coastalmanagement

Jacobs River Estuary

Broad Scale Habitat Mapping 2018

Prepared for

Environment Southland

October 2018

Cover Photo: Dense beds of *Gracilaria* growing in soft mud in the upper Aparima Arm, February 2018.

Mobile sand flats in the lower estuary, February 2018

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by

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EXECUTIVE SUMMARY

This report summarises the results of the 2018 broad scale intertidal habitat mapping of Jacobs River Estuary, a medium-sized (714ha) "tidal lagoon" type estuary that discharges to the sea at Riverton. It is one of the key estuaries in Environment Southland's long-term coastal monitoring programme. The following sections summarise broad scale monitoring results (from the current report and previous studies), condition ratings, overall estuary condition, and monitoring and management recommendations.

BROAD SCALE RESULTS

- Sandy substrate dominated the central basin of the estuary (290ha, 58%), but extensive areas of soft mud (158ha, 28%) were present in the sheltered upper reaches of both arms. There has been a 19ha decrease in soft mud since 2003 (a 12% reduction), but no significant change in dominant sand substrate from 2003-2018.
- Nuisance macroalgae (>50%) covered 138ha (28%) of the intertidal area excluding saltmarsh, with the highest densities in the sheltered upper reaches of both arms. There has been little change since 2003. The 2018 EQR score of 0.245 rated nuisance macroalgae as POOR. Remaining intertidal areas supported a sparse cover of non-nuisance macroalgal growths with localised growths of benthic microalgae near the Aparima River.
- Gross eutrophic conditions covered 144ha (29%) of the estuary. This was similar to the extent reported in 2013 and 2016 (see Robertson et al. 2017), but remains very high compared to the 20ha (4%) reported in 2008 (Stevens and Robertson 2008).
- Dense (>50%) seagrass cover was 16.2ha (3.3%), a 19% reduction from the 2003 baseline. Positively, there had been a small increase in seagrass cover on the Aparima River flats of the central basin since 2016 (see Robertson et al. 2017), an area previously smothered by macroalgae and fine sediments.
- Saltmarsh covered 63ha (9%) of the estuary, of which 54ha (84%) was dominated by rushland (jointed wire rush). Localised drainage and conversion to grassland at the edges of the estuary contributed to ongoing decreases in tussock and rushland, with an 18% reduction in cover since 2003.
- Densely vegetated 200m terrestrial margin (scrub and forest) cover was low (12%), with pasture (primarily dairy grazing) dominating the margin (72%), along with the urban features of Riverton (16%). There was no significant change from the previous margin cover reported in 2008 and 2013.
- The NZ ETI score for the estuary was 0.88 indicating it was in a POOR state with regard to 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, key parts of the estuary have had poor estuary quality since 2003. In particular, the sheltered upper parts of the Aparima and Pourakino Arms are excessively muddy, support extensive nuisance macroalgal growths, and contain poorly oxygenated sediments, many associated with toxic sulphides. These gross eutrophic zones are displacing high value seagrass beds and stressing saltmarsh habitat. The macroinvertebrate community in these areas is severely degraded (little animal life is able to establish in the anoxic sediments, and surface feeding species are few in number and limited to those tolerant of poor conditions). Such conditions limit food availability for fish and birdlife, and show the capacity of the estuary to assimilate nutrient and sediment loads from the catchment is currently exceeded. Aesthetic and amenity values in these parts of the estuary are also severely compromised.

Excessive nutrient inputs are the primary driver of the eutrophication symptoms being expressed, with ~85% of the nutrient load to Jacobs River Estuary estimated to be from the intensively developed Aparima Arm. Both the Pourakino and Aparima Arms arms exceed the 100mgN/m^2/day threshold where eutrophic symptoms are commonly expressed (350 and 508mgN/m^2/day respectively).

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

RECOMMENDED MONITORING AND MANAGEMENT

Eutrophication and sedimentation have previously been identified as major issues in Jacobs River Estuary (Stevens and Robertson 2008), with worsening eutrophication symptoms reported since 2008 (e.g. Stevens and Robertson 2012, Robertson and Stevens 2012, 2013, Robertson et al. 2017). To continue to monitor these issues, it is recommended that broad scale habitat mapping be undertaken every 5 years (next due in 2023), and sedimentation rates and macroalgal cover be assessed annually. Fine scale monitoring of sediment chemistry and biota at five existing sites (see Robertson and Stevens 2011 and 2013) is being undertaken by ES in 2019.

Previous management recommendations (e.g. Stevens and Robertson 2011, 2012, 2013, Robertson et al. 2017) 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 loads continue to exceed the estuary's assimilative capacity, it will continue to degrade. However, recent improvements to parts of the estuary provide a clear signal that recovery of degraded areas is possible if sediment and nutrient loads are managed at an appropriate level.

1. INTRODUCTION

Situated at the confluence of the Pourakino and Aparima Rivers near Riverton, Jacobs River Estuary is a moderate sized (714ha), shallow (mean depth ~2m) intertidal dominated, "tidal lagoon" type estuary (SIDE) that discharges to the western end of Oreti Beach. It drains a large 1527km^2 catchment comprising 54% intensive pasture, 5% low producing pasture, 18% native forest, and 11% exotic forest.

The estuary has a wide range of habitats including extensive mud and sand flats, cockle beds, seagrass and saltmarsh areas. Historically it has also lost extensive areas through drainage and reclamation, greatly reducing its ability to filter, dilute, and assimilate nutrient and sediment inputs. The estuary border is dominated by grazed pasture and urban development. Human use and ecological values of large parts of the estuary are high, but environmental issues are present including the frequent exceedance of bathing and shellfish faecal bacterial guidelines, excessive sedimentation and muddiness, stormwater discharges, drainage and reclamation, and nuisance blooms of opportunistic macroalgae (*Ulva* and *Gracilaria*).

To gather information necessary to help make 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, etc) using a combination of detailed ground-truthing and GIS-based digital mapping from aerial photography to record the features present. This work commenced in Jacobs River Estuary in February 2003 (Robertson et al. 2003), and was repeated in February 2008 and 2013 (Stevens and Robertson 2008, 2013). Additional substrate and seagrass mapping was undertaken in 2016 (see Robertson et al. 2017). In addition, fine scale physical, chemical and biological monitoring at representative mid-estuary sites was undertaken in 2003, 2004, 2005, 2006 (4 year baseline), and 2011. Monitoring of eutrophic arms was undertaken in 2012 and 2013 (see Robertson and Stevens 2013 for details, and Figure 1 for fine scale site locations).

Macroalgal cover was first mapped in 2007 (Stevens and Robertson 2007) and broad scale monitoring in 2008 highlighted an increase in localised areas of opportunistic macroalgal growth that was causing nuisance conditions. As the presence of opportunistic macroalgae is a primary symptom of estuary eutrophication (nutrient driven enrichment), annual monitoring of macroalgae was recommended to assess change (Stevens and Robertson 2008). This was undertaken from 2008-2013, and again in 2016. Results, summarised in Robertson et al. (2017), documented the estuary consistently supported a high cover and biomass of nuisance macroalgae, and experienced a large increase in the extent of gross eutrophic zones (GEZs) from 2007-2016, particularly in the sheltered upper reaches of the Pourakino and Aparima Arms (Robertson et al. 2017).

The current report focuses on detailed broad scale habitat mapping undertaken in February 2018 to characterise the current state of key habitat features and 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 and sediment oxygenation
- Macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*)
- Seagrass (i.e. *Zostera muelleri*)
- Gross Eutrophic Zones (GEZs)
- Saltmarsh vegetation
- 200m terrestrial margin and catchment land cover

1.1 REPORT STRUCTURE

The current report presents a brief introduction to Jacobs River Estuary (Section 1.2), 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).

1. INTRODUCTION (CONTINUED)

1.2 BACKGROUND

In pre-European times, Jacobs River Estuary was bounded by bush clad hills and low lying bush, and the sheltered waters at the confluence of the Aparima and Pourakino Rivers provided a safe harbour and ample seafood to support a substantial Maori Pa at Aparima. In the early nineteenth century, whalers and sealers came to the south coast and a whaling station was established at Riverton. By the end of the 1830s whaling was declining and pastoral farming of the rich alluvial soils of the river valleys resulted in the mass clearance of native forest far into the interior. By 1905 most of the agriculturally viable land around Jacob's River had been cleared of bush.

At the turn of the 20th Century the Pourakino River was navigable 10-15kms upstream allowing timber to be shipped to Riverton, which had become an important port shipping timber, wool, grain and other produce. A branch railway from Invercargill was opened in 1879, along with a railway bridge across the lower estuary, giving access to virgin podocarp and beech forest to the west of Riverton. In 1904 a new railway bridge and causeway was built through the estuary which remained open until 1978 when the Tuatapere Branch Line was closed, with the truss bridge and causeway removed in 2001.

Today Riverton remains a fishing port with the surrounding district supporting dairy, sheep and mixed farming. Human use of the estuary is high and is used for walking, shellfish collecting, boating, fishing, duck shooting, bird watching, and swimming.

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 future change.

Site boundaries were set as the seaward edge of the tidal delta 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 the area over 4 days in February 2018 to ground-truth the spatial extent of dominant vegetation and substrate types (see Figure 2, Appendix 6). From representative broad scale substrate types, 12 grain size samples were analysed to validate substrate classifications (Figure 2 Transects A and C, Appendix 4). When present, macroalgae and seagrass patches were mapped to the nearest 10% using a 6 category percent cover rating scale as a guide to describe density (see Figure 1). Notes on sampling, resolution and accuracy are presented in Appendix 4.

