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Fortrose (Toetoes) Estuary 2018

Broad Scale Habitat Mapping

Prepared for

Environment Southland

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Cover Photo: Royal spoonbills in the central basin of the estuary, Feb. 2018.


Native rushland and dunes on the southern edge of the estuary, Feb. 2018.

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Prepared for
Environment Southland

By

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EXECUTIVE SUMMARY

This report summarises the results of the 2018 broad scale intertidal habitat mapping of Fortrose (Toetoes) Estuary, a medium-sized (~500ha) short residence, tidal river (SSRTRE) type estuary with lagoon that discharges to Toetoes Beach at the mouth of the Mataura River and Titiroa Stream. It drains a large and primarily high productivity agricultural catchment, and has a large freshwater influence because the estuary is small in relation to the freshwater input. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. The following sections summarise broad scale monitoring results (from the current report and previous studies), condition ratings, estuary condition, and monitoring and management recommendations.

BROAD SCALE RESULTS

- Sandy substrate dominated the central basin of the estuary (236ha, 74%), but extensive areas of soft mud (33.5ha, 10.5%) were present. There has been a 6ha (28%) increase in soft mud since 2003, although the mud extent has been variable over the years reflecting flood deposition events and subsequent erosion.
- Nuisance macroalgae (>50%) covered 16ha (7%) of the intertidal area excluding saltmarsh, with the highest densities in sheltered embayments where stable high biomass beds have become established over the past 5 years. The 2018 EQR score of 0.453 rated nuisance macroalgae as MODERATE. The overall EQR score was mitigated by low macroalgal growth over much of the very strongly flushed and wave swept intertidal flats of the estuary which appears to limit the extent that dense beds of macroalgae can develop and persist.
- Gross eutrophic conditions covered 9ha (3%) of the estuary. This was similar to the extent reported in 2016, but reflects a significant change from the absence of such conditions prior to 2013.
- Dense (>50%) seagrass cover was 0.2ha (<0.1%), a 33% reduction from the 2003 baseline with losses directly attributable to displacement by excessive macroalgal growth and poor sediment conditions.
- Saltmarsh covered 74ha (15%) of the estuary, of which 55ha (75%) was dominated by rushland (jointed wire rush). Localised drainage and conversion to grassland at the edges of the estuary contributed to ongoing decreases, with a 9ha (11%) reduction in cover since 2003.
- Densely vegetated 200m terrestrial margin (scrub, shrub and rush) cover was very low (4%), with pasture (primarily dairy grazing) dominating the margin (66%). Coastal duneland (25%) also comprised a significant feature. There has been a decline in margin scrub cover since 2013 (conversion to pasture).
- The NZ ETI score was 0.75 indicating it was in a POOR state and expressing significant nutrient enrichment.

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sediment, eutrophication, and habitat modification), the 2018 results indicate that although large sections of the lower estuary remain in good condition, sheltered upper estuary embayments, in particular near Titiroa Stream, have developed stable nuisance macroalgal growths with poorly oxygenated sediments since 2013. These gross eutrophic zones are displacing high value seagrass beds and stressing saltmarsh and benthic habitat. Elsewhere, extensive subtidal growths of macroalgae, and low sediment oxygenation within unvegetated intertidal sediments highlights degradation that is likely to be causing significant ecological stress to the macroinvertebrate communities. Such conditions limit food availability for fish and birdlife, and show the estuary is in a "MODERATE" but declining condition in relation to eutrophication. The ongoing drainage and loss of saltmarsh and densely vegetated terrestrial margins is also placing the estuary under pressure.

Excessive nutrient inputs are the primary driver of the eutrophication symptoms being expressed, the estimated ~1700mgN/m^2/d close to where nuisance growths are expected in SSRTREs (>2000mgN/m^2/d), and well above the thresholds for SIDE estuaries (>100mgN/m^2/d). These high loads are well above natural inputs and highlight there are sufficient nutrients to fuel algal growths in the estuary.

Human health risks associated with shellfish consumption and bathing is addressed separately by ES.

RECOMMENDED MONITORING AND MANAGEMENT

Eutrophication and sediment muddiness have previously been identified as key stressors in Fortrose Estuary (Robertson and Stevens 2008), with worsening eutrophication symptoms reported since 2013 (Stevens and Robertson 2013,2016). To continue to monitor these issues, it is recommended that broad scale habitat mapping be reviewed at five yearly intervals (next scheduled for consideration in 2023), or undertaken at least every 10 years, and sedimentation rates and macroalgal cover be assessed annually. Fine scale monitoring of sediment chemistry and biota at two existing sites (see Robertson and Stevens 2009) is being undertaken by ES in 2019.

Previous management recommendations (e.g. Stevens and Robertson 2013, 2016) are reiterated for the prioritised development of catchment nutrient and sediment guideline criteria for the estuary to derive thresholds to manage and protect against adverse sediment and nutrient impacts. If catchment nutrient loads do not exceed the assimilative capacity of the estuary, then there is a strong expectation that the condition of the estuary will steadily improve and provide sustainable human use and ecological values in the long term.

1. INTRODUCTION

Fortrose (Toetoes) Estuary is a shallow (mean depth ~2m) medium-sized (~500ha) short residence, tidal river (SSRTRE) type estuary with lagoon that discharges to Toetoes Beach at Fortrose (Figure 1). Situated at the mouth of the Mataura River and Titiroa Stream, it drains a large 5637km^2, extensively developed catchment comprising 54% intensive pasture, 17% tall tussock grassland, 10% low producing pasture, 8% native forest, 4% scrub and 4% exotic forest (Landcare LCDBv4.1 2012/13).

The shallow estuary has a large freshwater influence due to the estuary volume being small in relation to the freshwater input. It has a wide range of habitats including extensive intertidal flats, saltmarsh and small patches of seagrass, but has historically lost ~75% (250ha) of estuary saltmarsh, with adjacent freshwater wetland also greatly diminished through reclamation, drainage and conversion to pasture. This has greatly reduced the estuary's ability to filter, dilute, and assimilate catchment nutrient and sediment inputs. In addition to these historical changes, the estuary is currently experiencing degraded water quality (reduced clarity, elevated faecal coliforms, elevated nutrients) particularly in high river flows, with elevated nutrient inputs causing localised macroalgal blooms.

To gather information to support effective estuary management decisions, Environment Southland (ES) has established a long-term coastal monitoring programme that includes use of the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002). The NEMP includes broad-scale mapping of habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland) using a combination of detailed ground-truthing and GIS-based digital mapping from aerial photography to record the features present.

This work commenced in Fortrose Estuary in February 2003 (Robertson et al. 2003), and was repeated in February 2013 (Stevens and Robertson 2013). Additional substrate and seagrass mapping was undertaken in 2016 (Stevens and Robertson 2016). In addition, fine scale physical, chemical and biological monitoring has been undertaken at 1-2 representative mid-estuary sites in 2004, 2005, 2006 (3 year baseline), and 2009 (see Robertson and Stevens 2006, 2009) - see Figure 1 for fine scale site locations. Fine scale monitoring is scheduled for re-sampling by ES in Feb. 2019.

Estuary-wide macroalgal cover, and sedimentation rates at fine scale site B, were monitored annually from 2009-2013 (see Stevens and Robertson 2013), and in 2016 (Stevens and Robertson 2016).

The current report focuses on detailed broad scale habitat mapping undertaken in February 2018 to characterise the current state of key habitat features and to assess changes over time. It uses a suite of indicator ratings developed for estuarine assessment (Table 1), many of which are included in the recently developed NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b). The ETI is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness. Key indicators used in the current report (described further in Appendices 1 and 2) include mapping and assessment of:

- Substrate types
- Sediment oxygenation
- Macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*)
- Seagrass (i.e. *Zostera muelleri*)
- Gross Eutrophic Zones (GEZs)
- Saltmarsh vegetation
- 200m terrestrial margin land cover
- Catchment land cover

1.1 REPORT STRUCTURE

The current report presents a brief introduction to Fortrose Estuary (Section 1), the sampling methods, monitoring indicators and assessment criteria used (Section 2), and results and discussion of the field sampling (Section 3). To help the reader interpret the findings, results are related to relevant condition ratings to facilitate the assessment of overall estuary condition (summarised in Section 4), and to guide monitoring and management recommendations (Sections 5 and 6).

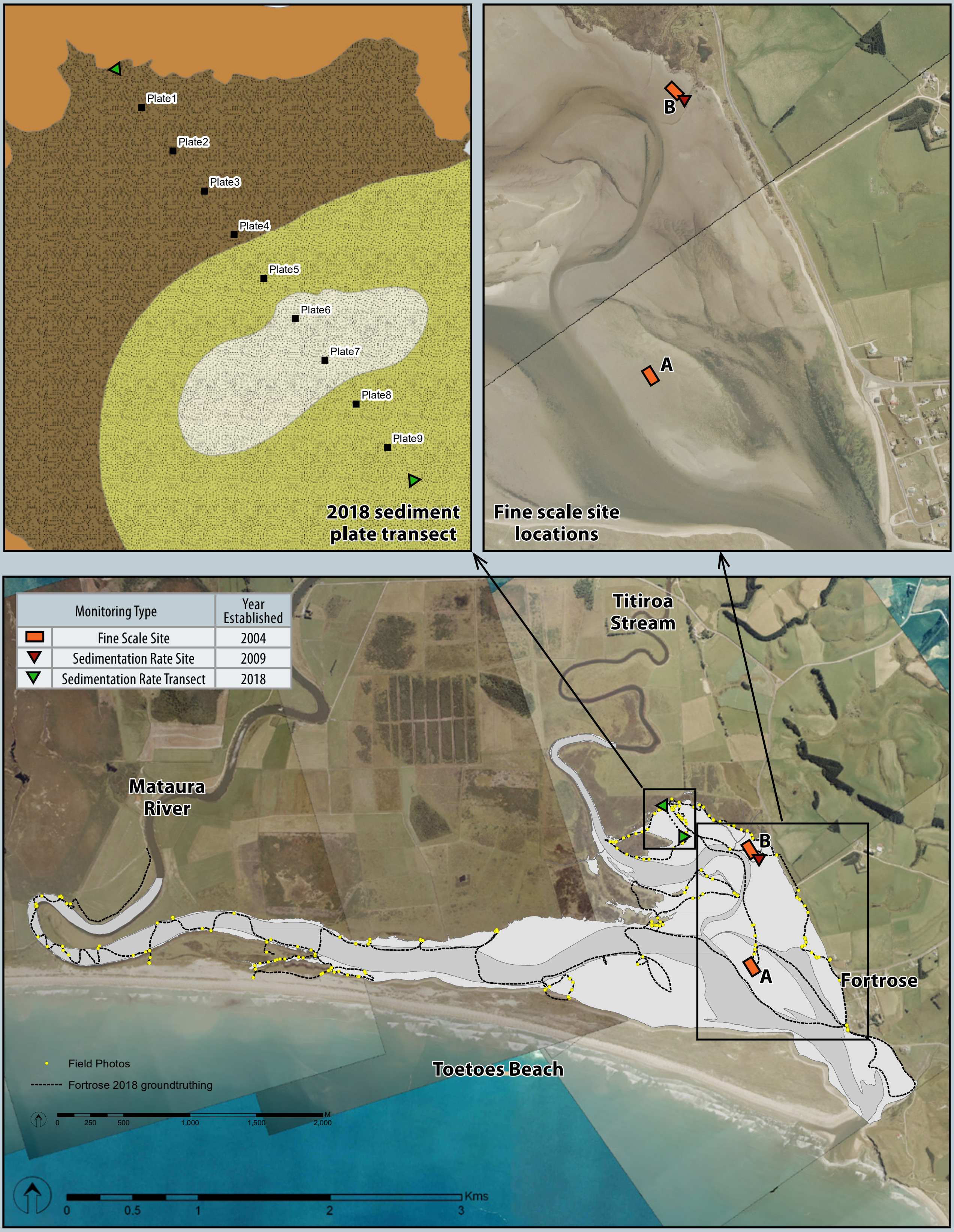


Figure 1. Fortrose Estuary showing the location of fine scale sites established in 2004, buried sediment plates established in 2009 and 2018, and 2018 ground-truthing and field photos.

2. METHODS

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland, etc). It follows the NEMP approach originally described for use in NZ estuaries by Robertson et al. (2002) with a combination of detailed ground-truthing of aerial photography, and GIS-based digital mapping from photography to record the primary habitat features present. Appendix 3 lists the definitions used to classify substrate and saltmarsh vegetation. Very simply, the method involves:

- Obtaining aerial photos of the estuary for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing) using laminated aerial photos.
- Digitising ground-truthed features evident on aerial photographs into GIS layers (e.g. ArcMap).

The georeferenced spatial habitat maps provide a robust baseline of key indicators that are used with indicators to assess estuary condition in response to common stressors, and assess change over time.

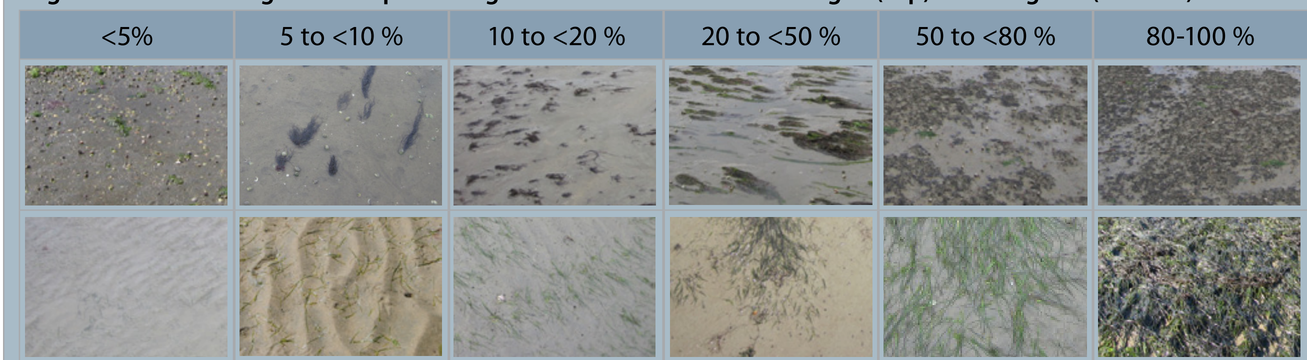
Site boundaries were set as the seaward edge of the entrance to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For the current study, LINZ rectified colour aerial photos (~0.1m/pixel resolution) flown in 2014 were laminated (scale of 1:3,000), and used by experienced scientists who walked and kayaked the area over 2 days in February 2018 to ground-truth the spatial extent of dominant vegetation and substrate types (Figure 1, Appendix 6). From representative broad scale substrate types, 18 grain size samples were analysed to validate substrate classifications (Appendix 4). When present, macroalgae and seagrass was mapped to the nearest 10% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2). Notes on sampling, resolution and accuracy are presented in Appendix 4. Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring:

- % cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of eutrophication issues).
- macroalgal biomass (providing a direct measure of areas of excessive growth).
- extent of algal entrainment in sediment (highlighting where nuisance conditions have a high potential for establishing and persisting).
- gross eutrophic zones (highlighting significant sediment degradation by measuring where there is a combined presence of high algal cover or biomass, low sediment oxygenation, and soft muds).

Where macroalgal cover exceeded 5% of the Available Intertidal Habitat (AIH), the Opportunistic Macroalgal Blooming Tool (OMBT) was used to rate macroalgal condition (WFD-UKTAG 2014). The OMBT is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands (i.e. bad/low, poor, good, moderate, high). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution.

