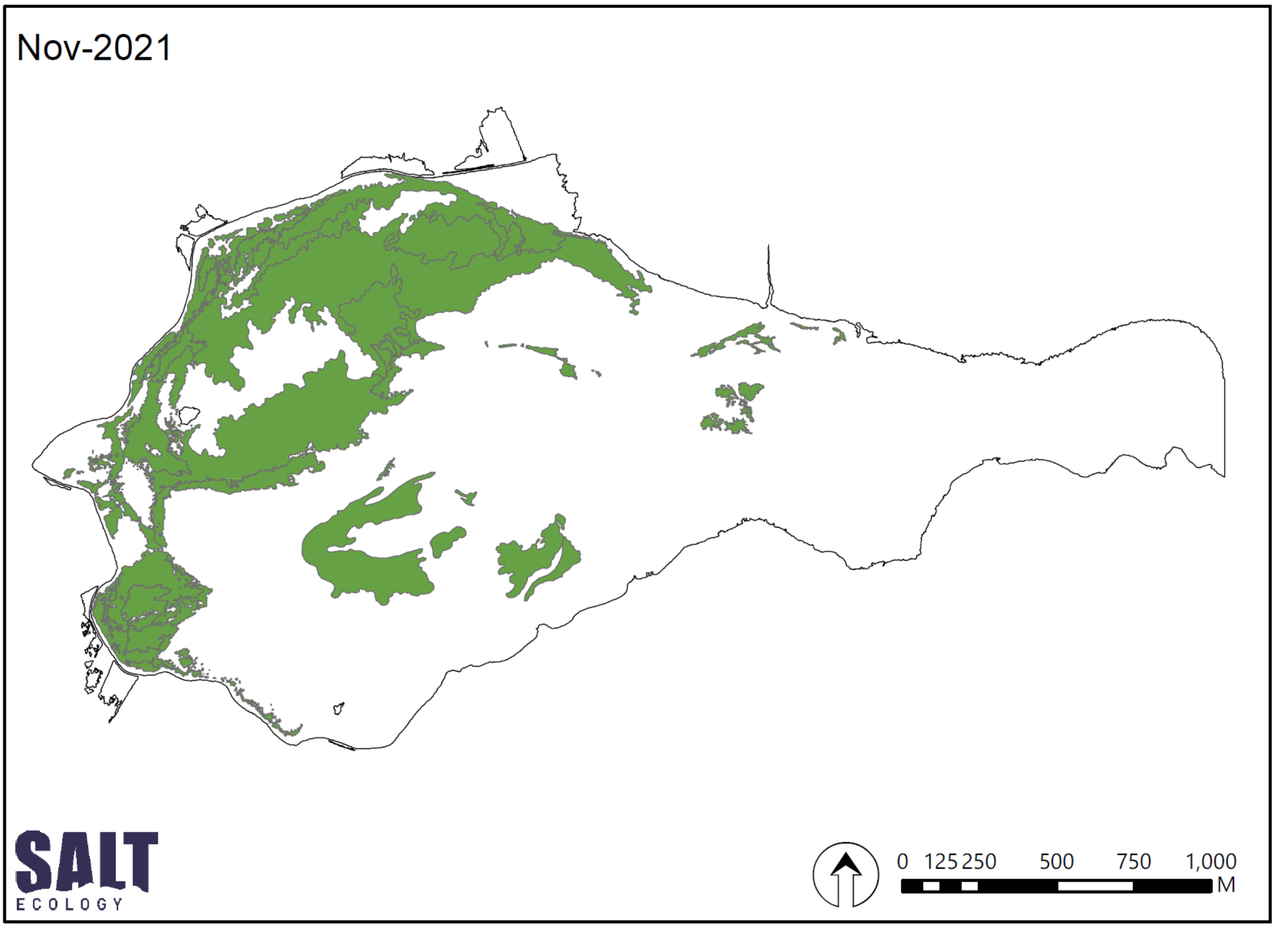
PatchID	Dominant Species	Sub-dominant spcies	% Cover	Percent Cover Category	Biomass (g/m^2)	CrsBiomass	Entrained	Substrate	Area (ha)
1	*Ulva* spp.	Unspecified Macroalgae	62	High-Moderate (50 to <70%)	600	High (501 - 1450)	0	firm sand	0.6
2	*Agarophyton* spp.	*Ulva* spp.	15	Sparse (10 to <30%)	100	Very low (1 - 100)	0	firm sand	0.2
3	*Agarophyton* spp.	*Ulva* spp.	16	Sparse (10 to <30%)	100	Very low (1 - 100)	0	firm sand	1.3
4	*Ulva* spp.	Unspecified Macroalgae	9	Very sparse (1 to <10%)	78	Very low (1 - 100)	0	firm sand	6.1
5	*Ulva* spp.		40	Low-Moderate (30 to <50%)	800	High (501 - 1450)	0	firm sand	0.4
6	*Ulva* spp.		90	Complete (>90%)	3680	Very high (>1450)	0	firm sand	0.0
7	*Ulva* spp.		43	Low-Moderate (30 to <50%)	833	High (501 - 1450)	0	firm sand	4.8
8	*Ulva* spp.		30	Low-Moderate (30 to <50%)	1150	High (501 - 1450)	0	firm sand	0.3
9	*Ulva* spp.		5	Very sparse (1 to <10%)	40	Very low (1 - 100)	0	firm sand	0.4
10	Unspecified Macroalgae	*Ulva* spp.	6	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	mobile sand	0.3
11	*Ulva* spp.	Unspecified Macroalgae	80	Dense (70 to <90%)	1760	Very high (>1450)	0	firm sand/shell	0.4

