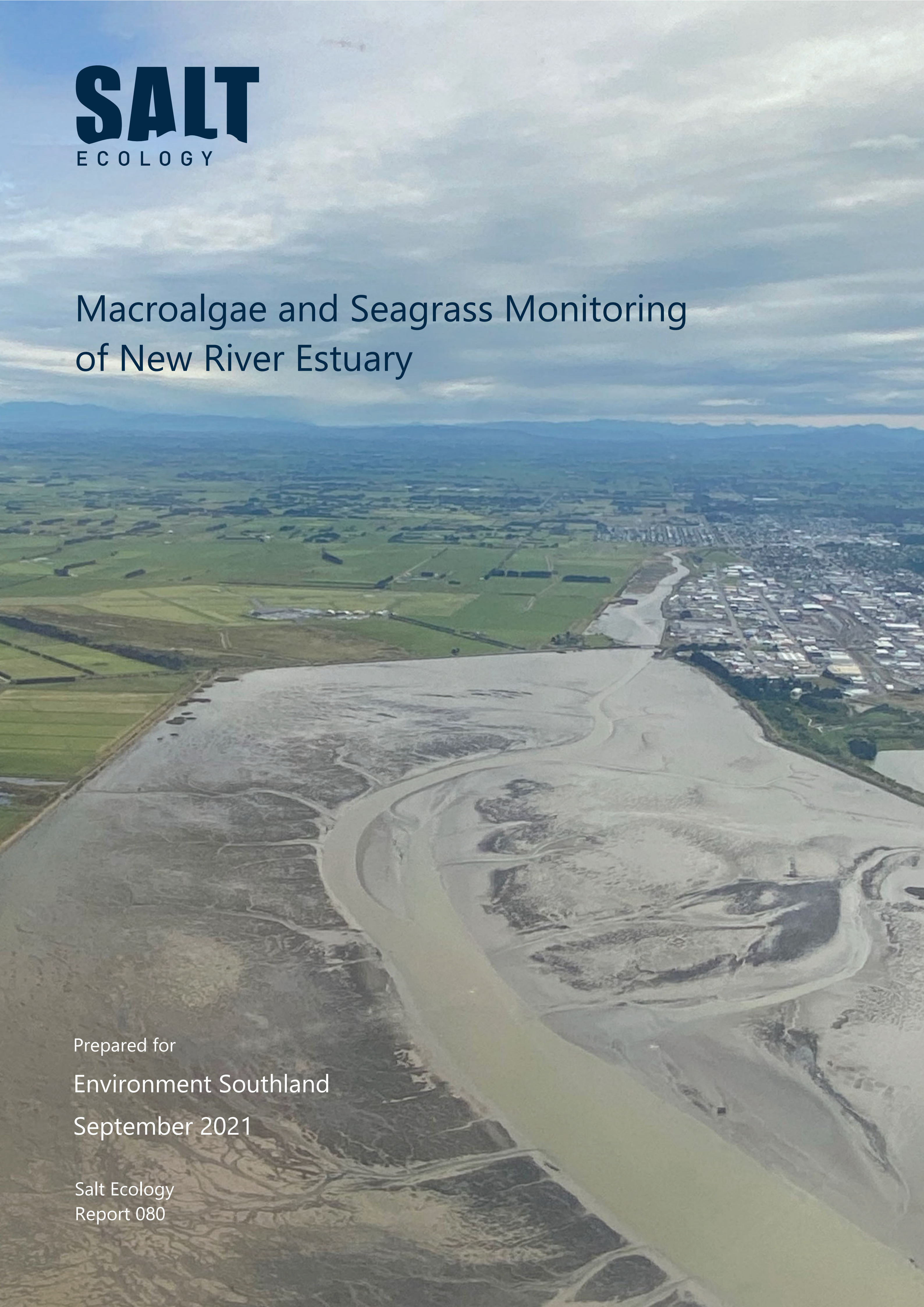

Macroalgae and Seagrass Monitoring of New River Estuary

Prepared for

Environment Southland

September 2021

Salt Ecology
Report 080

Cover photo: Waihopai Arm February 2021 showing extensive cover of nuisance macroalgae

RECOMMENDED CITATION

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SALT ECOLOGY

For the People
Mō ngā tāngata

Macroalgae and Seagrass Monitoring of New River Estuary

Prepared by

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for

Environment Southland

September 2021

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GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
ES	Environment Southland
HEC	High Enrichment Conditions (HECs) comprise mud-dominated sediments (>50% mud content) with macroalgal cover >50% that is entrained and growing as stable beds rooted within the sediment, the combined presence of which may result in adverse ecological outcomes. HECs can also be present in non-algal areas where sediments have an elevated organic content (>1% total organic carbon) and low sediment oxygenation (apparent Redox Potential Discontinuity (aRPD) depth <10mm) as a consequence of algal degradation.
MSL	Mean Sea Level
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

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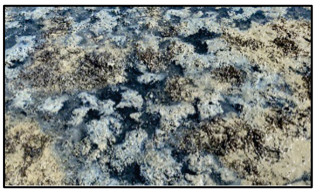
SUMMARY

As part of its State of the Environment programme, Environment Southland (ES) undertakes regular monitoring of New River Estuary. Significant and expanding growths of opportunistic nuisance macroalgae (seaweed) have been recorded during previous broad scale habitat mapping and more targeted assessments, and are coincident with increasing nutrient loads to the estuary. This report describes the most recent (February 2021) survey of nuisance macroalgae, and high value seagrass habitat, and compares findings to earlier surveys over 2001 to 2020.

KEY FINDINGS

- The 2021 survey recorded extensive, persistent beds of the opportunistic nuisance seaweed *Agarophyton chilense* (previously known as *Gracilaria*) in the Waihopai Arm, Bushy Point, near the Ōreti River mouth, in Daffodil Bay and in the east of the estuary near Woodend. *Ulva* spp. was commonly present but not at nuisance levels.
- High Enrichment Conditions (HECs) were present across 12% (340ha) of the estuary, with extensive (>50% cover) high-biomass *Agarophyton* beds growing entrained within soft, anoxic mud-dominated sediments. In some areas eutrophic symptoms were so severe that macroalgae appeared unable to survive; sediments were extremely anoxic with bacterial mats on the sediment surface (see photo).



- Due to extensive flood scouring and macroalgal die-off in extremely eutrophic areas in 2020, there was an overall reduction in macroalgae compared to 2012 to 2019 (see table below). However, in 2021 the rapid re-growth of macroalgal biomass in many previously flood-scoured areas saw a worsening of the macroalgal Ecological Quality Rating (EQR) score. Other areas remain extremely eutrophic and unable to support macroalgal growth.
- A loss in high-value seagrass of 82% from a 'baseline' (i.e. 2001) extent of 94ha was recorded between 2001 and 2021, with the decline attributed to smothering by fine sediment, declining sediment oxygenation, and macroalgal overgrowth. The largest seagrass losses have occurred in the west Waihopai Arm (~99% loss), with further losses becoming increasingly evident along the Ōreti River margin in 2021. Additional localised impacts on seagrass from vehicle tracks were also evident in 2021.

Broad scale indicator	Unit	2001	2007	2012	2016	2018	2019	2020	2021
Macroalgae (OMBT)[1]	EQR	0.616	0.532	0.398	0.303	0.284	0.234	0.481	0.408
HEC[2]	Ha	23	49	240	351	428	417	399	340
HEC[2]	% of estuary	0.8	1.7	8.6	12.6	15.3	14.9	14.3	11.6
Seagrass[3]	% decrease from baseline	na	na	44	55	61	61	67	82

[1] OMBT = Opportunistic Macroalgal Blooming Tool [2] High Enrichment Conditions [3] Data for 2001 used as baseline for seagrass. No available seagrass data for 2007

Very Good	Good	Fair	Poor

Overall, the widespread presence of persistent entrained *Agarophyton* beds, extensive patches of extreme sediment anoxia and progressive seagrass losses, serve as clear indicators that the capacity of the estuary to assimilate nutrient loads is being dramatically exceeded. These results are consistent with modelled nutrient estimates, which greatly exceed thresholds for nuisance macroalgal growths. The scale of eutrophic symptoms in New River Estuary is unprecedented in New Zealand and emphasises the urgent need to manage sediment and nutrient loads to prevent further adverse impacts in the estuary.

RECOMMENDATIONS

- Continue annual monitoring during summer to track long term changes in nuisance macroalgae and seagrass.
- Continue with planned work to determine limits on nutrient and sediment mass loads that would be expected to prevent further degradation and, where possible, mitigate current adverse impacts.
- Determine catchment nutrient and sediment sources and evaluate whether there are any effective and feasible management practices that could be undertaken to achieve ES's desired condition for the estuary.
- Explore options for the local scale removal of macroalgae to limit further loss of high value habitat (i.e. seagrass), and to prevent sediment from degrading to an extent that long-term severe eutrophication conditions to persist.

1. INTRODUCTION

1.1 BACKGROUND

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Environment Southland (ES) has undertaken monitoring of selected estuaries in the region since 2001, based on the methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP, Robertson et al. 2002), or extensions of that approach.

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

Although macroalgae is an important feature of estuaries that contributes to their high productivity and biodiversity, when high nutrient inputs combine with suitable growing conditions, nuisance blooms of rapidly-growing species can occur (Table 1). These are typically referred to as 'opportunistic' species, of which the most significant in Southland are the red seaweed *Agarophyton chilense* (previously known as *Gracilaria chilensis*) and the bright green *Ulva* spp. (commonly called 'sea lettuce').

At nuisance levels, muddy sediments and macroalgal growths can smother and deprive ecologically valuable seagrass (*Zostera muelleri*, see Table 1) of light, causing its eventual decline. Decaying macroalgae can also accumulate on shorelines causing localised depletion of sediment oxygen, and nuisance odours. When high macroalgal cover is associated with soft, muddy sediments, conditions for animal life in the sediments are generally very poor due to elevated organic matter, depleted oxygen and an accumulation of toxic sulphides.

New River Estuary (Fig. 1), the subject of this report, has been surveyed since 2001 and is one of the key estuaries monitored in Southland. Monitoring between 2001 and 2020 has included both broad scale habitat mapping and fine scale sediment monitoring. In 2007, broad scale habitat mapping highlighted an increase in localised areas of nuisance macroalgae, particularly around Waihopai, Daffodil Bay and Bushy Point (Robertson & Stevens 2007). Since then, targeted macroalgal and seagrass monitoring has been undertaken between 2007-2013, 2016 and 2018-2020 (e.g. Stevens & Robertson 2007, 2012; Stevens 2018; Stevens & Forrest 2020). The results of this work documented a steady expansion in the cover and biomass of nuisance macroalgae in the estuary, with 15% (or 428ha) of the estuary's intertidal area classified as eutrophic in February 2018 (Stevens 2018). A marginal decrease (1% or ~30ha) in the area of eutrophic conditions was recorded in 2019 and again in 2020. These decreases were attributed to flood scouring and 'self-pollution' of

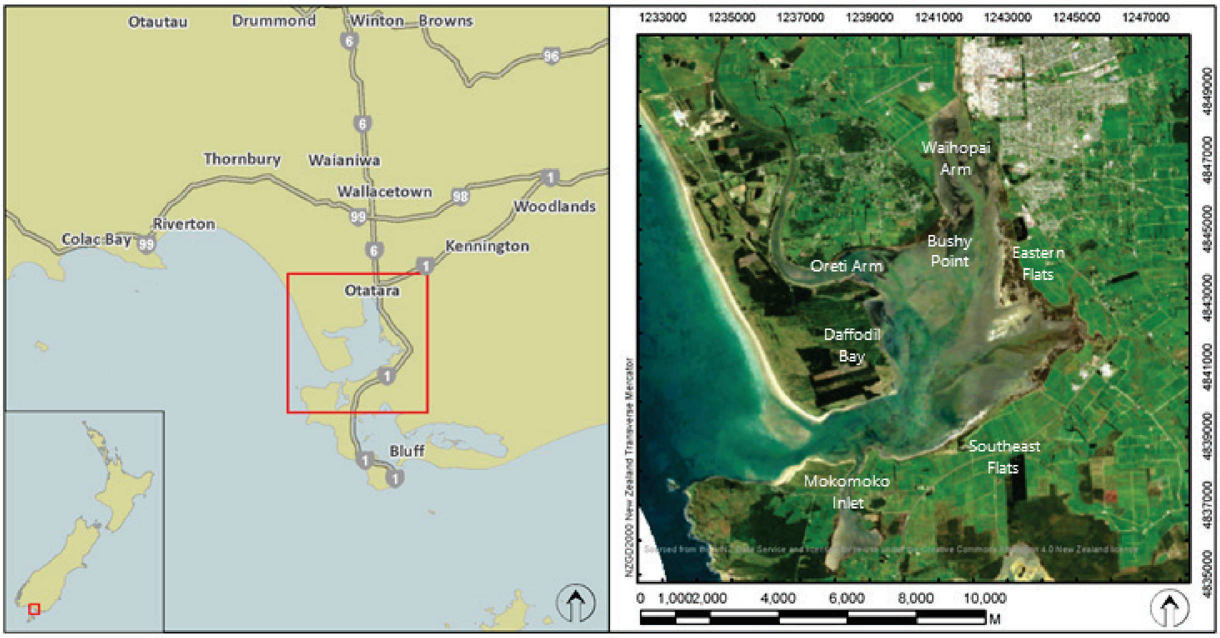


Fig. 1. Location of New River Estuary, Southland.

