SALT ECOLOGY

Broad Scale Intertidal Habitat Mapping of Te Awarua-o-Porirua Harbour

Prepared for

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GLOSSARY

AIH	Available Intertidal Habitat
aRPD	Apparent Redox Potential Discontinuity
DOC	Department of Conservation
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
GIS	Geographic Information System
GEZ	Gross Eutrophic Zone
GWRC	Greater Wellington Regional Council
HEC	Area of High Enrichment Conditions
LCDB	Land Cover Data Base
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
PCC	Porirua City Council
SOE	State of Environment (monitoring)
TOC	Total Organic Carbon

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BACKGROUND

As part of its State of the Environment programme, Greater Wellington Regional Council (GWRC) undertakes monitoring and assessment of estuaries and other coastal environments in its region. A focus of GWRC's work has been in Te Awarua-o-Porirua Harbour, where monitoring over the last decade or longer has included 'fine scale' and 'broad scale' surveys following methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). This report describes an intertidal broad scale survey conducted in the harbour in January 2020, which involved assessing the dominant substrate and vegetation features present in the estuary including seagrass, salt marsh and macroalgae. Previous mapping results for 2008 and 2013 were QAQC checked, updated to incorporate improvements in substrate classifications, and any errors in geometry or typology were addressed. These updated results were then used to assess temporal changes.

KEY FINDINGS

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

Broad scale indicators	Unit	2008	2013	2020
Mud-dominated substrate	% of intertidal area >50% mud	1.4	8.4	13.5
Macroalgae (OMBT) [1]	Ecological Quality Rating (EQR)	na	na	0.71
Seagrass[2]	% decrease from baseline	23.0	29.6	25.9
Salt marsh extent (current)	% of intertidal area	19.4	18.9	11.1
Historical salt marsh extent	% of historical remaining[3]	25.7	25.2	14.7
200m terrestrial margin[2]	% densely vegetated	19.3	17.0	23.3
High Enrichment Conditions	ha	na	na	1.0
High Enrichment Conditions	% of estuary	na	na	0.1

[1] OMBT=Opportunistic Macroalgal Blooming Tool. [2] Seagrass change assessed relative to baseline (64.9ha) derived from separate surveys of Onepoto (1962) and Pauatahanui (1980). [3] Historic salt marsh change assessed relative to historic baseline (~200ha).

Very Good	Good	Fair	Poor

- There was a gradual increase in the spatial extent of mud-dominated sediment since 2008, particularly in the Pauatahanui arm. The 2020 spatial extent was rated 'fair', but approaching the 'poor' threshold of >15%.
- A harbour-wide reduction in opportunistic macroalgal growth was reported from 2017 to 2020 (details included in the main body of this report), and the presence of only small hotspots of persistent macroalgal in 2020, was rated 'good'. However, conspicuous mats of filamentous green algae *Chaetomorpha ligustica* were present as drift material near the entrance in 2020, causing localised smothering of the seabed and its associated biota (e.g. seagrass, cockles).
- Seagrass was relatively extensive and has changed little in extent since 2008. It was rated 'good'.
- A significant (43%) decline in salt marsh extent between 2013 and 2020, was rated 'poor'. This was primarily in the eastern Pauatahanui arm where salt marsh is transitioning to terrestrially dominated vegetation as a consequence of ongoing drainage.
- Large historical losses of seagrass and salt marsh were rated 'poor'.

RECOMMENDATIONS

Based on the findings of this report, it is recommended that GWRC consider the following:

- A further harbour-wide broad-scale survey in 5-years to keep track of long-term changes.
- Annual or biennial mapping or qualitative assessment of the northeast Pauatahanui arm to track changes in the spatial extent of the muddy sediment zone.
- Investigate the potential sources of recent and ongoing sediments to the Pauatahanui arm (e.g. examine recent and current land uses, determine mass loads from streams, undertake sediment tracing studies).
- Incorporate data from complementary monitoring, e.g. Transmission Gully data in future reporting.
- Assess the broader ecological implications of changes in key indicators revealed by the present report, and recent (fine scale) or planned (subtidal) surveys.
- Develop a strategy to minimise future losses of high value salt marsh including recommending specific restoration options, e.g. replanting salt marsh, improving tidal flushing, recontouring shorelines, and removing barriers to salt marsh expansion.

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.

Greater Wellington Regional Council (GWRC) has undertaken monitoring of selected estuaries in the region using the NEMP methods and other approaches (e.g. synoptic surveys, sedimentation monitoring) for over a decade. A focus of GWRC's work has been in Te Awarua-o-Porirua Harbour (Fig. 1) where the first NEMP broad and fine scale surveys were undertaken in 2008 (Robertson & Stevens 2008; Stevens & Robertson 2008). Since then, GWRC has commissioned follow-up and related surveys, including:

- Two NEMP broad scale, and three fine scale surveys, most recently in 2013 and 2020, respectively (Stevens & Robertson 2013; Forrest et al. 2020).
- Targeted assessment of intertidal macroalgae, the most recent survey being in 2017 (Stevens & O'Neill-Stevens 2017).
- Subtidal habitat mapping and ecological surveys (Milne et al. 2008; Oliver & Conwell 2014; Stevens & Robertson 2014).
- Annual monitoring of sedimentation rates at intertidal and subtidal sites (e.g. Stevens & Forrest 2020a).

Salt Ecology was contracted to carry out further NEMP broad scale and fine scale surveys in the harbour in January 2020. This report describes the methods and results of the broad scale survey, compares findings with earlier intertidal NEMP surveys (2008, 2013) and earlier survey data (where available), and discusses the current status and trends in estuary health. Recommendations for future monitoring and assessment are also made.

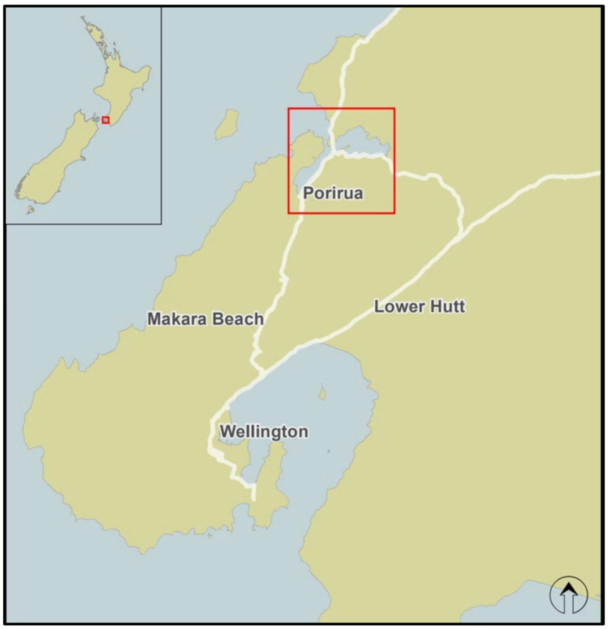


Fig. 1 Location of Te Awarua-o-Porirua Harbour.

1.2 BACKGROUND TO TE AWARUA-O-PORIRUA HARBOUR

Background information on Te Awarua-o-Porirua Harbour was most recently provided in the 2020 fine scale report (Forrest et al. 2020) and is summarised below.

The harbour is a large (807ha, Fig. 2), well-flushed estuary fed by a number of small streams. It comprises two arms, each a relatively simple shape, Onepoto (283ha) and Pauatahanui (524ha). The arms are connected by a narrow channel at Paremata, and the estuary discharges to the sea via a narrow entrance west of Plimmerton.

Residence time in the estuary is less than 3 days, however, compared to the majority of New Zealand's tidal lagoon estuaries which tend to drain almost completely at low tide, the harbour has a large shallow subtidal component (65%, mean depth ~1m). Nonetheless, the intertidal area is large (287ha).

The estuary has high human use and high ecological values. The last broad scale survey recorded extensive areas (59ha) of seagrass growing in firm mud/sand, as well as shellfish beds (Stevens & Robertson 2013). Other studies have recorded very high densities of cockles (*Austrovenus stutchburyi*) across both arms of the harbour (e.g. Lyon & Michael 2015, Michael & Wells 2017), with at least 43 fish species and 53 bird species also recorded (Jones & Hadfield 1985; Blaschke et al. 2010).

However, the harbour has been extensively modified over the years, particularly the Onepoto arm, where almost all of the historical shoreline and salt marsh have been reclaimed and most of the arm is now lined with steep straight rock walls flanked by road and rail corridors. The Pauatahanui arm is less modified (although most of the arm's margins are also encircled by roads), with extensive areas of salt marsh remaining in the north and east. Many areas have been improved through local community enhancement efforts such as replanting near Porirua Stream mouth, Kakaho and Horokiri.

Catchment land use in the Onepoto arm is dominated by urban (residential and commercial) development (Table 1, Fig. 2). In the steeper Pauatahanui arm, grazing is the dominant land use, although urban (residential) development is significant in some areas. Various reports have identified sedimentation as a major problem in the estuary, particularly in the Pauatahanui arm, where potential sources include land disturbance associated with urban subdivision (e.g. near Duck Creek), and the Transmission Gully motorway development (see Fig. 2).

Table 1. Summary of catchment land cover (LCDB5 2018) for Te Awarua-o-Porirua Harbour.

LCDB5 (2018) Class and Name		Ha	%
1	Built-up Area (settlement)	2463	14
2	Urban Parkland/Open Space	387	2
5	Transport Infrastructure	78	0.5
6	Surface Mine or Dump	30	0.2
16	Gravel or Rock	9	0.1
20	Lake or Pond	7	0.0
22	Estuarine Open Water	10	0.1
30	Short-rotation Cropland	6	0.0
33	Orchard, Vineyard, Other Perennial Crop	2	0.0
40	High Producing Exotic Grassland	6468	38
41	Low Producing Grassland	853	5
45	Herbaceous Freshwater Vegetation	15	0.1
46	Herbaceous Saline Vegetation	44	0.3
50	Fernland	1	0.0
51	Gorse and/or Broom	1460	8
52	Manuka and/or Kanuka	596	3
54	Broadleaved Indigenous Hardwoods	1745	10
64	Forest - Harvested	112	1
68	Deciduous Hardwoods	16	0.1
69	Indigenous Forest	251	1
71	Exotic Forest	2654	15
	Grand Total	17208	100

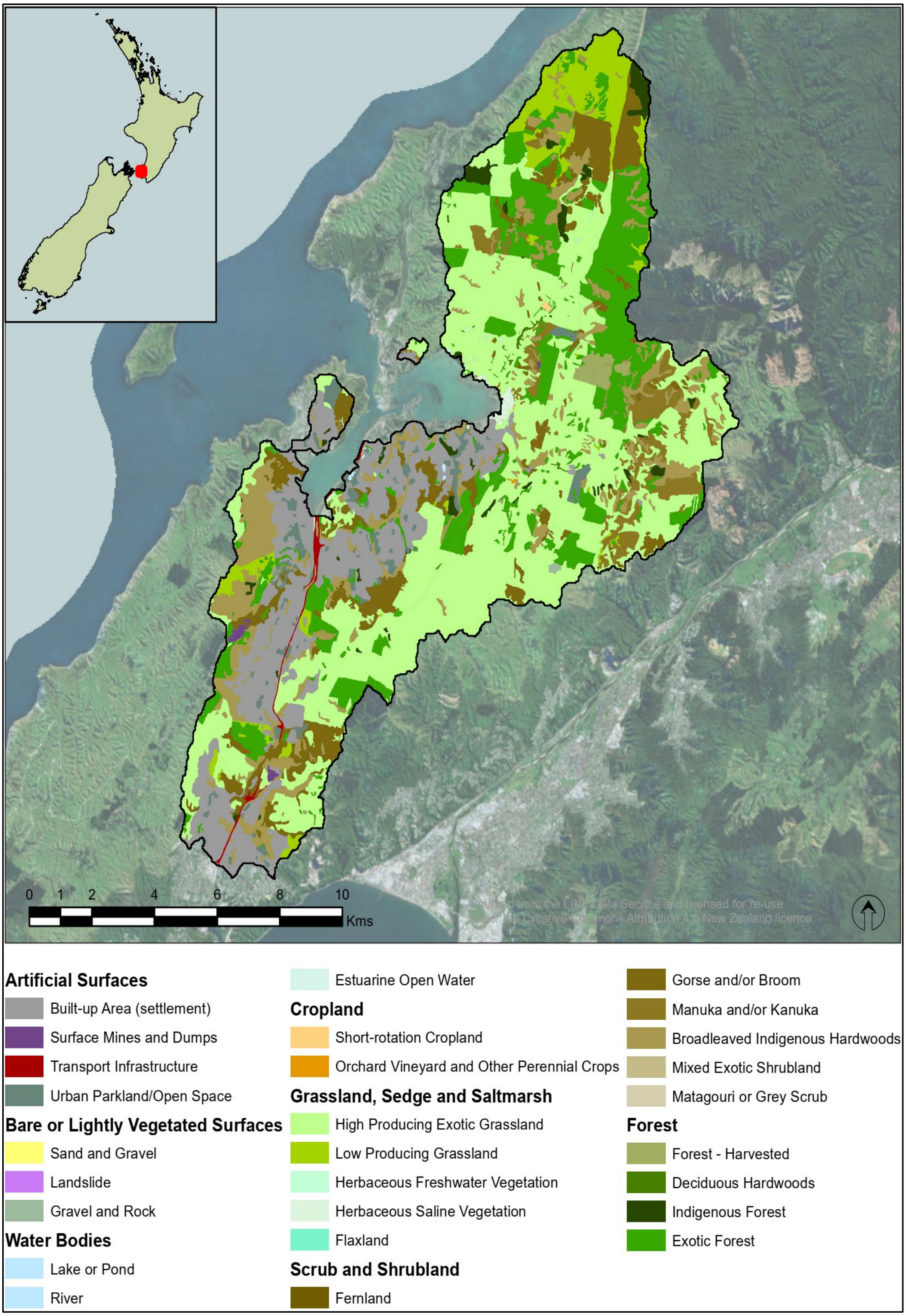


Fig. 1 Te Awarua-o-Porirua Harbour and surrounding catchment.