Macroalgal 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 algae was then thoroughly rinsed to remove sediment, and any non-algal material and large invertebrate fauna (e.g. crabs, shellfish) were removed. Remaining algae was then hand squeezed until water stopped running, and the wet weight of algae recorded to the nearest 10g using a 1kg Pesola light-line spring scale. Measured biomass was then used to extrapolate biomass estimates for each wider patch.

Figure 2. Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom).



2. METHODS (CONTINUED)

Broad scale habitat features were digitised into ArcMap 10.5 using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photos to produce habitat maps showing the dominant cover of: substrate, reduced sediment oxygenation, macroalgae (e.g. *Ulva, Gracilaria*), GEZs, seagrass, saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse. These results are summarised in Section 3, with supporting GIS files (supplied as a separate electronic output) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions.

In addition to the above measures, to provide an early indication of changes in muddiness and macroalgal growths within the upper estuary, a 275m long fixed transect was established in 2018 in an unvegetated deposition zone in the estuary's northern arm (see Appendix 4 for site coordinates). Nine sediment plates spaced 30m apart were buried approximately 50mm deep in the sediment along a transect line that transitioned through very soft muds / firm sandy muds / firm muddy sands / sandy muds (Figure 1), with grain size measured from the surface 20mm over each sediment plate. Repeat measures over time will enable fine scale changes in substrate composition and sediment deposition, and potential increases in macroalgal extent, to be accurately monitored at each sample location.

Table 1. Summary of estuary condition indicator ratings used in the present report.

INDICATOR CONDITION RATINGS / ETI BANDS				
BROAD AND FINE SCALE INDICATORS — Condition Rating	Very Good - Band A	Good - Band B	Moderate - Band C	Poor - Band D
Soft mud (% of intertidal substrate outside of saltmarsh)*	<1%	1-5%	>5-15%	>15%
Sediment Mud Content (%mud)*	<5%	5-10%	>10-25%	>25%
Apparent Redox Potential Discontinuity (aRPD)	>5cm	>2-5cm	0.5-2cm	<0.5cm
Sediment Oxygenation (aRPD <0.5cm or RP@3cm<-150mV)**	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Macroalgal Ecological Quality Rating (OMBT)*	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	0.0 - <0.4
Seagrass (% change from baseline)	<5% decrease	5%-10% decrease	>10-20% decrease	>20% decrease
Gross Eutrophic Zones (ha or % of intertidal area)	<0.5ha or <1%	≥0.5 to <5ha or ≥1 to <5%	≥5 to <20ha or ≥5 to <10%	≥20 ha or ≥10%
Saltmarsh Extent (% of intertidal area)	>20%	>10-20%	>5-10%	0-5%
Supporting indicator — **Extent** (% remaining from est. natural state)	>80-100%	>60-80%	>40-60%	<40%
Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	<25%
Percent Change (degradation) from Monitored Baseline	<5%	5-10%	>10-20%	>20%
NZ ETI score*	0 to <0.25	0.25 to <0.50	0.50 to <0.75	0.75 to 1.0

* NZ ETI (Robertson et al. 2016b), ** Hargrave et al. (2008), Keeley et al. (2012), See NOTES in Appendix 2 for further information.

Establishing the sediment transect on the northern flats, Feb. 2018

3. RESULTS AND DISCUSSION

3.1 BROAD SCALE MAPPING SUMMARY

The 2018 broad scale habitat mapping ground-truthed and mapped intertidal estuary substrate and vegetation as well as the dominant land cover of the 200m terrestrial margin. The dominant estuary features are summarised in Tables 2 and 3 and shown in Figures 3-15.

Fortrose River is a relatively simple estuary with defined channels and a large central basin. 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 recently become established. Extensive subtidal growths of macroalgae are also present throughout the estuary.

The high nitrogen load estimated from NIWA's CLUES model (~1700mgN/m^2/d Table 3) indicates the estuary is well above the threshold where nuisance growths are expected in SIDE estuaries (>100mgN/m^2/d), and within the 500-2000mgN/m^2/d range where nuisance growths are observed in SSRTREs elsewhere in NZ (unpublished Wriggle data). These high loads, while likely underestimating point source inputs, are well above natural inputs and highlight there are sufficient nutrients to fuel algal growths in the estuary.

The estuary is intertidally dominated (65%), with relatively extensive saltmarsh beds (15.1%) remaining, although these are under ongoing pressure from drainage. Intertidal seagrass is a very small habitat component in the estuary (0.04%), while dense beds (>50% cover) of opportunistic macroalgae were extensive (16%) and have resulted in the establishment of persistent GEZs in sheltered areas. The 200m wide terrestrial margin was dominated by grassland (66%), with only 4% densely vegetated.

In the following sections, various factors related to each of the key habitats mapped (e.g. area of soft mud) are used in conjunction with condition ratings to assess estuary issues of sedimentation, eutrophication, and habitat modification (Appendix 1). In addition, the GIS files underpinning this written report provide a more detailed spatial record of the features present throughout the estuary and are intended as the primary supporting tool to help the Council address a suite of estuary issues and management needs, and to act as a baseline to assess future change.

To facilitate the comparison of results for condition ratings (Table 1), the mapping extent mirrored as much as possible that presented previously in Robertson et al. (2003), and Stevens and Robertson (2013, 2016). Temporal changes are also summarised for each of the key indicators in the following sections.

Table 2. Summary of dominant broad scale features, Fortrose Estuary, Feb. 2018.

Dominant Estuary Feature	ha	%
Intertidal saltmarsh	74.1	15.1
Intertidal seagrass (>20% cover)	0.2	0.04
Intertidal macroalgal beds (>50% cover)	15.6	3.2
Intertidal substrate (unvegetated)	242.8	49.6
Intertidal Total	318.7	65.0
Subtidal Total	171.3	35.0
Total Estuary	**490**	**100.0**
200m Terrestrial Margin (% densely vegetated)		4

3. RESULTS AND DISCUSSION (CONTINUED)

Table 3. Supporting data used to assess estuary ecological condition.

Supporting Condition Measures	Total
Catchment Area (Ha)*	563,710
Indigenous forest cover (Ha [%])	40,311 [7%]
Mean freshwater flow (m^3/s)*	100.7
Catchment nitrogen load (T/yr)*	3110
Catchment phosphorus load (T/yr)*	345
Catchment sediment load (KT/yr)*	387.7
Estimated N areal load in estuary ($mg/m^2/d$)	1711
Estimated P areal load in estuary ($mg/m^2/d$)	190
Intertidal soft mud extent (%) ex. saltmarsh	13%
Macroalgal OMBT EQR score	0.453
Saltmarsh (estimated natural % remaining)	<40%
NZ ETI score	0.74

*source NIWA Coastal Explorer database and CLUES model output run Oct 2018 - CLUES 10.5 LCDBv41 in default mode.
The CLUES estimated N load (3110T/yr) is significantly lower than the more recently estimated realised N load of 4392T/yr reported by Aqualink (2014). The more conservative CLUES load has been used in the current study to maintain consistency with measures used to develop estuary load response relationships.

3.2 INTERTIDAL SUBSTRATE

Figure 3 and Table 4 summarise the intertidal substrate of Fortrose Estuary. Sand (236ha, 74%) was the dominant substrate class (including saltmarsh habitat), most located in the relatively well flushed central basin and lower estuary. The dominance of sands is likely to reflect the combined influence of high river flows, strong tidal flushing, and frequent wind driven waves which all limit the areas where deposits of fine mud accumulate in the estuary.

Despite this, soft and very soft muds were prominent (33.5ha, 10.5%) - the vast majority located in the sheltered upper estuary. The mud extent has a condition rating of "MODERATE".

Within vegetated areas, substrate among rushland was dominated by firm muddy sand, sedgeland (three square) was almost exclusively found growing in soft muds, and herbfield was predominantly in gravels. Seagrass beds (Section 3.10) were growing in both firm muddy sands and soft muds.

Hard substrates (e.g. rock, boulder and cobble) were very limited in extent and located mainly at the upper intertidal margins near Fortrose. No significant beds of mussels or other biogenic features (e.g. tube worm reefs) were recorded as dominant habitats, although shellfish are present in extensive beds throughout much of the estuary. Dense growths of macroalgae were predominantly present within soft muds (see Section 3.6).

Table 4. Summary of dominant intertidal substrate in Fortrose Estuary, Feb. 2018.

Dominant Substrate Type	ha	%
Intertidal substrate within saltmarsh		
Gravel field	0.05	0.02
Firm muddy sand	73.7	23.1
Firm mud	0.3	0.1
Soft mud	1.7	0.5
Intertidal substrate outside of saltmarsh		
Rock field	0.1	0.03
Cobble field	5.9	1.8
Gravel field	15.3	4.8
Mobile sand	10.8	3.4
Mobile muddy sand	45.5	14.3
Firm sand	7.6	2.4
Firm muddy sand	108.8	34.1
Firm sandy mud	13.3	4.2
Soft muddy sand	2.1	0.7
Firm mud	2.0	0.6
Soft mud	20.2	6.3
Very soft mud	11.3	3.6
Grand Total	**318.7**	**100**

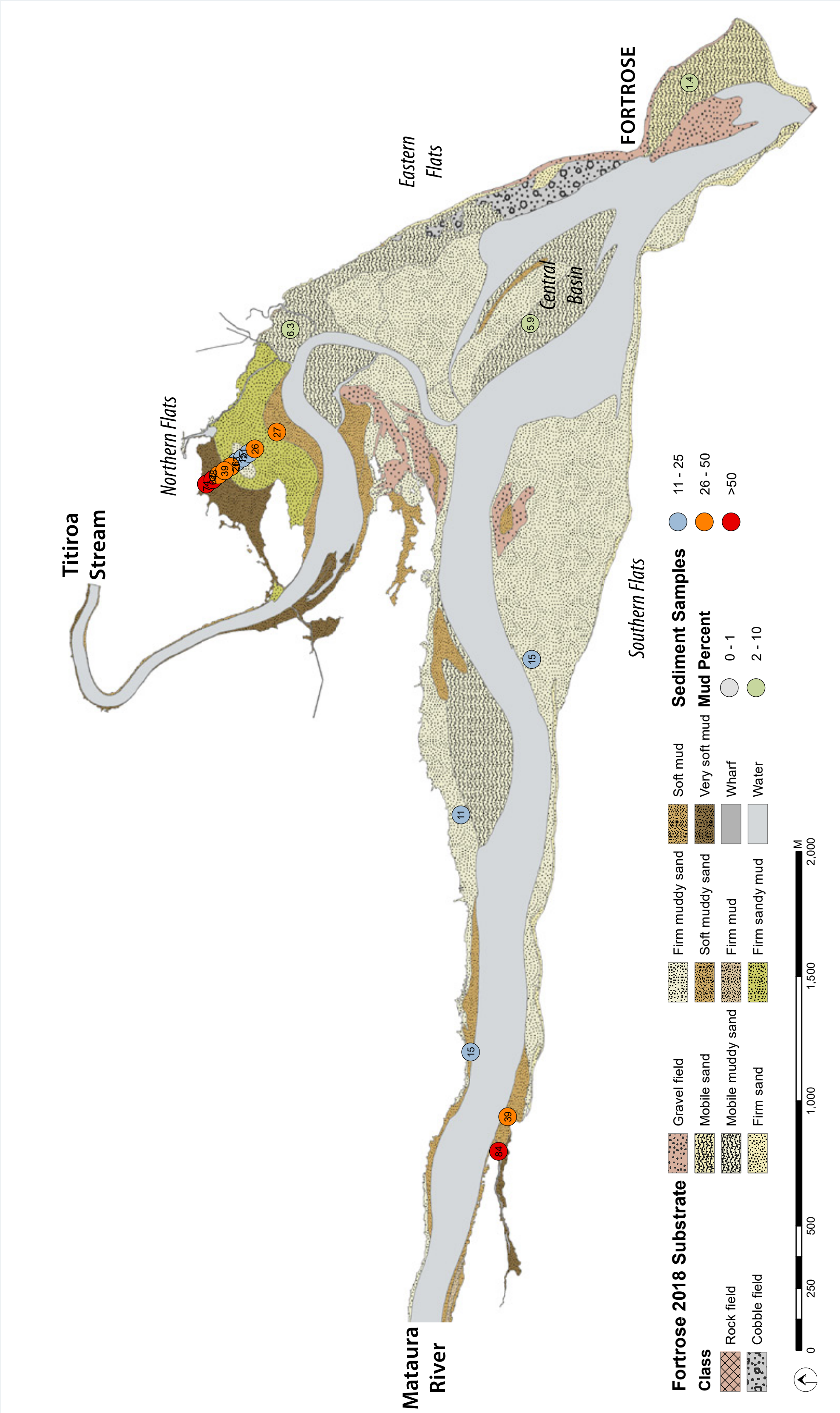


Figure 3. Map of dominant substrate types, Fortrose Estuary, Feb. 2018.

3.3 EXTENT OF SOFT MUD

Adverse impacts are commonly encountered when estuaries receive excessive inputs of fine sediment resulting in turbidity, shallowing, increased nutrients, increased organic matter degradation by anoxic processes (e.g. sulphide production), increased contaminant concentrations (where fine muds provide a sink for catchment contaminants like heavy metals), and alterations to saltmarsh, seagrass, fish and invertebrate communities through declining sediment oxygenation, smothering, and compromisation of feeding habits (e.g. see Mannino and Montagna 1997; Rakocinski et al. 1997; Peeters et al. 2000; Norkko et al. 2002; Ellis et al. 2002; Thrush et al. 2003; Lohrer et al. 2004; Sakamaki and Nishimura 2009; Wehkamp and Fischer 2012; Robertson 2013).

Because of such consequences, three key measures are commonly used to assess soft mud:

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 1).

ii. **Vertical buildup** (sedimentation rate) - measured using buried sediment plates or retrospectively through historical coring. Ratings are currently under development as part of national ANZECC guidelines.

iii. **Sediment mud content** - fine scale indicator of the degree of muddiness within sediments from representative habitat - recommended guideline is no increase from established baseline.

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Table 3 shows that 10% of the intertidal habitat was classified as being dominated by soft muds, a condition rating of "MODERATE". The extent of intertidal mud is relatively variable due to episodic deposition and erosion of muds on the Mataura River margins and intertidal flats, with mud deposits eroded by strong tidal and river flushing, particularly in the central basin. Measurements of sediment deposition at fine scale Site B since 2009 show -1.5mm yr^{-1} of sediment erosion over the past nine years (ES unpublished data) indicating no mud accumulation at the site. The main areas that muds are accumulating are within small sheltered embayments at the edge of the estuary, with the most extensive areas located near Titiroa Stream (Figure 3).

Figure 4 shows the results of the baseline sediment grain size measurements collected along the northern flats transect in 2018 substrate (Figure 1, Appendix 4). The results show sediments have a high mud content in the upper intertidal zone, decrease towards the middle of the transect, and then increase nearer the low tide river margin (e.g. Figure 5). The mud content highlights that the sediment macrofauna community in the majority of this part of the estuary will be dominated by mud tolerant species. Measurement of changes in sediment height over time will be used to assess rates of infilling, with grain size measurements used to track changes in sediment muddiness and to quantify any spatial shift in substrate classified by broad scale mapping.