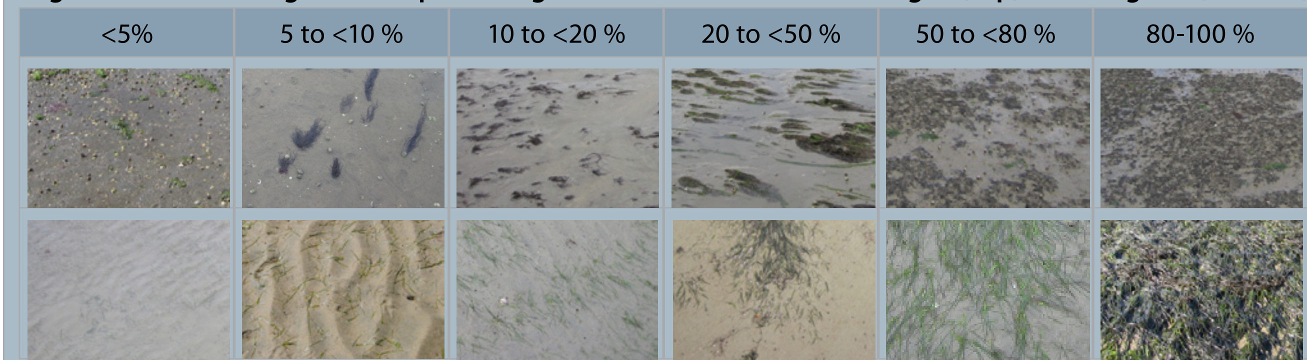
Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring:

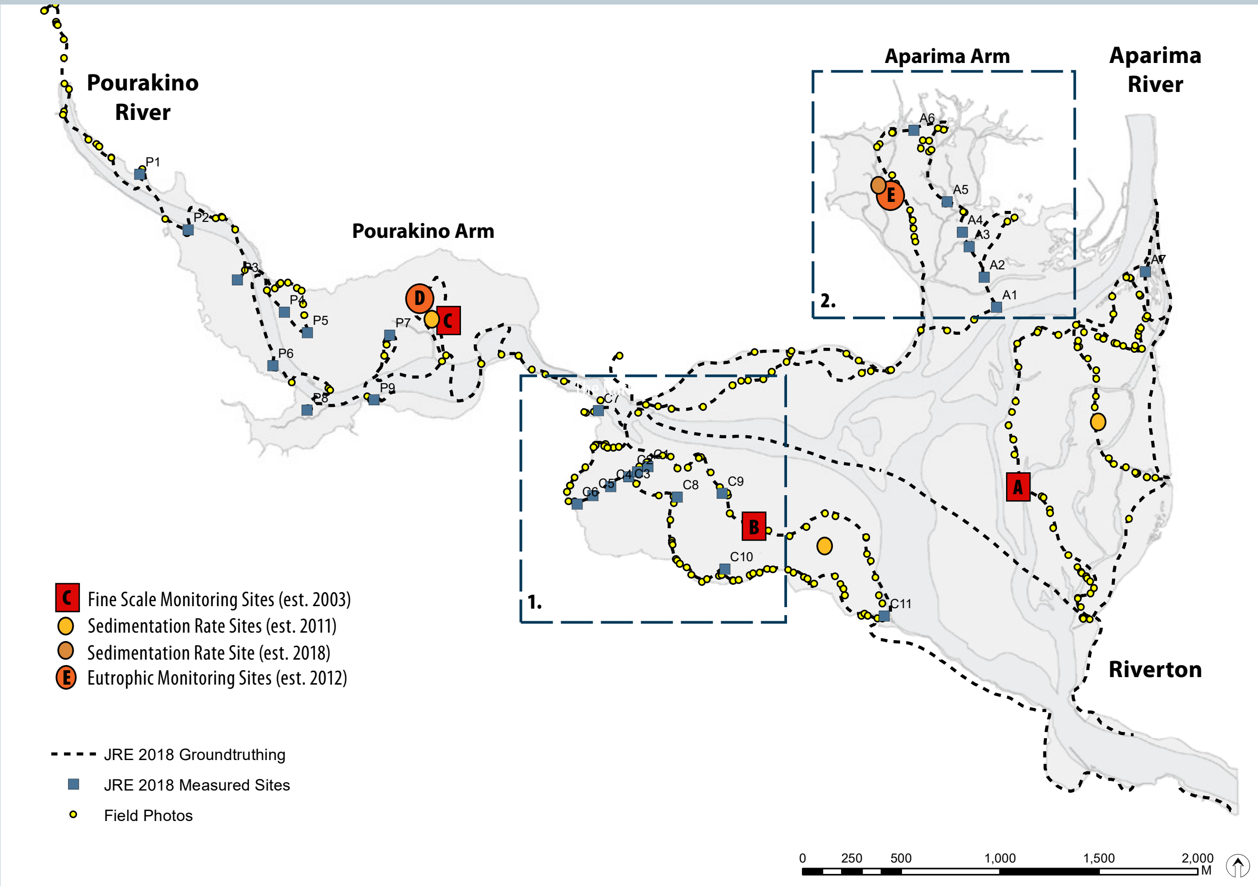
- % cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of eutrophication issues).
- macroalgal biomass (providing a direct measure of areas of excessive growth).
- extent of algal entrainment in sediment (highlighting where nuisance conditions 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), a modified 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.

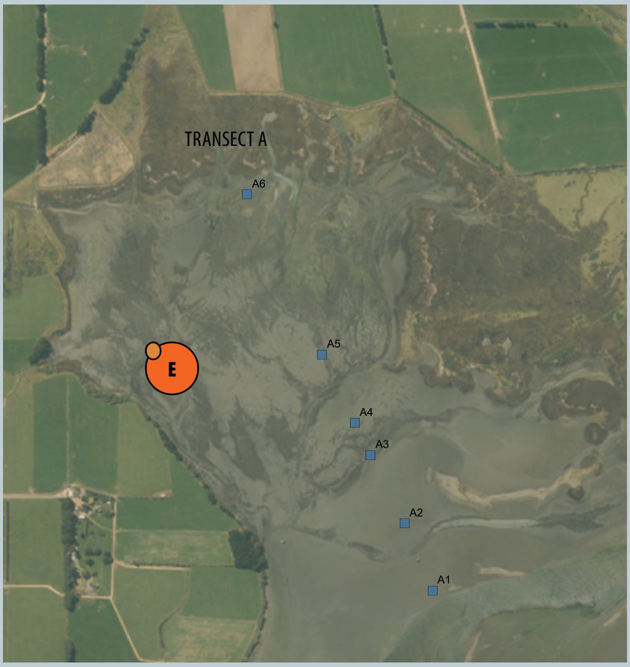
In order to provide a more comprehensive way to characterise broad scale changes in macroalgal biomass, a series of fixed transect based sampling locations were established in 2018 within dense macroalgal beds to enable repeat measurements to be made at the same sites over time. These are shown in Figure 2 with data in Appendix 8.

Figure 1. Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom).





1. Central Basin Transect C and fine scale Site B.



2. Aparima Arm Transect A and eutrophic Site E.

Figure 2. Jacobs River Estuary - location of fine scale and sedimentation rate monitoring sites, and transect sampling points established in 2018.

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.

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.

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.

View to the south from the bottom of the Neck overlooking the southern flats

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 3-12.

Jacobs River is a relatively complex estuary with regard to the expression of eutrophication symptoms, in that it receives freshwater inputs from two catchments. The Aparima River catchment contributes relatively large inputs of sediment and nutrients, however retention of these inputs in the Aparima Arm appears limited due to the relatively direct flow path of the river to the sea, with the intertidal flats of the central basin and eastern flats well flushed and having few deposition zones. The largest accumulation of sediment and associated nutrients is in the northern flats which supports extensive nuisance macroalgal growth. In contrast, the Pourakino River has lower inputs of catchment sediment and nutrients, but the Pourakino Arm is more extensively affected by eutrophication symptoms than the Aparima. This is likely due to the combined effects of river and tidal flows being restricted at the narrow rock-lined “Neck” that divides the two arms, leading to a regular backing up of water which promotes the settlement and retention of sediment and nutrients in the upper reaches. The nitrogen load to each arm ($mgN/m^2/d$) estimated from NIWA’s CLUES model (Table 3) indicates both arms are above estimated thresholds for nuisance growths to establish (>100$mgN/m^2/d$ - see Table 3).

It is also obvious that parts of the lower Pourakino Arm are subjected to strong hydraulic flushing which appears to prevent the settlement and accumulation of fine sediment and associated nuisance macroalgal growth in the lower reaches of the arm.

The estuary is intertidally dominated (78%), with relatively extensive saltmarsh beds (9%) remaining. In many areas saltmarsh is naturally limited by the surrounding hillsides, but was historically much more extensive. Intertidal seagrass is a relatively small, but significant, feature in the estuary (1.5%), while dense beds (>50% cover) of opportunistic macroalgae were extensive (19%) and have resulted in the establishment of persistent gross eutrophic zones in both arms. The 200m wide terrestrial margin was dominated by grassland (72%), with only 12% densely vegetated. Native forest/scrub cover was significantly different for the two catchments, 54% in the Pourakino and 11% in the Aparima.

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), Stevens and Robertson (2008, 2013) and Robertson et al. (2017). Temporal changes are also summarised for each of the key indicators in the following sections.

Table 2. Summary of dominant broad scale features, Jacobs River Estuary, February 2018.

Dominant Estuary Feature	ha	%
Intertidal saltmarsh	63.0	8.8
Intertidal seagrass (>20% cover)	22.3	2.9
Intertidal macroalgal beds (>50% cover)	137.8	19.3
Intertidal substrate (unvegetated)	493.7	69.1
Intertidal Total	556.8	78.0
Subtidal Total	157.3	22.0
Total Estuary	**714**	**100**
200m Terrestrial Margin (% densely vegetated)		12

3. RESULTS AND DISCUSSION (CONTINUED)

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

Supporting Condition Measures	Pourakino	Aparima	Total
Catchment Area (Ha)*	24,690	132,094	156,783
Indigenous forest cover (Ha [%])	13,339 [54%]	14,548 [11%]	27,887 [18%]
Mean freshwater flow (m^3/s)*	3.5	25.8	28.3
Catchment nitrogen load (T/yr)*	173.6	1072.4	1261.5
Catchment phosphorus load (T/yr)*	9.5	55.1	65.4
Catchment sediment load (KT/yr)*	8.5	49.6	58.4
Estimated N areal load in estuary ($mg/m^2/d$)	349.7	508.3	484.1
Estimated P areal load in estuary ($mg/m^2/d$)	17.1	23.5	25.1
Intertidal soft mud extent (%)	80%	20%	28%
Macroalgal OMBT EQR score			0.245
Saltmarsh (estimated natural % remaining)			<40%
NZ ETI score			0.88

*source NIWA Coastal Explorer database and CLUES model output run Oct 2018 - CLUES 10.5 LCDBv41 in default mode.