Table 1. Overview of the ecological significance of seagrass and opportunistic macroalgae in estuaries.

Habitat	Description
Seagrass	Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

macroalgae (where blooms have created conditions so poor that macroalgae is no longer able to survive) rather than any improvements in catchment management (Stevens & Forrest 2020).

The current report describes the methods and results of the most recent macroalgal and seagrass mapping undertaken in New River Estuary between 19-24 February 2021 (Fig. 1). The primary purpose of the current survey was to characterise the presence and extent of nuisance macroalgae and seagrass cover. Results are discussed in terms of current state and trends in estuary health, and recommendations for future monitoring and assessment are made.

1.2 OVERVIEW OF NEW RIVER ESTUARY

Background information on New River Estuary has been presented in previous reports (Robertson & Stevens 2007, Stevens & Robertson 2012; Stevens 2018; Stevens & Forrest 2020). This information has been summarised and paraphrased here.

New River Estuary is a relatively large (4,600ha) estuary situated at the confluence of the Ōreti and Waihopai Rivers near Invercargill, which discharges to the sea at the eastern end of Ōreti Beach. It is categorised as a shallow (mean depth ~2m) intertidal dominated, 'tidal lagoon' type estuary (SIDE).

The estuary drains a large 4,314km^2 catchment comprising ~60% intensive pasture, 17% low producing pasture, 13% native forest, and 8% exotic forest. The immediate terrestrial margin of the estuary has a mix of vegetation and land uses (urban, bush and grazed pasture). Within the estuary are a wide range of habitats including extensive mud and sand flats, and ecologically important cockle beds, seagrass beds (*Zostera muelleri*) and extensive salt marsh areas (~10% of the estuary).

The estuary is an important site and source of mahinga kai including species such as pātiki (flounder), tuna (eel), īnanga (whitebait), kanae (grey mullet) and shellfish (PCE 2020). Two main Māori settlements historically existed on the estuary margins - Ōue (Sandy Point) and Ōmāui - and the New River Estuary is acknowledged in the Statutory Acknowledgements of Rakiura/Te Ara a Kiwa (Rakiura/Foveaux Strait CMA) (Schedule 104) and the Ōreti River Statutory Acknowledgement.

During early Māori settlement lowland and swamp forests were cleared, promoting growth of harakeke (flax) and scrub (PCE 2020). Europeans introduced western crops and sealers and whalers were active from the two main settlements around the estuary in the early 1800's. Invercargill was established on the eastern estuary margin in the mid to late 1800's (PCE 2020). Flax milling and forestry were prominent and indigenous forest was cleared and replaced with exotic pastures. The catchment became an important area of agricultural growth. However, the modification of the catchment led to decreased soil fertility, altered hydrology, and increased hill country erosion susceptibility (PCE 2020).

Historically large areas of the estuary have been lost through drainage and reclamation (see photo on next page). The Waihopai Arm in the northern estuary is the most modified area, with around 1,200ha (75%) of the arm reclaimed in the early 1900's. Historic salt marsh extent has significantly reduced due to losses from reclamation.

The estuary has a high nutrient load (estimated 2020 catchment N areal loading of 279mgN/m^2/d) that exceeds the guideline for low susceptibility SIDE type estuaries of ~100mgN/m^2/d (Robertson et al. 2017b; Stevens & Forrest 2020) and is expressing significant signs of eutrophication (e.g. muddy sediments, nuisance macroalgae, poor sediment oxygen). The deterioration recorded in New River Estuary represents one of the worst examples of estuary condition in New Zealand (see aerial photo comparison 1985 and 2020).

Both catchment modification and estuary reclamation have greatly reduced the capacity of the estuary to filter, dilute, and assimilate nutrient and sediment inputs. In addition to nutrient enrichment and nuisance blooms of *Agarophyton chilense* and *Ulva* spp., environmental issues facing the estuary include excessive sedimentation and muddiness, discharges of leachate, stormwater and wastewater, and the frequent exceedance of bathing and shellfish faecal indicator bacteria guidelines (lawa.org.nz). Nonetheless, ecological values and human use of large parts of the estuary remain high.

Waihopai Arm macroalgae in 1985 (left) and 2020 (right)

Area of reclaimed land (orange) in New River Estuary. Image source: Google Earth

Agarophyton over anoxic soft muds, Daffodil Bay, February 2021

Patchy flood-scoured *Agarophyton* in Waihopai Arm east, 2021

High biomass *Agarophyton* in Waihopai Arm west, 2021

2. METHODS

2.1 OVERVIEW OF MAPPING

Mapping was undertaken according to the NEMP and New Zealand Estuary Trophic Index (ETI) methods used previously to delineate the spatial extent of macroalgae and seagrass. This procedure combined aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology.

In 2021, 1:5000 colour satellite imagery captured on 21 December 2020 was supplied to ES by Apollo Mapping (Colorado). During field ground-truthing, macroalgae and seagrass areas were drawn onto laminated aerial imagery, and percent cover and biomass were estimated or measured as described below. The macroalgae and seagrass features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field measurements and georeferenced photographs. From this information, maps were produced showing the spatial extent and density of macroalgae and seagrass.

Estuary boundaries for mapping purposes were based on ETI methods (Robertson et al. 2016a), and were 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 New Zealand coastal hydrosystems boundaries (Hume et al. 2016) developed in support of NIWA's CLUES estuary model.

Complete cover of *Agarophyton* in Waihopai Arm east

2.2 MACROALGAE ASSESSMENT

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

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

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

Using this approach in New River Estuary, opportunistic macroalgae patches were mapped during field ground truthing, using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (Fig. 2). Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the extent 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, 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 a five-point scale, using the biomass thresholds described in Table A3 of Appendix 1. These thresholds reflect OMBT values revised for use in New Zealand based on research by NIWA (Plew et al. 2020).

In addition to macroalgal proliferation, 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. Hence, as a supporting indicator, 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.

Photos illustrating macroalgal biomass sampling in New River Estuary

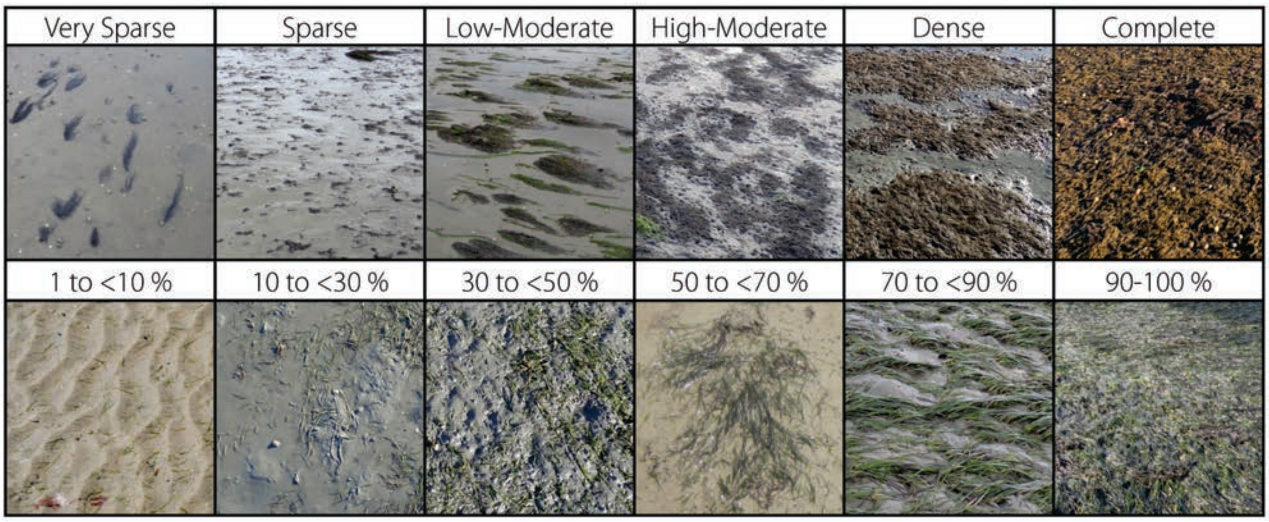


Fig. 2. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

2.3 SEAGRASS ASSESSMENT

As for macroalgae, the percent cover of seagrass patches was visually estimated through ground truthing, based on the 6-category percent cover scale in Fig. 2.

2.4 DATA RECORDING AND QA/QC

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

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

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

2.5 MACROALGAE AND SEAGRASS CONDITION AND ASSESSMENT OF TEMPORAL CHANGE

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 New Zealand and overseas (Table 2). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 2. The condition ratings are primarily sourced from the NZ ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 2. 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 described above (i.e. which range from 'high' to 'bad').

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 have been referred to as 'Gross Eutrophic Zones' (GEZs) in the ETI (Zeldis et al. 2017) and the 2018 monitoring report (Stevens 2018b). For our purposes, HECs are defined as mud-dominated sediments (≥50% mud content, based on expert judgement) with >50% macroalgal cover and with macroalgae entrained and growing as stable beds

Table 2. Indicators and condition rating criteria used to assess results in the current report.

Indicator	Unit	Very Good	Good	Fair	Poor
Broad scale indicators					
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥ 0.8 - 1.0	≥ 0.6 - < 0.8	≥ 0.4 - < 0.6	< 0.4
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%
Seagrass[2]	% decrease from baseline	< 5	≥ 5 - 10	≥ 10 - 20	≥ 20
Sediment quality					
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to < 20	< 10

[1] General indicator thresholds derived from a New Zealand Estuary Tropic Index (Robertson et al. 2016b), with adjustments for aRPD (FDGC 2012). See text and Appendix 2 for further explanation of the origin or derivation of the different metrics.

[2] Subjective indicator threshold for seagrass derived from previous broad scale mapping assessments.

within the sediment. These areas typically also have an aRPD depth shallower than 10mm due to sediment anoxia. In New River Estuary some areas are so degraded that macroalgae appear no longer able to survive, leaving large areas of sulfidic soft muds. Despite these areas not meeting the >50% macroalgal cover condition they are included in the assessment of HEC because these degraded areas are expressing severe levels of enrichment.

As many of the scoring categories in Table 2 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).

Note that the assessment of temporal change in macroalgae and seagrass between 2001 and 2021 is based on cover >50%, as in the earliest surveys these features were only mapped when they were dominant or conspicuous, which we assume to equate to >50% cover. It is also difficult to reliably distinguish cover <50% from aerial photos alone (see section 2.4).

As noted above, the thresholds used to place biomass into OMBT bands are based on revised values recommended for use in New Zealand (Plew et al. 2020; Appendix 1). This modification results in a relatively minor change to previously reported ETI scores and accompanying figures showing the spatial location of biomass. Note that biomass data for calculation of OMBT scores have been collected only for the five surveys undertaken since 2016, although retrospective values have been previously estimated for 2001, 2007 and 2012 (Stevens 2018).

High biomass *Agarophyton* in Waihopai Arm east in 2021

3. RESULTS

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

3.1 OPPORTUNISTIC MACROALGAE

Table 3 summarises macroalgal percentage cover and biomass classes for New River Estuary in 2021, with the mapped cover and biomass shown in Fig. 3 and Fig. 4, respectively. Macroalgal sampling stations and raw wet weights for biomass measurements are provided in Appendix 3. Key results were as follows:

- Across 52.5% of the 2,944ha intertidal area macroalgae cover was classified as absent or trace (i.e. <1% cover), and classified as 'very sparse' (1-<10%) across a further 22.1% of the intertidal area.
- *Agarophyton* was most extensive (>50% cover) in the sheltered Waihopai Arm and Daffodil Bay and at the Ōreti River mouth and Bushy Point.
- Biomass in these areas ranged from high (>0.50 – 1.45kg/m^2) to very high (>1.45kg/m^2) and consisted of mounds of *Agarophyton* (5-10cm high) deeply entrained in muddy sediment. The maximum biomass recorded was ~7.5kg/m^2, ~5 times higher than the 'very high' threshold (see photos on following page).
- In 2020, there was significant flood scouring at the Ōreti River mouth and Bushy Point. In 2021, these areas have quickly re-established with prolific *Agarophyton* present (see photos on page 12).
- In 2021, significant dieback of macroalgae was recorded in the western Waihopai Arm and Daffodil Bay, which was attributed to 'self-pollution' (see Section 1.1). These areas represent severe eutrophic conditions where macroalgae appear to no longer be able to survive and only very soft sulfidic muds remain (see photos).
- Near Woodend and in Mokomoko Inlet, small stable beds of *Agarophyton* persist.
- The green seaweed *Ulva* spp. was present in the lower estuary and Mokomoko Inlet and was generally associated with areas of firm sands or hard substrates (e.g. cobbles).

Decaying *Agarophyton* over very soft anoxic muds in the Waihopai Arm (top) and Daffodil Bay (bottom) in 2021

Entrained decaying *Agarophyton* in Daffodil Bay in 2021 with sulfur oxidizing bacteria present on the surface

Table 3. Summary of intertidal macroalgal cover (A) and biomass (B), New River Estuary 2021. Cover categories are shown in Fig. 2. Thresholds for biomass categories are based on Plew et al. (2020) as per Table A3 of Appendix 1.