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 Te Awarua-o-Porirua Harbour in 2020 used a combination of 2016 colour aerial photographs (~0.07m/pixel resolution) sourced from the LINZ data service, and more recent (2019) LINZ imagery accessed through ESRI online. Ground truthing was undertaken in January 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 harbour. 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 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 NIWAs CLUEs estuary model.

Table 1. 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. Results of the validation analyses will be used to refine the classification approach.

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.

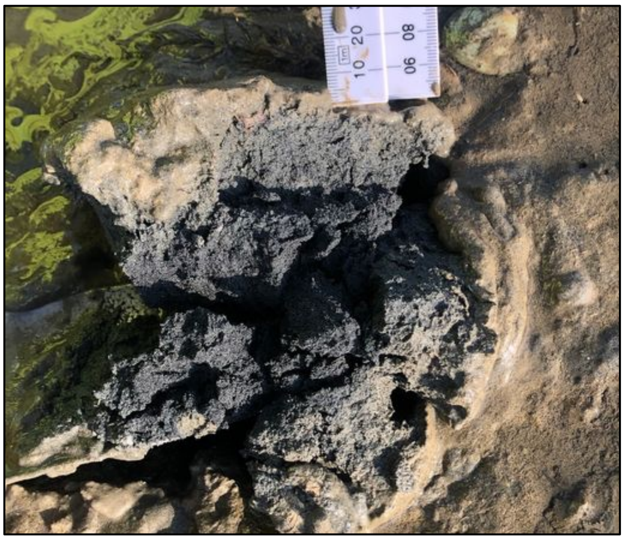
2.2.2 Sediment mud content and trophic status

Sediment mud content

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, mud 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 19 sites (14 intertidal, 5 subtidal) where sedimentation rate monitoring was undertaken concurrently (Stevens & Forrest 2020b). Analytical methods are provided in Appendix 2.

Sediment trophic status

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

Table 2. 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%)	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

As a supporting indicator of trophic status in Te Awarua-o-Porirua Harbour, 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 as 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 Te Awarua-o-Porirua Harbour, 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, 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 subjective biomass estimates were made following the OMBT method. Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on the five-point scale adopted by the method, for which descriptors range from 'high' to 'bad'.

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 50% 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

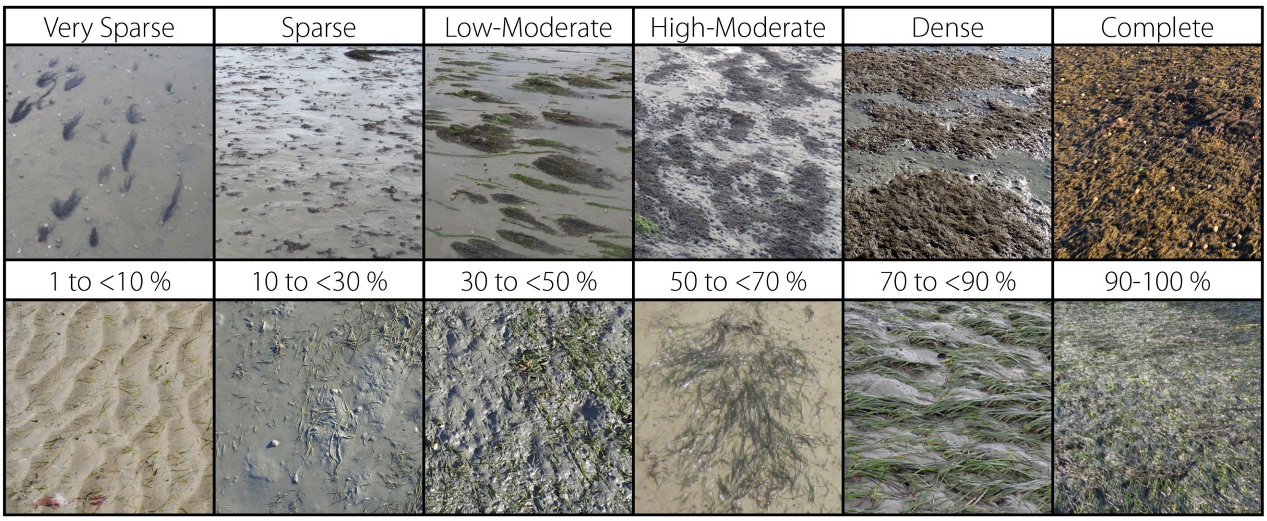


Fig. 2 Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

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.

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 GWRC.

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. 2016b). Additional supporting information on the ratings is provided in Appendix 4. To avoid confusion, 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 unfeasible 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.

Table 3. 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.*

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 in Table 5 and Fig. 4 show that substrate in the harbour is relatively heterogeneous across the mapped intertidal area of ~265ha. Example photographs of representative substrates are provided below and on following pages. Validation of 19 subjective sediment substrate classifications showed that 16 observations were assigned to the correct mud content class (Appendix 5). In three instances the field classification overestimated actual mud content due to a thin layer of muddy sediment deposited on top of a relatively coarse (primarily sandy) base. Hence, the substrate patterns described below can be considered a reliable representation of surface sediment conditions.

In 2020, substrates were dominated by firm muddy sands. In terms of the biologically relevant problematic mud fraction, ~45% (118.3ha) of the tidal flat area had a sediment mud content of >25% (Fig. 5). Of this component, 31.9ha were mud-dominated (i.e. excessively muddy) sediments (>50-90% mud content), which represents 12% of the total intertidal area (Fig. 5). Preliminary screening revealed an aRPD depth shallower than 5-10mm depth in the locations with the muddiest sediments (Appendix 5), or where there was a dense cover of macroalgae (see Section 3.2).

A comparison of the three broad scale surveys conducted to date reveals a steady increase in the spatial extent of mud-dominated sediment over a 12-year period, i.e. from 3.4ha recorded in 2008 to almost 32ha in 2020 (see Fig. 5 inset). Most of the mud-dominated sediments occur in the eastern and northern Pauatahanui arm of the harbour. Key areas are the Kakaho and Horokiri Stream deltas, and alongside Ration Point near the Pauatahanui Stream delta. In the Kakaho and Horokiri areas in particular, there was relatively fresh muddy surface sediment overlying the base of firm muddy sand present in previous surveys. This surface material could be scraped aside like a muddy 'slurry' (see photos below).

Table 4. Summary of dominant intertidal substrates.

Subclass	Dominant feature	Ha	%
Artificial	Artificial substrate	2.0	0.7
Bedrock	Rock field	4.9	1.8
Boulder/Cobble/Gravel	Boulder field	0.1	0.0
	Artificial boulder field	0.6	0.23
	Cobble field	4.2	1.6
	Artificial cobble field	0.1	0.05
	Gravel field	25.1	9.4
Sand (0-10% mud)	Mobile sand	10.1	3.8
	Firm sand	23.6	8.9
Muddy Sand (>10-25% mud)	Firm muddy sand	74.0	27.9
Muddy Sand (>25-50% mud)	Firm muddy sand	84.6	31.9
	Soft muddy sand	1.8	0.7
Sandy Mud (>50-90% mud)	Firm sandy mud	6.0	2.3
	Soft sandy mud	21.4	8.1
	Very soft sandy mud	4.5	1.7
Zootic	Shell bank	2.3	0.9
	Cocklebed	0.01	0.003
	Tubeworm reef	0.04	0.01
Total		**265.2**	**100**

Layer of recent soft mud overlying firm muddy sand, Horokiri

Eroding soft mud deposits overlying firm muddy sand, upper Pauatahanui arm

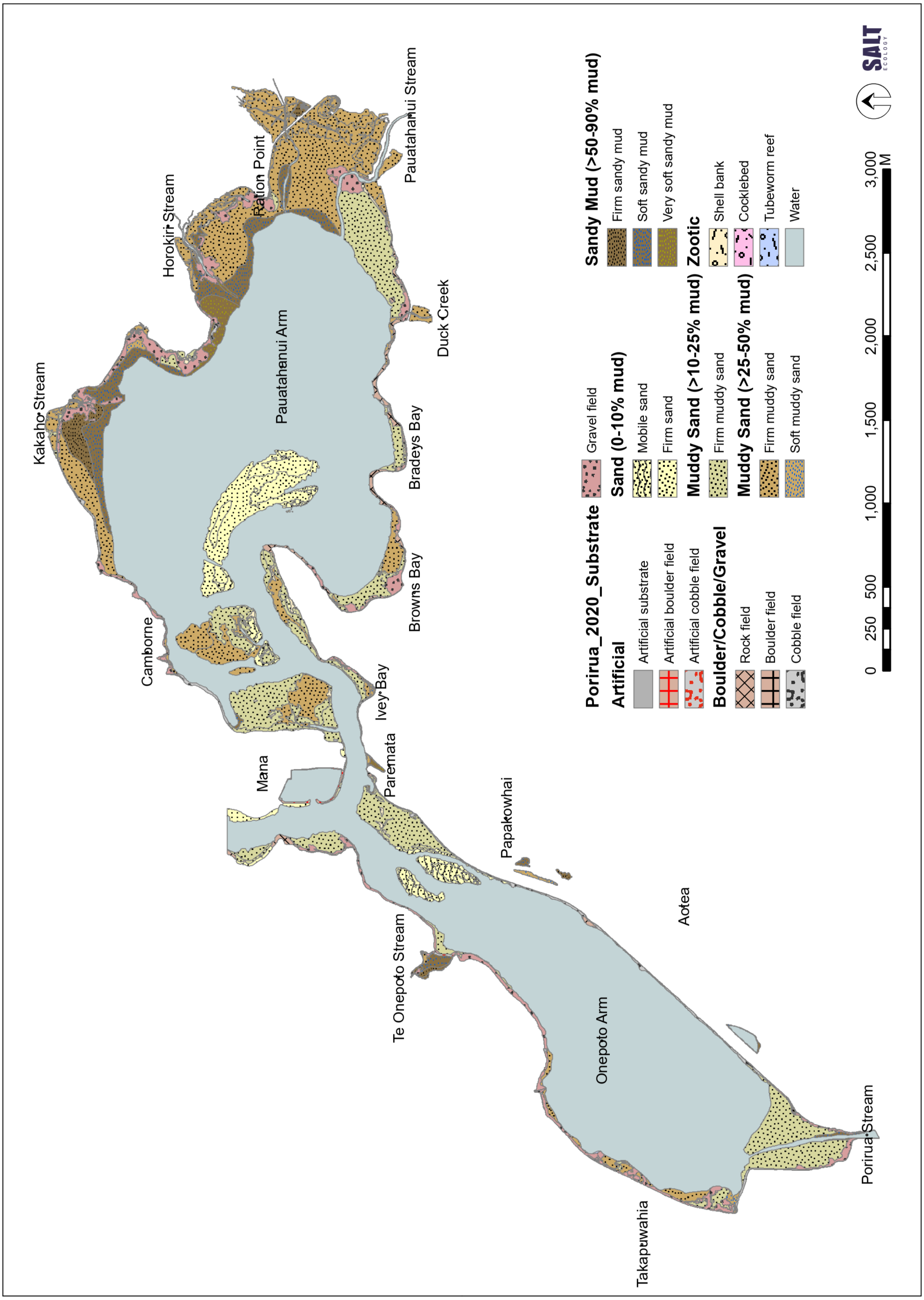


Fig. 3 Map of dominant intertidal substrate types, Te Awarua-o-Porirua Harbour January 2020.