3.2 INTERTIDAL SUBSTRATE

Figure 3 and Table 4 summarise the intertidal substrate of Jacobs River Estuary. Sand (336ha, 60%) was the dominant substrate class, mostly located in the relatively well flushed central basin of the estuary. Soft and very soft muds were very extensive (158ha, 28%) - the vast majority located in the sheltered upper estuary arms. The dominance of extensive mud areas has a condition rating of "POOR".

Within vegetated areas, substrate among herbfields was predominantly cobble and gravel, while substrate among rushland was dominated by firm muddy sand. Sedgeland (three square) was almost exclusively found growing in soft muds.

Seagrass beds (Section 3.10) were most commonly found growing in sand dominated substrates, often growing in the shelter of slightly elevated gravel or shell beds.

Hard substrates (e.g. rock, boulder and cobble) were limited in extent and located mainly at the upper intertidal margins. 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 Jacobs River Estuary, February 2018.

Dominant Substrate Type	ha	%
Intertidal substrate within saltmarsh		
Gravel field	4.7	0.8
Firm muddy sand	45.6	8.2
Soft mud	12.1	2.2
Very soft mud	0.7	0.1
Intertidal substrate outside of saltmarsh		
Wharf	0.3	0.05
Rock field	1.3	0.2
Rock field man-made	0.0	0.01
Boulder field man-made	0.6	0.1
Cobble field	7.2	1.3
Gravel field	27.5	4.9
Shell bank	0.3	0.1
Mobile sand	0.9	0.2
Mobile muddy sand	14.8	2.7
Firm sand	149.8	26.9
Firm muddy sand	124.8	22.4
Firm sandy mud	21.5	3.9
Soft mud	22.4	4.0
Very soft mud	122.3	22.0
Grand Total	**556.8**	**100**

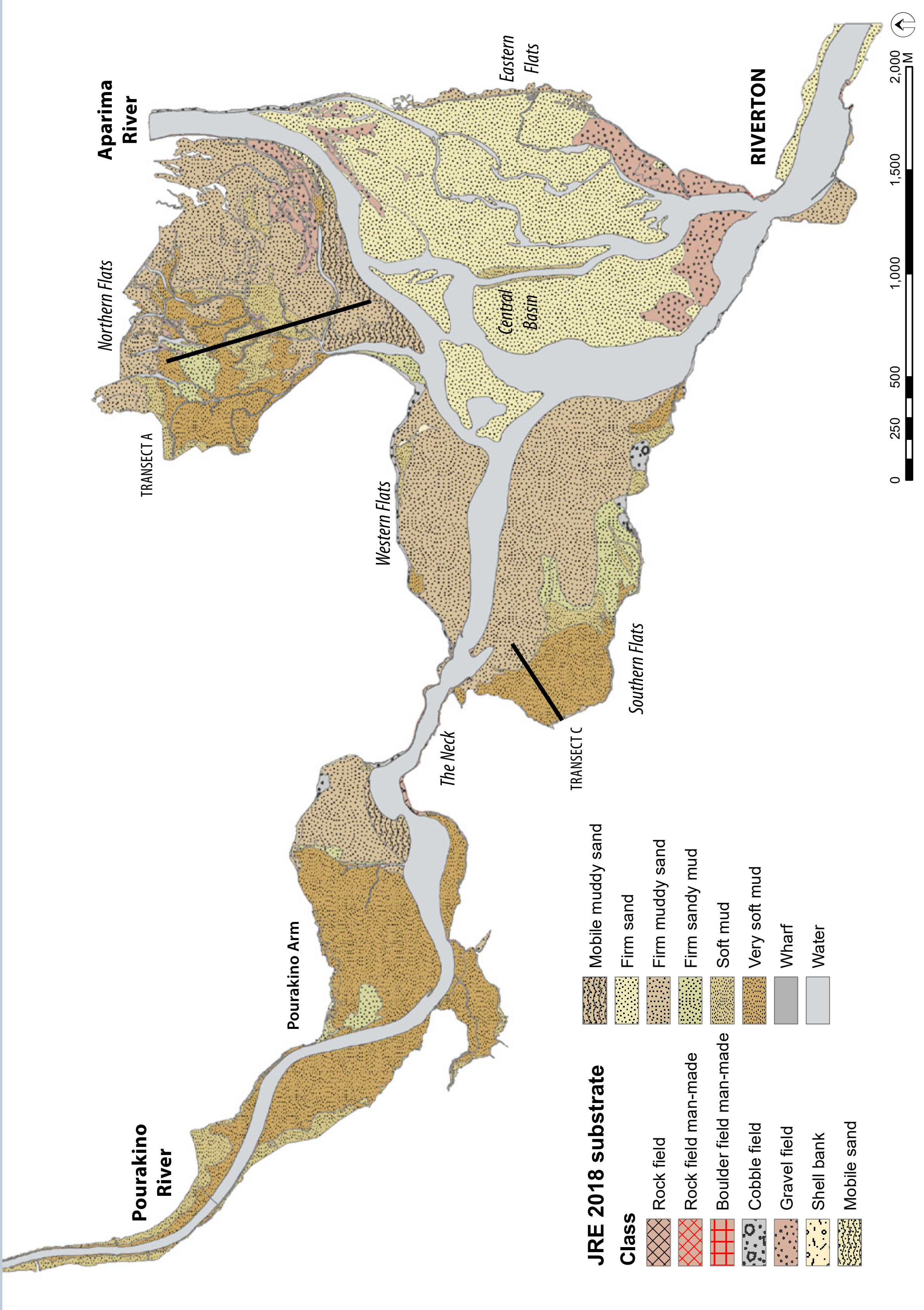


Figure 3. Map of dominant intertidal substrate types - Jacobs River Estuary, February 2018.

3. RESULTS AND DISCUSSION (CONTINUED)

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 28% of the intertidal habitat was classified as being dominated by soft muds, a condition rating of "POOR". The largest soft mud deposition zones were in relatively quiescent zones in the upper reaches of sheltered tidal flats located in the Pourakino Arm, the northern flats of the Aparima Arm, and on the southern flats below the Neck. Within the central basin and eastern flats, strong tidal and river flushing prevents significant accumulation of muddy sediment.

Regular annual measurements of sediment deposition have been made at three sites in the estuary since 2010, with a new site established in the northern flats of the Aparima Arm in 2018 (see Figure 2 for locations). Measurements show that sediment accumulation in the relatively well flushed central basin and southern flats has been very low over the past eight years (0.4-0.8mm yr^{-1}). These sites also have a low mud content (3-5% measured in 2018, ES unpublished data). The Pourakino deposition zone site, where sediment accumulation is expected to be higher, has shown an overall loss of 3mm yr^{-1}, although this net result does not reflect the high variability evident at this location. This is primarily due to the strong influence of flood flows across the upper estuary, combined with the presence of dense entrained *Gracilaria* at the site which is very effective at trapping fine sediment and has an obvious influence on measured results. Episodic deposition and scouring events also mean there is high variability in the sedimentation rate recorded at this site as indicated by the results:

Period	2010-11	2011-12	2012-13	2013-16	2016-18
change in mm*	-16.8	+2.5	-45.0	+49.3	-14.3

* average over 4 plates in the Pourakino Arm.

Consequently trends in sediment accumulation are difficult to interpret, which is compounded by the relatively short monitoring period and limited sampling undertaken to date (5 measurements over 8 years). However, there has been a consistently high sediment mud content (38-54%) recorded from this deposition zone site (ES unpublished data), and the overall condition of the site with respect to muddiness is rated as "POOR".

To enable better characterisation of changes in sediment mud content within deposition zones, and to validate broad scale substrate classifications, sediment grain size was measured from 12 sites established along two transects in 2018, one in the northern flats (Transect A) and one in the southern flats (Transect C) of the estuary (Figures 2 and 3). Data are included in Appendix 4. The intent was to establish baseline measurements of grain size across a transition from firm sands to soft muds. Future measurements will enable changes in sediment muddiness to be tracked at each specific location, as well as to quantify any spatial shift in the extent of mud-dominated substrate measured by broad scale mapping at these locations.


Dominant gravel habitat in the central basin and upper shore of the northern flats.

Firm muddy sand.

Mobile muddy sands.

Soft poorly oxygenated muds.

Very soft poorly oxygenated muds.

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 decrease (19.1ha) in the area of soft mud. This reduction has occurred on the southern flats immediately south of the Neck, in the central basin, but mostly in the northern flats of the Aparima Arm.

Table 5. Soft mud extent, Jacobs River Estuary, 2003, 2008, 2013, 2016 and 2018 (excludes substrate within saltmarsh).

Substrate Class	2003		2008		2013		2016		2018	
	ha	%	ha	%	ha	%	ha	%	ha	%
Soft muds	163.8	33.2	165.1	33.1	166.0	34.1	155.1	31.3	144.7	29.3
TOTAL	493	100	499	100	489	100	496	100	494	100

Overall, despite the moderate decrease in the soft mud extent since the 2003 baseline was established, the percent cover condition rating remains in the “POOR” category (>15%), and the soft mud extent of the estuary remains very high.