A. Cover

Percent cover category	Ha	%
Absent or trace	1546.3	52.5
Very sparse (1 to <10%)	650.7	22.1
Sparse (10 to <30%)	147.5	5.0
Low-Moderate (30 to <50%)	157.7	5.4
High-Moderate (50 to <70%)	131.8	4.5
Dense (70 to >90%)	180.0	6.1
Complete (>90%)	130.0	4.4
Total	2944	100

B. Biomass

Biomass category (g/m^2)	Ha	%
Absent or trace (<1)	1546.3	52.5
Very low (1 - 100)	657.1	22.3
Low (101 - 200)	31.0	1.1
Moderate (201 - 500)	117.6	4.0
High (501 - 1450)	230.8	7.8
Very high (>1450)	361.2	12.3
Total	2944	100

High biomass *Agarophyton* in Daffodil Bay (top) and Waihopai Arm east (bottom)

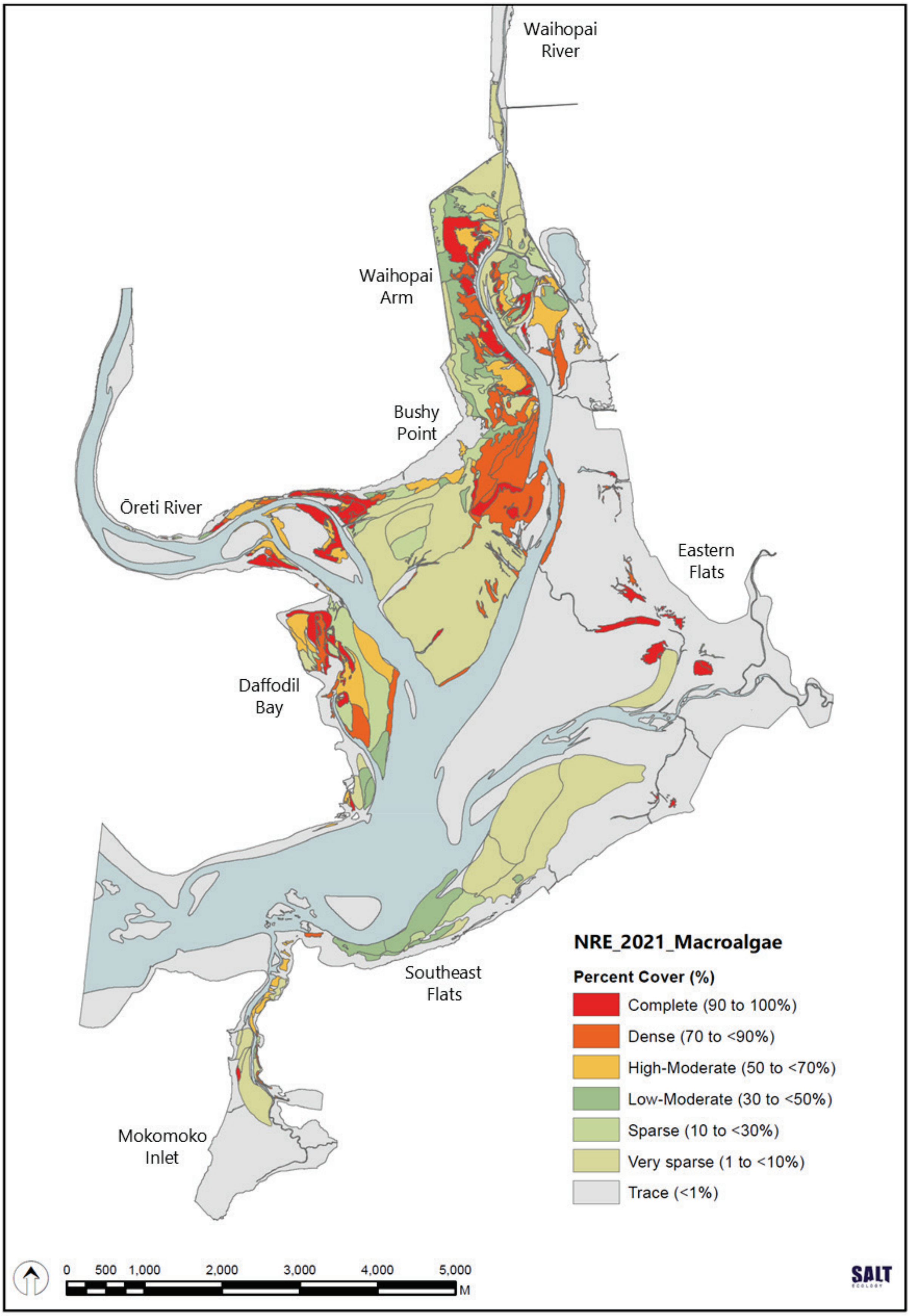


Fig. 3. Distribution and percentage cover classes of macroalgae, New River Estuary, February 2021.

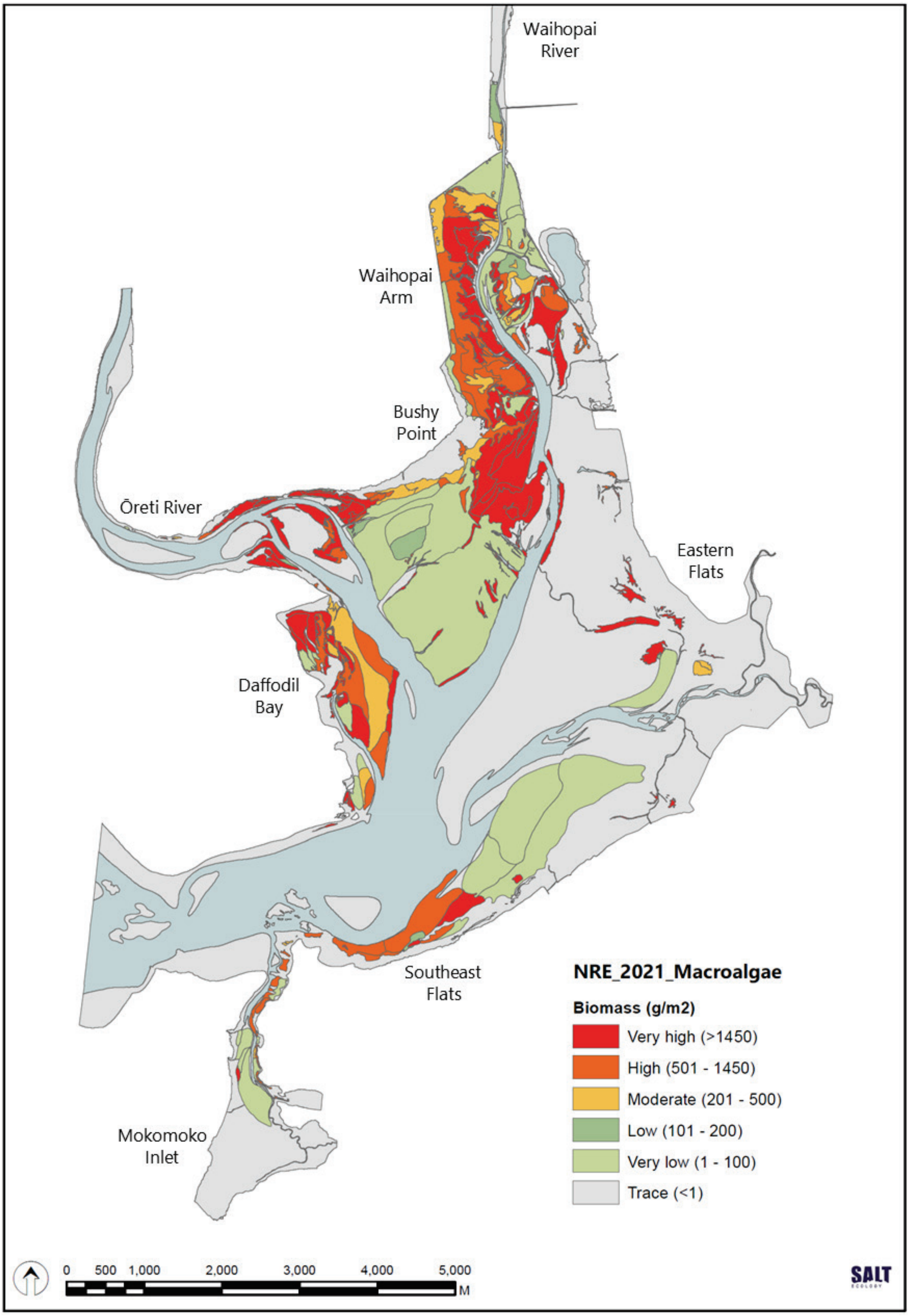


Fig. 4. Biomass (wet weight; g/m^2) classes of macroalgae, New River Estuary, February 2021.

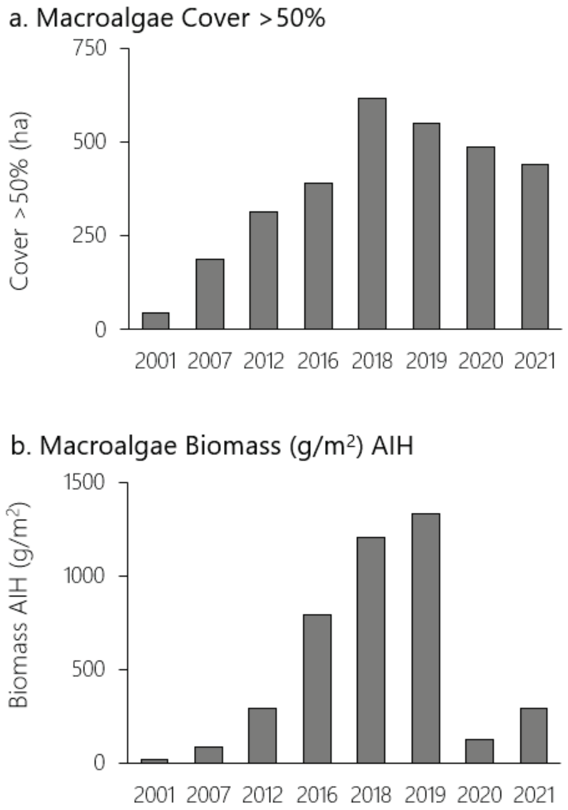


Fig. 5. (a) Temporal change in macroalgal percent cover (>50%) and (b) OMBT biomass (g/m^2) of the available intertidal habitat in New River Estuary 2001-2021.

In New River Estuary between 2001-2018 there was a steady increase in the area of macroalgal cover exceeding high-moderate (i.e. >50% cover, the most reliable threshold for comparison to baseline; see Methods), concomitant with an increase in macroalgal biomass (Fig. 5). A small decline in cover was observed between 2019-2020, attributed to die-off of macroalgae due to 'self-pollution' and scouring from a major flood event in February 2020. In 2021, further die-off of macroalgae was observed in Daffodil Bay and the Waihopai Arm. In these areas the decay of macroalgae has led to almost bare anoxic sediments that have a strong rotten egg (hydrogen sulfide) smell when disturbed, with sulfur oxidising bacteria visible at the surface in some areas. The extent of these severe eutrophic conditions in New River Estuary is unprecedented in New Zealand.

In 2021, the EQR calculated using the OMBT method was 0.408, corresponding to a condition rating of 'fair' (Table 4; Fig. 6a), and has worsened since 2020. The decrease in EQR score in 2021, evident in the individual input metrics, was primarily due to an increase in biomass in the available intertidal habitat (AIH), and particularly an increase in biomass in the affected area (AA; Table 4) compared to 2020 (Stevens & Forrest 2020).

Agarophyton can grow readily from fragments or thalli ('roots') that break off plants and are transported around the estuary. Where entrained beds are present in the sediment there is greater potential for the establishment of new growths from the entrained thalli (see photos on following page; Luxton 1981; Guillemin et al. 2008; Stevens & Robertson 2011). Inter-annual field observations between 2019 to 2021 in New River Estuary highlighted rapid re-growth of macroalgae since flood scouring in February 2020, particularly at the Ōreti River mouth (see photos on following page). While re-growth following scouring of established beds was expected, the rapid re-establishment of high cover and biomass in flood scoured areas could have implications for active management of macroalgae. A worsening EQR score following recovery from a natural flood scouring event highlights conditions in New River Estuary remain suitable for nuisance macroalgal growth (i.e. elevated nutrients, entrained beds). This is not unexpected, given there have been no significant changes in catchment management between the surveys.

Table 4. Summary of OMBT input metrics and calculation of overall macroalgal Ecological Quality Rating (EQR), New River Estuary February 2021.

