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Macroalgal and Seagrass Monitoring of Toetoes (Fortrose) Estuary

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for

Environment Southland

October 2020

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GLOSSARY

AA	Affected Area
AIH	Available Intertidal Habitat
aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ES	Environment Southland
ETI	Estuary Trophic Index
GEZ	Gross Eutrophic Zones
GIS	Geographic Information System
HEC	High Enrichment Conditions (eutrophic area)
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
SOE	State of the Environment (monitoring)

ACKNOWLEDGEMENTS

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BACKGROUND

As part of its State of the Environment programme, Environment Southland (ES) undertakes monitoring and assessment of estuaries and other coastal environments. Toetoes (Fortrose) Estuary has been identified by ES as a priority for monitoring, as nuisance macroalgal (seaweed) growths have previously been identified during broad scale habitat mapping and more targeted assessments. This report describes a survey of nuisance macroalgae and seagrass (a high value habitat) conducted in the estuary in February 2020, and compares findings with monitoring conducted in 2019 by Salt Ecology and in earlier surveys over 2003-2018. Results are discussed in terms of the current status and trends in estuary health, and recommendations for future monitoring and management are made.

KEY FINDINGS

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

- Seagrass is a minor feature of the estuary, but has been steadily declining since 2003. Further seagrass loss between 2019 and 2020 was attributed to smothering by fine sediment and macroalgal overgrowth.
- The latest survey revealed persistent beds of the opportunistic nuisance seaweed *Gracilaria chilensis* in the upper estuary, with nuisance beds of *Ulva* spp. covering a less extensive area and being more prominent on hard substrates along the northeast estuary margin.
- The main locations where high biomass *Gracilaria* beds formed eutrophic 'High Enrichment Conditions' (HECs), whereby extensive (>50% cover) growths are entrained into soft, anoxic mud-dominated sediments, are sheltered depositional zones in parts of the upper estuary (particularly in the northern arm). These HEC beds trap muddy sediments and build raised mounds 5-10cm high, and have been present since 2016.
- Erosion of the *Gracilaria* beds (and of mud deposits on the adjacent tidal flats) was apparent between 2019 and 2020, and is presumed to be attributable to flood flows in Titiroa Stream. In general, flood-related scouring of growths from the wider estuary is a probable explanation for a high level of temporal variability in macroalgal proliferation across all surveys.
- Overall, the entrained growths and localised persistence of the *Gracilaria* mounds since 2016 serve as clear indicators that the assimilative capacity of the estuary is being exceeded. This situation is consistent with NIWA's CLUES model, which estimates high nutrient loads for the estuary that exceed thresholds for nuisance growths. These high loads reflect the extensively modified nature of the catchment, of which more than half is in pasture.
- Despite the high nutrient loads and localised areas of eutrophication reflected by the HECs, the overall Environmental Quality Rating score was assessed as 'fair' according to the rating criteria. Macroalgal growth over much of the estuary is likely mitigated by strong flushing and wave action on the main intertidal flats.

Broad scale indicator	Unit	2016	2018	2019	2020
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	0.447	0.453	0.473	0.581
High Enrichment Conditions	Ha	7.19	7.18	4.92	3.29
Seagrass[2]	% decrease from baseline	75	86	87	90

[1] OMBT = Opportunistic Macroalgal Blooming Tool [2] Data for 2003 used as baseline for seagrass

Condition rating colour key:

Very Good	Good	Fair	Poor

RECOMMENDATIONS

Based on the 2020 survey and evaluation of trends since 2003, our recommendations are as follows:

- Given the persistent eutrophic areas indicated by areas expressing High Enrichment Conditions (HECs), continue periodic monitoring (e.g. annual or biennial) during summer to track long term changes.
- Given that HECs are likely a reflection of very high nutrient inputs, and associated inputs of muddy sediments, determine limits on mass loads that would be expected to mitigate effects, or at least prevent further degradation.
- 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.

1. INTRODUCTION

1.1 BACKGROUND

Monitoring the ecological condition of estuarine habitats is critical to their management. Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Environment Southland (ES) has undertaken monitoring of selected estuaries in the Southland region for over a decade. Much of the monitoring has been based on methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP, Robertson et al. 2002), or extensions of that approach.

The focus of monitoring efforts by ES has been on estuaries at risk from problems relating to catchment land use. Of particular concern are muddy sediment inputs that alter estuary habitats, and excessive nutrient loads that lead to symptoms of eutrophication such as excessive macroalgal (seaweed) growth. 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. These are typically referred to as 'opportunistic' species, of which the most significant in Southland are the red seaweed *Gracilaria chilensis* and the bright green *Ulva* spp. (often called 'sea lettuce').

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

Toetoes (Fortrose) Estuary (Fig. 1) is one of the key estuaries in ES's long term monitoring programme, as high nutrient inputs and nuisance macroalgal growths have previously been identified as key issues (e.g. Stevens 2018). Monitoring of macroalgal status has been conducted in the estuary on nine previous occasions, following an initial survey conducted in February 2003. The last of these was a broad scale survey of macroalgae and other habitats undertaken in 2018 (Stevens 2018).

Salt Ecology was contracted to carry out further assessments of macroalgal status in February 2019 and 2020, and to map changes in the small areas of seagrass previously described. This report details the latest survey, and compares findings with monitoring conducted in 2019 and in the earlier work (2003-2018) described by Stevens (2018). Results are discussed in terms of the current status and trends in estuary health, and recommendations for future monitoring and assessment are made.

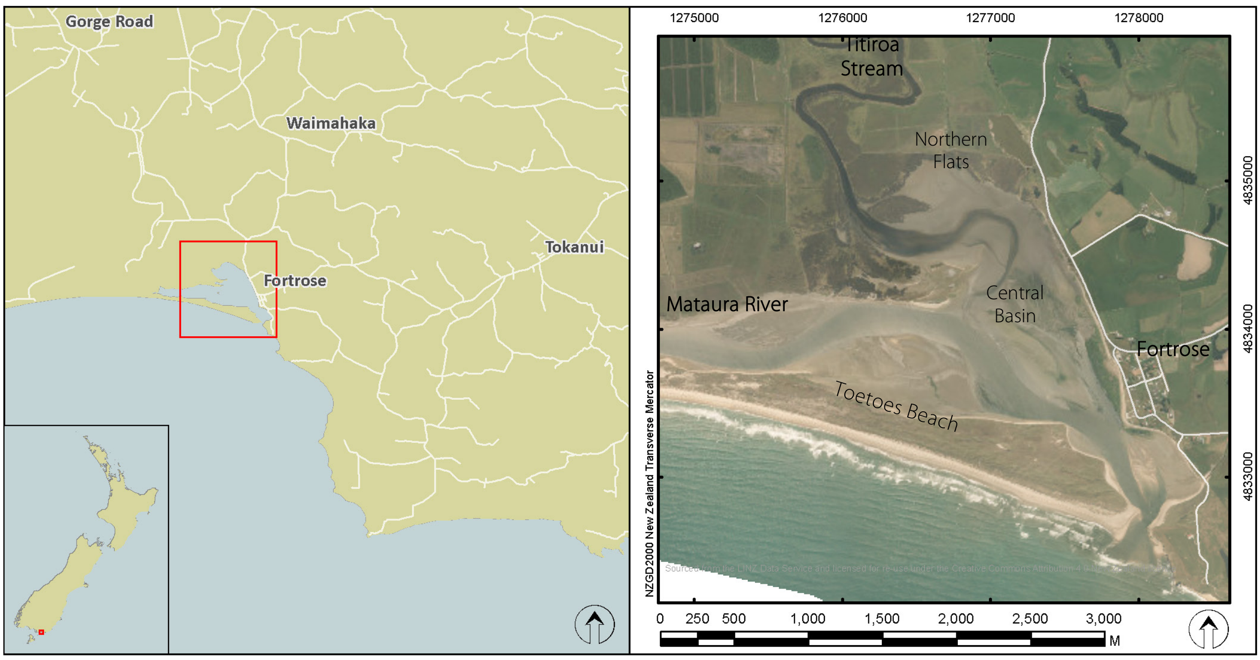

Fig. 1 Location of Toetoes (Fortrose) Estuary.

1.2 DESCRIPTION OF TOETOES (FORTROSE) ESTUARY

Toetoes (Fortrose) Estuary is situated at the mouth of the Mataura River and Titiroa Stream, and drains a large (~5,637km^2) catchment that is extensively modified. Catchment land use comprises 54% intensive pasture, 17% tall tussock grassland, 10% low producing pasture, 8% native forest, 4% scrub and 4% exotic forest. The 200m wide terrestrial margin was dominated by grassland (66%), with only 4% densely vegetated.

Stevens (2018) described Toetoes (Fortrose) as a relatively simple estuary with defined channels and a large central basin/lagoon that discharges to Toetoes Beach at Toetoes (Fortrose). It is defined as a shallow (mean depth ~2m) medium-sized (~500ha) short residence, tidal river type estuary (SSRTRE). It has a wide range of habitats including extensive intertidal flats. Only small patches of seagrass are present. In contrast, salt marsh is relatively extensive (~15% of intertidal area) but much of this habitat (~75%, 250ha) has been lost historically and the adjacent Fortrose wetland has also greatly diminished through reclamation, drainage and conversion to pasture. These changes have greatly reduced the estuary's ability to filter, dilute, and assimilate catchment nutrient and sediment inputs.

In addition to these historical changes, the estuary experiences degraded water quality (reduced clarity, elevated faecal coliforms, elevated nutrients) particularly in high river flows, with elevated nutrient inputs causing localised macroalgal blooms. The Mataura River catchment contributes high sediment and nutrient loads, however retention of these inputs in the estuary is limited by the relatively direct flow path of the river to the sea, with the intertidal flats of the central basin and eastern flats very well flushed and having few fine sediment accumulation zones.

The largest accumulation of fine sediment (and associated nutrients) is in the relatively sheltered northern flats near Titiroa Stream where nuisance macroalgal growths have been previously described. At the time of the 2018 survey, nuisance macroalgae (>50% cover) were described for 16ha (7%) of the intertidal area (excluding salt marsh), with the highest densities in sheltered embayments. Within these areas, 9ha (3%) of the estuary sediments were considered to be expressing symptoms of eutrophication (high nutrient enrichment). Extensive subtidal growths of macroalgae were also present throughout the estuary.

2. MONITORING METHODS

2.1 OVERVIEW OF MAPPING

Mapping was undertaken to delimit the spatial extent of macroalgae and seagrass. This procedure combined aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology.

Broad scale mapping of Toetoes (Fortrose) Estuary in 2019 and 2020 used colour satellite imagery (~0.05 - 0.07m/pixel resolution) supplied to Environment Southland by Apollo Mapping (Colorado). During field ground truthing, macroalgae and seagrass areas were drawn onto laminated aerial photographs and percent cover and biomass estimated or measured as described below. The 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, habitat maps were produced showing the spatial extent and density of macroalgae and seagrass.

Estuary boundaries for mapping purposes were based on the New Zealand Estuary Trophic Index (ETI; 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 the New Zealand coastal hydrosystems boundaries (Hume et al. 2016) developed in support of NIWA's CLUES estuary model.

2.2 MACROALGAE ASSESSMENT

The United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach was used for 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 overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

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

If an estuary supports <5% opportunistic macroalgal cover 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 Toetoes (Fortrose) Estuary, opportunistic macroalgae patches were mapped to the nearest 10% 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 depth of macroalgal entrainment were measured.

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

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-

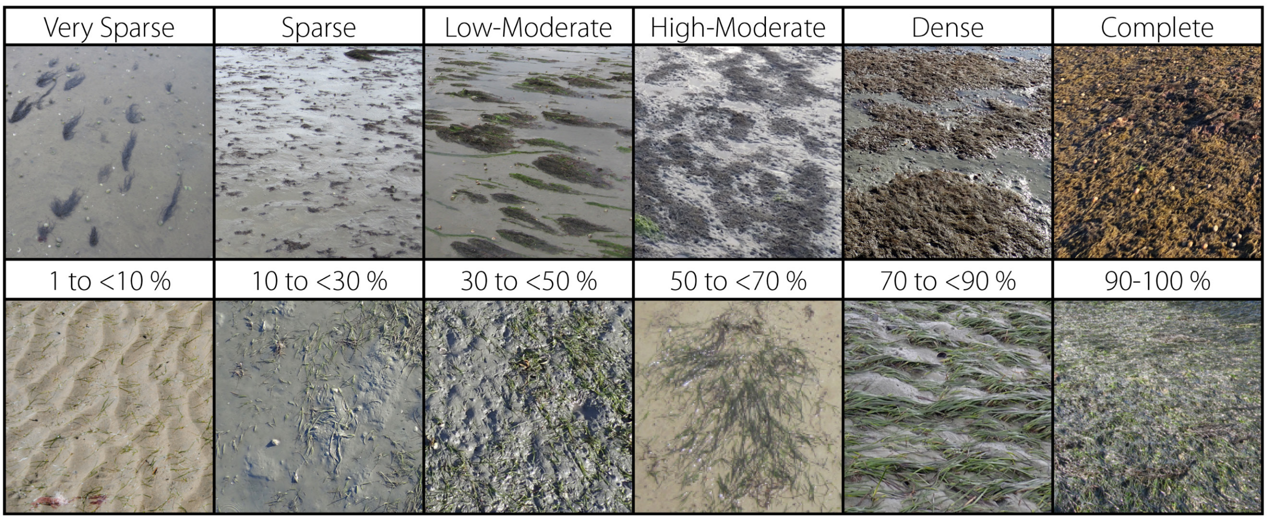

Fig. 2 Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

surface conditions accurately, the approach was intended as a preliminary screening tool to determine the need for additional sampling effort.

Above: sampling macroalgal biomass and rinsing sample bags

2.3 SEAGRASS ASSESSMENT

As for macroalgae, the percent cover of discrete seagrass patches was visually assessed to the nearest 10% during field ground truthing, based on the 6-category percent cover scale in Fig. 2.

2.4 DATA RECORDING AND QA/QC

Broad scale mapping was intended to provide a rapid overview of estuary macroalgae and seagrass condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial photos, the extent of ground truthing undertaken to validate features visible on photographs, and the experience of those undertaking the mapping. In most instances features with readily defined edges 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 for such features, and generally limited to features with a percent cover >50%.

In 2020, following digitising of habitat features, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables. Using these same tools, the earlier GIS layers were similarly checked for any errors in basic geometry (e.g. overlapping polygons), and updated to fix any identified issues.

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 (Appendix 3) 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.