The improvements noted in 2016 and 2018 have generally come in areas previously dominated by nuisance macroalgae (see Section 3.6). Between 2013 and 2016, small areas of macroalgae in both the Aparima and Pourakino Arms were lost due to die off within a “soup” of highly organically enriched, anoxic muds with sulphide rich sediments. Such sediment conditions are so extreme that macroalgae, the primary source of oxygenation to the underlying sediments, appeared unable to survive in these areas. In other areas it appeared that flood scouring had resulted in a likely temporary reduction of macroalgal cover. As a consequence of reduced sediment trapping and retention by macroalgae, muddy sediment from these areas appears to have been flushed from the estuary uncovering previously firm muddy sands that had been buried in soft muds.

From 2016 and 2018, the most obvious change has occurred following the loss of dense *Gracilaria* beds in parts of the Aparima Arm’s northern flats. These *Gracilaria* beds were previously trapping and retaining soft muds. However following the loss of *Gracilaria* there has been a corresponding loss of soft muds from these areas and a return to firmer sandier substrate. The specific cause of the patchy *Gracilaria* loss is uncertain (flood scouring seems most likely in this instance) but the very positive implication is that if nuisance macroalgal growth is able to be reduced, then there is a strong indication provided by the observed changes that the estuary can potentially recover quickly, with excessive mud deposits flushed away (see photo below). This type of improvement was also evident in the central basin where localised areas previously with mud dominated substrate have been flushed from the estuary. It remains to be seen if this change has occurred in direct response to an episodic event (i.e. flood) or whether it is part of an ongoing improvement in estuary condition.

Sandflats uncovered following the loss of *Gracilaria* beds and soft muds in the Aparima Arm.

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, 144ha (29%) of the estuary was classified as having reduced sediment oxygenation in 2018. 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 estuary to be generally well oxygenated with the average aRPD depth at ~2-5cm. 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. Where muds supported seagrass, oxygen levels were good, but in unvegetated muds the average aRPD depth was ~0.5 to 1cm, generally equating to a measured RP of -50 to -150mV at 1cm. In some areas, enrichment associated with macroalgal growth had reduced sediment oxygenation near the surface, but vertical profiles revealed relatively clean underlying sediments (see photo lower left).

The areas showing the most pronounced reduction in sediment oxygenation were soft or very soft muds located in the highly eutrophic areas of the upper Pourakino Arm, the northern flats of the Aparima Arm, and the Southern Flats (Figure 4). Here sediments were often characterised by strong hydrogen sulphide odours and, when disturbed near water, released black sulphide-rich plumes (see photo lower right). The overall extent of reduced sediment oxygenation had a condition rating of "POOR".

Sediment core showing a thin pale brown layer of well oxygenated surface sediments (1cm) on top of darker band of anoxic sediment. Cleaner grey sands underlying this band suggest relatively recent enrichment within this core.

Highly anoxic and sulphide-rich sediments from within *Gracilaria* beds in the Pourakino Arm.

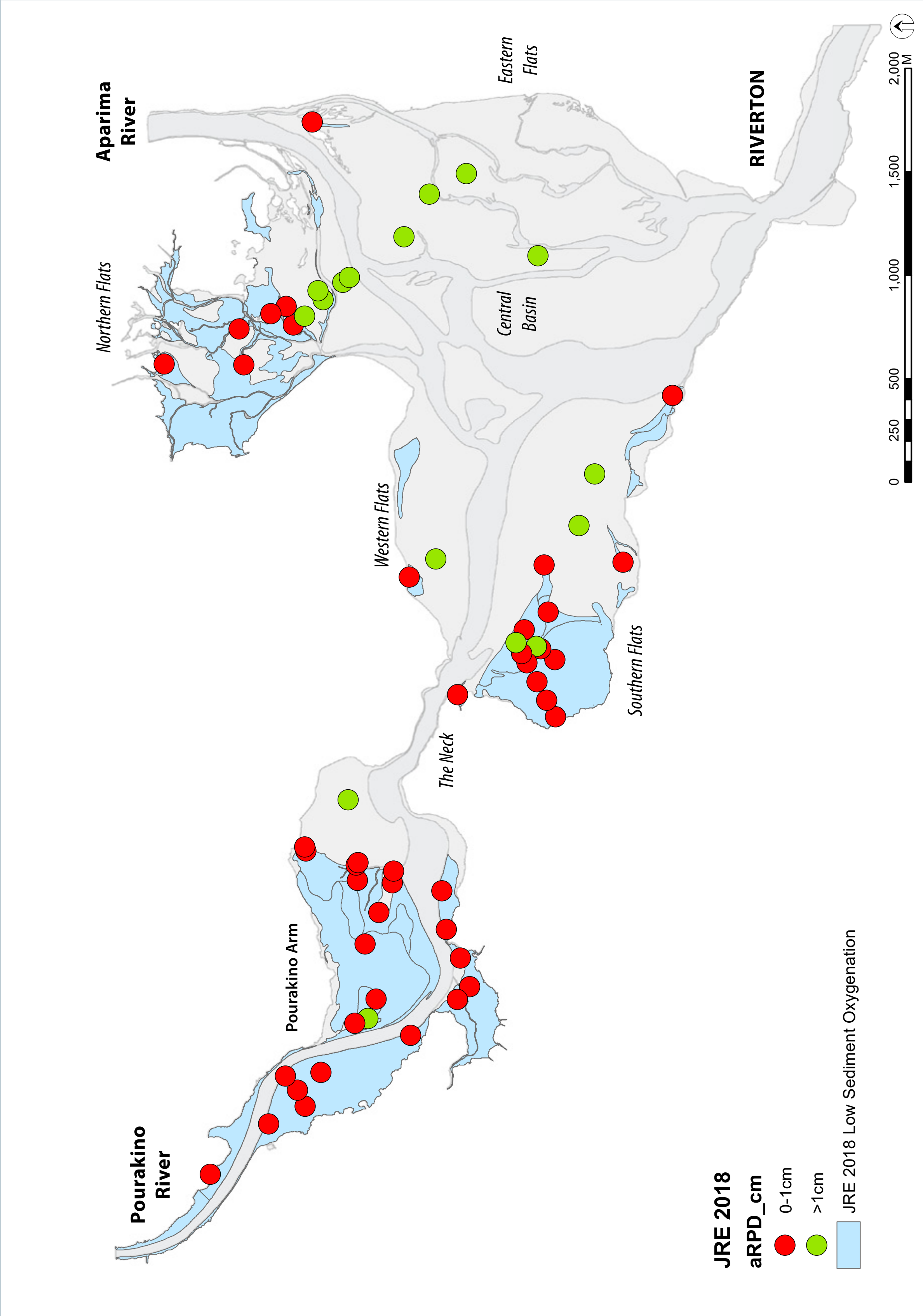


Figure 4. Map of areas with depleted sediment oxygenation - Jacobs River Estuary, February 2018.

3.6 OPPORTUNISTIC MACROALGAE

Opportunistic macroalgae are a primary symptom of estuary eutrophication. They are highly effective at utilising excess nitrogen enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Macroalgae that becomes detached can also accumulate and decay in subtidal areas and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the subsequent impacts.

Opportunistic macroalgal growth was assessed by mapping the spatial extent and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 5), and calculating an “Ecological Quality Rating” (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT). 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/low, poor, good, moderate, high - Section 2, Table 1, Appendix 7). The individual metrics used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area) also have quality status threshold bands to guide key drivers of change. If the estuary supports <5% opportunistic macroalgal cover within the AIH, the overall quality status is reported as HIGH with no further sampling required.

The overall opportunistic macroalgal EQR for Jacobs River Estuary in February 2018 was 0.245 (Table 6, Figure 5), a quality status of “POOR” and indicates that the estuary is expressing significant eutrophication symptoms. The dominant macroalgae was the red alga *Gracilaria chilensis,* with the green alga *Ulva* spp. present but far less prominent. *Ulva* tended to have a relatively low biomass (<500g.m^2) and was not entrained in sediment, but grew on top of *Gracilaria* in parts of the upper estuary. *Gracilaria* was present throughout the estuary, but was most obvious in very extensive high biomass (>5000-10,000g.m^2 w.w.) beds in the soft mud depositional zones. The Pourakino Arm in particular supported beds that remained bathed in shallow ponded surface water over most of the tidal cycle, with the dense growths restricting the natural drainage of tidal waters into low tide channels.

Further reductions in macroalgal biomass driven by extreme sediment anoxia and high sulphide levels evident in 2013 and 2016 were not observed in 2018. However, in the Aparima Arm in 2018, patches of previously dense macroalgal growth had changed to be largely unvegetated. This appeared to be due to hydraulic scouring from elevated river flows which had also swept macroalgal growth from most of the central basin and eastern flats. Importantly from an ecological perspective, where dense *Gracilaria* had been lost, there was a corresponding transition in underlying substrate from soft mud to firm sandy muds or muddy sand - an improved ecological condition.

