SALT
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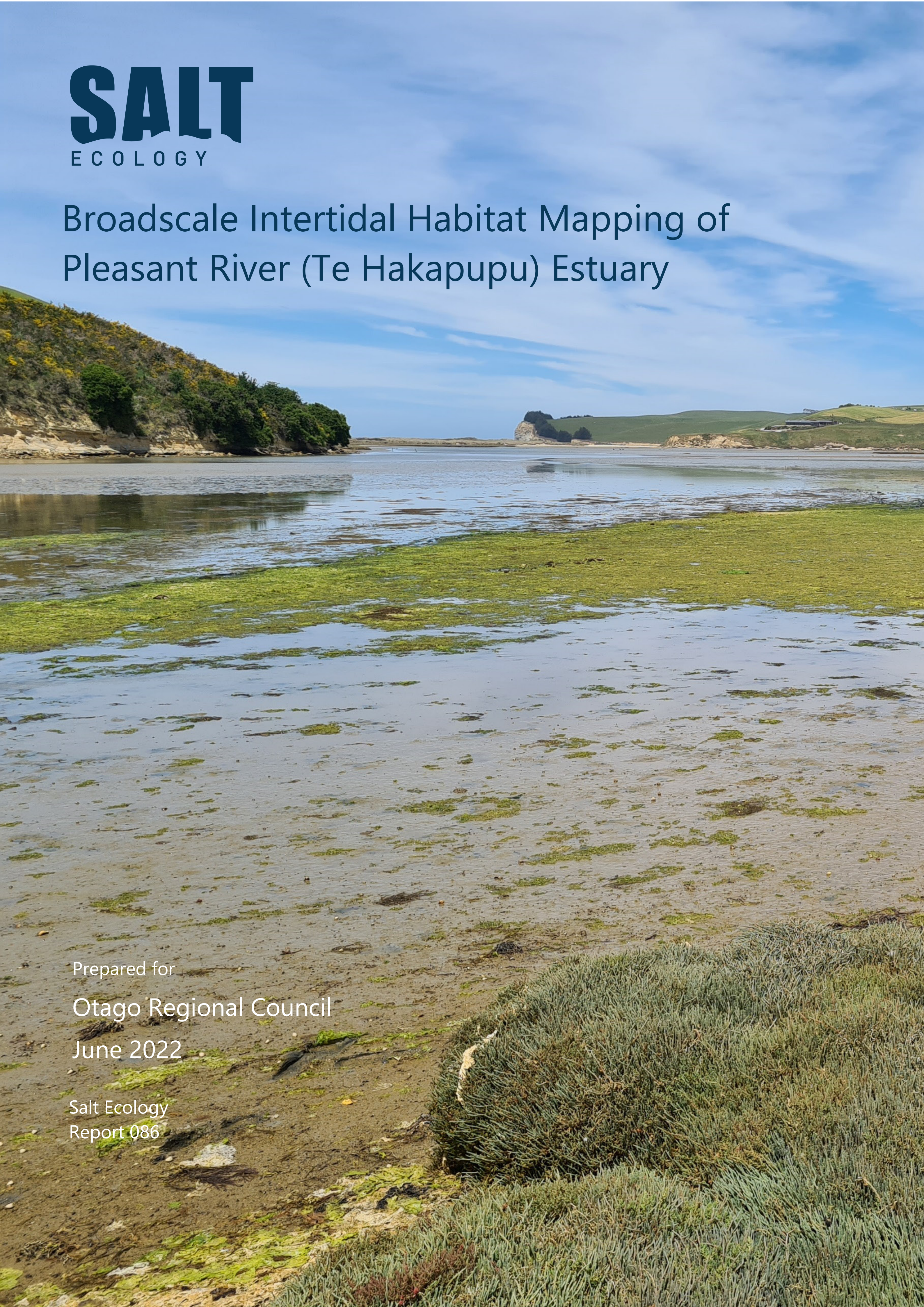
Broadscale Intertidal Habitat Mapping of Pleasant River (Te Hakapupu) Estuary



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Cover photo: Pleasant River (Te Hakapupu) Estuary looking toward the estuary entrance, November 2021, showing herb field and *Ulva* spp.

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Broadscale Intertidal Habitat Mapping of Pleasant River (Te Hakapupu) Estuary

Prepared by

Keryn Roberts,

Leigh Stevens,

and Barrie Forrest

for

Otago Regional Council

June 2022

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

www.saltecology.co.nz

GLOSSARY

AMBI	AZTI Marine Biotic Index
AA	Affected Area (OMBT metric)
AIH	Available Intertidal Habitat (OMBT metric)
aRPD	Apparent Redox Potential Discontinuity
DO	Dissolved Oxygen
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
HEC	High Enrichment Conditions
LiDAR	Light Detection and Ranging
NEMP	National Estuary Monitoring Protocol
NIWA	National Institute of Water and Atmospheric Research
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
QA/QC	Quality Assurance/Quality Control
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TS	Total sulfur

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SUMMARY

Pleasant River (Te Hakapupu) Estuary is a medium sized (216ha) estuarine system located ~50km north of Dunedin. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary monitored by Otago Regional Council (ORC) as part of its State of the Environment programme, using methodologies described in New Zealand's National Estuary Monitoring Protocol. This report describes a survey conducted in November 2021, which assessed the dominant substrate and vegetation features present in the estuary, including seagrass, salt marsh and macroalgae.

KEY FINDINGS

- Mud-dominated sediments (>50% mud) comprised 16.7% of the intertidal area and were localised to the estuary side arms or salt marsh habitat where fine sediments tend to accumulate.
- Eutrophic conditions, especially in side arms and parts of the mid estuary, were evident in the form of:
  - Extensive growths of nuisance opportunistic macroalgae and other filamentous algae, often accompanied by poorly-oxygenated or anoxic muddy sediments (see photo).
  - A large area (8% of the total estuary) classified as exhibiting 'High Enrichment Conditions' (>50% algal growth in poorly oxygenated sediments with high mud content)
  - An Estuary Trophic Index score of 0.766, which is representative of 'poor' conditions.

- No intertidal seagrass was recorded, with salt marsh (mainly herbfield) being the dominant vegetation type (80.4ha or 42.8% of the intertidal area). Approximately 37% (48ha) of historic salt marsh has been lost to reclamation, drainage and conversion to pasture.
- The catchment has been extensively developed with pasture (61.9%) and exotic forest (31.1%) being the dominant land use types. Only 6.6% of the 200m terrestrial margin was densely vegetated.

Overall, with the exception of salt marsh, the other broad scale indicators in Pleasant River Estuary were rated 'fair' to 'poor'. The results suggest that the estuary's capacity to assimilate nutrient and sediment inputs is currently being exceeded.

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) score	No unit	0.766	Poor
Mud-dominated substrate	% of intertidal area >50% mud	16.7	Poor
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.445	Fair
Seagrass	% decrease from baseline	0.0	na (no data before Nov-2021)
Salt marsh extent (current)	% of intertidal area	42.8	Very Good
Historical salt marsh extent*	% of historical remaining	63	Good
200m terrestrial margin	% densely vegetated	6.6	Poor
High Enrichment Conditions	ha	17.2[1]	Fair
High Enrichment Conditions	% of estuary	8.0	Fair
Sedimentation rate[2]	CSR:NSR ratio[3]	3.4	Fair
Sedimentation rate[2]	mm/yr	3.8	Poor

Colour bandings are reported in Table 3. OMBT=Opportunistic Macroalgal Blooming Tool. [1]Includes intertidal and ponded areas [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)

RECOMMENDATIONS

- Repeat the broad scale habitat mapping at 5 yearly intervals to track long term changes in estuary condition. Consider more frequent targeted nuisance macroalgae and filamentous algae monitoring (e.g. every 1-2 years), especially if conditions are observed to deteriorate.
- Protect and enhance existing salt marsh to prevent further losses and consider restoration in suitable areas.
- Include Pleasant River Estuary in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will improve the ecological quality of the estuary.

1. INTRODUCTION

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

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

The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results provide a baseline assessment 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 Pleasant River (Te Hakapupu) Estuary between 25-27 November 2021 (Fig. 1). The primary purpose of the current work was to characterise substrate types and the presence and extent of seagrass, macroalgae and salt marsh. Fine scale monitoring, undertaken at the time of sampling, is reported in Forrest et al. (2022).

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Fig. 1. Location of Pleasant River (Te Hakapupu) Estuary, Otago.

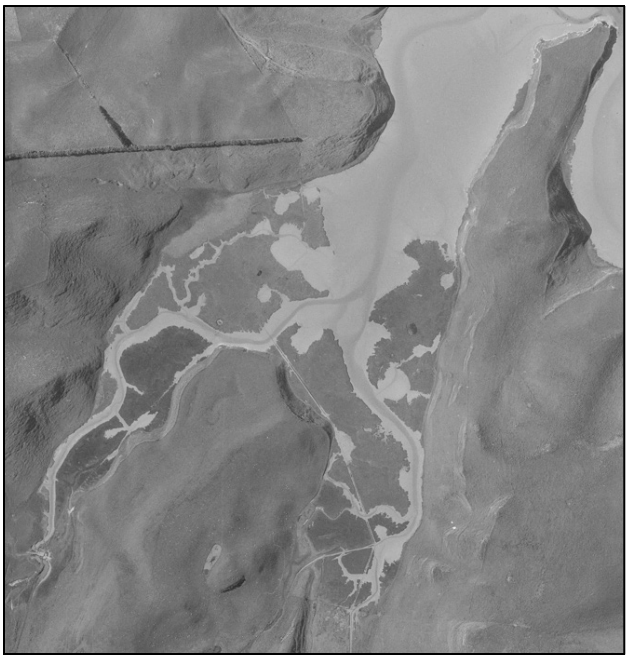
Salt marsh herbfield in the foreground and steep grass-dominated margin in the background, Pleasant River Estuary

2. BACKGROUND TO PLEASANT RIVER ESTUARY

Pleasant River Estuary is a medium sized (216ha) estuarine system located ~50km north of Dunedin on New Zealand's southeast coast. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary (SIDE) with a flushing time of ~5 days (Plew et al. 2018). Unlike the well-flushed mid to lower estuary, the narrow channels in the upper estuary are susceptible to stratification and water column nutrient problems. The estuary also has the capacity to retain fine sediments and sediment bound nutrients in deposition areas (e.g. side arms) making it moderately susceptible to nutrient enrichment impacts.

The main freshwater inflow to the estuary is Pleasant River along with several smaller tributaries. Freshwater inputs represent ~30% of the total estuary volume (Plew et al. 2018). The estuary drains almost completely at low tide exposing ~86% of the estuary area. The lower estuary is protected from the ocean by a sand spit dominated by marram grass dunes.

The extensive areas of salt marsh herbfield (mainly glasswort; *Sarcocornia quinqueflora*) and rushland are recognised as a regionally significant wetland in the Otago Regional Plan: Water. However, historic drainage and reclamation of salt marsh for pasture is a common feature of the estuary, particularly in the side arms (see photo). Fencing of herbfield for grazing continues and flapgates and causeways restrict saltwater inundation of salt marsh habitat. A causeway that blocked the entrance of the southern arm was removed in 2009 to reinstate tidal flushing (Moller & Moller 2012; southern arm shown in photo). Despite this, previous salt marsh habitat has not re-established.



Salt marsh in the southwest side arm 1958 (top; source Retrolens) and 2019 (bottom; source ORC)

Remnants of the causeway removed in 2009

Pleasant River Estuary was traditionally utilised by Māori as an important kāinga mahinga kai (food gathering settlement). A significant archeological site at the Pleasant River mouth has identified early hunting of moa and seals before a transition to kaimoana (seafood). The estuary provides extensive spawning and nursery habitat for marine and freshwater fish species including patiki (flatfish), inanga (whitebait) and tuna (long-finned eel and short-finned eel; Ngāi Tahu Atlas). The establishment of a marine reserve that would extend from Pleasant River to Stony Creek has been proposed to protect important reef, estuary, and kelp forest habitats (SMPF 2018).

The estuary is a coastal protection area in the Otago Regional Plan: Coast for its cultural and ecological values. The estuary is particularly important for waders and waterfowl including godwits, South Island pied oystercatcher, variable oystercatcher, pied stilt, banded dotterel white-faced heron, gulls, shags and ducks (WDC 2004).

The estuary drains a 12,747ha catchment comprising ~38.1% intensive pasture, ~23.8% low producing pasture and ~31.1% exotic forest. 37.7% of the catchment is densely vegetated (Table 1; Fig. 2). The immediate terrestrial margin of Pleasant River Estuary is dominated by pasture on gently sloping hill country that falls steeply to the estuary (Moore 2015). The bedrock is sedimentary, meaning there is moderate to high susceptibility of overland flow, and sediment and particulate phosphorus issues (LandscapeDNA.org).

Recently, the Tūmai Beach Development on the southern margin of the estuary has prepared an environmental enhancement plan as part of their consent conditions. The long-term restoration plan aims to integrate ecosystem restoration and sustainable pasture production by planting natives on the terrestrial margin, salt marsh plantings, stock exclusion and reducing vehicle use in the estuary (TBEEG 2021).

While there has been extensive reclamation and modification to the estuary margin, the estuary retains high ecological, cultural and human use values.

Native plantings on the terrestrial margin

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

LCDB5 (2017/2018) Catchment Land Cover		Ha	%
1	Built-up Area (settlement)	0.5	0.00
6	Surface Mine or Dump	3.4	0.03
10	Sand or Gravel	7.2	0.06
12	Landslide	2.9	0.02
20	Lake or Pond	3.5	0.03
30	Short-rotation Cropland	21.2	0.2
40	High Producing Exotic Grassland	4860	38.1
41	Low Producing Grassland	3037	23.8
46	Herbaceous Saline Vegetation	116.1	0.9
51	Gorse and/or Broom	419.7	3.3
52	Manuka and/or Kanuka	56.6	0.4
54	Broadleaved Indigenous Hardwoods	64.2	0.5
56	Mixed Exotic Shrubland	54.4	0.4
58	Matagouri or Grey Scrub	33.2	0.3
64	Forest - Harvested	80.5	0.6
68	Deciduous Hardwoods	13.2	0.1
69	Indigenous Forest	6.8	0.05
71	Exotic Forest	3967	31.1
Grand Total		12747	100
Total densely vegetated area (LCDB classes 45-71)		4812	37.7

Native plantings on the terrestrial margin adjacent to salt marsh

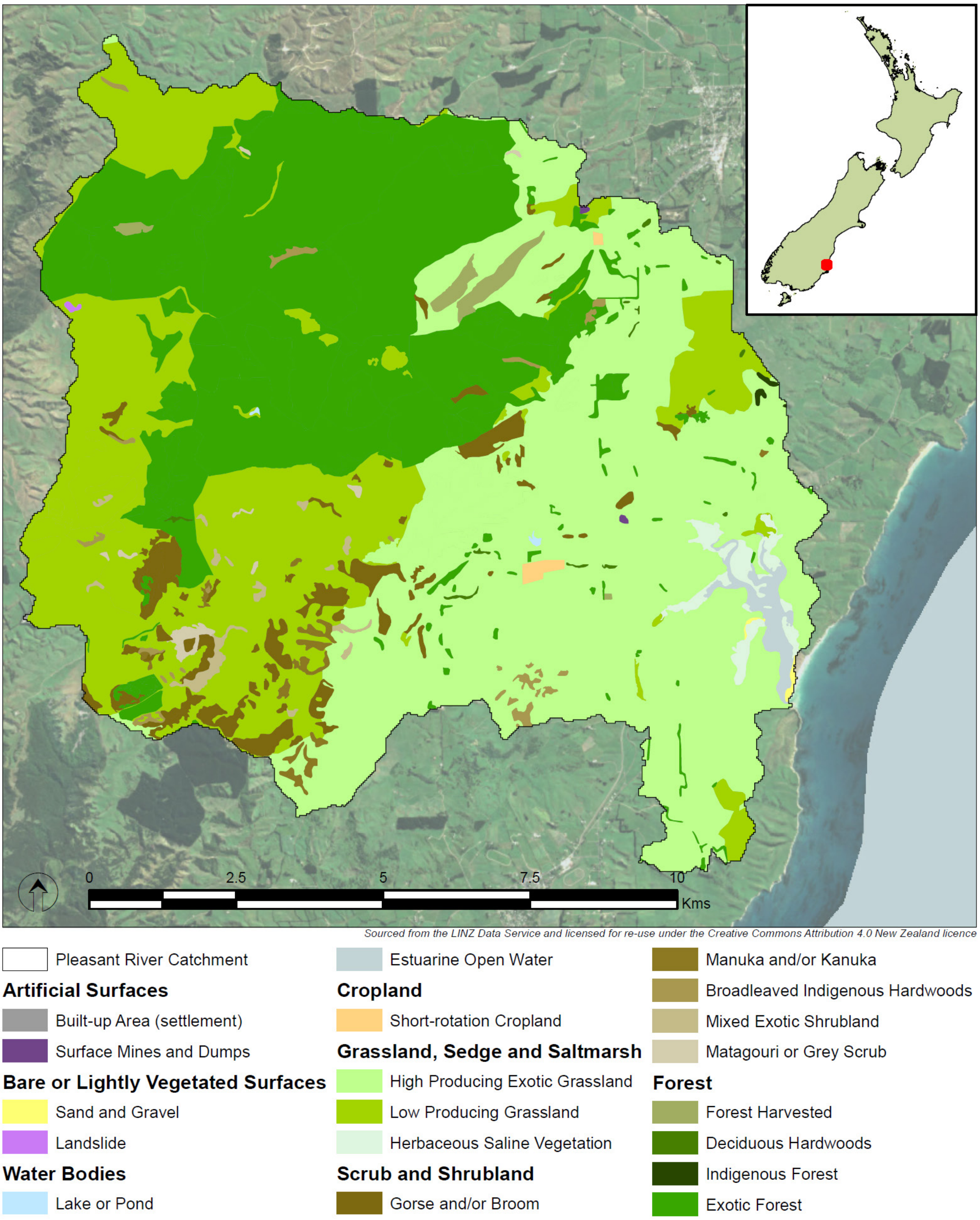


Fig. 2. Pleasant River Estuary catchment land use classifications from LCDB5 (2017/2018) database.