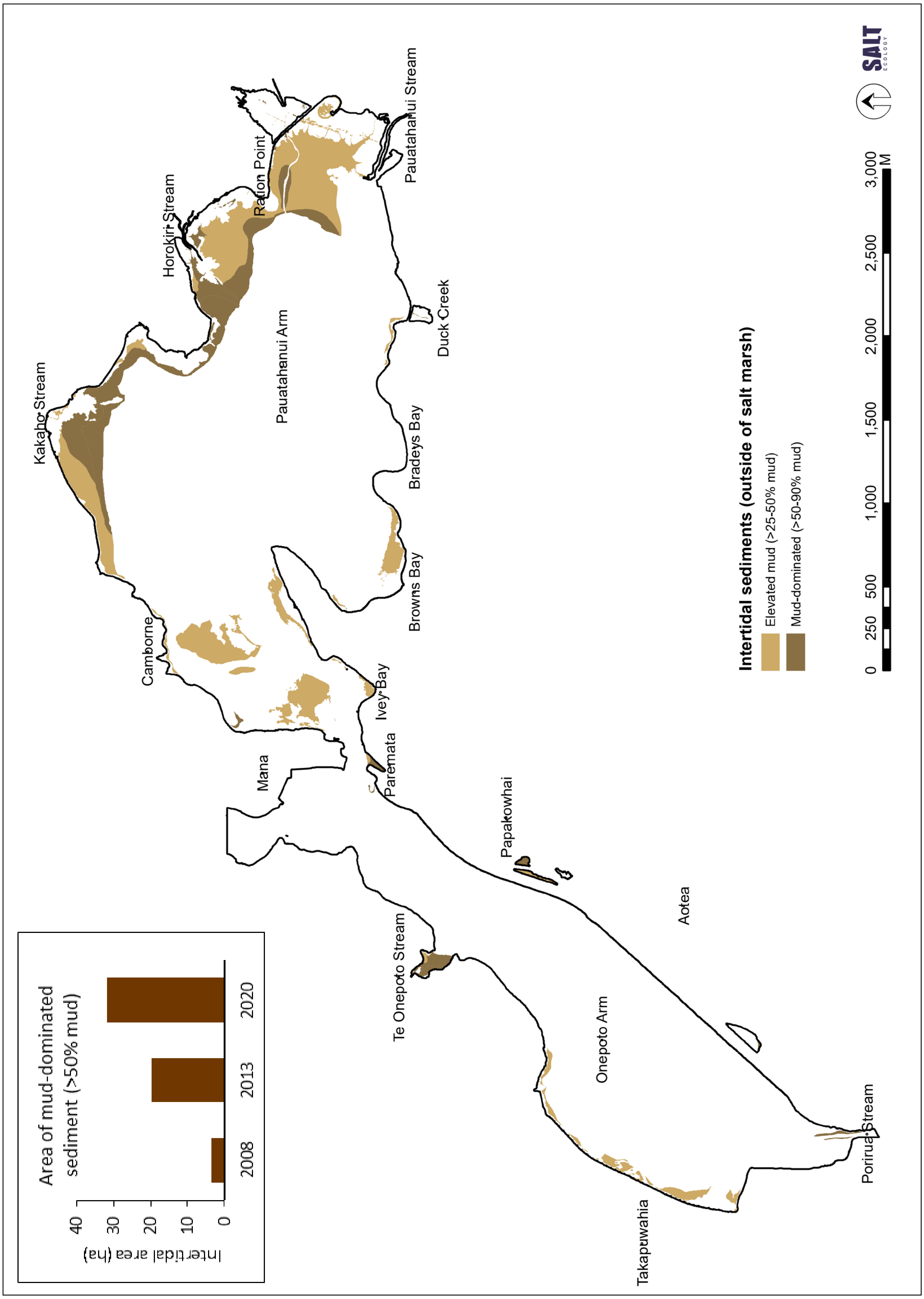


Fig. 4 Map of intertidal substrate types showing area of mud-elevated (>25-50% mud) and mud-dominated (>50% mud) sediment, Te Awarua-o-Porirua Harbour January 2020. Inset bar graph shows change in mud-dominated sediments since 2008, not including areas within salt marsh (see text for explanation).


Typical upper tidal gravel field and narrow strip of salt marsh


Typical firm muddy sand tidal flats


Resuspension of muddy sediment layer, Kakaho


Firm muddy sands near Porirua Stream mouth

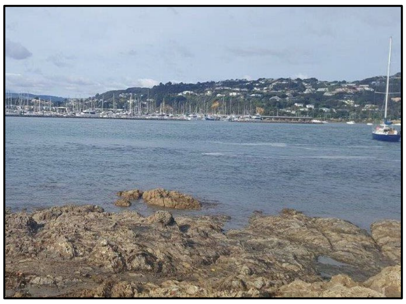

Soft muddy sand at Horokiri


Shell bank in central Pauatahanui arm


Gravel and shell bank in the upper Pauatahanui arm


Rippled mobile sand in the lower Onepoto arm


Sarcocornia among gravel fields in eastern Pauatahanui arm


Natural bedrock was most prevalent in outer harbour areas


Orange sea sponge among biogenic habitat provided by tube worm reef


Modified margin with restoration planting, Paremata railway


Modified margin of eastern Onepoto arm


Rip rap wall in western Onepoto arm


Eroding margin along Titahi Bay Road, western Onepoto

Note that the temporal comparison excludes sediment within salt marsh areas, as this was not recorded in 2008 or 2013. Also, it has been assumed that the NEMP classifications for soft mud and very soft mud used in the earlier surveys reflect mud-dominated sediments (>50% mud content), and that firm muddy sands reflect sediments with mud contents of 10-25%. This assumption is necessary as earlier NEMP surveys did not provide the detailed sediment classifications used in 2020 (see Table 3).

While the sediment in the Horokiri and Kakaho areas often remained firm to walk on, the extensive presence of relatively deep surface mud is likely to have significantly adversely impacted the sediment dwelling communities present, while the associated infilling of interstitial spaces is likely to have shifted the macrofaunal community to one that is less diverse and dominated by mud-tolerant species. However, it is unclear whether this state will persist, as there was evidence during the field survey of the muddy surface layer being eroded and remobilised (see photos).

In addition to these muddy or sandy soft sediments, other less prevalent but ecologically important habitats across the harbour included gravel fields and hard natural substrates (bedrock, boulder, cobble) around the harbour margins, representing ~13% of the mapped intertidal area. Minor habitats (<1% of area) were artificial substrates (rock wall around parts of the harbour margin) and 'zootic' features, namely cockle beds, shell banks, and tube worm reefs. The latter reef features characterised the low tide margin in some areas, creating 'biogenic' habitat for a variety of other organisms, such as sponges, bryozoans, top shells, chitons, limpets, sea squirts and macroalgae.

3.2 OPPORTUNISTIC MACROALGAE

Table 6 summarises macroalgal percentage cover classes for the harbour, with the mapped cover and biomass shown in Fig. 6 and Fig. 7, respectively.

Macroalgae cover was classified as 'trace' (< 1% cover) across ~76% of the intertidal area, and 'very sparse' (1-<10%) or sparse (10-<30%) across a further 23%. In these areas the red seaweed *Gracilaria chilensis* was the main species present, along with a lesser amount of the green seaweed *Ulva* spp. (see photos on page 17).

Areas exceeding 30% cover were highly localised, representing <2% of the total mapped area. These areas were the tidal flats around Mana and Paremata (on both sides of the channel), the southern Onepoto arm, and the Te Onepoto Stream embayment. The key features of these areas were as follows:

Te Onepoto Stream embayment had an extensive cover (70-90%) and the greatest biomass (>3kg/m^2) of macroalgae, consisting primarily of *Gracilaria chilensis* and lesser amounts of a filamentous green seaweed, recently identified by NIWA as *Chaetomorpha ligustica*

In the southern Onepoto arm, *Gracilaria* was conspicuous, with small patches of dense cover (70-90%) around the Wi Neera Drive boat ramp and adjacent stormwater outfall.

Along the Paremata railway flats and Mana area, one of the conspicuous features was extensive mats of *Chaetomorpha ligustica*, which appeared to mainly be drift (unattached) material. The Paremata railway flats area also had sparser areas of *Ulva* and *Gracilaria* (see photos).

While *Gracilaria* and *Ulva* are well-recognised opportunistic species, *Chaetomorpha ligustica* belongs to a poorly understood seaweed group with a disjointed distribution in New Zealand. It appears to be the same species described as being present in Te Awarua-o-Porirua Harbour since the 1950's (Adams 1994), although anecdotally has become more conspicuous in recent years. For example, these mats were not recorded in any of the previous NEMP surveys and were not noted during the sedimentation monitoring conducted one year earlier in January 2019 (authors, pers. obs.).

Table 6. Summary of intertidal macroalgae cover classes.

Percent cover category	Ha	%
Trace (<1%)	201.8	75.9
Very sparse (1 to <10%)	45.5	17.1
Sparse (10 to <30%)	14.5	5.4
Low-Moderate (30 to <50%)	2.9	1.1
High-Moderate (50 to <70%)	0.2	0.1
Dense (70 to <90%)	0.5	0.2
Complete (>90%)	0.5	0.2
Grand Total	**265.9**	**100**

Where macroalgal mats had an extensive cover or high biomass they had a smothering effect, creating a black anoxic sediment (i.e. aRPD at the sediment surface) that has a 'rotten egg' sulfide smell. This effect was especially evident in the Te Onepoto Stream embayment, and beneath *Chaetomorpha* mats in the Paremata area. Some of these mats had smothered cockle beds or killed patches of seagrass beneath them (see photos).

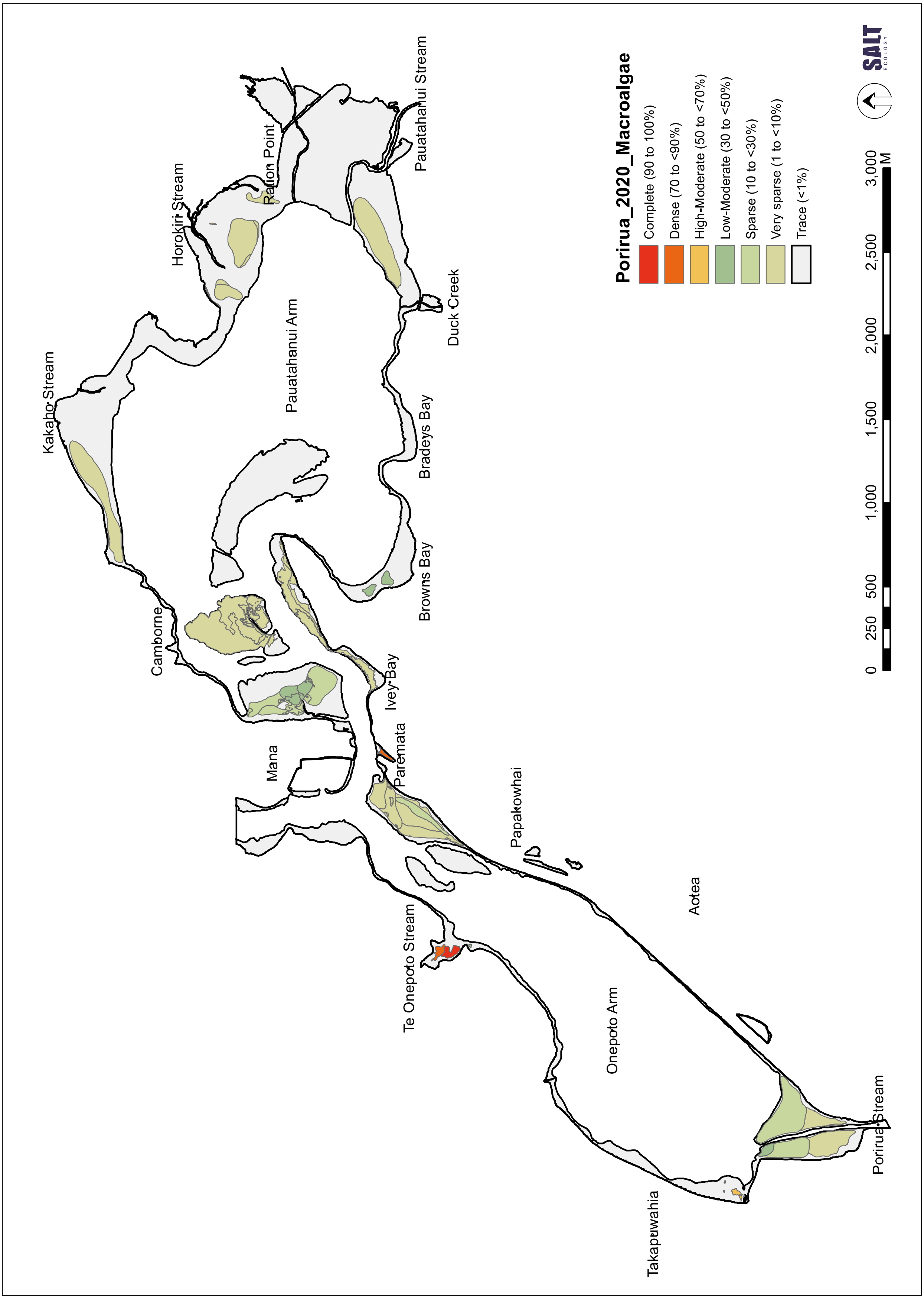


Fig. 5 Distribution and percentage cover classes of opportunistic macroalgae, Te Awarua-o-Porirua Harbour January 2020.