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

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	498		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	23.2	0.435	Moderate
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	2533.3	0.184	Bad
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	3966.0	0.163	Bad
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	43.4	0.244	Poor
Affected Area (use the lowest of the following two metrics)		0.198	Bad
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	318.2	0.198	Bad
Size of AA in relation to AIH (%) = (AA / AIH) x 100	63.9	0.289	Poor
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.245**	**POOR**

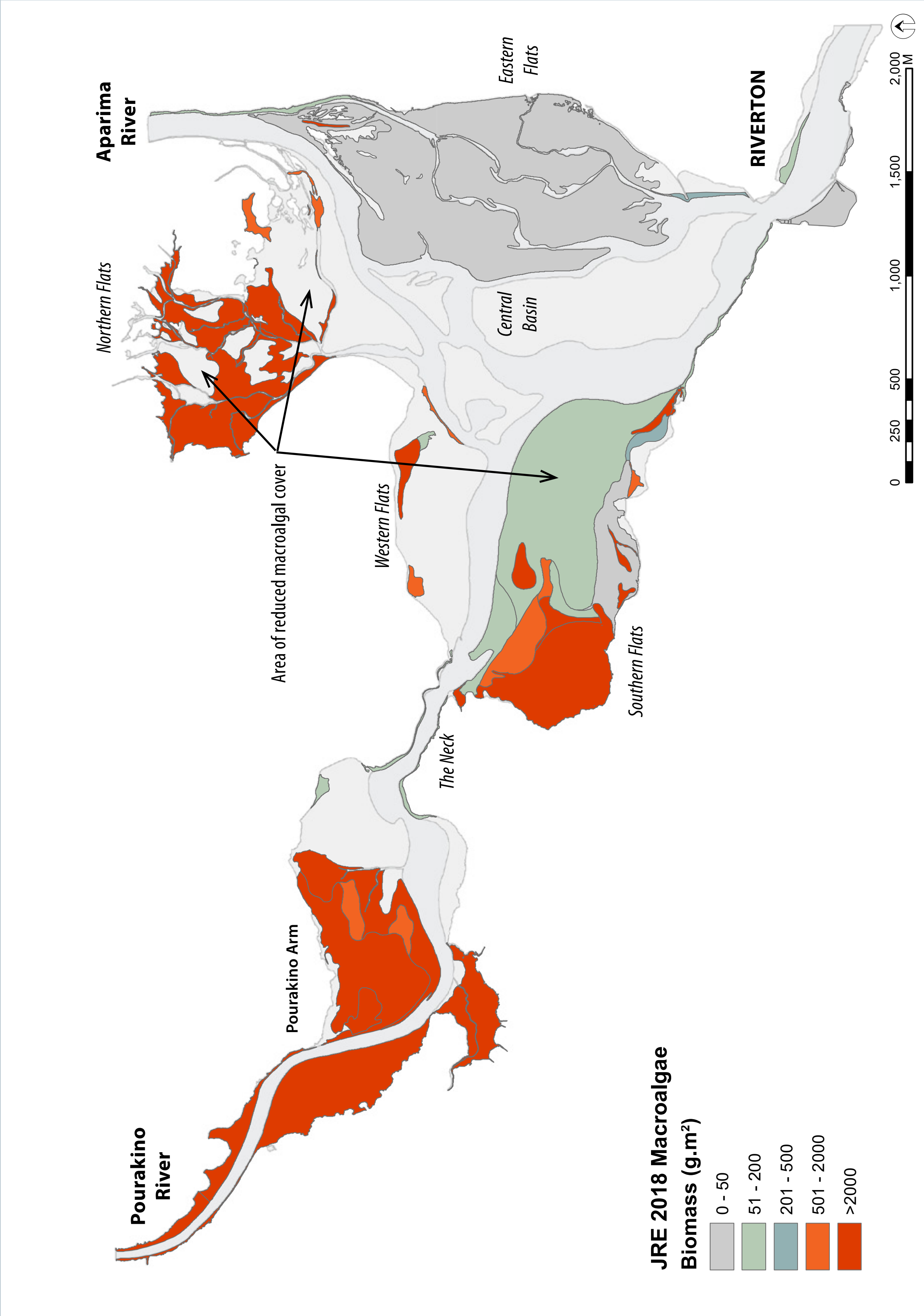


Figure 5. Map of dominant intertidal macroalgal biomass - Jacobs River Estuary, February 2018.

Dense *Gracilaria* among soft muds in the Aparima Arm, Feb. 2018.

Unvegetated sand flats in the Aparima Arm, Feb. 2018. These areas were covered in dense *Gracilaria* beds in 2016.

Ulva beds (left) on sand and gravels adjacent to the Aparima River, Feb. 2016, and the same area in Feb. 2018.

3.7 CHANGES IN MACROALGAL CONDITION 2003-2018

Figure 6 shows estimates of the percentage of the estuary covered by dense (>50%) macroalgal cover, with maps showing the spatial cover of macroalgae over the monitored period presented in Appendix 9. To address uncertainty raised by Robertson et al. (2017) about the 2003 and 2007 percentage cover estimates, aerial photographs were compared to the original data. This indicated that previously reported macroalgal cover for these years appeared to underestimate the actual extent, with dense macroalgal beds covering ~25% of the estuary evident since at least 2003. Previously, the assumption that macroalgal growth in the estuary was relatively sparse, despite high nutrient inputs, suggested a lag time in the development of eutrophication problems, or the presence of other physical limitations on the expression of nuisance growths (e.g. hydraulic scouring). It now appears that this may not be the case and the macroalgal growth response in Jacobs River Estuary is similar to that observed elsewhere. Consequently, it is recommended that a more thorough assessment be made of macroalgal cover in 2003 (and earlier if aerial photos are available), with revised coverage maps prepared to more accurately assess changes to the estuary over time.

In the interim, using 25% cover of the estuary in 2003 as a baseline, the results indicate dense macroalgal cover has likely remained consistently high in the estuary over the past 15 years, with an inter-annual range between 25-36%. There is a tentative trend of gradual increase (decline in quality) over this period.

Monitoring in 2016 recorded the highest cover of dense macroalgae to date, primarily reflecting an expansion of problem growths on the southern flats, while the subsequent decrease recorded in 2018 reflects an observable reduction in nuisance macroalgal growth in the estuary, particularly on the southern flats, and in both the Pourakino and Aparima Arms.

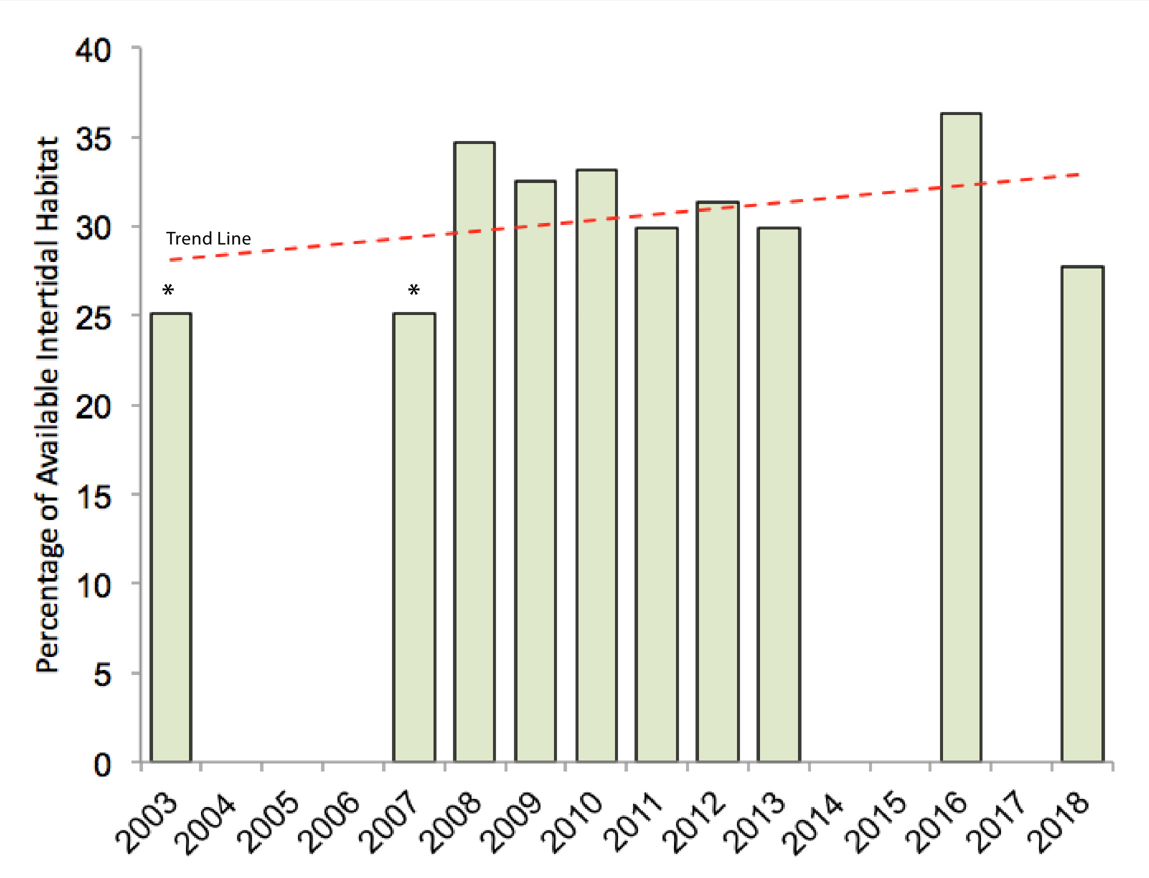


Figure 6. Percent cover of dense (>50%) macroalgae in Jacobs River Estuary 2003-2018.

*Revised estimates based on aerial photographs (further validation recommended for these years). ----- = trend line.

3. RESULTS AND DISCUSSION (CONTINUED)

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 Jacobs River), 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 determined for each year in which full broad scale mapping has been undertaken (Table 7). In 2018 the GEZ extent was 144ha (29% of the estuary), a condition rating of "POOR". These GEZs are concentrated in natural deposition zones within the estuary (Figure 7) where the combined influence of flocculation at the saltwater/freshwater interface, widening of river channels entering the main body of the estuary (reducing flow velocities), and limited tidal flushing all serve to concentrate catchment inputs of sediments and nutrients, and provide good conditions for the growth of macroalgae.