Table 1. 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	0.0 - < 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, with adjustments for aRPD. 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.

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 NZ and overseas (Table 1). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 1. The condition ratings are primarily sourced from the NZ ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 4. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores (i.e. which range from 'high' to 'bad').

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HEC) was evaluated. HECs are referred to alternatively as 'Gross Eutrophic Zones' (GEZs) in the ETI (Zeldis et al. 2017). For our purposes HECs are defined as mud-dominated sediments (≥50% mud content, subjectively assessed) with >50% macroalgal cover and with macroalgae entrained (growing >30mm deep) within the sediment. These areas typically also have an aRPD depth shallower than 10mm due to sediment anoxia.

As many of the scoring categories in Table 1 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 2003 and 2020 used a threshold cover of >50%. A cover of <50% cannot be reliably distinguished from aerial photographs alone, and in the earliest surveys these features were only mapped when they were dominant or conspicuous, which we assume to equate to >50% cover. Also, note that sufficient data for calculation of OMBT scores have been collected only for the four surveys undertaken since 2016.

Dense *Gracilaria* on the northern shore around Titiroa Stream

Trace/sparse cover on the mobile sands of the lower central basin

3. RESULTS AND DISCUSSION

Data summaries are provided below and in the appendices. 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 2 summarises macroalgal percentage cover and biomass classes for the estuary in 2020, 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 4. Key results were as follows:

- Across 71.3% of the 243.1ha intertidal area macroalgae cover was classified as absent or trace (i.e. < 1% cover), and classified as 'very sparse' (1-<10%) across a further 20.9% of the mapped area.
- Macroalgae cover was conspicuous (≥10% cover) across only 7.9% of the intertidal, primarily consisting of *Gracilaria* and small patches of *Ulva*.
- *Gracilaria* was most extensive (>70% cover) in sheltered areas among salt marsh around Titiroa Stream, with lesser patches adjacent to salt marsh along the northern margin and in parts of the southern side.
- *Gracilaria* biomass in this highest cover area ranged from high (1-3kg/m^2) to very high (>3kg/m^2), and consisted of mounds of *Gracilaria* (5-10cm high) deeply entrained in muddy sediment around the mouth of Titiroa Stream. The maximum biomass recorded was ~33kg/m^2, 10 times higher than the 'very high' threshold.
- The green seaweed *Ulva* covers a less extensive area of the estuary, and is more prominent in areas where there are hard substrates (e.g. cobbles) for its attachment.
- Between Feb 2019 and Feb 2020 there was considerable erosion of surface mud and *Gracilaria*, as well as burial of *Gracilaria* with eroded sediment around Titiroa Stream. Prior to Feb 2020 sampling there was a significant (1 in 50 year) flood event in the Mataura River and Titiroa stream.

Flood scoured *Gracilaria* along the banks of Titiroa Stream

Table 2. Summary of intertidal macroalgal cover (A) and biomass (B), Toetoes (Fortrose) Estuary February 2020.

A. Cover

Percent cover category	Ha	%
Absent or trace	173.3	71.3
Very sparse (1 to <10%)	50.7	20.9
Sparse (10 to <30%)	8.4	3.5
Low-Moderate (30 to <50%)	0.8	0.3
High-Moderate (50 to <70%)	1.7	0.7
Dense (70 to >90%)	1.9	0.8
Complete (>90%)	6.3	2.6
Total	243.1	100

B. Biomass

Biomass category (g/m^2)	Ha	%
Trace (<1)	173.3	71.4
Very low (1 - 100)	51.7	21.3
Low (101 - 500)	7.0	2.9
High (1001 - 3000)	4.8	2.0
Very high (>3000)	6.1	2.5
Total	242.9	100

Gracilaria was most prolific in the upper estuary on the northern shore around Titiroa Stream

Eroding patch of *Gracilaria* adjacent to northern shore salt marsh in 2020. In 2019 *Gracilaria* completely covered this area.

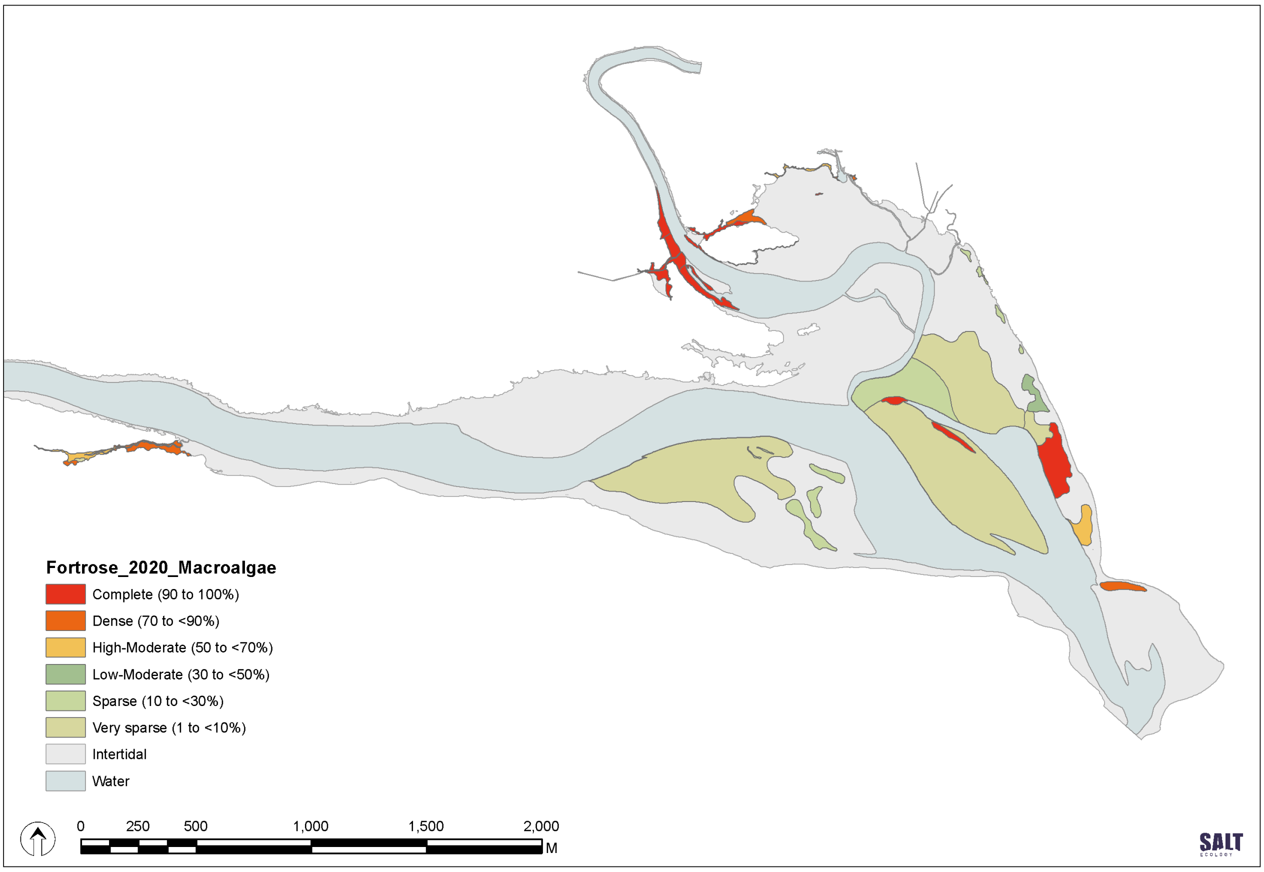

Fig. 3 Distribution and percentage cover classes of macroalgae, Fortrose Estuary February 2020.

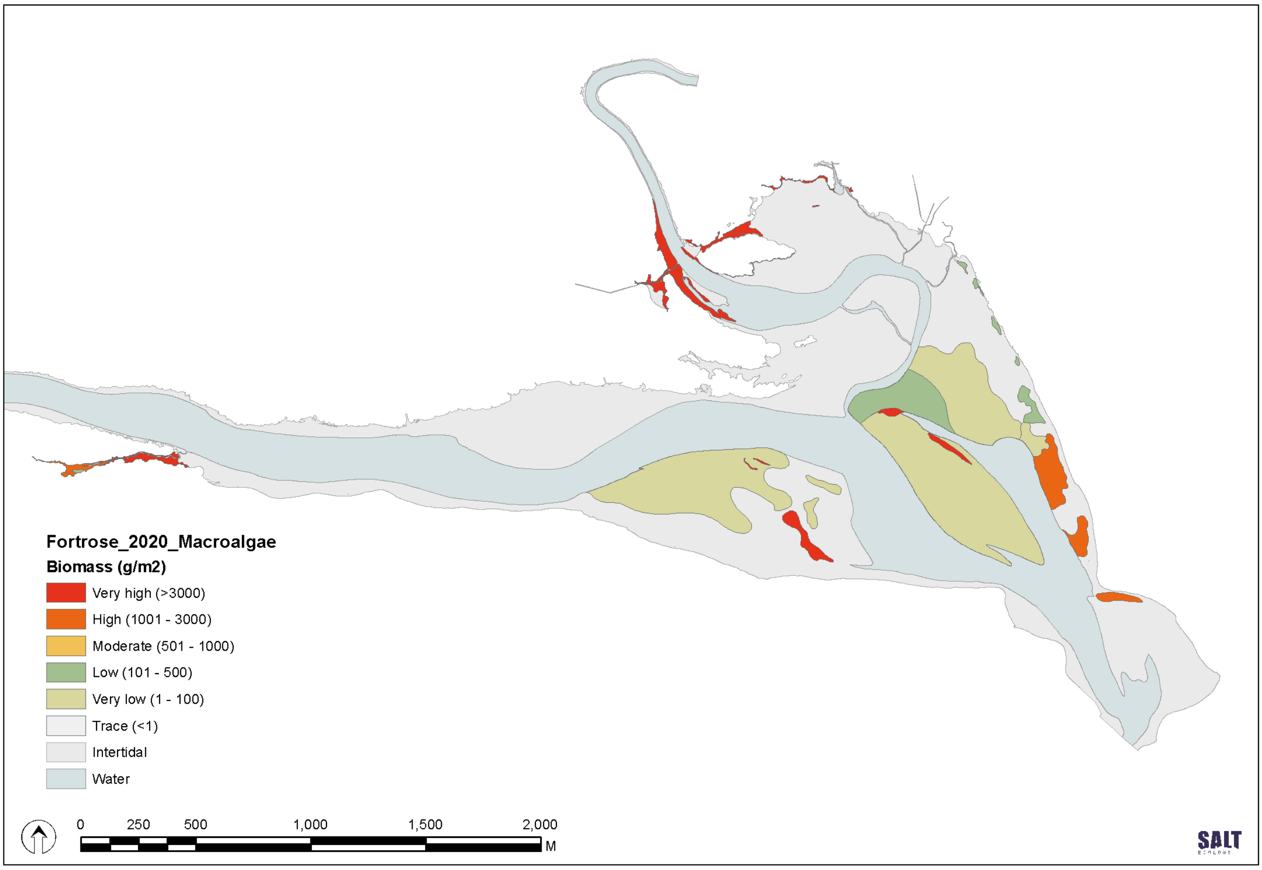

Fig. 4 Biomass (wet weight g/m^2) classes of macroalgae, Fortrose Estuary February 2020.

Eroding substrate along the northern shore near Titiroa Stream had the appearance of a ploughed paddock. All deposits of soft surface muds and nuisance macroalgae had been washed away leaving hard muds and sands.

A 70mm layer of sediment relatively recently deposited on top of *Gracilaria* near Titiroa Stream

Fig. 5 shows the temporal change in macroalgal cover since 2003. Results indicate a marked inter-annual variability despite the surveys typically having been undertaken in February. Comparing the total area having a cover ≥50% (i.e. the most reliable threshold for assessing change with the data available; see Methods) it is apparent that macroalgae proliferation in 2020 (9.8ha of >50% cover) was less than half that recorded in some of the previous surveys (e.g. range of 20-30ha in 2010, 2013 and 2019). Nonetheless, the *Gracilaria* beds in the upper estuary areas are in the same location as previously and are clearly persistent despite the extensive erosion that was evident in 2020, post-flood.

The OMBT input metrics and overall macroalgal EQR for four surveys from 2016 to 2020 are provided in Table 3. The EQR calculated using the OMBT method was 0.71 in 2020, which is an improvement on the scores from previous surveys (Fig. 6), although in all cases the values are rated as 'fair' according to the OMBT criteria (see Appendix 1). The 2020 results reflect improved scores for the individual input metrics that make up the overall EQR. Nonetheless, the biomass per m^2 of the Affected Area has a 'poor' rating in 2020, indicating that the estuary is expressing significant local symptoms of eutrophication.

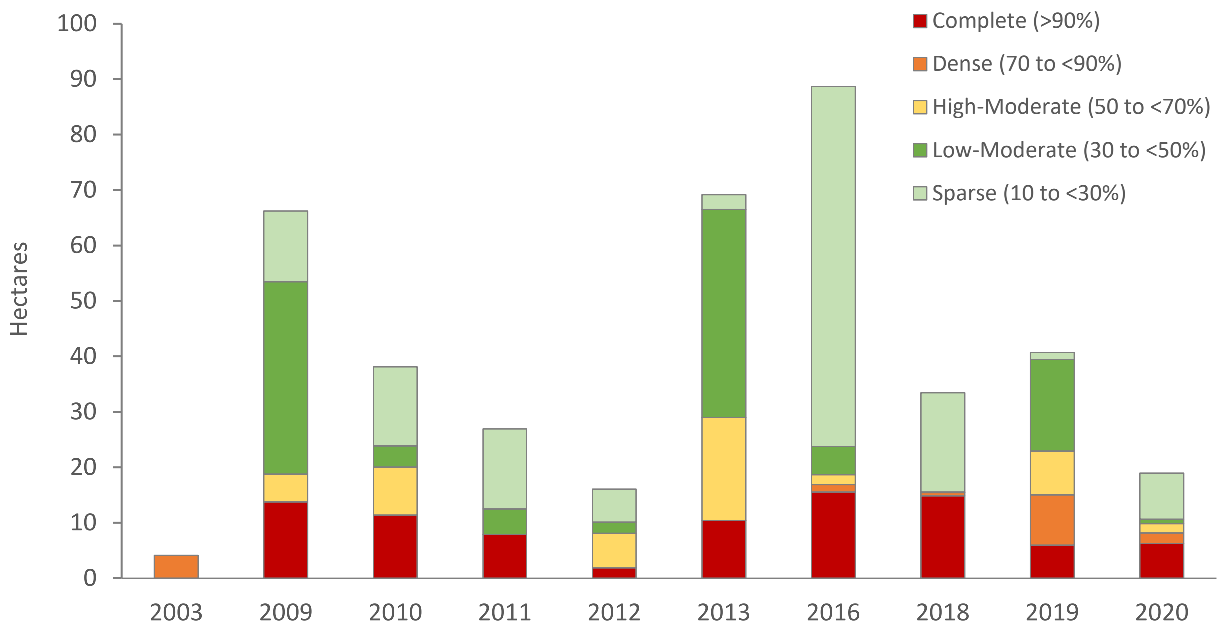

Fig. 5 Temporal change in macroalgal %cover, Fortrose Estuary 2003-2020. Although all cover classes are shown, a threshold of >50% is the most reliable indicator of temporal change (see text).

