SALT ECOLOGY

Broad Scale Intertidal Habitat Mapping of Freshwater Estuary

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Broad Scale Intertidal Habitat Mapping of Freshwater Estuary

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for

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October 2020

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GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
GIS	Geographic Information System
GEZ	Gross Eutrophic Zone
ES	Environment Southland
HEC	Area of High Enrichment Conditions
LCDB	Land Cover Data Base
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
SOE	State of Environment (monitoring)

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BACKGROUND

As part of its State of the Environment programme, Environment Southland (ES) undertakes monitoring and assessment of estuaries and other coastal environments. Freshwater Estuary on Rakiura/Stewart Island has been identified by ES as a priority for monitoring, as its relatively pristine condition makes it a valuable reference system against which regionally degraded estuaries can be compared. This report describes an intertidal 'broad scale' survey conducted in the estuary in February 2020, following methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). The survey involved assessing the dominant substrate and vegetation features present in the estuary including seagrass, salt marsh and macroalgae. The results from the 2020 survey are compared to two earlier surveys (2008 & 2013), the status and long-term trends in estuary health are evaluated, and future monitoring needs are discussed.

KEY FINDINGS

The following bullet points summarise key broad scale monitoring results, and the table below rates them using preliminary criteria for assessing estuary health.

- Freshwater Estuary is in a native forest catchment with an intertidal area of ~663ha characterised by clean (unenriched) sand-dominated substrates. Mud-dominated sediment (>50% mud), a feature that typifies estuaries in modified catchments elsewhere in Southland, was a minor component (14.2ha, 2.1%), and located almost exclusively within salt marsh habitat.
- In February 2020, macroalgal growth was reasonably extensive in some seaward low tide areas. However, it consisted of a healthy mix of species not typically seen in other estuaries regionally or nationally. There was no proliferation of opportunistic species that occur in nutrient-enriched estuaries elsewhere in Southland.
- Extensive seagrass beds were a dominant feature of the intertidal flats, most likely reflecting the very low sediment mud content in the estuary and the high water clarity. The estuary provides one of the few remaining examples of the likely previous extent of important seagrass habitat in New Zealand estuaries. A 45ha reduction in seagrass extent was recorded from 2013 to 2020. Of this ~3ha were losses attributable to seagrass erosion along the edge of the river channel. The remaining changes were attributable to improved mapping accuracy as a direct result of higher resolution imagery being available in 2020.
- The salt marsh was not particularly extensive (4.6% of the intertidal area), being confined to the western margins and consisting predominantly of jointed wire rush. Although the major estuarine salt marsh weed tall fescue was present, it was relatively scarce. The 'fair' condition rating for salt marsh area when expressed as a percentage of the estuary area reflects that Freshwater Estuary has limited suitable habitat available for salt marsh growth because of the open nature of the delta, the generally steep surrounding hills, and the confined nature of the upper river estuary contained within incised river banks.

Cockle beds across intertidal flats of Freshwater estuary, with seagrass and native forest in the background

Broad scale indicator	Unit	2008	2013	2020
Mud-dominated substrate[1]	% of intertidal area >50% mud	0	0.3	0.1
Macroalgae (OMBT)[2]	Ecological Quality Rating (EQR)	na	na	0.71
Seagrass[3]	% decrease from baseline	0	6.3	13.3
Salt marsh extent (current)	% of intertidal area	6.0	14.8	6.0
Historical salt marsh extent[3]	% of historical remaining	100	100	94.7
200m terrestrial margin	% densely vegetated	99.5	99.5	99.5
High Enrichment Conditions	ha	na	na	0
High Enrichment Conditions	% of estuary	na	na	0

[1] To enable comparison across years, mud dominated substrate assessed as percentage of intertidal area excluding salt marsh (235.9ha)
[2] OMBT = Opportunistic Macroalgal Blooming Tool
[3] Data for 2008 used as baseline for seagrass and salt marsh
Condition rating colour key as follows:

Very Good	Good	Fair	Poor

There have been no substantive changes in estuary condition since the first survey in 2008. As Freshwater Estuary lies within Rakiura National Park and the waters of Te Whaka a Te Wera Mataitai Reserve, there is little potential for direct human modification of the estuary, salt marsh or terrestrial margin, and past habitat disturbance has been minimal. Consequently, it provides an important reference system against which to assess the condition of other estuaries in Southland and New Zealand, especially in the context of drivers of future changes expected from global stressors such as climate change and sea level rise.

RECOMMENDATIONS

Given that Freshwater Estuary is in a relatively pristine state and not vulnerable to the stressors that adversely affect most estuarine systems in New Zealand, no specific management actions are needed. However, repeated broad scale surveys every few years (e.g. 5-yearly) will enable long term changes to be tracked.

Salt marsh in the upper estuary and native forest in the background

1. INTRODUCTION

1.1 GENERAL BACKGROUND

Monitoring the ecological condition of estuarine habitats is critical to their management. Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP, Robertson et al. 2002). The NEMP is intended to provide resource managers nationally with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results establish a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale monitoring to map 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.

Environment Southland (ES) has undertaken monitoring of selected estuaries in the Southland region using the NEMP methods and other approaches (e.g. synoptic surveys, sedimentation monitoring) since 1999. Much of the monitoring effort has focused on estuaries at risk from problems relating to catchment land use. Particular risks arise from muddy sediment inputs that alter estuary habitats, and excess nutrient loads that lead to symptoms of eutrophication such as excessive macroalgal (seaweed) growth (e.g. Stevens 2018).

In this context, ES also has an interest in monitoring estuaries that are less susceptible to human-induced changes, as they provide comparative systems for understanding the condition of estuaries in a more natural state. Such systems are commonly referred to as reference estuaries, of which one of the most important nationally is Freshwater Estuary in Paterson Inlet, Rakiura/Stewart Island (Fig. 1).

NEMP broad scale surveys have been undertaken in Freshwater Estuary in 2008 and 2013 (Stevens & Robertson 2008, 2013) with four fine scale surveys conducted between 2009 and 2013 (Robertson & Stevens 2009, 2010, 2011, 2013).

Salt Ecology was contracted to carry out a further NEMP broad scale survey in the estuary in February 2020, which was conducted alongside a fine scale survey being undertaken by ES staff. This report describes the methods and results of the broad scale work, compares findings with the two earlier surveys, and discusses the current status and trends in estuary health. Recommendations for future monitoring and assessment are also made.

1.2 BACKGROUND TO FRESHWATER ESTUARY

Background information on Freshwater Estuary is provided in the previous survey reports and is summarised below. Freshwater Estuary is a relatively large (818ha), unmodified 'tidal river plus intertidal delta' type estuary located within the confines of Paterson Inlet. Fed by the largest river on Stewart Island, Freshwater River, it drains the native forest catchment of the Mt Anglem highlands and Ruggedy Mountains area (Table 1, Fig. 2).

Its lower reaches meander across Freshwater Valley, the largest area of flat land on Stewart Island. The estuary itself is relatively shallow (mean depth ~2m), has an extensive intertidal area (77% of the estuary is exposed at low tide), and supports large seagrass beds. The combination of a native bush catchment with clear freshwater inflows, as well as good flushing and wave resuspension, means that the majority of the delta sediments are sandy and homogeneous, with muddy sediments described in previous surveys as being a very minor component (<1%).

Ecologically, habitat diversity within the estuary is high, given the benefits of extensive sandy intertidal flats and seagrass beds, clear seawater, salt marsh, and a native forest catchment. It also provides important habitat for the endangered NZ dotterel. Recreational use of the estuary is predominantly walking, sea kayaking, bird study, scenic values, and where allowed, fishing and shellfish collection. Commercially, the estuary is used for access to the Stewart Island walkway.

The presence of stressors or threats is relatively low. The native forest surrounding the estuary is protected within Rakiura National Park, while the waters of Paterson Inlet are managed under a mataitai (Te Whaka a Te Wera Mataitai Reserve). The main threats to the estuary are weed and pest invasions, climate change, and sea level rise. Overall, the unmodified nature of the estuary and its catchment make Freshwater Estuary a valuable reference system in a regional and national context.

Fig. 1 Location of Freshwater Estuary.

Table 1. Summary of catchment land cover (LCDB5 2018) for Freshwater Estuary.

LCDB5 (2018) Class and Name	Ha	%
10 Sand or Gravel	26.1	0.1
12 Landslide	12.1	0.04
20 Lake or Pond	307.6	0.9
21 River	24.7	0.1
43 Tall Tussock Grassland	1217.0	3.7
45 Herbaceous Freshwater Vegetation	2097.4	6.4
46 Herbaceous Saline Vegetation	20.5	0.1
52 Manuka and/or Kanuka	5144.0	15.7
54 Broadleaved Indigenous Hardwoods	4168.0	12.8
55 Sub Alpine Shrubland	2587.0	7.9
69 Indigenous Forest	17070.0	52.2
Grand Total	32674	100

Salt marsh near Freshwater River, with native forest in the background

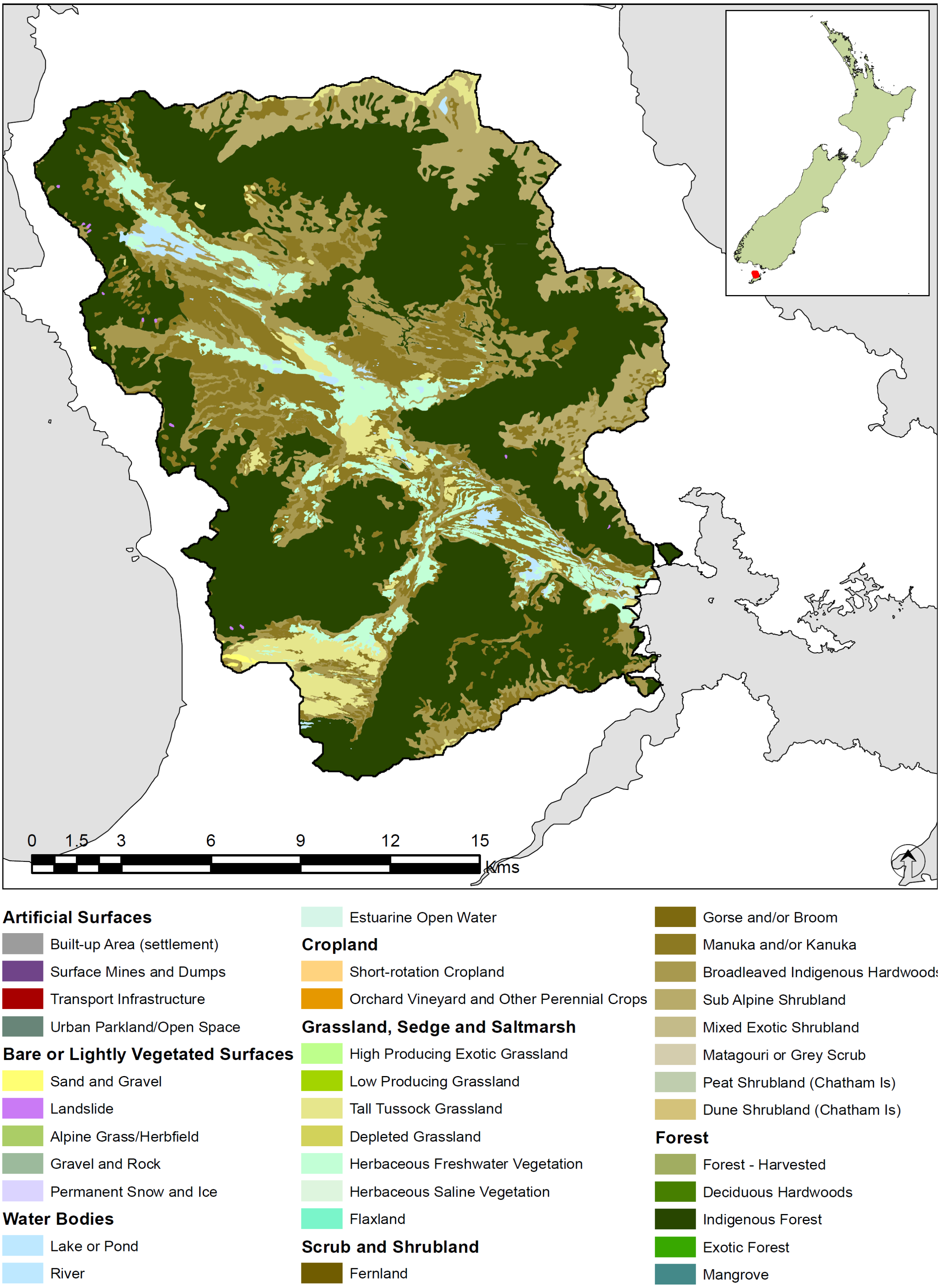


Fig. 2 Freshwater Estuary and surrounding catchment.

2. BROAD SCALE METHODS

2.1 OVERVIEW OF MAPPING

Broad-scale surveys involve describing and mapping estuaries according to dominant surface habitat features (substrate and vegetation). This 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.

Broad scale mapping of the estuaries of Freshwater Estuary in 2020 used 1:3000 colour satellite imagery (29 November 2019) supplied to ES by Apollo Mapping (Colorado). Ground truthing was undertaken in February 2020 to map the spatial extent of dominant substrate and vegetation. 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 these broad scale habitat features were drawn onto laminated aerial photographs. The features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant substrate, macroalgae, seagrass and salt marsh) and the vegetation and other features (e.g. extent of medication) of the terrestrial margin.