2021 Metric	Face value	FEDS	Environmental Quality Class
%cover in AIH	14.4	0.611	Good
Biomass per m^2 AIH	289.6	0.540	Moderate
Biomass per m^2 AA	616.2	0.376	Poor
%entrained in AA	20.4	0.397	Poor
Worst of AA (ha) and AA (% of AIH)		0.118	Bad
AA (ha)	1383.6	0.118	Bad
AA (% of AIH)	47.0	0.417	Moderate
Survey EQR		**0.408**	**Fair**

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

Temporal changes due to flood scouring in the lower Ōreti River

2019 - pre flood extent

2020 - post flood scouring

2021 – post flood re-establishment

Macroalgal beds at the Ōreti River mouth near Bushy Point

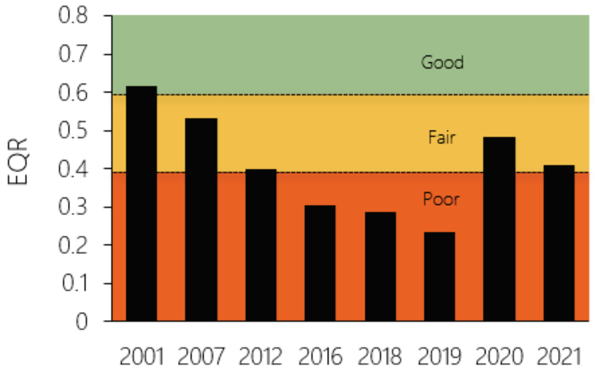
2019 – pre flood extent

2020 - post flood scouring

2021 – post flood re-establishment

Macroalgal beds in the lower Ōreti River

a. Macroalgae OMBT



b. HEC

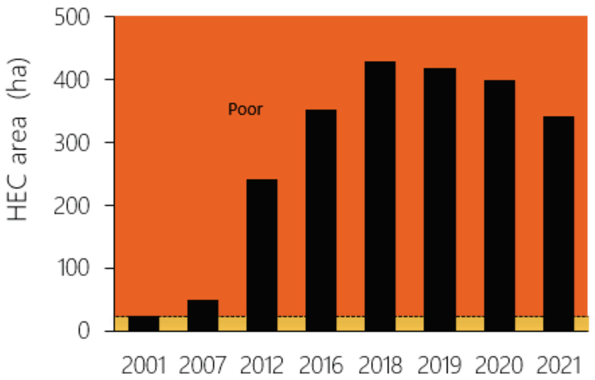
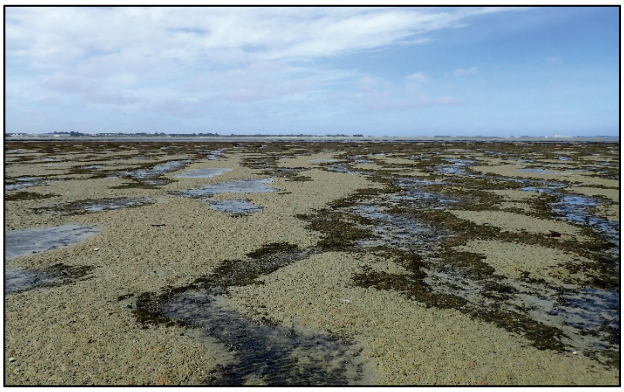


Fig. 6. (a) Macroalgal OMBT Ecological Quality Rating (EQR) scores and (b) HEC area, New River Estuary 2001-2021. Ratings are outlined in Table 2.

In 2021, widespread eutrophication symptoms persisted in New River Estuary, highlighted by the large areas classified as HEC (Fig. 6b and Fig. 7). Since monitoring began there has been a large increase in HEC area between 2007 and 2012, with the peak observed in 2018 and small declines in 2019 to 2020 associated with the erosion of established beds (Stevens & Forrest 2020). There has been a small decline again in 2021, with erosion of beds above Stead Street bridge and the Ōreti River mouth, coupled with die-off of macroalgae in the upper Waihopai Arm as discussed above.

Fig. 7 highlights the extensive areas of eutrophic conditions in the Waihopai Arm, Daffodil Bay, Bushy Point and the Ōreti River mouth, with localised patches observed near Woodend and Mokomoko Inlet. In a healthy state, an estuary would not be expected to have any significant areas of HEC (e.g. <1% or 0.5ha, Table 2). In 2021, 340ha of HEC were present covering 12% of the estuary intertidal area.



Bushy Point: Bare mounds of flood-scoured *Agarophyton* (top) and very soft anoxic muds (bottom)

Very soft anoxic muds with decaying *Agarophyton* in west Waihopai Arm (top) and Daffodil Bay (bottom)

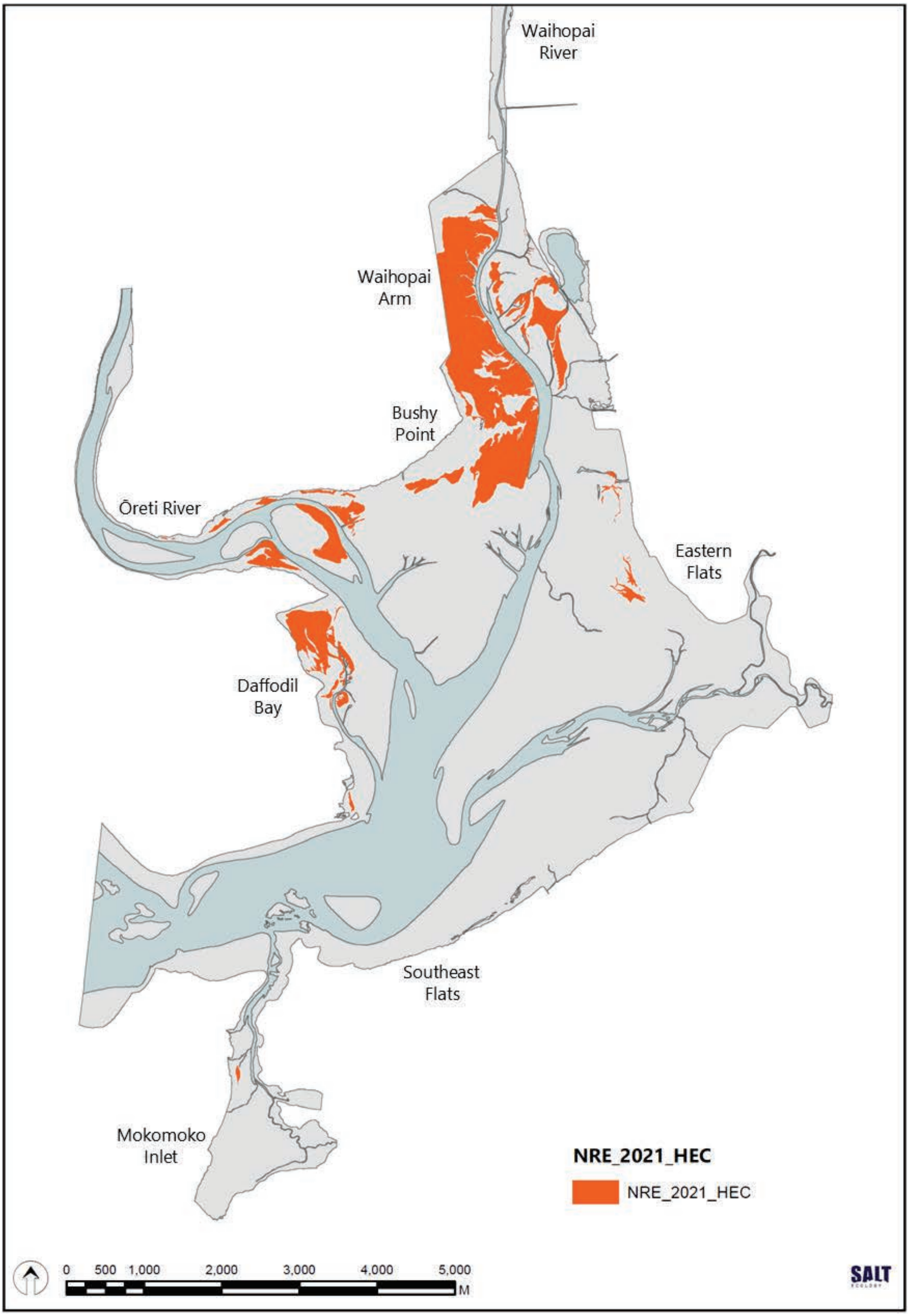


Fig. 7. Area categorised as showing High Enrichment Conditions (HECs) in New River Estuary, February 2021.

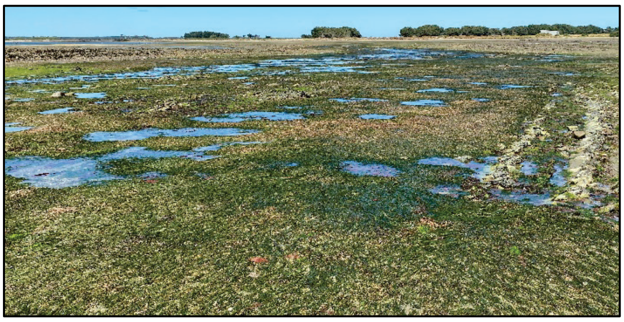
3.2 SEAGRASS

Table 5 and Fig. 8 summarise seagrass percent cover for the estuary in 2021 and Table 6 summarises seagrass (>50% cover) loss since 2001.

In 2021, there was 37.5ha (1.3% of the intertidal area) of intertidal seagrass (*Zostera muelleri*) cover in New River Estuary. High to moderate (50 to 70%) and dense (70 to 90%) cover beds were located on the margins of the Ōreti River mouth, Woodend and near the entrance of Mokomoko Inlet. Several small remnant patches were present in the upper Waihopai Arm (Fig. 8).

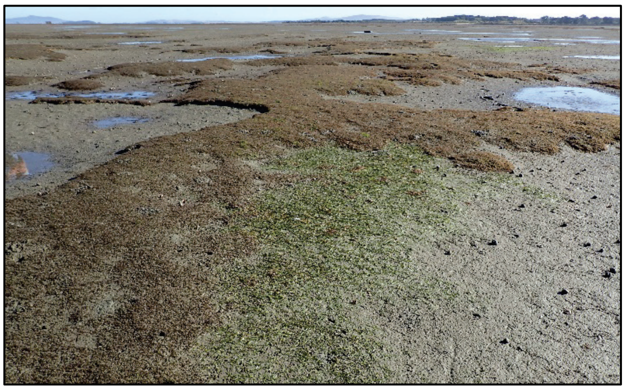
Table 5. Summary of seagrass percent cover categories, New River Estuary 2021.

Percent cover category	Ha	%
Absent or trace	2906.5	98.7
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	14.6	0.5
Low-Moderate (30 to <50%)	6.3	0.2
High-Moderate (50 to <70%)	11.3	0.4
Dense (70 to >90%)	4.3	0.1
Complete (>90%)	0.9	0.0
Total	2944	100



Dense seagrass beds near the Mokomoko Inlet entrance in the lower estuary

Since 2001 there has been a loss of 82% of the seagrass from the estuary (Table 6). The most extensive losses have occurred in the west Waihopai Arm where the ~58ha reduction since 2001 represents a near complete loss of seagrass from this part of the estuary. The losses are attributed primarily to initial smothering by fine sediments and subsequent proliferation of nuisance macroalgae. In 2021 these stressors appear to be causing adverse impacts to seagrass in the east Waihopai Arm and the Ōreti River mouth, with fine sediment accrual and mounds of *Agarophyton* encroaching on seagrass beds (see photos). Other impacts observed include damage from vehicle tracks evident at the Ōreti River mouth (see following photos).



Mounds of *Agarophyton* growing over seagrass in east Waihopai Arm (top) and Ōreti River mouth (bottom)

Vehicle tracks over seagrass beds on the Ōreti River margin

Table 6. Summary of area of seagrass >50% cover, New River Estuary 2001-2021. Colour shading aligns with condition ratings in Table 2. The % reduction is relative to 2001.

Year	Ha	Change (ha)	% Reduction
2001	94.0		
2007	na	na	na
2012	53.0	-41.0	44
2016	42.6	-51.4	55
2018	36.9	-57.1	61
2019	36.4	-57.6	61
2020	31.1	-62.9	67
2021	17.0	-77.0	82

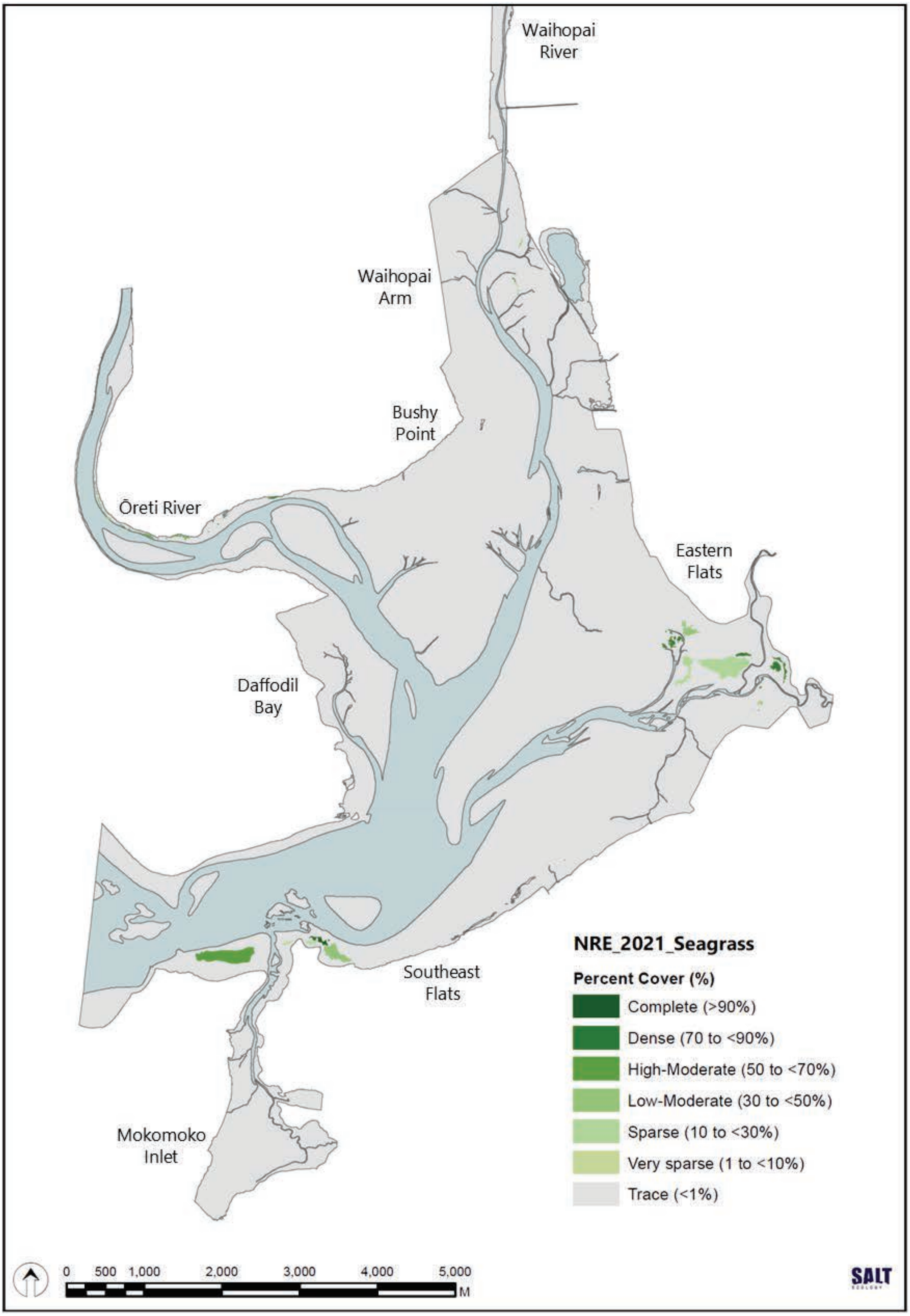


Fig. 8. Seagrass distribution in New River Estuary, February 2021.