3. METHODS

3.1 BROAD SCALE MAPPING METHODS

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

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

Imagery for the present study was supplied by ORC (1:3000 colour aerial imagery captured between February to March 2021). Ground-truthing was undertaken between 25-27 November 2021 by experienced scientists, who assessed the estuary on foot to map the spatial extent of dominant vegetation and substrate. A particular focus was to characterise 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 10.8 shapefiles using a Huion Kamvas 22 drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features, e.g. salt marsh, and its underlying substrate type.

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

Assessment criteria, developed largely from previous broad scale mapping assessments, apply thresholds for helping to assess estuary condition. Additional details on specific broad scale measures are provided in Sections 3.3-3.8.

Mapping salt marsh vegetation in Pleasant River Estuary

Table 2. Overview of the ecological significance of 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 (mainly via secondary impacts from macroalgal smothering), and sediment quality (e.g. low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae (e.g. *Agarophyton* spp. & *Ulva* spp.) are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at using excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

3.2 SUBSTRATE CLASSIFICATION AND MAPPING

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 relating to 'muddiness' and 'firmness' characteristics, which were assessed in the field. In November 2021, 12 samples for sediment grainsize were collected to validate field classifications of substrate type (Appendix 2).

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

Mobile sands near the estuary entrance

Gravel field in the mid estuary

Very soft sandy mud in the estuary arm adjacent to salt marsh

3.3 SEDIMENT OXYGENATION

The apparent Redox Potential Discontinuity (aRPD) depth was used to assess the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment. The aRPD depth is the depth of 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 was 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, showing brown oxygenated sediments on the surface down to ~10mm

3.4 MACROALGAE ASSESSMENT

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature. To improve the macroalgal assessment, the ETI (Robertson et al. 2016b) adopted the United Kingdom Water Framework Directive (WFD-UKTAG 2014; Appendix 3) Opportunistic Macroalgal Blooming Tool (OMBT) approach. The OMBT, described in detail in Appendix 2, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within five overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

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

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

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

Sampling macroalgal biomass in Pleasant River Estuary

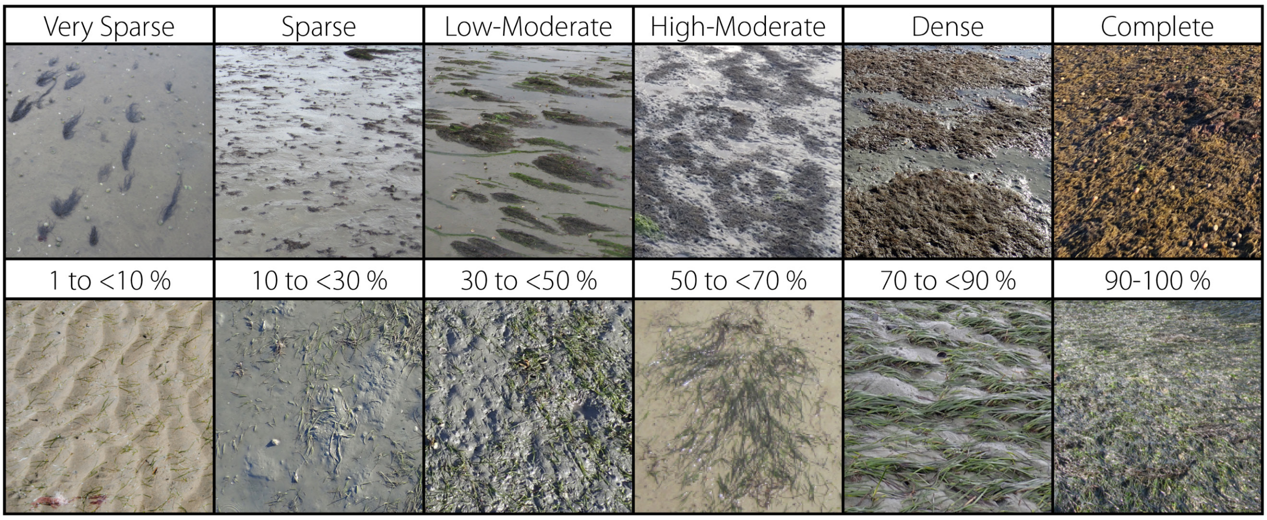


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algal material was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale. When sufficient representative patches had been measured to enable biomass to be reliably estimated, biomass estimates were made following the OMBT method. Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on the five-point scale adopted by the method as noted above.

3.5 SEAGRASS ASSESSMENT

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

3.6 SALT MARSH

NEMP methods were used to map and categorise salt marsh, with dominant estuarine plant species used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock; Robertson et al. 2002a-c; Appendix 1). Two measures were used to assess salt marsh condition: i) intertidal extent (percent cover) and ii) current extent compared to estimated historical extent.

LiDAR and historic aerial imagery were used to estimate historic salt marsh extent. The earliest available aerial image from 1958 (retrolens.co.nz) was georeferenced in ArcMap and visible saltmarsh was digitised in ArcMap 10.8 as described in Section 3.1. LiDAR data were supplied by ORC as an elevation raster of the Pleasant River Estuary area and as a terrain dataset of the coastal margin. All geoprocessing was performed using ArcGIS Pro 2.9.3. The terrain dataset was converted to raster using the Terrain to Raster (3D Analyst) tool. Both raster datasets were converted to simplified elevation polygons using the Raster to Polygon tool. The upper estuary boundary elevation was determined using existing estuary mapping and a visual assessment of aerial imagery. Elevation polygons at and below the upper estuary boundary elevation were combined using the Merge tool. A combination of buffering (Pairwise Buffer tool) and smoothing (Smooth Polygon tool) were used to simplify the resulting estuary boundary polygon. For estuary areas not covered by either of the raster layers, the upper estuary boundary was digitised based on aerial imagery interpretation.

Weighing macroalgae in a sample rinse bag

3.7 TERRESTRIAL MARGIN

Broadscale 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.

Native plantings on the terrestrial margin adjacent to salt marsh

Pasture adjacent to the estuary

3.8 WATER QUALITY

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

3.9 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 to 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).

3.10 DATA RECORDING AND QA/QC

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

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

As well as annotation of field information onto aerial photographs during the field ground-truthing, point estimate macroalgal data (i.e. biomass and cover measurements, entrainment), along with supporting measures of sediment aRPD, texture and sediment type were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP 10.8.

3.11 ASSESSMENT OF ESTUARY CONDITION

In addition to the authors' expert interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 3). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3. The condition ratings are primarily sourced from the ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 4. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores (i.e. which range from 'high' to 'bad'). The thresholds used to place biomass into OMBT bands have been recently revised for use in New Zealand (Plew et al. 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 (≥50% mud content) soft-sediments with >50% macroalgal cover (often with macroalgae entrained and growing as stable beds 'rooted' within the sediment), which typically also have a sediment 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).

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

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

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

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

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

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

4. RESULTS

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

4.1 SUBSTRATE

Table 4 and Fig. 4 show intertidal substrate was dominated by firm muddy sand (117.9ha, 62.8%) in the upper estuary and side arms. Substrate within salt marsh habitat also comprised firm muddy sand in the range of >25 to 50% mud. Rock fields were a prominent feature near the estuary entrance (see photo; Table 4). Small areas of gravel field (2.5ha, 1.3%) were located on the mid estuary flats. Mud-dominated sediments (>50% mud) were localised to the large side arms or salt marsh habitat where fine sediments tend to naturally accumulate (see photos & Fig. 4). Zootic habitat (shellbank) was only a small feature of the estuary comprising 0.02% of the intertidal area. In general, there was good agreement between the subjective assessment of substrate class and the laboratory-analysed sediment validation samples (Appendix 2).

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

Substrate Class	Features	Ha	%
Artificial	Boulder field	0.2	0.1
	Cobble field	0.03	0.01
Bedrock	Rock field	0.5	0.3
Boulder/Cobble/ Gravel	Boulder field	0.2	0.1
	Cobble field	0.08	0.04
	Gravel field	2.5	1.3
Sand (0-10% mud)	Mobile sand	7.5	4.0
	Firm sand	12.5	6.7
Muddy Sand (>10-25% mud)	Firm muddy sand	33.4	17.8
	Soft muddy sand	3.2	1.7
Muddy Sand (>25-50% mud)	Firm muddy sand	84.6	45.0
	Soft muddy sand	11.9	6.3
Sandy Mud (>50-90% mud)	Firm sandy mud	4.4	2.3
	Soft sandy mud	15.2	8.1
	Very soft sandy mud	10.5	5.6
Mud (>90% mud)	Firm mud	1.0	0.5
	Soft mud	0.3	0.2
Zootic	Shell bank	0.03	0.02
Total		**187.9**	**100**

Rock field (top) and mobile sand (bottom) in the lower estuary near the entrance

Dried mud and filamentous algae (top) and very soft sandy mud (bottom) in the mid estuary

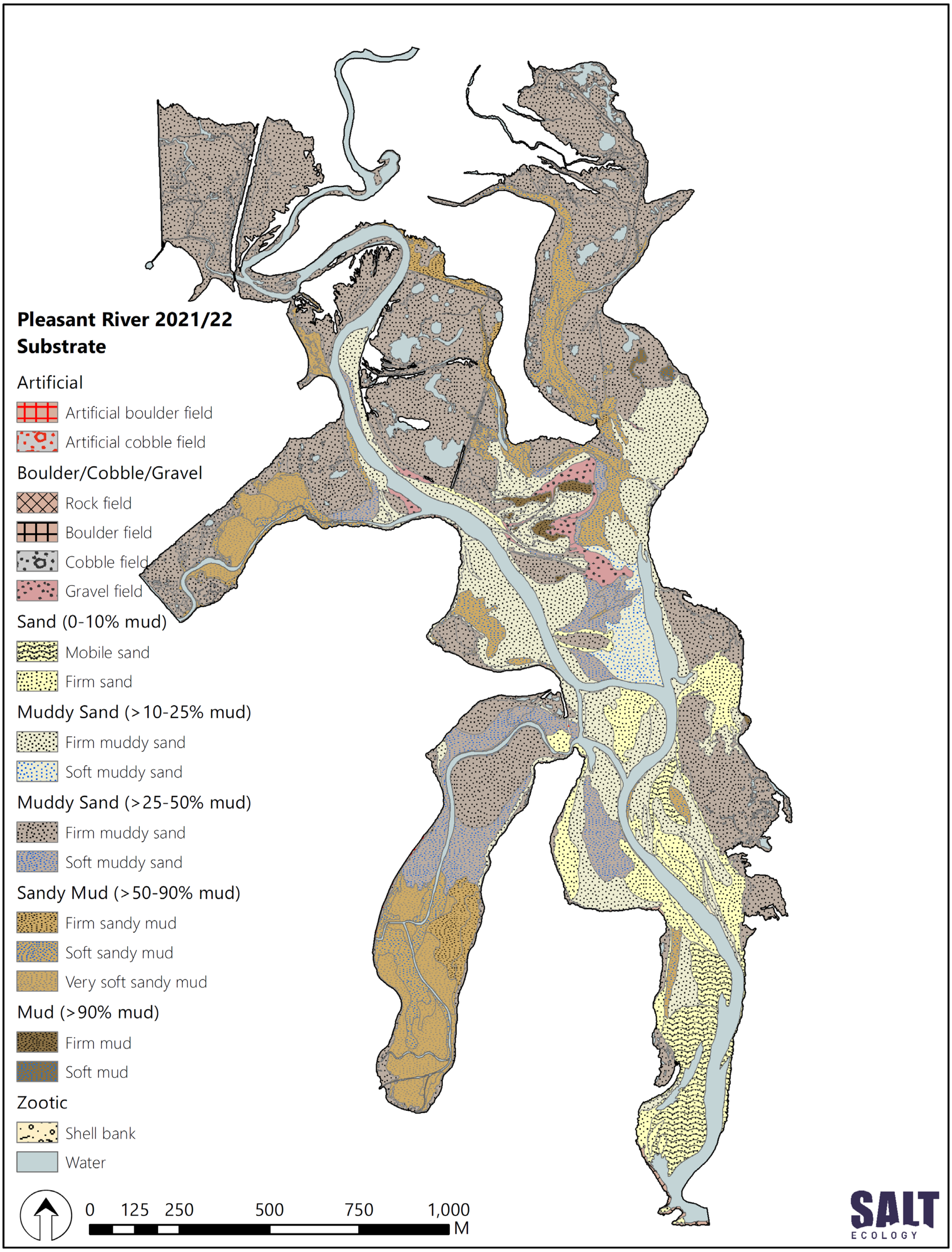


Fig. 4. Distribution of type of substrate recorded in Pleasant River Estuary, November 2021.

4.2 SEDIMENT OXYGENATION

Sediment oxygenation (aRPD) was measured within representative substrate types to assess the trophic state of the sediment. Spot measurements of aRPD showed that sand-dominated sediments in the lower estuary were well-oxygenated, particularly areas of mobile sand. While there were no obvious signs of oxygen depletion on the surface of unvegetated soft, muddy-sands in the upper estuary, in these areas aRPD depths were close to the sediment surface (see photo).

In general, the shallowest aRPD depths occurred in sediments with increasing mud content or organic content. For example, near stream inputs, deposition areas, or in the presence of macroalgae (see photos).

Soft, muddy sand (top), opportunistic macroalgae growing on top of very soft sandy mud (middle) and filamentous macoalgae growing on top of soft, sandy mud (bottom)

4.3 MACROALGAE

4.3.1 Opportunistic macroalgae

Table 5 summarises percentage cover and biomass classes for opportunistic macroalgae (*Agarophyton* spp. & *Ulva* spp.), with the mapped cover and biomass shown in Fig. 5 and Fig. 6 respectively. Macroalgal sampling stations and data are provided in Appendix 5. Non-opportunistic marine species and drift macroalgae were not recorded as part of the nuisance macroalgae assessment.

Table 5. Summary of intertidal cover (A) and biomass (B) of opportunistic macroalgae.

A. Percent Cover

Percent cover category	Ha	%
Absent or trace (<1%)	162.3	86.4
Very sparse (1 to <10%)	5.1	2.7
Sparse (10 to <30%)	6.3	3.4
Low-Moderate (30 to <50%)	2.4	1.3
High-Moderate (50 to <70%)	0.8	0.4
Dense (70 to >90%)	6.8	3.6
Complete (>90%)	4.0	2.1
Total	187.9*	100

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	162.3	86.4
Very low (1 - 100)	7.5	4.0
Low (101 - 200)	1.7	0.9
Moderate (201 - 500)	4.1	2.2
High (501 - 1450)	4.5	2.4
Very high (>1450)	7.7	4.1
Total	187.9*	100

* Total intertidal area including salt marsh

Measuring macroalgae biomass

Key opportunistic macroalgae results were as follows:

- A cover exceeding 50% was recorded across 11.6ha of the intertidal habitat, with the highest cover recorded in the mid estuary and side arms (Table 5A; Fig. 5). Overall, the Affected Area (AA), where opportunistic macroalgae was growing, was 23.8% (25.4ha) of the available intertidal habitat (AIH; Fig. 5; Table 6).
- Macroalgal patches exceeding 90% cover (4.0ha) were a mix of the green seaweed *Ulva* spp. and red seaweed *Agarophyton* spp. growing on soft sediments (see photos). Underlying sediments had a shallow aRPD, indicating organic enrichment.
- In the lower estuary, opportunistic cover was generally <50%. In these areas, wave fetch and channel scouring likely limit excess macroalgal growth. However, entrained *Agarophyton* spp. was common on the channel margins (see photo pg. 17).
- Mean wet weight biomass was rated 'moderate' across the AIH (321g/m^2), and 'poor' in the AA (1348g/m^2; Table 6).
- Marine macroalgal species were common in the deep channel near the estuary entrance (see photo pg. 17), and other estuarine macroalgae were prolific in some areas, as described in the next section.

The overall quality status using the OMBT method was reported as 'moderate', equivalent to an ETI condition rating of 'fair' (Table 3). The numeric OMBT EQR score (0.445), reflects that opportunistic macroalgae were present across large areas of the estuary and were generally associated with areas of fine sediment deposition.

Mixed *Ulva* spp. and *Agarophyton* spp. on soft sediments

Table 6. Summary of OMBT input metrics, overall Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 3) for opportunistic macroalgae. The survey EQR score has an ETI rating of 'fair' based on criteria in Table 3.