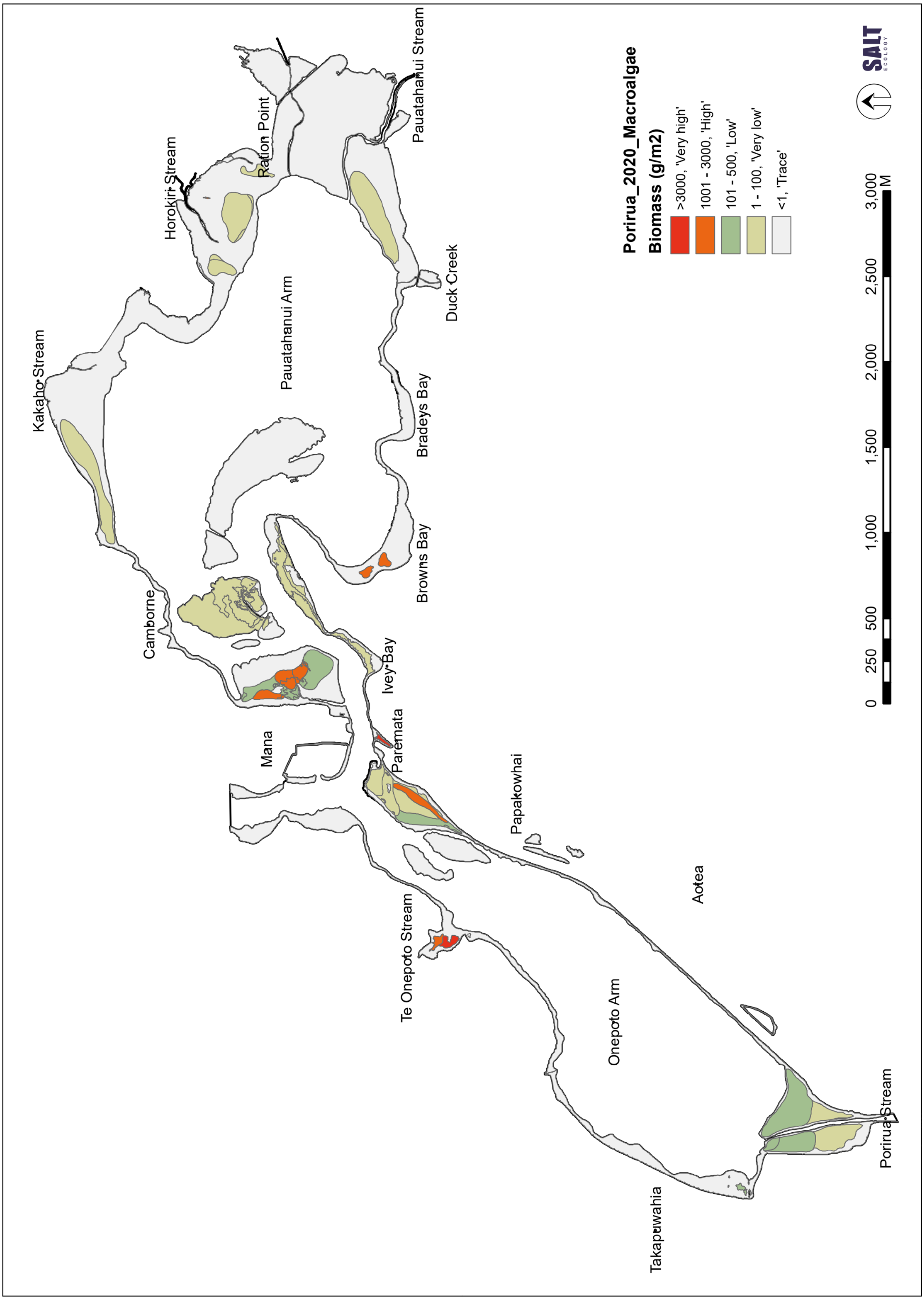


Fig. 6 Biomass (wet weight g/m^2) classes of opportunistic macroalgae, Te Awarua-o-Porirua Harbour January 2020.

Gracilaria was the most widespread macroalgae but was typically at low prevalence

Problem growths of *Gracilaria* in the Te Onepoto Stream embayment

Drift (unattached) *Chaetomorpha* mats around Mana boatshed area

Chaetomorpha drift mats among cockles on Paremata railway flats

Broad-bladed *Ulva* (aka 'sea lettuce') was most prevalent in gravel and cobble areas

Ulva, *Chaetomorpha* and *Gracilaria* among seagrass on Paremata railway flats

Chaetomorpha mats had a smothering effect leading to sediment anoxia and killing organisms beneath

High biomass beds of *Gracilaria* were entrained into the sediment with anoxic sediments beneath

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.

Data from previous macroalgal surveys (2008-2017) are summarised by Stevens and O'Neill-Stevens (2017), with EQR scores having being calculated since 2015. These scores are provided in Table 8. As for 2020, the EQR was rated as 'good' in 2016, whereas it 2015 and 2017 the rating was 'moderate'. Stevens and O'Neill-Stevens (2017) noted the presence in 2017 of high density intertidal macroalgal growths on the verge of nuisance conditions. They described a doubling of macroalgal biomass between the 2016 and 2017 surveys, with the most notable increases being on the Pauatahanui, Kakaho and, to a lesser extent, Horokiri stream deltas. Data provided in their 2017 survey report indicate a biomass of up to 2kg/m^2 in the eastern end of the Pauatahanui arm, and typically 0.2-0.5kg/m^2 in the Horokiri and Kakaho area. By contrast, in 2020 the spatial extent of macroalgae was much reduced in those areas, and high biomass beds were absent (biomass in 2020 was <0.1kg/m^2, see Fig. 7).

Despite the 2020 monitoring showing improved conditions in the eastern and northern Pauatahanui arm, there are nonetheless temporally persistent small 'hotspots' where macroalgae are at nuisance levels. Of particular interest is the apparent recent 'bloom' of *Chaetomorpha ligustica*, especially given its propensity to form dense mats that smother the sediment beneath. The reasons for these temporal changes are unknown, but suggest that continued monitoring of macroalgal status is worthwhile despite the overall improvement in EQR in 2020.

Table 8. Summary of EQR scores for the four most macroalgal surveys in Te Awarua-o- Porirua Harbour.

Year	EQR	Rating
2015	0.58	Moderate
2016	0.61	Good
2017	0.55	Moderate
2020	0.71	Good

In addition to the nuisance macroalgae described in the report, natural bedrock and cobble areas contained a mixed of seaweed species that were conspicuous in places

Table 5. Summary of OMBT input metrics and calculation of overall macroalgal ecological quality rating, Te Awarua-o-Porirua Harbour January 2020.

Metric	Face Value	FEDS	Quality Status
% cover in AIH	2.3	0.908	High
Biomass per m^2 AIH	89.9	0.820	High
Biomass per m^2 AA	322.6	0.518	Moderate
% entrained in AA	1.6	0.770	Good
Worst of AA (ha) and AA (% of AIH)		0.526	Moderate
AA (ha)	64.108	0.544	Moderate
AA (% of AIH)	27.9	0.526	Moderate
Survey EQR		**0.709**	**Good**

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

3.3 SEAGRASS

Table 9 summarises intertidal seagrass (*Zostera muelleri*) cover in 2020, with the distribution shown in Fig. 8.

Intertidal seagrass beds are extensive across parts of both arms of the harbour, especially in outer areas, with a total mapped area of ~60ha in 2020. Of this total, 48ha was categorised as being at least 'moderate' density (≥30% cover), of which 32ha was in the Pauatahanui arm. In that arm, dense beds (70-90% cover) existed next to Mana and on the mid-arm intertidal banks. A notable feature of these banks was an extensive area of bleached seagrass fronds (see adjacent photo), although the bottom sections of the fronds appeared to be unaffected. By contrast, beds in Brown's Bay and Bradey's Bay, while relatively small, had the most complete (>90%) cover and showed no signs of bleaching.

In the Onepoto arm, there was ~16ha in 2020 that exceeded the 'moderate' density threshold, most of which was located near the harbour entrance (e.g. Paremata railway flats), with 0.9ha (2% of the seagrass in the harbour) in the upper estuary. The latter consisted mainly of small patches along the edge of reclaimed land beside Titahi Bay Road.

In addition to the three broad-scale NEMP surveys (2008, 2013, 2020), records of seagrass occurrence exist for 1962 in the Onepoto arm and for 1980 in the Pauatahanui arm. These records were compiled from existing data by Stevens and Robertson (2013) and are summarised together with the 2020 data in (Table 10). From these data the following patterns are evident:

- In the Onepoto, from an estimated 28ha of 'moderate' (≥30% cover) or greater density of intertidal seagrass in 1962, there has been a 44% net decline. This figure primarily reflects loss due to harbour reclamation at Mana and Elsdon.
- In the Pauatahanui, there has been a net loss of 12% of ~37ha of 'moderate' or greater density seagrass recorded in 1980. Of interest is that extensive beds have disappeared from the north east of the arm (from intertidal flats at the mouth of Pauatahanui Stream, Ration Point & Kakaho Bay), but the loss has been offset to some extent by a seagrass expansion on the mid-harbour intertidal banks.

For the overall harbour, the decline in seagrass with a cover ≥30% has been in the order of 26% since the first reliable records. The extent of seagrass prior to human development of the estuary is unknown but is likely to have been significantly larger. In more recent years, overall seagrass cover has fluctuated, and in fact was slightly greater in 2020 than in the earlier 2013 survey. This reflects a contraction in cover on the flats around Paremata railway (which appears due to smothering by *Chaetomorpha*) but an expansion of the bed in Brown's Bay. While some temporal changes may reflect variability in the mapping accuracy between different observers, in particular delineation of the intertidal-subtidal interface, overall the reported broad scale results are considered to be a true reflection of sea grass extent and change over time

Table 9. Summary of intertidal seagrass cover classes, Te Awarua-o-Porirua Harbour Jan 2020.

Percent cover category	Ha	%
Absent or Trace (<1%)	205.0	77.3
Very sparse (1 to <10%)	5.5	2.1
Sparse (10 to <30%)	6.5	2.5
Low-Moderate (30 to <50%)	0.04	0.02
High-Moderate (50 to <70%)	5.85	2.2
Dense (70 to <90%)	37.8	14.3
Complete (>90%)	4.4	1.7
Grand Total	**265.2**	**100**

Bleached seagrass next to healthy beds on mid-Pauatahanui intertidal banks

Seagrass smothered by *Chaetomorpha* mats

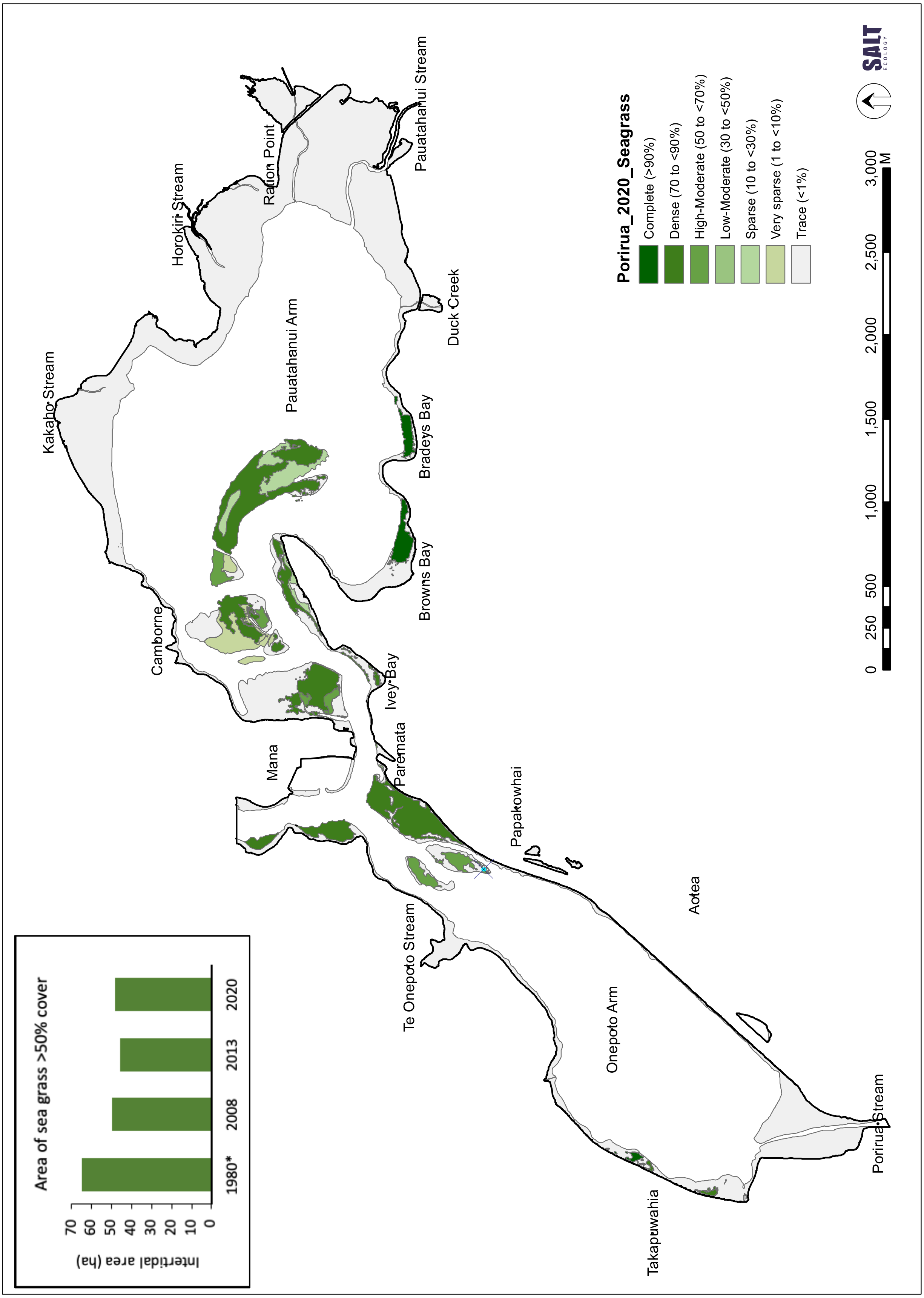


Fig. 7 Distribution and percentage cover classes of seagrass, Te Awarua-o-Porirua Harbour January 2020. Inset bar graph shows change in seagrass cover ≥50% from baseline of 64.9ha. The baseline represents the combined area from separate historic surveys of Onepoto and Pauatahanui arms (1962 Onepoto, 1980 Pauatahanui; see Table 10).