Estuary boundaries for mapping purposes were based on the definition used in the New Zealand Estuary Trophic Index (ETI; Robertson et al. 2016a) and are defined as the area between the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt) and seaward to a straight line between the outer headlands where the angle between the head of the estuary and the two outer headlands is <150°. This is consistent with the New Zealand coastal hydrosystems boundaries (Hume et al. 2016) developed in support of NIWA's CLUEs estuary model.

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

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 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. Salt marsh generally has the densest cover in sheltered and more strongly freshwater-influenced upper estuary areas, and is relatively sparse in the lower (more exposed and saltwater dominated) parts of an estuary. The tidal limit of salt marsh growth for most species is restricted to above the height of mean high-water neap tide.
Seagrass: Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (particularly if there is a lack of oxygen and production of sulfides).
Opportunistic macroalgae: Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to outcompete 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. Macroalgae that becomes detached (e.g. *Ulva* spp.) can also accumulate and decay in subtidal areas and on shorelines causing oxygen depletion and nuisance odours and conditions. One species in NZ, *Gracilaria chilensis*, can become entrained in sediments (i.e. grow within the sediment matrix) and establish persistent growths that trap fine sediment and lead to surface smothering of habitat. Trapped sediments provide a source of nutrients that facilitate further algal growth, and lead to other changes in the sediment that become difficult to reverse.

2.2 SUBSTRATE ASSESSMENT

2.2.1 Substrate mapping

The NEMP approach to substrate classification has been extended by Salt Ecology to record substrate beneath vegetation (salt marsh, seagrass and macroalgae) to provide a continuous substrate layer for the estuary. Furthermore, the NEMP substrate classifications themselves have been revised to provide a more meaningful classification of sediment based on mud content (Table 3, Appendix 1).

Under the original NEMP classification, mud/sand mixtures can have a mud content ranging from 1-100% within the same class, and classes are separated only by sediment firmness (how much a person sinks), with increasing softness being a proxy measure of increasing muddiness. Not only is sinking variable between individuals (heavier people sink more readily than lighter people), but also in many cases the relationship between muddiness and sediment firmness does not hold true. Very muddy sediments may be firm to walk on, e.g. sun-baked muds or muds deposited over gravel beds. In other instances, soft sediments may have low mud contents, e.g. coarse muddy sands. Further, many of the NEMP fine sediment classes have ambiguous definitions making classification subjective, or are inconsistent with commonly accepted geological criteria (e.g. the Wentworth scale).

To address these issues, mud and sand classifications have been revised to provide additional resolution based on the estimated mud content of fine-grained substrates, with sediment firmness used as an independent descriptor (Table 3, Appendix 1). Lower-case abbreviations are used to designate sediment firmness (f=firm, s=soft, vs=very soft). Mobile substrate (m) is classified separately. Upper-case abbreviations are used to designate four fine unconsolidated substrate classes consistent with existing geological terminology (S=Sand, MS=Muddy Sand, SM=Sandy Mud, M=Mud). These are based on sediment mud content (Table 3) and reflect both biologically meaningful thresholds where key changes in sediment macrofaunal communities occur, and categories that can be subjectively assessed in the field by experienced scientists and validated by laboratory analyses.

In developing the revised classifications, care has been taken to ensure that key metrics such as the area of mud dominated habitat can be assessed using both the NEMP and the revised classifications so that comparisons with existing work can be made.

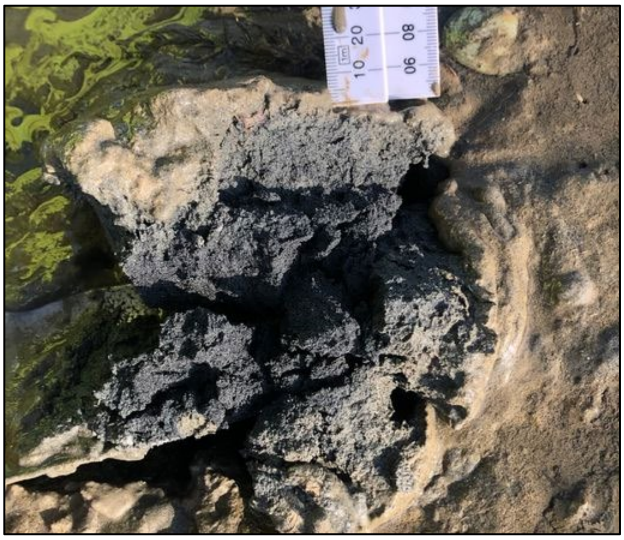
Table 3. Substrate classification codes used in the current report.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.096m	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)	Mud (>90%-100%)	Firm mud	fM90
		Soft muddy sand	sM90
		Very soft mud	vsM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Sabellid field	TUBE
Artifical Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aBF
		Cobble field	aCF
		Gravel field	aGF
		Sand field	aSF

2.2.2 Sediment mud content and trophic status

A focus of substrate mapping is on documenting changes in the area (horizontal extent) of intertidal muddy sediment. As a supporting indicator to this broad scale measure, and to validate the subjective sediment classifications used as part of the mapping method, the mud, sand and gravel content in representative sediment samples was also determined by laboratory analysis. Samples consisted of surface sediments (0-20mm deep) collected with a trowel. For present purposes, samples were collected from 23 sites in total, some of which were fine scale survey and sedimentation rate monitoring sites sampled by ES staff. Analytical methods are provided in Appendix 2.

A subjective indication of the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment is provided by 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). This transition is referred to as the apparent Redox Potential Discontinuity (aRPD) depth, and provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions.



Sediment trophic status is indicated by the depth of transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour).

As a supporting indicator of trophic status in Freshwater Estuary, aRPD was assessed in representative areas by digging into the underlying sediment with a hand trowel to determine whether there were any significant areas where sediment oxygenation was depleted close to the surface. 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.

2.3 OPPORTUNISTIC MACROALGAE ASSESSMENT

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant feature. Because the occurrence of opportunistic macroalgae is a primary indicator of nutrient enrichment (see Table 2), the ETI (Robertson et al. 2016a,b) has adopted the United Kingdom Water Framework Directive (WFD-UKTAG 2014)) Opportunistic Macroalgal Blooming Tool (OMBT) for macroalgal assessment. The OMBT, described in detail in Appendix 3, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within 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. Estimates of mean biomass are made within areas affected by macroalgal growth, as well across the total estuary intertidal area.
- *Extent of algal entrainment into the sediment matrix*: Macroalgae was defined as entrained when growing >30mm deep within sediments, which indicates that persistent macroalgal growths have established.

If an estuary supports <5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' with no further sampling required.

Using this approach in Freshwater Estuary, macroalgae patches were mapped to the nearest 10% using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (see Fig. 3). The focus was on opportunistic species associated with nutrient enrichment problems in New Zealand (in particular in several Southland estuaries), namely *Gracilaria chilensis* and *Ulva* spp.

Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the depth of macroalgal entrainment were measured. 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, additional biomass estimates were made following the OMBT method.

2.4 SEAGRASS ASSESSMENT

The NEMP provides no guidance on the assessment of seagrass beyond recording its presence when it is a dominant feature. To improve on the NEMP method, the mean percent cover of discrete seagrass patches was visually assessed to the nearest 10% based on the 6-category percent cover scale in Fig. 3.

To assess temporal changes in estuary seagrass, 2020 data were compared to data from previous broad scale reports (Stevens & Robertson 2008, 2013) based on the extent of estuary with seagrass cover >50%. The 30% threshold was used as it was assumed that previous NEMP mapping recorded seagrass beds when present as moderate to complete cover (i.e. cover >50%), noting that it is also difficult to distinguish seagrass cover of <50% when assessing historical aerial photographs.

2.5 SALT MARSH ASSESSMENT

Salt marsh was mapped and classified using an interpretation of the Atkinson (1985) system defined in the NEMP (Appendix 1), whereby dominant estuarine plant species were used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock). Vegetation was coded using the two first letters of the genus and species, e.g. sea rush *Juncus kraussii*, was coded as Jukr. Plants were listed in order of dominance with subdominant species placed in parentheses, e.g. Jukr(Caed) indicates that sea rush was dominant over ice plant (*Carpobrotus edulis*). A relative measure of vegetation height can be derived from its structural class (e.g. rushland is taller than herbfield).

As well as generating summaries (e.g. maps, tables) of salt marsh type and extent in 2020 relative to other years, two additional measures were used to assess salt marsh condition: i) Intertidal extent (percent cover), and ii) Current extent compared to estimated historical extent.

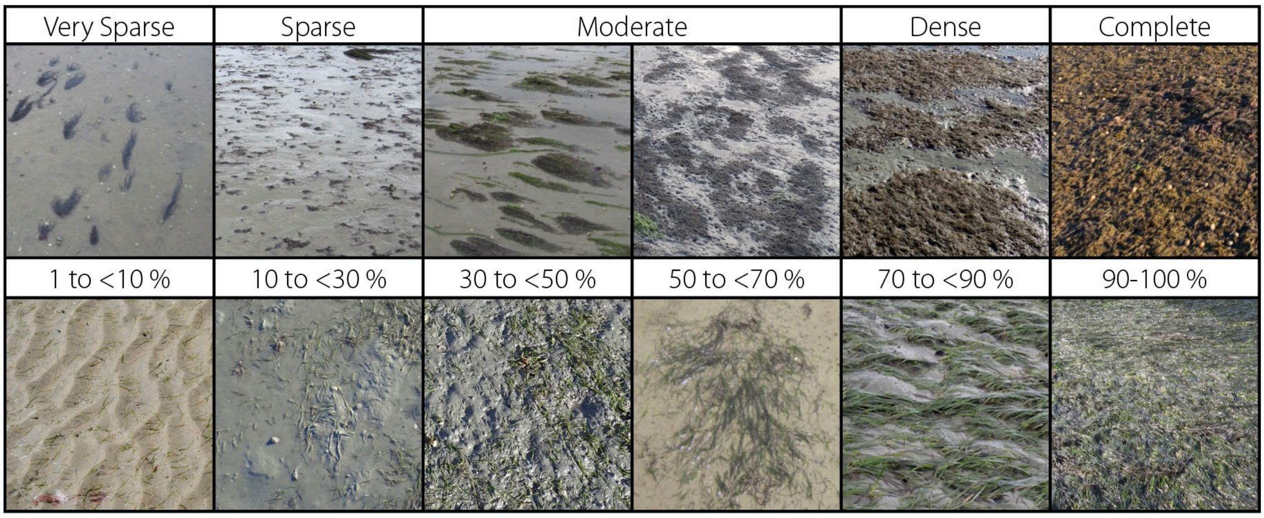


Fig. 3 Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

2.6 TERRESTRIAL MARGIN ASSESSMENT

The 200m terrestrial margin surrounding the estuary was mapped and classified using the dominant land cover classification codes described in the Landcare Research Land Cover Data Base (LCDB5). Classes are shown in Fig. 2 and detailed in Appendix 1.

2.7 DATA RECORDING, QA/QC AND ANALYSIS

Broad scale mapping is intended to provide a rapid overview of estuary condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial photos, 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 such as rushland, rockfields, dense seagrass, etc. 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 beds, or where there is a transition between features that appear visually similar, e.g. sand, muddy sand, mud. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground truthed, but accuracy is unlikely to be better than ±20-50m for such features when relying on photographs alone.

In 2020, 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. Using these same tools, the 2008 and 2013 GIS layers were similarly checked for any errors in basic geometry (e.g. overlapping polygons), and updated to fix any identified issues.

In addition, the substrate types were updated to reflect the revised classifications presented in Table 3. The original classification codes have been retained in the GIS attribute tables with any changes shown alongside. In addition, detailed metadata describing data sources and any changes made have been provided with each GIS layer and supplied to ES.

During the field ground truthing, sediment grain size and macroalgal data 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. Macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template.

2.8 ASSESSMENT OF ESTUARY CONDITION AND TEMPORAL CHANGE

Broad-scale results are used primarily to assess estuary condition in response to common stressors such as fine sediment inputs, nutrient enrichment or habitat loss. In addition to the authors' interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from NZ and overseas (Table 4). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 4. The condition ratings are primarily sourced from the NZ ETI (Robertson et al.

Table 4. Indicators and condition rating criteria used to assess results in the current report.

Indicator	Unit	Very Good	Good	Fair	Poor
Broad scale indicators					
Mud-dominated substrate[1]	% of intertidal area >50% mud	< 1	1-5	> 5-15	> 15
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥ 0.8 - 1.0	≥ 0.6 - < 0.8	≥ 0.4 - < 0.6	0.0 - < 0.4
Seagrass[2]	% decrease from baseline	< 5	≥ 5-10	≥ 10-20	≥ 20
Salt marsh extent (current)[2]	% of intertidal area	≥ 20	≥ 10-20	≥ 5-10	0-5
Historical salt marsh extent[2]	% of historical remaining	≥ 80-100	≥ 60-80	≥ 40-60	< 40
200m terrestrial margin[2]	% densely vegetated	≥ 80-100	≥ 50-80	≥ 25-50	< 25
High Enrichment Conditions[1]	ha	< 0.5ha	≥ 0.5-5ha	≥ 5-20ha	≥ 20ha
High Enrichment Conditions[1]	% of estuary	< 1%	≥ 1-5%	≥ 5-10%	≥ 10%
Sediment Quality					
Mud content[1]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to < 20	< 10

[1]*General indicator thresholds derived from a New Zealand Estuary Tropic Index, with adjustments for aRPD. See text and Appendix 5 for further explanation of the origin or derivation of the different metrics.*

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

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'.

As a supporting measure for the broad scale indicator of 'mud-dominated' sediment extent (areas >50% mud), we also consider the 'mud-elevated' (>25% mud) sediment component, as this is the threshold above which ecological communities can become degraded (hence the sediment quality rating of 'poor' in Table 4.