4. SYNTHESIS AND RECOMMENDATIONS

4.1 SYNTHESIS OF KEY FINDINGS

Eutrophication and fine sediment deposition have been identified as issues in New River Estuary since at least 1973 (see Stevens 2018 and references therein). For macroalgae to proliferate to nuisance levels, there needs to be a sufficient supply of nutrients available to fuel growth. Since at least 2007, modelled nitrogen loads to New River Estuary have been more than double the threshold (~100mgN/m^2/d in SIDE type estuaries) at which significant eutrophication problems are predicted to occur, and have been steadily increasing since that time.

Persistent eutrophic symptoms (nuisance opportunistic macroalgae and the development of HEC areas) had begun to establish in parts of the lower Waihopai Arm, Bushy Point and Daffodil Bay in 2007. These areas represent relatively sheltered depositional zones where fine sediments create an ideal environment for nuisance algal growth, in particular *Agarophyton chilense*. HEC areas comprising high biomass beds of entrained *Agarophyton* or *Ulva*, associated with mud-dominated, nutrient-rich, anoxic sediments, were present across 49ha of the estuary in 2007.

Between 2007 and 2020, eutrophic HEC areas in the Waihopai Arm, Bushy Point and Daffodil Bay expanded significantly, and established in the Ōreti River mouth and localised areas on the eastern flats near Woodend, in Mokomoko Inlet and on the banks of the Waihopai River. The development and expansion of persistent and severe eutrophic symptoms highlight that catchment nutrient loads currently exceed the assimilative capacity of the estuary, with problems expected to persist until there are significant reductions in nutrient inputs.

Table 7 summarises changes in key indicators between 2001 and 2021, and assesses the results against the condition ratings presented in Table 2. Overall New River Estuary continues to express significant widespread symptoms of eutrophication at a scale that is unprecedented in New Zealand. HEC areas comprised 340ha (12% of the estuary area) equivalent to >450 rugby fields, with values well above the 'poor' threshold of 20ha within an estuary (Table 7). There have also been ongoing losses of high value seagrass habitat, evident in parts of the estuary impacted by excessive macroalgal growth or fine sediment deposition.

Compared to recent surveys (2016-2019), there have been apparent improvements in macroalgae and HEC extent in 2020 and 2021. However, rather than a meaningful reduction in eutrophication, these changes primarily reflect widespread macroalgal scouring following a large flood event recorded in February 2020 (see photos in Section 3.1), and a reduction in macroalgal growth in parts of the estuary that are now so degraded the severely eutrophic sediments appear no longer able to support macroalgal growth.

As predicted in Stevens & Forrest (2020), the effects of flood scouring appear to have resulted in a short-term improvement in EQR score rather than a sustained improvement in estuary condition, evident by many of the *Agarophyton* beds affected by flood scouring in 2020 re-establishing at high cover and high biomass in 2021. These areas were located primarily along the banks of the lower Ōreti River, along the low tide channel margins of the Waihopai River channel, and near Bushy Point.

Reductions in macroalgal biomass as a consequence of die-off in extremely eutrophic parts of the estuary have been more sustained. In these areas, macroalgae has yet to re-establish within sediments that are mud-dominated, and have extreme sediment anoxia, sulfide production and bacterial mats on the sediment surface (see photo below). The largest of these areas are in the west Waihopai Arm, Daffodil Bay and Whalers Bay (at the south end of Daffodil Bay).

Table 7. Summary of condition rating scores between 2001 and 2021 based on the key indicators and criteria in Table 2.

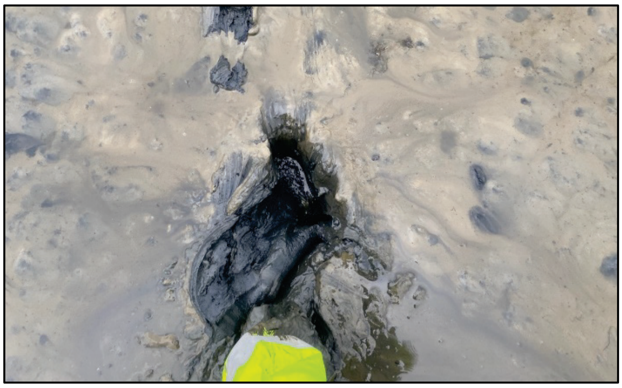
Broad scale indicator	Unit	2001	2007	2012	2016	2018	2019	2020	2021
Macroalgae (OMBT)[1]	EQR	0.616	0.532	0.398	0.303	0.284	0.234	0.481	0.408
HEC[2]	Ha	23	49	240	351	428	417	399	340
HEC[2]	% of estuary	0.8	1.7	8.6	12.6	15.3	14.9	14.3	11.6
Seagrass[3]	% decrease from baseline	na	na	44	55	61	61	67	82

[1] OMBT = Opportunistic Macroalgal Blooming Tool [2] High Enrichment Conditions [3] Data for 2001 used as baseline for seagrass. No available seagrass data for 2007

Condition rating colour key:

Very Good	Good	Fair	Poor

Decaying macroalgae and sulfur oxidising bacteria (white colour) on the sediment surface in Daffodil Bay



Very soft anoxic sediments in Waihopai Arm west

Dense *Agarophyton* in the Waihopai Arm

Low-moderate cover of *Agarophyton* east of the Mokomoko Inlet entrance

The timeframe or likely extent of recovery from enrichment in these HEC areas is uncertain. In other Southland estuaries (e.g. Jacobs River Estuary and Toetoes (Fortrose) Estuary) macroalgal die-off has destabilised sediments and made them more prone to erosion, facilitating the release of fine sediments previously trapped among entrained macroalgae (Stevens 2018a; Roberts et al. 2021). However, in New River Estuary the areas of macroalgal die-off due to 'self-pollution' are relatively sheltered from wind and wave action and are buffered from high channel flows due to persistent entrained macroalgal beds separating eutrophic zones from the channel margins. As such, sediment erosion in these areas is predicted to be limited and in the absence of flushing of enriched sediments from the estuary, recovery from severe enrichment is likely to be slow. If some recovery does occur it is much more likely to result in the re-establishment of nuisance macroalgae (*Agarophtyon*) than a return to non-nuisance conditions.

The rapid re-establishment of macroalgae after physical removal (i.e. scouring) has implications for active management where the removal of macroalgal biomass has been considered as a possibility for mitigating the adverse impacts of excessive macroalgal growth. It suggests that while physical removal of excessive macroalgae has a positive effect on the estuary, it is likely to be short-lived where nutrient loads remain excessive and suitable growing conditions exist.

Despite the widespread eutrophic symptoms in the upper estuary, most of the well-flushed mid to lower estuary remains in good health. Although *Ulva* and non-entrained *Agarophtyon* are present in some areas, they are generally not at nuisance levels and are not causing widespread sediment degradation. The largest increase in non-nuisance growths were in the southeast flats of the estuary, east of the entrance to Mokomoko Inlet (see photo bottom left). In previous years, this part of the estuary has supported relatively dense growths of *Ulva* or been where large volumes of drift algae have accumulated. However, in 2021, patches of *Agarophyton* were becoming established with a shallow degree of entrainment. Because of relatively high wind and wave exposure, persistent beds may not be able to establish in this location, although the increased growth and biomass evident in 2021 is of concern.

Regarding seagrass, there has been an 82% reduction in mapped seagrass extent (>50% cover) since 2001, reducing from 94ha in 2001 to 17ha in 2021 (Table 7). The largest losses (~58ha) have occurred in the west Waihopai Arm which now has <1% of the 2001 cover remaining. The losses in this part of the estuary are attributed primarily to significant increases in fine sediment deposition, followed by an increase in *Ulva* growth, followed by the establishment of entrained beds of *Agarophyton*.

This sequence of change continues to cause losses in 2021 where mounds of *Agarophyton* are now growing over seagrass beds at the Ōreti River mouth and in the east Waihopai Arm (see photos). Additional localised impacts in 2021 include vehicle tracks through seagrass beds at the Ōreti River mouth.

Seagrass beds appear to be in a relatively healthy and stable condition in those parts of the estuary which are well-flushed with seawater, where water clarity appears to be relatively good, and where there is little fine sediment deposition, e.g. near the estuary entrance and along sand-dominated channel edges.

Mounds of *Agarophyton* growing over seagrass in east Waihopai Arm

Agarophyton mounds growing over seagrass at Ōreti River mouth in New River Estuary (2021)

Overall, the 2021 monitoring results highlight that persistent growths of opportunistic *Agarophyton*, and to a lesser extent *Ulva*, are causing some of the most extreme and widespread estuary degradation ever recorded in New Zealand, including ongoing losses of high value seagrass habitat. There remains an urgent need to manage sediment and nutrient loads to the estuary, as without loads reductions, widespread areas of nuisance macroalgae and high enrichment conditions can be expected to persist and potentially worsen.

4.2 RECOMMENDATIONS

Based on the 2021 survey findings, and those of previous surveys documenting persistent areas with HECs and nutrient loads more than the estuaries' assimilative capacity, it is recommended that ES:

- Continue annual monitoring during summer to track long term changes in nuisance macroalgae and seagrass. Review current sampling effort required to calculate the macroalgae OMBT score, to optimise the sampling design in future surveys.
- Continue with planned work to determine limits on nutrient and sediment mass loads that would be expected to prevent further degradation and, where possible, mitigate current adverse impacts.
- Determine catchment nutrient and sediment sources as part of the mass load assessment and evaluate whether there are any effective and feasible management practices that could be undertaken to achieve ES's desired condition for the estuary.
- Explore options for the local scale removal of macroalgae to limit further loss of high value habitat (i.e. seagrass), and to prevent otherwise healthy sediment from degrading to an extent that long-term severe eutrophication conditions are likely to persist.

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Appendix 1. Opportunistic 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 opportunistic macroalgae growth on sedimentary shores due to nutrient pressure.

TIMING

The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification; e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

SUITABLE LOCATIONS

The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing ICOLLs due to the particular challenges in setting suitable reference conditions for these water bodies.

DERIVATION OF THRESHOLD VALUES

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

REFERENCE THRESHOLDS

A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g/m^2 wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

CLASS THRESHOLDS FOR PERCENT COVER

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

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to

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

ECOLOGICAL QUALITY RATING (EQR)	High	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

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).

Thresholds applied in the current study are described on page 24 and presented in Table A3.