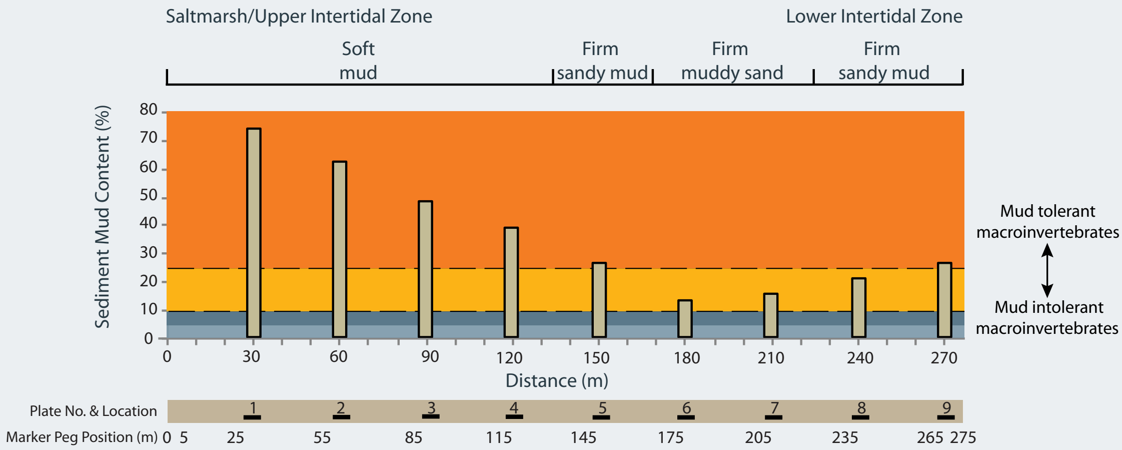


Figure 4. Percent mud content at each sediment plate site along the transect established in the northern flats of Fortrose Estuary, Feb. 2018. (refer to Figure 1 for plate configuration).

3.4 CHANGES IN ESTUARY SOFT MUD 2003-2018

Changes in the area of soft mud recorded by broad scale mapping in the estuary since 2003 are summarised in Table 5. Compared to the 2003 baseline, there has been a net 28% increase in the area of soft mud (6ha), although the mud extent has been variable over the years reflecting flood deposition events and subsequent erosion. Despite the temporal variation present, there has been a discernible increase in the accumulation of muds near Titiroa Stream in the northern arm of the estuary, most associated with sediment entrained macroalgal (*Gracilaria*) beds, with the percent change in mud rated “POOR”.

Table 5. Soft mud extent, Fortrose Estuary, 2003, 2013, 2016 and 2018 (excludes substrate within saltmarsh).

Substrate Class	2003		2013		2016		2018	
	ha	%	ha	%	ha	%	ha	%
Soft muds	24.7	8	60.6	19	27.8	9	31.5	10

Figure 5. Soft muds (mud content 60-80%) on the upper northern flats (left) and firm sandy muds (mud content 30-50%) on the lower northern flats (right) of Fortrose Estuary, Feb. 2018.

3. RESULTS AND DISCUSSION (CONTINUED)

3.5 SEDIMENT OXYGENATION

Closely linked to sediment muddiness is sediment oxygenation. The primary indicator used to assess sediment oxygenation was the visually apparent aRPD depth. This indicator was measured within representative intertidal sediments and results used to assess which parts of the estuary had sediment oxygen depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) might be expected i.e. aRPD 0-1cm. In total, 50ha (21%) of the unvegetated intertidal area was classified as having reduced sediment oxygenation in 2018, a condition rating of "POOR". Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that reduced oxygen zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

The broad scale field measurements found sand and gravel sediments in the lower estuary to be generally well oxygenated with the average aRPD depth at ~2 to>5cm. This appears to be maintained largely as a consequence of open interstitial spaces within the sediment matrix allowing for the free exchange of oxygen from either the atmosphere or from seawater.

The areas showing the most pronounced reduction in sediment oxygenation were soft or very soft muds located in eutrophic areas near Titiroa Stream, and in a small embayment on the south side of the Mataura River (Figure 6). Here sediments were anoxic to the surface (see photos below left) and characterised by strong hydrogen sulphide odours. When disturbed near water, sediments released black sulphide-rich plumes. Further downstream to the south there were also extensive areas of low sediment oxygenation on the unvegetated sand flats. Here the surface sediments showed no outward signs of oxygen depletion, but were highly anoxic immediately below the surface (see photos below right). This is likely to be having a significant adverse impact on sediment dwelling animals. The specific cause of the high anoxia on exposed sand flats, also evident in 2016, is uncertain but likely relates to Mataura River inputs depleting sediment oxygen and promoting the growth of benthic microalgae within the sediment matrix. Monitoring sediment macrofauna and fine scale enrichment and contamination indicators in this part of the estuary is recommended to better understand the cause and impact of the current degradation.

Highly anoxic and sulphide-rich sediments from within *Gracilaria* beds.

Anoxic sediment beneath shallow oxygenated surface sediments on exposed sand flats.

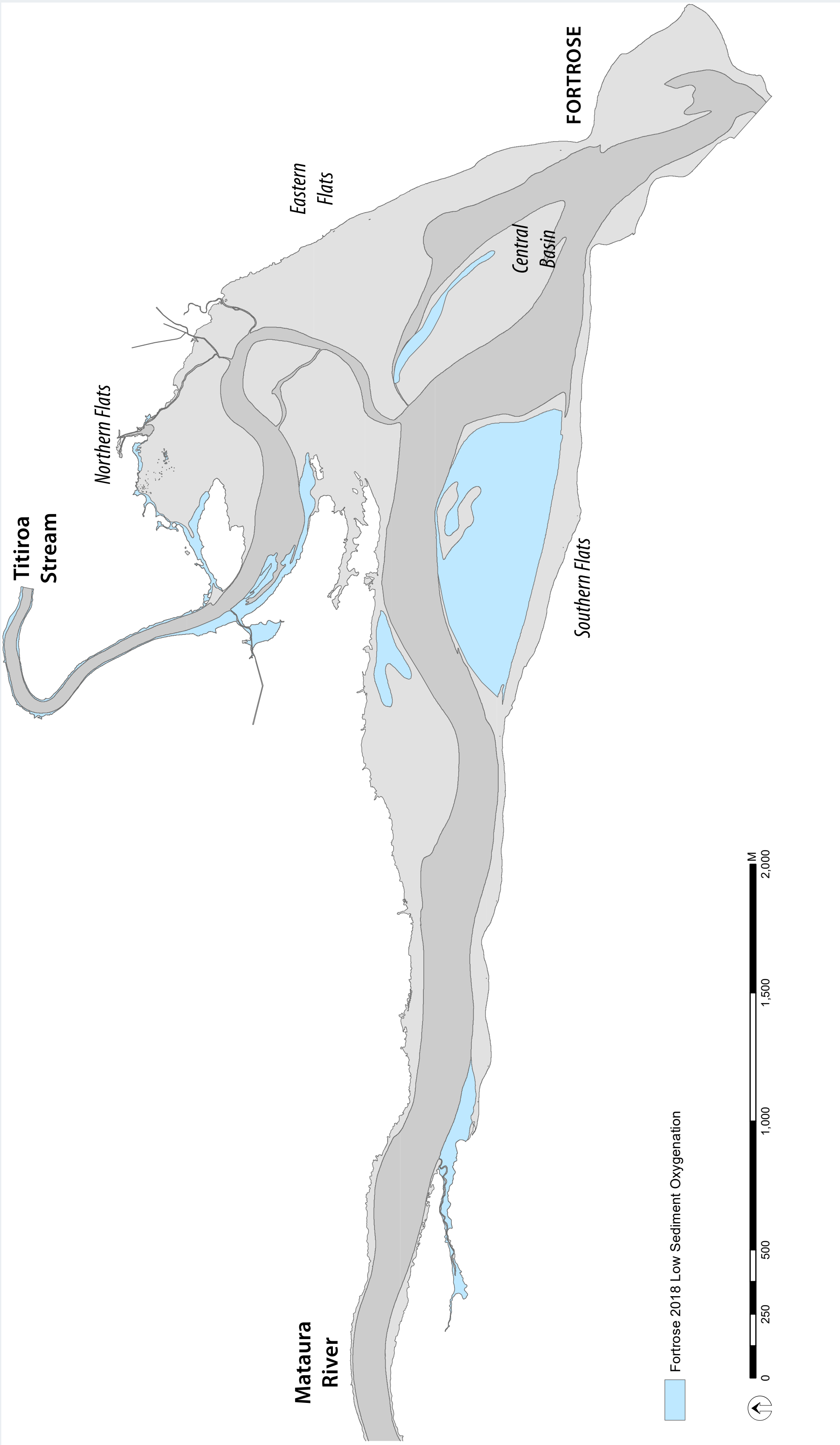


Figure 6. Map of areas with depleted sediment oxygenation, Fortrose Estuary, Feb. 2018.

3.6. OPPORTUNISTIC MACROALGAE

Opportunistic macroalgal growth was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 7), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT). A conservative approach was taken of including all intertidal substrate (excluding saltmarsh) in the AIH.

The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and relates to a quality status threshold band (i.e. bad, poor, good, moderate, high - Section 2, Table 1). The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change.

The overall opportunistic macroalgal EQR for Fortrose Estuary in February 2018 was 0.453 (Table 6), a quality status of "MODERATE" with the "Poor" Quality Status scores for biomass and the presence of entrained algae indicating that the estuary is expressing significant local symptoms of eutrophication. The main locations where high biomass beds were present were in soft mud depositional zones in sheltered parts of the upper estuary, and particularly in the northern arm where stable beds have become established over the past 5 years. In these areas the red alga *Gracilaria chilensis* was dominant, with very high biomass (~15,000gm^{-2}) beds trapping fine muds and building raised (5-10cm high) and stable beds (Figure 8). These conditions serve as a clear indicator that the assimilative capacity of the estuary is being exceeded and reflect the very high estimated nutrient loads (3,110 tonnes N year^{1}, NIWA's CLUES model N load based on with 2012/13 land cover, Table 3).

The overall EQR score was mitigated by low macroalgal growth over much of the very strongly flushed and wave swept intertidal flats of the estuary which appears to limit the extent that dense beds of macroalgae can develop and persist in these areas. Widespread microalgae growth on the surface of these sediments in 2018 (see Figure 9) provides further evidence that macroalgal production was being limited by physical conditions, not nutrient limitation.

Two other issues identified in the estuary but not captured by the OMBT score are: 1. Significant deposits of rotting beach-cast algae on the eastern shoreline, and: 2. Prolific growths of the green alga *Ulva* spp (which is very tolerant of low salinity) and *Gracilaria* growing within much of the sheltered shallow subtidal zone, and *Ulva* on cobbles in the lower estuary near Fortrose.

Beach cast material, deposited by wind and current action from other parts of the estuary, can have a significant impact on sediment quality where it decays and depletes underlying sediment oxygenation, and particularly where it results in the production of toxic sulphides.

Table 6. Summary of intertidal opportunistic macroalgal cover, Fortrose Estuary, Feb. 2018.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	243		
Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	7.1	0.758	Good
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	572.4	0.385	Poor
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	4154.9	0.160	Bad
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	29.3	0.338	Poor
Affected Area (use the lowest of the following two metrics)		0.624	Good
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	33.5	0.683	Good
Size of AA in relation to AIH (%) = (AA / AIH) x 100	13.8	0.624	Good
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.453**	Moderate

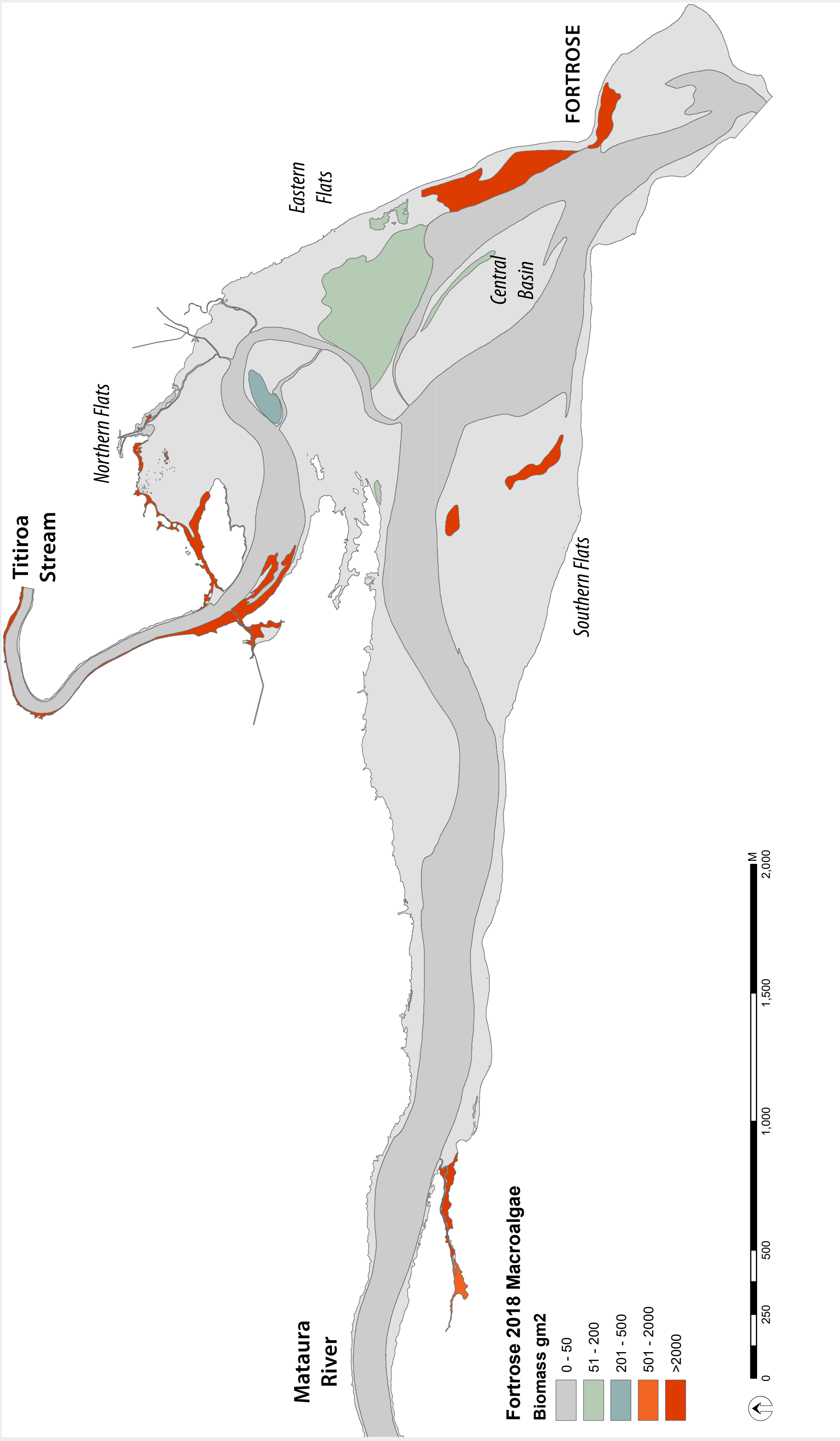


Figure 7. Map of Macroalgal Biomass (g.m^2), Fortrose Estuary, Feb. 2018.

3.7 CHANGES IN MACROALGAL COVER 2003-2018

Table 7 summarises the major changes in dense macroalgal cover since it was first assessed in 2003, with maps showing the spatial cover of macroalgae over the monitored period presented in Appendix 9 (see also Robertson et al. 2002, Stevens and Robertson 2009, 2010, 2011, 2012, 2013, 2016). Results show there was very little intertidal growth in 2003, but that by 2009, extensive areas were present. From 2009 to 2012 cover remained relatively consistent, anecdotal evidence suggesting variance was mostly due to flood related scouring of growths from the estuary. However in 2013 a significant increase in cover was evident that was accompanied by an increase in biomass (not measured). Between 2013 and 2016, biomass increased significantly, macroalgae became entrained in sediment, and there was a rapid deterioration of sediment quality in affected areas with the establishment of GEZs not previously present in the estuary. In 2018 lower density macroalgae had significantly decreased in the estuary compared to 2016, most likely as a result of physical scouring. Dense nuisance beds in sheltered areas were stable and remained similar in area to those mapped in 2016.