Nov-2021 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	10.5	0.690	Good
Average biomass (g/m^2) in AIH	320.6	0.520	Moderate
Average biomass (g/m^2) in AA	1348.0	0.221	Poor
% entrained in AA	43.1	0.246	Poor
Worst of AA (ha) and AA (% of AIH)		0.550	Moderate
AA (ha)	25.6	0.722	Good
AA (% of AIH)	23.8	0.550	Moderate
Survey EQR		0.445	Fair

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

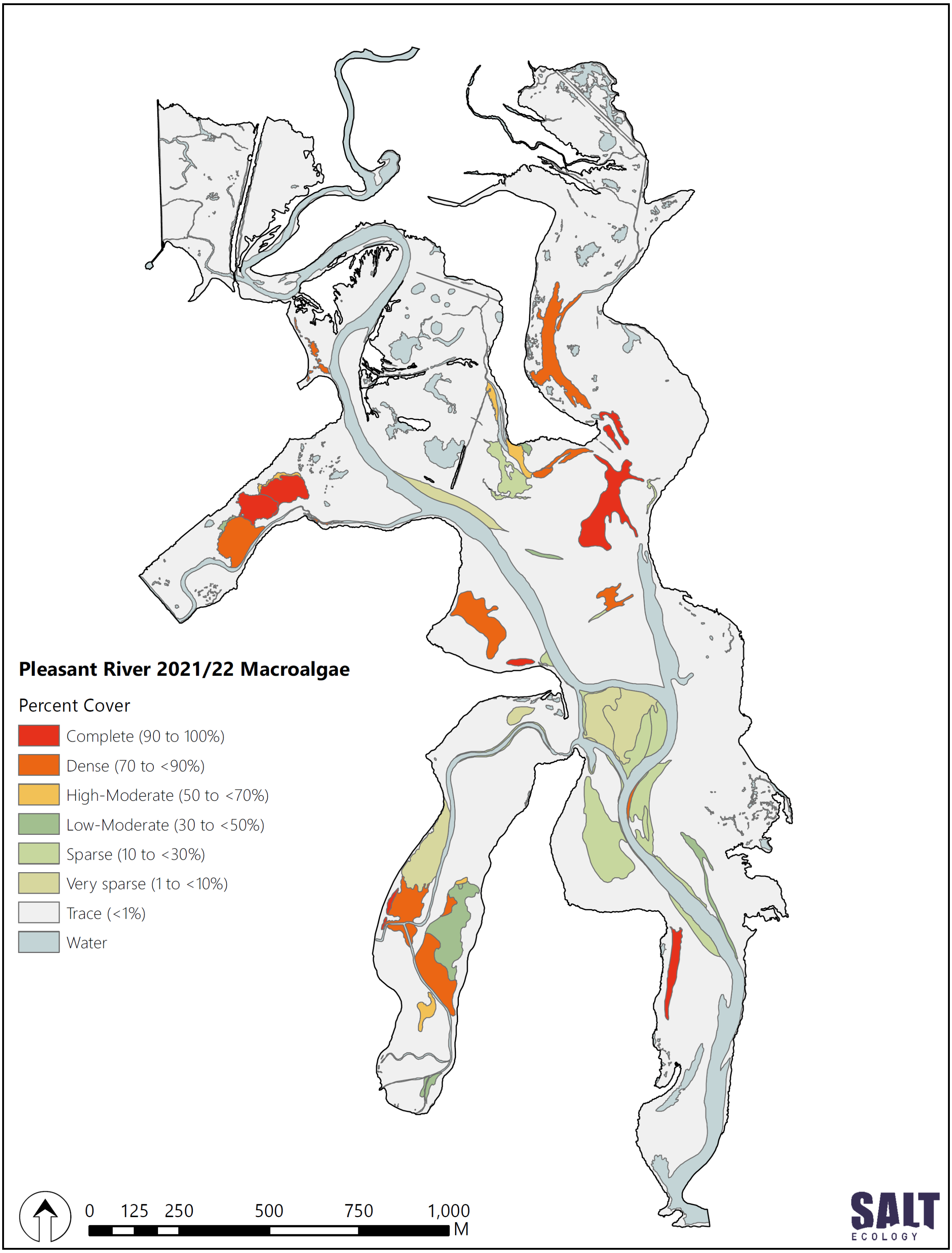


Fig. 5. Distribution and percent cover classes of opportunistic macroalgae in Pleasant River Estuary, November 2021.

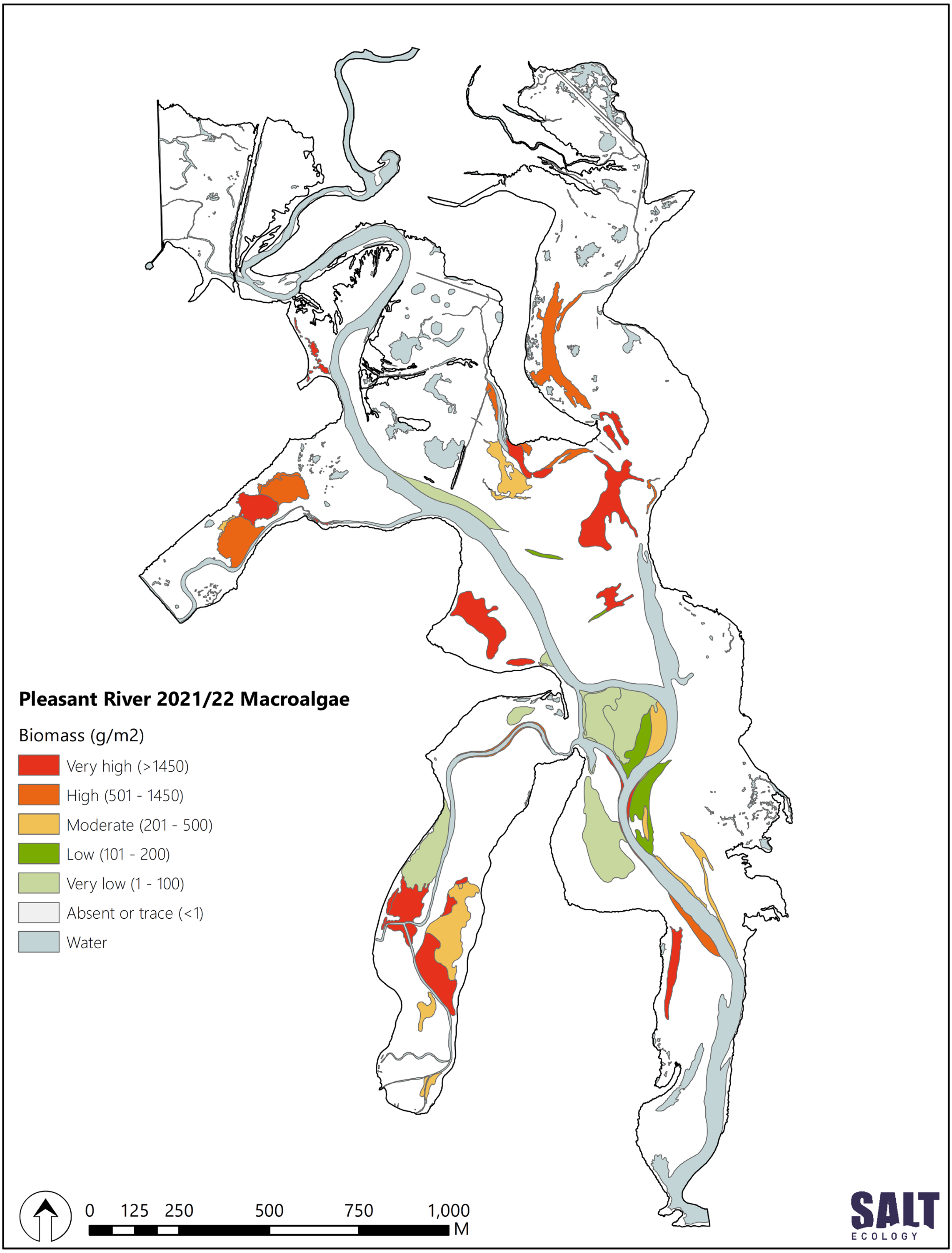
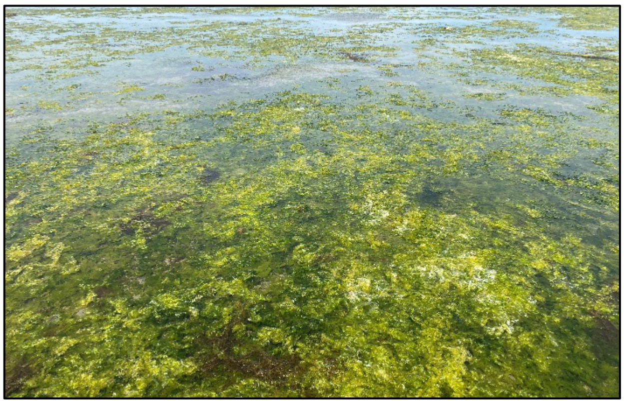


Fig. 6. Distribution and biomass classes of opportunistic macroalgae in Pleasant River Estuary, November 2021.

Mixed *Ulva* spp. and *Agarophyton* spp. on soft muddy sands



Ulva spp. growing on soft muddy sands

Entrained *Agarophyton* spp. on the channel margin

Scouring on channel margin, *Agarophyton* spp. and *Ulva* spp.

Marine algae attached to rock substrate at the estuary entrance

Entrained *Agarophyton* spp. mixed with *Ulva* spp.

4.3.2 Other macroalgae

In addition to opportunistic macroalgal species, other filamentous algae were also prolific in parts of the estuary (Fig. 7). These species included the following:

- A mat-forming macroalga (identified by NIWA as *Vaucheria* sp.), was relatively abundant across 8.3ha or 7.7% of the available intertidal habitat (i.e. excluding salt marsh). In general, this species was associated with very soft (4.4ha) and soft (2.6ha) sandy-mud. Below the thick mats (and often in adjacent bare areas), underlying sediments were enriched and anoxic and had a strong sulfide odour, (Fig. 7; see photo adjacent and below).
- Other long-stranded filamentous green algae, which superficially appeared to comprise more than one species, were prolific in areas of ponded water within herbfields. Sediments were similar, enriched and anoxic in these areas (Fig. 7; see photo adjacent).

Low oxygen sediments below mat-forming patches of a filamentous algae, identified as *Vaucheria* sp. Below the thick mats, underlying sediments were enriched, anoxic and had a strong sulfide odour. This photo illustrated black, anoxic surface sediments between the *Vaucheria* sp. patches. This species was particularly extensive in the south-west arm of the estuary (see photo at bottom).

4.3.3 High Enrichment Conditions

High Enrichment Condition areas (HECs) are generally defined in relation to the proliferation of opportunistic macroalgae. However, due to the extensive areas of other algae species in Pleasant River Estuary, the definition was broadened to include areas with >50% cover filamentous algal cover (i.e. of *Vaucheria* sp. and ponded filamentous species) because of the contribution made by these species to sediment degradation. Based on this broader definition, HEC areas covered a total of 17.2ha (Fig. 8), comprising:

- 11.8ha (6.3% of the intertidal) consisting of intertidal *Agarophyton* spp., *Ulva* spp. and *Vaucheria* sp. in deposition zones (e.g. south-west & west arms, mid estuary).
- 5.4ha of filamentous algae within herbfield ponds.

Filamentous green algae growing in ponds within salt marsh. Like the areas of *Vaucheria* sp., sediments were also strongly enriched and anoxic in these ponded areas.

Filamentous green algae *Vaucheria* sp. growing prolifically at the head of the south-west arm

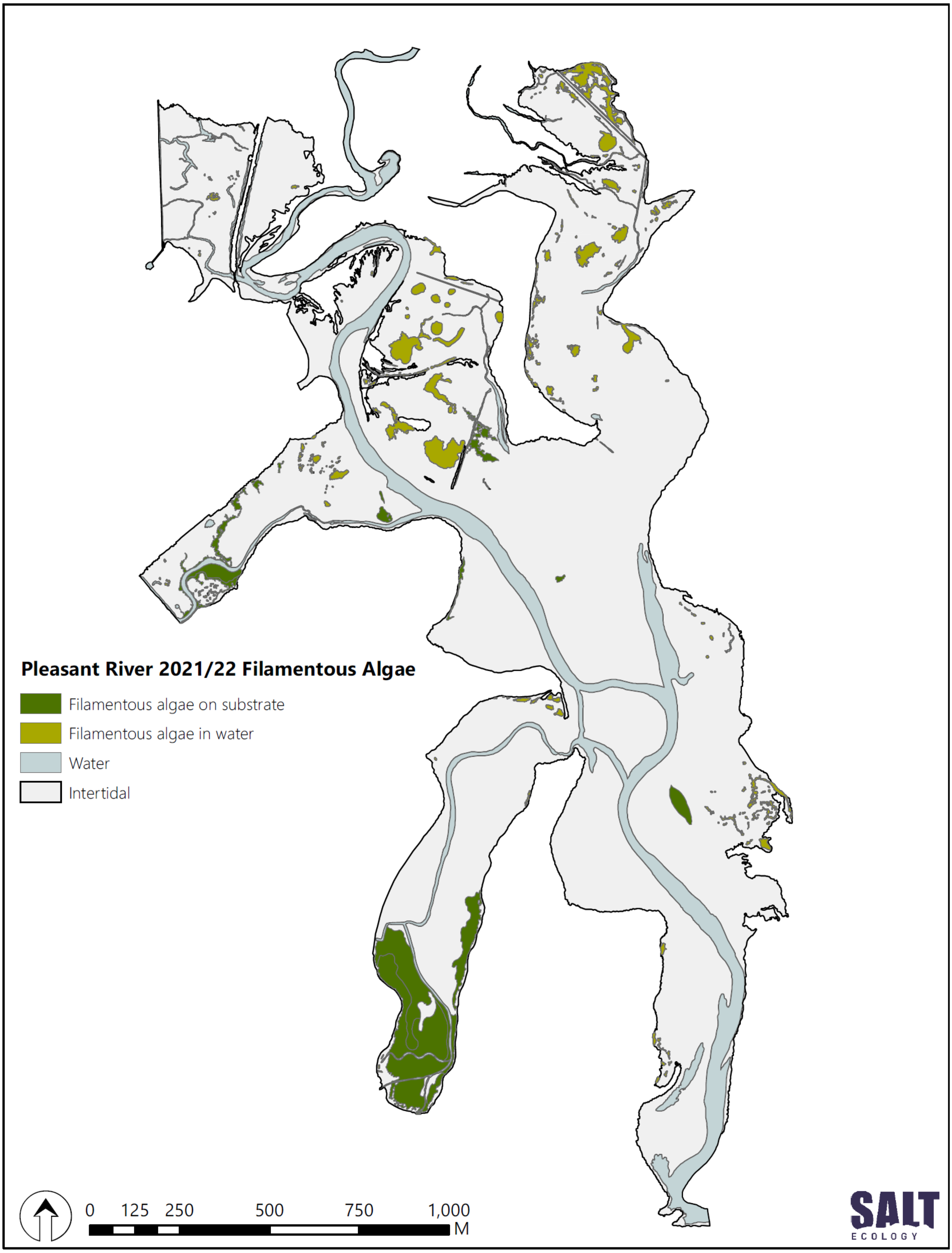


Fig. 7. Distribution of filamentous algae (presence/absence) in Pleasant River Estuary, November 2021. Filamentous algae in water refers to areas of green filamentous algae in ponds within salt marsh herbfields.