Table 3. Summary of OMBT input metrics and calculation of overall macroalgal ecological quality rating, Fortrose Estuary February 2020.

2020 Metric	Face Value	FEDS	Environmental Quality Status
%cover in AIH	4.5	0.820	High
Biomass per m^2 AIH	196.0	0.608	Good
Biomass per m^2 AA	683.7	0.361	Poor
%entrained in AA	5.4	0.594	Moderate
Worst of AA (ha) and AA (% of AIH)		0.521	Moderate
AA (ha)	69.7	0.521	Moderate
AA (% of AIH)	28.7	0.522	Moderate
Survey EQR		0.581	Moderate

2019 Metric	Face Value	FEDS	Environmental Quality Status
%cover in AIH	7.2	0.757	Good
Biomass per m^2 AIH	545.8	0.390	Poor
Biomass per m^2 AA	3260.5	0.173	Bad
%entrained in AA	15.8	0.456	Moderate
Worst of AA (ha) and AA (% of AIH)		0.590	Moderate
AA (ha)	40.7	0.647	Good
AA (% of AIH)	16.7	0.590	Moderate
Survey EQR		0.473	Moderate

2018 Metric	Face Value	FEDS	Environmental Quality Status
%cover in AIH	7.1	0.758	Good
Biomass per m^2 AIH	572.4	0.385	Poor
Biomass per m^2 AA	4154.9	0.160	Bad
%entrained in AA	29.3	0.338	Poor
Worst of AA (ha) and AA (% of AIH)		0.624	Good
AA (ha)	33.5	0.683	Good
AA (% of AIH)	13.8	0.624	Good
Survey EQR		0.453	Moderate

2016 Metric	Face Value	FEDS	Environmental Quality Status
%cover in AIH	14.0	0.621	Good
Biomass per m^2 AIH	487.1	0.409	Moderate
Biomass per m^2 AA	709.1	0.356	Poor
%entrained in AA	5.1	0.599	Moderate
Worst of AA (ha) and AA (% of AIH)		0.250	Poor
AA (ha)	166.9	0.311	Poor
AA (% of AIH)	68.7	0.250	Poor
Survey EQR		0.447	Moderate

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

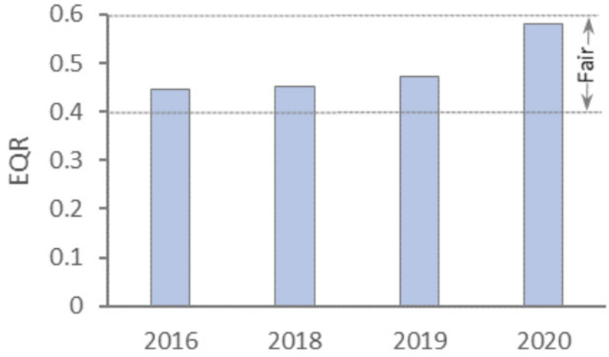

Fig. 6 Macroalgal OMBT Ecological Quality Rating (EQR) scores, Toetoes (Fortrose) Estuary 2016-2020. The OMBT method assigns EQR scores in the band from 0.4 to 0.6 as 'fair'.

Extensive mound of entrained *Gracilaria* in the upper estuary northern arm in 2019

Patch of *Ulva* along the mid estuary northeast shore

Areas classified as expressing high enrichment conditions (HECs) were absent at the time of the 2003 and 2013 surveys. They were first described in 2016 following the establishment of mounds of entrained *Gracilaria* in which mud-dominated and reasonably anoxic sediments were present.

The estuary intertidal area affected in 2016 was just over 7ha, with a similar HEC extent described in 2018 (Table 4). Subsequently the HEC area has reduced by about half. The reduction from 2019 to 2020 is attributable to the erosion of the high biomass beds as described earlier as a consequence of flood scouring.

Although macroalgal proliferation was extensive in some of the surveys prior to 2016, degraded conditions meeting HEC criteria were not present in the underlying sediments.

Table 4. Summary of area classified as expressing High Enrichment Conditions, Toetoes (Fortrose) Estuary 2003-2020.

Year	Ha
2003	0
2013	0
2016	7.19
2018	7.18
2019	4.92
2020	3.29

Example of High Enrichment Conditions (HECs): muddy, enriched and anoxic sediment beneath entrained *Gracilaria*.

3.2 SEAGRASS

Intertidal seagrass (*Zostera muelleri*) cover in 2020 was very low, with a total area of 0.13ha comprising only a few small high density patches of >70% cover (Fig. 7). Based on a cover threshold of >50%, the maximum area recorded in previous surveys was 1.26ha in 2003. The estuary supports a relatively small total seagrass area compared to many other estuaries, and there has been a steady decline at Toetoes (Fortrose) estuary from 2003-2020 (Table 5). The most recent reduction by 381m^2 from 2019 to 2020 reflects a loss of cover in the northern arm due to macroalgal and fine sediment smothering.

Only a few small patches of seagrass (*Zostera muelleri*) remain in the estuary, with this area being on the southern side in 2020.

Table 5. Summary of area of seagrass >50% cover, Toetoes (Fortrose) Estuary 2003-2020.

Year	Ha	Change (ha)	% Reduction
2003*	1.26	na	na
2013	0.49	-0.77	61
2016	0.31	-0.95	75
2018	0.18	-1.08	86
2019	0.16	-1.10	87
2020	0.13	-1.13	90

* 2003 figure revised from original survey based on correction of error identified during QA undertaken in 2020 (large seagrass bed in the northern arm mistakenly mapped as macroalgae)

Small seagrass patches in the east of the estuary near the main road

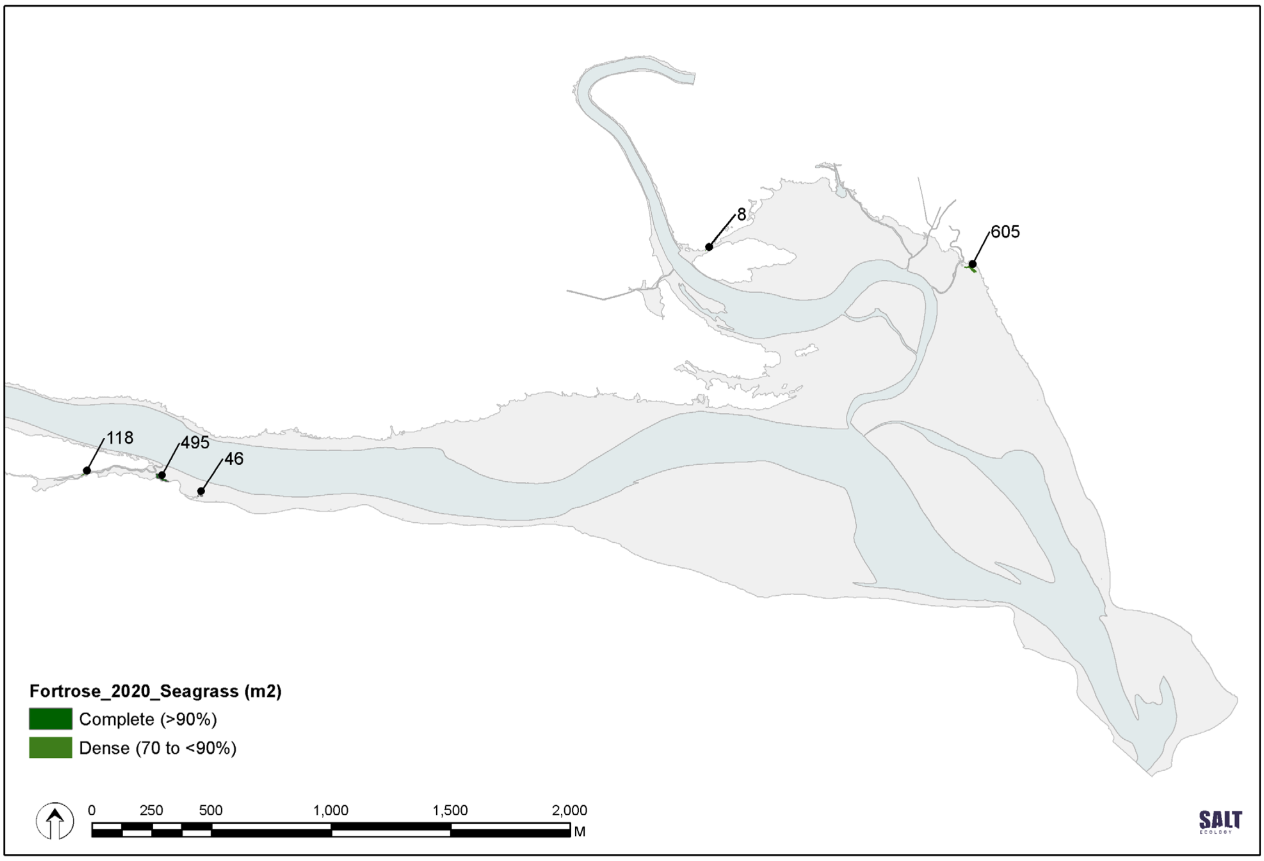

Fig. 6 Distribution of seagrass, Fortrose Estuary February 2020. Patch sizes are too small for percentage cover classes to show on the map. Numbers show patch area in m^2.

4. SYNTHESIS AND RECOMMENDATIONS

4.1 Synthesis of key findings

This report has described a broad scale macroalgae and seagrass survey of Toetoes (Fortrose) Estuary in 2020 and, to the extent enabled by available data, compared findings with earlier surveys conducted since 2003.

Seagrass is a minor feature of the estuary, but has been steadily declining since 2003. The latest seagrass loss from 2019 and 2020 was attributed to smothering by fine sediment and macroalgal overgrowth. The 2020 survey revealed persistent *Gracilaria* beds in the upper estuary, with *Ulva* beds covering a less extensive area and being more prominent on hard substrates along the northeast estuary margin.

The main locations where high biomass *Gracilaria* beds meet the definition of HECs are sheltered depositional zones in parts of the upper estuary, and particularly in the northern arm. These beds trap fine muddy sediments and build raised mounds 5-10cm high. Erosion of these beds (and of mud deposits on the adjacent tidal flats) was apparent between 2019 and 2020, and is presumed to be attributable to flood flows. Stevens (2018) similarly suggested that flood-related scouring of growths from the wider estuary was a probable explanation for temporal variability in earlier years. Nonetheless, the entrained conditions and localised persistence of the mounds since 2016 serve as clear indicators that the assimilative capacity of the estuary is being exceeded. This situation is consistent with NIWA's CLUES model estimates presented in Stevens (2018), which revealed very high nutrient loads to the estuary (1700mgN/m^2/d). This mass load is well above the threshold where nuisance growths are expected in intertidally-dominated estuaries (>100mgN/m^2/d), and within the 500-2000mgN/m^2/d range where nuisance growths are observed in SSRTREs (i.e. such as Toetoes (Fortrose) estuary) elsewhere in New Zealand (Stevens 2018). These high loads, while likely underestimating point source inputs, reflect the extensively modified nature of the catchment, of which more than half is in pasture (see Section 1.2). The loads are clearly well above natural inputs and highlight there are sufficient nutrients to fuel nuisance opportunistic algal growth in the estuary.

However, despite these high nutrient loads and localised areas of eutrophication reflected by the HECs, the overall EQR score was rated as 'fair' according to both the OMBT (see Appendix 1) and ETI (see Table 1) criteria, respectively. Macroalgal growth over much of the estuary is likely to be mitigated by strong flushing and wave action on the main intertidal flats. Stevens (2018) suggested that widespread microalgae growth on the surface of these sediments in 2018 provided further evidence that nutrient concentrations in the estuary were elevated and unlikely to be limiting with regards to macroalgal growth. Rather, physical conditions, e.g. flood scouring and uprooting by wave action, were more likely to be preventing the establishment of persistent nuisance macroalgal growths in the main basin of the estuary.

Stevens (2018) described two related issues in the estuary that were also evident in 2019 and 2020, namely: (ii) Prolific growths of *Gracilaria* and *Ulva* in sheltered shallow subtidal areas; and (ii) Significant deposits of rotting beach-cast algae in some areas. Beach cast material, deposited by wind and water current action from other parts of the estuary, can have a significant impact on sediment quality through creation of anoxic conditions when it decays.

Table 6. Summary of condition rating scores over the last four surveys based on the key indicators and criteria in Table 1. High Enrichment Conditions were absent before 2016.

Broad scale indicator	Unit	2016	2018	2019	2020
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	0.447	0.453	0.473	0.581
High Enrichment Conditions	Ha	7.19	7.18	4.92	3.29
Seagrass[2]	% decrease from baseline	75	86	87	90

[1] OMBT = Opportunistic Macroalgal Blooming Tool [2] Data for 2003 used as baseline for seagrass

Condition rating colour key:

Very Good	Good	Fair	Poor

4.2 Recommendations

Toetoes (Fortrose) Estuary has been identified by ES as a priority for monitoring, and is a key part of the monitoring programme being undertaken throughout the region. Based on the 2020 survey and evaluation of trends since 2003, our recommendations are as follows:

- Given the persistent eutrophic state indicated by areas expressing High Enrichment Conditions (HECs), continue periodic monitoring (e.g. annual or biennial) during summer to track long term changes.
- Given that HECs are likely a reflection of very high nutrient inputs, and associated inputs of muddy sediments, determine limits on mass loads that would be expected to mitigate effects, or at least prevent further degradation.
- 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.

Upper estuary small marsh (Top). Sandy flats of the lower estuary (Below).

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APPENDICES

APPENDIX 1. OPPORTUNTISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multimetric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5-part multimetric OMBT, modified for NZ estuary types, is fully described below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of *mud, muddy sand, sandy mud, sand, stony mud and mussel beds.* Areas which are judged unsuitable for algal blooms e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. Percentage cover of the available intertidal habitat (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH, %).