THRESHOLDS FOR ENTRAINED ALGAE

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

EQR CALCULATION

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

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

The EQR calculation process is as follows:

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

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

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

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

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

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

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

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

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

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

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CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

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

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

ECOLOGICAL QUALITY RATING (EQR)	High	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 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g/m^2) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

Appendix 2. Information supporting ratings in the report

SEDIMENT MUD CONTENT

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

APPARENT REDOX POTENTIAL DISCONTINUITY (aRPD)

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

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

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

OPPORTUNISTIC MACROALGAE

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

SEAGRASS

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

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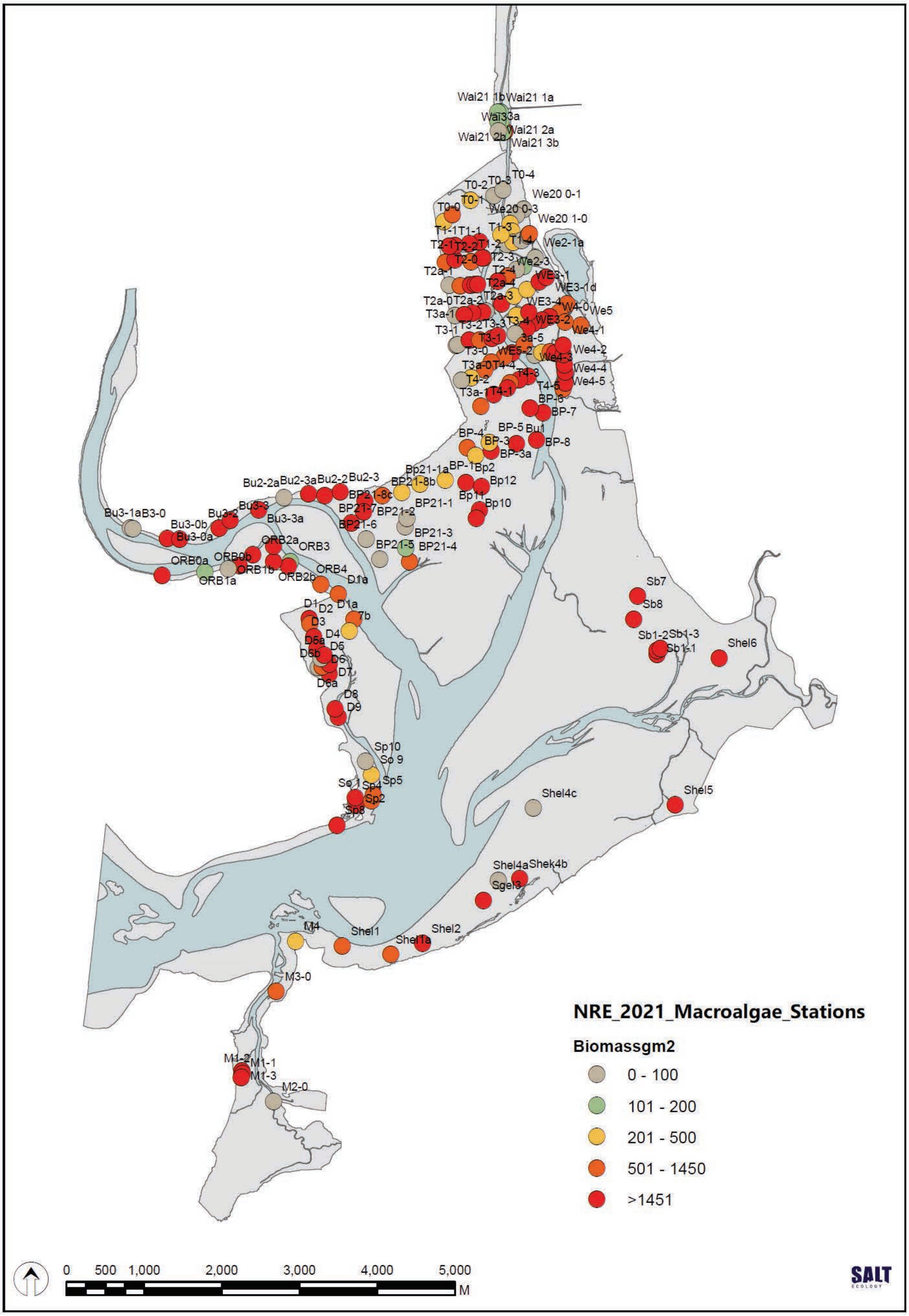
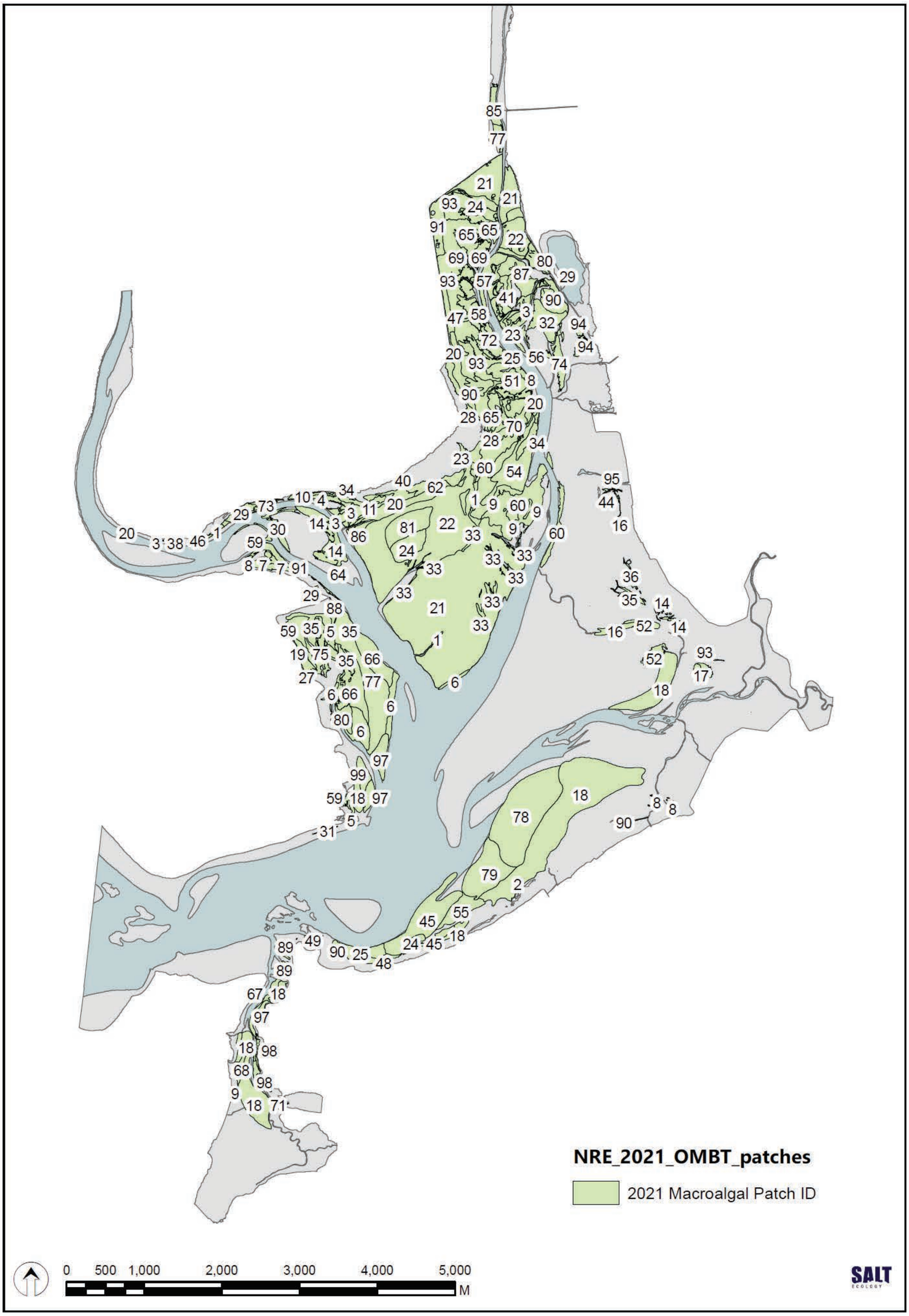
Appendix 3. Macroalgal biomass stations, OMBT patch ID and data

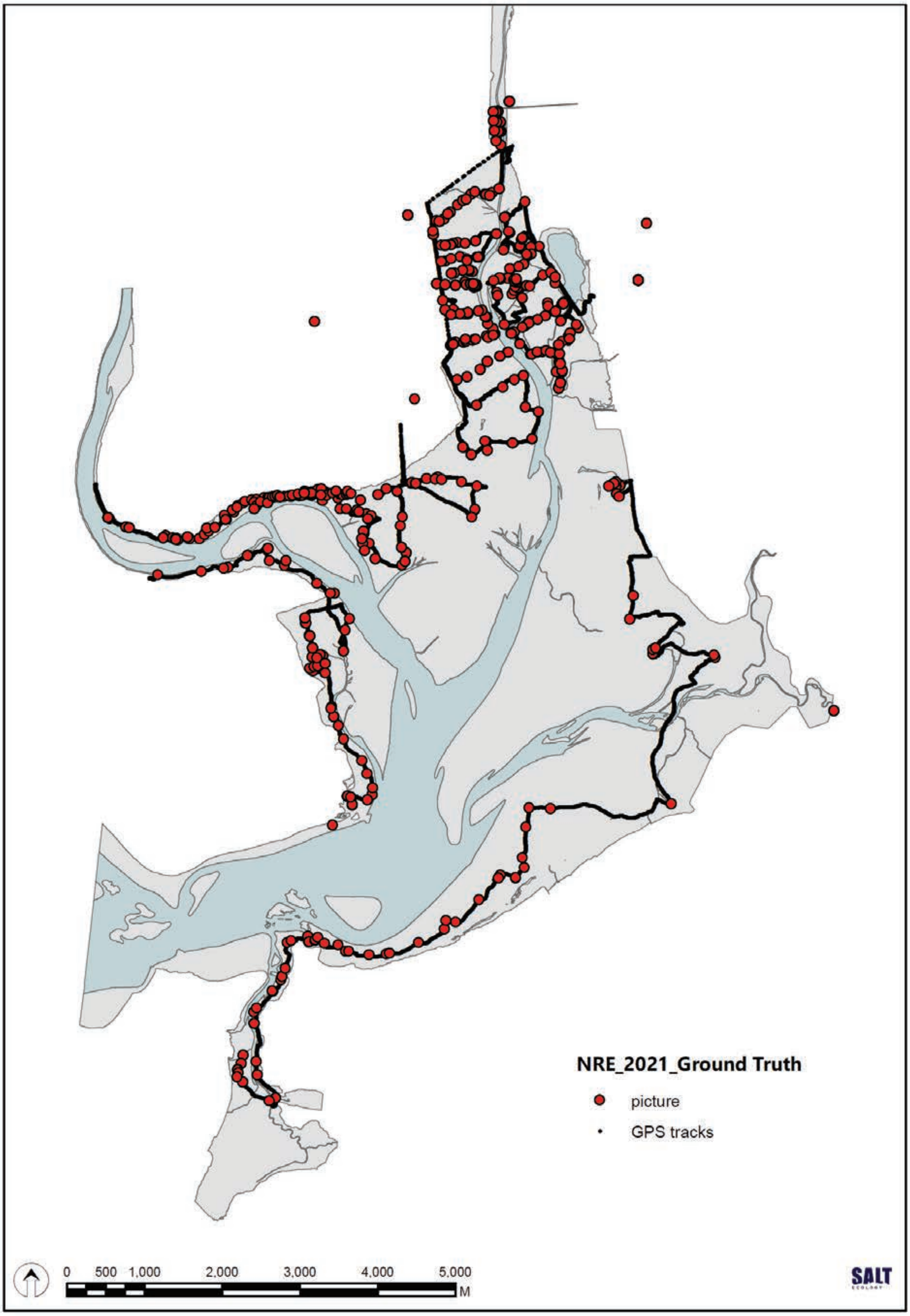



NRE_2021_OMBT_patches
2021 Macroalgal Patch ID
0 500 1,000 2,000 3,000 4,000 5,000
M