APPENDIX 6. TIME SERIES OF SEAGRASS CHANGE IN PAPANUI INLET





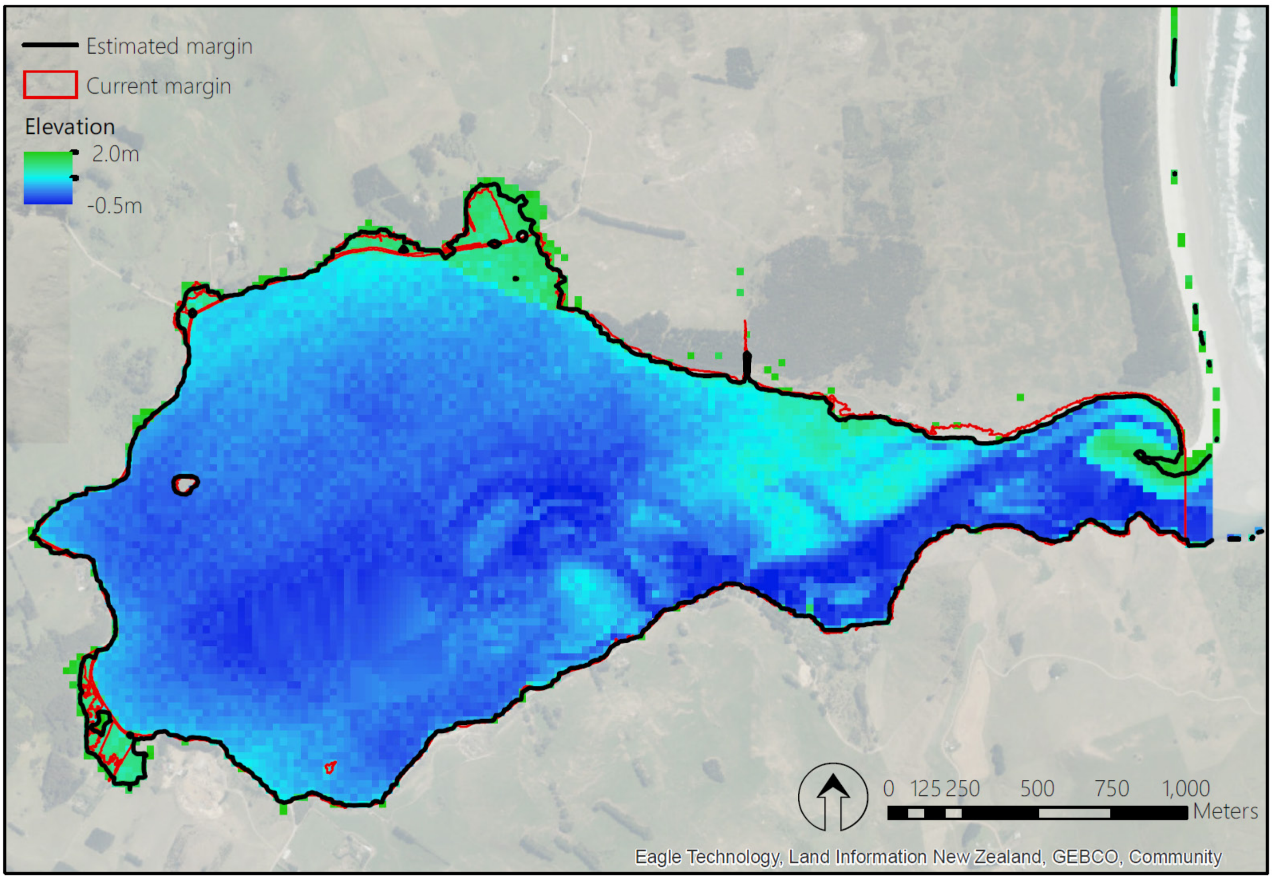

Feb-1985
Mar-2000
0 125 250 500 750 1,000
M


Nov-2021
0
125
250
500
750
1,000
M

APPENDIX 7: DOMINANT SALT MARSH SPECIES IN PAPANUI INLET (MAKAHOE)

SubClass	Dominant species	Subdominant Species 1	Subdominant Species 2	Ha	%
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Apodasmia similis (Jointed wirerush)		0.02	0.15
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Carpobrotus edulis (Ice Plant)		0.04	0.31
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Festuca arundinacea (Tall fescue)		0.14	1.07
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Ficinia (Isolepis) nodosa (Knobby clubrush)		0.01	0.06
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Ficinia (Isolepis) nodosa (Knobby clubrush)	Schoenoplectus pungens (Three square)	0.02	0.13
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)			0.83	6.42
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Sarcocornia quinqueflora (Glasswort)		0.01	0.09
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Sarcocornia quinqueflora (Glasswort)	Poa cita (Silver tussock)	0.03	0.20
Tussockland	Puccinella stricta (Salt grass)			0.00	0.02
Sedgeland	Schoenoplectus pungens (Three square)	Ficinia (Isolepis) nodosa (Knobby clubrush)	Selliera radicans (Remuremu)	0.00	0.02
Sedgeland	Schoenoplectus pungens (Three square)			0.21	1.66
Sedgeland	Schoenoplectus pungens (Three square)	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	0.02	0.13
Grassland	Festuca arundinacea (Tall fescue)	Ficinia (Isolepis) nodosa (Knobby clubrush)		0.06	0.45
Grassland	Festuca arundinacea (Tall fescue)	Introduced weeds		0.01	0.11
Grassland	Festuca arundinacea (Tall fescue)	Lupinus arboreus (Tree lupin)		0.10	0.78
Grassland	Festuca arundinacea (Tall fescue)			0.08	0.65
Grassland	Festuca arundinacea (Tall fescue)	Plagianthus divaricatus (Salt marsh ribbonwood)		0.20	1.54
Grassland	Festuca arundinacea (Tall fescue)	Pteridium esculentum (Bracken fern)	Ficinia (Isolepis) nodosa (Knobby clubrush)	0.13	1.05
Grassland	Festuca arundinacea (Tall fescue)	Ulex europaeus (Gorse)		0.03	0.26
Rushland	Apodasmia similis (Jointed wirerush)			0.02	0.17
Rushland	Apodasmia similis (Jointed wirerush)	Plagianthus divaricatus (Salt marsh ribbonwood)	Sarcocornia quinqueflora (Glasswort)	0.01	0.11
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Festuca arundinacea (Tall fescue)		0.05	0.35