In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric established is the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse-case scenario.

3. Biomass of AIH (g.m-^{2}).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within ±5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. Biomass of AA (g.m-^{2}).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. Presence of Entrained Algae (% of quadrats).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool. All the metrics are equally weighted and combined within the multimetric, in order to best describe the changes in the nature and degree of opportunist macroalgae growth on sedimentary shores due to nutrient pressure.

Timing

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

Suitable Locations

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

Derivation of Threshold Values

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

Reference Thresholds

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

Class Thresholds for Percent Cover

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

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

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

Class Thresholds for Biomass

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

Thresholds for Entrained Algae

Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of

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

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

potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.
Each metric in the OMBT has equal weighting and is combined to produce the ecological quality rating score (EQR).

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.

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

Metric	Quality status	Face value ranges			Equidistant class range values		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.99	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.99	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.9	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.9	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.99	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.99	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.9	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.9	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.99	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.9	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

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

APPENDIX 2. INFORMATION SUPPORTING RATINGS IN 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, becomes released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

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

Opportunistic Macroalgae

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

Seagrass

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

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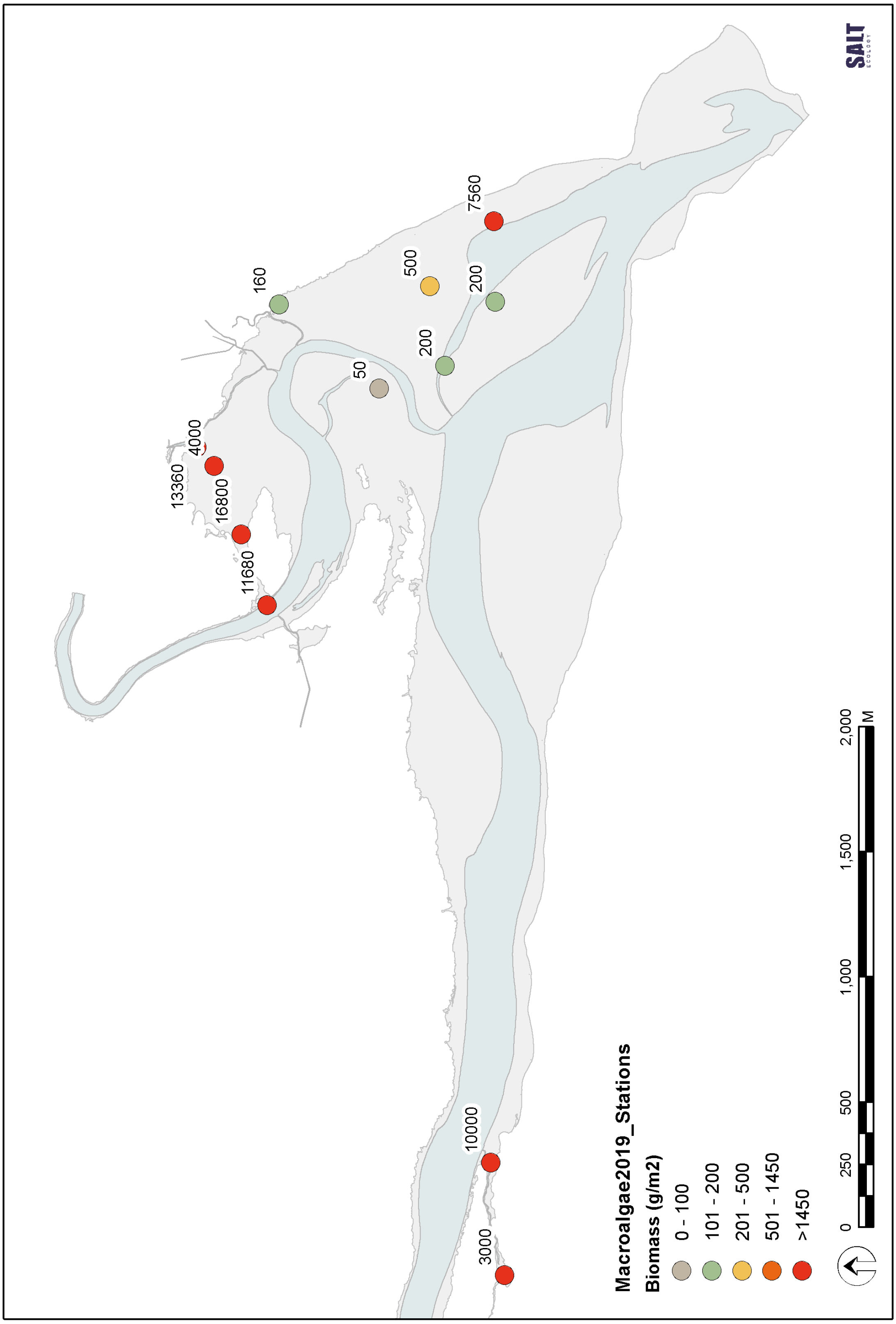
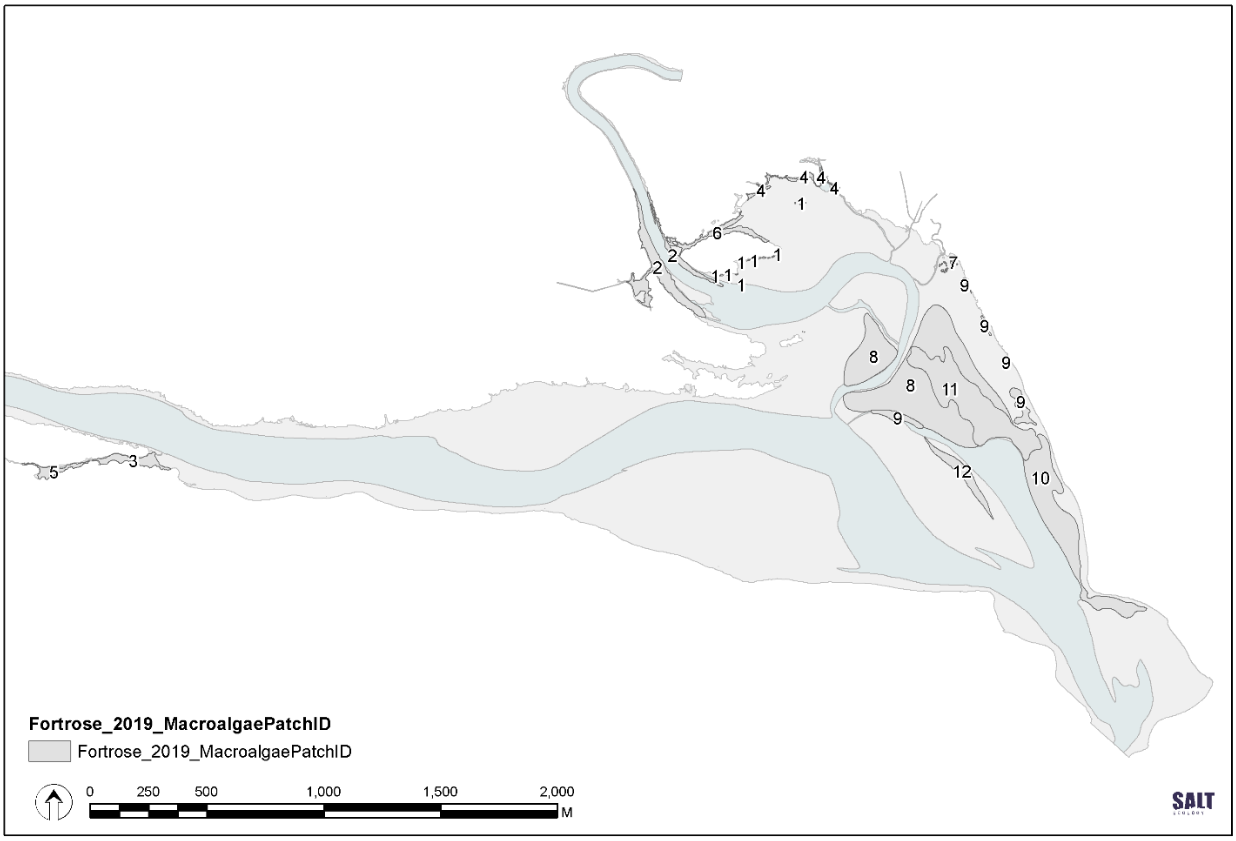
Zeldis J, Whitehead A, Plew D, Madarasz-Smith, A, Oliver M, Stevens L, Robertson B, Storey R, Burge O, Dudley B. 2017. The New Zealand Estuary Trophic Index (ETI) Tools: Tool 2 - Assessing Estuary Trophic State using Measured Trophic Indicators. Ministry of Business, Innovation and Employment Envirolink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

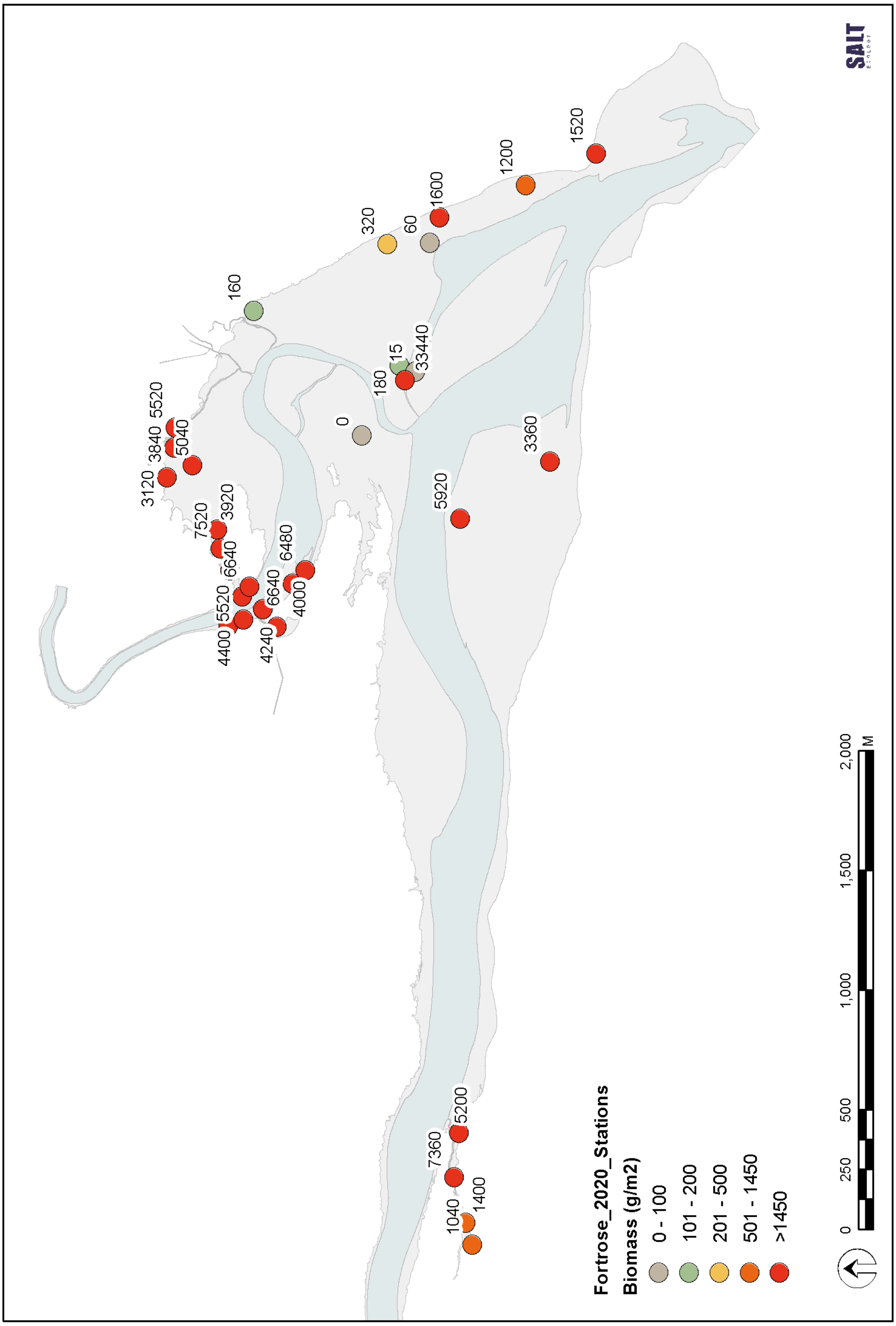
APPENDIX 3. 2019 AND 2020 MACROALGAL BIOMASS SAMPLING STATIONS, PATCH LOCATIONS AND MEASURED DATA



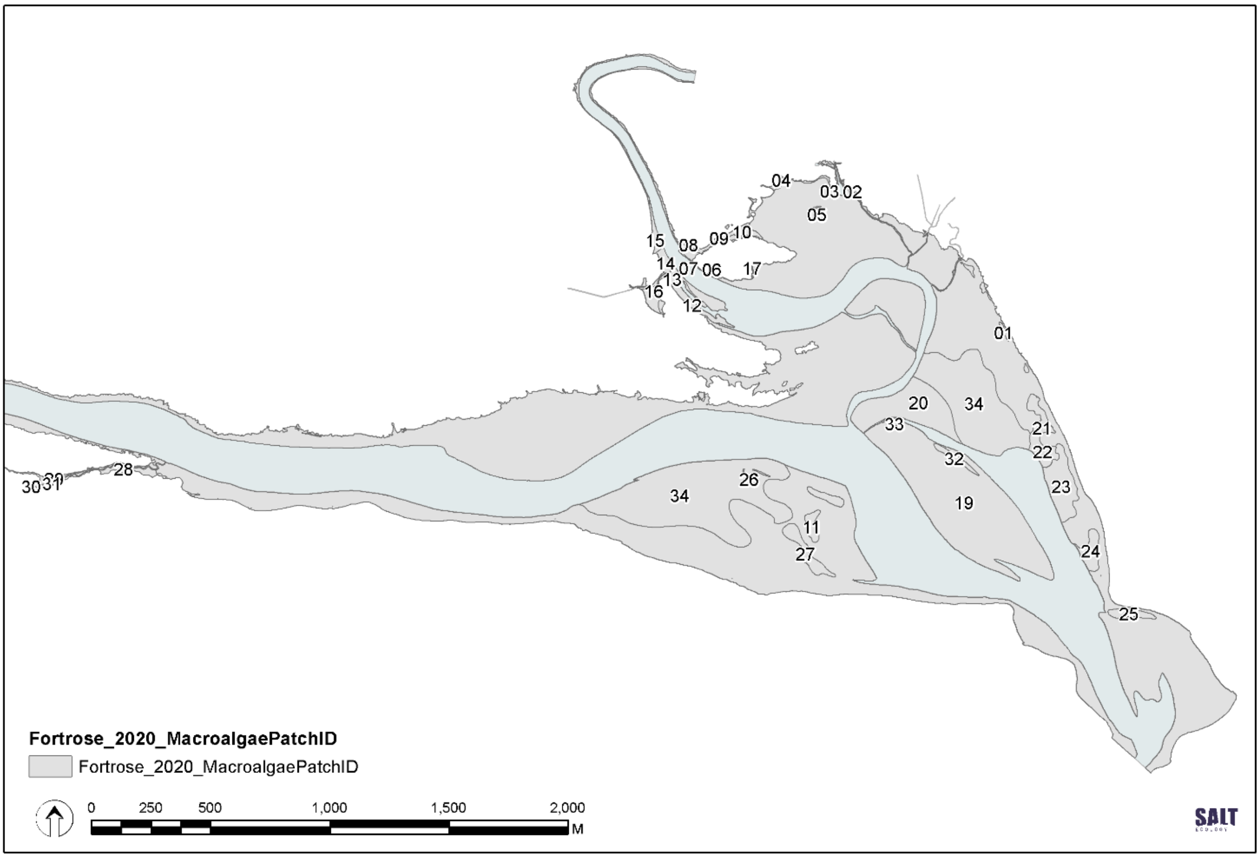
2019 Biomass stations and macroalgal wet weight (g/m^2)