Table 7. Summary of intertidal opportunistic macroalgal cover, Fortrose Estuary, 2003-2018.

Year	% cover (Ha)		Result
	20-50%	>50%	
2003	<1	<1	Very little macroalgal growth present in the estuary.
2009	35	20	Widespread growth in central basin and eastern side of estuary. Little growth in the west and across the lower estuary, but localised concentrations of windblown algae.
2010	4	20	Most macroalgal growth and localised concentrations of windblown algae located on the Eastern Flats. Little growth across the north, west or lower estuary flats.
2011	1	12	Most extensive as windblown deposits on the Eastern Flats. Little growth across the north, west or lower estuary flats. Reduced cover in central basin.
2012	2	8	Little growth across the north, west or lower estuary flats. Low cover in central basin. Most extensive growths near river channel margins.
2013	38	23	Widespread growth in central basin and eastern side of estuary. Little growth in the west and across the lower estuary. Most extensive growths near river channel margins.
2016	38	17	Widespread growth in central basin and eastern side of estuary. Little growth in the west and across the lower estuary. Most extensive growths near river channel margins. Significant establishment of dense raised beds of entrained *Gracilaria* in sheltered areas, particularly near Titiroa Stream which were retaining substantial amounts of soft mud.
2018	2	16	Significant dense raised muddy beds of entrained *Gracilaria* in sheltered areas, particularly near Titiroa Stream. Low cover over most well flushed intertidal flats, but extensive microalgal growth present.

Subtidal growths of *Gracilaria* in Fortrose Estuary, Feb. 2018.

Figure 8. Photos illustrating the high biomass macroalgal cover in sheltered upper intertidal areas, Fortrose Estuary Feb. 2018.

Figure 9. Photos illustrating green microalgal growths on sandy sediments in the central basin of Fortrose Estuary, Feb. 2018.

3.8 GROSS EUTROPHIC ZONES

GEZs occur where there are elevated nutrient and organic concentrations and sediments exhibit combined symptoms of a high mud content, a shallow RPD (<1cm), and high macroalgal growth (>50% cover). These conditions will displace most sensitive estuarine animals and shellfish, and sediment anoxia will cause the release of nutrients previously bound in the sediments. As these nutrients will predominantly be released in the form of ammonia, which is much more readily available to fuel macroalgal growth, a cycle of increasing habitat deterioration can establish that is likely to be difficult to reverse. These conditions are most likely to be present in the sheltered tidal flats of an estuary which are often those most favourable for the growth of high value seagrass habitat. GEZs should not be present in short residence time estuaries (like Fortrose Estuary), with their presence providing a clear signal that the assimilative capacity of the estuary is being exceeded.

The extent of GEZs in the estuary have been assessed for each year in which full broad scale mapping has been undertaken (Table 8). In 2018 the GEZ extent was 9ha (3% of the estuary), a condition rating of "MODERATE". The GEZs are predominantly located in sheltered embayments in the upper tidal reaches (Figure 10) which provide good conditions for the growth of macroalgae. There are also sites in the central basin that have developed through the growth and subsequent decay of macroalgae causing underlying sediments to become highly enriched with sulphides.

Table 8. Gross eutrophic intertidal zones, Fortrose Estuary, 2003, 2013, 2016 and 2018.

Gross Eutrophic Zones	2003		2013		2016		2018	
	ha	%	ha	%	ha	%	ha	%
	not present		not present		8.3	3	9.0	3

Figure 10. Location of gross eutrophic zones, Fortrose Estuary, Feb. 2018.

3.9 CHANGES IN GROSS EUTROPHIC CONDITIONS 2003-2018

Table 8 shows a shift from no GEZs in 2003 or 2013, to 8-9ha of stable and persistent GEZs in 2016-2018. The increase in GEZ from 2013 to 2018 reflects a change rating of "POOR".

3.10 INTERTIDAL SEAGRASS COVER

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. Seagrass meadows are also a major source of detrital material, and the bacteria and fungi that decompose this material contribute significantly to the sediment nitrogen pool supporting macroalgal growth and provide a food source for zooplankton, macrofauna and other species. Although tolerant of a wide range of conditions, seagrass is vulnerable in particular to fine sediment, excessive nutrients, and low sediment oxygenation (especially where sediments are rich in sulphides).

Because of the strong riverine influence, Fortrose Estuary is not expected to have historically supported extensive seagrass beds, although seagrass would have been much more common on the relatively sheltered intertidal flats in the lower estuary than it currently is. The remaining seagrass beds are shown in Figure 11. The results of the 2018 intertidal seagrass survey showed that <0.1% (0.2ha) of the estuary had dense (>50%) seagrass cover. No beds of lower density seagrass were observed.

Figure 11. Location of seagrass beds, Fortrose Estuary, Feb. 2018.

3.11 CHANGES IN INTERTIDAL SEAGRASS COVER 2003-2018

A comparison of seagrass area with >20% cover in 2003 and 2018 shows a decrease in seagrass cover of 0.3ha, a 33% loss that is directly attributable to displacement by excessive macroalgal growth and poor sediment conditions evident since 2013, a condition rating of "POOR". The largest losses of seagrass have been on the northern flats where beds have reduced by ~80% with only two small patches remaining.

Macroalgae in the upper northern flats, Feb. 2018, an area dominated by *Zostera* in 2013.

Healthy raised *Zostera* beds on the south side of the Mataura River.

Sediment covered *Zostera* on the northern flats - part of a large healthy bed in 2016.

Zostera in the embayment on the south of the Mataura River where stream flows flush sediment away.

Gracilaria displacing *Zostera* on the northern flats.

Sediment and macroalgal impacted *Zostera* in the embayment on the south of the Mataura River.

Residual shoots of a once dense *Zostera* bed on the northern flats now dominated by *Gracilaria*.

Figure 12. Examples of seagrass beds in Fortrose Estuary, Feb. 2018.

3.12 SALTMARSH EXTENT

Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, and provides an important habitat for a variety of species including fish and birds. Saltmarsh generally has the most dense cover in the sheltered and more strongly freshwater influenced upper estuary, and is relatively sparse in the lower (more exposed and saltwater dominated) parts of the estuary, with the lower extent of saltmarsh growth limited for most species to above the height of mean high water neap (MHWN).

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 9 and Figure 13 summarise the 2018 saltmarsh mapping results. Overall, 15% of the estuary (74ha) was classified as saltmarsh, a condition rating of "GOOD".

Table 9. Summary of saltmarsh cover, Fortrose Estuary, Feb. 2018.

Saltmarsh Class, Dominant and subdominant species	Ha	%
Scrub	0.6	0.8
Ulex europaeus (Gorse)		
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.6	0.8
Estuarine Shrub	6.6	8.9
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.0	0.0
Apodasmia similis (Jointed wirerush)	1.2	1.6
Festuca arundinacea (Tall fescue)	5.4	7.3
Grassland	10.9	14.7
Festuca arundinacea (Tall fescue)	0.4	0.5
Apodasmia similis (Jointed wirerush)	3.5	4.8
Plagianthus divaricatus (Saltmarsh ribbonwood)	2.0	2.7
Puccinella stricta (Salt grass)	1.1	1.5
Apodasmia similis (Jointed wirerush)	1.1	1.5
Festuca arundinacea (Tall fescue)	1.5	2.1
Selliera radicans (Remuremu)	1.3	1.7
Rushland	55.1	74.4
Apodasmia similis (Jointed wirerush)	7.8	10.5
Eleocharis acuta (Spike sedge)	0.5	0.7
Festuca arundinacea (Tall fescue)	19.6	26.4
Phormium tenax (New Zealand flax)	3.3	4.5
Plagianthus divaricatus (Saltmarsh ribbonwood)	23.1	31.2
Puccinella stricta (Salt grass)	0.7	1.0
Sedgeland	0.005	0.01
Schoenoplectus pungens (Three-square)	0.005	0.01
Herbfield	0.9	1.2
Samolus repens (Primrose)	0.1	0.1
Leptinella dioica	0.01	0.02
Selliera radicans (Remuremu)	0.1	0.1
Selliera radicans (Remuremu)	0.03	0.04
Samolus repens (Primrose)	0.8	1.1
Total	**74.1**	**100**

Saltmarsh was dominated by rushland (74%) comprising relatively wide beds of jointed wire rush in the high tide range of the upper estuary, with smaller stands of spike sedge commonly growing in narrow bands along the river margins. Most rushland was growing within firm sandy muds, although the seaward edge of saltmarsh in the northern flats, where persistent macroalgal beds have established, was relatively muddy. Grassland (salt grass and tall fescue) was also prominent (15%), and combined with estuarine shrubs and scrub (10%), was the dominant habitat feature of saltmarsh at the upper tidal fringe. Because Fortrose has a strong freshwater influence, and because freshwater floats on seawater, the upper tidal reaches of the estuary are predominantly inundated with brackish water rather than full strength seawater. Consequently, these upper tidal areas reflect a less obvious delineation between saltmarsh vegetation and salt intolerant species than is evident in other estuary types. These areas support an increased presence of transitional species like tall fescue. The extensive drainage of low lying land surrounding the estuary also exacerbates the shift towards saltmarsh mixed with terrestrial vegetation.

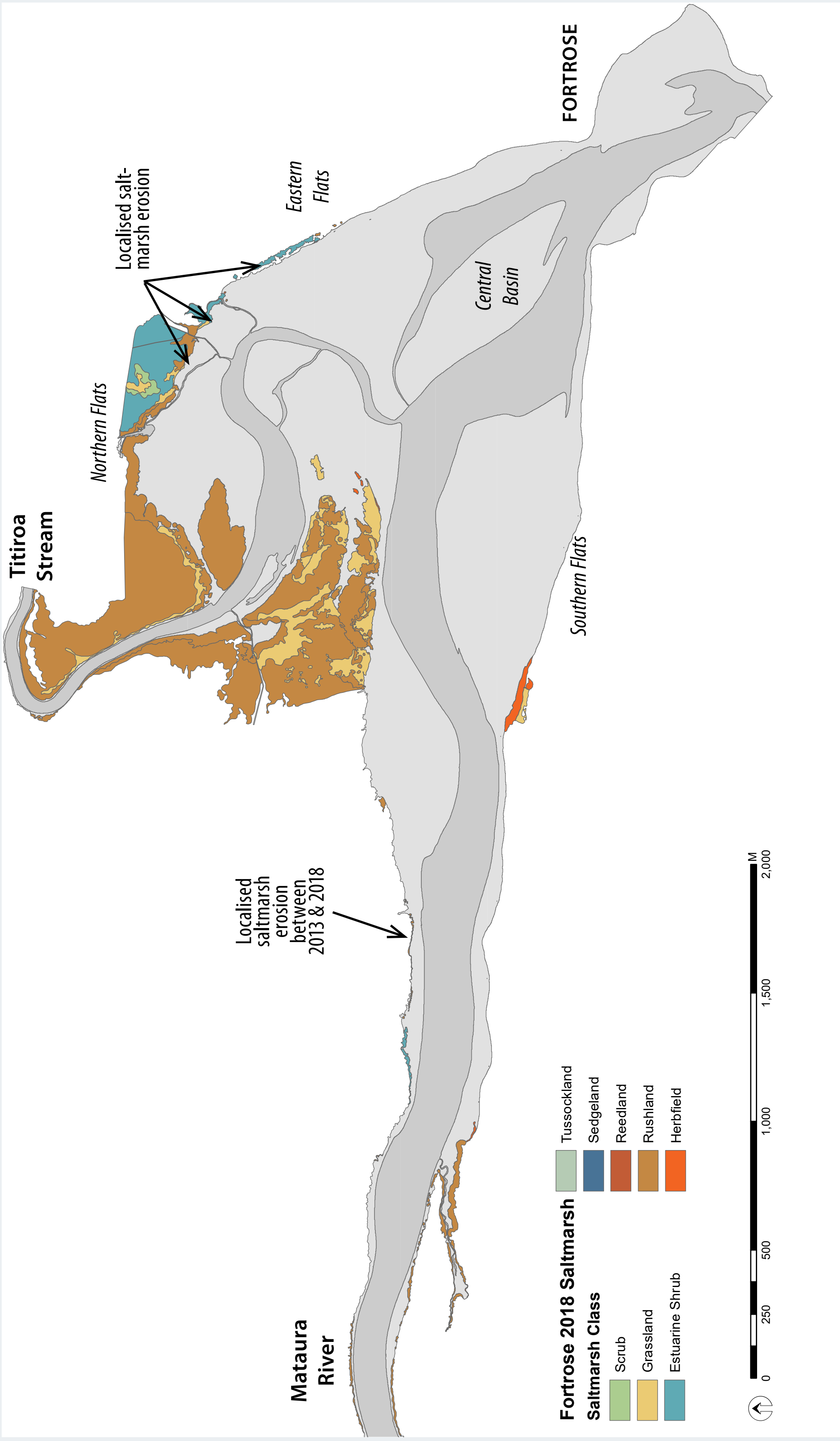


Figure 13. Map of dominant intertidal saltmarsh, Fortrose Estuary, Feb. 2018.

A supporting measure for saltmarsh is estimated loss compared to natural state cover. While assumptions need to be made regarding likely historical extent, Stevens and Robertson (2016) estimated that ~75% of saltmarsh had been lost through drainage and conversion to grassland, a supporting risk rating of "POOR".

Historical land clearance and margin development, particularly drainage, reclamation and channelisation of the many small freshwater inflows and inlets around the estuary edge, has greatly diminished the extent and cohesiveness of the saltmarsh remaining in the estuary and significantly reduced the capacity of the estuary to assimilate sediment and nutrient inputs. This has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary. Because much of the estuary is now surrounded by pasture, terrestrial weeds have infiltrated previously native-dominated saltmarsh areas and become well established. The extensive development of estuary margins places a high importance on the protection and enhancement of remaining saltmarsh areas. In particular, the capacity of estuary saltmarsh to migrate inland in response to predicted sea level rise is significantly constrained by past modification, and future losses are expected if the current approach to the management of these areas continues.

3.13 CHANGES IN INTERTIDAL SALTMARSH COVER 2003-2018

The condition rating for saltmarsh measures a percentage change from an established baseline. Based on the summary information in Table 10, and using 2003 data as a baseline, the 2018 saltmarsh extent has reduced by 9ha (11%), a change rating of "MODERATE".

Table 10. Summary of changes in saltmarsh extent - 2003, 2013 and 2018.

Vegetation Class	2003		2013		2018	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Scrub	0.8	0.9	0.1	0.2	0.6	0.8
Estuarine Shrub	2.7	3.2	2.5	3.1	6.6	8.9
Grassland	21.8	26.2	21.1	25.7	10.9	14.7
Rushland	56.9	68.3	57.2	69.7	55.1	74.4
Sedgeland	0.03	0.03	0.03	0.0	0.005	0.0
Herbfield	1.1	1.3	1.1	1.4	0.9	1.2
TOTAL	83.3	100	82.1	100	74.1	100

This reflects a significant reduction in the remaining saltmarsh habitat considering the extensive saltmarsh losses in the estuary that occurred prior to the 2003 baseline being established. The changes since 2003 primarily reflect ongoing drainage and conversion of grassland/tussock and rushland to terrestrial grassland at the edges of the estuary, with the most extensive changes occurring near the Titiroa Stream where the largest area of saltmarsh remains. These areas, no longer regularly inundated by saline water, have become functionally terrestrial. Several small areas of saltmarsh have also been eroded by hydraulic scouring from river flows, or by wind generated waves (Figure 14). While localised in extent, the loss of vegetation and the steep edges formed create an increased risk of further erosion in these areas.