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Festuca arundinacea (Tall fescue)	Plagianthus divaricatus (Salt marsh ribbonwood)	0.02	0.16
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Lupinus arboreus (Tree lupin)	Festuca arundinacea (Tall fescue)	0.16	1.24
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)			0.22	1.72
Rushland	Ficinia (Isolepis) nodosa (Knobby clubrush)	Plagianthus divaricatus (Salt marsh ribbonwood)		0.02	0.14
Herbfield	Disphyma australe (NZ Ice Plant, Horokaka)			0.01	0.11
Herbfield	Samolus repens (Primrose)	Apium prostratum (Native celery)	Isolepis cernua (Slender clubrush)	0.01	0.05
Herbfield	Samolus repens (Primrose)			0.01	0.11
Herbfield	Samolus repens (Primrose)	Sarcocornia quinqueflora (Glasswort)	Suaeda novaezelandiae (Sea blite)	0.22	1.70
Herbfield	Samolus repens (Primrose)	Selliera radicans (Remuremu)		0.53	4.13
Herbfield	Sarcocornia quinqueflora (Glasswort)	Cotula coronopifolia (Bachelor's button)	Selliera radicans (Remuremu)	0.01	0.09
Herbfield	Sarcocornia quinqueflora (Glasswort)	Isolepis cernua (Slender clubrush)		0.01	0.07
Herbfield	Sarcocornia quinqueflora (Glasswort)			0.14	1.08
Herbfield	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)		0.02	0.17
Herbfield	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	Selliera radicans (Remuremu)	0.04	0.30
Herbfield	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	Suaeda novaezelandiae (Sea blite)	0.11	0.87
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	Isolepis cernua (Slender clubrush)	0.58	4.53
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)		2.11	16.43
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	Samolus repens (Primrose)	3.79	29.50
Herbfield	Sarcocornia quinqueflora (Glasswort)	Selliera radicans (Remuremu)	Suaeda novaezelandiae (Sea blite)	0.02	0.18
Herbfield	Sarcocornia quinqueflora (Glasswort)	Suaeda novaezelandiae (Sea blite)		0.29	2.22
Herbfield	Selliera radicans (Remuremu)			0.85	6.61
Herbfield	Selliera radicans (Remuremu)	Samolus repens (Primrose)		0.33	2.53
Herbfield	Selliera radicans (Remuremu)	Sarcocornia quinqueflora (Glasswort)		0.35	2.71
Herbfield	Selliera radicans (Remuremu)	Sarcocornia quinqueflora (Glasswort)	Samolus repens (Primrose)	0.96	7.48
Herbfield	Selliera radicans (Remuremu)	Schoenoplectus pungens (Three square)	Samolus repens (Primrose)	0.02	0.14
Grand Total				12.86	100.0