PatchID	Pct_Cover	TotPctCov	PctCovrClass	Biomassgm2	BiomassClass	Entrained	DomSpp	SubDomSpp	Area_ha	FieldCode
1	100	100	Complete (>90%)	4000	Very high (>3000)	1	Gracilaria chilensis		0.1	Grch
2	100	100	Complete (>90%)	11680	Very high (>3000)	1	Gracilaria chilensis		3.4	Grch
3	100	100	Complete (>90%)	10000	Very high (>3000)	1	Gracilaria chilensis		0.9	Grch
4	80	80	Dense (70 to <90%)	13360	Very high (>3000)	1	Gracilaria chilensis		0.5	Grch
5	90	90	Complete (>90%)	3000	High (1001 - 3000)	1	Gracilaria chilensis		0.5	Grch
6	90 10	100	Complete (>90%)	16800	Very high (>3000)	1	Gracilaria chilensis	Ulva sp (Sea lettuce)	1.0	Grch Ulsp
7	10	10	Sparse (10 to <30%)	10	Very low (1 - 100)	0	Ulva sp (Sea lettuce)		0.03	Ulsp
8	5	5	Very sparse (1 to <10%)	50	Very low (1 - 100)	0	Ulva sp (Sea lettuce)		16.5	Ulsp
9	80	80	Dense (70 to <90%)	180	Low (101 - 500)	0	Ulva sp (Sea lettuce)		1.6	Ulsp
10	80	80	Dense (70 to <90%)	7560	Very high (>3000)	0	Ulva sp (Sea lettuce)		7.0	Ulsp
11	15 15	30	Low-Moderate (30 to <50%)	500	Low (101 - 500)	0	Ulva sp (Sea lettuce)	Gracilaria chilensis	7.9	Ulsp Grch
12	8 2	10	Sparse (10 to <30%)	200	Low (101 - 500)	0	Ulva sp (Sea lettuce)	Gracilaria chilensis	1.3	Ulsp Grch

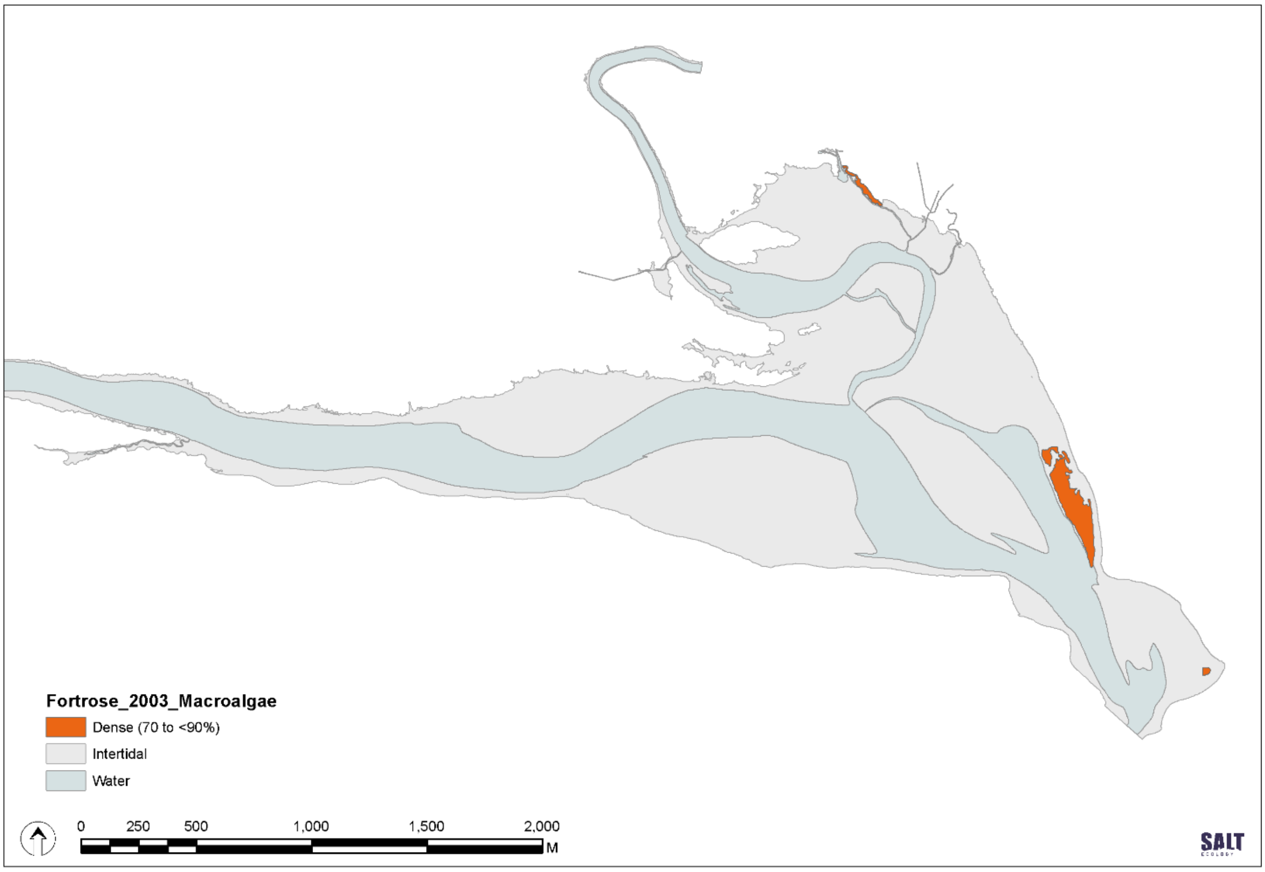


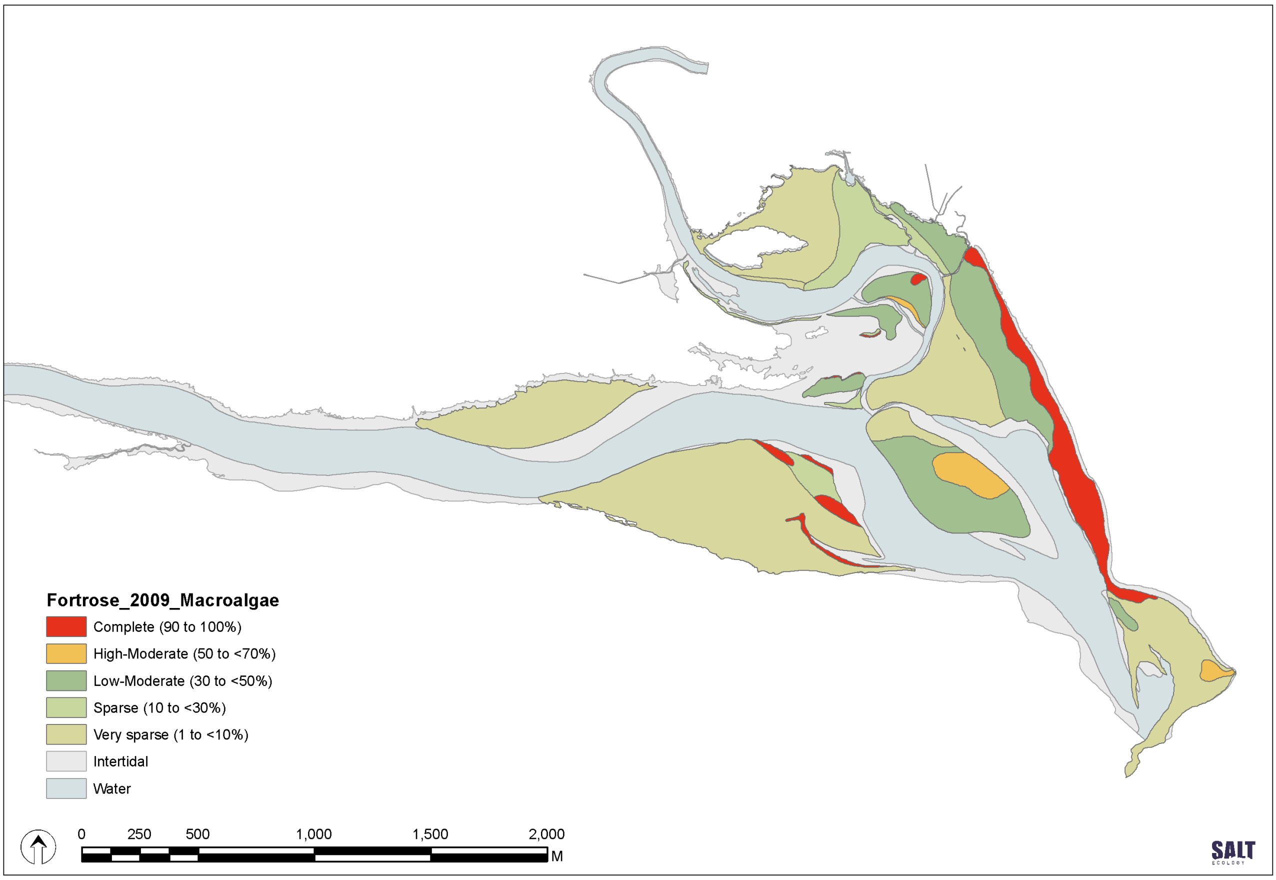
2020 Biomass stations and macroalgal wet weight (g/m²)