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HEC) was evaluated. HECs are referred to alternatively as 'Gross Eutrophic Zones' (GEZs) in the ETI (Zeldis et al. 2017). For our purposes HECs are defined as mud-dominated sediments (≥50% mud content) with >50% macroalgal cover and with macroalgae entrained (growing >30mm deep) within the sediment. HECs can also be present in non-algal areas where sediments have an elevated organic content (>1% total organic carbon) combined with low sediment oxygenation (aRPD <10mm). It is generally not feasible to incorporate these latter sediment profile measures into broad scale mapping as they are not routinely assessed over the entire estuary.

In addition to the Table 4 indicators, the percent change from the first measured (or estimated) baseline is used to qualitatively describe broad changes in estuary condition over time. It is assumed that increases in high value habitat such as seagrass, salt marsh, and a densely vegetated terrestrial margin are desirable, and decreases are undesirable. The converse is true for the establishment of degraded conditions, e.g. spatial extent of sediment with elevated mud contents or HECs.

As many of the scoring categories in Table 4 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).


Sandflats were extensive across the estuary


Mobile sands of the central estuary


Sandy sediments were generally well-oxygenated, with aRPD typically deeper than ~20mm except where organic detrital decay was occurring.


Fringing bedrock habitat around Mudflat Island

3. RESULTS AND DISCUSSION

The 2020 broad scale results are summarised in the following sections, with the supporting GIS files (supplied as a separate electronic output) providing a more detailed data set designed for easy interrogation and to address specific monitoring and management questions.

3.1 INTERTIDAL SUBSTRATE

Results from the 2020 survey are given in Table 5 and Fig. 4, with photographs of representative substrates provided below and on following pages. Validation of the 23 subjective sediment substrate classifications showed that 22 observations were assigned to the correct mud content class of ≤10% (Appendix 5). A misclassification occurred for a single sample whose measured mud content of 9% was subjectively assessed as being in the >10-25% class. Overall, therefore, the substrate patterns described below can be considered a reliable representation of surface sediment conditions. Key results were as follows:

- Consistent with the forested catchment, substrates were dominated by sandy sediments, comprising mainly firm sand (61.5% of intertidal area in 2020) but also reflecting areas of mobile sand (21.6% of intertidal in 2020).
- Sediments were muddy only along the western margin of the estuary, adjacent to Freshwater Stream. In 2020, 14.2ha (2.1%) was rated as mud-dominated, reflecting sediments with a mud content of >50-90% (Table 5).

Table 5. Summary of dominant intertidal substrates, Freshwater Estuary February 2020.

Subclass	Dominant feature	Ha	%
Boulder/Cobble/	Boulder field	0.0	0.0
Gravel	Cobble field	0.2	0.0
Bedrock	Rock field	0.6	0.1
Sand (0-10% mud)	Mobile sand	143.0	21.6
	Firm sand	407.7	61.5
Muddy Sand	Firm muddy sand	18.3	2.8
(>10-25% mud)	Soft muddy sand	0.7	0.1
Muddy Sand (>25-50% mud)	Soft muddy sand	8.8	1.3
Sandy Mud	Soft sandy mud	12.8	1.9
(>50-90% mud)	Very soft sandy mud	1.4	0.2
Zootic	Shell bank	14.2	2.1
	Cocklebed	1.4	0.2
	Mussel reef	54.1	8.2
Grand Total		663.3	100

- In 2020 mud-dominated sediments outside of salt marsh habitat comprised just 0.5ha (0.1% of the intertidal area).
- A comparison of the three broad scale surveys conducted to date (Fig. 4 inset, Appendix 6) reveals no substantive change in the spatial extent of mud-dominated sediment outside of salt marsh habitat over a 12-year period since 2008 (see Fig. 4 inset).

In addition to these muddy or sandy sediments, a reasonably common habitat was 54.1ha of mussel reef (8.2% of intertidal), consisting of beds of the 'blue' mussel *Mytilus galloprovincialis*. Other less prevalent but ecologically important habitats included cockle beds, and hard natural substrates provided by shell backs and fringing habitats of bedrock, boulder and cobble. These hard substrata provided important habitats for a diverse range of invertebrates and macroalgae.

Beds of blue mussels, *Mytilus galloprovincialis*, were extensive in places

Soft, mud-dominated sediments were uncommon, being limited to the western margin of the estuary

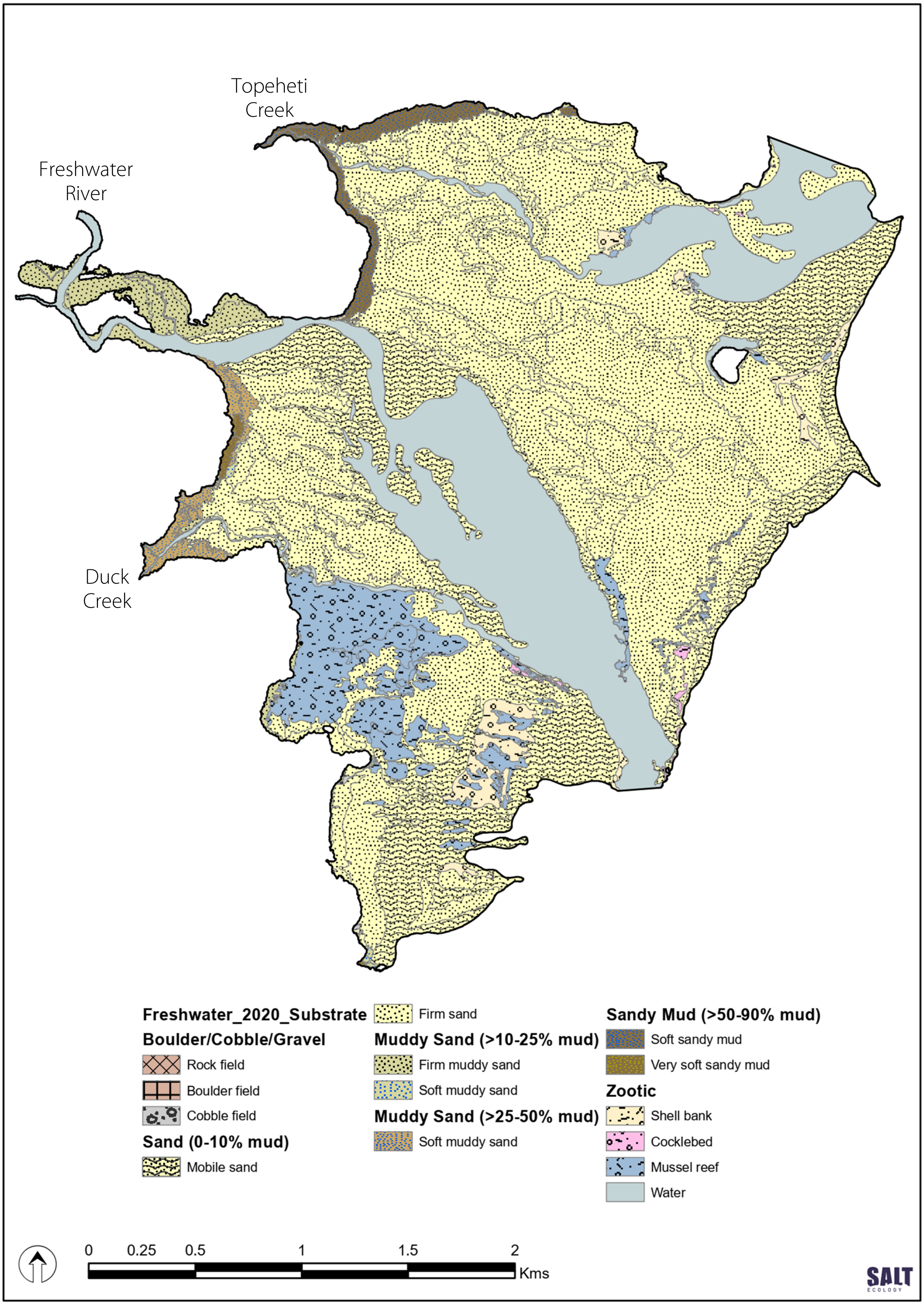


Fig. 4 Map of dominant intertidal substrate types, Freshwater Estuary February 2020. Inset bar graph shows the change in mud-dominated sediments since 2008, not including muddy areas within salt marsh (see text).

3.2 OPPORTUNISTIC MACROALGAE

Table 6 summarises macroalgal percentage cover classes for the estuary, with the mapped cover and biomass shown in Fig. 5 and Fig. 6, respectively. Key results were as follows:

- Across 69.2% of the intertidal area macroalgae cover was classified as 'trace' (<1% cover), and classified as 'very sparse' (1-<10%) or sparse (10-<30%) across a further 26.9% of the mapped area. In these areas the species present included the red seaweed *Gracilaria chilensis* and the green seaweed *Ulva* spp.
- Highest cover areas (30-<70% cover) were primarily localised to the eastern low tide margin of the estuary, representing <4% of the total mapped area. Algal biomass in these areas was in the 1-3kg/m^2 range.
- The inset graph in Fig. 5 indicates a decline in algal cover above the ≥50% threshold since the first survey in 2008.

Although the recognised nuisance taxa *Gracilaria chilensis* and *Ulva* spp. were among the algae present, there was a relatively diverse mix of other species as well, especially in areas that had shell habitat, or which retained water at low tide. Common among the species present were red algae such as *Brongniartella australis* and epiphytic *Ceramium* spp. Additional species included broad bladed reds (e.g. *Pachymenia dichotoma*), common browns such as *Splachnidium rugosum* and *Scytothamnus australis*, and the green 'Neptune's necklace' *Hormosira banksii*.

The diverse nature of the macroalgal assemblage is atypical for Southland estuaries, where *Gracilaria* and *Ulva* are often the only conspicuous species. Although *Ulva* is conspicuous on aerial photographs, *Gracilaria* cannot be distinguished from many of the other associated or epiphytic species. As such, the mapped areas of elevated percentage cover and biomass do not solely reflect the known opportunistic species, but illustrate total algal cover.

Table 6. Summary of intertidal macroalgae cover, Freshwater Estuary February 2020.

Percent cover category	Ha	%
Trace (<1%)	459.3	69.2
Very sparse (1 to <10%)	80.5	12.1
Sparse (10 to <30%)	98.3	14.8
Low-Moderate (30 to <50%)	23.3	3.5
High-Moderate (50 to <70%)	1.9	0.3
Grand Total	663.3	100

Macroalgae were at a low prevalence (<1% cover) almost 70% of the estuary

Along the low tide margins of the estuary, shell hash, blue mussels and cockles provided hard substrates for the establishment of a diverse macroalgal assemblage

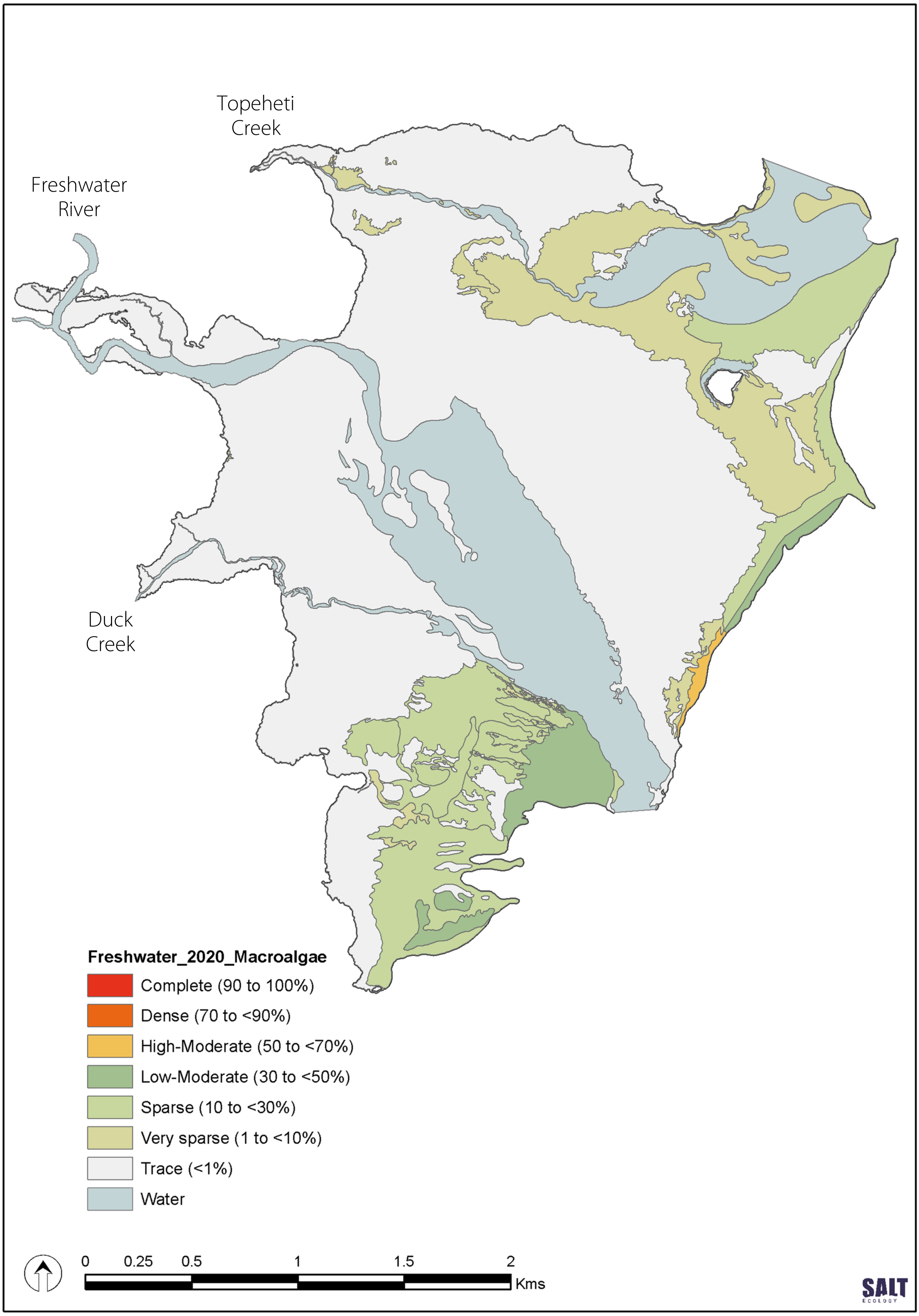


Fig. 5 Distribution and percentage cover classes of macroalgae, Freshwater Estuary February 2020.