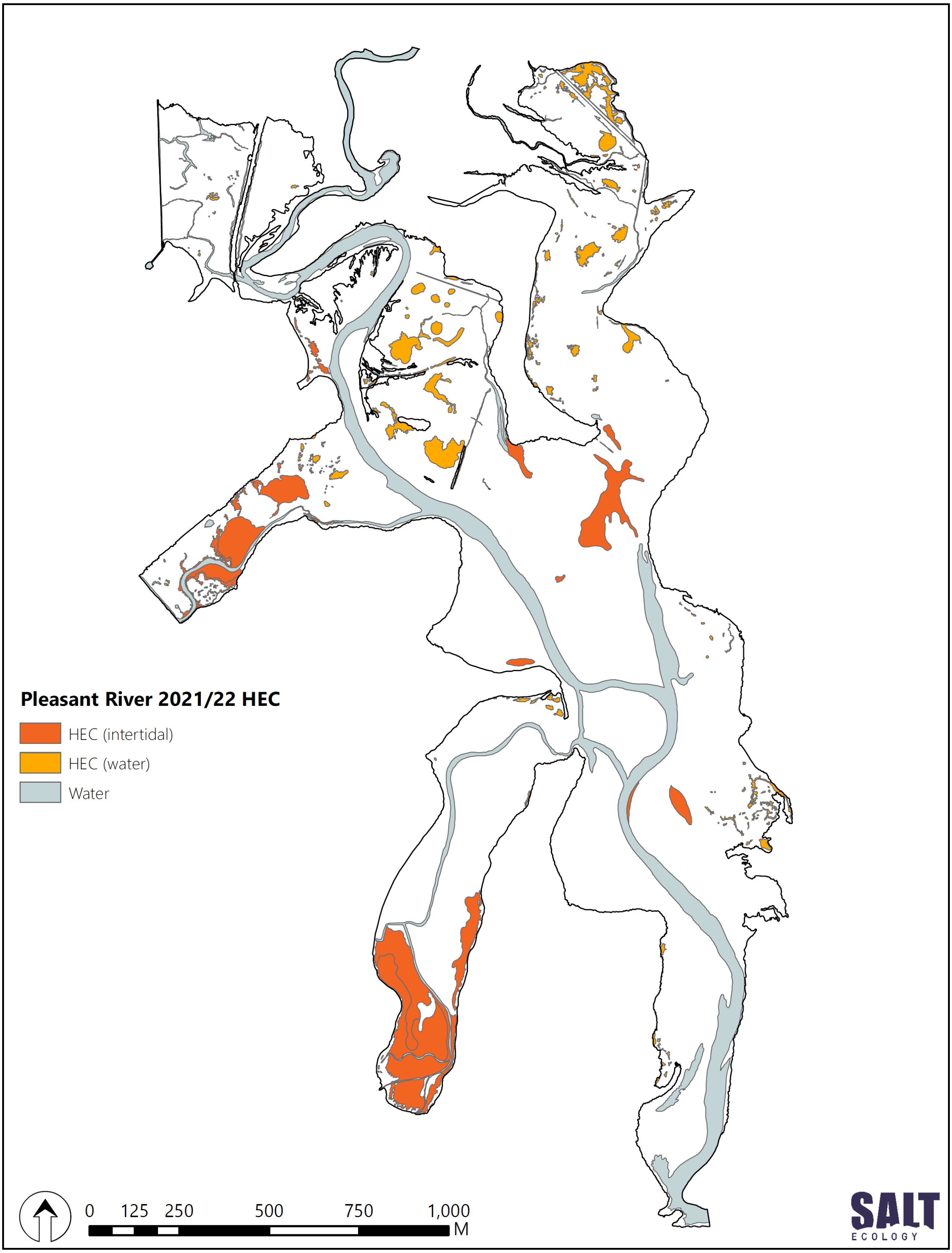


Fig. 8. Areas of High Enrichment Conditions (HEC) in Pleasant River Estuary, November 2021, including opportunistic macroalgae and other areas where filamentous algal species were prolific. HEC (water) refers to areas of green filamentous algae in ponds within salt marsh herbfields.

4.4 SEAGRASS

No seagrass was recorded in Pleasant River Estuary in November 2021.

4.5 SALT MARSH

Table 7 summarises intertidal salt marsh, with the distribution mapped in November 2021 presented in Fig. 9. Dominant and subdominant species are recorded in Appendix 6. Salt marsh covered 80.4ha (42.8%) of the intertidal area and was most extensive in the upper estuary and on the eastern margin (Fig. 9).

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

Subclass	Ha	%
Estuarine Shrub	0.8	0.9
Grassland	0.3	0.4
Tussockland	0.1	0.1
Sedgeland	0.2	0.3
Rushland	1.1	1.4
Herbfield	77.9	96.9
Total	80.4	100.0

The dominant class was herbfield, comprising 77.9ha (96.9% of total salt marsh), with the main species being *Sarcocornia quinqueflora* (glasswort; see photo) and *Selliera radicans* (remuremu; see photo). Other herbfield species included *Samolus repens* (primrose), *Suaeda novaezelandiae* (sea blite) and *Thyridia repens* (New Zealand musk).

Nest in *Sarcocornia quinqueflora* (glasswort) herbfield

Selliera radicans (Remuremu)

Rushland comprised 1.1ha (1.4% of total salt marsh), with the dominant species being *Apodasmia similis* (jointed wirerush; see photo) and *Ficinia (Isolepis) nodosa* (knobby clubrush). Estuarine shrubs comprised 0.8ha (0.9% of total salt marsh), with the dominant species being *Plagianthus divaricatus* (salt marsh ribbonwood). Sedgeland (*Schoenoplectus pungens*; three square) comprised only a small area of the estuary 0.2ha (0.3% total salt marsh; see photo). Introduced weeds and the grass *Festuca arundinacea* (tall fescue) were present in some areas.

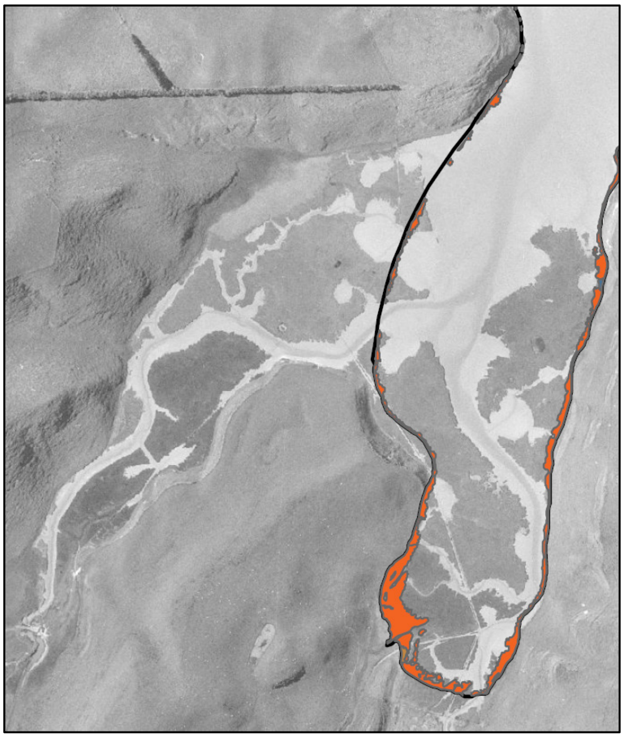
Apodasmia similis (jointed wirerush) and herbfield foreground, with *Plagianthus divaricatus* (salt marsh ribbonwood) in the background

Schoenoplectus pungens (three square sedge)

Fig. 9. Distribution and type of salt marsh in Pleasant River Estuary, November 2021.

LiDAR data (Appendix 7) and historic aerial imagery (Appendix 8) were used to estimate the extent of salt marsh prior to estuary drainage and reclamation. It was estimated that salt marsh historically covered ~128ha of the intertidal area (Fig. 10) and the dominant class was herbfield. Compared with the current salt marsh extent described in this report, we therefore estimate that there has been a loss of 47.6ha (or 37% of salt marsh) when compared to the historic extent (i.e. 63% of natural cover remains). Despite the magnitude of the loss, the percentage of salt marsh remaining equates to a condition rating of 'good' (see Table 3).

The largest losses have occurred in the north of the estuary and south-west and west arms, where salt marsh has been drained and reclaimed for pasture. Drainage channels remain common, particularly in the north (see photo). In the south-west arm there has been >90% loss of salt marsh, particularly herbfield, through reclamation (see photos adjacent; Fig. 10). Flapgates are common in the side arms and upper estuary, preventing inundation of remaining herbfield. While some herbfield species persist, these areas were freshwater dominated. Fencing and grazing of herbfield continues in most areas.



Current estuary boundary and salt marsh extent overlaid on the 1958 aerial image of the south-west arm prior to reclamation. The black outline is the current mapped estuary, illustrating former salt marsh along the left half of the image that has been lost (now farmland).

Causeway across the west arm, with water flow into the upper arm restricted by a flapgate (left farmland and right salt marsh)

Fencing through salt marsh habitat, with many areas still grazed

Drainage channels through *Sarcocornia quinqueflora* (glasswort) herbfield

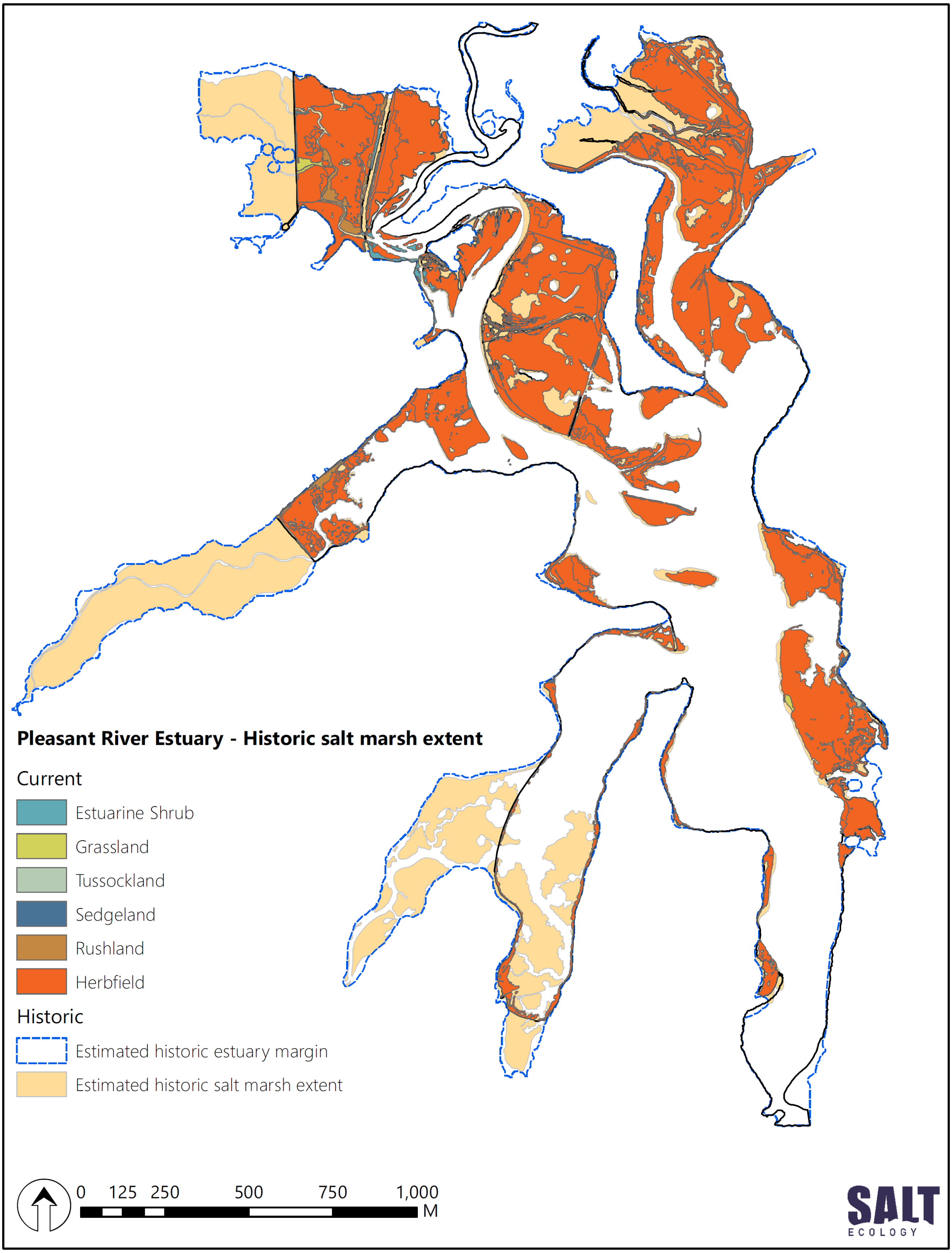


Fig. 10. Estimated distribution of historic salt marsh in Pleasant River Estuary. Estimated using LiDAR and aerial imagery from 1958 (source: retrolens.co.nz). The current mapped area (black line) and salt marsh extent is overlaid onto the historic salt marsh extent (yellow) and historic estuary margin (blue dashed line). See Appendix 8.

4.6 TERRESTRIAL MARGIN

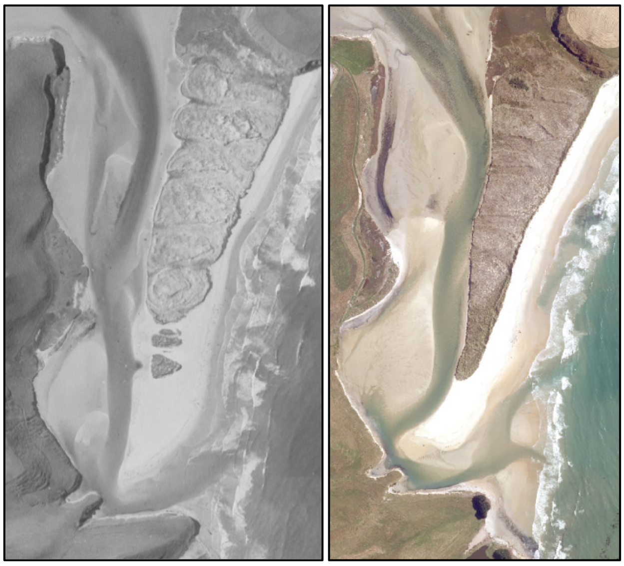
Table 8 and Fig. 11 summarises the land cover of the 200m terrestrial margin, which was 59.3% high producing grassland and 28.4% low producing grassland. Only 6.6% of the terrestrial margin was densely vegetated and mostly comprised exotic vegetation (e.g. exotic forest, mixed exotic shrubland and gorse).

Gorse growing on the estuary margin (top) and the dominant land use, grassland, on sloping hill country (bottom)

Rail infrastructure transects herbfield in the upper estuary and traverses the margin of the north-west and western arms. While transport infrastructure was only a small portion (1.3%) of the terrestrial margin, its relative impact is significant with both reclamation and shoreline hardening having been undertaken to accommodate rail infrastructure. The built-up area within the terrestrial margin comprised 0.9% of the margin area.

Rail infrastructure transecting herbfield in the upper estuary

The herbaceous saline vegetation described in Fig. 11 is 3% of the terrestrial margin, and represents the dune area near the estuary entrance, which was dominated by exotic marram grass (*Ammophilia arenaria*). Historically dunes in this area were likely active and dominated by the native sand binder pīngao (*Ficinia spiralis*).



Aerial image of marram (*Ammophila arenaria*) dune system in 1958 (left) and 2018 (right)

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

LCDB5 Class	Ha	%
1 Built-up Area (settlement)	2.9	0.9
5 Transport Infrastructure	4.0	1.3
10 Sand and Gravel	8.0	2.6
20 Lake or Pond	1.1	0.4
21 River	1.4	0.5
40 High Producing Grassland	183.4	59.3
41 Low Producing Grassland	88.0	28.4
46 Herbaceous Saline Vegetation	9.3	3.0
51 Gorse and/or Broom	5.9	1.9
54 Broadleaved Indigenous Hardwoods	0.4	0.1
56 Mixed Exotic Shrubland	0.9	0.3
58 Matagouri or Grey Scrub	0.4	0.1
71 Exotic Forest	3.7	1.2
Grand Total	309.3	100
Total dense vegetated margin (LCDB5 classes 45-71)	20.5	6.6

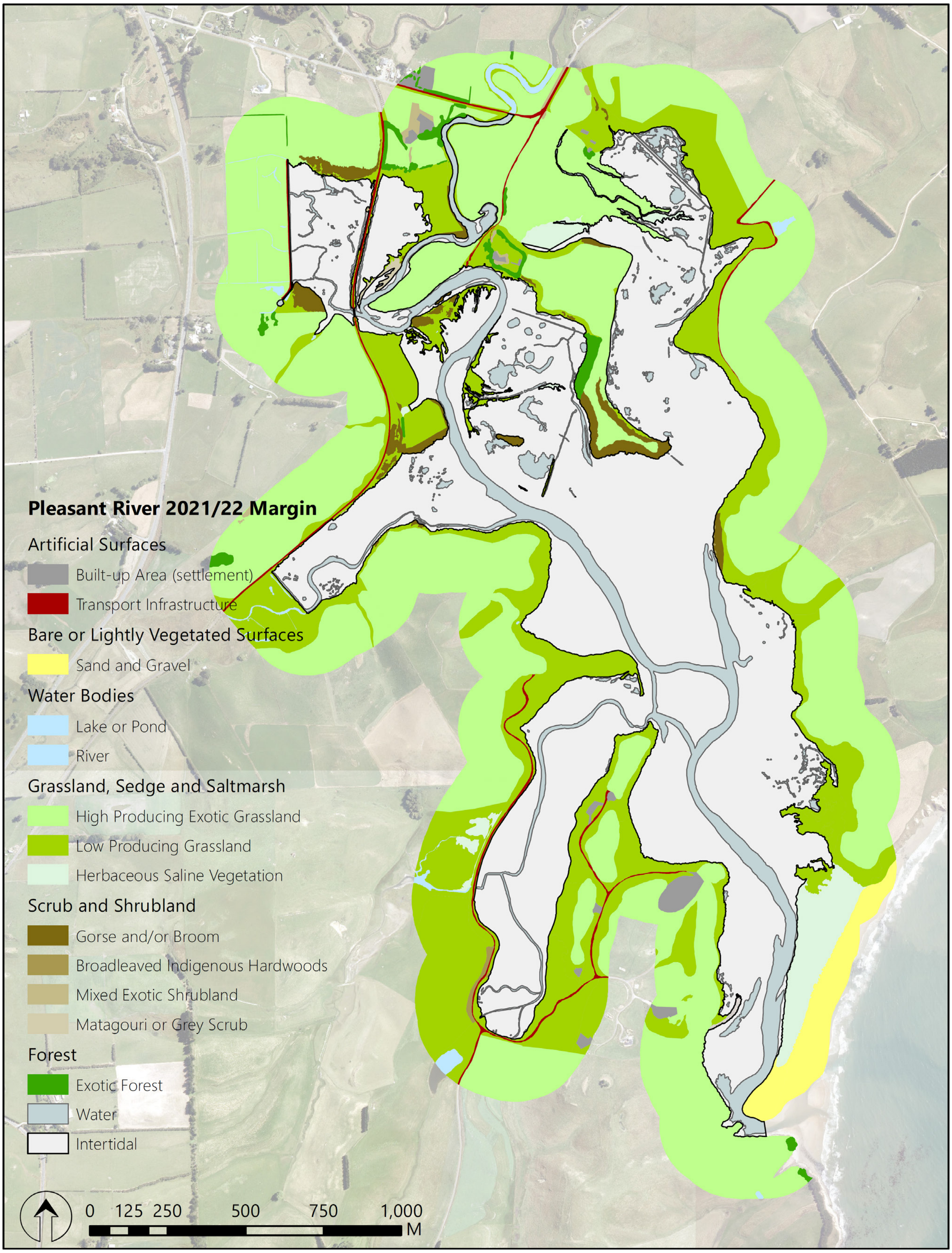


Fig. 11. Map of 200m terrestrial margin land cover, Pleasant River Estuary, November 2021. Dunes, near the entrance, were categorised as 'herbaceous saline vegetation' to maintain consistency with LCDB5.