Rushland eroded by river flows on the north side of the Mataura River.

Saltmarsh fringe along the east of Fortrose Estuary.

Rushland eroded by waves on the east side of the northern flats.

Terrestrial grass established among rush and estuary shrubland near Titiroa Stream.

Rushland eroded by waves on the east side of the northern flats.

Terrestrial grass established within a narrow band of herbfield in the central basin.

Figure 14. Examples of saltmarsh features in Fortrose Estuary, Feb. 2018.

3.14 200m TERRESTRIAL MARGIN

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species including whitebait, provides shade to help moderate temperature fluctuations in smaller tributaries, and improves estuary biodiversity.

The results of the 200m terrestrial margin mapping of the estuary presented in Table 11 and Figure 15 show just 4% of the margin remains densely vegetated (scrub, shrub and rush), a condition rating of "POOR". The majority of the 200m margin was grassland (66%), predominantly high producing pasture. Grazing to the estuary edge along much of the northwestern part of the estuary means there is very little capacity to filter sediment and nutrients, and there is now little natural erosion protection of stream banks. The drainage and loss of most lowland wetlands also means the vulnerability of the estuary to floods is much greater than in the past, while sediment and nutrient assimilation is much reduced and overall ecological values have been significantly compromised. To the east of the estuary, margin vegetation contained a range of introduced weeds with the natural sequence of estuarine to terrestrial vegetation intersected by the road creating a significant barrier to the estuary responding naturally to predicted sea level rise.

Dune habitat (25%) remains a significant feature around the south and east margins of the lower estuary. While dominated by the introduced marram grass these areas contains some impressive habitat dominated by native species (see photos below).

Overall, the terrestrial margin is highly developed and retains very few unmodified habitat features that are in their natural state. Since the margin was first mapped in 2013, there has been a decrease in scrub cover in the west, and an expansion of pasture to near the estuary edge, indicating ongoing reductions in the small extent of remaining dense vegetative cover.

Native pingao (left) and cushion plant (right) growing along the southern shore of the estuary. Lower photo shows introduced marram grass growing along the road edge near Fortrose.

Table 11. Summary of the 200m terrestrial margin, Fortrose Estuary, Feb. 2018.

Dominant 200m terrestrial margin cover	2018 %
Scrub	0.9
Estuarine Shrub	0.7
Rushland	2.2
Duneland	25.3
Water	1.1
Grassland	65.9
Transport Infrastructure	1.0
Residential	3.0
% Dense vegetated 200m margin	**4%**

Grazed tall fescue grassland extending to the northern edge of the estuary (left) and depleted grass land in the south west of the estuary.

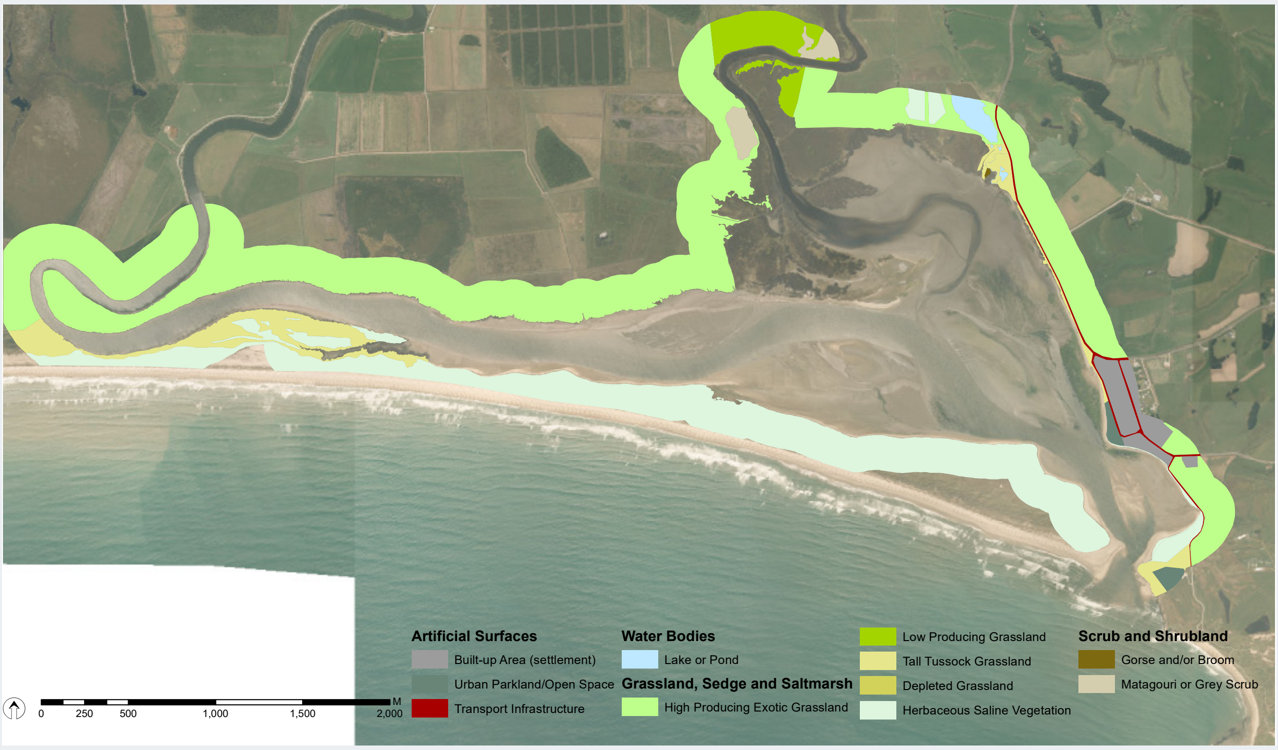
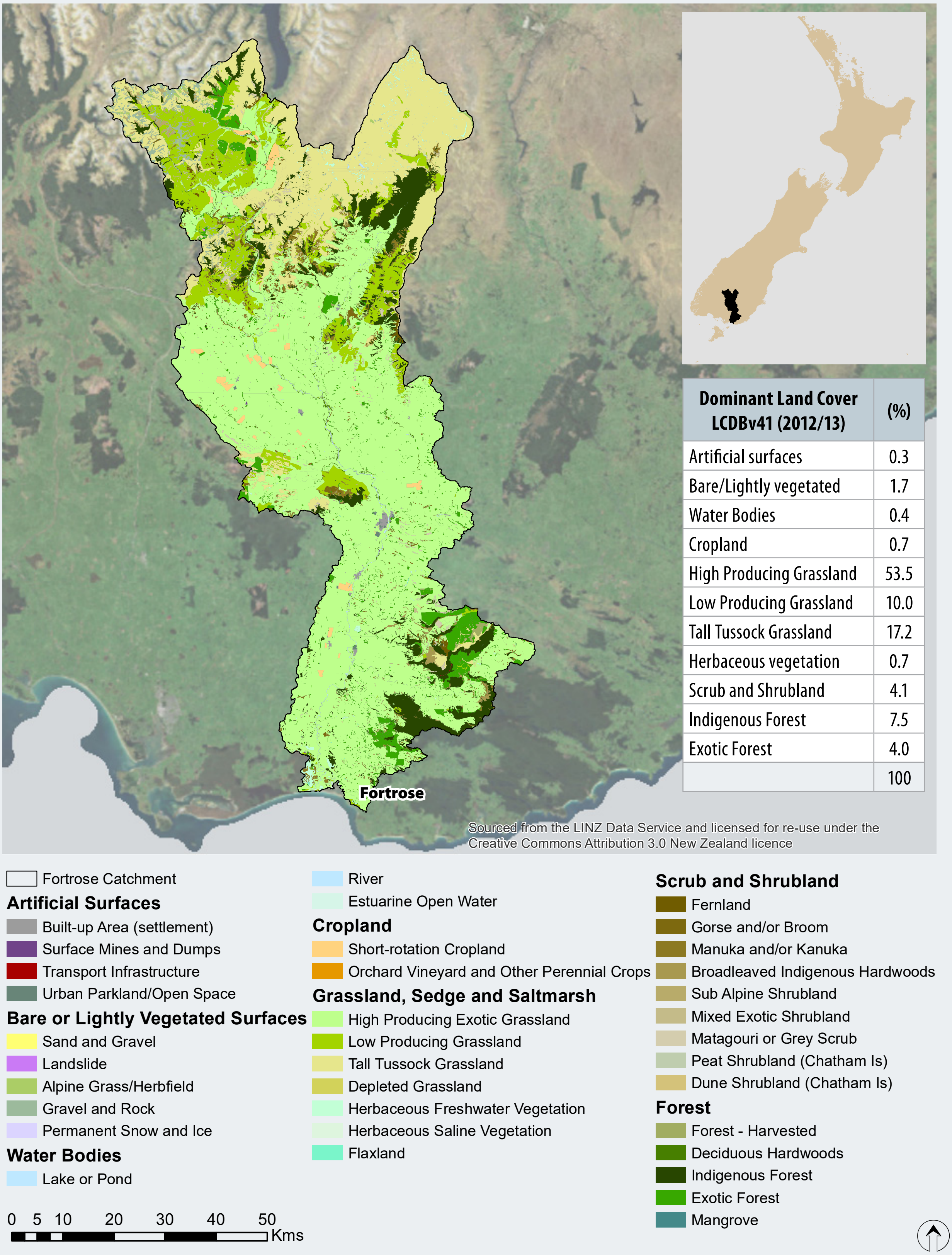


Figure 15. Map of dominant 200m terrestrial margin land cover - Fortrose Estuary, Feb. 2018.

Catchment scale land cover, shown in Figure 16, highlights the presence of extensive pasture (54% high producing and 10% low producing) and tall tussock grassland (17%), with native forest (8%), exotic forest cover (4%), and scrub/shrub cover all relatively low (source LCDBv41, 2012/13). The significant modification of the catchment from its natural state, and intensive farming within it, greatly increase the risk of inputs of sediments, nutrients and disease causing organisms exceeding the estuary's capacity to readily assimilate them.



Dominant Land Cover LCDBv41 (2012/13)	(%)
Artificial surfaces	0.3
Bare/Lightly vegetated	1.7
Water Bodies	0.4
Cropland	0.7
High Producing Grassland	53.5
Low Producing Grassland	10.0
Tall Tussock Grassland	17.2
Herbaceous vegetation	0.7
Scrub and Shrubland	4.1
Indigenous Forest	7.5
Exotic Forest	4.0
	100

Figure 16. Summary of Catchment Land Cover (LCDBv41 2012/13), Fortrose Estuary.

3. RESULTS AND DISCUSSION (CONT...)

3.15 NZ ESTUARY TROPHIC INDEX

The NZ ETI (Robertson et al. 2016a,b) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness. An integrated online calculator is available [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/] to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary), as well as trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]. The more indicators included, the more robust the ETI score becomes. Where established ratings are not yet incorporated into the NIWA ETI online calculator they can be included via spreadsheet calculator. It is also noted that improvements made to the ETI calculator may alter scores presented using earlier iterations.

The indicators used to derive an ETI score for Fortrose Estuary are presented in Table 12 using the broad scale monitoring results presented in this report. Because the fine scale monitoring sites in the estuary are both located in well flushed intertidal flats, they do not reflect conditions in the most degraded 10% of the estuary, the area intended for assessment using the ETI. Consequently, fine scale data from these locations have not been used.

ETI Tool 1 rates the nutrient load susceptibility as “VERY HIGH”.

ETI Tool 2 rates eutrophic symptom scores as “HIGH”.

The ETI score highlights the presence of significant eutrophication symptoms in the estuary.

Table 12. Primary and supporting indicator values used to calculate an ETI score for Fortrose Estuary, Feb.2018.

PRIMARY SYMPTOM INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)				Primary Symptom Value	Primary Symptom Score
Required	Opportunistic Macroalgae	OMBT EQR	shallow intertidal	0.453	11
Required	Macroalgal GEZ %	% Gross Eutrophic Zone (GEZ)/Estuary Area	shallow intertidal	3	7
Required	Macroalgal GEZ Ha	Ha Gross Eutrophic Zone (GEZ)	shallow intertidal	9	10
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	-	-
Optional	Cyanobacteria (if issue identified) NOTE ETI rating not yet developed		water column	-	-
SUPPORTING INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)				**Supporting Indicator Value**	**Supporting Indicator Score**
Required Indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	-	-
Required Indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow intertidal	21	13
Required Indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow intertidal	50	14
Required Indicators	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	-	-
Required Indicators	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	-	-
Required Indicators	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	-	-
Optional Indicators	Muddy sediment	Proportion of estuary area with >25% mud content	shallow intertidal	13	12
Optional Indicators	Sedimentation Rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL)	shallow intertidal	-	-
Optional Indicators	Dissolved oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) ($mg.m^3$)	water column	-	-
NZ ETI Score		**Final Primary Indicator Score**			11
		Final Supporting Indicator Score			13
		ETI SCORE		**0.75**	
		ETI BAND		**HIGH**	

4. SUMMARY AND CONCLUSIONS

Fortrose Estuary has been identified by ES as a priority for monitoring, and is a key part of ES's coastal monitoring programme. The estuary is large, has moderate ecological and human use values (particularly whitebaiting), is rated as of outstanding importance in the "Wetlands of National Significance to Fisheries Database", and is internationally recognised as part of the 'Awarua wetland complex' in the Ramsar convention list. Broad scale mapping of Fortrose Estuary was first undertaken in February 2003 and has been repeated in 2013, 2016 (limited survey) and 2018. Macroalgal mapping was also undertaken annually in February from 2009 to 2013 inclusive. As far as practicable, standardised extents and classifications have been applied when comparing changes in the estuary over time. To achieve this, the spatial extent of broad scale mapping has been standardised across all surveys in Fortrose Estuary by matching the 2018 coverage to that mapped in 2003, 2013 and 2016 as closely as possible. At the same time, improvements in mapping classifications have been retrospectively applied. For example, the substrate beneath macroalgal beds was not recorded in 2003 (and was therefore not included in estimates of mud extent), but has been subsequently added based on field notes, photographs and expert judgement. As a result, some of the summary data presented in Table 13 below varies slightly from that presented in the original reports.

Table 13. Summary of macroalgal cover, EQR , soft mud, oxygenation, GEZ, and seagrass, Fortrose Estuary, 2003-2018.

Condition (Impairment) Band			No Rating	Band A - Very Low		Band B - Low		Band C - Moderate		Band D - High	
Year	NZ ETI Score	Macroalgae		Soft Mud		Low Sed O_2 Zone		GEZ		Seagrass >20%	
		Cover >50% Ha	EQR Score	Ha	%	Ha	%	Ha	%	Ha	% loss
2003	na	<1	0.9*	24.7	10.2%	na	na	0	0	0.3	baseline
2009	na	20	na	na	na	na	na	na	na	na	na
2010	na	20	na	na	na	na	na	na	na	na	na
2011	na	12	na	na	na	na	na	na	na	na	na
2012	na	8	na	na	na	na	na	na	na	na	na
2013	na	23	na	60.6	24.9%	na	na	0	0	0.5	0%
2016	0.77	17	0.447	27.8	11.4%	57	23%	8.4	3.5%	0.3	0%
2018	0.75	16	0.453	31.4	13.0%	50	21%	9.0	3.7%	0.2	33%

*Estimated following reanalysis of existing data. '-' = data not available or not assessed.
NOTE: % cover calculations are determined using the area of intertidal flats (i.e. excludes saltmarsh and subtidal water).