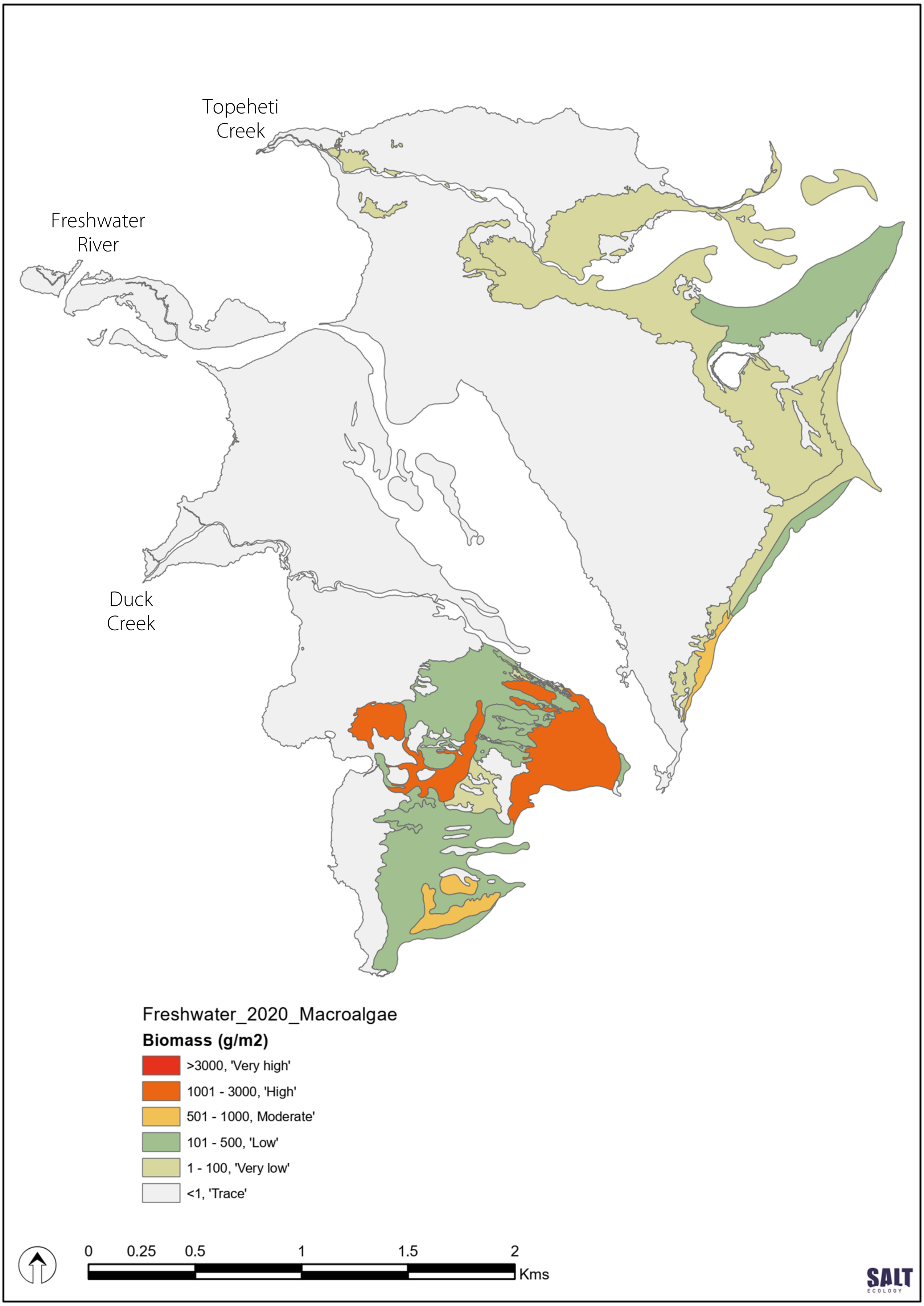
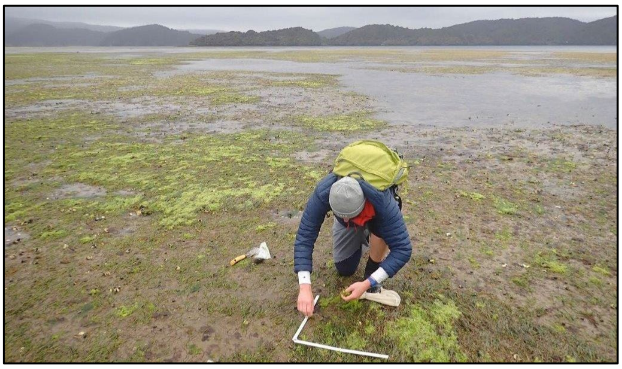


Fig. 6 Biomass (wet weight g/m^2) classes of macroalgae, Freshwater Estuary February 2020.

The OMBT input metrics and overall macroalgal EQR for 2020 are provided in Table 7. The overall EQR calculated using the OMBT method was 0.71, which equates to a rating of 'good' according to the Table 4 criteria. Note, however, that the OMBT approach rates an increased macroalgal prevalence as undesirable, and is geared towards assessing and tracking systems degraded by nutrient enrichment and that experience summer blooms of opportunistic species (Appendix 3). As such, this method does not provide a fully accurate reflection of quality status in the case of Freshwater Estuary.



Macroalgae were enhanced in areas that retained water at low tide

Ulva was conspicuous in some areas, overgrowing seagrass in the top photo

Neptune's necklace, *Hormosira banksii*, and *Ulva*

Table 7. Summary of OMBT input metrics and calculation of overall macroalgal ecological quality rating, Freshwater Estuary February 2020.

Metric	Face Value	FEDS	Environmental Quality Status
%cover in AIH	4.1	0.835	High
Biomass per m^2 AIH	111.1	0.794	Good
Biomass per m^2 AA	361	0.67	Good
%entrained in AA	0	1	High
Worst of AA (ha) and AA (% of AIH)		0.261	Poor
AA (ha)	204	0.261	Poor
AA (% of AIH)	30.8	0.51	Moderate
Survey EQR		0.712	Good

AA = Affected Area
AIH = Available Intertidal Habitat
FEDS = Final Equidistant Score

3.3 SEAGRASS

Table 8 summarises intertidal seagrass (*Zostera muelleri*) cover in 2020 with the distribution map shown in Fig. 7. Key results were as follows:

- Seagrass was widespread across the estuary in 2020, other than in areas where macroalgae were abundant or which were characterised by mobile sand. More than half of the estuary (~340ha) had seagrass exceeding 1% cover in 2020, and it could often be seen growing amongst salt marsh.
- The most luxuriant bed, where seagrass was rated as having a 'complete' cover (≥90%), occurred towards the seaward low tide margin in the area north of the Freshwater River channel. Comparably dense, although less extensive beds, also occurred in the north of the estuary and along parts of the western margin. The total area with ≥90% cover was 101.4ha, representing >15% of the intertidal area.
- The spatial extent of luxuriant (≥90% cover) seagrass was greater in 2020 than reported previously, however the ≥50% cover threshold (i.e. the lowest threshold considered reliable for determining temporal change from aerial photos), shows a decline over time, from ~346ha in 2008, to ~259ha in 2020 (see Fig. 7 inset).

In relation to the last point, a comparison of the mapped area in 2020 with earlier surveys (see Appendix 6) suggests that ~3ha of the losses since 2008 were attributable to seagrass erosion along the edge of the river channel. While there may have been some minor natural variation as described above, the remaining apparent decline was attributable to improved mapping accuracy as a direct result of higher resolution imagery being available in 2020, and greater effort made in the field and during the digitising process to delineate boundaries and percentage cover classes. Overall, therefore, the temporal differences appear to be no cause for concern.

Table 8. Summary of intertidal seagrass cover, Freshwater Estuary February 2020.

Percent cover category	Ha	%
Trace (<1%)	323.4	48.8
Very sparse (1 to <10%)	15.5	2.3
Sparse (10 to <30%)	25.0	3.8
Low-Moderate (30 to <50%)	40.2	6.1
High-Moderate (50 to <70%)	51.3	7.7
Dense (70 to <90%)	106.5	16.0
Complete (>90%)	101.4	15.3
Grand Total	663.3	100

Seagrass on the central estuary flats

Luxuriant 'complete' (≥90%) cover of seagrass north of the Freshwater River channel near low tide

Seagrass bordering high tide salt marsh in the western estuary

Seagrass was often among other diverse habitat including blue mussels and macroalgae. Macroalgae visible here are *Ulva*, *Gracilaria*, *Hormosira banksii* and *Splachnidium rugosum* (aka 'deadman's fingers')

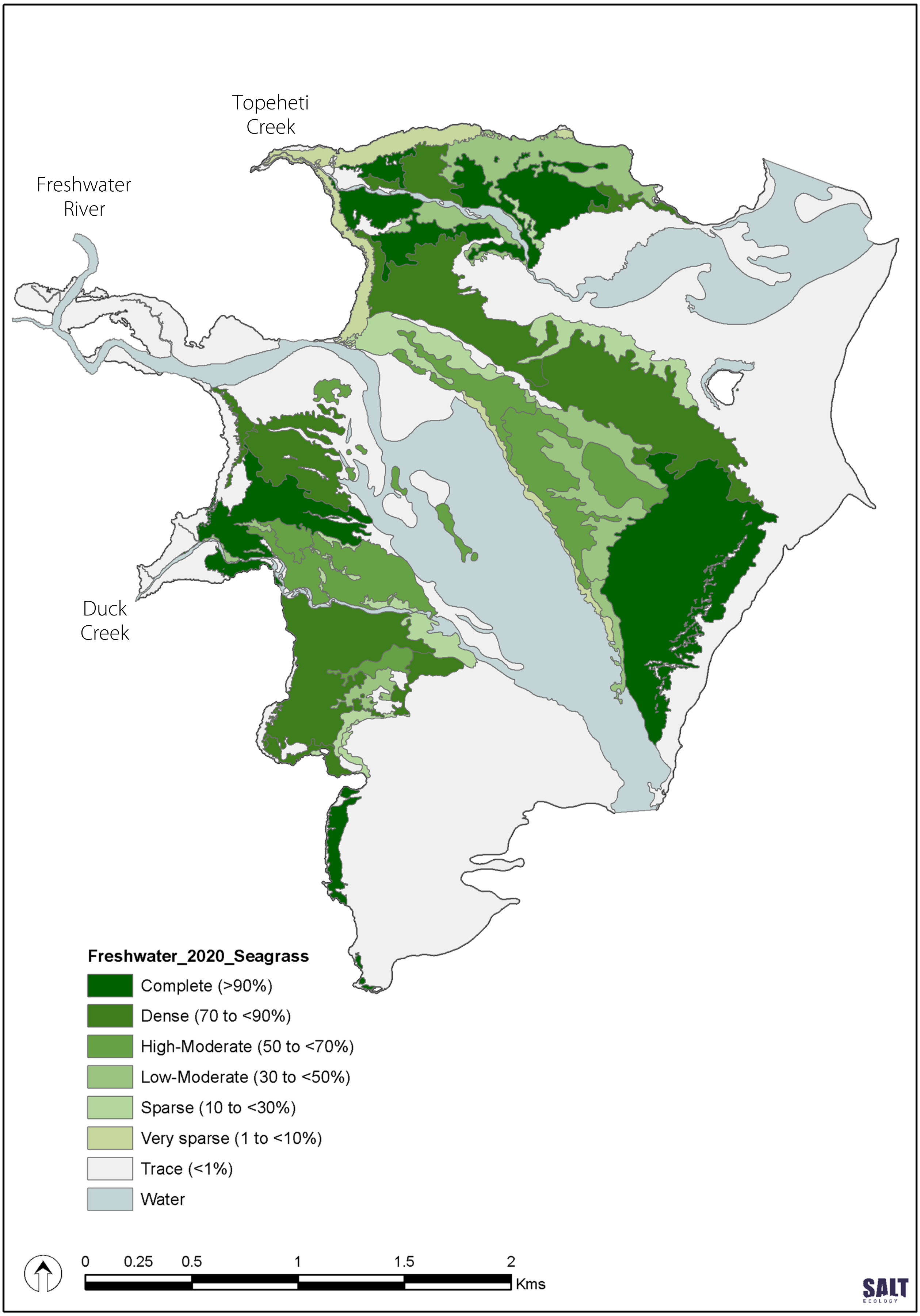


Fig. 7 Distribution and percentage cover classes of seagrass, Freshwater Estuary February 2020. Inset bar graph shows change in seagrass cover ≥50%.

3.4 SALT MARSH

Table 9 summarises intertidal salt marsh subclasses and cover for the three NEMP surveys, with the mapped distribution in 2020 shown in Fig. 8. Detail regarding the dominant and subdominant species recorded in 2020 is provided in Appendix 7.