4.7 WATER QUALITY

Water quality data presented in Table 9 provide ancillary information to support the broad scale mapping survey. Site locations are presented in Appendix 2.

Table 9. Water quality for Pleasant River Estuary, November 2021.

Station	WQ 1	WQ 2	WQ 3
NZTM East	1422378	1421814	1421720
NZTM North	4952499	4951544	4951616
Distance from mouth (m)	1200	3000	3000
Stratified	No	No	Yes
Surface measurements			
Measurement depth (m)	0.2	0.1	0.1
Temperature (°C)	14.4	15.6	13.0
DO saturation (%)	133.1	154.3	35.3
DO concentration (g/m^3)	10.9	15.0	3.7
Salinity	34.1	3.9	0.6
pH	7.85	8.49	8.60
Chlorophyll-*a* (mg/m^3)	1.3	12.5	3.6
Bottom measurements			
Measurement depth (m)	0.7	0.25	0.2
Temperature (°C)	14.4	15.6	14.5
DO saturation (%)	133.1	154.3	132.6
DO concentration (g/m^3)	10.9	15.0	11.7
Salinity	34.1	3.9	18.5
pH	7.85	8.49	7.85
Chlorophyll-*a* (mg/m^3)	1.3	12.5	7.5
Secchi depth (m)	>0.75	>0.3	>0.25
Max depth (m)	0.75	0.30	0.3
Channel width (m)[1]	35	1	0.5
Sediment texture	firm	soft	very soft
Sediment type	s	sm	sm

[1] Estimated at the time of sampling.

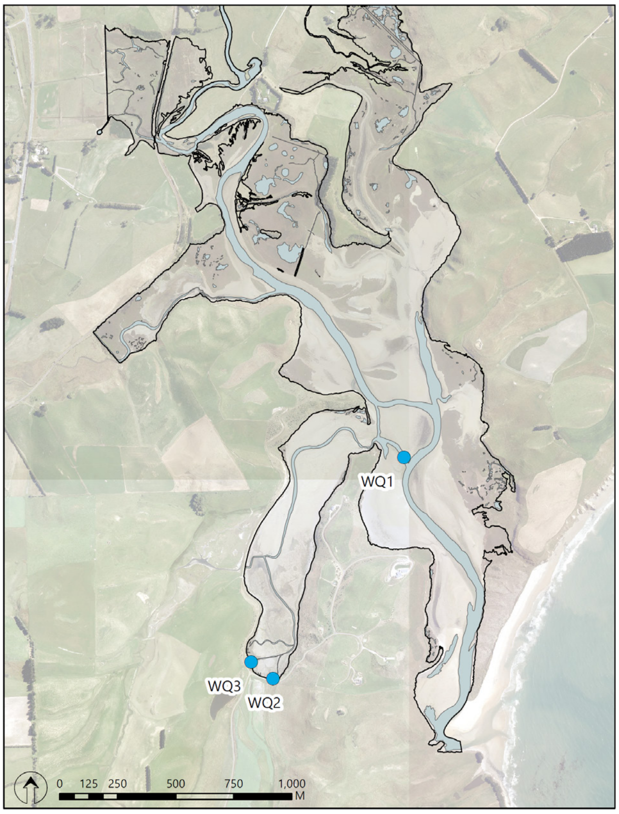
As expected, the site closest to the estuary entrance (WQ1) exhibited higher salinity and lower chlorophyll-*a* owing to the marine influence in this area. The water column at site WQ1 was well oxygenated (>100% dissolved oxygen saturation) at the time of sampling.

Smaller streams in the south-west arm were shallow (~0.3m) and water quality was variable. At site WQ2 the water column was well mixed, salinity low, oxygen was over-saturated and chlorophyll-*a* was elevated at 12.5mg/m^3. Site WQ3 was shallow and stratified with low oxygen recorded at the surface, possibly due to the source (i.e. the reservoir) of the input stream. These results suggest that the smaller input streams were enriched with elevated chlorophyll-*a* and low oxygen conditions at the time of sampling.

Furthermore, drainage channels and ponds in salt marsh habitat were highly enriched and expressing signs of eutrophication with excess filamentous algal growth and low oxygen.

Stream input, with seawater incursion restricted by flapgates

Drainage channel with a dark organic substrate



Location of water quality sites in Pleasant River Estuary

4.8 ESTUARY TROPHIC INDEX (ETI)

Table 10 summarises the indicators used to calculate an overall ETI score for the estuary. Raw data are presented in Appendix 9. The primary indicator of eutrophication response in SIDE type estuaries, like Pleasant River Estuary, is macroalgae (OMBT EQR), with supporting sediment indicators of macrofauna (AZTI Marine Biotic Index; AMBI), total nitrogen (TN), total organic carbon (TOC) and sediment oxygenation (aRPD). The overall ETI score of 0.776 was rated 'poor' in terms of eutrophication, which is reflected in constituent metrics such as the low macroalgal EQR and poor sediment oxygenation and other broad scale indicators such as the presence of HEC areas.

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

Indicator	Raw Value	Equivalent ETI Score[1]
Primary indicator		
Macroalgae (EQR)	0.445[2]	0.688
Supporting Indicator		
AMBI	4.89	0.875
TN (mg/kg)	2470	0.813
TOC (%)	1.80	0.688
aRPD (mm)	1.7	1.00
Final ETI Score	0.766	Poor

[1]Zeldis et al. 2017, [2]EQR from Table 6

Dry filamentous algae, likely only indundated on spring tides, in the foreground and macroalgae in the background (top), and very soft sand muds devoid of oxygen (bottom)

Dense *Ulva* spp. and *Agarophyton* spp. on anoxic and very soft sandy-muds

5. SYNTHESIS OF KEY FINDINGS

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

Pleasant River Estuary was intertidally dominated (187.9ha or 87% of the estuary area) with the subtidal areas restricted to relatively narrow river channels. Overall, the estuary was in 'fair' to 'poor' condition with highly eutrophic side arms expressing excess algal growth on soft, muddy sediments with low sediment oxygen. The compromised ecological quality of the estuary likely reflects high freshwater inputs (~30% of the estuary volume; Plew et al. 2018) from a developed catchment, extensive estuary reclamation, and restricted flushing of side arms.

Mud-dominated sediments, a common stressor in New Zealand estuaries, comprised 31.3ha or 16.7% of the intertidal area and were common in side arms and in the mid-estuary. Deposition of fine sediments is promoted in the side arms due to a combination of direct freshwater inputs from developed hill country, and reduced flushing. A partial causeway in the north-east arm and the natural geology of the north-west arm minimise flushing in those areas. In the south-west arm, tidal inundation was impeded by a causeway that was installed across the entrance in the 1960's, with the area used for cattle grazing up until the causeway was removed in 2009, reflooding some of the tidal flats (Moller and Moller 2012). The mid estuary comprised muddy sands (>10 to 50% mud) that were exhibiting symptoms of mild stress in terms of biota living in the sediment (Forrest et al. 2022). The lower estuary flats were marine influenced and dominated by clean firm or mobile sands.

Table 12. Summary of key broad scale features as a percentage of total estuary, intertidal or margin area, Pleasant River Estuary, November 2021.

a. Area summary	ha	% Estuary
Intertidal area	187.9	86.8
Subtidal area	28.5	13.2
Total estuary area	**216.3**	**100**

b. Key fine sediment features	ha	% Intertidal
Mud-enriched (25 to <50% mud)	96.4	51.3
Mud-dominated (≥50% mud)	31.3	16.7

c. Key vegetation features	ha	% Intertidal
Salt marsh	80.4	42.8
Seagrass (≥50% cover)	0.0	0.0
Opportunistic macroalgal (≥50% cover)	11.6	6.2
Filamentous algae (≥50% cover)	7.9	4.2

d. Terrestrial margin (200m)	ha	% Margin
200m densely vegetated margin	20.5	6.6

Mud dominated sediments in the north-west arm

Table 11. Summary of key broad scale indicator results and ratings.

Broad scale Indicators	Unit	Value	November 2021
Estuary Trophic Index (ETI) score	No unit	0.766	Poor
Mud-dominated substrate	% of intertidal area >50% mud	16.7	Poor
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.445	Fair
Seagrass	% decrease from baseline	0.0	na (no data before Nov-2021)
Salt marsh extent (current)	% of intertidal area	42.8	Very Good
Historical salt marsh extent*	% of historical remaining	63	Good
200m terrestrial margin	% densely vegetated	6.6	Poor
High Enrichment Conditions	ha	17.2[1]	Fair
High Enrichment Conditions	% of estuary	8.0	Fair
Sedimentation rate[2]	CSR:NSR ratio[3]	3.44[4]	Fair
Sedimentation rate[2]	mm/yr	3.8	Poor

Colour bandings are reported in Table 3. OMBT=Opportunistic Macroalgal Blooming Tool. [1]Includes intertidal and ponded areas [2]Estimated. [3]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted), [4]Assumes 50% wetland attenuation under natural conditions

The observations of soft, muddy sediment accumulation are consistent with NIWA's national estuary sediment load estimator (Hicks et al., 2019), which is designed to predict sediment input and retention. This tool indicated that Pleasant River Estuary is predicted to be highly efficient at trapping sediment (91% retention). Spreading all of the retained sediment evenly throughout the estuary would result in average estuary infilling of ~3.8mm/yr (Table 13), which equates to a condition rating of 'poor' (Table 12). Based on the relative difference in estimated yields from an undisturbed catchment, and assuming a further 50% attenuation from the historical presence of wetlands, the current sedimentation rate (CSR) is estimated to be 3.4 times the natural sedimentation rate (NSR; Table 13). The condition rating for the CSR:NSR ratio is rated 'fair' (Table 12). These sedimentation rate results and the large area of mud-dominated sediments (16.7%), reinforce that fine sediment issues are a cause for concern.

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

Supporting Condition Measure	Pleasant River
Mean freshwater flow (m^3/s)[1]	0.98
Catchment Area (Ha)	12847
Catchment nitrogen load (TN/yr)[2]	17.0
Catchment phosphorus load (TP/yr)[2]	2.9
Catchment sediment load (KT/yr)[1]	9.8
Estimated N areal load in estuary ($mg/m^2/d$)[2]	47.7
Estimated P areal load in estuary ($mg/m^2/d$)[2]	8.2
CSR:NSR ratio[1]	3.4
Trap efficiency (sediment retained in estuary)[1]	91%
Estimated rate of sed. trapped in estuary (mm/yr)[1]	3.8

[1]Hicks et al. 2019.

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

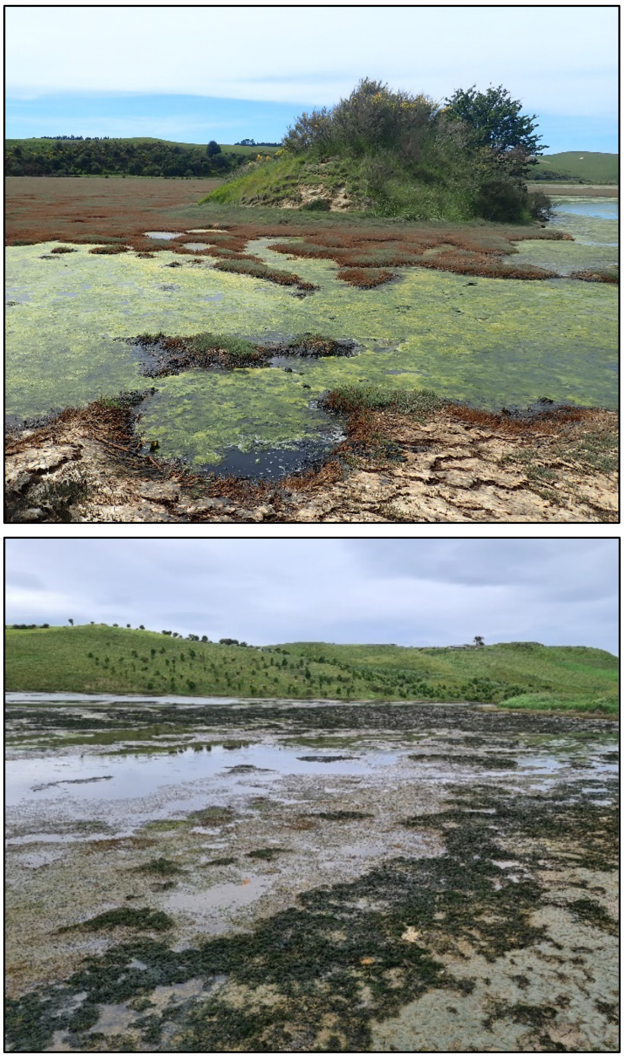
Algae is an important natural feature in estuaries and contributes to their high productivity and biodiversity. However, when nutrients are in excess and growing conditions are suitable, nuisance blooms of algae can have detrimental effects on estuary health (e.g. seagrass smothering, trapping fine sediments, increasing the organic loading, and causing low oxygen conditions). In Pleasant River Estuary prolific growths of opportunistic macroalgae and filamentous algae were present in the side arms, mid estuary, and ponds within herbfields.

The macroalgae OMBT-EQR score (0.445) was rated 'fair', with an ETI score of 0.776 (rated 'poor'), indicating that the estuary is expressing significant signs of eutrophication. As the EQR does not include the large areas of filamentous algal growth, it under-states the current degradation of the estuary. It is assumed that the proliferation of filamentous species is in part a trophic response, although the drivers of prolific *Vaucheria* sp. growth are unclear. This species is rare in South Island estuaries, and appears more common in the North Island, although is poorly understood in New Zealand (Wilcox 2012; Muralidhar 2014). Of interest from overseas studies is that extensive mats of *Vaucheria* sp., with enriched anoxic and sulfidic sediments beneath, have been described in estuarine systems (e.g. Simons 1974; Reise et al. 2022). These effects, and the mechanisms that are thought to contribute to proliferation, have similarities to that described for the opportunistic *Agarophyton* spp. (see Table 2 & Section 3). The mechanisms include rapid growth and spread via asexual reproduction, and the infiltration of rhizoids into the sediment matrix, which lead to the formation of stable beds and enhance the trapping of muddy sediments. For example, Reise et al. (2022) described an increase in sediment level of 20cm over three years that was attributed to the establishment of one particular *Vaucheria* species.

Accordingly, to better characterise the extent of eutrophic conditions, *Vaucheria* and other filamentous algae were included in the assessment of high enrichment conditions (HEC). A total of 17.2ha, or 8% of the estuary area, was expressing HEC, with high biomass algal growths associated with muddy sediments and severe sediment anoxia. This situation suggests that catchment sediment and nutrient loads currently exceed the estuary's assimilative capacity and problems can be expected to persist and worsen without management intervention. In relation to nutrients, of interest is that the modelled nitrogen load ($47.7mgN/m^2/d$) is below the ~$100mgN/m^2/d$ threshold at which nuisance macroalgae problems are predicted to occur (Robertson et al. 2017; Table 13). This apparent contradiction is likely due to the cumulative effects of nitrogen loads and other pressures, including extensive reclamation, poor flushing and altered hydrology (i.e. flapgates, causeways) in the estuary.

While poor water quality (Table 9) is the largest contributor to excess algal growth in estuaries, sediments that retain a eutrophic legacy (i.e. sediments rich in nutrients) can lead to a lag in the recovery response to management interventions. For example, the largest area of *Vaucheria* sp. in the south-west arm was growing on previously grazed and eroded herbfield sediments that were rich in organic matter, sulfur, and nutrients (Appendix 9). It is likely that, in these areas, any recovery response (i.e. decrease in algal blooms) will be delayed until other internal nutrient sources are depleted.