- In February 2003, <1% of the estuary was assessed as having high density macroalgal cover (i.e. >50% cover). Soft mud was prominent and covered 24ha (10%) of the estuary. While not formally assessed at the time, gross eutrophic zones (GEZs) were unlikely to have been present.
- Annual monitoring of macroalgal cover between 2009 and 2013, showed relatively consistent high density cover of 8-23ha but few indications of intertidal nuisance conditions developing.
- Repeat broad scale monitoring in 2013 showed a significant expansion of soft mud cover to 61ha, likely as a result of recent flood deposition, but no GEZs. Seagrass had not declined from the baseline, with reported increases more likely to reflect improved measurement in 2013.
- Monitoring in February 2016 showed identified the presence of GEZs in sheltered embayments, a decrease in sediment oxygenation, and the establishment of persistent nuisance macroalgal beds. Seagrass had declined slightly by 0.2ha (a 40% loss since 2013), displaced by dense macroalgae. A significant reduction in soft mud (33ha) was recorded between 2013 and 2016 highlighting the dynamic deposition and erosion processes in a large tidal river estuary.
- From 2016 to 2018 there was little change in soft mud, macroalgal cover, low sediment oxygenation and GEZs. Seagrass had decreased further, displaced by dense macroalgae and muds. Persistent high biomass nuisance macroalgal beds remained in the estuary. The 2018 ETI score of 0.75 (Band D) shows the estuary is expressing significant adverse symptoms of nutrient enrichment.

The results highlight the establishment of persistent high density (>50% cover) opportunistic macroalgal beds, combined with soft, poorly oxygenated mud. From 2003 to 2018 there has also been a net trend of increasing GEZ and decreasing seagrass and saltmarsh. The estuary is in a "MODERATE" but declining condition in relation to eutrophication, muddiness, and habitat loss.

5. RECOMMENDED MONITORING

Future monitoring recommendations are as follows:

Broad Scale Habitat Mapping
To characterise any issues of change in habitat (e.g. soft mud extent, salt marsh or seagrass area) it is recommended that broad scale habitat mapping needs be reviewed at five yearly intervals (next scheduled for consideration in 2023), or undertaken at least every 10 years.

Macroalgae
Because of the significant growth and impact of nuisance macroalgae in the estuary it is recommended that ES continues with the programme of annual broad scale mapping of macroalgae in February/March each year. To better characterise the trophic status and support the use of the ETI, the establishment of a fine scale site in an area representing the worst 10% of estuary sediment is recommended.

Sedimentation Rate Monitoring
Because sedimentation is a priority issue in the estuary it is recommended that all sediment plate depths be measured annually and that grain size samples be collected. Establishment of sediment plates at fine scale Site A in the central basin of the estuary is also recommended.

Fine Scale Monitoring
To characterise changes in sediment physical, chemical and biological condition it is recommended that fine scale monitoring be repeated at 5 yearly intervals following establishment of a baseline. It is also recommended that a high level review of the fine scale sampling programme be undertaken to ensure current sampling and analysis is providing ES with the information required for effective estuary management.

6. RECOMMENDED MANAGEMENT

The primary drivers of the decline in estuary condition identified in this report are almost certainly related to elevated catchment inputs of nutrients and fine sediments, and nutrient inputs in particular need to be reduced below current levels to achieve a more moderately enriched estuary and to protect it from further degradation.

To address these issues, it has been recommended that appropriate catchment nutrient and sediment guideline criteria be developed for each estuary type in Southland, and that these guideline criteria are then used to assess the extent to which catchment loads meet these guidelines. This work is currently underway under a range of ES initiatives. The key steps in such an approach are as follows:

- Assign catchment nutrient and sediment load guideline criteria to each Southland estuary (using criteria appropriate to each type of estuary e.g. Robertson et al. 2017). Guideline criteria should be based on available catchment load/estuary response information from relevant estuaries, in this case SSRTREs.
- Estimate catchment nutrient and suspended sediment loads to each estuary using available catchment models and stream monitoring data.
- Determine the extent to which each estuary meets guideline catchment load criteria.
- Rank estuaries according to exceedance of recommended guideline criteria.
- Assess the potential for requiring more detailed assessments of priority estuaries (e.g. estuary response modelling, stream and tributary monitoring, catchment load modelling).
- Develop plans for restoration of priority estuaries.

Overall, if the approach is followed, and the estuary and its surroundings are managed to ensure that the assimilative capacity is not exceeded, then there is a strong expectation that the condition of the estuary will steadily improve and provide sustainable human use and ecological values in the long term.

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APPENDIX 1. SUMMARY OF THE MAJOR ENVIRONMENTAL ISSUES AFFECTING MOST NEW ZEALAND ESTUARIES.

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007, 2010, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension of fine sediments is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include;

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sediment Changes	Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
	Seagrass Area/biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Mud Content	Grain size - estimates the % mud content of sediment.
	Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
	Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
	Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

2. Eutrophication

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll a concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

APPENDIX 1. SUMMARY OF THE MAJOR ENVIRONMENTAL ISSUES AFFECTING MOST NEW ZEALAND ESTUARIES.

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003) and campylobacter. Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven and currently addressed by ES through their recreational bathing programme).

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).

5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
	Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
	Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

APPENDIX 2. NOTES SUPPORTING INDICATOR RATINGS (TABLE 1)

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change; Appendix 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "indicator ratings" have been proposed that assign a condition band (e.g. very good, good, moderate, poor) based on specific indicators of intertidal estuary condition (see Table 1). Each condition rating is designed to be used in combination with relevant information and other indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue e.g. community aspirations, cost/benefit considerations.
- That rating and ranking systems can easily mask or oversimplify results. For instance, significant changes can occur within the same condition band, but small changes near the edge of the band may shift the rating to the next band.
- Most issues will have a mix of primary and supporting indicators, primary indicators being given more weight in assessing the significance of results. It is noted that many supporting estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data and presented in the NZ Estuary Trophic Index (Robertson et al. 2016a and 2016b). However, where such data are lacking, or have yet to be processed, ratings have been proposed using professional judgement based on experience monitoring estuaries throughout NZ. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

Supporting notes explaining the use and justifications for each rating indicator are presented below. The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and, to a lesser extent, tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing. See Robertson et al. (2016a, 2016b) for further information supporting these ratings.

Soft Mud Percent Cover. Soft mud (>25% mud content) has been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are a sink for sediments, the presence of large areas of soft mud is likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, its presence indicates where changes in land management may be needed. If an estuary is suspected of being an outlier (e.g. has >25% mud content but substrate remains firm to walk on), it is recommended that the initial broad scale assessment be followed by particle grain size analyses of relevant areas to determine the extent of the estuary with sediment mud contents >25%.

Sedimentation Rate. Elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse, and indicate where changes in land use management may be needed. Note the very low risk category is based on a typical NZ pre-European average rate of <1mm/year, which may underestimate sedimentation rates in soft rock catchments.

Sedimentation Mud Content. Below mud contents of 20-30% sediments are relatively incohesive and firm to walk on. Above this, they become 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 concentrations, which typically increase with mud content, as do the concentrations of sediment bound nutrients and heavy metals. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, 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 resuspension of fine muds, impacting on seagrass, birds, fish and aesthetic values.

apparent Redox Potential Discontinuity (aRPD). aRPD depth, the transition between oxygenated sediments near the surface and deeper anoxic sediments, is a primary estuary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Knowing if the aRPD is close to the surface is important for two main reasons:

1. As the aRPD layer gets close to the surface, a "tipping point" is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and to worsen sediment conditions.
2. Anoxic sediments contain toxic sulphides and support very little aquatic life.

In sandy porous sediments, the aRPD layer is usually relatively deep (>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 and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

Opportunistic Macroalgae. The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic 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 Section 3 and Appendix 7), with results combined with those of other indicators to determine overall condition.

Gross Eutrophic Conditions. Gross eutrophic conditions occur when sediments exhibit combined symptoms of: a high mud content, a shallow Redox Potential Discontinuity (RPD) depth, elevated nutrient and total organic carbon concentrations, displacement of invertebrates sensitive to organic enrichment, and high macroalgal growth (>50% cover). Persistent and extensive areas of gross nuisance conditions should not be present in short residence time estuaries, and their presence provides a clear signal that the assimilative capacity of the estuary is being exceeded. Consequently, the actual area exhibiting nuisance conditions, rather than the % of an estuary affected, is the primary condition indicator. Natural deposition and settlement areas, often in the upper estuary where flocculation at the freshwater/saltwater interface occurs, are commonly first affected. The gross eutrophic condition rating is based on the area affected by the combined presence of poorly oxygenated and muddy sediments, and a dense (>50%) macroalgal cover.

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 is likely to indicate an increase in these types of pressures.

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. A supporting metric is also proposed of % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. The interim risk ratings proposed are Very Low≥80-100%, Low≥60-80%, Moderate≥40-60%, and High≤40%. The "early warning trigger" for initiating management action/further investigation is a trend of a decreasing saltmarsh area.

Vegetated Margin. The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the saltmarsh and estuary. This buffer is sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. It protects the estuary against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat. Reduction in the vegetated terrestrial buffer around the estuary is likely to result in a decline in estuary quality. The "early warning trigger" for initiating management action is <50% of the estuary with a densely vegetated margin.

Change from Baseline Condition. Where natural state conditions for high value habitat of seagrass, saltmarsh, and densely vegetated terrestrial margin are unknown it is proposed that % change from the first measured baseline condition be used to determine trends in estuary condition. It is assumed that increases in such habitat are desirable (i.e. represent a Very Low risk rating), and decreases are undesirable. For decreases, the interim risk ratings proposed are: Very Low≤5%, Low≥5-10%, Moderate≥10-20%, and High≥20%. For indicators of degraded habitat e.g. extent of soft mud or gross eutrophic conditions, the same interim risk rating bands are proposed, but are applied to increases in extent.

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APPENDIX 3. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

Vegetation was classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the two first letters of their Latin genus and species names e.g. marram grass, *Ammophila arenaria*, was coded as Amar. An indication of dominance is provided by the use of ( ) to distinguish subdominant species e.g. Amar(Caed) indicates that marram grass was dominant over ice plant (*Carpobrotus edulis*). The use of ( ) is not always based on percentage cover, but the subjective observation of which vegetation is the dominant or subdominant species within the patch. A measure of vegetation height can be derived from its structural class (e.g. rushland, scrub, forest).

VEGETATION (mapped separately to the substrates they overlie).

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.

Treeland: Cover of trees in the canopy is 20-80%. Trees are woody plants >10cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.

Scrub: Cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.

Shrubland: Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.

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

Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.

Grassland: Vegetation in which the cover of grass (excluding tussock-grasses) in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground.

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

Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Leptocarpus*.

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

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

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

Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and where lichen cover exceeds that of any other growth form or bare ground.

Introduced weeds: Vegetation in which the cover of introduced weeds in the canopy is 20-100% and in which the weed cover exceeds that of any other growth form or bare ground.

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

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

SUBSTRATE (physical and biogenic habitat)

Artificial structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

Cliff: A steep face of land which exceeds the area covered by any one class of plant growth-form. Cliffs are named from the dominant substrate type when unvegetated or the leading plant species when plant cover is ≥1%.

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

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

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

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

Mobile sand: Granular beach sand characterised by a rippled surface layer from strong tidal or wind-generated currents. Often forms bars and beaches.

Firm or soft sand: Sand flats may be mud-like in appearance but are granular when rubbed between the fingers and no conspicuous fines are evident when sediment is disturbed e.g. a mud content <1%. Classified as firm sand if an adult sinks <2 cm or soft sand if an adult sinks >2 cm.

Firm muddy sand: A sand/mud mixture dominated by sand with a moderate mud fraction (e.g. 1-10%), the mud fraction conspicuous only when sediment is mixed in water. The sediment appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm sandy mud, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers.

Firm sandy mud: A sand/mud mixture dominated by sand with an elevated mud fraction (e.g. 10-25%), the mud fraction visually conspicuous when walking on it. The surface appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers, but with a smoother consistency than firm muddy sand.

Firm or soft mud: A mixture of mud and sand where mud is a major component (e.g. >25% mud). Sediment rubbed between the fingers retains a granular component but is primarily smooth/silken. The surface appears grey or brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm sandy mud, and very soft mud. Classified as firm mud if an adult sinks <5 cm (usually if sediments are dried out or another component e.g. gravel prevents sinking) or soft mud if an adult sinks >5 cm.

Very soft mud: A mixture of mud and sand where mud is the major component (e.g. >50% mud), the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink >5 cm unless another component e.g. gravel prevents sinking. From a distance appears visually similar to firm muddy sand, firm sandy mud, and firm or soft mud. Sediment rubbed between the fingers may retain a slight granular component but is primarily smooth/silken.

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

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

Shell bank: Area that is dominated by dead shells.

APPENDIX 4. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

Sediment sampling and analysis

Grain size samples were collected from representative mud and sand habitats to validate substrate classifications by sampling a composite of the top 20mm of sediment (approx. 250gms in total) using a plastic trowel. Samples were placed inside a numbered plastic bag, refrigerated within 4 hours of sample collection before being frozen and sent by ES to R.J. Hill Laboratories for grain size analysis (% mud, sand, gravel). Details of lab methods and detection limits are presented in Appendix 5. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

Grain size results from representative sediments in Fortrose Estuary, February 2018.

Broad Scale Classification	Site #	% mud	% sand	% gravel	NZTM EAST	NZTM NORTH
Very soft MUD (vsm)	2018_01	84.4	15.5	0.1	1273905	4833932
Soft muddy SAND (sms)	2018_02	39.2	59.5	1.3	1274043	4833895
Firm muddy SAND (fms)	2018_03	15.3	83.6	1.1	1274303	4834045
Firm muddy SAND (fms)	2018_04	11.2	86.1	2.7	1275254	4834084
Firm muddy SAND (fms)	2018_05	14.8	85.0	0.2	1275877	4833798
Mobile SAND (ms)	2018_06	1.4	98.5	0.1	1278189	4833162
Very soft MUD (vsm)	2018_T1	73.6	25.9	0.5	1276581	4835111
Very soft MUD (vsm)	2018_T2	62.3	35.9	1.9	1276599	4835086
Very soft MUD (vsm)	2018_T3	48.2	51.6	0.2	1276617	4835063
Soft MUD (sm)	2018_T4	38.5	61.0	0.5	1276634	4835038
Firm sandy MUD (fsm)	2018_T5	26.2	71.2	2.6	1276651	4835013
Firm sandy MUD (fsm)	2018_T6	13.3	82.2	4.5	1276669	4834990
Firm sandy MUD (fsm)	2018_T7	15.2	83.4	1.4	1276685	4834966
Firm sandy MUD (fsm)	2018_T8	21.1	78.1	0.7	1276704	4834941
Firm sandy MUD (fsm)	2018_T9	26.1	73.1	0.8	1276722	4834916
Firm sandy MUD (fsm)	2018_T10	27.0	72.0	1.0	1276789	4834827
Firm muddy SAND (fms)	2018FS_A	5.9	72.4	21.7	1277225	4833804
Firm muddy SAND (fms)	2018FS_B	6.3	93.5	0.2	1277200	4834772

See Figure A1 (following page) for site locations.

Sampling resolution and accuracy

Broad scale mapping is intended to provide a rapid overview of estuary condition based on the mapping of features visible on aerial photographs, supported by ground-truthing to validate the visible features. The ability to correctly identify and map features is primarily determined by the resolution of the available photos, the extent of ground-truthing undertaken, and the experience of those undertaking the mapping.