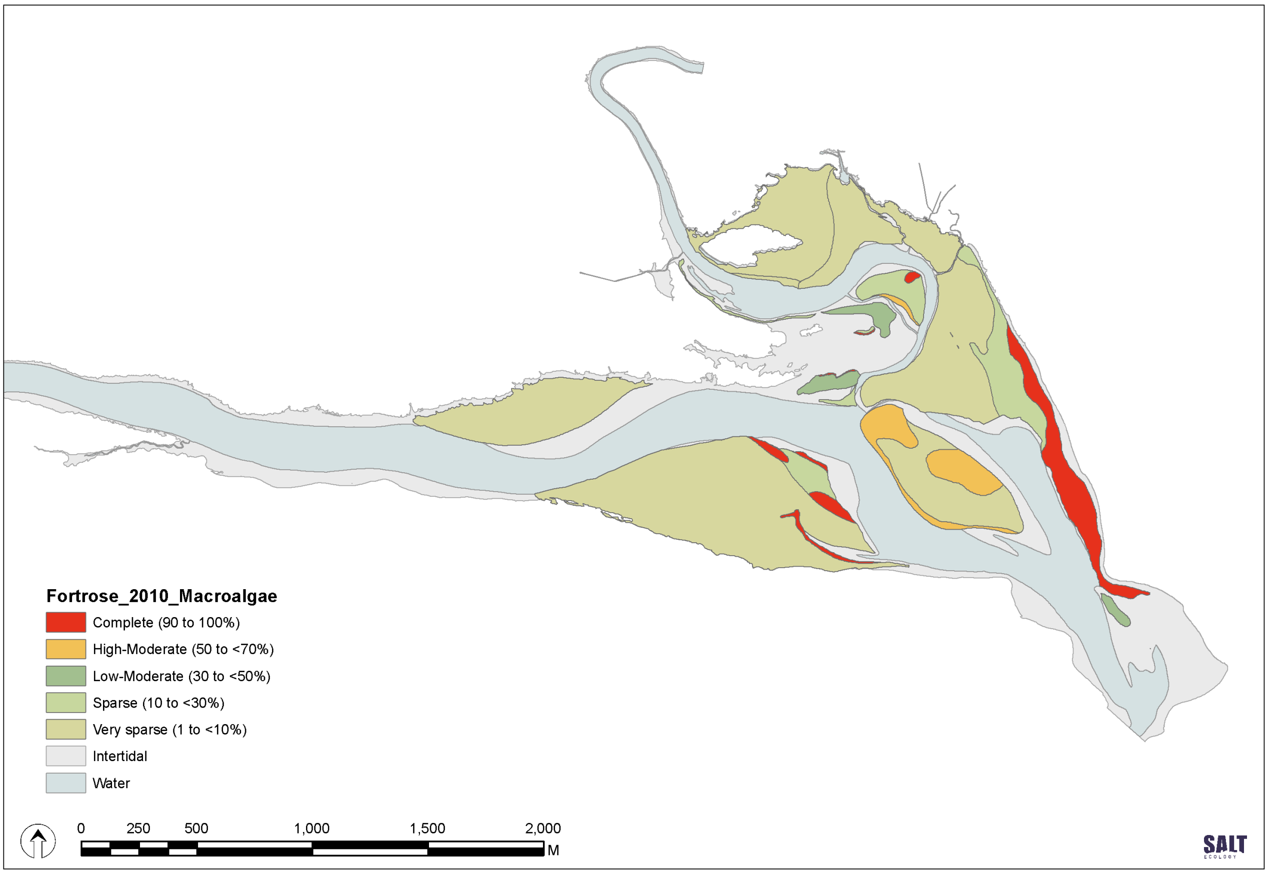


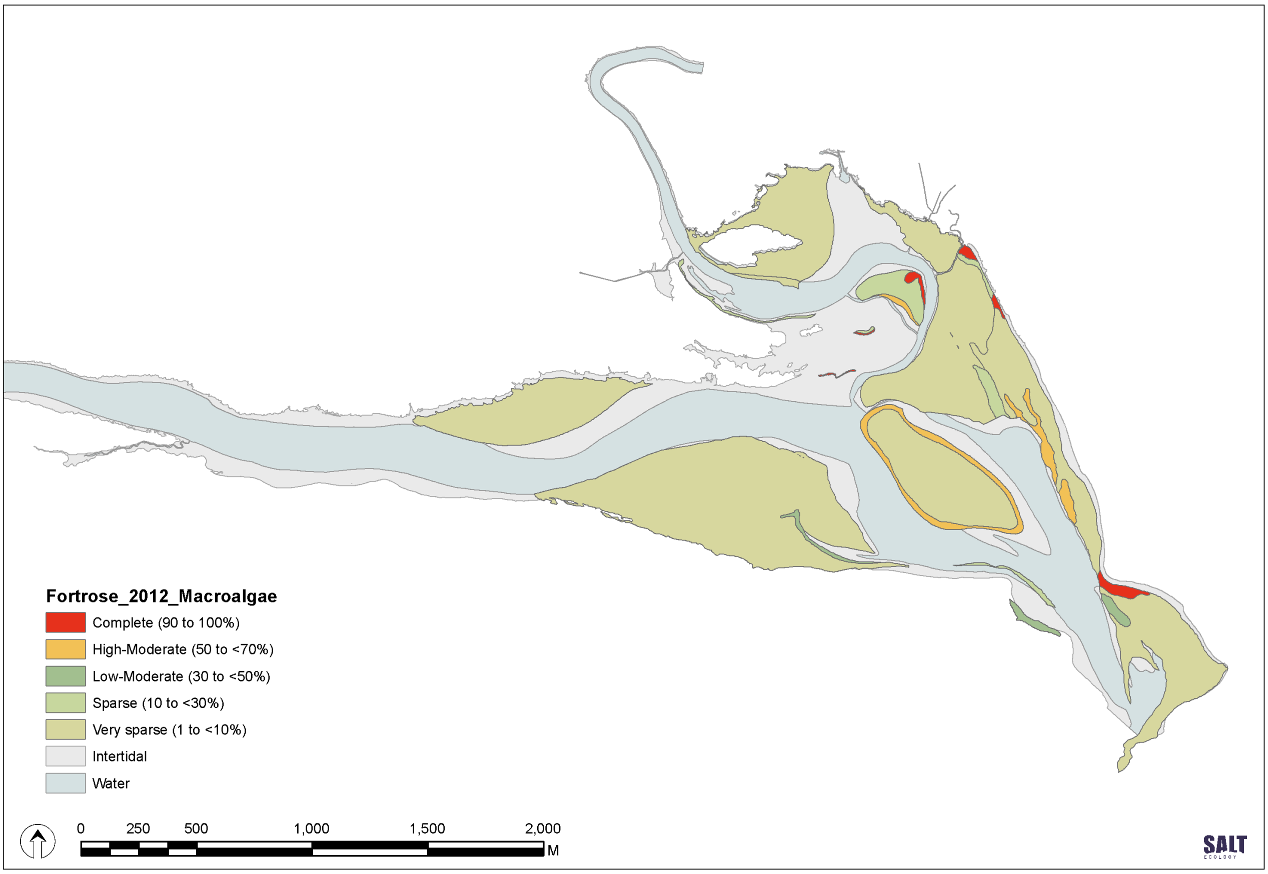
PatchID	Pct_Cover	TotPctCov	PctCovrClass	Biomassgm2	BiomassClass	Entrained	DomSpp	SubDomSpp	Area_ha	FieldCode
01	9 1	10	Sparse (10 to <30%)	160	Low (101 - 500)	0	Ulva (Sea lettuce)	Gracilaria chilensis	0.4	Ulva Grch
02	80	80	Dense (70 to <90%)	5520	Very high (>3000)	1	Gracilaria chilensis		0.0	Grch
03	80	80	Dense (70 to <90%)	3840	Very high (>3000)	1	Gracilaria chilensis		0.0	Grch
04	50	50	Moderate (30 to <70%)	3120	Very high (>3000)	1	Gracilaria chilensis		0.2	Grch
05	100	100	Complete (>90%)	5040	Very high (>3000)	1	Gracilaria chilensis		0.0	Grch
10	75 5	80	Dense (70 to <90%)	3920	Very high (>3000)	1	Gracilaria chilensis	Ulva (Sea lettuce)	0.5	Grch Ulva
09	60 40	100	Complete (>90%)	7520	Very high (>3000)	1	Gracilaria chilensis	Ulva (Sea lettuce)	0.1	Grch Ulva
06	100	100	Complete (>90%)	6640	Very high (>3000)	1	Gracilaria chilensis		0.0	Grch
07	100	100	Complete (>90%)	5520	Very high (>3000)	1	Gracilaria chilensis		0.0	Grch
08	100	100	Complete (>90%)	4800	Very high (>3000)	1	Gracilaria chilensis		0.2	Grch
12	100	100	Complete (>90%)	6560	Very high (>3000)	1	Gracilaria chilensis		0.9	Grch
13	95 5	100	Complete (>90%)	4240	Very high (>3000)	1	Gracilaria chilensis	Ulva (Sea lettuce)	0.3	Grch Ulva
14	100	100	Complete (>90%)	4400	Very high (>3000)	1	Gracilaria chilensis		0.4	Grch
16	99 1	100	Complete (>90%)	4000	Very high (>3000)	0	Gracilaria chilensis	Ulva (Sea lettuce)	0.5	Grch Ulva
15	100	100	Complete (>90%)	5360	Very high (>3000)	0	Gracilaria chilensis		0.4	Grch
17	50	50	Moderate (30 to <70%)	5000	Very high (>3000)	1	Gracilaria chilensis		0.0	Grch
19	2	2	Very sparse (1 to <10%)	15	Very low (1 - 100)	0	Ulva (Sea lettuce)		21.0	Ulva
20	9 1	10	Sparse (10 to <30%)	180	Low (101 - 500)	0	Ulva (Sea lettuce)	Unspecified Macroalgae	5.8	Ulva Other
21	30	30	Moderate (30 to <70%)	320	Low (101 - 500)	0	Ulva (Sea lettuce)		0.8	Ulva
22	2 1	3	Very sparse (1 to <10%)	60	Very low (1 - 100)	0	Gracilaria chilensis	Ulva (Sea lettuce)	1.0	Grch Ulva
23	90	90	Complete (>90%)	1600	High (1001 - 3000)	0	Ulva (Sea lettuce)		2.7	Ulva
24	50	50	Moderate (30 to <70%)	1200	High (1001 - 3000)	0	Ulva (Sea lettuce)		1.0	Ulva
25	80	80	Dense (70 to <90%)	1520	High (1001 - 3000)	0	Ulva (Sea lettuce)		0.6	Ulva
26	20	20	Sparse (10 to <30%)	5920	Very high (>3000)	0	Ulva (Sea lettuce)		0.1	Ulva
27	5 5	10	Sparse (10 to <30%)	3360	Very high (>3000)	0	Ulva (Sea lettuce)	Gracilaria chilensis	1.2	Ulva Grch
31	5 1	6	Very sparse (1 to <10%)	400	Low (101 - 500)	1	Gracilaria chilensis	Ulva sp (Sea lettuce)	0.1	Grch Ulsp
30	75	75	Dense (70 to <90%)	1040	High (1001 - 3000)	0	Ulva (Sea lettuce)		0.1	Ulva
28	75	75	Dense (70 to <90%)	6280	Very high (>3000)	1	Gracilaria chilensis		0.7	Grch
29	60 1	61	Moderate (30 to <70%)	1400	High (1001 - 3000)	0	Gracilaria chilensis	Ulva (Sea lettuce)	0.4	Grch Ulva
11	10 5	15	Sparse (10 to <30%)	0	Very low (1 - 100)	0	Ulva sp (Sea lettuce)	Gracilaria chilensis	1.0	Ulsp Grch
32	100	100	Complete (>90%)	5000	Very high (>3000)	0	Ulva sp (Sea lettuce)		0.4	Ulsp
33	100	100	Complete (>90%)	33440	Very high (>3000)	1	Ulva sp (Sea lettuce)		0.2	Ulsp
34	3 2	5	Very sparse (1 to <10%)	50	Very low (1 - 100)	0	Ulva sp (Sea lettuce)	Gracilaria chilensis	11.1	Ulsp Grch
34	2	2	Very sparse (1 to <10%)	20	Very low (1 - 100)	0	Ulva sp (Sea lettuce)		17.7	Ulsp
	0	0	Trace (<1)	0	Trace (<1)	0			173.3	unve

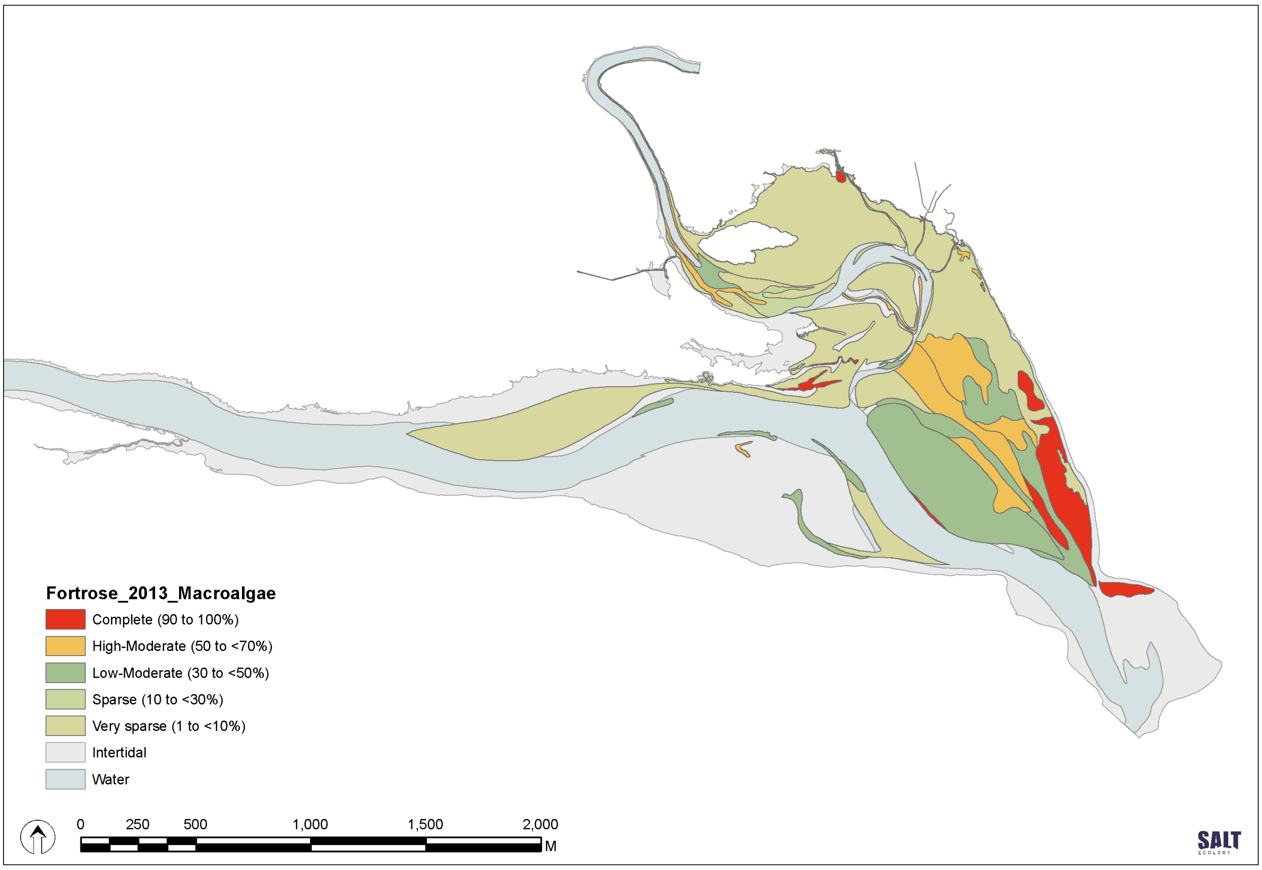
APPENDIX 4. MAP LAYERS FOR MACROALGAL COVER 2003 TO 2020

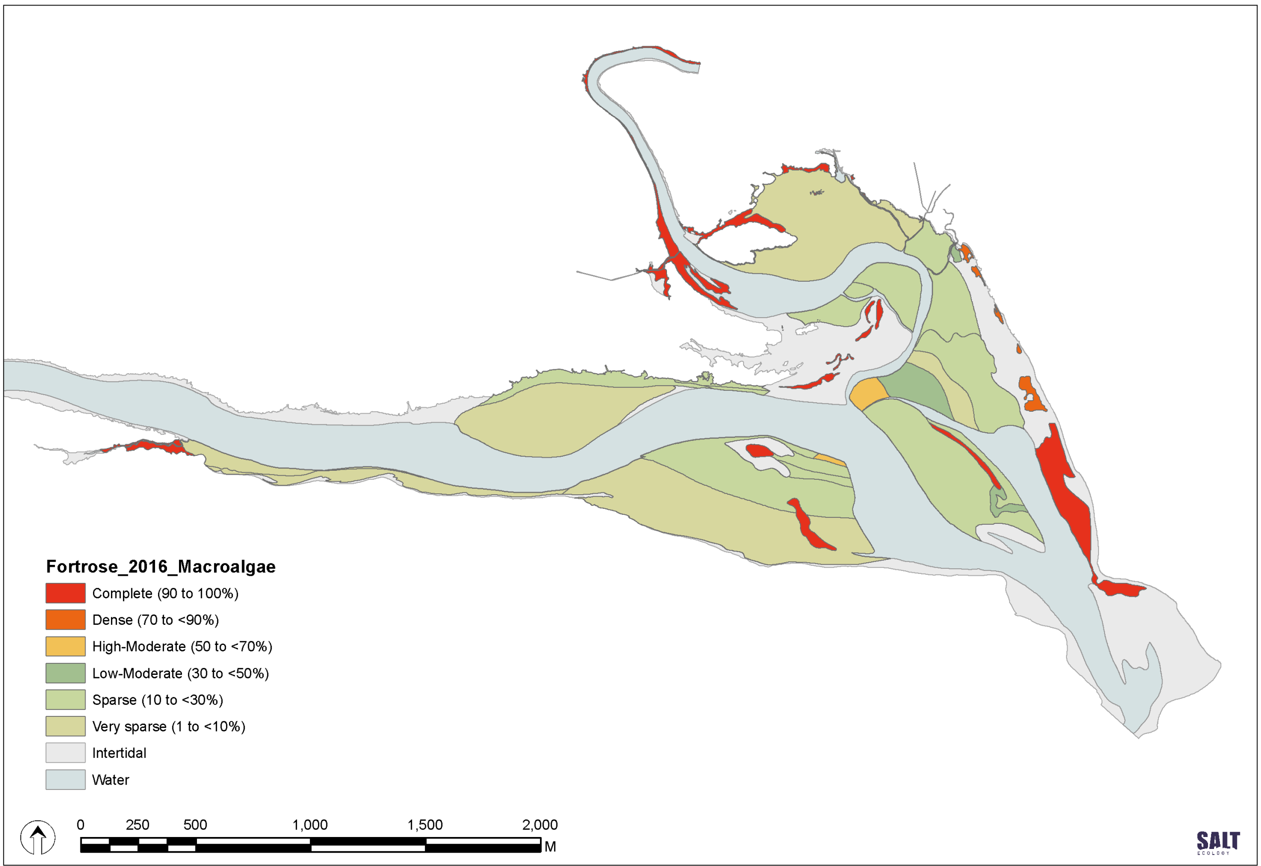

Fortrose_2003_Macroalgae
Dense (70 to <90%)
Intertidal
Water
0
250
500
1,000
1,500
2,000
M
SALT