Estuary	Year	PatchID	ValidCode	Pct_Cover	TotPctCov	Pct Cover Category	Biomass (g/m^2)	Biomass Category	Entrained	DomHab	SubDom1	Area_ha
NRE-Sout	2021	1	Grch	100	100	Complete (>90%)	7040	Very high (>1450)	1	Agarophyton chilense		2.1
NRE-Sout	2021	1	Grch	100	100	Complete (>90%)	7520	Very high (>1450)	1	Agarophyton chilense		0.8
NRE-Sout	2021	2	Grch Ulva	30 2	32	Low-Moderate (30 to <50%)	7360	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.9
NRE-Sout	2021	3	Grch	100	100	Complete (>90%)	6400	Very high (>1450)	1	Agarophyton chilense		3.0
NRE-Sout	2021	3	Grch	100	100	Complete (>90%)	6400	Very high (>1450)	1	Agarophyton chilense		6.2
NRE-Sout	2021	3	Ulva Grch	50 50	100	Complete (>90%)	6640	Very high (>1450)	1	Ulva (Sea lettuce)	Agarophyton chilense	0.1
NRE-Sout	2021	4	Grch	95	95	Complete (>90%)	6880	Very high (>1450)	1	Agarophyton chilense		4.2
NRE-Sout	2021	5	Grch Ulva	97 2	99	Complete (>90%)	6120	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	6.1
NRE-Sout	2021	6	Grch	80	80	Dense (70 to <90%)	4160	Very high (>1450)	1	Agarophyton chilense		0.6
NRE-Sout	2021	6	Grch	80	80	Dense (70 to <90%)	4000	Very high (>1450)	1	Agarophyton chilense		17.0
NRE-Sout	2021	6	Grch	80	80	Dense (70 to <90%)	4000	Very high (>1450)	1	Agarophyton chilense		1.2
NRE-Sout	2021	6	Grch	80	80	Dense (70 to <90%)	4000	Very high (>1450)	1	Agarophyton chilense		0.6
NRE-Sout	2021	7	Grch Ulva	90 10	100	Complete (>90%)	4940	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	2.6
NRE-Sout	2021	7	Grch Ulva	80 20	100	Complete (>90%)	4880	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	3.5
NRE-Sout	2021	8	Grch	100	100	Complete (>90%)	6000	Very high (>1450)	1	Agarophyton chilense		1.9
NRE-Sout	2021	8	Grch Ulva	80 20	100	Complete (>90%)	5760	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	1.0
NRE-Sout	2021	8	Grch Ulva	80 20	100	Complete (>90%)	5920	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.4
NRE-Sout	2021	9	Grch	90	90	Complete (>90%)	5440	Very high (>1450)	1	Agarophyton chilense		9.5
NRE-Sout	2021	9	Grch	90	90	Complete (>90%)	6080	Very high (>1450)	1	Agarophyton chilense		0.8
NRE-Sout	2021	10	Grch	75	75	Dense (70 to <90%)	5280	Very high (>1450)	1	Agarophyton chilense		1.1
NRE-Sout	2021	11	Grch	90	90	Complete (>90%)	4640	Very high (>1450)	1	Agarophyton chilense		4.4
NRE-Sout	2021	12	Grch Ulva	75 10	85	Dense (70 to <90%)	4000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.4
NRE-Sout	2021	13	Grch Ulva	99 1	100	Complete (>90%)	3120	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.7
NRE-Sout	2021	13	Grch	100	100	Complete (>90%)	3280	Very high (>1450)	1	Agarophyton chilense		2.0
NRE-Sout	2021	14	Grch Ulva	90 10	100	Complete (>90%)	3000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	2.1
NRE-Sout	2021	14	Grch	100	100	Complete (>90%)	3000	Very high (>1450)	1	Agarophyton chilense		11.6
NRE-Sout	2021	15	Grch	70	70	Dense (70 to <90%)	2000	Very high (>1450)	1	Agarophyton chilense		0.3
NRE-Sout	2021	15	Grch	70	70	Dense (70 to <90%)	2000	Very high (>1450)	1	Agarophyton chilense		0.6
NRE-Sout	2021	16	Grch	90	90	Complete (>90%)	2000	Very high (>1450)	1	Agarophyton chilense		0.2
NRE-Sout	2021	16	Grch Ulva	80 10	90	Complete (>90%)	2000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	3.5
NRE-Sout	2021	16	Grch	90	90	Complete (>90%)	2000	Very high (>1450)	1	Agarophyton chilense		0.0
NRE-Sout	2021	17	Ulva	90	90	Complete (>90%)	200	Low (101 - 200)	0	Ulva (Sea lettuce)		0.3
NRE-Sout	2021	17	Ulva	90	90	Complete (>90%)	300	Moderate (201 - 500)	0	Ulva (Sea lettuce)		2.8
NRE-Sout	2021	17	Ulva	90	90	Complete (>90%)	300	Moderate (201 - 500)	0	Ulva (Sea lettuce)		1.1
NRE-Sout	2021	18	Ulva Grch	1 1	2	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	Ulva (Sea lettuce)	Agarophyton chilense	133.7
NRE-Sout	2021	18	Grch	1	1	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	Agarophyton chilense		4.5
NRE-Sout	2021	18	Ulva	1	1	Very sparse (1 to <10%)	2	Very low (1 - 100)	0	Ulva (Sea lettuce)		2.3
NRE-Sout	2021	18	Grch	2	2	Very sparse (1 to <10%)	10	Very low (1 - 100)	0	Agarophyton chilense		3.2
NRE-Sout	2021	18	Ulva	1	1	Very sparse (1 to <10%)	2	Very low (1 - 100)	0	Ulva (Sea lettuce)		4.5
NRE-Sout	2021	18	Ulva Grch	1 1	2	Very sparse (1 to <10%)	5	Very low (1 - 100)	0	Ulva (Sea lettuce)	Agarophyton chilense	1.8
NRE-Sout	2021	19	Grch	50	50	High-Moderate (50 to <70%)	4784	Very high (>1450)	1	Agarophyton chilense		3.6
NRE-Sout	2021	20	Grch	5	5	Very sparse (1 to <10%)	50	Very low (1 - 100)	0	Agarophyton chilense		5.3
NRE-Sout	2021	20	Grch	5	5	Very sparse (1 to <10%)	60	Very low (1 - 100)	0	Agarophyton chilense		10.4
NRE-Sout	2021	20	Grch	5	5	Very sparse (1 to <10%)	50	Very low (1 - 100)	0	Agarophyton chilense		12.3
NRE-Sout	2021	20	Grch	5	5	Very sparse (1 to <10%)	60	Very low (1 - 100)	0	Agarophyton chilense		0.1
NRE-Sout	2021	21	Grch	1	1	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	Agarophyton chilense		12.5
NRE-Sout	2021	21	Grch	1	1	Very sparse (1 to <10%)	18	Very low (1 - 100)	0	Agarophyton chilense		20.5
NRE-Sout	2021	21	Grch	1	1	Very sparse (1 to <10%)	15	Very low (1 - 100)	0	Agarophyton chilense		205.9
NRE-Sout	2021	22	Grch	2	2	Very sparse (1 to <10%)	38	Very low (1 - 100)	0	Agarophyton chilense		11.6
NRE-Sout	2021	22	Grch	1	1	Very sparse (1 to <10%)	45	Very low (1 - 100)	0	Agarophyton chilense		99.1
NRE-Sout	2021	22	Grch	2	2	Very sparse (1 to <10%)	40	Very low (1 - 100)	0	Agarophyton chilense		0.1
NRE-Sout	2021	23	Grch Ulva	20 2	22	Sparse (10 to <30%)	420	Moderate (201 - 500)	1	Agarophyton chilense	Ulva (Sea lettuce)	5.4
NRE-Sout	2021	23	Grch Ulva	30 2	32	Low-Moderate (30 to <50%)	480	Moderate (201 - 500)	1	Agarophyton chilense	Ulva (Sea lettuce)	2.1
NRE-Sout	2021	24	Grch	10	10	Sparse (10 to <30%)	240	Moderate (201 - 500)	0	Agarophyton chilense		14.5
NRE-Sout	2021	24	Grch Ulva	8 2	10	Sparse (10 to <30%)	150	Low (101 - 200)	0	Agarophyton chilense	Ulva (Sea lettuce)	2.2
NRE-Sout	2021	24	Grch Ulva	8 2	10	Sparse (10 to <30%)	150	Low (101 - 200)	0	Agarophyton chilense	Ulva (Sea lettuce)	11.4
NRE-Sout	2021	24	Grch	10	10	Sparse (10 to <30%)	240	Moderate (201 - 500)	0	Agarophyton chilense		1.1
NRE-Sout	2021	25	Grch Ulva	37 5	42	Low-Moderate (30 to <50%)	930	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	5.3
NRE-Sout	2021	25	Grch Ulva	10 50	60	High-Moderate (50 to <70%)	900	High (501 - 1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	0.5
NRE-Sout	2021	25	Ulva Grch	30 5	35	Low-Moderate (30 to <50%)	720	High (501 - 1450)	0	Ulva (Sea lettuce)	Agarophyton chilense	8.3
NRE-Sout	2021	25	Grch	32	32	Low-Moderate (30 to <50%)	920	High (501 - 1450)	1	Agarophyton chilense		5.5
NRE-Sout	2021	26	Grch	50	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	Agarophyton chilense		0.4
NRE-Sout	2021	26	Grch	50	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	Agarophyton chilense		0.3
NRE-Sout	2021	26	Ulva	50	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	Ulva (Sea lettuce)		0.4
NRE-Sout	2021	26	Ulva	50	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	Ulva (Sea lettuce)		0.0
NRE-Sout	2021	27	Grch	2	2	Very sparse (1 to <10%)	5	Very low (1 - 100)	1	Agarophyton chilense		3.1
NRE-Sout	2021	28	Grch	30	30	Low-Moderate (30 to <50%)	900	High (501 - 1450)	1	Agarophyton chilense		5.5
NRE-Sout	2021	28	Grch	30	30	Low-Moderate (30 to <50%)	900	High (501 - 1450)	1	Agarophyton chilense		0.9
NRE-Sout	2021	28	Grch	35	35	Low-Moderate (30 to <50%)	800	High (501 - 1450)	1	Agarophyton chilense		2.7
NRE-Sout	2021	28	Grch	30	30	Low-Moderate (30 to <50%)	800	High (501 - 1450)	1	Agarophyton chilense		0.4
NRE-Sout	2021	28	Grch Ulva	25 5	30	Low-Moderate (30 to <50%)	640	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.3
NRE-Sout	2021	29	Grch	60	60	High-Moderate (50 to <70%)	1500	Very high (>1450)	1	Agarophyton chilense		1.9
NRE-Sout	2021	29	Grch	60	60	High-Moderate (50 to <70%)	1500	Very high (>1450)	1	Agarophyton chilense		2.2
NRE-Sout	2021	29	Grch	65	65	High-Moderate (50 to <70%)	1440	High (501 - 1450)	1	Agarophyton chilense		0.8
NRE-Sout	2021	29	Grch Ulva	40 20	60	High-Moderate (50 to <70%)	1500	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	4.0
NRE-Sout	2021	30	Grch	50	50	High-Moderate (50 to <70%)	1500	Very high (>1450)	1	Agarophyton chilense		0.7
NRE-Sout	2021	30	Grch	50	50	High-Moderate (50 to <70%)	1500	Very high (>1450)	1	Agarophyton chilense		6.3
NRE-Sout	2021	30	Grch	50	50	High-Moderate (50 to <70%)	1500	Very high (>1450)	1	Agarophyton chilense		0.7
NRE-Sout	2021	31	Ulva	50	50	High-Moderate (50 to <70%)	1600	Very high (>1450)	0	Ulva (Sea lettuce)		0.5
NRE-Sout	2021	32	Grch	63	63	High-Moderate (50 to <70%)	1660	Very high (>1450)	1	Agarophyton chilense		12.3
NRE-Sout	2021	33	Grch	80	80	Dense (70 to <90%)	1760	Very high (>1450)	1	Agarophyton chilense		9.8
NRE-Sout	2021	33	Grch	80	80	Dense (70 to <90%)	1760	Very high (>1450)	1	Agarophyton chilense		1.6
NRE-Sout	2021	34	Grch	70	70	Dense (70 to <90%)	1720	Very high (>1450)	1	Agarophyton chilense		8.5
NRE-Sout	2021	34	Grch Ulva	65 5	70	Dense (70 to <90%)	1120	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	1.0
NRE-Sout	2021	34	Grch Ulva	67 7	74	Dense (70 to <90%)	1680	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	3.6
NRE-Sout	2021	34	Grch Ulva	69 1	70	Dense (70 to <90%)	1760	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.3
NRE-Sout	2021	34	Grch Ulva	65 5	70	Dense (70 to <90%)	2200	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.4
NRE-Sout	2021	35	Grch	100	100	Complete (>90%)	2240	Very high (>1450)	1	Agarophyton chilense		1.4
NRE-Sout	2021	35	Grch Ulva	80 20	100	Complete (>90%)	2000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	3.2
NRE-Sout	2021	35	Grch	100	100	Complete (>90%)	2000	Very high (>1450)	1	Agarophyton chilense		3.8
NRE-Sout	2021	35	Grch	100	100	Complete (>90%)	2720	Very high (>1450)	1	Agarophyton chilense		7.9
NRE-Sout	2021	36	Grch Ulva	70 10	80	Dense (70 to <90%)	2000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	1.4
NRE-Sout	2021	37	Grch Ulva	78 2	80	Dense (70 to <90%)	2080	Very high (>1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	0.1
NRE-Sout	2021	38	Grch Ulva	20 1	21	Sparse (10 to <30%)	320	Moderate (201 - 500)	0	Agarophyton chilense	Ulva (Sea lettuce)	3.1
NRE-Sout	2021	38	Grch	20	20	Sparse (10 to <30%)	350	Moderate (201 - 500)	0	Agarophyton chilense		0.2
NRE-Sout	2021	39	Grch	45	45	Low-Moderate (30 to <50%)	400	Moderate (201 - 500)	1	Agarophyton chilense		0.6
NRE-Sout	2021	40	Grch	20	20	Sparse (10 to <30%)	250	Moderate (201 - 500)	1	Agarophyton chilense		4.5