Key results were as follows:

- A total of 37.7ha of salt marsh was recorded from the estuary in 2020, representing 4.6% of the intertidal area. The most extensive areas of salt marsh were located near the mouth of Freshwater River, and in a narrow strip around Duck Creek.
- There has been no substantive change in salt marsh extent over time (see Fig. 8 inset graph), with the total area mapped in 2020 being ~1ha less than mapped previously.
- As described in the 2008 and 2013 reports, salt marsh was dominated by rushland (>98%). There was a very small component of estuarine shrub, tussockland and herbfield.

Rushland comprised mainly jointed wire rush (*Apodasmia similis*), with a small amount of Knobby clubrush (*Ficinia nodosa*). As the terrestrial influence increased, rushland transitioned through areas of estuarine shrub in which salt marsh ribbonwood (*Plagianthus divaricatus*) was present along with New Zealand flax (*Phormium tenax*), cabbage trees (*Cordyline australis*) and the introduced weed, tall fescue (*Festuca arundinacea*).

Table 9. Summary of salt marsh area (ha), Freshwater Estuary February 2020.

Subclass	Ha	%
Estuarine Shrub	0.41	0.9
Tussockland	0.28	0.3
Rushland	37.05	2.9
Herbfield	0.01	0.0
Grand Total	**37.7**	**100**

Jointed wire rush along the western margin of the estuary

Rushland north of Freshwater River with Gracilaria established in a margin habitat of soft sandy mud

Extensive rushland around the Duck Creek area

New Zealand flax behind a small area of remuremu (*Selliera radicans*) herbfield

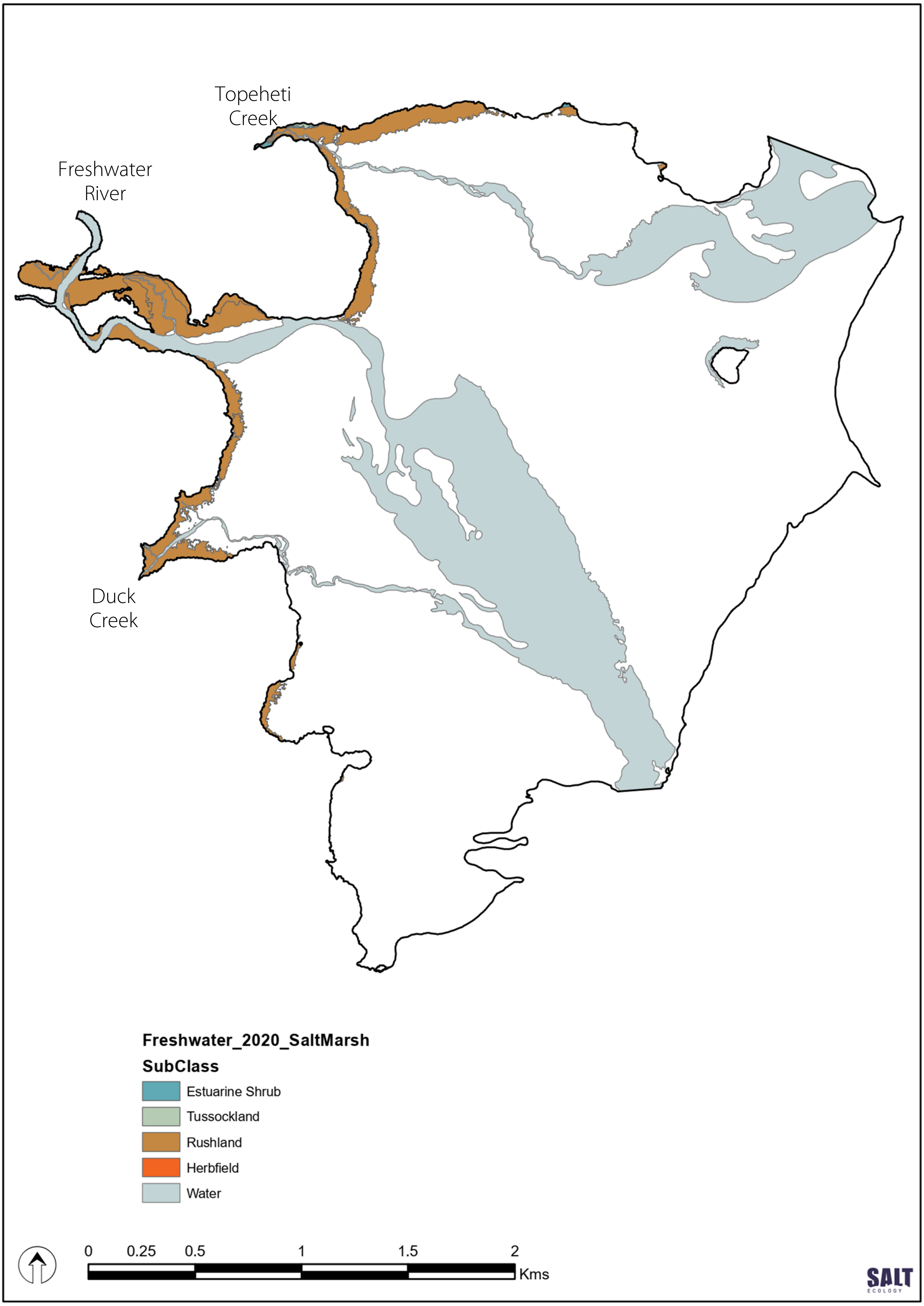


Fig. 8 Distribution and type of salt marsh, Freshwater Estuary February 2020.

3.5 TERRESTRIAL MARGIN

Mapping of the 200m wide terrestrial margin (Table 10, Fig. 9) in 2020 confirmed previous survey findings, which showed that the entire area consisted of native forest and scrub. Forest dominated on the steep hillsides along the estuary margins, while scrub was dominant on the river flats of Freshwater River.

Table 10. Terrestrial margin features in 2020.

LCDB5 (2018) Class and Name		Ha	%
21	River	1.4	0.5
54	Broadleaved Indigenous Hardwoods	128.8	49.8
69	Indigenous Forest	128.4	49.7
Grand Total		**258.5**	**100**
Total dense vegetated margin (LCDB classes 45-71)		257.1	99.5

Forest covered hillsides along much of the estuary edge often terminate in a 2-4m high near-vertical cliff

Native scrub adjoining rushland near Duck Creek

Native forest on the hillsides near Duck Creek

The 200m terrestrial margin comprises dense native forest growing to the estuary edge

Fig. 9 Distribution and classes (LCDB5 2018) of vegetation in the 200m terrestrial margin, Freshwater Estuary February 2020.

4.2 Recommendations

Freshwater Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's coastal monitoring programme being undertaken in a staged manner throughout the region.

Given that the estuary is in a relatively pristine state and not vulnerable to the stressors that adversely affect most of Southlands other estuaries, no specific management actions are needed. However, repeated broad scale surveys every few years (e.g. 5-yearly) will enable long term changes to be tracked and comparisons made to mainland estuaries. Freshwater estuary is an important reference system against which to assess the condition of other estuaries in Southland and New Zealand, especially in the context of drivers of future changes expected from global stressors such as climate change and sea level rise.

Table 11. Summary of broad scale indicators, Freshwater Estuary 2020.

Component	Ha	% Estuary	% Intertidal	% Salt Marsh	% Margin
Area					
Estuary area	820.4				
Intertidal area	663.3	80.8			
Subtidal area	157.2	19.2			
Substrate					
Mud-elevated sediment (>25% mud)	23.0				
Mud-dominated sediment (>50% mud)	14.2	1.7	2.1		
Macroalgae and seagrass					
Macroalgal beds ≥50% cover	1.9	1.7	2.1		
Seagrass ≥50% cover	259.2	31.6	39.1		
Salt Marsh	37.7	4.6	5.7		
Estuarine Shrub	0.4			1.1	
Herbfield	0.01			0.02	
Tussockland	0.3			0.7	
Rushland	37.1			98.2	
200m Terrestrial margin					
% Densely vegetated (LCDB classes 45-71)					99.5

Table 12. Summary of broad scale condition rating scores based on the key indicators and criteria in Table 4.

Broad scale indicator	Unit	2008	2013	2020
Mud-dominated substrate[1]	% of intertidal area >50% mud	0	0.3	0.1
Macroalgae (OMBT)[2]	Ecological Quality Rating (EQR)	na	na	0.71
Seagrass[3]	% decrease from baseline	0	6.3	13.3
Salt marsh extent (current)	% of intertidal area	6.0	14.8	6.0
Historical salt marsh extent[3]	% of historical remaining	100	100	94.7
200m terrestrial margin	% densely vegetated	99.5	99.5	99.5
High Enrichment Conditions	ha	na	na	0
High Enrichment Conditions	% of estuary	na	na	0

[1] To enable comparison across years, mud dominated substrate assessed as percentage of intertidal area excluding salt marsh (235.9ha)
[2] OMBT = Opportunistic Macroalgal Blooming Tool
[3] Data for 2008 used as baseline for seagrass and salt marsh
Condition rating colour key as follows:

Very Good	Good	Fair	Poor

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APPENDICES

APPENDIX 1. BROADSCALE 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).

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 the 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: 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, stop-gates. 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 or Tubeworm field: Area that is dominated by raised beds of 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 4.096m	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%)	Firm shell/sand	fSS
		Mobile sand	mS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Firm muddy shell/sand	fSS10
		Mobile muddy sand	mMS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Firm muddy shell/sand	fSS25
		Mobile muddy sand	mMS25
		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)	Mud (>90%)	Firm mud	fM90
		Soft or very soft mud	sM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Sabellid field	TUBE
Artifical Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aBF
		Cobble field	aCF
		Gravel field	aGF
		Sand field	aSF

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
14 Permanent Snow and Ice
15 Alpine Grass/Herbfield
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
43 Tall-Tussock Grassland
44 Depleted 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
55 Sub Alpine Shrubland
56 Mixed Exotic Shrubland
58 Matagouri or Grey Scrub

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

Field codes used in the report

Substrate Class	Feature	Code
Bedrock	Rock field	RF
Boulder/Cobble/Gravel	Boulder field	BF
	Cobble field	CF
Sand (0-10% mud)	Firm sand	fS
	Mobile sand	mS
Muddy Sand (>10-25% mud)	Firm muddy sand	fMS10
	Soft muddy sand	sMS10
Muddy Sand (>25-50% mud)	Firm muddy sand	fMS25
	Soft muddy sand	sMS25
Sandy Mud (>50-90% mud)	Soft sandy mud	sSM
	Very soft sandy mud	vsSM
Zootic	Cocklebed	CKLE
	Mussel reef	MUSS
	Shell bank	shel

Salt marsh Class	Feature	Code
Estuarine Shrub	*Plagianthus divaricatus (Salt marsh ribbonwood)*	Pldi
Tussockland	*Phormium tenax (New Zealand flax)*	Phte
	Carex spp. (Sedge)	Casp
	Cortaderia sp. (Toetoe)	Cosp
Grassland	*Festuca arundinacea (Tall fescue)*	Fear
Rushland	*Apodasmia similis (Jointed wirerush)*	Lesi
	Ficinia (Isolepis) nodosa (Knobby clubrush)	Isno
Herbfield	*Selliera radicans (Remuremu)*	Sera

APPENDIX 2. ANALYTICAL METHODS FOR SEDIMENT SAMPLES (RJ HILL LABORATORIES)

Only the grain size fraction methods are relevant to this report.

Sample Type: Sediment		
Test	**Method Description**	**Default Detection Limit**
Individual Tests		
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
3 Grain Sizes Profile as received		
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt

APPENDIX 3. OPPORTUNTISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multimetric 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 multimetric OMBT, modified for NZ estuary types, is fully described 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, %).

In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric established is 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. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. 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 multimetric, in order to best describe the changes in the nature and degree of opportunist 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), although 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 ICOLLs 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 the natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g m^{-2} wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

Class Thresholds for Percent Cover

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

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 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 <500 $g.m^{-2}$ wet weight was an acceptable level above the reference level of <100 $g.m^{-2}$ wet weight. In Good status only slight deviation from High status is permitted so 500 $g.m^{-2}$ 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 >500 $g.m^{-2}$ but less than 1,000 $g.m^{-2}$ would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1$kg.m^{-2}$ wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).

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

Table A1. The final face value thresholds and metrics for levels of the ecological quality status.

ECOLOGICAL QUALITY RATING (EQR)	High	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)*	≥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	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass ($g.m^2$) of AA	≥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.					

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.
Each metric in the OMBT has equal weighting and is combined to produce the ecological quality ratio score (EQR).

EQR calculation

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

The EQR calculation process is as follows:

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

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

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

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

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

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

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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 Rang e	Lower 0-1 Equidistan t range value	Upper 0-1 Equidistan t range value	Equidistan t 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	399.99	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.99	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.9	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.9	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	399.99	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.99	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.9	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.9	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	149.99	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.9	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.

APPENDIX 4. INFORMATION SUPPORTING RATINGS IN REPORT TABLE 4

Sedimentation 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.

Soft Mud Percent Cover

Sediments with >25% mud content have been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and an excessive mud content decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are sinks for sediments, the presence of large areas of soft mud are likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, the widespread presence of sediments dominated by fine mud indicates where changes in land management may be needed. In most instances sediments with >25% mud content are soft and can be identified using the NEMP protocols based on how much a person sinks when walking (Robertson et al. 2002). If an estuary is suspected of having >25% mud content but has substrate that remains firm to walk on (e.g. dried muds, presence of underlying gravels), it is recommended that particle grain size analyses of relevant areas be used to determine the extent of the estuary with sediment mud contents greater than 25%.

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, becomes 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 (greater than 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 less than 1cm (Jørgensen and 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 and 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.