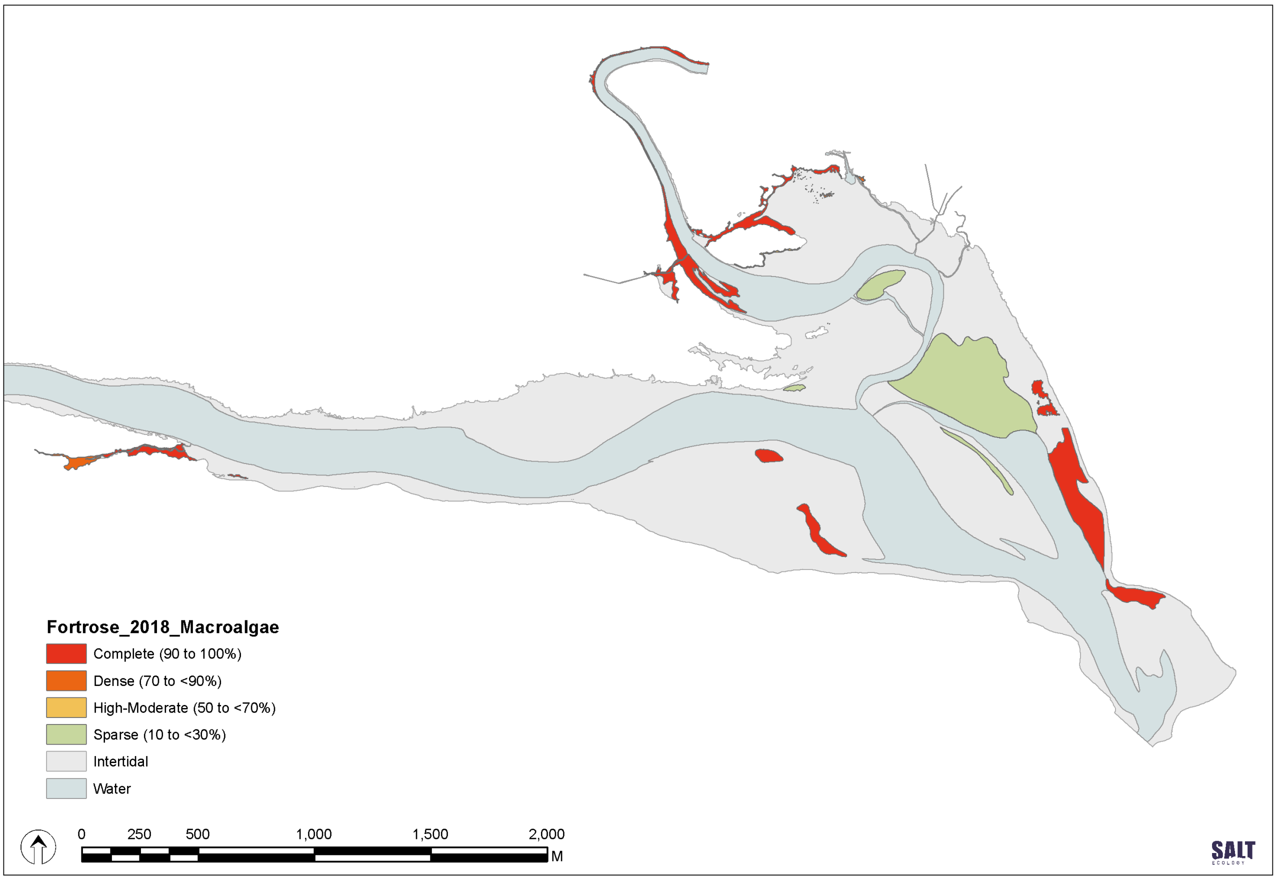

Fortrose_2009_Macroalgae
Complete (90 to 100%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Intertidal
Water
0
250
500
1,000
1,500
2,000
M
SALT

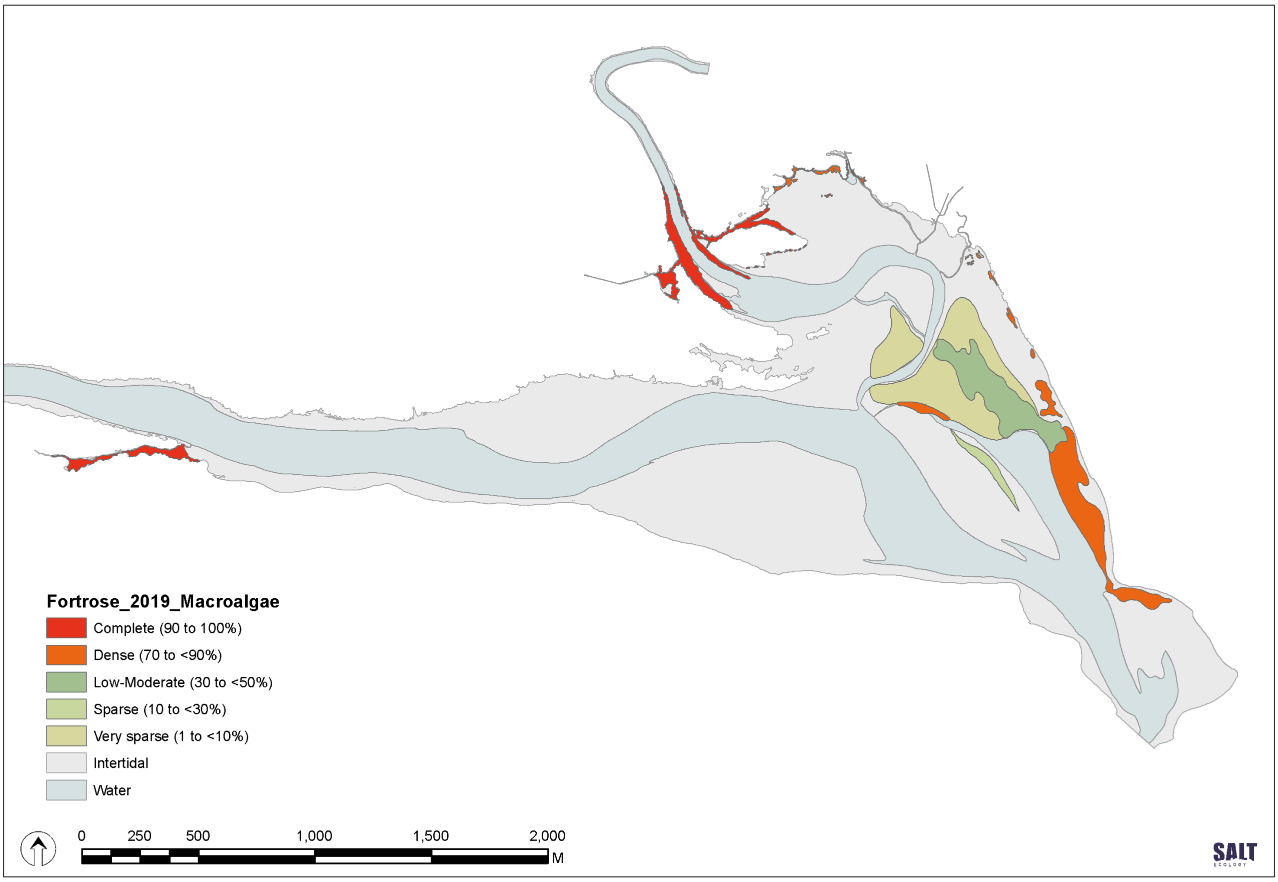

Fortrose_2010_Macroalgae
Complete (90 to 100%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Intertidal
Water
0 250 500 1,000 1,500 2,000
M
SALT
ECOLOGY

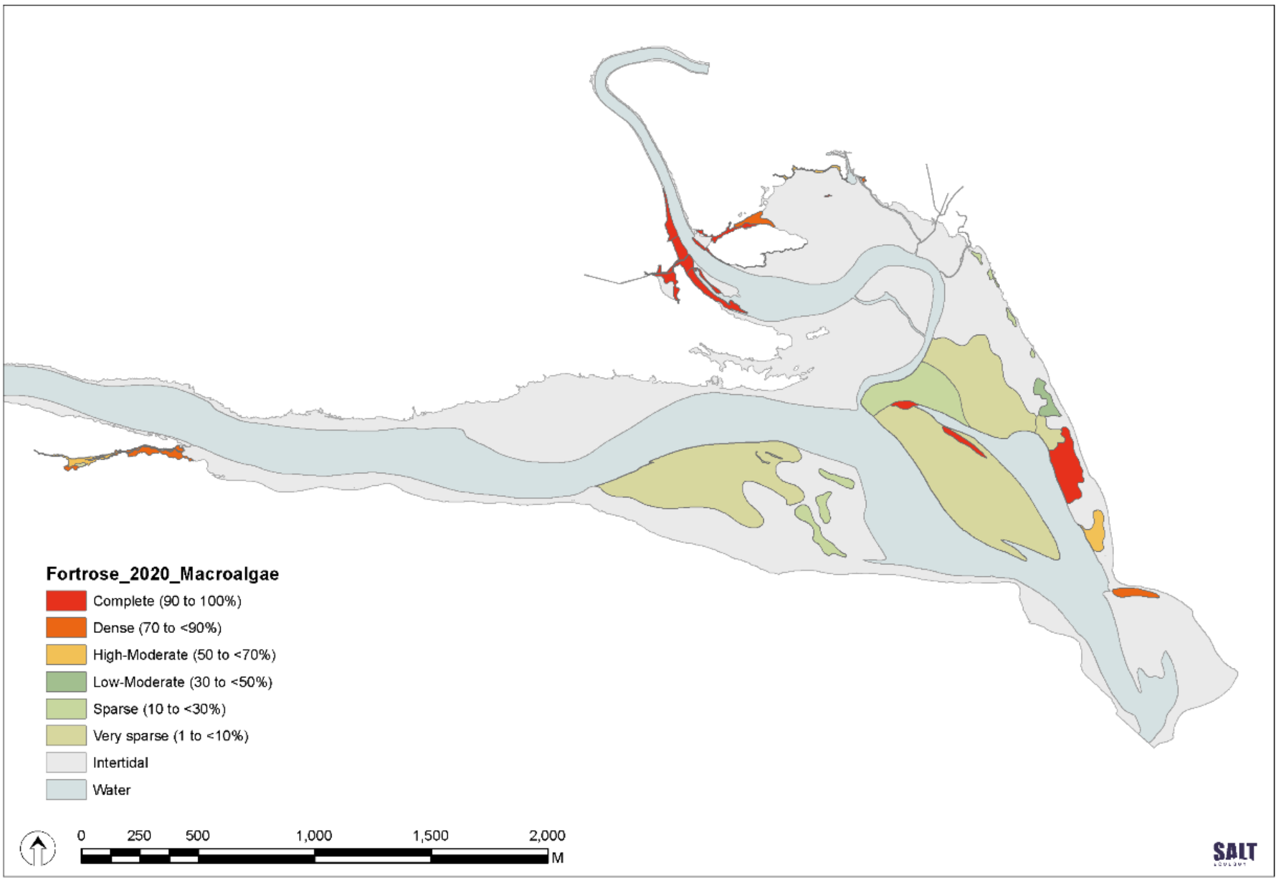

Fortrose_2012_Macroalgae
Complete (90 to 100%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Intertidal
Water
0 250 500 1,000 1,500 2,000
M
SALT
ECOLOGY


Fortrose_2013_Macroalgae
Complete (90 to 100%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Intertidal
Water
0
250
500
1,000
1,500
2,000
M
SALT