Estuary	Year	PatchID	ValidCode	Pct_Cover	TotPctCov	Pct Cover Category	Biomass (g/m^2)	Biomass Category	Entrained	DomHab	SubDom1	Area_ha
NRE-Sout	2021	40	Grch	20	20	Sparse (10 to <30%)	320	Moderate (201 - 500)	1	Agarophyton chilense		5.2
NRE-Sout	2021	41	Grch	35	35	Low-Moderate (30 to <50%)	320	Moderate (201 - 500)	1	Agarophyton chilense		4.6
NRE-Sout	2021	42	Grch	50	50	High-Moderate (50 to <70%)	320	Moderate (201 - 500)	0	Agarophyton chilense		0.6
NRE-Sout	2021	43	Grch	30	30	Low-Moderate (30 to <50%)	300	Moderate (201 - 500)	1	Agarophyton chilense		0.2
NRE-Sout	2021	44	Grch	80	80	Dense (70 to <90%)	800	High (501 - 1450)	1	Agarophyton chilense		0.5
NRE-Sout	2021	45	Grch Ulva	20 20	40	Low-Moderate (30 to <50%)	1100	High (501 - 1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	33.7
NRE-Sout	2021	46	Grch	40	40	Low-Moderate (30 to <50%)	720	High (501 - 1450)	0	Agarophyton chilense		1.3
NRE-Sout	2021	46	Grch	40	40	Low-Moderate (30 to <50%)	1040	High (501 - 1450)	1	Agarophyton chilense		0.1
NRE-Sout	2021	46	Grch Ulva	40 5	45	Low-Moderate (30 to <50%)	1000	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.7
NRE-Sout	2021	47	Grch Ulva	25 15	40	Low-Moderate (30 to <50%)	1120	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	15.2
NRE-Sout	2021	48	Ulva Grch	20 20	40	Low-Moderate (30 to <50%)	1120	High (501 - 1450)	0	Ulva (Sea lettuce)	Agarophyton chilense	2.5
NRE-Sout	2021	49	Ulva	70	70	Dense (70 to <90%)	1200	High (501 - 1450)	0	Ulva (Sea lettuce)		1.0
NRE-Sout	2021	50	Grch	70	70	Dense (70 to <90%)	1200	High (501 - 1450)	1	Agarophyton chilense		1.3
NRE-Sout	2021	51	Grch	53	53	High-Moderate (50 to <70%)	1300	High (501 - 1450)	1	Agarophyton chilense		11.7
NRE-Sout	2021	52	Grch Ulva Other	80 10 8	98	Complete (>90%)	3500	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	3.1
NRE-Sout	2021	52	Grch Ulva	85 11	96	Complete (>90%)	3573	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	4.8
NRE-Sout	2021	53	Grch Ulva	30 10	40	Low-Moderate (30 to <50%)	3520	Very high (>1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	0.8
NRE-Sout	2021	54	Grch	80	80	Dense (70 to <90%)	3520	Very high (>1450)	1	Agarophyton chilense		22.4
NRE-Sout	2021	55	Grch Ulva	9 1	10	Sparse (10 to <30%)	3360	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	10.6
NRE-Sout	2021	56	Grch	89	89	Dense (70 to <90%)	3120	Very high (>1450)	1	Agarophyton chilense		1.2
NRE-Sout	2021	57	Grch Ulva	80 1	81	Dense (70 to <90%)	3000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	3.1
NRE-Sout	2021	57	Grch	80	80	Dense (70 to <90%)	3000	Very high (>1450)	1	Agarophyton chilense		1.1
NRE-Sout	2021	58	Grch	90	90	Complete (>90%)	2640	Very high (>1450)	1	Agarophyton chilense		0.9
NRE-Sout	2021	58	Grch Ulva	90 1	91	Complete (>90%)	2160	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	1.2
NRE-Sout	2021	58	Grch	90	90	Complete (>90%)	2160	Very high (>1450)	1	Agarophyton chilense		0.2
NRE-Sout	2021	58	Grch Ulva	43 30	73	Dense (70 to <90%)	2160	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	10.9
NRE-Sout	2021	59	Grch Ulva	45 5	50	High-Moderate (50 to <70%)	2000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.9
NRE-Sout	2021	59	Grch	50	50	High-Moderate (50 to <70%)	1920	Very high (>1450)	1	Agarophyton chilense		6.7
NRE-Sout	2021	59	Grch	50	50	High-Moderate (50 to <70%)	1880	Very high (>1450)	1	Agarophyton chilense		3.9
NRE-Sout	2021	60	Grch	70	70	Dense (70 to <90%)	2200	Very high (>1450)	1	Agarophyton chilense		35.9
NRE-Sout	2021	60	Grch	70	70	Dense (70 to <90%)	2500	Very high (>1450)	1	Agarophyton chilense		19.2
NRE-Sout	2021	61	Grch	50	50	High-Moderate (50 to <70%)	2500	Very high (>1450)	1	Agarophyton chilense		0.2
NRE-Sout	2021	62	Grch Ulva	50 10	60	High-Moderate (50 to <70%)	480	Moderate (201 - 500)	1	Agarophyton chilense	Ulva (Sea lettuce)	7.3
NRE-Sout	2021	63	Grch Ulva	50 5	55	High-Moderate (50 to <70%)	900	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	1.4
NRE-Sout	2021	64	Grch	60	60	High-Moderate (50 to <70%)	1000	High (501 - 1450)	1	Agarophyton chilense		5.4
NRE-Sout	2021	65	Grch Ulva	60 10	70	Dense (70 to <90%)	2000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	6.0
NRE-Sout	2021	65	Grch Ulva	62 5	67	High-Moderate (50 to <70%)	1840	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	10.3
NRE-Sout	2021	66	Grch	60	60	High-Moderate (50 to <70%)	800	High (501 - 1450)	0	Agarophyton chilense		31.4
NRE-Sout	2021	67	Ulva	50	50	High-Moderate (50 to <70%)	560	High (501 - 1450)	0	Ulva (Sea lettuce)		2.6
NRE-Sout	2021	68	Ulva	5	5	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	Ulva (Sea lettuce)		1.0
NRE-Sout	2021	68	Grch Ulva	3 2	5	Very sparse (1 to <10%)	15	Very low (1 - 100)	0	Agarophyton chilense	Ulva (Sea lettuce)	1.5
NRE-Sout	2021	69	Grch Ulva	84 13	97	Complete (>90%)	2520	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	25.2
NRE-Sout	2021	70	Grch Ulva	80 2	82	Dense (70 to <90%)	1960	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	12.3
NRE-Sout	2021	71	Grch	80	80	Dense (70 to <90%)	1000	High (501 - 1450)	0	Agarophyton chilense		0.2
NRE-Sout	2021	72	Grch Ulva	77 21	98	Complete (>90%)	2200	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	6.9
NRE-Sout	2021	73	Grch Ulva	70 10	80	Dense (70 to <90%)	2500	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	1.1
NRE-Sout	2021	73	Grch Ulva	70 20	90	Complete (>90%)	2240	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.1
NRE-Sout	2021	74	Grch	74	74	Dense (70 to <90%)	1771	Very high (>1450)	1	Agarophyton chilense		7.4
NRE-Sout	2021	75	Grch	75	75	Dense (70 to <90%)	1120	High (501 - 1450)	1	Agarophyton chilense		6.3
NRE-Sout	2021	76	Grch	70	70	Dense (70 to <90%)	1360	High (501 - 1450)	1	Agarophyton chilense		0.2
NRE-Sout	2021	77	Grch Ulva	7 1	8	Very sparse (1 to <10%)	217	Moderate (201 - 500)	0	Agarophyton chilense	Ulva (Sea lettuce)	3.2
NRE-Sout	2021	77	Ulva Grch	7 7	14	Sparse (10 to <30%)	400	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Agarophyton chilense	42.6
NRE-Sout	2021	78	Grch Ulva	3 2	5	Very sparse (1 to <10%)	45	Very low (1 - 100)	0	Agarophyton chilense	Ulva (Sea lettuce)	63.6
NRE-Sout	2021	78	Grch Ulva	5 2	7	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	Agarophyton chilense	Ulva (Sea lettuce)	0.1
NRE-Sout	2021	79	Grch Ulva	2 1	3	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	Agarophyton chilense	Ulva (Sea lettuce)	26.4
NRE-Sout	2021	80	Grch	10	10	Sparse (10 to <30%)	60	Very low (1 - 100)	0	Agarophyton chilense		0.4
NRE-Sout	2021	80	Grch	10	10	Sparse (10 to <30%)	48	Very low (1 - 100)	0	Agarophyton chilense		4.9
NRE-Sout	2021	80	Grch	10	10	Sparse (10 to <30%)	50	Very low (1 - 100)	0	Agarophyton chilense		0.3
NRE-Sout	2021	80	Grch Ulva	5 5	10	Sparse (10 to <30%)	50	Very low (1 - 100)	0	Agarophyton chilense	Ulva (Sea lettuce)	5.0
NRE-Sout	2021	80	Grch	10	10	Sparse (10 to <30%)	80	Very low (1 - 100)	0	Agarophyton chilense		0.5
NRE-Sout	2021	81	Grch	4	4	Very sparse (1 to <10%)	64	Very low (1 - 100)	0	Agarophyton chilense		2.5
NRE-Sout	2021	81	Grch	5	5	Very sparse (1 to <10%)	70	Very low (1 - 100)	0	Agarophyton chilense		16.7
NRE-Sout	2021	82	Grch	10	10	Sparse (10 to <30%)	80	Very low (1 - 100)	0	Agarophyton chilense		1.7
NRE-Sout	2021	82	Grch	10	10	Sparse (10 to <30%)	80	Very low (1 - 100)	0	Agarophyton chilense		1.0
NRE-Sout	2021	83	Grch	15	15	Sparse (10 to <30%)	100	Very low (1 - 100)	0	Agarophyton chilense		0.2
NRE-Sout	2021	83	Grch	15	15	Sparse (10 to <30%)	80	Very low (1 - 100)	0	Agarophyton chilense		0.1
NRE-Sout	2021	84	Grch Ulva Other	13 1 1	15	Sparse (10 to <30%)	80	Very low (1 - 100)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.3
NRE-Sout	2021	85	Grch	5	5	Very sparse (1 to <10%)	155	Low (101 - 200)	0	Agarophyton chilense		4.8
NRE-Sout	2021	86	Grch	15	15	Sparse (10 to <30%)	200	Low (101 - 200)	0	Agarophyton chilense		2.9
NRE-Sout	2021	86	Grch	10	10	Sparse (10 to <30%)	200	Low (101 - 200)	0	Agarophyton chilense		1.1
NRE-Sout	2021	87	Grch	35	35	Low-Moderate (30 to <50%)	240	Moderate (201 - 500)	0	Agarophyton chilense		0.1
NRE-Sout	2021	87	Grch	30	30	Low-Moderate (30 to <50%)	240	Moderate (201 - 500)	0	Agarophyton chilense		0.4
NRE-Sout	2021	87	Grch	30	30	Low-Moderate (30 to <50%)	128	Low (101 - 200)	0	Agarophyton chilense		7.4
NRE-Sout	2021	88	Grch	20	20	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	Agarophyton chilense		0.8
NRE-Sout	2021	88	Grch	20	20	Sparse (10 to <30%)	500	Moderate (201 - 500)	0	Agarophyton chilense		0.0
NRE-Sout	2021	89	Grch Ulva	5 50	55	High-Moderate (50 to <70%)	550	High (501 - 1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	1.5
NRE-Sout	2021	90	Grch	20	20	Sparse (10 to <30%)	1120	High (501 - 1450)	1	Agarophyton chilense		16.3
NRE-Sout	2021	90	Grch Ulva	25 5	30	Low-Moderate (30 to <50%)	1120	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	6.9
NRE-Sout	2021	90	Grch Ulva	13 2	15	Sparse (10 to <30%)	2000	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.4
NRE-Sout	2021	90	Grch	20	20	Sparse (10 to <30%)	2000	Very high (>1450)	1	Agarophyton chilense		0.1
NRE-Sout	2021	91	Grch	15	15	Sparse (10 to <30%)	240	Moderate (201 - 500)	1	Agarophyton chilense		9.5
NRE-Sout	2021	91	Grch	20	20	Sparse (10 to <30%)	200	Low (101 - 200)	1	Agarophyton chilense		0.7
NRE-Sout	2021	92	Grch Ulva	50 1	51	High-Moderate (50 to <70%)	1360	High (501 - 1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	4.4
NRE-Sout	2021	93	Grch	30	30	Low-Moderate (30 to <50%)	1360	High (501 - 1450)	1	Agarophyton chilense		7.7
NRE-Sout	2021	93	Grch Ulva	30 5	35	Low-Moderate (30 to <50%)	1760	Very high (>1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	0.6
NRE-Sout	2021	93	Grch Ulva	30 5	35	Low-Moderate (30 to <50%)	1280	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	14.0
NRE-Sout	2021	93	Grch Ulva	30 5	35	Low-Moderate (30 to <50%)	1280	High (501 - 1450)	1	Agarophyton chilense	Ulva (Sea lettuce)	14.0
NRE-Sout	2021	94	Ulva Grch	40 10	50	High-Moderate (50 to <70%)	1200	High (501 - 1450)	1	Ulva (Sea lettuce)	Agarophyton chilense	2.8
NRE-Sout	2021	95	Grch	100	100	Complete (>90%)	1000	High (501 - 1450)	1	Agarophyton chilense		0.5
NRE-Sout	2021	96	Grch	20	20	Sparse (10 to <30%)	800	High (501 - 1450)	1	Agarophyton chilense		0.2
NRE-Sout	2021	97	Grch Other Ulva	30 10 10	50	High-Moderate (50 to <70%)	650	High (501 - 1450)	0	Agarophyton chilense	Unspecified Macroalgae	2.5
NRE-Sout	2021	97	Ulva Grch	20 20	40	Low-Moderate (30 to <50%)	630	High (501 - 1450)	0	Ulva (Sea lettuce)	Agarophyton chilense	10.8
NRE-Sout	2021	98	Grch Ulva	35 15	50	High-Moderate (50 to <70%)	1160	High (501 - 1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	1.2
NRE-Sout	2021	98	Grch Ulva	40 40	80	Dense (70 to <90%)	800	High (501 - 1450)	0	Agarophyton chilense	Ulva (Sea lettuce)	1.1
NRE-Sout	2021	99	Grch Ulva	15 15	30	Low-Moderate (30 to <50%)	400	Moderate (201 - 500)	0	Agarophyton chilense	Ulva (Sea lettuce)	0.4
NRE-Sout	2021	99	Ulva Grch	15 15	30	Low-Moderate (30 to <50%)	400	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Agarophyton chilense	3.7
NRE-Sout	2021	100	Grch	50	50	High-Moderate (50 to <70%)	480	Moderate (201 - 500)	1	Agarophyton chilense		2.5

Appendix 4. Ground truthing in New River Estuary, February 2021



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