Salt marsh

Salt marshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine salt marsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Salt marsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest salt marsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between

MHWS and MHWN, salt marsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to Mean Sea Level (MSL) range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive salt marsh metric for NZ. As an interim measure, the % of the intertidal area comprising salt marsh is used to indicate salt marsh condition, with a supporting metric proposed of % loss from Estimated Natural State Cover. This assumes that a reduction in natural state salt marsh cover corresponds to a reduction in ecological services and habitat values. The interim condition ratings proposed for these ratings are Very Good 80-100%, Good 60-80%, Fair 40-60%, and Poor <40%. The "early warning trigger" for initiating management action/further investigation is a trend of a decreasing salt marsh area.

Vegetated Margin

The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the salt marsh and estuary. This buffer is sensitive to a wide range of pressures including land reclamation and drainage, margin development, flow regulation, sea level rise, grazing, and weed invasion. A dense buffer protects the estuary against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat. Reduction in the vegetated terrestrial buffer around the estuary is likely to result in a decline in estuary quality. The "early warning trigger" for initiating management action is less than 50% of the estuary with a densely vegetated 200m terrestrial margin. Land cover at a catchment-wide scale is also a very valuable metric. Landcare Research provide regular national-scale GIS layers (Land Cover Data Base - LCDB) which can be used to develop relationships between estuary state and land cover type, and changes in catchment land cover over time.

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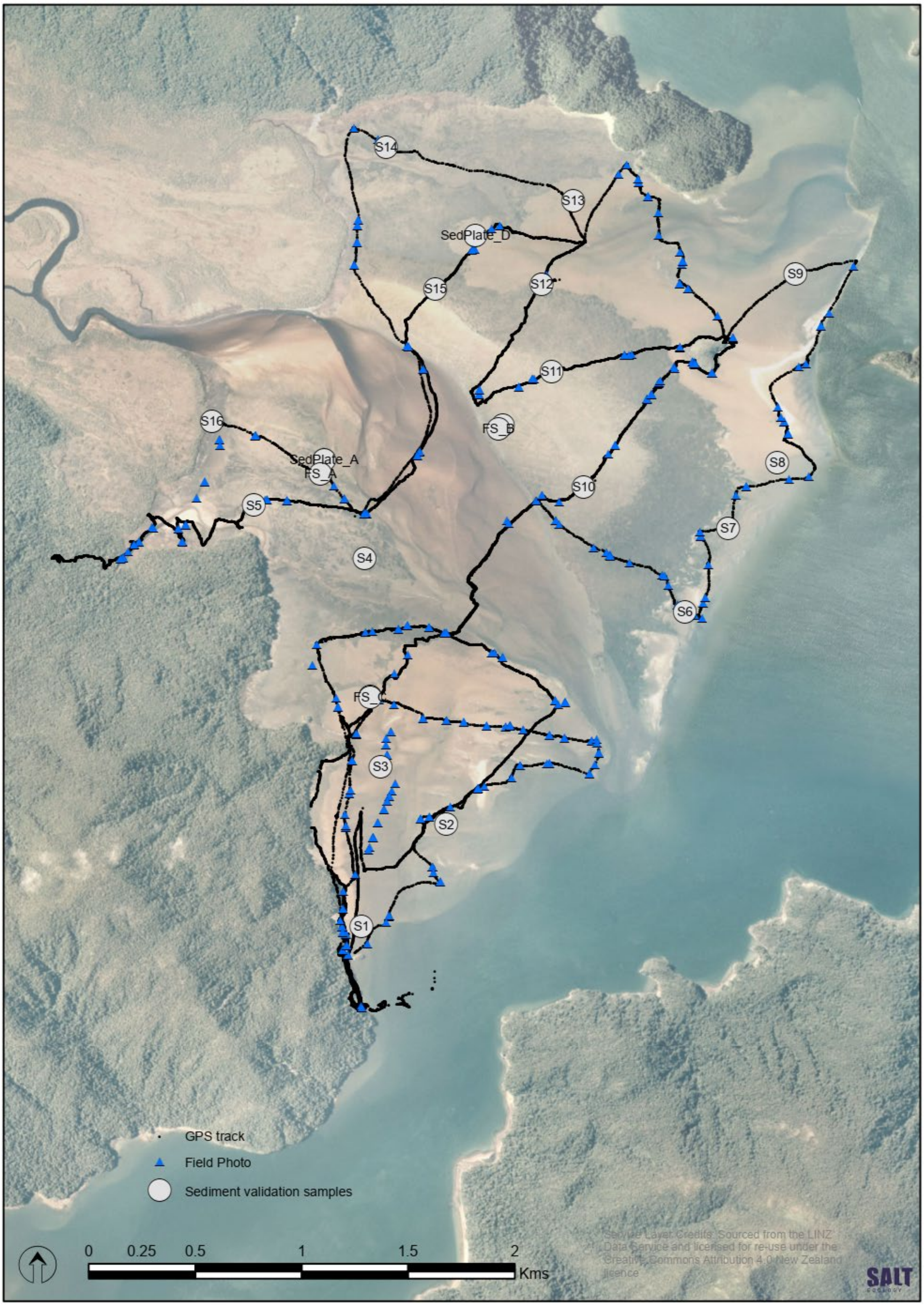
APPENDIX 5. SEDIMENT SAMPLING VALIDATION DATA

Comparison of field sedimentation type classifications against laboratory analysis of grain size. Depth of apparent redox potential discontinuity (aRPD) also shown. One discrepancy is highlighted with grey shading, which reflect locations where the field classification slightly overestimated actual mud content.

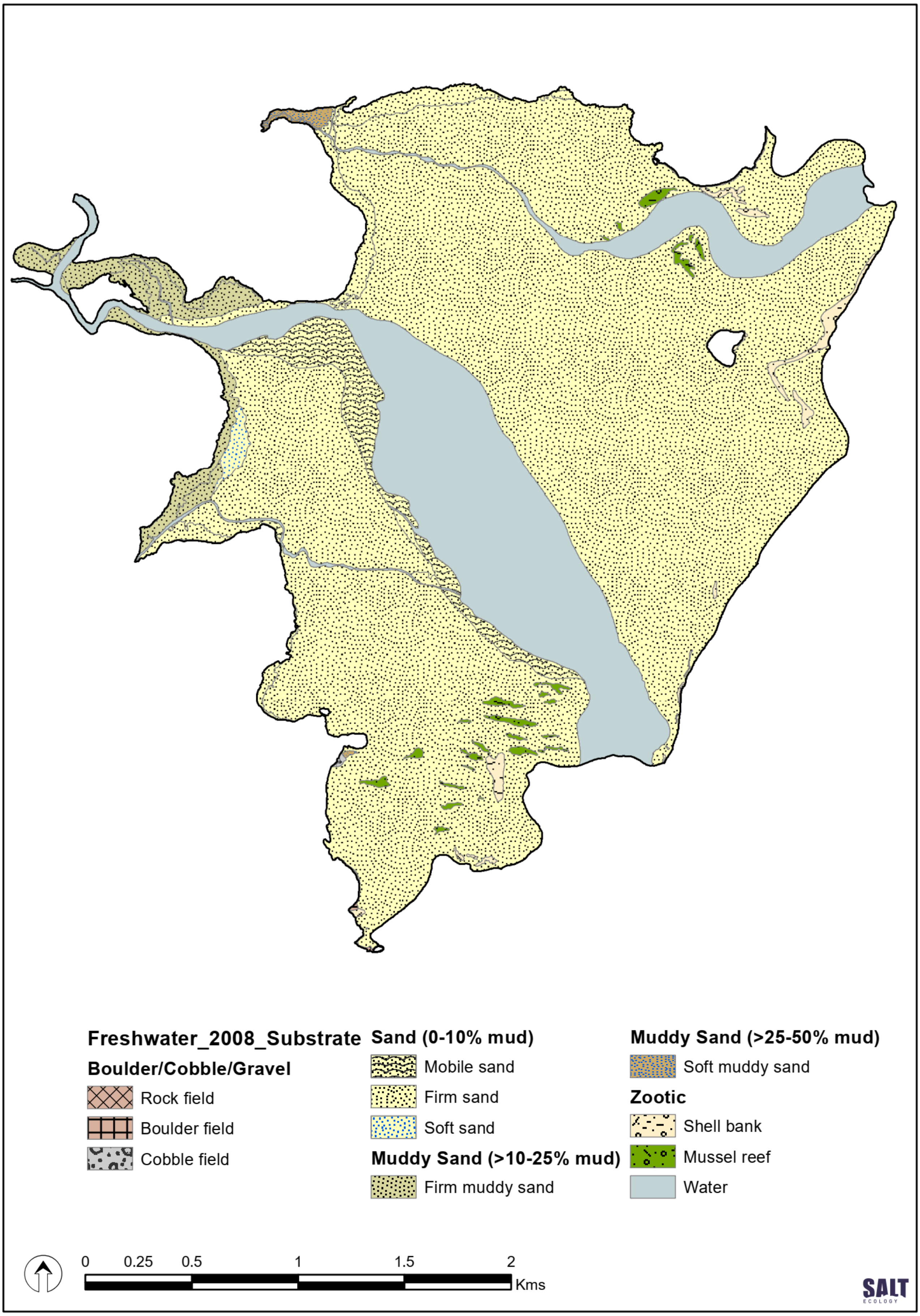
A. Comparative data. See Table in Appendix 1 for field classification codes.

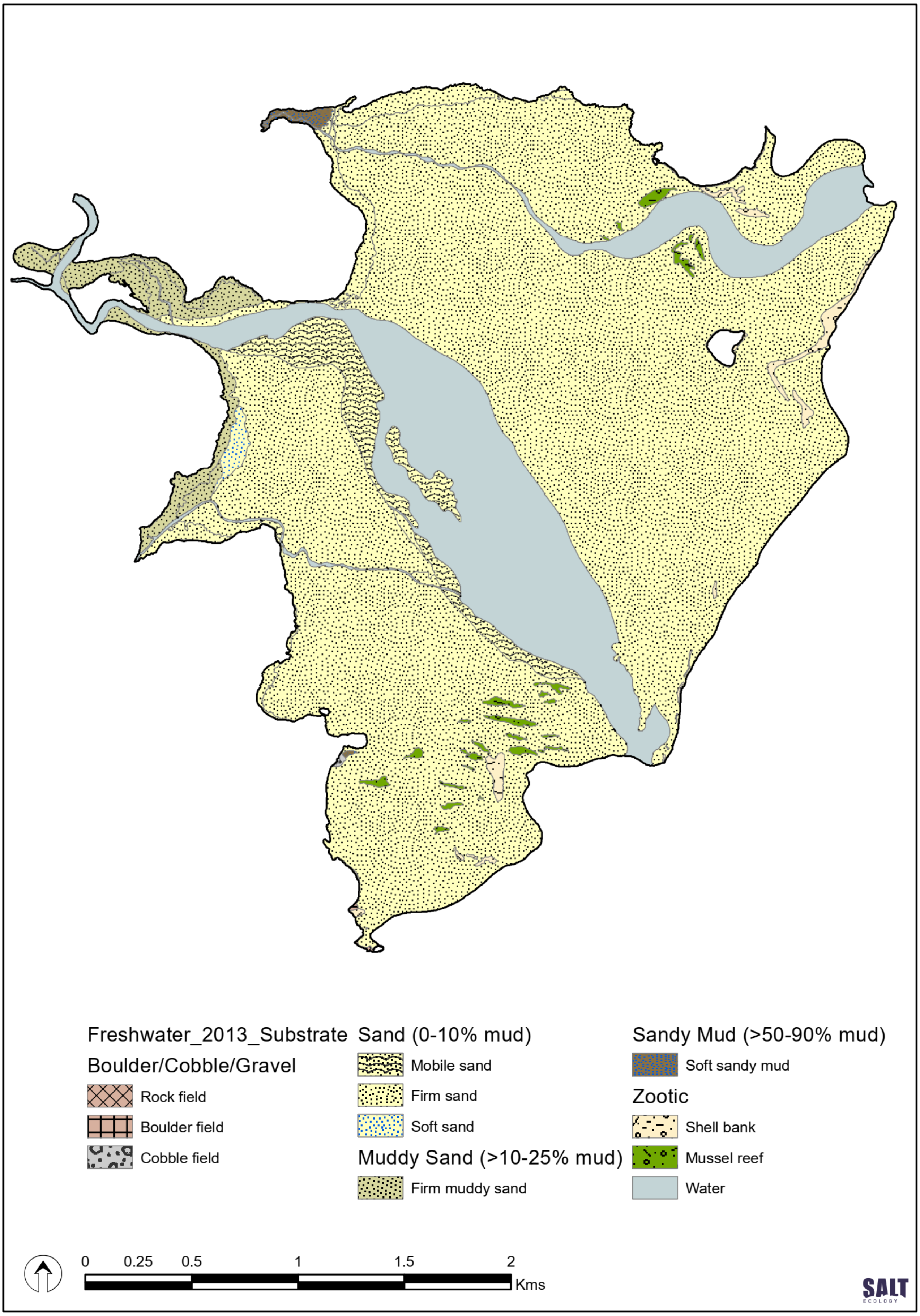
Site	NZTM_E	NZTM_N	Field code	Subjective %mud	Lab %mud	Lab %sand	Lab %gravel	aRPD (mm)
SedPlate_A	1217543	4793099	fS	≤10	1.7	97.9	0.4	7
SedPlate_B	1218383	4793265	fS	≤10	1.6	98.0	0.4	15
SedPlate_C	1217759	4791990	fS	≤10	1.1	98.4	0.5	-
SedPlate_D	1218254	4794155	fS	≤10	<0.1	100.0	0.2	>150
S1	1217718	4790912	fS	≤10	3.4	95.5	1.1	10
S2	1218116	4791389	fS	≤10	1.2	98.2	0.6	100
S3	1217808	4791661	fS	≤10	1.6	98.1	0.2	13
S4	1217733	4792639	fS	≤10	1.1	98.8	<0.1	20
S5	1217213	4792888	fS	≤10	1.2	98.5	0.2	30
S6	1219238	4792389	fS	≤10	1.1	98.7	0.3	60
S7	1219441	4792778	fS	≤10	0.9	98.5	0.5	150
S8	1219671	4793089	fS	≤10	1.1	98.9	<0.1	45
S9	1219757	4793973	fS	≤10	1.2	98.7	0.2	150
S10	1218761	4792975	fS	≤10	1.7	98.2	0.2	20
S11	1218611	4793517	fS	≤10	1.4	98.3	0.3	40
S12	1218565	4793925	fS	≤10	0.1	99.8	<0.1	20
S13	1218713	4794319	fS	≤10	0.6	99.2	0.2	5
S14	1217836	4794570	fS	≤10	1.6	98.4	<0.1	150
S15	1218065	4793904	fS	≤10	1.6	98.1	0.3	5
S16	1217049	4793211	fmS10	>10 - 25	9.0	90.3	0.7	2
FS_A	1217526	4793035	fS	≤10	1.4	98.4	0.5	33
FS_B	1218362	4793247	fS	≤10	1.1	98.8	0.2	33
FS_C	1217758	4791985	fS	≤10	1.5	98.3	0.2	23