Table 7. Gross eutrophic intertidal zones, Jacobs River Estuary, 2003*, 2008, 2013, 2016 and 2018. ***assumed to be less than the GEZ extent first measured in 2008.**

Gross Eutrophic Zones	2003		2008		2013		2016		2018	
	ha	%	ha	%	ha	%	ha	%	ha	%
	<20	<4%	20	4%	141	30%	145	30%	144	29%

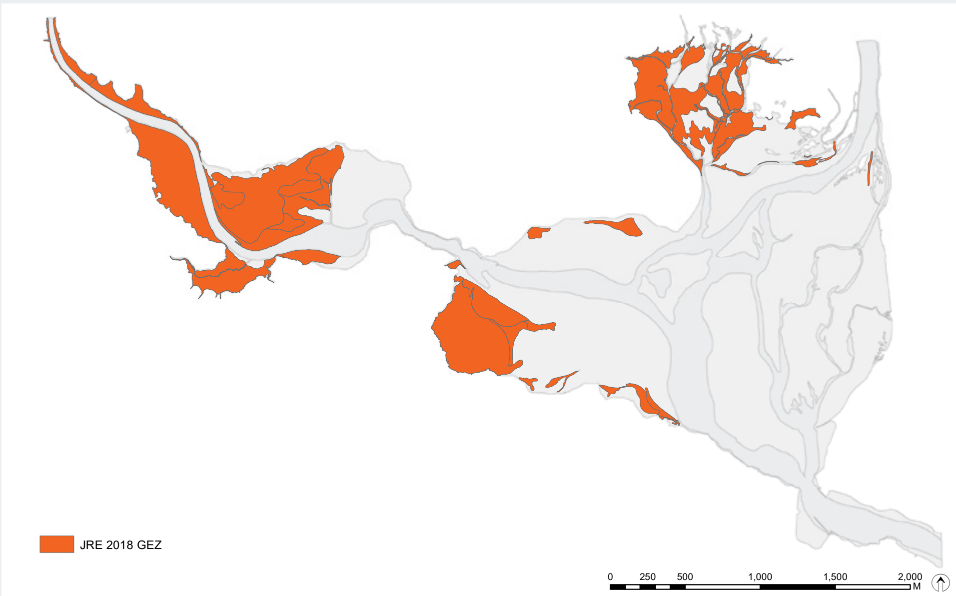


Figure 7. Location of gross eutrophic zones - Jacobs River Estuary, February 2018.

3.9 CHANGES IN GROSS EUTROPHIC CONDITIONS 2003-2018

Results, summarised in Table 7, show a significant expansion in GEZs from 2003 to 2013, with the change largely driven by a decline in sediment oxygenation in the Pourakino Arm. Since 2013, changes have been negligible indicating GEZs have remained relatively stable.

3. RESULTS AND DISCUSSION (CONTINUED)

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).

The results of the 2018 intertidal seagrass survey are summarised in Table 8 and Figure 8. The extent of seagrass with a percentage cover >20% was relatively low (5% of the estuary) and represents a moderate area (22.3ha) in an estuary that historically would have had a much larger seagrass extent. Due to the presence of excessive macroalgal growth and poor sediment conditions in the sheltered upper arms which have displaced the seagrass beds previously located there, seagrass is now almost exclusively confined to the well flushed central basin of the estuary. These seagrass beds appeared in relatively good condition with little fine mud, relatively well oxygenated sediments, and no significant macroalgal smothering (see upper photo). In contrast, seagrass condition in the more sheltered parts of the estuary continue to be compromised by extensive mud and excessive macroalgal growth. For example, seagrass beds smothered by 20-50% macroalgal (*Ulva*) cover in 2016 had increased in density on the Aparima River flats of the central basin in 2018, but still supported thick epiphytic growth (see lower photos).

Table 8. Summary of seagrass *(Z. muelleri)* cover, Jacobs River Estuary, Feb. 2018.

Density	Ha	%
<1%	465.8	93.5
1-5%	0	0.0
5-10%	1.5	0.3
10-20%	2.7	0.5
20-50%	12.4	2.5
50-80%	6.3	1.3
>80%	9.9	2.0
Total	498	100

Healthy *Zostera* in the well flushed lower estuary (top) and smothered in thick epiphytic algal growth (bottom left) and microalgal growth (bottom right) in the upper Aparima Arm, Feb. 2018.

3.11 CHANGES IN INTERTIDAL SEAGRASS COVER 2003-2018

A comparison of seagrass area with >20% cover in 2003 and 2018 shows an 6.8ha (19%) reduction in the estuary, a condition rating of "MODERATE". Seagrass losses have occurred almost exclusively in the upper Pourakino Arm and sheltered northern flats of the Aparima Arm (Figures 9 and 10) as a consequence of displacement by dense macroalgae and soft muds. This has been offset by a recent small increase in seagrass on the Aparima River flats of the central basin.

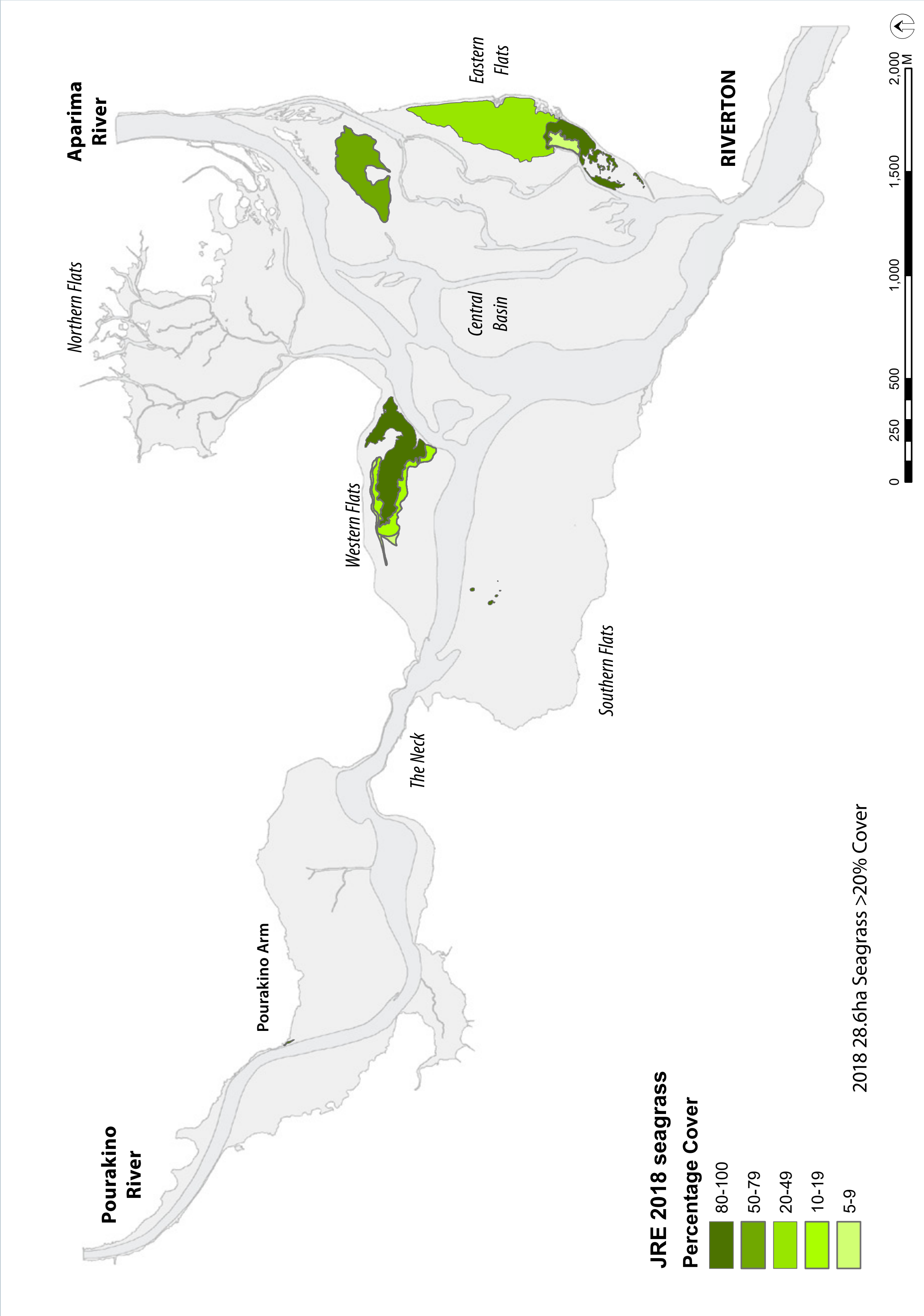
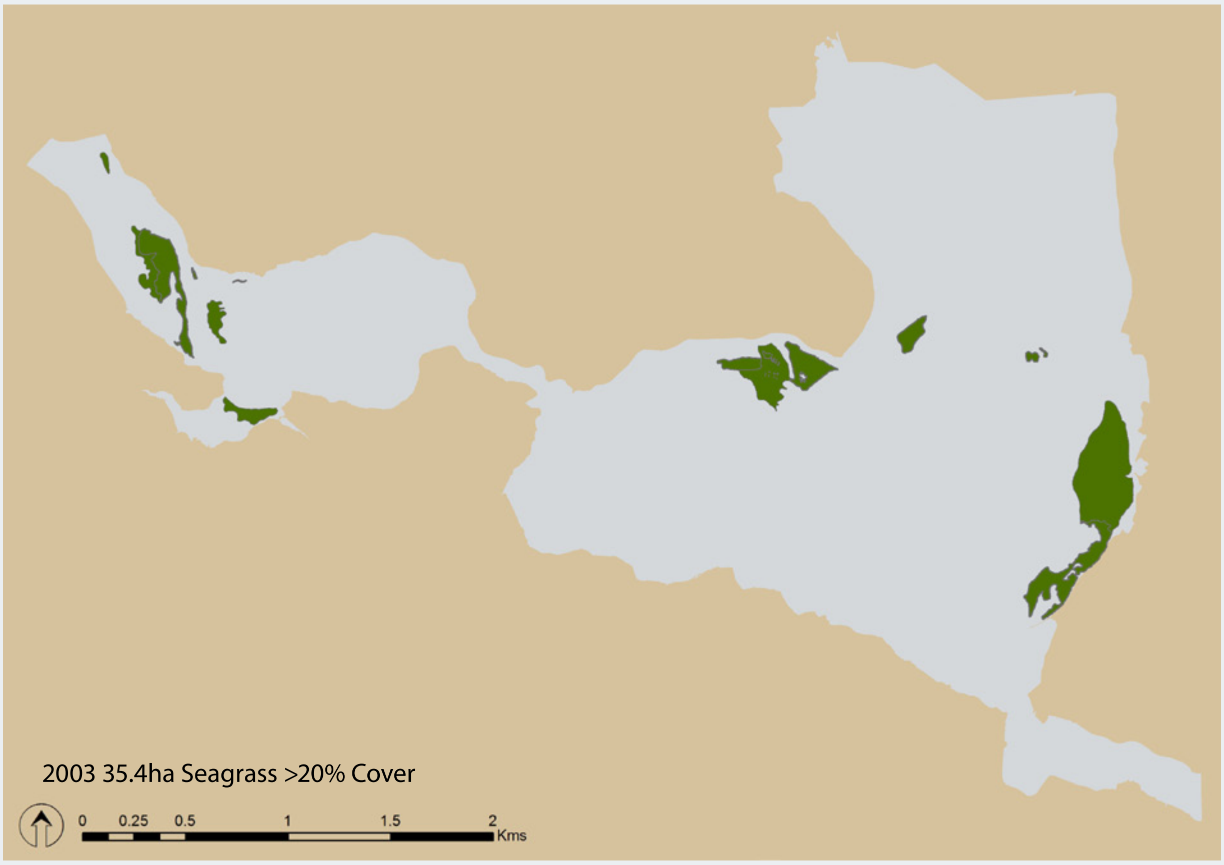


Figure 8. Map of dominant intertidal seagrass - Jacobs River Estuary, February 2018.