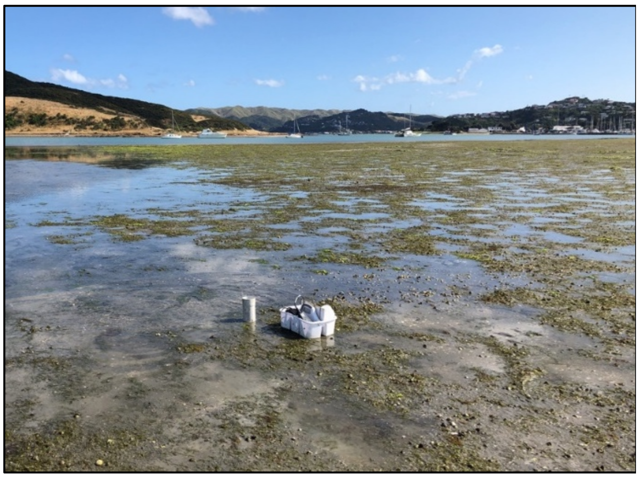
Table 6. Summary of changes in seagrass area (ha) from baseline measures in 1962 (Onepoto) and 1980 (Pauatahanui) based on areas where % cover exceeded the 'moderate' threshold of ≥50%.

Pauatahanui	1980	2008	2013	2020
Mana	1.2	4.3	4.3	6.1
Camborne	0.2	0	0	0
Kakaho	6.2	0	0	0
Ration Point (head of arm)	26	0	0	0
Duck Creek	0.2	0	0	0
Bradey's Bay	0.2	1.4	1.4	1.6
Browns Bay	0	0.9	0.9	2.5
Ivey Bay-Morehouse Point	2.7	4.4	4.2	2.8
Mid harbour	0	19.1	17.3	19.39
Pauatahanui seagrass >50% cover (ha)	36.7	30.1	28.1	32.2
% Reduction from baseline	-	18	23	12

Onepoto	1962	2008	2013	2020
Western entrance	1.8	4.2	4.2	3.5
Mana marina	3.1	0	0	0
Railway	14.8	14.1	11.9	11.5
Upper Onepoto	8.5	1.6	1.5	0.9
Onepoto seagrass >50% cover (ha)	28.2	19.9	17.6	15.9
% Reduction from baseline		29	38	44

Total Harbour	1962/1980	2008	2013	2020
Total seagrass >50% cover (ha)	64.9	50.0	45.7	48.1
% Reduction from baseline	-	23	30	26

Note: Historic data derived from 2013 broad-scale survey report (Stevens & Robertson 2013, and references therein).



Seagrass on Paremata railway flats

Seagrass in Bradey's Bay

3.4 SALT MARSH

Table 11 summarises intertidal salt marsh subclasses and cover for the three NEMP surveys, with the mapped distribution in 2020 shown in Fig. 9. Detail regarding the dominant and subdominant species recorded in 2020 is provided in Appendix 6.

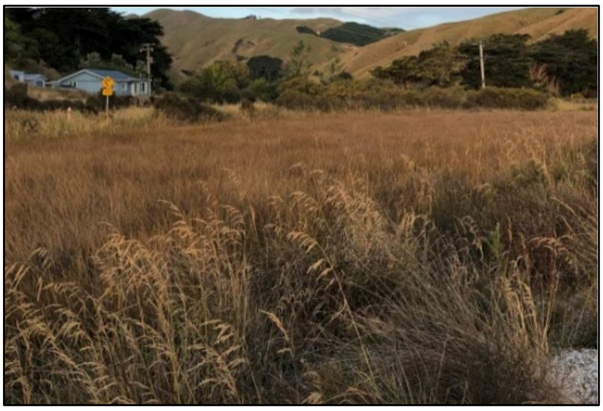
A total of 29.3ha of salt marsh was recorded from the estuary in 2020. Of this, 28.7ha (98%) was located in the Pauatahanui arm, with just 0.6ha (2%) in the Onepoto arm. The salt marsh is dominated by rushland (21ha, 8.2% of the intertidal area), estuarine shrubs (5.9ha, 2.2%) and herbfield 1ha, 0.4%).

Rushland comprised mainly searush (*Juncus kraussii*) and jointed wire rush (*Apodasmia similis*) which, as the terrestrial influence increased, transitioned through areas dominated by saltmarsh ribbonwood (*Plagianthus divaricatus*) and grassland (mostly tall fescue, *Festuca arundinacea*). Within the rushland and grassland vegetation subclasses, a wide variety of common estuarine plants were present (Appendix 6), with introduced weeds a common subdominant cover, particularly among the grassland. Herbfields, dominated by glasswort (*Sarcocornia quinqueflora*), were also common on raised shell banks at the upper tidal zone in the north and east.

The relatively small area of salt marsh in the harbour reflects historic and ongoing modification. At the time of the 2013 survey, it was estimated that there had been an historic salt marsh loss of 50% from the Pauatahanui arm and 99% from the Onepoto arm, (Stevens & Robertson 2013), with an estimated historic total harbour-wide salt marsh loss of ~200ha. The loss from the Onepoto will reflect extensive reclamation undertaken in that arm (Blaschke et al. 2010; Dahm & Gibberd 2019). However, across the harbour generally, creation of artificial margins (e.g. rock walls) around the perimeter have also displaced much of the historical salt marsh cover.

The 2008 NEMP survey appears to be the first comprehensive assessment of salt marsh habitat. Table 11 shows that the area of salt marsh remained stable from 2008 to 2013 at just over 50ha, but there has been a subsequent decline to ~29ha in 2020. This decline is primarily a reflection of a reduced area of estuarine shrub, grassland and rushland in the Pauatahanui arm. While much of this vegetation remains, it is now largely cut off from tidal flows and criss-crossed with drainage channels and bunds to the extent that the upper reaches are transitioning to terrestrially dominated vegetation. An example of this is shown in the following photograph

The upper Pauatahanui is largely cut off from tidal flows and is extensively drained resulting in salt marsh becoming increasingly terrestrially dominated



Salt marsh was dominated by rushland,- dense searush (*Juncus kraussii*) and sparse tall fescue behind a shell ridge near Kakaho

Herbfield (primrose and glasswort) and rushland (sea rush) near Ration Point

Table 11. Summary of temporal change in salt marsh area (ha), showing % reduction since 2008.

Subclass	2008	2013	2020
Tussockland	1.2	0.7	0.5
Sedgeland	0	0	0.002
Grassland	7.9	7.7	0.04
Rushland	29.4	29	21.8
Reedland	0.6	0.5	0.1
Herbfield	1.1	1.3	1.0
Total area (ha)	51.5	50.2	29.3
% Reduction	-	3	43

One of the visible changes occurring in the estuary is the effort being put into salt marsh restoration by the community, Department of Conservation, Porirua City Council and GWRC. These efforts include the ongoing development of a boardwalk around the Pauatahanui arm which is re-establishing public access to the estuary margin previously cut off in many places by roads that flank much of the estuary (photo below).

Shared pathway separating the road from the estuary in the eastern Pauatahanui arm. Small areas of saltmarsh on the right

Elsewhere margin plantings are evident in many locations. Because of the greatly reduced cover of saltmarsh, even small areas of restoration have the potential to substantially increase the extent and quality of saltmarsh in the estuary. This is particularly so in the Onepoto arm where recent planning initiatives led by PCC and GWRC have sought to identify priority areas for restoration. These include margins near the Porirua Stream mouth, Motukaraka Point, and along Wi Neera Beach and Titahi Bay Road.

Terrestrial restoration plantings in the embayment between the road and rail corridors where the two arms of the estuary meet

Narrow band of glasswort growing within the artificial boulder walls near Porirua Stream mouth (top) and adjacent to Titahi Bay Road (bottom)

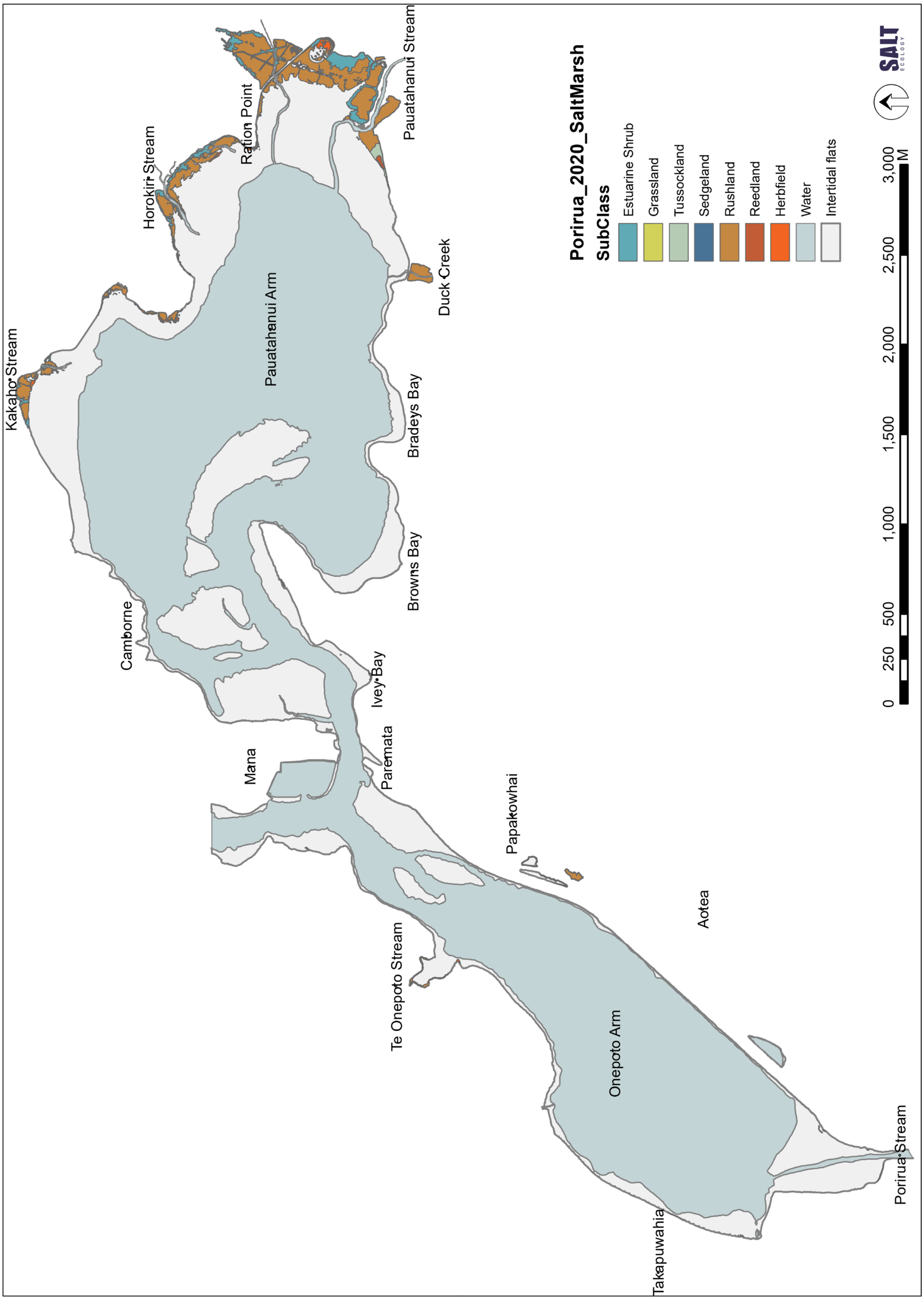


Fig. 8 Distribution and type of saltmarsh, Te Awarua-o-Porirua Harbour January 2020.

3.5 TERRESTRIAL MARGIN

Mapping of the 200m wide terrestrial margin (Table 12, Fig. 10) in 2020 confirmed previous survey findings, which showed that most of the immediate estuary margin has been modified by roading, causeways, seawalls, or reclamations. In 2020, the margin was dominated by built-up area (35.0%), grassland (22.2%) and native scrub/broadleaved indigenous hardwoods (19.7%). The latter was primarily located within Whitireia Park in the northwest of the Onepoto arm, and in pockets among residential areas in Pauatahanui arm.