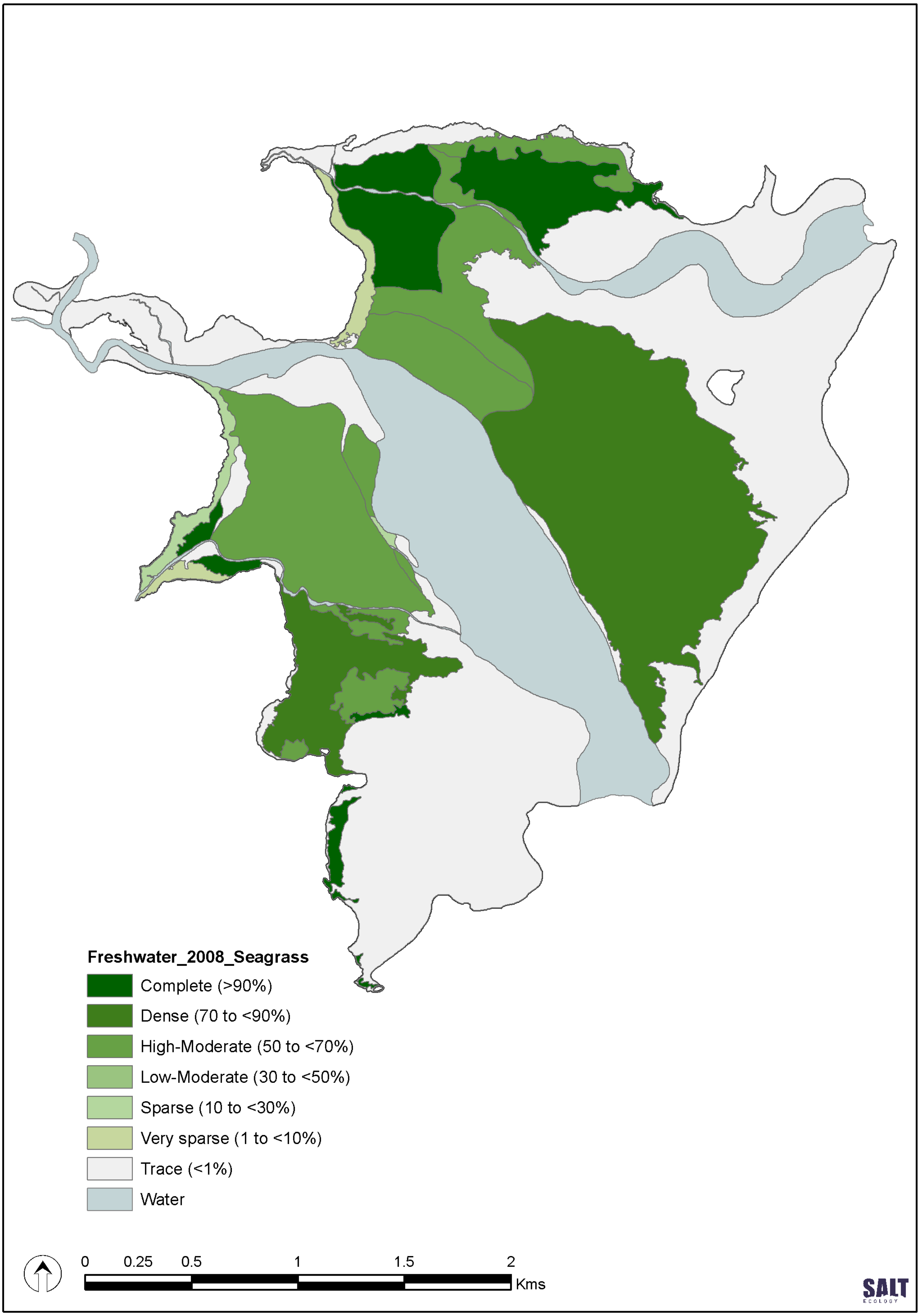
B. Map of sediment sampling stations and ground-truthing walking tracks.



APPENDIX 6. MAP LAYERS FOR 2008 AND 2013




Freshwater_2013_Substrate
Boulder/Cobble/Gravel
Rock field
Boulder field
Cobble field
Sand (0-10% mud)
Mobile sand
Firm sand
Soft sand
Muddy Sand (>10-25% mud)
Firm muddy sand
Sandy Mud (>50-90% mud)
Soft sandy mud
Zootic
Shell bank
Mussel reef
Water
0 0.25 0.5 1 1.5 2
Kms