The spatial accuracy of the subsequent digital maps is determined largely by the photo resolution and spatial accuracy of the orthorectified imagery. In most instances features with readily defined edges such as rushland, rockfields, dense seagrass etc. can be mapped at a scale of ~1:1000 to within 1-2m of their boundaries. The largest area for potential error is where boundaries are not readily visible on photographs e.g. sparse seagrass beds, or where there is a transition over a continuum between features, e.g. where firm muddy sands transition to soft muds. Defining such boundaries requires field validation. Extensive mapping experience has shown that such boundaries can be mapped to within ±10m where they have been thoroughly ground truthed using NEMP classifications.

Because of the inherent variation introduced when estimating boundaries not readily visible on photographs, or when grouping variable or non-uniform patches (e.g. seagrass), the overall broad scale accuracy is unlikely to be better than ±10% for such features.

Where initial broad scale mapping results indicate a need for greater resolution of boundaries (e.g. to increase certainty about the extent of soft mud areas), or to define changes within NEMP categories (e.g. to define the mud content within firm muddy sand habitat), then issue-specific approaches are recommended. The former includes more widespread ground-truthing, and the latter the use of transect or grid based grain size sampling.

APPENDIX 4. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

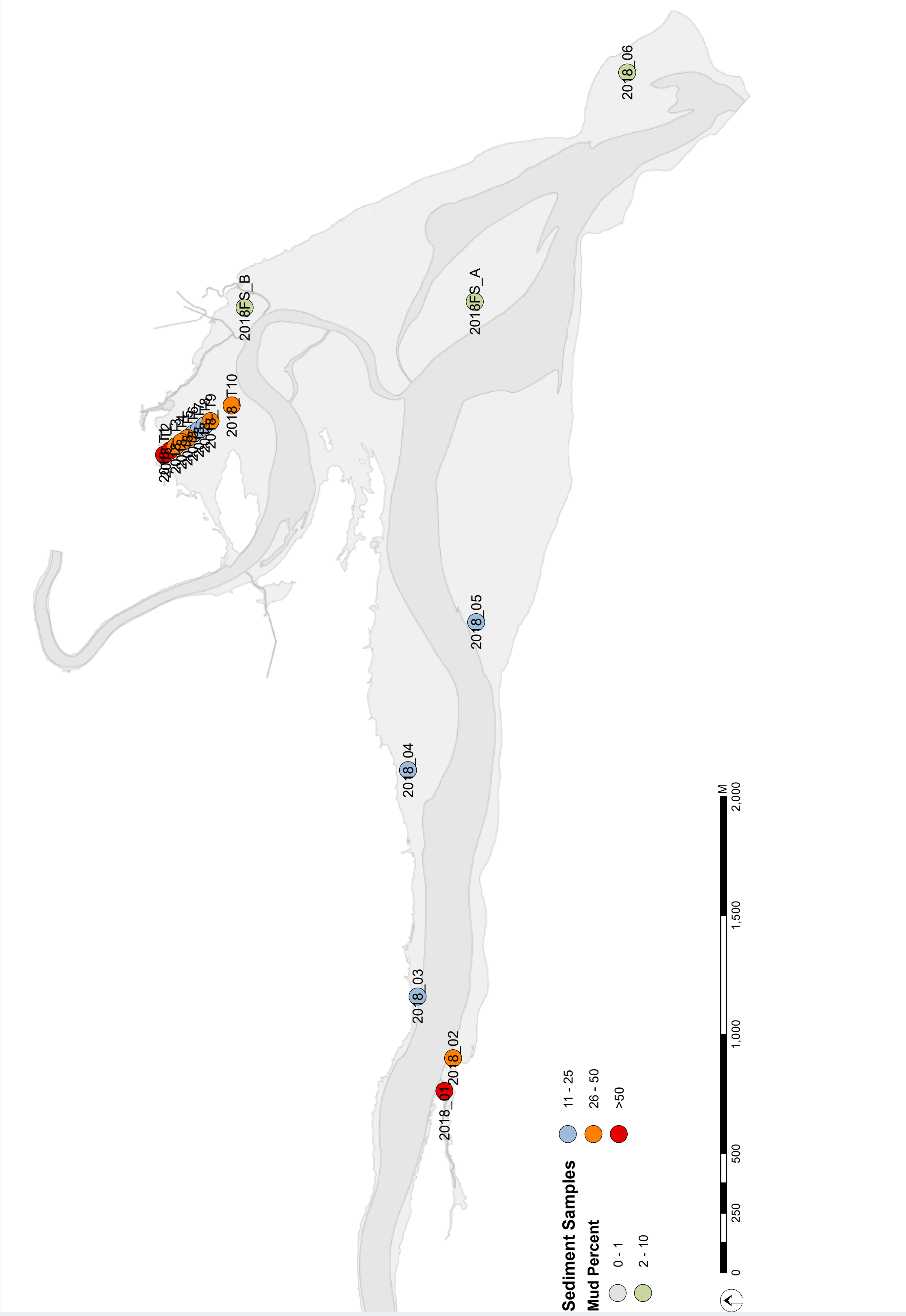

Figure A1. Location of grain size samples used in assessing Fortrose Estuary, Feb. 2018.

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Certificate of Analysis

SUPv1

Client:	Environment Southland	**Lab No:**	1940881
Contact:	Keryn Roberts	**Date Received:**	09-Mar-2018
	C/- Environment Southland	**Date Reported:**	04-May-2018
	Private Bag 90116	**Quote No:**	54752
	Invercargill 9840	**Order No:**	4060.1375.412
		Client Reference:	Fortrose Estuary Sediment Transect 1 on 18-Feb-2018
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		20180862 18-Feb-2018 3:00 pm	20180863 18-Feb-2018 3:10 pm	20180864 18-Feb-2018 3:20 pm	20180865 18-Feb-2018 3:25 pm
Lab Number:		1940881.1	1940881.2	1940881.3	1940881.4
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	62	79	82	82
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	1.3	1.1	2.7
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	15.5	59.5	83.6	86.1
Fraction < 63 µm*	g/100g dry wt	84.4	39.2	15.3	11.2

Sample Name:		20180866 18-Feb-2018 3:30 pm	20180867 18-Feb-2018 3:45 pm		
Lab Number:		1940881.5	1940881.6		
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	82	82	-	-
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	0.2	0.1	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	85.0	98.5	-	-
Fraction < 63 µm*	g/100g dry wt	14.8	1.4	-	-

The reported uncertainty is an expanded uncertainty with a level of confidence of approximately 95 percent (i.e. two standard deviations, calculated using a coverage factor of 2). Reported uncertainties are calculated from the performance of typical matrices, and do not include variation due to sampling.

For further information on uncertainty of measurement at Hill Laboratories, refer to the technical note on our website: www.hill-laboratories.com/files/Intro_To_UOM.pdf, or contact the laboratory.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
3 Grain Sizes Profile*		0.1 g/100g dry wt	1-6
3 Grain Sizes Profile			
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-6
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

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Certificate of Analysis

Client:	Environment Southland	**Lab No:**	1940893 SUPv1
Contact:	Keryn Roberts	**Date Received:**	09-Mar-2018
	C/- Environment Southland	**Date Reported:**	08-May-2018
	Private Bag 90116	**Quote No:**	54752
	Invercargill 9840	**Order No:**	4060.1375.412
		Client Reference:	Fortrose Estuary Sediment Plate Transect_Northern Flats on 27-Fe
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		20180868 27-Feb-2018 3:30 pm	20180869 27-Feb-2018 3:35 pm	20180870 27-Feb-2018 3:40 pm	20180871 27-Feb-2018 3:45 pm
Lab Number:		1940893.1	1940893.2	1940893.3	1940893.4
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	71	73	77	78
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	0.5	1.9	0.2	0.5
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	25.9	35.9	51.6	61.0
Fraction < 63 µm*	g/100g dry wt	73.6	62.3	48.2	38.5

Sample Name:		20180872 27-Feb-2018 3:46 pm	20180873 27-Feb-2018 3:50 pm	20180874 27-Feb-2018 3:55 pm	20180875 27-Feb-2018 3:59 pm
Lab Number:		1940893.5	1940893.6	1940893.7	1940893.8
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	81	82	81	82
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	2.6	4.5	1.4	0.7
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	71.2	82.2	83.4	78.1
Fraction < 63 µm*	g/100g dry wt	26.2	13.3	15.2	21.1

Sample Name:		20180876 27-Feb-2018 4:00 pm			
Lab Number:		1940893.9			
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	83	-	-	-
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	0.8	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	73.1	-	-	-
Fraction < 63 µm*	g/100g dry wt	26.1	-	-	-

The reported uncertainty is an expanded uncertainty with a level of confidence of approximately 95 percent (i.e. two standard deviations, calculated using a coverage factor of 2). Reported uncertainties are calculated from the performance of typical matrices, and do not include variation due to sampling.

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Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			

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The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

APPENDIX 6. GROUND-TRUTHING

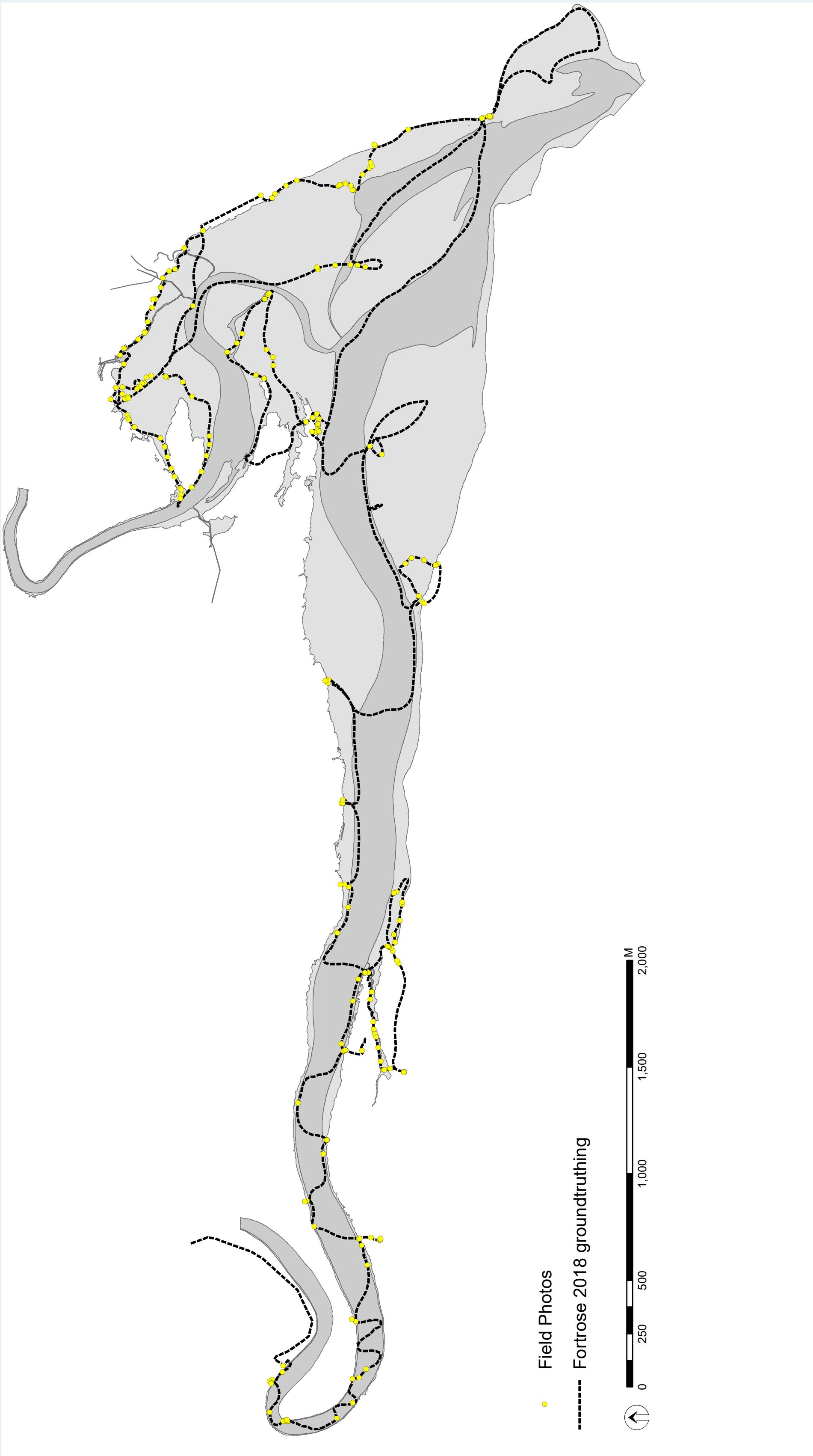

Figure A2. Fortrose Estuary - showing 2018 ground truthing coverage and location of field photos.

APPENDIX 7. 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 with 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 water body. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worst 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 (percentage 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: Because the OMBT has been developed to classify data over the maximum growing season, sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, therefore 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.

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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 A2).

- **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 potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

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

Table A2. The final face value thresholds and metrics for levels of ecological quality status in the UK-WFD 2014.

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥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) of >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 >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

APPENDIX 7. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

EQR calculation

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

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2

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 A3).

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 A3 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.

References

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APPENDIX 7. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

Table A3. 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

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

Table A4. The final face value thresholds and metrics for levels of ecological quality status used to rate opportunistic macroalgae in the current in the study (modified from UK-WFD 2014).

MACROALGAL INDICATORS (OBMT approach - WFD_UKTAG 2014)					
QUALITY RATING	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥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} wet wgt) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^{2} wet wgt) 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 is used in the final EQR calculation.

APPENDIX 8. FORTROSE ESTUARY 2018 MACROALGAL DATA

Macroalgal cover >5% used in calculating the OMBT EQR (see Figure A3 on the following page for locations).