Approximately 23% of the margin was classified as densely vegetated, which is an aggregation of LCDB classes 45-69. The extent of densely vegetated terrestrial buffer fits the condition rating of 'poor', with no significant change from 2008.

Table 12. Terrestrial margin features in 2020.

LCDB5 Class and name		%
1	Built-up Area (settlement)	35.0
2	Urban Parkland/Open Space	8.6
5	Transport Infrastructure	9.7
16	Gravel and Rock	0.4
20	Lake or Pond	0.6
21	River	0.2
41	Low Producing Grassland	22.2
45	Herbaceous Freshwater Vegetation	1.3
46	Herbaceous Saline Vegetation	0.03
54	Broadleaved Indigenous Hardwoods	19.7
56	Mixed Exotic Shrubland	0.0
69	Indigenous Forest	2.2
	Total	**100**

The extensive presence of road and rail corridors directly bordering about two-thirds of each arm of the estuary greatly impinges upon the aesthetic and natural values of the estuary, and breaks the natural sequence of estuarine to terrestrial vegetation. This is most pronounced in the Onepoto arm where small remnant, poorly-flushed estuary embayments are cut off from the main body of the estuary, e.g. Aotea Lagoon. The reclaimed areas of railway and motorway are dominated by introduced weeds and grass. Accumulations of rubbish from Porirua continue to be a feature of the Onepoto arm (see following photo). Whitireia Park continues to recover well from the fire that destroyed much of the scrub cover in 2010. Residential areas in the north west and south of Pauatahanui arm are notable for the scrub/forest corridors remaining among the housing and bordering the estuary. Public access tracks are well utilised in these areas, but roading still presents a significant barrier to public access to the estuary.

The northern and eastern margin of Pauatahanui remains relatively undeveloped grassland (grazed pasture), with a few pockets of scrub/forest and residential development. Grassland adjacent to the estuary generally contained a range of introduced weeds. Overall, the terrestrial margin is dominated by artificial structures, residential, and commercial or industrial developments, and grazed pasture. As a consequence of this significant past development, it retains very few unmodified habitat features that are in their natural state.

Accumulation of organic material and litter near Porirua Stream mouth

Wooden seawall on the Mana flats

Vertical wooden seawall and vehicle access route on the southern side of the Pauatahanui arm

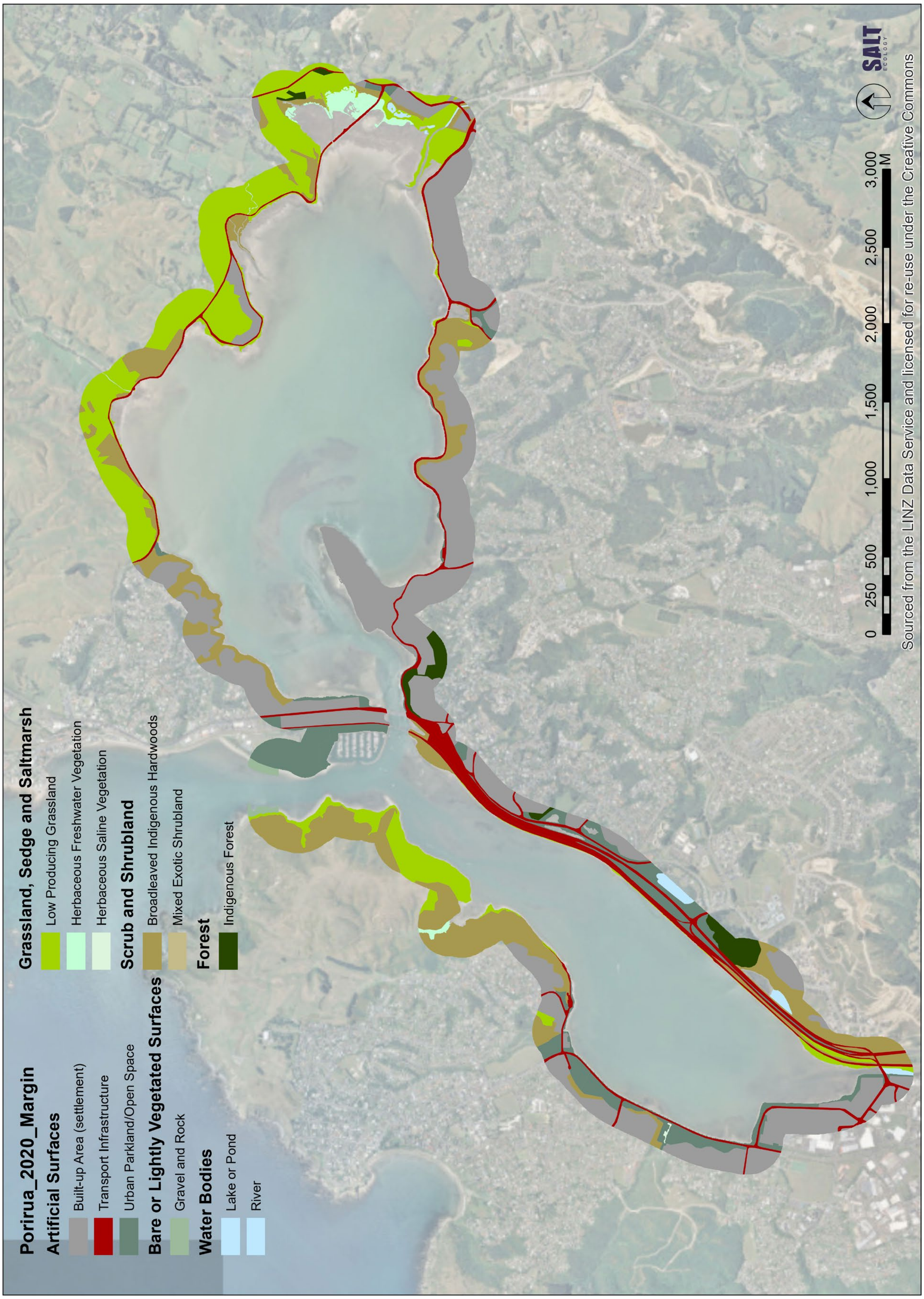


Fig. 9 Distribution and classes (LCDB5 20018) of vegetation in the 200m terrestrial margin, Te Awarua-o-Porirua Harbour January 2020.

4. SYNTHESIS AND RECOMMENDATIONS

4.1 Synthesis of key findings

This report has described a broad scale habitat mapping and assessment survey of Te Awarua-o-Porirua Harbour, largely following the broad scale survey methods described in New Zealand's NEMP.

A summary of key broad scale features measured in 2020 is provided in Table 13. In Table 14 these indicators are assessed in relation to the condition rating criteria in Table 4 and compared with other years. Note that, to enable comparison across years, the mud-dominated substrate rating in Table 14 was assessed as a percentage of the intertidal area excluding salt marsh (235.9ha) rather than the total intertidal area of 265.2ha. This adjustment was necessary as the 2008 and 2013 surveys did not assess sediment type within salt marsh habitats.

Table 14 highlights that there have been significant losses of seagrass and salt marsh relative to estimated historic conditions, giving a 'poor' rating for these assessment indicators. In recent years seagrass has been relatively stable, and the salt marsh rating has not changed. However, there has nonetheless been a significant (43%) decline in remnant salt marsh extent between 2013 and 2020. The latter was discussed above in relation to the eastern Pauatahanui arm which is largely cut off from tidal flows and criss-crossed with drainage channels and bunds to the extent that the upper reaches are transitioning to terrestrially dominated vegetation.

One of the key indicators of estuary health in unvegetated areas is the extent of muddy sediment. The 2020 survey has revealed a gradual increase in the spatial extent of mud-dominated sediment since

Table 7. Summary of broad scale indicators, Te Awarua-o-Porirua Harbour 2020.

Component	Ha	% Harbour	%Intertidal	%Salt marsh	%Margin
Area					
Harbour area	785.9	100			
Intertidal area	265.2	33.7			
Subtidal area (not assessed)	520.7	66.3			
Substrate					
Mud-elevated sediment (>25% mud)	118.2	15.0	44.6		
Mud-dominated sediment (>50% mud)	31.9	4.1	12.0		
Nuisance Macroalgae					
Macroalgal beds (≥50% cover)	1.2	0.2	0.5		
Seagrass					
Seagrass (≥50% cover)	48.0	6.1	18.1		
Saltmarsh					
Estuarine shrub	5.9	0.7	2.2	20.0	
Tussockland	0.5	0.1	0.2	1.6	
Sedgeland	0.002	0.0	0.0	0.01	
Grassland	0.04	0.0	0.0	0.1	
Rushland	21.8	2.8	8.2	74.4	
Reedland	0.1	0.0	0.0	0.4	
Herbfield	1.0	0.1	0.4	3.4	
Total	**29.3**	**3.7**	**11.1**	**100**	
200m Terrestrial margin					
%densely vegetated (LCDB classes 45-71)					23.3

2008, primarily reflecting an expansion in the northeast Pauatahanui arm. The overall condition rating has declined from 'good' in 2008 to 'fair' in the last two surveys. In the 2020 survey, the spatial extent of mud-dominated sediment was in fact approaching the 'poor' threshold of >15%.

The increased mud extent is consistent with the results of concurrent monitoring undertaken for GWRC in 2020. That monitoring revealed increased deposition of muddy sediment in the Pauatahanui arm, and increased mud and associated ecological changes at a 'fine scale' monitoring site in the eastern Pauatahanui arm (Stevens & Forrest 2020a, Forrest et al. 2020). The reports describing those monitoring programmes suggested potential sediment sources as being ongoing land disturbances in the catchment on the east and south side of the harbour, for example, residential subdivision and the Transmission Gully motorway development. Forest harvesting presents another potential source. As the broad scale mapping shows the greatest accumulation of mud on the northeast side of the Pauatahanui arm, not on the east and south side of the harbour as expected, the importance of these recognised catchment disturbances remain unclear.

It is possible that the recent mud deposits in fact reflect inputs from adjacent streams on the north side of the arm (i.e. Horokiri and Kakaho Streams). On the other hand, the deposits may have originated from other parts of the harbour (including southern catchments) and have settled on the north side given that the system is highly dynamic in terms of sediment transport (Gibb & Cox 2009). Clearly, further investigation would be required to understand potential sediment sources and their relative importance.

A related consideration, which is particularly important from a management perspective, is whether the increase in muddy sediment extent reflects an ongoing low-level input or a 'pulse' disturbance associated with events (e.g. high rainfall coupled with catchment land disturbance) that deliver a high mass load of muddy sediment to the Pauatahanui arm. Recent event-related inputs are arguably more likely on the basis that:

- The sediment exists as a surface layer over otherwise firm muddy sand, i.e. it hasn't been 'reworked' into the sediment matrix as a result of bioturbation by cockles and other animals.
- Previous event-based deposition has been recorded following a significant (1 in 20 year) rainfall event in Nov in 2016 (Stevens 2017).
- There is clear erosion of the deposited material, suggesting a pulse event that may abate naturally in intertidal areas by processes of sediment resuspension and local or far-field transport.

In relation to the last point, sediment transport away from the main depositional areas does not mean it

Table 8. Summary of broad scale condition rating scores based on the key indicators and criteria in Table 4.

Indicator	Unit	2008	2013	2020
Broad scale indicators				
Mud-dominated substrate[1]	% of intertidal area >50% mud	1.4	8.4	13.5
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	na	na	0.71
Seagrass[2]	% decrease from baseline	23.0	29.6	25.9
Salt marsh extent (current)	% of intertidal area	19.4	18.9	11.1
Historical salt marsh extent	% of historical remaining[3]	25.7	25.2	14.7
200m terrestrial margin[2]	% densely vegetated	19.3	17.0	23.3
High Enrichment Conditions	ha	na	na	1.0
High Enrichment Conditions	% of estuary	na	na	0.1

[1] To enable comparison across years, mud-dominated substrate assessed as percentage of intertidal area excluding salt marsh (235.9ha).
[2] Seagrass change rated for ≥50% cover assessed relative to baseline (64.9ha) derived from separate surveys of Onepoto (in 1962) and Pauatahanui (in 1980).
[3] Historic salt marsh change assessed relative to estimated historic baseline area of 200ha.

Condition rating key:

Very Good	Good	Fair	Poor

will necessary be flushed from the harbour; it may simply be deposited elsewhere (e.g. in the subtidal zone). Various estimates have noted a gradual infilling of the harbour basins due to ongoing and rapid sedimentation (Swales et al. 2005; Gibb & Cox 2009).

In terms of other indicators, there were small hotspots of persistent opportunistic macroalgal growth in 2020, but the overall EQR value placed macroalgae in the 'good' rating. Although EQR scores were not calculated in 2008 and 2013, separate monitoring (Stevens & O'Neill-Stevens 2017) revealed more extensive macroalgae in 2017 (rated as 'moderate' at that time). The apparent 'improvement' since then may be related to the deposition of muddy sediment in the Kakaho and Horokiri areas discussed above, i.e. the main area where macroalgae was no longer present in 2020 was the area where muddy sediment has increased. This soft surface mud would almost certainly provide a poor habitat for macroalgae to persist in following a pulse deposition event, or subsequently colonise via dispersal from adjacent areas.