Ulva spp. and *Agarophyton* spp. in the north-west arm



Unidentified filamentous algae growing in shallow anoxic ponds within salt marsh (top) and *Vaucheria* sp. growing on eroded herbfield in the south-west arm (bottom)

Seagrass is a key feature in estuaries, providing food and habitat for fish, birds and macroinvertebrates. Seagrass can also influence water quality by trapping fine sediments, stabilising substrate, and assimilating nutrients. Unlike other Otago estuaries (Blueskin Bay, Otago Harbour, Hoopers Inlet, Catlins Lake/Pounawea) where seagrass is a prominent vegetation type, no seagrass was recorded in Pleasant River Estuary. A review of the aerial imagery from 1958 confirms the absence of seagrass, although by this time the estuary was already heavily modified, therefore it is uncertain whether seagrass would have grown in the estuary historically. The lack of seagrass potentially reflects the large-scale estuary modification and/or other conditions that would limit seagrass growth, in particular, a strong freshwater influence (low salinity), high sediment deposition, macroalgal growth in the likely areas seagrass would grow (i.e. side arms), and wave fetch and substrate mobility in the mid to lower estuary that could prevent establishment.

Salt marsh (mainly herbfield) was the dominant vegetation type in the estuary (80.4ha or 42.8% of the intertidal area). Salt marsh is an important feature of estuaries because it traps sediments and assimilates nutrients, in addition to providing habitat for birds and insects. An estimated ~63% of the historic salt marsh extent remains, equating to a condition rating of 'good'; however, the relative area of salt marsh lost, compared to the historic extent, is large (47.6ha loss). The greatest losses are due to reclamation, with salt marsh historically drained and converted to pasture (Fig. 10). Despite the salt marsh in Pleasant River Estuary being classified as a regionally significant wetland in the Regional Plan: Water for Otago, drainage and grazing are still occurring, particularly in the upper estuary and side arms. Smaller losses are attributed to erosion on channel margins and die-off of herbfield vegetation around ponds that have prolific filamentous algal growth and severe anoxia. Without active management, ongoing losses of salt marsh habitat can be expected.

Reclamation, drainage and structures that impede salt marsh growth are common in the estuary (i.e. causeways, flapgates, shoreline hardening for rail infrastructure). These modifications have significantly altered estuary hydrology and disrupted the natural connectivity between the land and the sea, compromising overall ecological health. There is significant scope for salt marsh protection and restoration, with the largest gains likely achieved through restoring the natural connectivity (i.e. removal of flapgates, causeways), and re-flooding areas of existing or previous estuary habitat, particularly in the upper estuary where herbfield vegetation persists. In the south-west arm, tidal inundation was restored to part of the arm when the causeway was removed in 2009. While some salt marsh has re-established, the legacy of almost 50 years of pasture and grazing remains.

In conclusion, the most significant issues identified in Pleasant River Estuary were large scale estuary reclamation (~20% loss), altered hydrology and ongoing drainage and grazing of salt marsh habitat, and excessive growths of opportunistic macroalgae and filamentous algal species. Coupled with current elevated catchment nutrient and sediment loads, the estuary's assimilative capacity has been greatly reduced resulting in large areas of eutrophic conditions (i.e. excess algal growth coupled with poor sediment oxygen and muddy sediments), particularly in the side arms.

Fenced and grazed herbfield with drainage channel in foreground

Bird nest in herbfield habitat

Filamentous algae growing on substrate that used to be herbfield habitat

Artificial boulder field restricting water movement through the channel

Highly enriched drainage channels with profilic filamentous algae growth and low oxygen

Ulva spp. in the mid estuary

6. RECOMMENDATIONS

Overall, the November 2021 monitoring results highlight that Pleasant River Estuary is under stress, and is expressing signs of excess sedimentation and eutrophication. These features are evident as prolific growths of opportunistic macroalgae and filamentous algae, in addition to muddy sediments with poor sediment oxygenation in the affected areas. Coupled with historic losses of salt marsh habitat, the estuary is in 'fair'' to 'poor' condition. Without active management to reduce catchment nutrient and sediment loads, and to prevent further salt marsh losses and enhance existing habitat, these symptoms can be expected to persist and worsen. Based on the findings of the current survey it is recommended that ORC consider the following:

- Repeat the broad scale habitat mapping at 5-yearly intervals to track long term changes in estuary condition.
- Consider more frequent targeted nuisance macroalgae and filamentous algae monitoring (e.g. every 1-2 years), especially if conditions are observed to deteriorate.
- Protect existing salt marsh from further losses and consider restoration in suitable areas (i.e. re-connecting salt marsh to the estuary) to enhance and expand existing habitat.
- Include Pleasant River Estuary in the ORC limit-setting programme and establish limits for catchment sediment and nutrient inputs that will improve the ecological quality of the estuary.

Ulva spp. growing on very soft sandy-muds

7. REFERENCES

FGDC. 2012. Coastal and Marine Ecological Classification Standard Catalog of Units, Federal Geographic Data Committee FGDC-STD-018-2012. p343.

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

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

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

Moore, M. 2015. Coastal Environment of Otago: Natural Character and Outstanding Natural Features and Landscapes Assessment, Dunedin City Section Report, 63p.

Moller H, Moller SI. 2012. Environmental and lifestyle values at Tūmai Beach Sanctuary. Ecosystems Consultants Report No. 2012/03. 32p.

Muralidhar, A 2014. Turgor regulation in species of *Vaucheria* (Xanthophyceae, Heterokontophyta) from habitats of contrasting salinities. PhD thesis, University of Canterbury, New Zealand. 185p.

Otago Regional Council 2004. Regional Plan: Coast. Published by the Otago Regional Council, Dunedin.

Otago Regional Council 2004. Regional Plan: Water for Otago. Published by the Otago Regional Council, Dunedin.

Plew D, Zeldis J, Dudley B, Shankar U. 2018. Assessment of the eutrophication susceptibility of New Zealand Estuaries. NIWA client Report No 2018206CH, prepared for the Ministry of Environment, New Zealand. 64p.

Plew D, Zeldis J, Dudley B, Whitehead A, Stevens L, Robertson BM, Robertson BP. 2020. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts (2020) 43:2015–2033, https://doi.org/10.1007/s12237-020-00729-w

Reise K, Michaelis M, Rybalka N 2022. Invading grass-like alga transforms rippled sand bars into bumpy muddy flats: arrival of a game changer in the Wadden Sea? Aquatic Invasions 17(1): 1-20.

Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002a. Estuarine environmental assessment and monitoring: A national protocol part A. Development of the monitoring protocol for New Zealand estuaries. Introduction, rationale and methodology. Sustainable Management Fund Contract No. 5096, Cawthron Institute, Nelson, New Zealand. 93p.

Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002b. Estuarine environmental assessment and monitoring: a national protocol part B: development of the monitoring protocol for New Zealand Estuaries. Appendices to the introduction, rationale and methodology. Sustainable Management Fund Contract No. 5096, Cawthron Institute, Nelson, New Zealand. 159p.

Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002c. Estuarine environmental assessment and monitoring: a national protocol part C: application of the estuarine monitoring protocol. Sustainable Management Fund Contract No. 5096, Cawthron Institute, Nelson, New Zealand. 40p.

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

Robertson BM, Stevens LM, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M. 2016b. NZ Estuary Trophic Index. Screening Tool 2. Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

Robertson BM, Stevens LM, Ward N, Robertson BP. 2017. Condition of Southland's Shallow, Intertidal Dominated Estuaries in Relation to Eutrophication and Sedimentation: Output 1: Data Analysis and Technical Assessment - Habitat Mapping Vulnerability Assessment and Monitoring Recommendations Related to Issues of Eutrophication and Sedimentation. Report prepared by Wriggle Coastal Management for Environment Southland. 172p.

Simons J 1974. *Vaucheria compacta*: A euryhaline estuarine algal species. Acta Botanica Neerlandica 23(5-6): 613–626.

South-East Marine Protection Forum (SMPF). 2018. Recommendations to the Minister of Conservation and the Minister of Fisheries: Recommendations towards implementation of the Marine Protected Areas Policy on the South Island's south-east coast of New Zealand. Department of Conservation. Wellington. 314p.

Stevens LM, Forrest BM, Dudley BD, Plew DR, Zeldis JR, Shankar U, Haddadchi A, Roberts KL. 2022. Use of a multi-metric macroalgal index to document severe eutrophication in a New Zealand estuary. New Zealand Journal of Marine and Freshwater Research. doi: 10.1080/00288330.2022.2093226.

Tūmai Beach Environmental Enhancement Group. (TBEEG). 2021. Environmental Enhancement at Tūmai Beach. A restoration plan prepared by the Tūmai residents. Tūmai Beach Report No. 2021/01. 25p.

Waitaki District Council (2004) Waitaki District Plan - Appendix C. Published by the Waitaki District Council, Oamaru.

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

Wilcox MD 2012. Occurrence of the marine yellow-green algae *Vaucheria velutina* C. Agardh and *Vaucheria longicauli*s Hoppaugh (Xanthophyceae: Vaucheriaceae) in Auckland, New Zealand. New Zealand Journal of Marine and Freshwater Research 46(2): 285-290.

Zeldis J, Whitehead A, Plew D, Madarasz-Smith, A, Oliver M, Stevens L, Robertson B, Storey R, Burge O, Dudley B. 2017. The New Zealand Estuary Trophic Index (ETI) Tools: Tool 2 - Assessing Estuary Trophic State using Measured Trophic Indicators. Ministry of Business, Innovation and Employment Envirolink Tools: C01X1420.

APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[1]*Additions to the NEMP classification.*

SUBSTRATE (physical and zoogenic habitat)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Shell bank: Area that is dominated by dead shells

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

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

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

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

Water Bodies
- 20 Lake or Pond
- 21 River

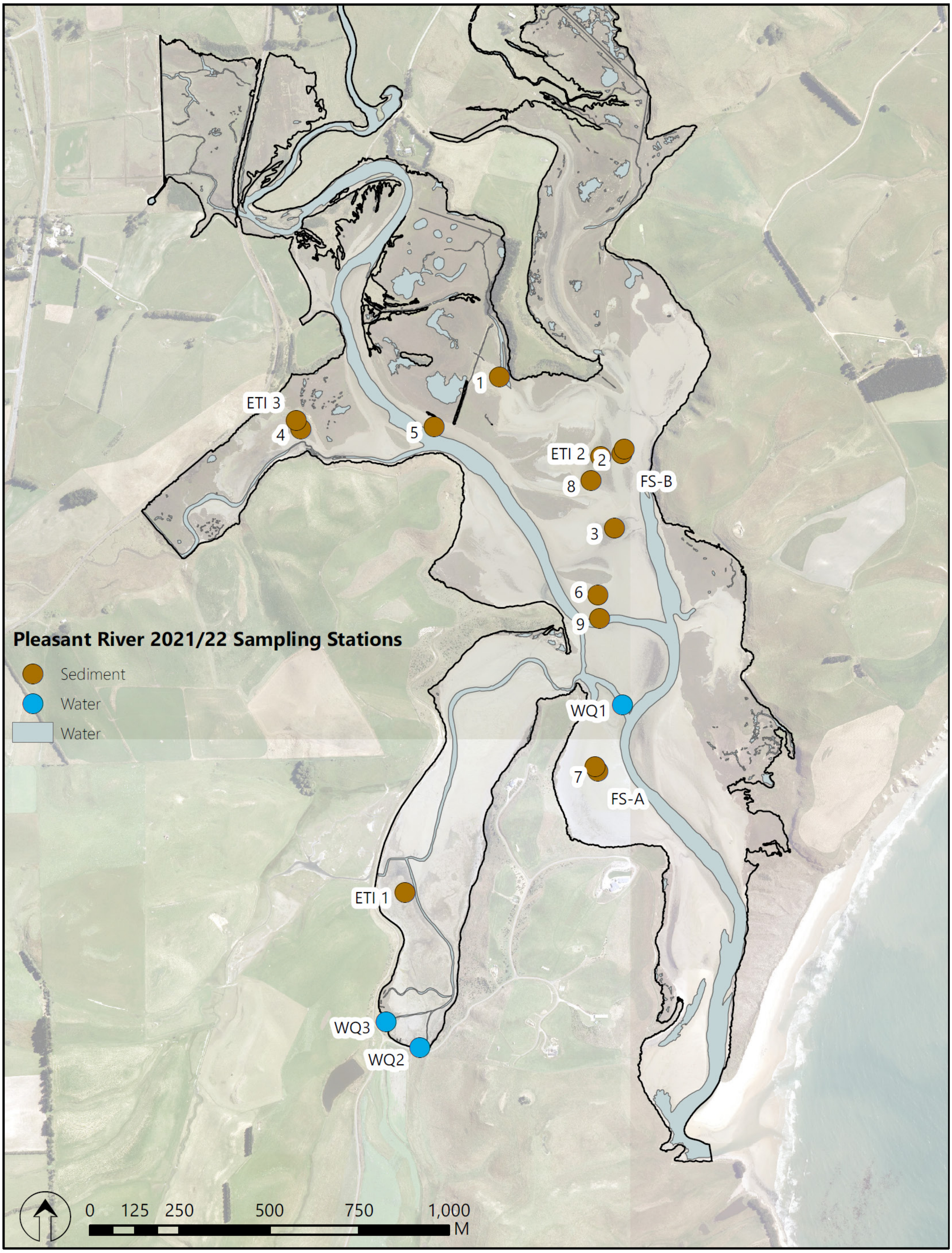
Cropland
- 30 Short-rotation Cropland
- 33 Orchard Vineyard & Other Perennial Crops

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

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

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

APPENDIX 2. SEDIMENT SAMPLING STATIONS PLEASANT RIVER ESTUARY, NOVEMBER 2021



Station	Easting	Northing	Field Code	Subjective % mud	% mud	% sand	% gravel	aRPD (mm)
Sediment - 1	1422035.8	4953411.8	vssm50_90	50 to 90%	74.0	25.0	1.0	1
Sediment - 2	1422375.4	4953197.5	sms10_25	10 to 25%	45.6	53.8	0.5	3
Sediment - 3	1422355.7	4952990.3	fs0_10	<10%	12.3	87.3	0.4	10
Sediment - 4	1421481.4	4953267.2	vssm50_90	50 to 90%	72.8	27.1	< 0.1	1
Sediment - 5	1421853.2	4953273.5	sms10_25	10 to 25%	26.5	73.3	0.2	30
Sediment - 6	1422310.7	4952803.9	sms25_50	25 to 50%	68.5	30.9	0.6	5
Sediment - 7	1422309.7	4952313.7	sms25_50	25 to 50%	46.5	53.4	< 0.1	2
Sediment - 8	1422290.2	4953124	sms50_90	50 to 90%	41.9	57.7	0.4	nd.
Sediment - 9	1422315.2	4952740	sms25_50	25 to 50%	61.2	38.5	0.3	nd.
ETI 1	1421772	4951977	sms50_90	50 to 90%	81.1	17.9	1.1	1
ETI 2	1422317	4953190	vssm50_90	50 to 90%	63.0	36.6	0.4	0
ETI 3	1421470	4953291	sms50_90	50 to 90%	75.2	24.4	0.4	2
FS-A	1422302	4952327	sms25_50	25 to 50%	38.5	61.5	0.1	3
FS-B	1422384	4953211	sms25_50	25 to 50%	41.7	57.5	0.8	3

In general, there was good agreement between the subjective % mud content and measured % mud content, except for four samples, particularly around the 50% mud range. Sediment samples are collected from a surface scraping down to 20mm in some instances a fine layer of mud is observed on the sediment surface and could contribute to the higher mud contents observed in the laboratory analysed samples (see photos).

Sediment – 2

Sediment – 6

Hill Laboratories
TRIED, TESTED AND TRUSTED
R J Hill Laboratories Limited
28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand
T 0508 HILL LAB (44 555 22)
T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	2783401
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:	114513
		Order No:	
		Client Reference:	Broadscale- Pleasant River
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		Ples-Otag-1 25-Nov-2021 12:50 pm	Ples-Otag-2 25-Nov-2021 1:30 pm	Ples-Otag-3 25-Nov-2021 2:30 pm	Ples-Otag-4 25-Nov-2021 6:00 pm	Ples-Otag-5 25-Nov-2021 12:40 pm
Lab Number:		2783401.1	2783401.2	2783401.3	2783401.4	2783401.5
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	54	72	81	68	69
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	1.0	0.5	0.4	< 0.1	0.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	25.0	53.8	87.3	27.1	73.3
Fraction < 63 µm*	g/100g dry wt	74.0	45.6	12.3	72.8	26.5

Sample Name:		Ples-Otag-6 25-Nov-2021 3:30 pm	Ples-Otag-7 25-Nov-2021 4:30 pm	Ples-Otag-8 25-Nov-2021 9:10 am	Ples-Otag-9 25-Nov-2021 3:00 pm	Ples-Otag-ETI-1 26-Nov-2021 6:30 pm
Lab Number:		2783401.6	2783401.7	2783401.8	2783401.9	2783401.10
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	57	66	63	63	44
Total Recoverable Phosphorus	mg/kg dry wt	-	-	-	-	780
Total Sulphur*‡	g/100g dry wt	-	-	-	-	0.83
Total Nitrogen*	g/100g dry wt	-	-	-	-	0.46
Total Organic Carbon*	g/100g dry wt	-	-	-	-	3.5
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.6	< 0.1	0.4	0.3	1.1
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	30.9	53.4	57.7	38.5	17.9
Fraction < 63 µm*	g/100g dry wt	68.5	46.5	41.9	61.2	81.1

Sample Name:		Ples-Otag-ETI-2 26-Nov-2021 5:00 pm	Ples-Otag-ETI-3 26-Nov-2021 6:00 pm			
Lab Number:		2783401.11	2783401.12			
Individual Tests						
Dry Matter of Sieved Sample*	g/100g as rcvd	62	67	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	530	550	-	-	-
Total Sulphur*‡	g/100g dry wt	0.42	0.29	-	-	-
Total Nitrogen*	g/100g dry wt	0.18	0.10	-	-	-
Total Organic Carbon*	g/100g dry wt	1.17	0.72	-	-	-
3 Grain Sizes Profile as received*						
Fraction >/= 2 mm*	g/100g dry wt	0.4	0.4	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	36.6	24.4	-	-	-
Fraction < 63 µm*	g/100g dry wt	63.0	75.2	-	-	-

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

Analyst's Comments

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

Appendix No.1 - SGS Report

Summary of Methods

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

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	10-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	10-12
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-12
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	10-12
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	10-12
Total Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g dry wt	10-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	10-12
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	10-12
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-12
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12

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

Testing was completed between 08-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.