Freshwater_2008_Seagrass
Complete (>90%)
Dense (70 to <90%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Trace (<1%)
Water
0
0.25
0.5
1
1.5
2
Kms
SALT
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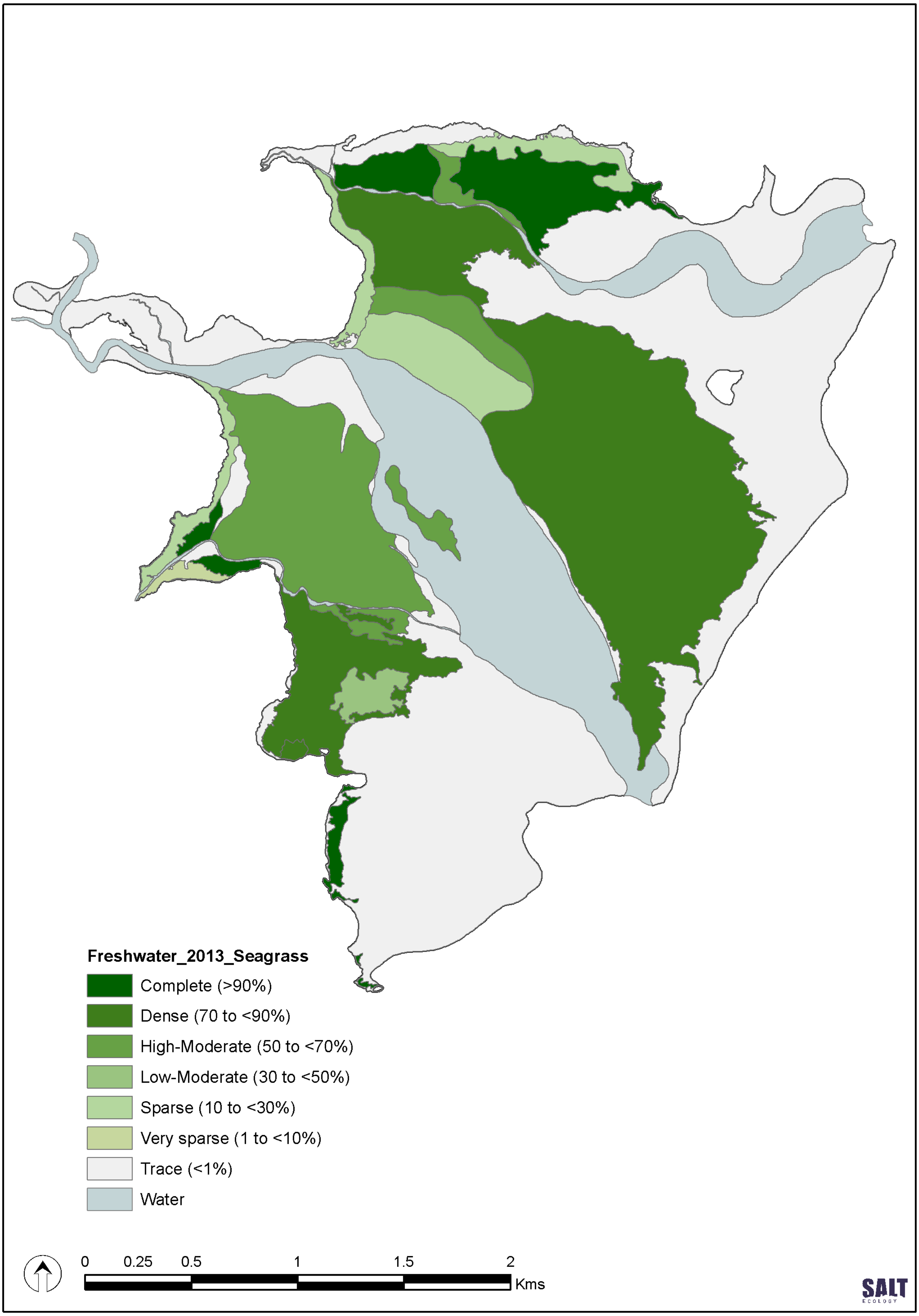
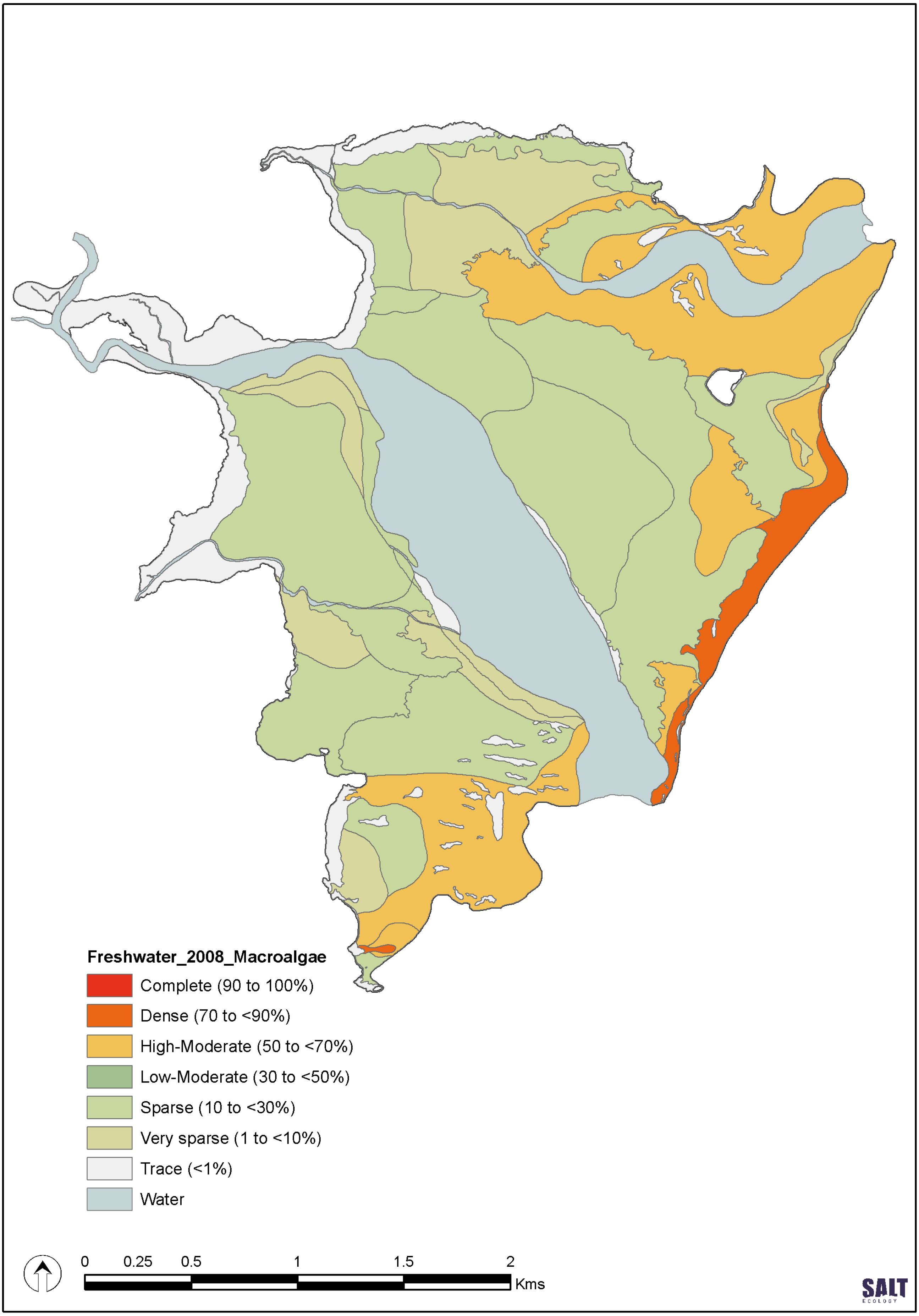
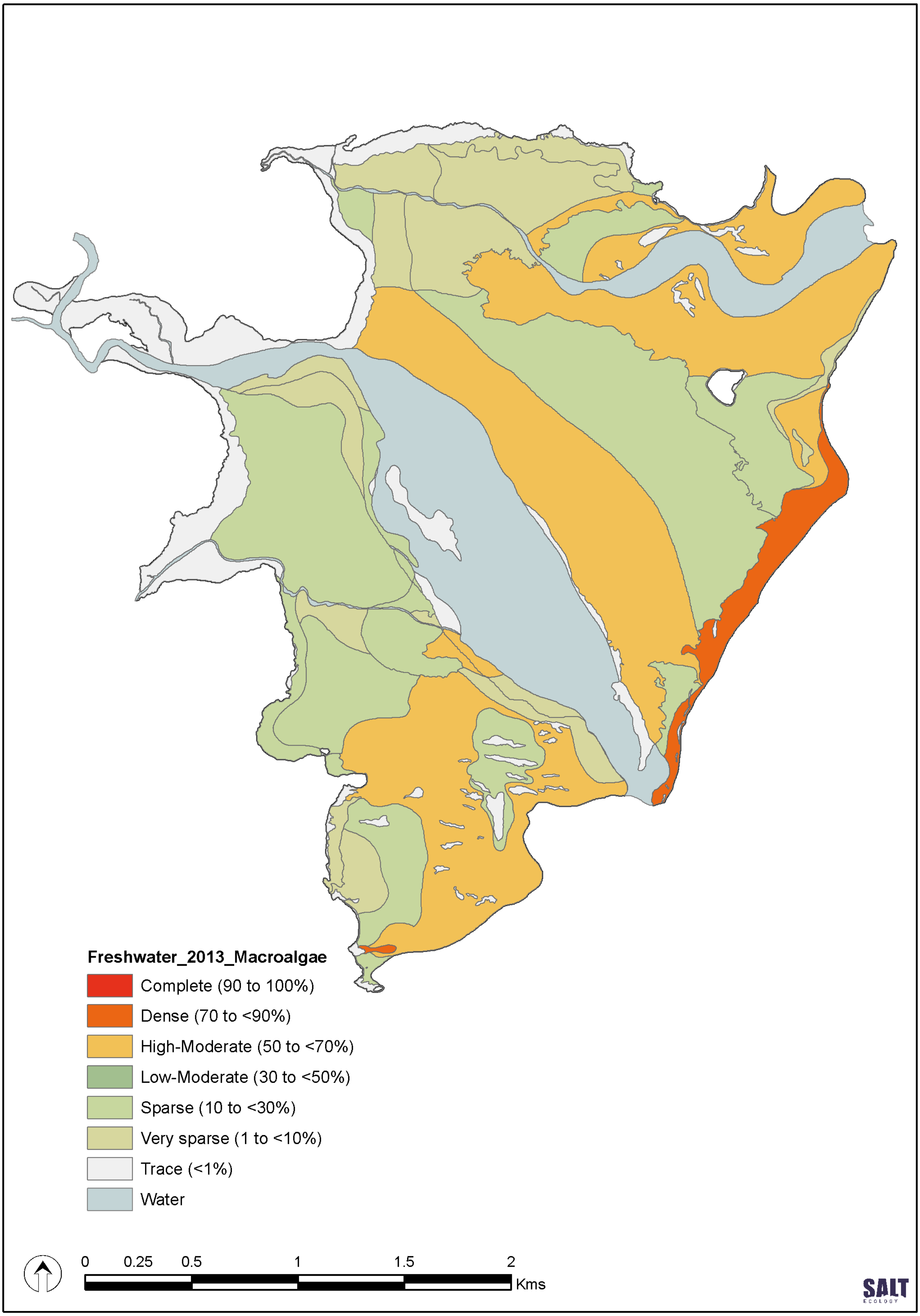
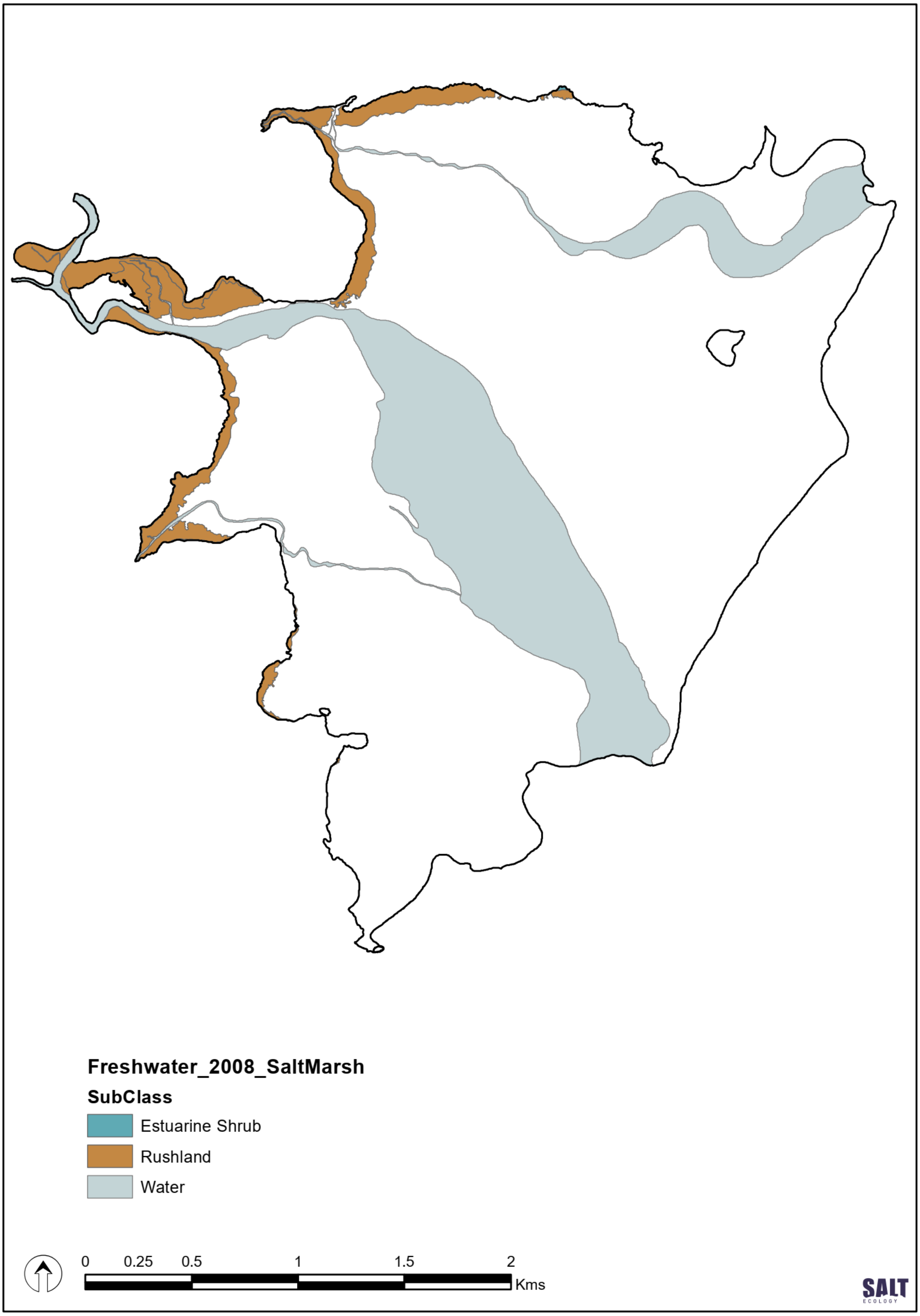
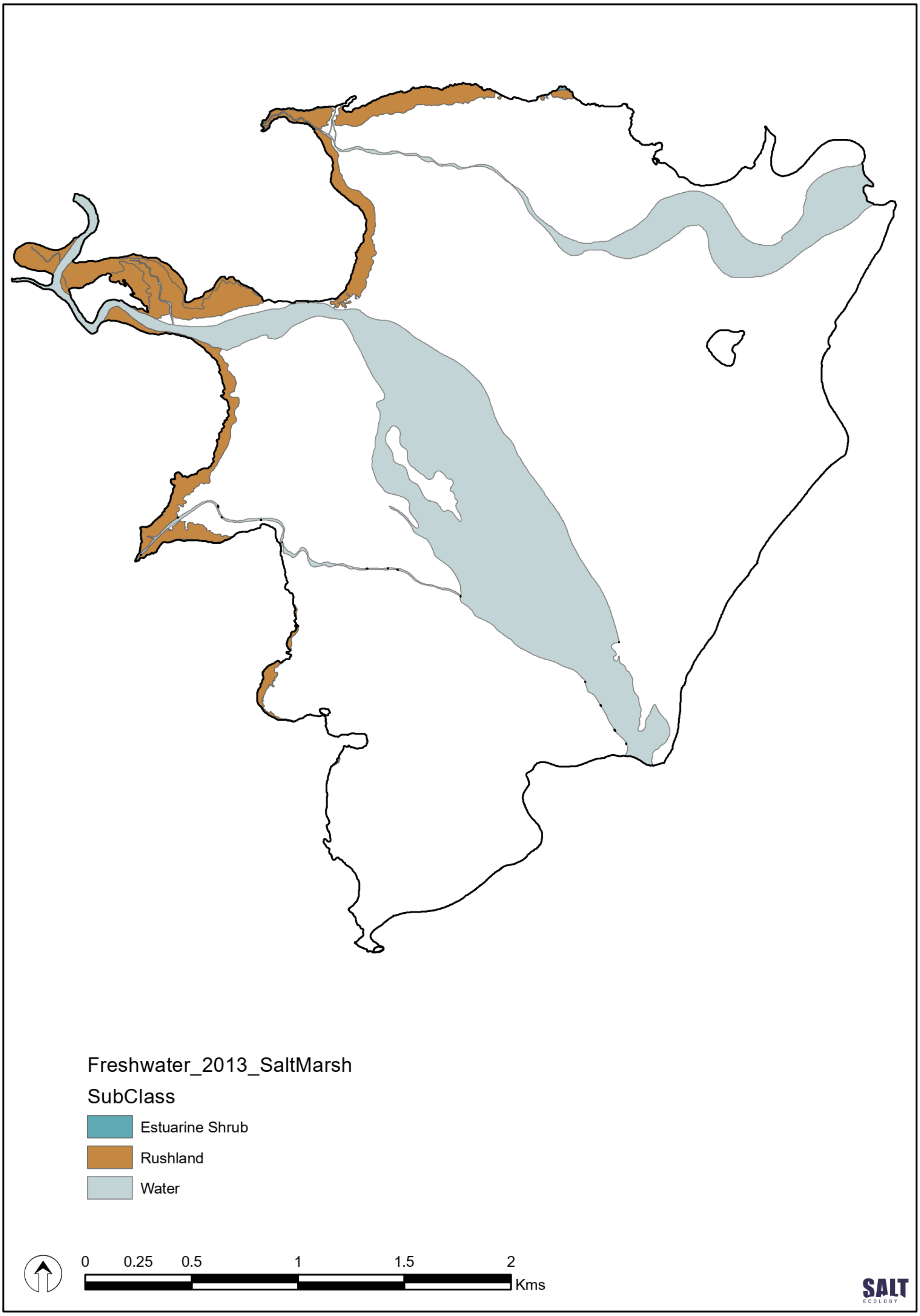

Freshwater_2013_Seagrass
Complete (>90%)
Dense (70 to <90%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Trace (<1%)
Water
0
0.25
0.5
1
1.5
2
Kms
SALT
ECOLOGY



Freshwater_2008_Macroalgae
Complete (90 to 100%)
Dense (70 to <90%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Trace (<1%)
Water
0
0.25
0.5
1
1.5
2
Kms


Freshwater_2013_Macroalgae
Complete (90 to 100%)
Dense (70 to <90%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Trace (<1%)
Water
0
0.25
0.5
1
1.5
2
Kms
SALT
ECOLOGY


Freshwater_2008_SaltMarsh
SubClass
Estuarine Shrub
Rushland
Water
0
0.25
0.5
1
1.5
2
Kms


Freshwater_2013_SaltMarsh
SubClass
Estuarine Shrub
Rushland
Water
0
0.25
0.5
1
1.5
2
Kms
SALT
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APPENDIX 7. SALT MARSH VEGETATION DETAIL

Subclass	Dominant species	SubDom1	SubDom2	Ha	%
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)			0.34	0.90
	P. divaricatus (Salt marsh ribbonwood)	Phormium tenax (New Zealand flax)		0.07	0.18
Tussockland	Phormium tenax (New Zealand flax)	Cordyline australis (Cabbage tree)		0.10	0.27
	Phormium tenax (New Zealand flax)			0.17	0.46
Rushland	Apodasmia similis (Jointed wirerush)	Festuca arundinacea (Tall fescue)	Ficinia (Isolepis) nodosa (Knobby clubrush)	1.09	2.88
	Apodasmia similis (Jointed wirerush)			20.63	54.66
	Apodasmia similis (Jointed wirerush)	Phormium tenax (New Zealand flax)	Festuca arundinacea (Tall fescue)	0.18	0.48
	Apodasmia similis (Jointed wirerush)	Phormium tenax (New Zealand flax)		12.10	32.05
	Apodasmia similis (Jointed wirerush)	P. divaricatus (Salt marsh ribbonwood)	Phormium tenax (New Zealand flax)	3.05	8.09
Herbfield	Selliera radicans (Remuremu)			0.01	0.02
Grand Total				**37.74**	**100**

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