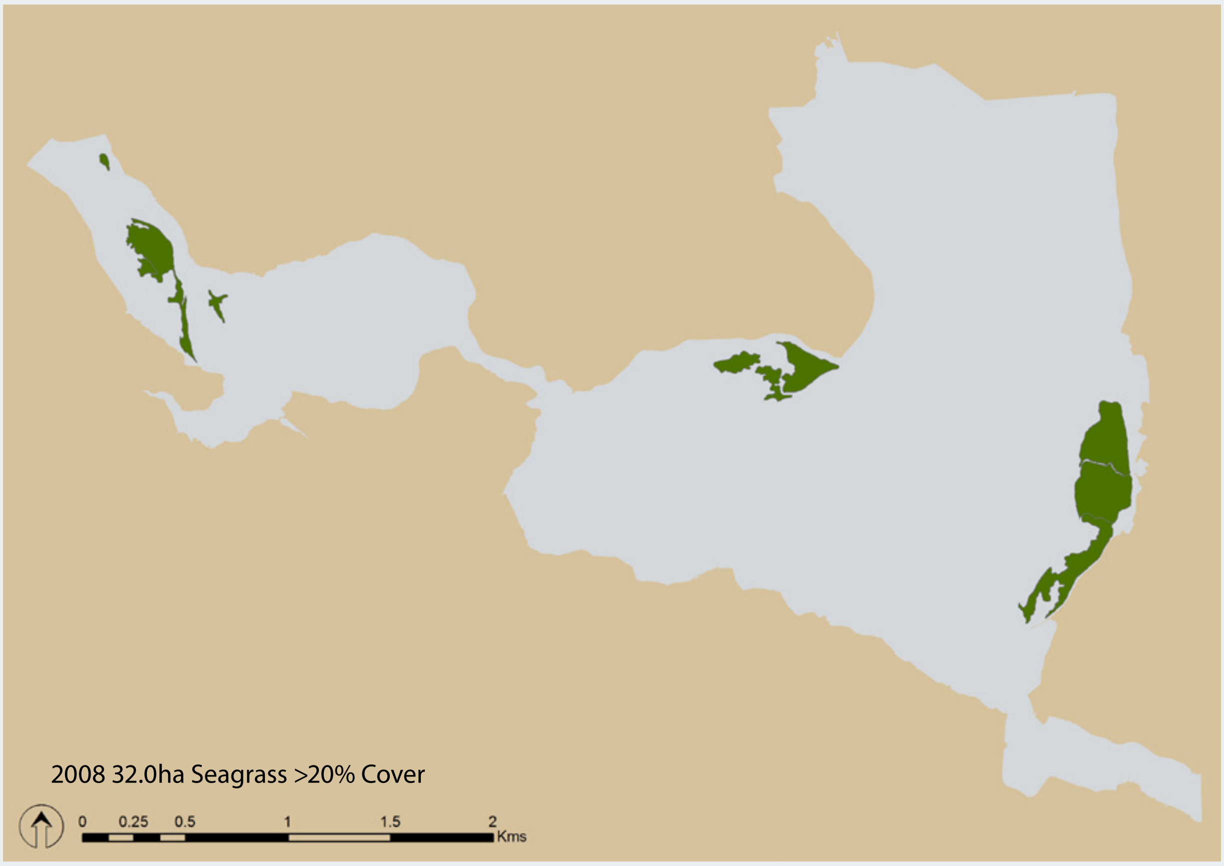
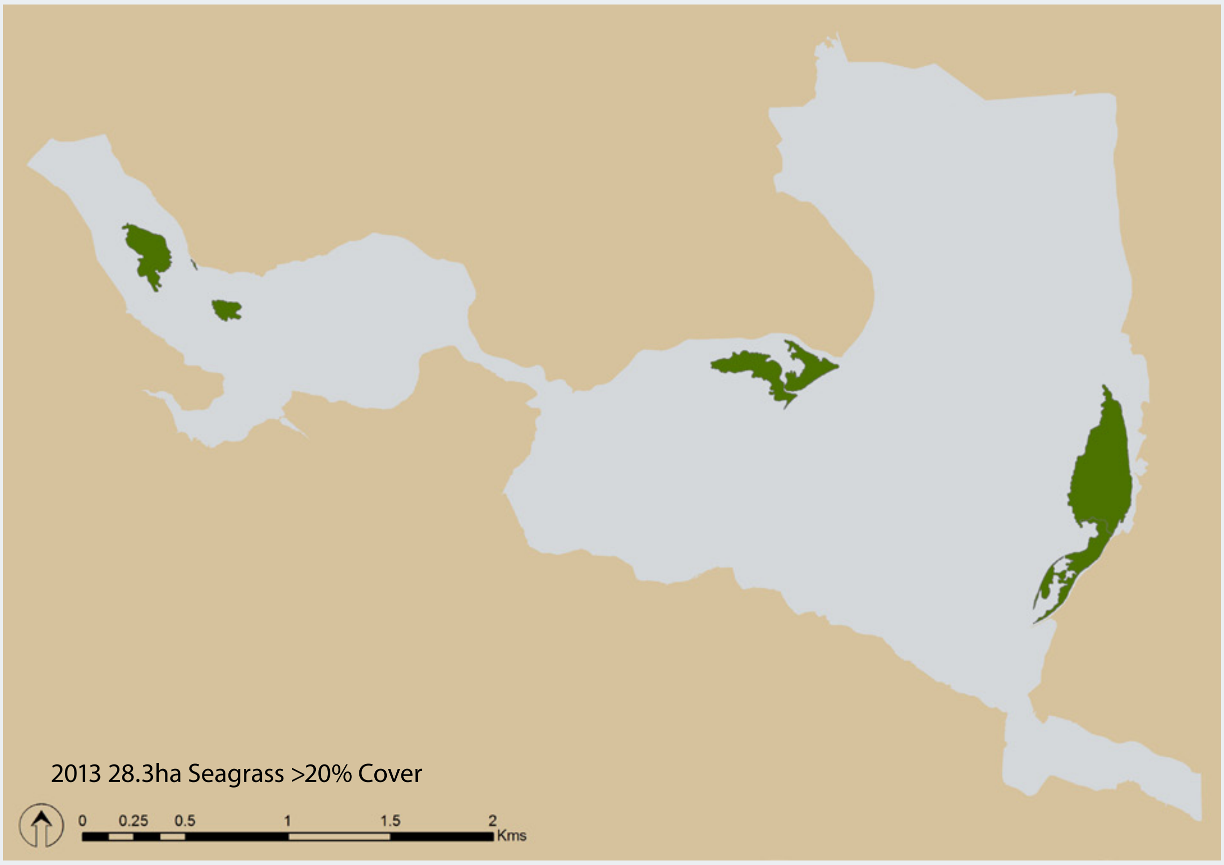


Figure 9. Map of dense seagrass cover (>20%) in Jacobs River Estuary, 2003 and 2008.