APPENDIX 8: HISTORIC MARGIN ESTIMATED FROM LIDAR DATA



The black line represents the estimated margin derived from the 1.6m contour extracted from the LiDAR data. The area historical salt marsh was estimated to be ~16.4ha.

APPENDIX 9: RAW SEDIMENT AND MACROFAUNA DATA

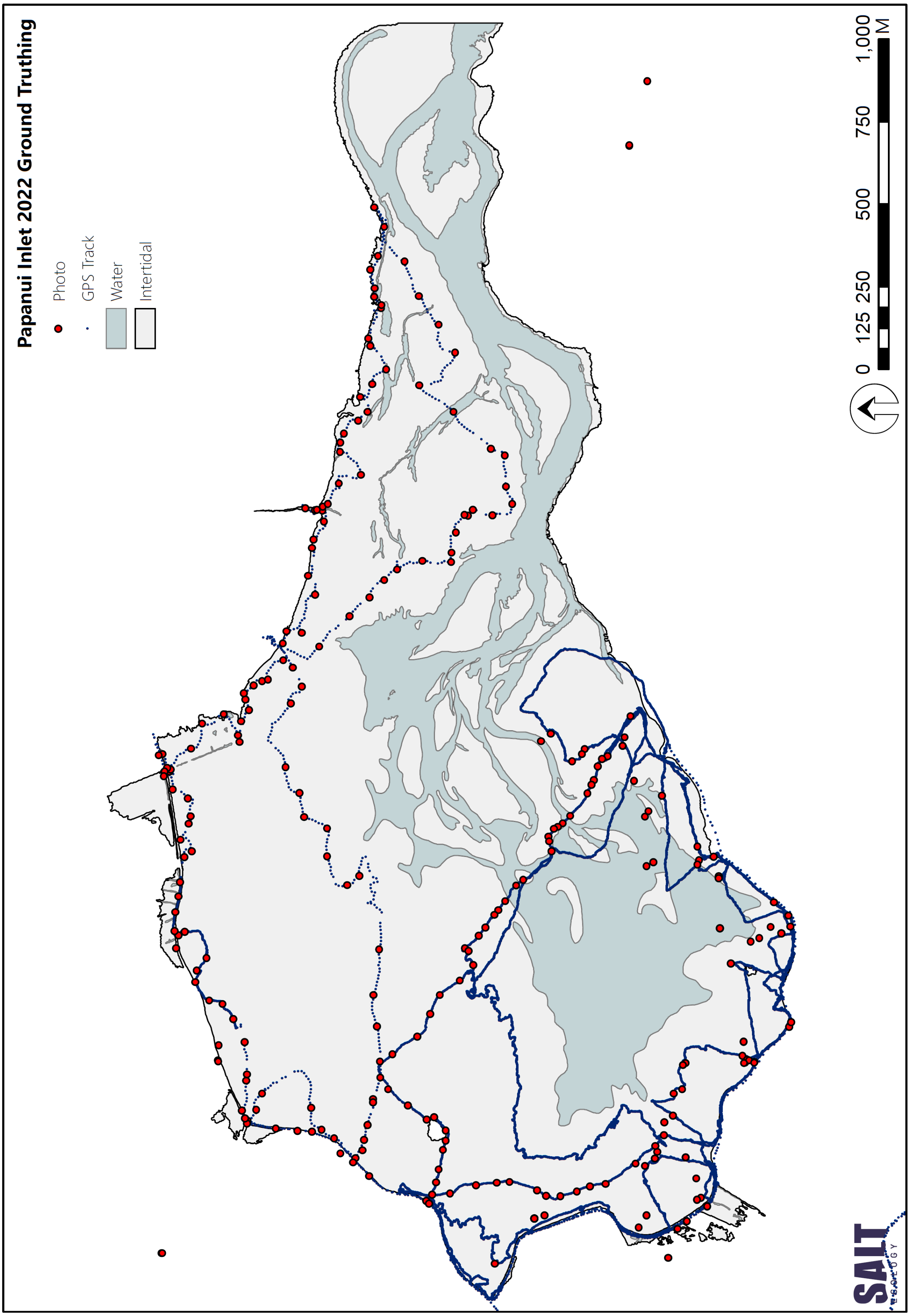
Sediment data and macrofauna indices

Parameter	Unit	PAPA-OTAG ETI - 1	PAPA-OTAG ETI - 2	PAPA-OTAG ETI - 3
Sediment Chemistry				
Total Phosphorus (TP)	mg/kg dry wt	198	280	133
Total Sulfur (TS)	g/100g dry wt	0.04	0.04	0.03
Total Nitrogen (TN)	g/100g dry wt	< 0.05	< 0.05	< 0.05
Total Organic Carbon (TOC)	g/100g dry wt	0.12	0.1	0.13
Gravel (≥2mm)	g/100g dry wt	< 0.1	0.2	< 0.1
Sand (≥63mm to <2mm)	g/100g dry wt	94.2	97.4	97.2
Mud (≤63mm)	g/100g dry wt	5.8	2.4	2.8
aRPD	mm	20	20	20
Macrofauna indices				
AMBI	no unit	0.49	0.85	3.32
Overall Abundance	no unit	329	137	693
Overall Diversity	no unit	17	14	12

Raw macrofauna data. EG refers to ecological sensitivity group used to calculate the AMBI.

Main group	Taxa	Habitat	EG	PAPA ETI 1	PAPA ETI 2	PAPA ETI 3
Amphipoda	*Paracalliope novizealandiae*	Infauna	I	5	24	16
Amphipoda	*Paracorophium excavatum*	Infauna	IV	1	8	236