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.

REFERENCES

DETR 2001. Development of ecological quality objectives with regard to eutrophication. Final report, unpublished.

Foden J, Wells E, Scanlan C, Best MA. 2010. Water Framework Directive development of classification tools for ecological assessment: Opportunistic Macroalgae Blooming. UK TAG Report for Marine Plants Task Team, January 2010, Publ. UK TAG.

Green L, Sutula M, and Fong P. 2014. How much is too much? Identifying benchmarks of adverse effects of macroalgae on the macrofauna in intertidal flats. Ecological Applications 24: 300–314.

Hull SC. 1987. Macroalgal mats and species abundance: a field experiment. Estuaries and Coastal Shelf Science 25, 519-532.

Lowthion D, Soulsby PG, Houston MCM. 1985. Investigation of a eutrophic tidal basin: 1. Factors affecting the distribution and biomass of macroalgae. Marine Environmental Research 15: 263–284.

McLaughlin K, Sutula M, Busse L, Anderson S, Crooks J, Dagit R, Gibson D, Johnston K, Stratton L. 2014. A regional survey of the extent and magnitude of eutrophication in Mediterranean Estuaries of Southern California, USA. Estuaries and Coasts 37: 259–278.

Plew D, Zeldis J, Dudley B, Whitehead A, Stevens L, Robertson BM, Robertson BP. 2020a. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts (2020) 43:2015–2033, https://doi.org/10.1007/s12237-020-00729-w

Raffaelli D, Hull S, Milne H, 1989. Long-term changes in nutrients, weedmats and shore birds in an estuarine system. Cahiers de Biologie Marine. 30, 259–270.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Oliver M. 2016b. NZ estuary trophic index screen tool 2. Determining monitoring indicators and assessing estuary trophic

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.

state. Prepared for Environlink tools project: estuarine trophic index, 68: MBIE/NIWA Contract No: COX1420.

Sutula M, Green L, Cicchetti G, Detenbeck N, Fong P. 2014. Thresholds of adverse effects of macroalgal abundance and sediment organic matter on benthic habitat quality in estuarine intertidal flats. Estuaries and Coasts 37: 1532–1548.

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

Wither A, 2003. Guidance for sites potentially impacted by algal mats (green seaweed). EC Habitats Directive Technical Advisory Group report WQTAG07c.

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.

REFERENCES

Jørgensen, N. and Revsbech, N.P. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. Limnology and Oceanography 30:111-122.

Nelson, Walter G. (ed.) 2009. Seagrasses and Protective Criteria: A Review and Assessment of Research Status. Office of Research and Development, National Health and Environmental Effects Research Laboratory, EPA/600/R-09/050.

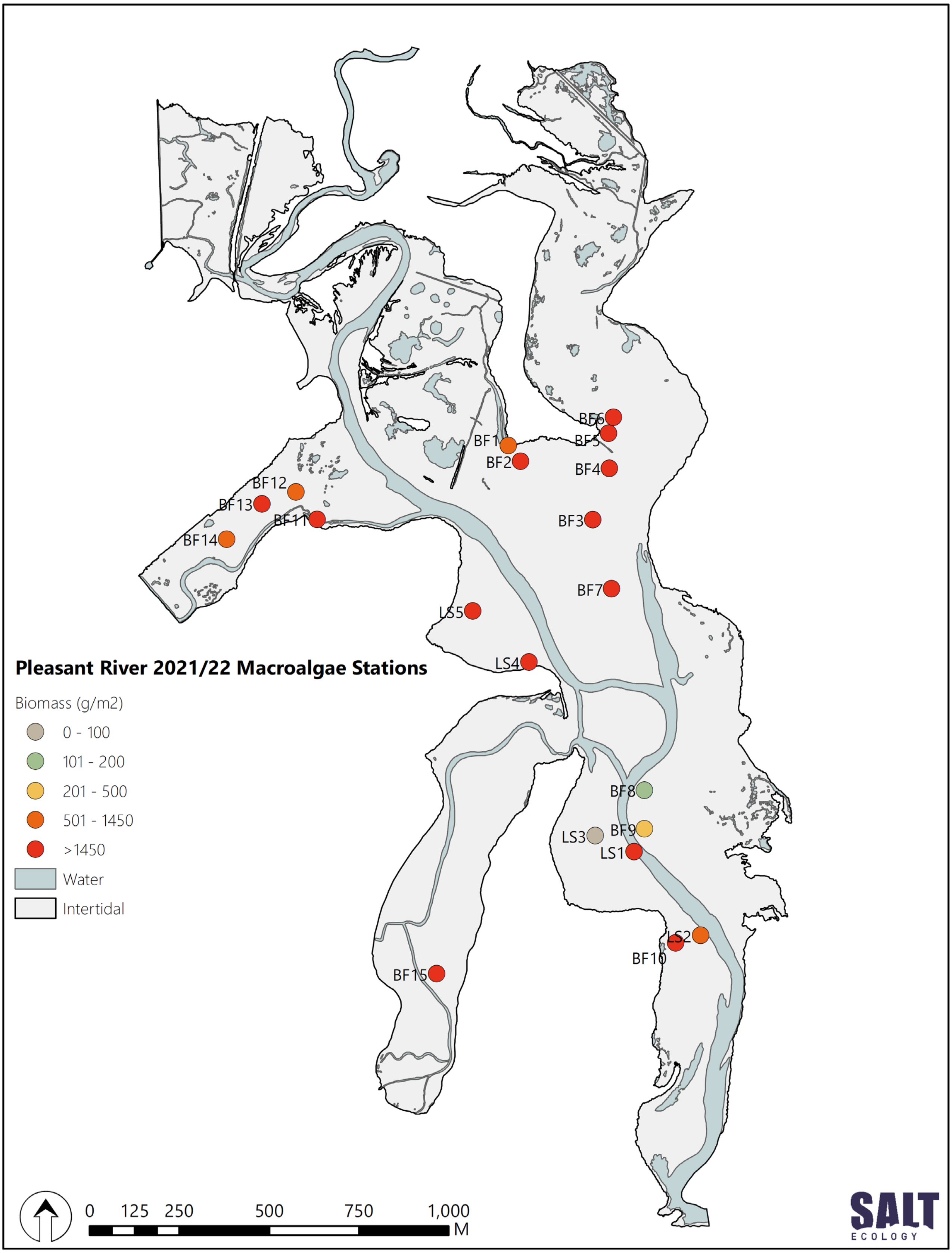
Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016a, b. NZ Estuary Trophic Index. Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data (47p). Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State (68p). Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group) 2014. UKTAG Transitional and Coastal Water

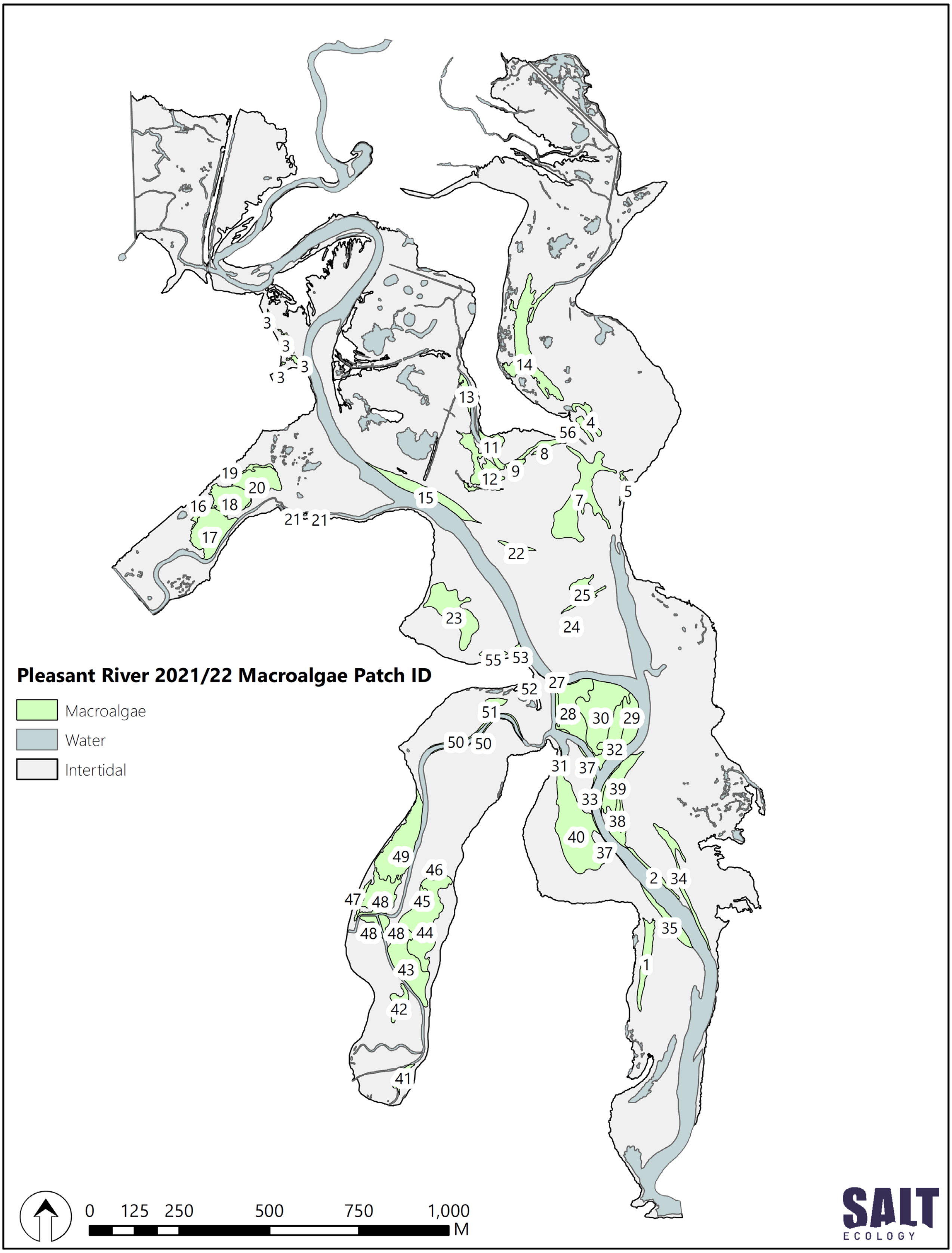
Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool.http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

Zeldis J, Whitehead A, Plew D, Madarasz-Smith, A, Oliver M, Stevens L, Robertson B, Storey R, Burge O, Dudley B. 2017. The New Zealand Estuary Trophic Index (ETI) Tools: Tool 2 - Assessing Estuary Trophic State using Measured Trophic Indicators. Ministry of Business, Innovation and Employment Envirolink Tools C01X1420.

APPENDIX 5: MACROALGAL BIOMASS STATIONS & OMBT, PLEASANT RIVER ESTUARY



Macroalgal patch ID for the OMBT-EQR



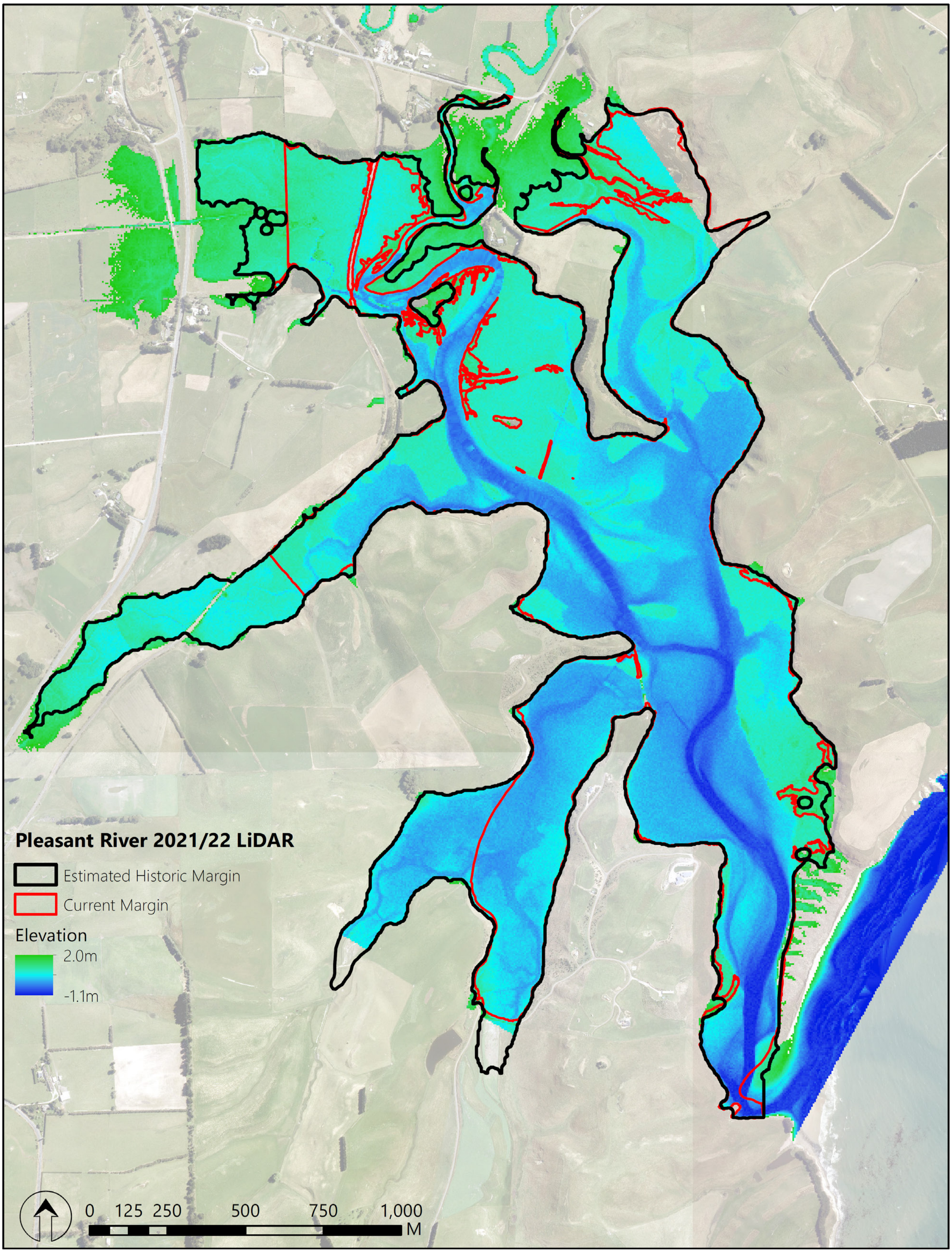
Macroalgal patch information used in the calculation of the OMBT-EQR