Despite the harbour-wide reduction in opportunistic macroalgae, conspicuous mats of the filamentous green species *Chaetomorpha ligustica* were recorded in 2020, mainly as drift material in harbour areas near the entrance. Although this species is not considered new to the harbour, it appears to have 'bloomed' in very recent times. Its propensity to form thick mats that smother the seabed and its associated biota (e.g. seagrass, cockles) raises the possibility of significant harbour-wide impacts in the event that this species became widespread and prolific. At present the ecology and population biology (e.g. seasonality, reproduction, dispersal processes) of the species appears to be unknown.

As a final point, it is worth commenting on the enrichment status of harbour sediments. As noted in Section 2.8, High Enrichment Conditions (HECs) for our purposes 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% TOC) combined with low sediment oxygenation (aRPD <10mm).

In the assessment in Table 14 we have made the assumption that TOC will be <1% in most instances, based on data reported by Forrest et al. (2020). Hence, the small HEC area of 1ha (0.1% of the intertidal area) reflects those macroalgae areas with >50% cover that also had muddy sediments with entrained macroalgae. As such, where *Chaetomorpha* mats overlay anoxic sandy sediments, these small areas were not included. Overall, therefore, despite these hotspots, the enrichment status of the harbour is rated as 'very good'

4.2 Recommendations

Based on the findings of this report, it is recommended that GWRC consider the following:

- A further harbour-wide broad-scale survey in 5-years to keep track of long-term changes.
- Annual or biennial mapping or qualitative assessment of the northeast Pauatahanui arm to track changes in the spatial extent of the muddy sediment zone. An option would to conduct this assessment during annual sediment plate monitoring.
- Investigate the potential sources of recent and ongoing sediments to the Pauatahanui arm (e.g. examine recent and current land uses, determine mass loads from streams, undertake sediment tracing studies).
- Incorporate data from complementary monitoring, e.g. Transmission Gully data in future reporting.
- Assess the broader ecological implications of changes in key indicators revealed by the present report, and recent (fine scale) or planned (subtidal) surveys.
- Develop a strategy to minimise future losses of high value salt marsh including recommending specific restoration options, e.g. replanting salt marsh, improving tidal flushing, recontouring shorelines, and removing barriers to salt marsh expansion.

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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 current report

Substrate Class	Feature	Code
Artificial	Artificial substrate	aS
Transport Infrastructure	Ramp	Ramp
Barrier	Seawall	Wall
Bedrock	Rock field	RF
Boulder/Cobble/Gravel	Artificial boulder field	aBF
	Artificial cobble field	aCF
	Boulder field	BF
	Cobble field	CF
	Gravel field	GF
Muddy Sand (>10-25% mud)	Firm muddy sand	fMS10
Muddy Sand (>25-50% mud)	Firm muddy sand	fMS25
	Soft muddy sand	sMS25
Sand (0-10% mud)	Firm sand	fS
	Mobile sand	mS
Sandy Mud (>50-90% mud)	Firm sandy mud	fSM
	Soft sandy mud	sSM
	Very soft sandy mud	vsSM
Zootic	Cocklebed	CKLE
	Sabellid field	TUBE
	Shell bank	shel

Salt marsh Class	Feature	Code
Estuarine Shrub	*Plagianthus divaricatus (Salt marsh ribbonwood)*	Pldi
Tussockland	*Phormium tenax (New Zealand flax)*	Phte
Grassland	*Festuca arundinacea (Tall fescue)*	Fear
Sedgeland	*Cyperus ustulatus (Giant umbrella sedge)*	Cyus
	Isolepis cernua (Slender clubrush)	Isce
	Schoenoplectus validus (Lake clubrush)	Scpu
Reedland	*Typha orientalis (Raupo)*	Tyor
Rushland	*Apodasmia similis (Jointed wirerush)*	Lesi
	Ficinia (Isolepis) nodosa (Knobby clubrush)	Isno
	Juncus kraussii (Searush)	Jukr
Herbfield	*Samolus repens (Primrose)*	Sare
	Sarcocornia quinqueflora (Glasswort)	Saqu
	Selliera radicans (Remuremu)	Sera

LCDB5 Class (Margin)	Feature	Code
Artificial Surfaces	Built-up Area (settlement)	1
	Urban Parkland/Open Space	2
	Transport Infrastructure	5
Bare or Lightly Vegetated Surfaces	Gravel and Rock	16
Water Bodies	Lake or Pond	20
	River	21
Grassland Sedge and Salt Marsh	Low Producing Grassland	41
	Herbaceous Freshwater Vegetation	45
	Herbaceous Saline Vegetation	46
Scrub and Shrubland	Broadleaved Indigenous Hardwoods	54
	Mixed Exotic Shrubland	56
Forest	Indigenous Forest	69

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

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

Summary of Methods

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

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-27
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-12
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
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	1-12
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-27
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27

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

Dates of testing are available on request. Please contact the laboratory for more information.

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

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

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 3. 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

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. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).

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.					

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.

Thresholds for Entrained Algae

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

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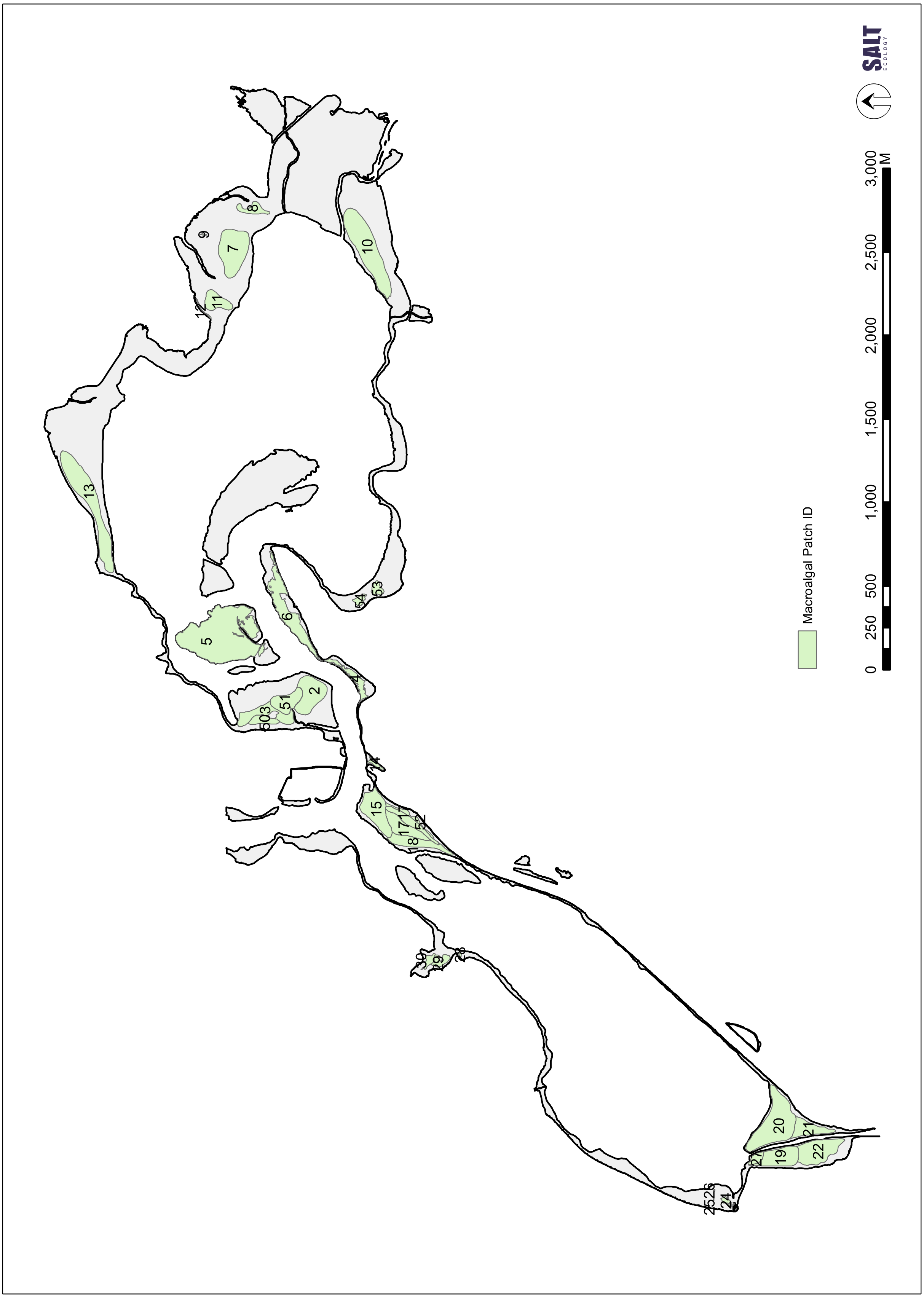
Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

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 Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.99	≥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.

Te Awarua-o-Porirua Harbour - location of macroalgal patches and data summary, January 2020.



PatchID	Code	Pct_Cover	TotPctCov	Class	Biomass (gm2ww)	DomHab	SubDom1
1	Ulsp	50	50	Moderate (30 to <70%)	100	*Ulva sp (Sea lettuce)*	
2	Grch Ulsp	20 1	21	Sparse (10 to <30%)	500	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
3	Grch	25	25	Sparse (10 to <30%)	160	*Gracilaria chilensis*	
4	Grch	2	2	Very sparse (1 to <10%)	10	*Gracilaria chilensis*	
5	Grch	2	2	Very sparse (1 to <10%)	80	*Gracilaria chilensis*	
6	Grch	2	2	Very sparse (1 to <10%)	25	*Gracilaria chilensis*	
7	Grch	5	5	Very sparse (1 to <10%)	50	*Gracilaria chilensis*	
8	Grch Ulsp	1 1	2	Very sparse (1 to <10%)	20	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
9	Grch	50	50	Moderate (30 to <70%)	2500	*Gracilaria chilensis*	
10	Grch	2	2	Very sparse (1 to <10%)	50	*Gracilaria chilensis*	
11	Grch	5	5	Very sparse (1 to <10%)	40	*Gracilaria chilensis*	
12	Ulsp	15	15	Sparse (10 to <30%)	100	*Ulva sp (Sea lettuce)*	
13	Grch	1	1	Very sparse (1 to <10%)	20	*Gracilaria chilensis*	
14	Grch	80	80	Dense (70 to <90%)	3120	*Gracilaria chilensis*	
15	Grch Ulsp	5 1	6	Very sparse (1 to <10%)	100	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
17	Grch	1	1	Very sparse (1 to <10%)	10	*Gracilaria chilensis*	
18	Grch Ulsp	5 1	6	Very sparse (1 to <10%)	250	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
19	Grch Ulsp	10 5	15	Sparse (10 to <30%)	250	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
20	Grch Ulsp	9 1	10	Sparse (10 to <30%)	250	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
21	Grch Ulsp	1 1	2	Very sparse (1 to <10%)	10	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
22	Grch Ulsp	1 1	2	Very sparse (1 to <10%)	10	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
23	Grch Ulsp	60 5	65	Moderate (30 to <70%)	400	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
24	Grch Ulsp	45 5	50	Moderate (30 to <70%)	400	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
25	Grch	50	50	Moderate (30 to <70%)	100	*Gracilaria chilensis*	
26	Grch	50	50	Moderate (30 to <70%)	100	*Gracilaria chilensis*	
27	Grch Ulsp	30 10	40	Moderate (30 to <70%)	400	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
28	Grch Ulsp	30 5	35	Moderate (30 to <70%)	100	*Gracilaria chilensis*	*Ulva sp (Sea lettuce)*
29	Grch	100	100	Dense (70 to <90%)	4500	*Gracilaria chilensis*	
30	Grch Chli	70 10	80	Dense (70 to <90%)	3000	*Gracilaria chilensis*	*Chaetomorpha ligustica*
50	Chli	10	10	Sparse (10 to <30%)	3000	*Chaetomorpha ligustica*	
51	Chli Grch	10 20	30	Moderate (30 to <70%)	2500	*Chaetomorpha ligustica*	*Gracilaria chilensis*
52	Chli Grch	10 1	11	Sparse (10 to <30%)	2500	*Chaetomorpha ligustica*	*Gracilaria chilensis*
53	Chli	30	30	Moderate (30 to <70%)	1500	*Chaetomorpha ligustica*	
54	Chli	30	30	Moderate (30 to <70%)	1500	*Chaetomorpha ligustica*	