Amphipoda	*Proharpinia sp.*	Infauna	I	2		
Amphipoda	*Torridoharpinia hurleyi*	Infauna	I	50	33	29
Amphipoda	*Urothoe sp. 1*	Infauna	II	1	2	
Anthozoa	*Edwardsia sp.*	Epibiota	II	14	5	34
Bivalvia	*Arthritica sp. 5*	Infauna	III	2	4	151
Bivalvia	*Austrovenus stutchburyi*	Infauna	II		1	
Bivalvia	*Lasaea parengaensis*	Infauna	II	13		49
Bivalvia	*Legrandina turneri*	Infauna	NA	113	46	159
Bivalvia	*Nucula nitidula*	Infauna	I	98	2	
Gastropoda	*Cominella glandiformis*	Epibiota	III	1	2	
Gastropoda	*Notoacmea scapha*	Epibiota	II		1	
Polychaeta	*Leodamas sp.*	Infauna	III			1
Polychaeta	*Boccardia syrtis*	Infauna	II	1	1	
Polychaeta	*Capitella cf. capitata*	Infauna	V		1	1
Polychaeta	*Macroclymenella stewartensis*	Infauna	II	9	7	
Polychaeta	*Nereididae (juv)*	Infauna (juvenile)	NA			8
Polychaeta	*Paradoneis lyra*	Infauna	III	13		
Polychaeta	*Perinereis vallata*	Infauna	III	2		2
Polychaeta	*Protocirrineris nuchalis*	Infauna	III	1		
Polychaeta	*Scolecolepides benhami*	Infauna	IV			7
Tanaidacea	*Tanaidacea*	Infauna	II	3		

APPENDIX 10. GROUND-TRUTHING IN PAPANUI INLET (MAKAHOE), NOV. 2021

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