PatchID	Dominant Species	Sub-dominant spcies	% Cover	Percent Cover Category	Biomass (g/m^2)	Biomass Category	Entrained	Substrate	Area (ha)
1	*Agarophyton* spp.	*Ulva* spp.	95	Complete (>90%)	3400	Very high (>1450)	0	sSM	0.50
2	*Agarophyton* spp.		10	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fS	0.16
3	*Agarophyton* spp.	*Ulva* spp.	80	Dense (70 to <90%)	2500	Very high (>1450)	1	vsSM	0.16
4	*Ulva* spp.	*Agarophyton* spp.	90	Complete (>90%)	3000	Very high (>1450)	0	sSM	0.18
5	*Agarophyton* spp.		25	Sparse (10 to <30%)	1000	High (501 - 1450)	1	fMS10	0.07
6	*Ulva* spp.	*Agarophyton* spp.	25	Sparse (10 to <30%)	100	Very low (1 - 100)	0	sSM	0.01
7	*Ulva* spp.	*Agarophyton* spp.	100	Complete (>90%)	7560	Very high (>1450)	1	sSM	1.59
8	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1000	High (501 - 1450)	0	sSM	0.20
9	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1500	Very high (>1450)	0	sMS25	0.10
10	*Ulva* spp.		40	Low-Moderate (30 to <50%)	600	High (501 - 1450)	0	sSM	0.07
11	*Agarophyton* spp.	*Ulva* spp.	69	High-Moderate (50 to <70%)	1480	Very high (>1450)	1	sSM	0.26
12	*Ulva* spp.	*Agarophyton* spp.	20	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fMS10	0.78
13	*Agarophyton* spp.	*Ulva* spp.	50	High-Moderate (50 to <70%)	1000	High (501 - 1450)	1	sSM	0.14
14	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1300	High (501 - 1450)	1	sSM	1.52
15	*Agarophyton* spp.		1	Very sparse (1 to <10%)	10	Very low (1 - 100)	0	fMS10	0.76
16	*Ulva* spp.	*Agarophyton* spp.	35	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	1	vsSM	0.06
17	*Ulva* spp.	*Agarophyton* spp.	70	Dense (70 to <90%)	1000	High (501 - 1450)	1	vsSM	1.04
18	*Ulva* spp.	*Agarophyton* spp.	90	Complete (>90%)	1600	Very high (>1450)	1	vsSM	0.67
19	*Ulva* spp.	*Agarophyton* spp.	50	High-Moderate (50 to <70%)	700	High (501 - 1450)	1	vsSM	0.11
20	*Ulva* spp.	*Agarophyton* spp.	100	Complete (>90%)	1200	High (501 - 1450)	1	vsSM	0.75
21	*Agarophyton* spp.		85	Dense (70 to <90%)	5680	Very high (>1450)	1	vsSM	0.03
22	*Agarophyton* spp.	*Ulva* spp.	30	Low-Moderate (30 to <50%)	200	Low (101 - 200)	0	sMS25	0.09
23	*Ulva* spp.	*Agarophyton* spp.	80	Dense (70 to <90%)	2240	Very high (>1450)	1	sSM	1.17
24	*Agarophyton* spp.		10	Sparse (10 to <30%)	200	Low (101 - 200)	0	sSM	0.04
25	*Ulva* spp.	*Agarophyton* spp.	75	Dense (70 to <90%)	2000	Very high (>1450)	0	sMS25	0.28
26	*Ulva* spp.		5	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	fMS10	0.02
27	*Ulva* spp.	*Agarophyton* spp.	11	Sparse (10 to <30%)	80	Very low (1 - 100)	0	fMS10	0.12
28	*Agarophyton* spp.		1	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	fMS10	1.13
29	*Agarophyton* spp.	*Ulva* spp.	20	Sparse (10 to <30%)	350	Moderate (201 - 500)	1	fMS10	0.55
30	*Agarophyton* spp.		1	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	fS	1.54
31	*Ulva* spp.		10	Sparse (10 to <30%)	40	Very low (1 - 100)	0	fMS10	0.03
32	*Agarophyton* spp.		10	Sparse (10 to <30%)	200	Low (101 - 200)	1	fMS10	0.61
33	*Agarophyton* spp.	*Ulva* spp.	80	Dense (70 to <90%)	2500	Very high (>1450)	1	sSM	0.07
34	*Agarophyton* spp.		30	Low-Moderate (30 to <50%)	350	Moderate (201 - 500)	0	fMS10	0.42
35	*Agarophyton* spp.	*Ulva* spp.	12	Sparse (10 to <30%)	1280	High (501 - 1450)	1	fS	0.40
36	*Agarophyton* spp.		10	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fMS10	0.01
37	*Agarophyton* spp.		20	Sparse (10 to <30%)	1840	Very high (>1450)	0	fMS10	0.05
37	*Agarophyton* spp.		20	Sparse (10 to <30%)	1840	Very high (>1450)	0	fS	0.04
38	*Agarophyton* spp.	*Ulva* spp.	26	Sparse (10 to <30%)	250	Moderate (201 - 500)	0	fMS10	0.11
39	*Agarophyton* spp.	*Ulva* spp.	12	Sparse (10 to <30%)	110	Low (101 - 200)	0	fMS10	0.91
40	*Agarophyton* spp.		10	Sparse (10 to <30%)	90	Very low (1 - 100)	1	sMS25	2.17
41	*Ulva* spp.		30	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	0	vsSM	0.15
42	*Ulva* spp.		50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	vsSM	0.24
43	*Ulva* spp.	*Agarophyton* spp.	80	Dense (70 to <90%)	4240	Very high (>1450)	0	vsSM	1.17
44	*Ulva* spp.	*Agarophyton* spp.	35	Low-Moderate (30 to <50%)	300	Moderate (201 - 500)	0	fSM	1.61
44	*Ulva* spp.	*Agarophyton* spp.	35	Low-Moderate (30 to <50%)	300	Moderate (201 - 500)	0	fSM	0.01
45	*Ulva* spp.	*Agarophyton* spp.	80	Dense (70 to <90%)	3000	Very high (>1450)	0	vsSM	0.11
46	*Agarophyton* spp.	*Ulva* spp.	50	High-Moderate (50 to <70%)	3000	Very high (>1450)	0	fSM	0.04
47	*Ulva* spp.		90	Complete (>90%)	1500	Very high (>1450)	0	sSM	0.09
48	*Ulva* spp.	*Agarophyton* spp.	85	Dense (70 to <90%)	1500	Very high (>1450)	0	vsSM	1.00
49	Unspecified Macroalgae	*Agarophyton* spp.	2	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	sMS25	1.46
50	*Agarophyton* spp.		10	Sparse (10 to <30%)	1000	High (501 - 1450)	1	sMS25	0.20
51	*Agarophyton* spp.		5	Very sparse (1 to <10%)	40	Very low (1 - 100)	0	sMS25	0.22
52	*Agarophyton* spp.	*Ulva* spp.	11	Sparse (10 to <30%)	80	Very low (1 - 100)	0	fMS10	0.01
53	*Agarophyton* spp.		10	Sparse (10 to <30%)	100	Very low (1 - 100)	0	fMS10 shel	0.08
54	*Agarophyton* spp.		40	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	1	sSM	0.01
55	*Agarophyton* spp.		100	Complete (>90%)	1680	Very high (>1450)	1	sSM	0.12
56	*Ulva* spp.	*Agarophyton* spp.	95	Complete (>90%)	1840	Very high (>1450)	1	fMS10	0.00
56	*Ulva* spp.	*Agarophyton* spp.	95	Complete (>90%)	1840	Very high (>1450)	1	sSM	0.10

APPENDIX 6: DOMINANT SALT MARSH SPECIES IN PLEASANT RIVER ESTUARY

SubClass	Dominant species	Sub-dominant species 1	Sub-dominant species 2	Area (Ha)	% Salt marsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	0.07	0.08
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)		0.02	0.03
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)		0.05	0.06
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	*Ulex europaeus* (Gorse)	0.01	0.01
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)			0.12	0.14
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Poa cita* (Silver tussock)	*Apodasmia similis* (Jointed wirerush)	0.02	0.03
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)	*Apodasmia similis* (Jointed wirerush)	0.17	0.21
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)		0.05	0.06
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.18	0.22
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	0.01	0.01
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Stipa stipoides*	*Festuca arundinacea* (Tall fescue)	0.04	0.05
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Ulex europaeus* (Gorse)		0.03	0.04
Tussockland	*Poa cita* (Silver tussock)	*Sarcocornia quinqueflora* (Glasswort)		0.00	0.00
Tussockland	*Poa cita* (Silver tussock)	*Selliera radicans* (Remuremu)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.05	0.06
Sedgeland	*Schoenoplectus pungens* (Three square)			0.19	0.24
Sedgeland	*Schoenoplectus pungens* (Three square)	*Samolus repens* (Primrose)	*Apodasmia similis* (Jointed wirerush)	0.01	0.01
Sedgeland	*Schoenoplectus pungens* (Three square)	*Samolus repens* (Primrose)		0.01	0.01
Sedgeland	*Schoenoplectus pungens* (Three square)	*Sarcocornia quinqueflora* (Glasswort)		0.02	0.02
Grassland	*Festuca arundinacea* (Tall fescue)	*Atriplex prostrata* (Orache, Creeping saltbush)		0.01	0.02
Grassland	*Festuca arundinacea* (Tall fescue)	*Ficinia nodosa* (Knobby clubrush)	*Poa cita* (Silver tussock)	0.07	0.08
Grassland	*Festuca arundinacea* (Tall fescue)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	0.20	0.25
Grassland	*Festuca arundinacea* (Tall fescue)	*Ulex europaeus* (Gorse)		0.04	0.05
Rushland	*Apodasmia similis* (Jointed wirerush)			0.53	0.65
Rushland	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		0.60	0.75
Rushland	*Ficinia nodosa* (Knobby clubrush)			0.00	0.00
Rushland	*Ficinia nodosa* (Knobby clubrush)	*Thyridia repens* (New Zealand musk)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.01	0.02
Herbfield	*Cotula coronopifolia* (Bachelor's button)			0.08	0.10
Herbfield	*Leptinella dioica*			0.01	0.01
Herbfield	*Leptinella dioica*	*Selliera radicans* (Remuremu)		0.02	0.03
Herbfield	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)		0.10	0.13
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.10	0.12
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	*Selliera radicans* (Remuremu)	0.06	0.07
Herbfield	*Sarcocornia quinqueflora* (Glasswort)			14.09	17.52
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)		0.01	0.02
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Suaeda novaezelandiae* (Sea blite)	0.00	0.00
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.76	0.94
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)		0.67	0.83
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	0.44	0.55
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Atriplex prostrata* (Orache, Creeping saltbush)	6.15	7.65
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Leptinella dioica*	0.30	0.37
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Lycium ferocissimum* (Boxthorn)	0.07	0.09
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)		36.23	45.06
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	0.11	0.14
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	5.88	7.31
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Suaeda novaezelandiae* (Sea blite)	2.24	2.79
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.24	0.30
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Disphyma australe* (NZ Ice Plant, Horokaka)	0.00	0.00
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)		2.74	3.41
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Selliera radicans* (Remuremu)	0.67	0.84
Herbfield	*Selliera radicans* (Remuremu)	*Atriplex prostrata* (Orache, Creeping saltbush)	*Sarcocornia quinqueflora* (Glasswort)	0.04	0.05
Herbfield	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Samolus repens* (Primrose)	0.07	0.09
Herbfield	*Selliera radicans* (Remuremu)	*Leptinella dioica*	*Sarcocornia quinqueflora* (Glasswort)	0.22	0.27
Herbfield	*Selliera radicans* (Remuremu)			0.86	1.07
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Atriplex prostrata* (Orache, Creeping saltbush)	0.25	0.32
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)		3.48	4.33
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	0.79	0.99
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.31	0.39
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	0.85	1.06
Herbfield	*Suaeda novaezelandiae* (Sea blite)			0.00	0.01
Herbfield	*Suaeda novaezelandiae* (Sea blite)	*Sarcocornia quinqueflora* (Glasswort)		0.00	0.00
Herbfield	*Thyridia repens* (New Zealand musk)			0.04	0.05
Grand Total				80.4	100

APPENDIX 7: HISTORIC MARGIN ESTIMATED FROM LIDAR AND AERIAL IMAGERY



APPENDIX 8: HISTORIC SALT MARSH EXTENT ESTIMATED FROM LIDAR AND AERIAL IMAGERY

Historic salt marsh digitised from 1958 aerial image (source: retrolens.co.nz). Where reclamation or margin modification was already present salt marsh extent was extrapolated using the upper estuary boundary and imagery.

APPENDIX 9: RAW SEDIMENT AND MACROFAUNA DATA

Sediment data and macrofauna indices used for ETI calculation.

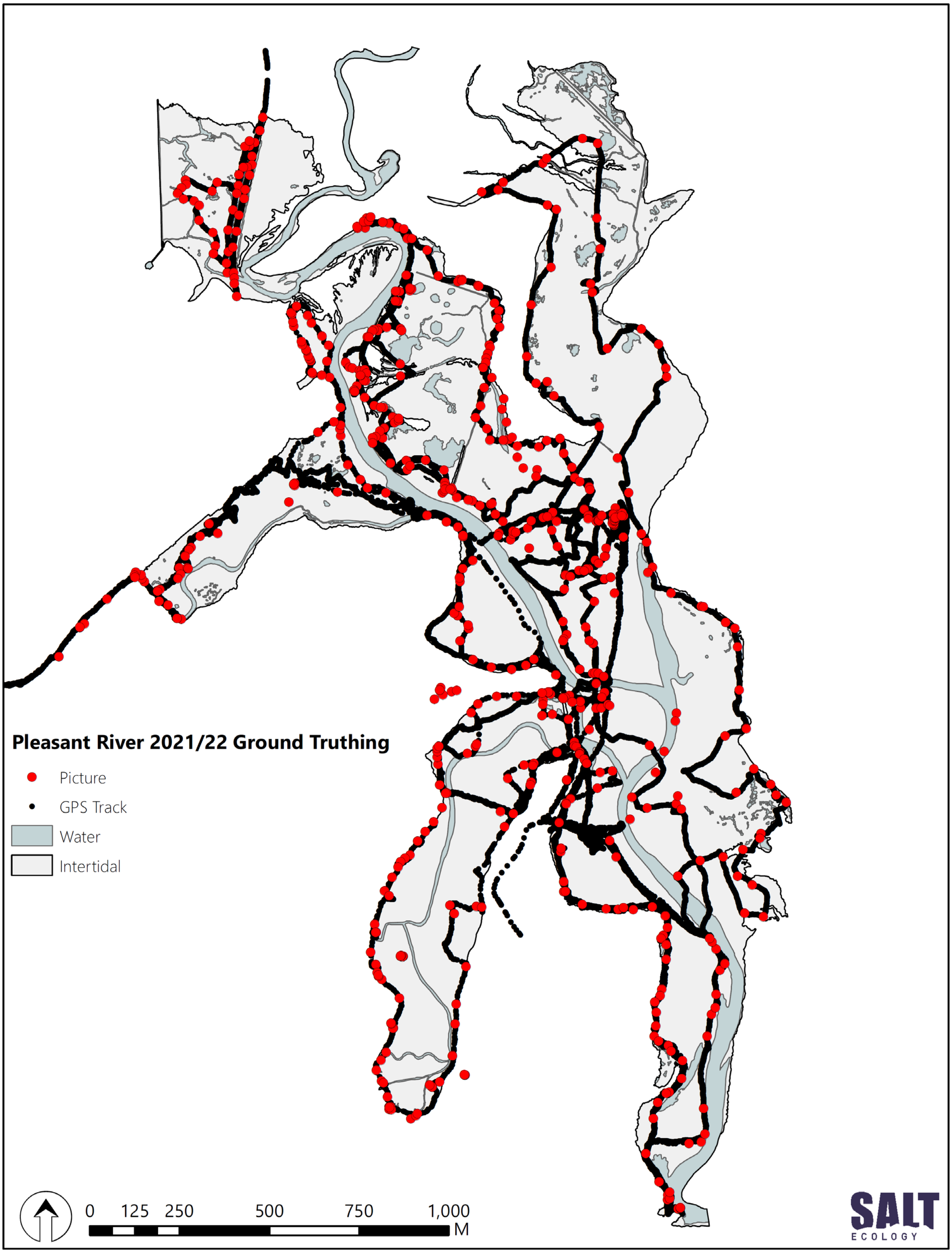
Parameter	Unit	PLES-OTAG ETI - 1	PLES-OTAG ETI - 2	PLES-OTAG ETI - 3
Sediment Chemistry				
Total Phosphorus (TP)	mg/kg dry wt	780	530	550
Total Sulfur (TS)	g/100g dry wt	0.83	0.42	0.29
Total Nitrogen (TN)	g/100g dry wt	0.46	0.18	0.10
Total Organic Carbon (TOC)	g/100g dry wt	3.50	1.17	0.72
Gravel (≥2mm)	g/100g dry wt	1.1	0.4	0.4
Sand (≥63mm to <2mm)	g/100g dry wt	17.9	36.6	24.4
Mud (≤63mm)	g/100g dry wt	81.1	63.0	75.2
aRPD	mm	1	0	2
Macrofauna indices				
AZTI Marine Biotic index	no unit	4.50	5.29	nd.
Overall Abundance	no unit	279	1462	nd.
Overall Diversity	no unit	7	17	nd.

*nd. = no data

Raw macrofauna data. EG refers to ecological sensitivity group used to calculate the AZTI Marine Biotic index.

Main group	Taxa	Habitat	EG	PLES-OTAG ETI-1	PLES-OTAG ETI-2
Amphipoda	*Paracalliope novizealandiae*	Infauna	I	42	26
Amphipoda	*Paracorophium excavatum*	Infauna	IV	2	
Amphipoda	*Paramoera chevreuxi*	Infauna	II		2
Amphipoda	*Parawaldeckia kidderi*	Infauna	II		10
Bivalvia	*Arthritica* sp. 5	Infauna	III	4	99
Decapoda	*Hemiplax hirtipes*	Infauna	III		1
Gastropoda	*Cominella glandiformis*	Epibiota	III		1
Gastropoda	*Micrelenchus huttonii*	Epibiota	NA		1
Gastropoda	*Notoacmea scapha*	Epibiota	II		1
Gastropoda	*Zeacumantus subcarinatus*	Epibiota	II	100	411
Nemertea	*Nemertea*	Infauna	III		3
Oligochaeta	*Naididae*	Infauna	V	56	
Polychaeta	*Boccardia syrtis*	Infauna	II		32
Polychaeta	*Capitella cf. capitata*	Infauna	V	74	841
Polychaeta	*Paradoneis lyra*	Infauna	III		2
Polychaeta	*Perinereis vallata*	Infauna	III		1
Polychaeta	*Platynereis sp.*	Infauna	III		3
Polychaeta	*Scolecolepides benhami*	Infauna	IV	1	23
Polychaeta	*Scoloplos cylindrifer*	Infauna	I		5

APPENDIX 10: GROUND-TRUTHING IN PLEASANT RIVER ESTUARY

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