Patch ID	Dominant species	Patch area (ha)	Percent cover of macroalgae	Presence (1) or absence (0) of entrained algae	Mean Biomass (g.m-2 wet weight)	Total Patch Biomass (kg wet weight)	Presence (1) or absence (0) of RPD <0.5cm	Presence (1) or absence (0) of soft mud
1	ulsp grch	0.5	70	1	1200	6165	1	1
2	grch	0.8	90	1	9000	76476	1	1
3	ulsp	0.04	100	0	120	54	0	0
4	ulin	0.5	100	1	6000	28863	1	1
5	ulin	1.1	100	1	4000	43223	1	0
6	grch	0.2	25	0	100	164	0	0
7	grch	0.001	100	1	10000	61	1	1
8	grch	1.4	20	1	400	5510	0	0
9	grch	15.7	10	0	150	23501	0	0
10	ulin	0.7	10	0	100	695	1	1
11	ulin	0.6	100	0	120	744	0	0
12	ulin	6.5	100	0	2500	161626	0	0
13	grch	3.6	100	1	20000	721634	1	1
14	grch	1.2	100	1	20000	235148	1	1
15	grch ulin	0.1	50	1	500	565	0	1
16	grch	0.5	100	1	15000	81507	1	1
17	grch	0.04	80	1	9000	3819	1	1
18	grch	0.04	80	1	3500	1291	1	1

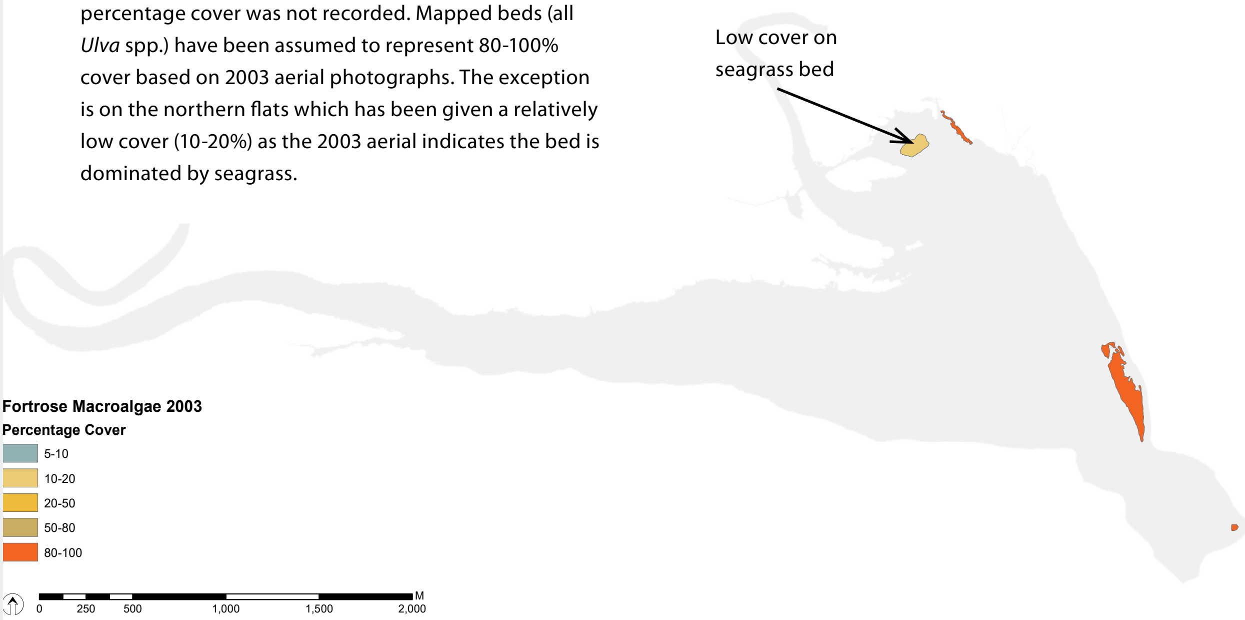
grch= *Gracilaria chilensis*, ulsp= *Ulva lactuca* or *Ulva intestinalis*

APPENDIX 8. FORTROSE ESTUARY 2018 MACROALGAL DATA

Figure A3. Location of macroalgal patches (>5% cover) used in assessing Fortrose Estuary, Feb. 2018.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018

In 2003 the extent of macroalgal beds was mapped but percentage cover was not recorded. Mapped beds (all *Ulva* spp.) have been assumed to represent 80-100% cover based on 2003 aerial photographs. The exception is on the northern flats which has been given a relatively low cover (10-20%) as the 2003 aerial indicates the bed is dominated by seagrass.



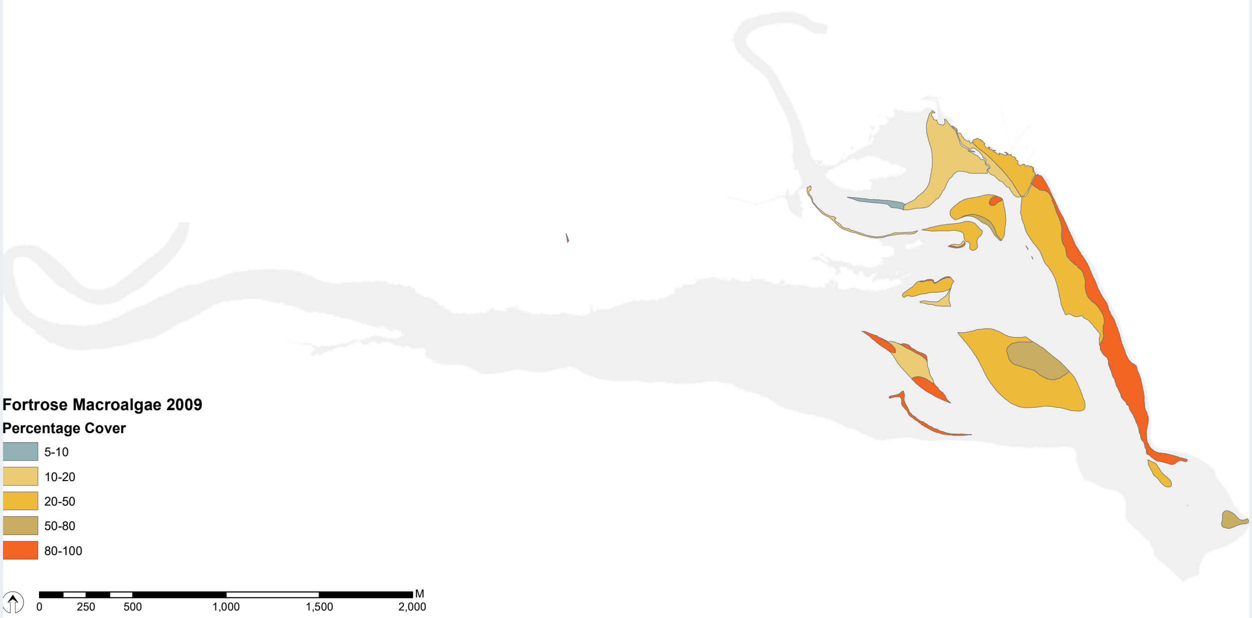
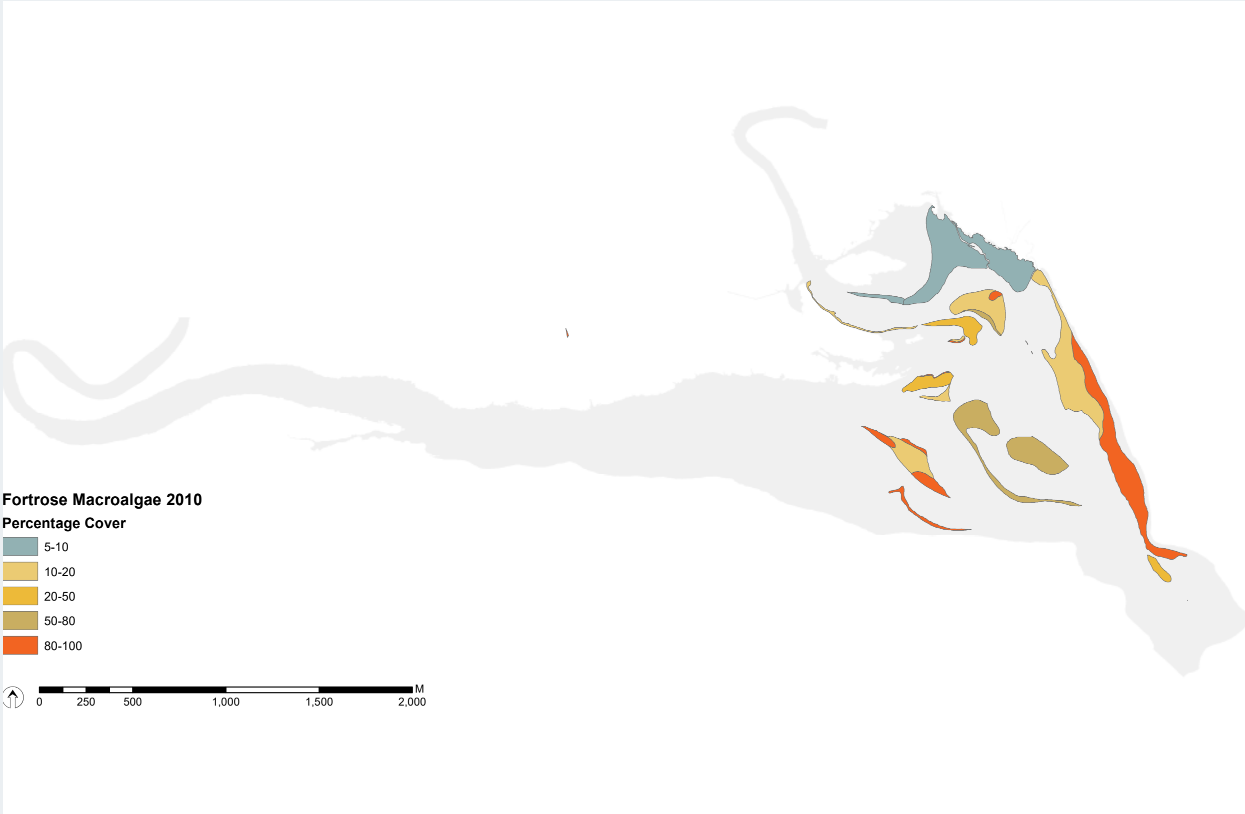


Figure A4. Map of Macroalgal Percentage Cover - Fortrose Estuary, Feb. 2003 and 2009.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018



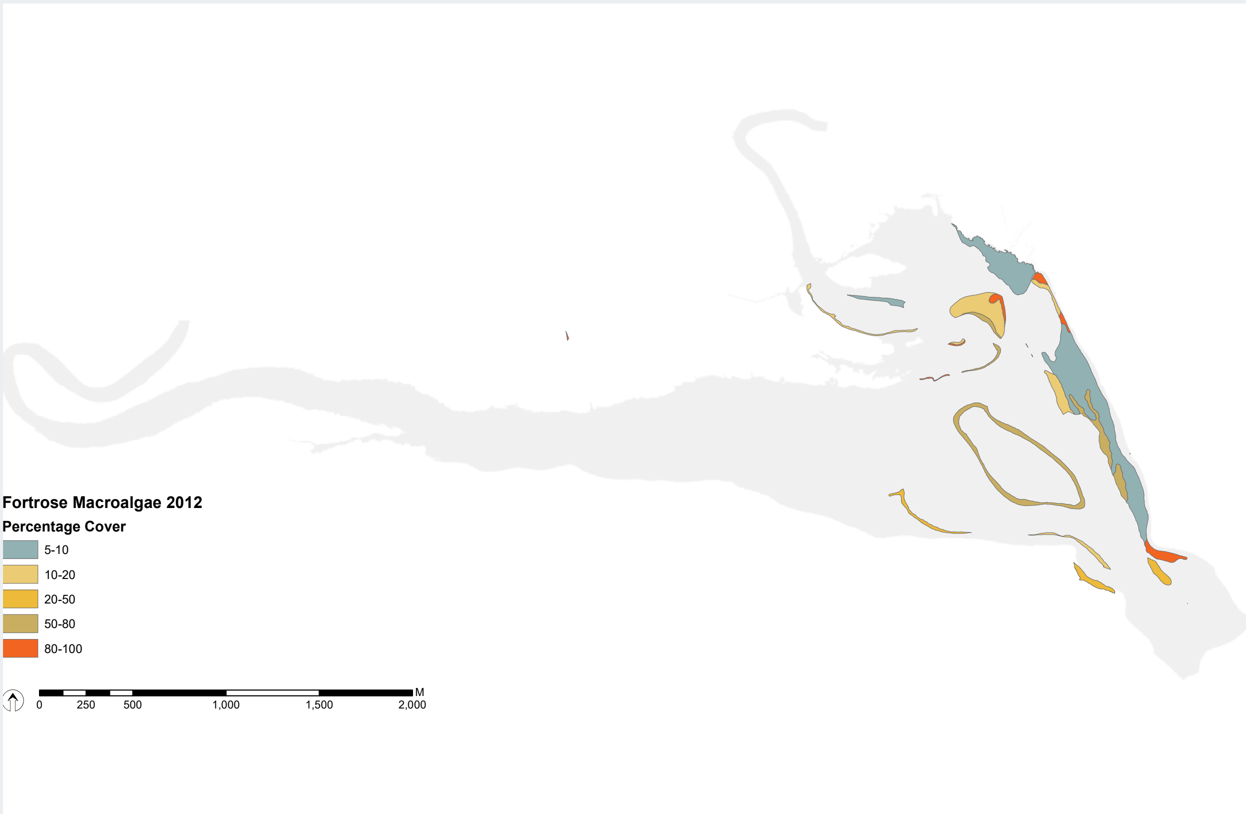


Figure A5. Map of Macroalgal Percentage Cover - Fortrose Estuary, Feb. 2010 and 2012.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018

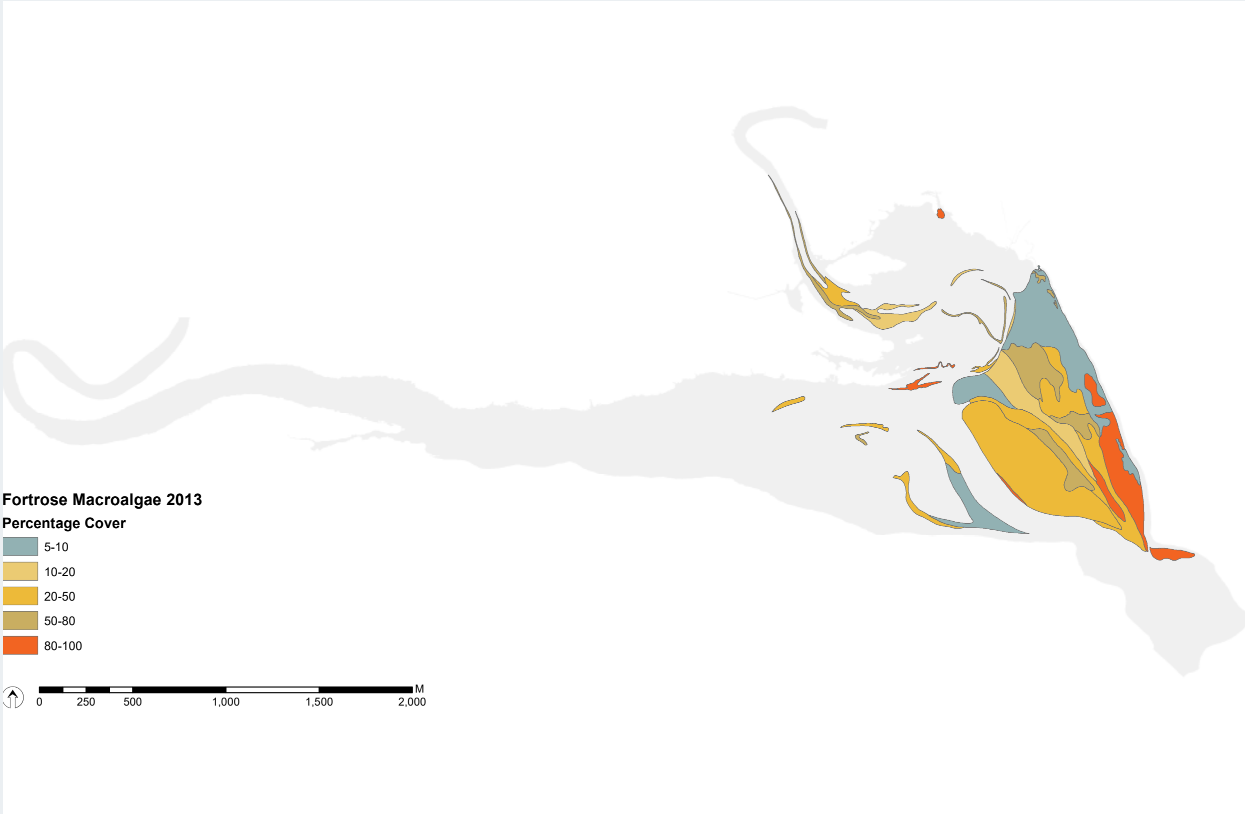


Figure A6. Map of Macroalgal Percentage Cover - Fortrose Estuary, Feb. 2013 and 2016.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018

Figure A7. Map of Macroalgal Percentage Cover - Fortrose Estuary, Feb. 2018.