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 & 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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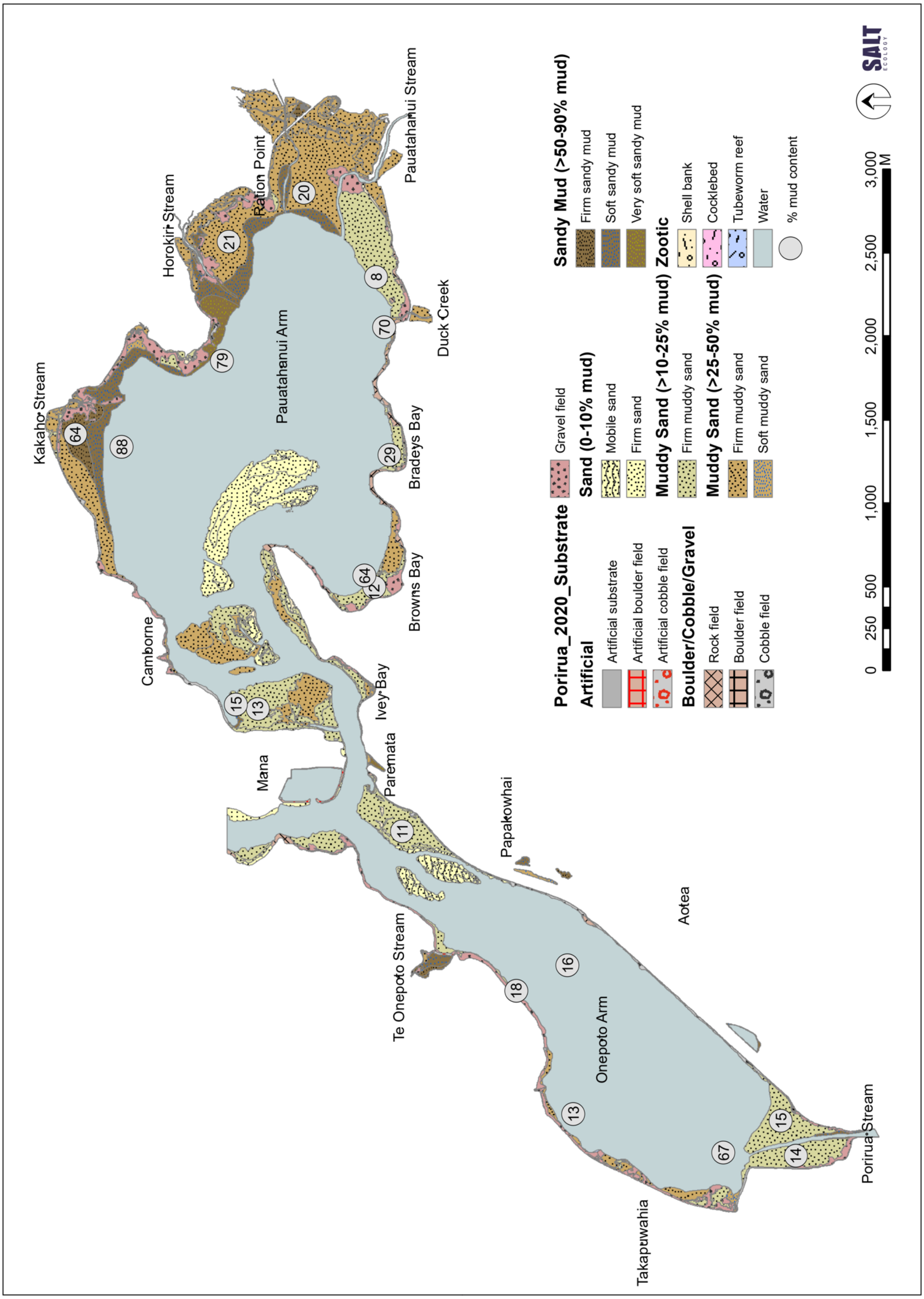
APPENDIX 5. SEDIMENT SAMPLING VALIDATION DATA

Comparison of field sedimentation type classifications against laboratory analysis of grain size. Depth of apparent redox potential discontinuity (aRPD) also shown. Three discrepancies are highlighted with grey shading, which reflect locations where the field classification slightly overestimated actual mud content due to a thin layer of muddy sediment deposited on top of a relatively coarse primarily sandy base.

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

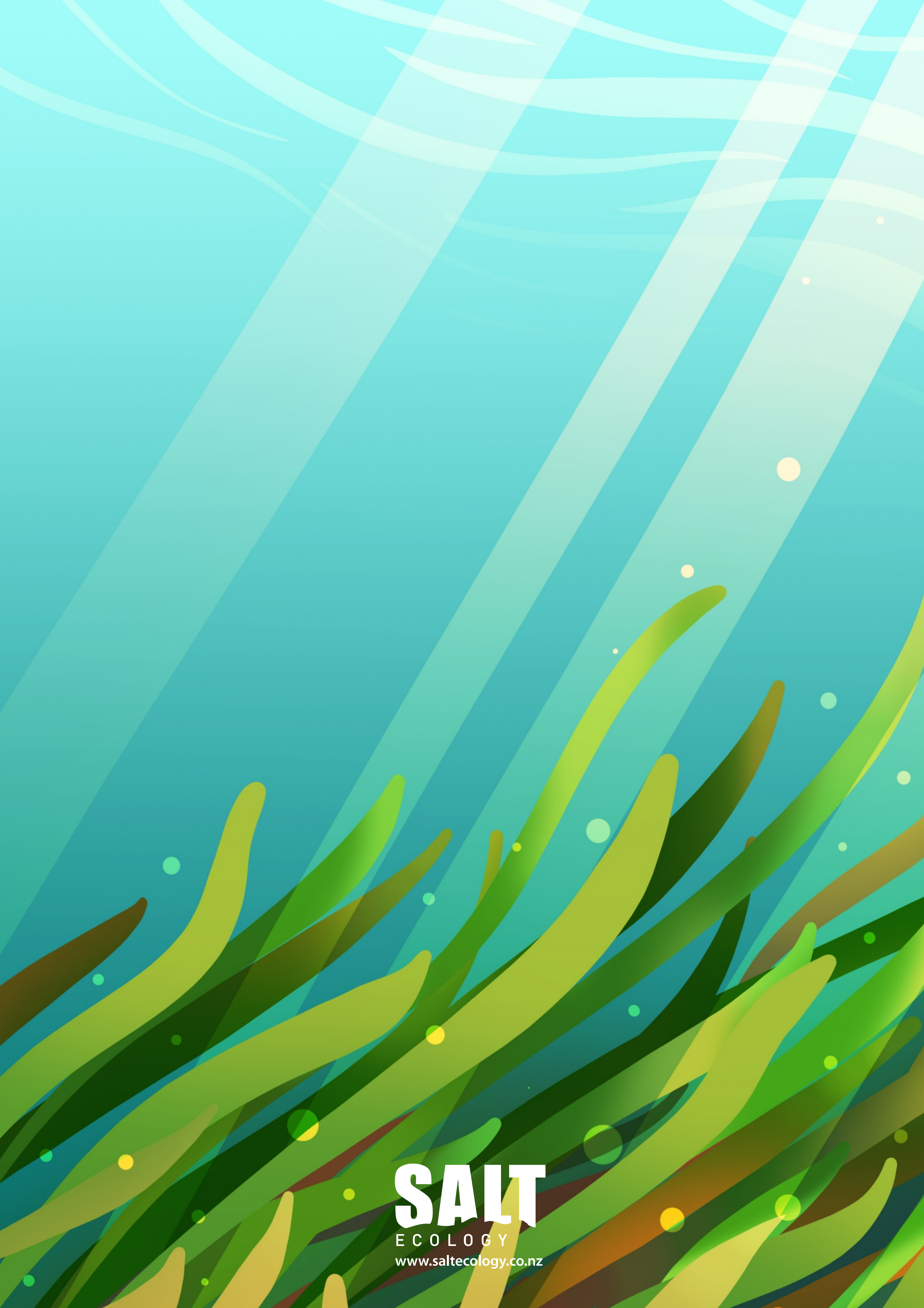
Arm	Zone	Site	Name	NZTM_E	NZTM_N	Field code	Subjective %mud	Measured %mud	%sand	%gravel	aRPD (mm)
Onepoto	Intertidal	O1	Por A Railway (FS)	1756506	5447789	fms10	>10-25	11	88.1	0.9	8
Onepoto	Intertidal	O2	Aotea	1754772	5445520	fms10	>10-25	14.5	84.4	1.2	25
Onepoto	Intertidal	O3	Por B Polytech (FS)	1754562	5445430	fms10	>10-25	14.1	83.6	2.3	13
Onepoto	Subtidal	OS6	Titahi	1754581	5445864	ssm	>50-90	66.8	29.2	4.0	5
Onepoto	Subtidal	OS7	Onepoto	1754811	5446763	fms10	>10-25	12.6	86.9	0.4	15
Onepoto	Subtidal	OS8	Papakowhai	1755704	5446798	sms10	>10-25	16.4	83.5	< 0.1	>50
Onepoto	Subtidal	OS9	Te Onepoto	1755552	5447105	fms10	>10-25	17.5	80.8	1.7	>50
Pauatahanui	Intertidal	P10	Duck Creek	1759829	5447945	fms10	>10-25	7.5	92.5	< 0.1	30
Pauatahanui	Intertidal	P11	Browns Bay	1757971	5447957	fms10	>10-25	12	86.7	1.3	10
Pauatahanui	Intertidal	P5	P5 (FS A)	1757240	5448655	fms10	>10-25	12.7	84.8	2.5	15
Pauatahanui	Intertidal	P6	Boatsheds	1757268	5448786	fms10	>10-25	14.9	76.8	8.3	9
Pauatahanui	Intertidal	P7	Kakaho	1758885	5449748	fsm	>50-90	63.5	35.3	1.1	7
Pauatahanui	Intertidal	P8	Horokiri	1760040	5448828	fms25	>25-50	20.6	75.7	3.6	5
Pauatahanui	Intertidal	P9	Paua B (FS)	1760334	5448379	fms25	>25-50	19.7	79.0	1.3	5
Pauatahanui	Subtidal	PS1	Kakaho	1758811	5449471	ssm	>50-90	88.1	11.9	< 0.1	5
Pauatahanui	Subtidal	PS2	Horokiri	1759325	5448868	ssm	>50-90	78.5	21.3	0.2	4
Pauatahanui	Subtidal	PS3	Duck Creek	1759529	5447896	ssm	>50-90	69.7	29.8	0.5	2
Pauatahanui	Subtidal	PS4	Bradeys Bay	1758763	5447865	sms25	>25-50	28.7	70.8	0.6	10
Pauatahanui	Subtidal	PS5	Browns Bay	1758041	5448015	ssm	>50-90	63.7	35.4	0.9	10

B. Map of sediment sampling stations and mud content (rounded to nearest whole number).



APPENDIX 6. SALT MARSH VEGETATION DETAIL

Subclass	Dominant species	Primary Subdominant	Secondary Subdominant	Ha	%SaltMarsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	0.1	0.4
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Juncus kraussii* (Searush)	3.5	11.9
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	*Apodasmia similis* (Jointed wirerush)	1.2	3.9
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Juncus kraussii* (Searush)	*Apodasmia similis* (Jointed wirerush)	0.7	2.5
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Juncus kraussii* (Searush)	*Festuca arundinacea* (Tall fescue)	0.3	1.0
	Plagianthus divaricatus (Salt marsh ribbonwood)	*Juncus kraussii* (Searush)		0.1	0.2
	Plagianthus divaricatus (Salt marsh ribbonwood)			0.04	0.1
Tussockland	*Phormium tenax* (New Zealand flax)	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	0.5	1.6
Sedgeland	*Cyperus ustulatus* (Giant umbrella sedge)			0.00	0.01
Grassland	*Festuca arundinacea* (Tall fescue)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		0.04	0.1
Reedland	*Typha orientalis* (Raupo)			0.1	0.4
Rushland	*Apodasmia similis* (Jointed wirerush)	*Ficinia (Isolepis) nodosa* (Knobby clubrush)	*Festuca arundinacea* (Tall fescue)	0.0	0.1
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	1.7	5.8
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		0.9	3.1
	Juncus kraussii (Searush)	*Apodasmia similis* (Jointed wirerush)		1.8	6.2
	Juncus kraussii (Searush)	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.2	0.7
	Juncus kraussii (Searush)	*Apodasmia similis* (Jointed wirerush)	*Sarcocornia quinqueflora* (Glasswort)	0.04	0.1
	Juncus kraussii (Searush)			16.7	56.8
	Juncus kraussii (Searush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	0.3	1.1
	Juncus kraussii (Searush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	0.03	0.1
	Juncus kraussii (Searush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		0.01	0.03
	Juncus kraussii (Searush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Sarcocornia quinqueflora* (Glasswort)	0.03	0.1
	Juncus kraussii (Searush)	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	0.0	0.1
	Juncus kraussii (Searush)	*Sarcocornia quinqueflora* (Glasswort)		0.03	0.1
	Juncus kraussii (Searush)	*Schoenoplectus pungens* (Three square)		0.02	0.1
Herbfield	*Samolus repens* (Primrose)			0.1	0.2
	Samolus repens (Primrose)	Sarcocornia quinqueflora (Glasswort)	*Selliera radicans* (Remuremu)	0.1	0.3
	Samolus repens (Primrose)	Selliera radicans (Remuremu)		0.4	1.3
	Sarcocornia quinqueflora (Glasswort)			0.03	0.1
	Sarcocornia quinqueflora (Glasswort)	*Samolus repens* (Primrose)		0.1	0.3
	Sarcocornia quinqueflora (Glasswort)	*Selliera radicans* (Remuremu)		0.02	0.1
	Sarcocornia quinqueflora (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	0.2	0.8
	Selliera radicans (Remuremu)			0.01	0.02
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)		0.01	0.03
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	0.1	0.3
Grand Total				**29.3**	**100.0**



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