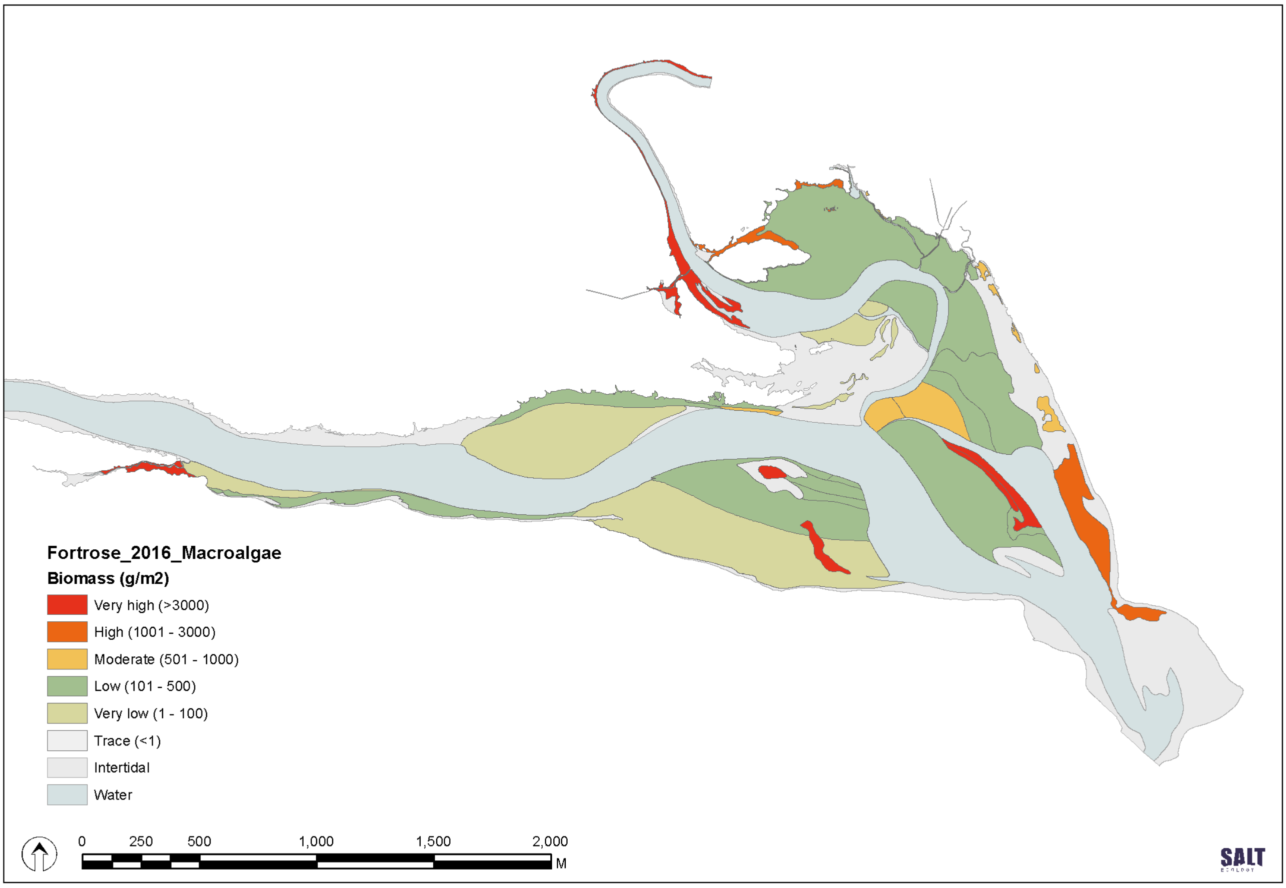

Fortrose_2016_Macroalgae
Complete (90 to 100%)
Dense (70 to <90%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Intertidal
Water
0
250
500
1,000
1,500
2,000
M
SALT

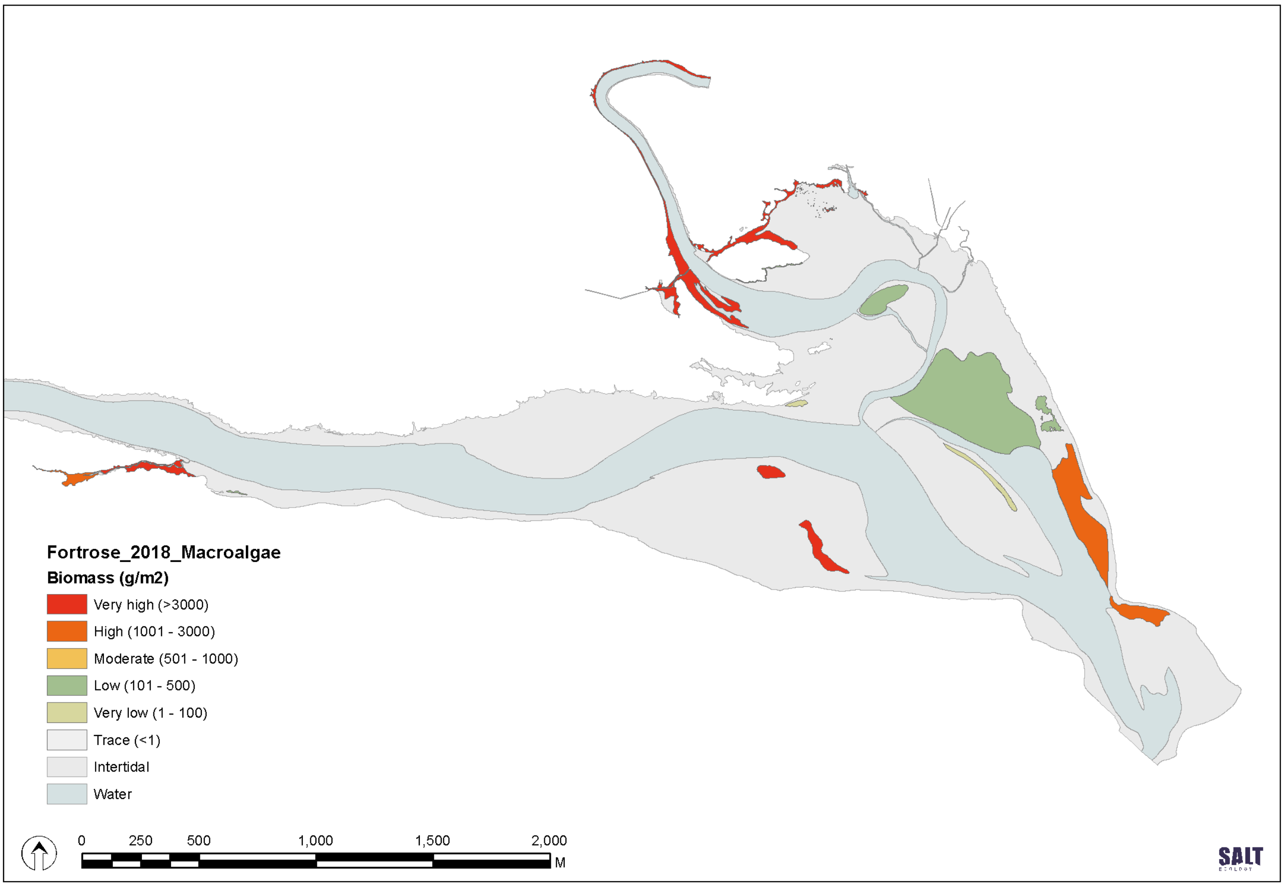

Fortrose_2018_Macroalgae
Complete (90 to 100%)
Dense (70 to <90%)
High-Moderate (50 to <70%)
Sparse (10 to <30%)
Intertidal
Water
0 250 500 1,000 1,500 2,000
M
SALT

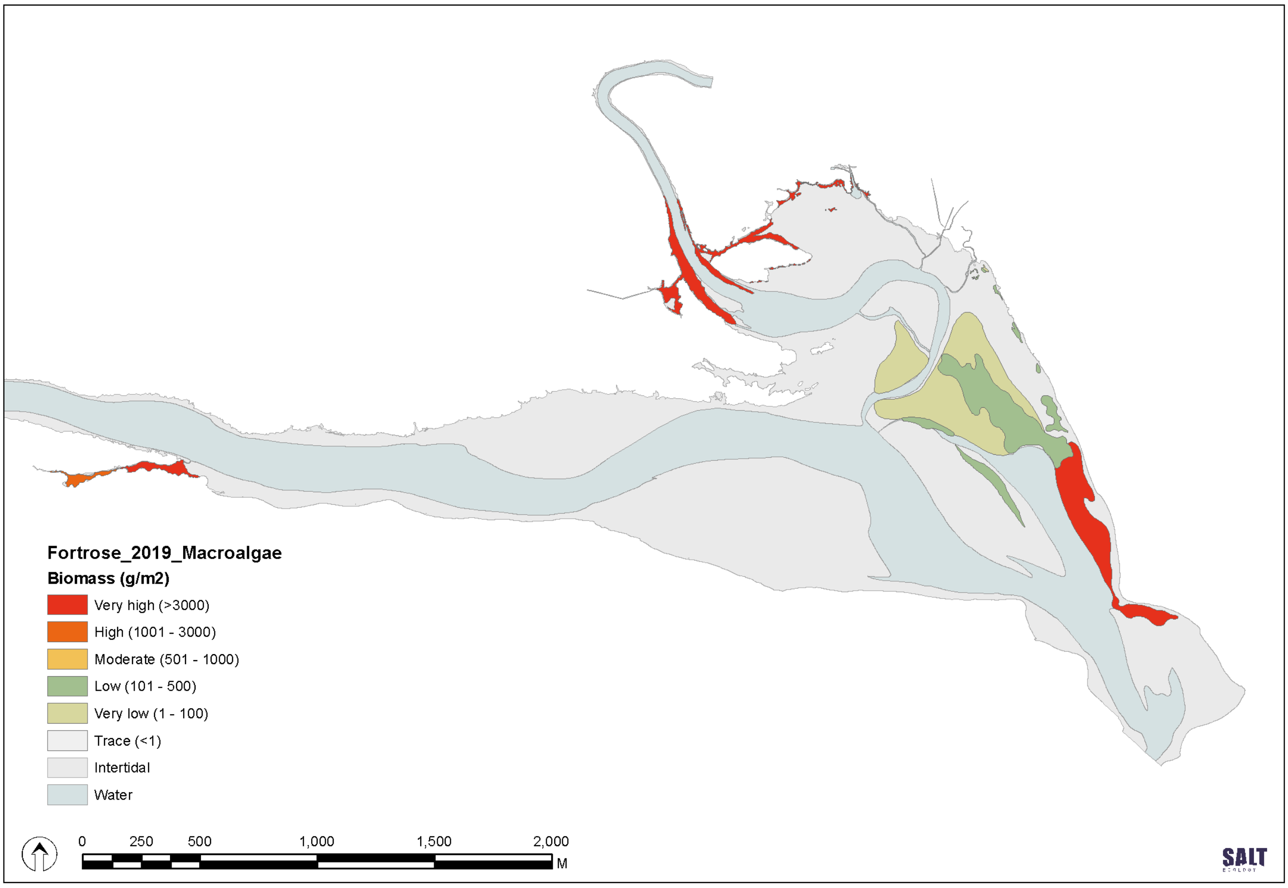

Fortrose_2019_Macroalgae
Complete (90 to 100%)
Dense (70 to <90%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Intertidal
Water
0 250 500 1,000 1,500 2,000
M
SALT

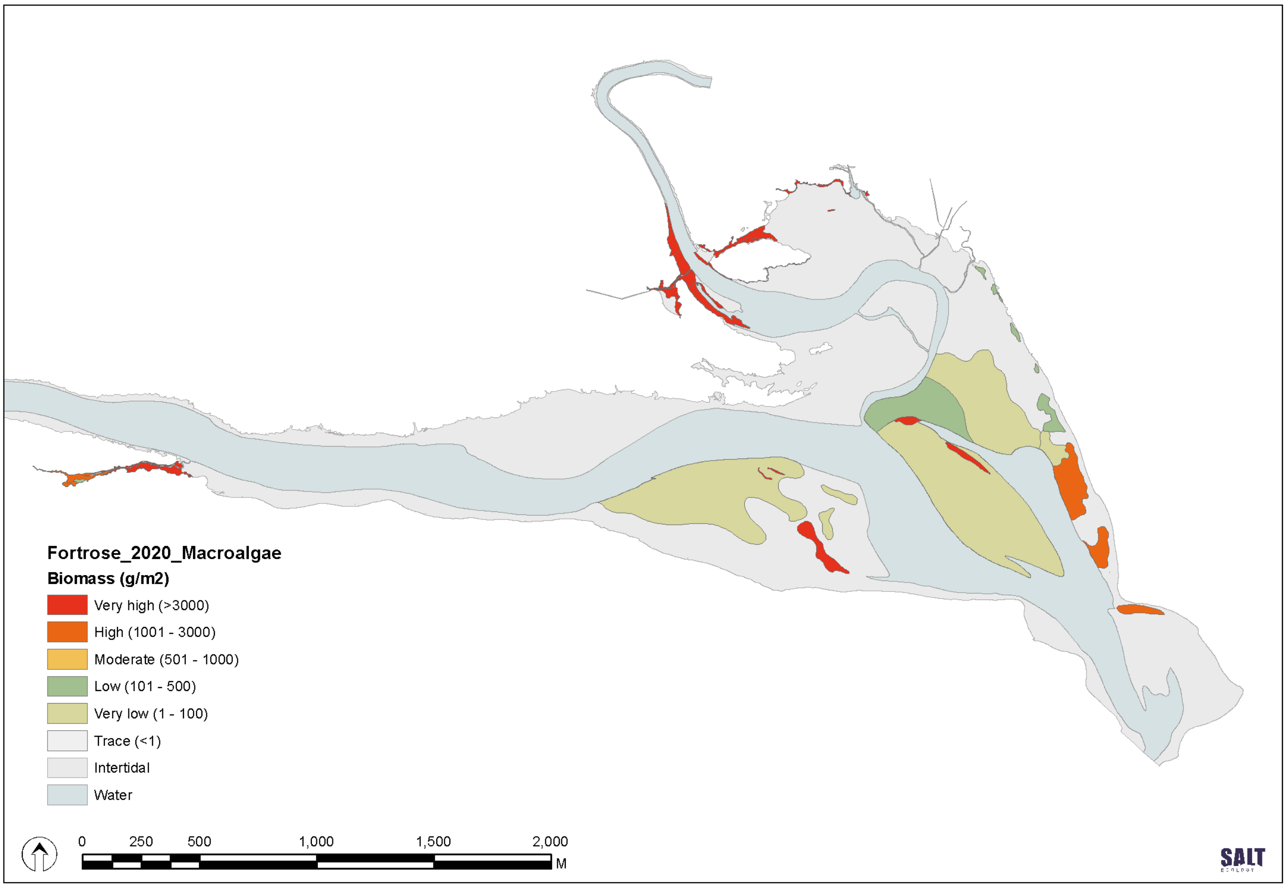

Fortrose_2020_Macroalgae
Complete (90 to 100%)
Dense (70 to <90%)
High-Moderate (50 to <70%)
Low-Moderate (30 to <50%)
Sparse (10 to <30%)
Very sparse (1 to <10%)
Intertidal
Water
0 250 500 1,000 1,500 2,000
M
SALT

APPENDIX 5. MAP LAYERS FOR MACROALGAL BIOMASS 2016 TO 2020






Fortrose_2019_Macroalgae
Biomass (g/m2)
Very high (>3000)
High (1001 - 3000)
Moderate (501 - 1000)
Low (101 - 500)
Very low (1 - 100)
Trace (<1)
Intertidal
Water
0 250 500 1,000 1,500 2,000
M
SALT


Fortrose_2020_Macroalgae
Biomass (g/m2)
Very high (>3000)
High (1001 - 3000)
Moderate (501 - 1000)
Low (101 - 500)
Very low (1 - 100)
Trace (<1)
Intertidal
Water
0 250 500 1,000 1,500 2,000
M
SALT

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