3. RESULTS AND DISCUSSION (CONTINUED)



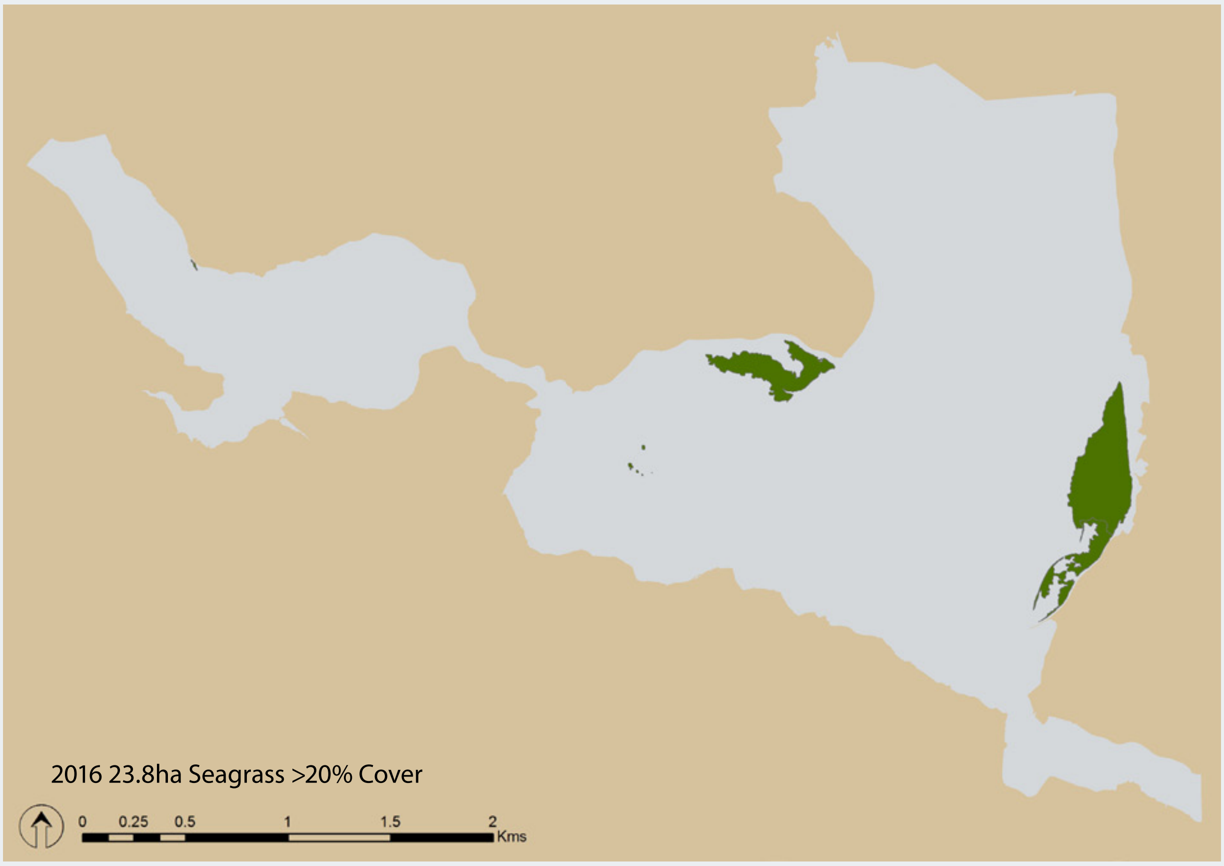


Figure 10. Map of dense seagrass cover (>20%) in Jacobs River Estuary, 2013 and 2016.

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 11 summarise the 2018 saltmarsh mapping results. Overall, 9% of the estuary (63ha) was classified as saltmarsh, a condition rating of "MODERATE".

Table 9. Summary of saltmarsh cover, Jacobs River Estuary, February 2018.

Saltmarsh Class, Dominant and subdominant species	Ha	%
Tussockland	**0.8**	**1.3**
Phormium tenax (New Zealand flax)		
Apodasmia similis (Jointed wirerush)	0.8	1.3
Grassland	**3.0**	**4.8**
Festuca arundinacea (Tall fescue)	0.1	0.2
Ammophila arenaria (Marram grass)	0.3	0.4
Apodasmia similis (Jointed wirerush)	0.7	1.2
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.2	0.3
Samolus repens (Primrose)	0.3	0.4
Ulex europaeus (Gorse)	1.4	2.3
Rushland	**54.0**	**86.1**
Apodasmia similis (Jointed wirerush)	22.7	36.2
Festuca arundinacea (Tall fescue)	21.0	33.5
Phormium tenax (New Zealand flax)	0.2	0.3
Plagianthus divaricatus (Saltmarsh ribbonwood)	10.1	16.2
Sedgeland	**1.1**	**1.7**
Schoenoplectus pungens (Three-square)	0.9	1.4
Apodasmia similis (Jointed wirerush)	0.02	0.03
Selliera radicans (Remuremu)	0.1	0.2
Herbfield	**3.7**	**5.9**
Samolus repens (Primrose)		
Selliera radicans (Remuremu)	3.0	4.8
Selliera radicans (Remuremu)		
Samolus repens (Primrose)	0.7	1.2
Total	**62.7**	**100**

Saltmarsh was dominated by rushland comprising relatively wide beds of jointed wire rush in the high tide range of the upper estuary, with smaller stands of three square commonly growing seaward of rushes in muds in narrow bands near freshwater seeps. Most rushland was growing within firm sandy muds, although saltmarsh in the upper Pourakino Arm was relatively muddy. Herbfields comprising primarily primrose and remuremu formed dense turf communities among gravel beds in the well flushed parts of the central basin near the Aparima River.

In many areas saltmarsh was largely cut off from direct tidal inundation by drainage ditches running parallel to the shore and the vegetation reflected this, being dominated by freshwater tolerant species e.g. flax, tall fescue, and three square. Nearer to the sea, saltmarsh was often restricted to narrow strips because of habitat limitations caused by seawalls and reclamations, or by natural rockfields or low cliffs and eroding margins.

A supporting measure for saltmarsh is estimated loss compared to natural state cover. While assumptions need to be made regarding likely historical extent, it is estimated that >60% of saltmarsh has been lost through drainage and conversion to grassland, a supporting risk rating of "POOR".

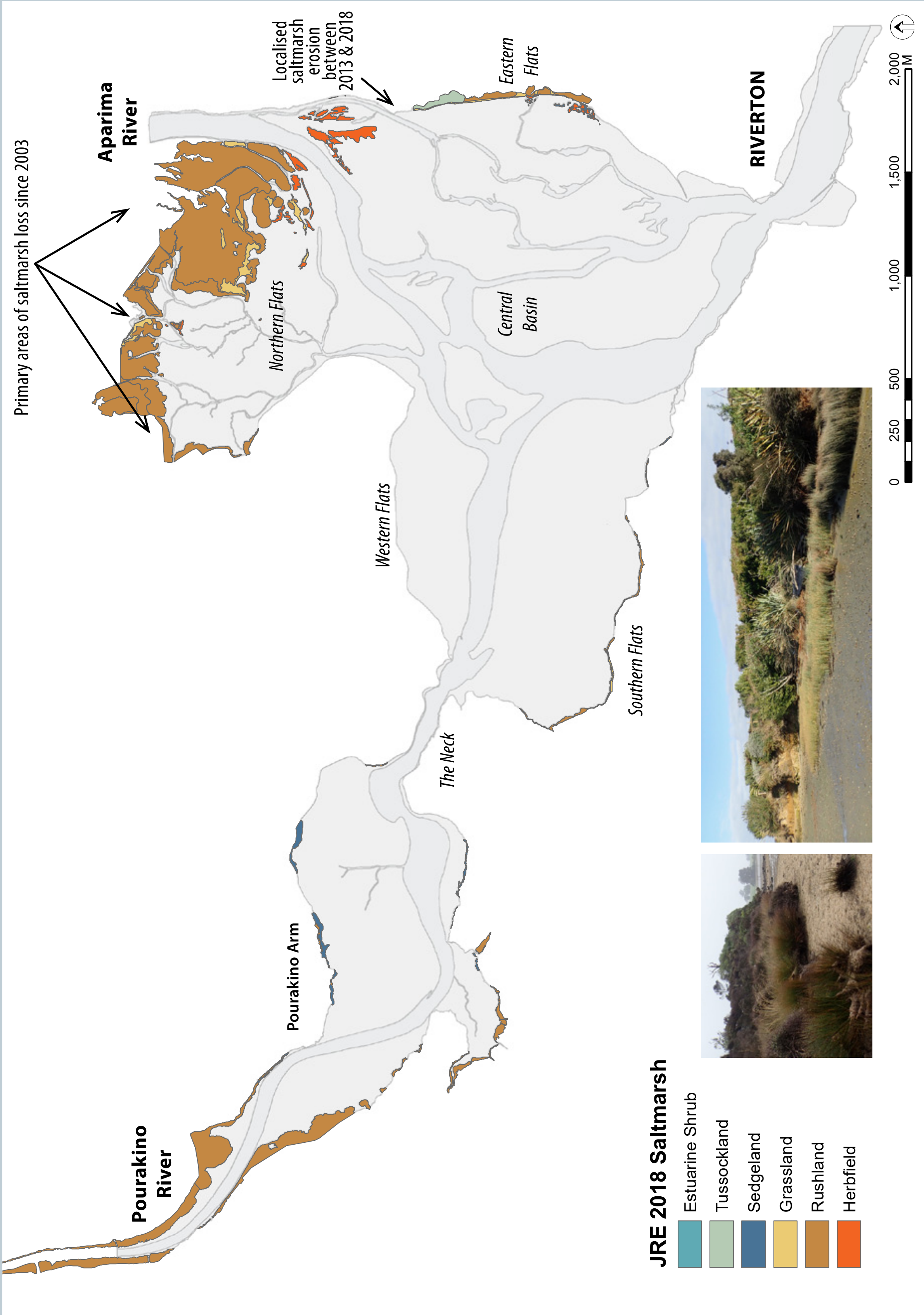


Figure 11. Map of dominant intertidal saltmarsh - Jacobs River Estuary, February 2018.

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 (e.g. tall fescue) 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 13ha (18%), a change rating of "MODERATE". 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 grass dominated tussock and rushland to terrestrial grassland at the edges of the estuary, with the most extensive changes occurring adjacent to the northern flats in the Aparima Arm. These areas are still occasionally covered by flood flows but are no longer regularly inundated by saline water and have become functionally terrestrial. A small area of saltmarsh has also been eroded on the eastern flats by flood flows from the Aparima River (Figure 11).

Table 10. Summary of changes in saltmarsh extent - 2003, 2008, 2013 and 2018.

Vegetation Class	2003		2008		2013		2018	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Scrub	1.0	1.3	0	0	0.3	0.4	0	0
Tussockland	8.2	10.9	4.3	5.8	4.4	5.8	0.8	1.3
Sedgeland	1.5	2.0	0.9	1.3	1.4	1.8	1.1	1.7
Grassland	7.9	10.4	12.4	16.9	13.2	17.4	3.0	4.8
Rushland	57.3	75.5	55.0	74.6	54.1	71.1	54.0	86.1
Herbfield	0	0	1.1	1.5	2.8	3.6	3.7	5.9
TOTAL	76	100	74	100	76	100	63	100



Rushland in the Pourakino Arm (left) and tall fescue growing along the estuary margin in the main basin.

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 are presented in Table 11 and Figure 12 and show Jacobs River Estuary has 12% of the margin densely vegetated, a condition rating of "POOR".

The majority of the 200m margin was grassland (72%) primarily used for dairy farming, but includes small areas of unmanaged grassland. This was located predominantly where saltmarsh has been historically drained. Previously, these areas supported lowland wetlands which, apart from their high ecological value, are also very effective at assimilating catchment derived nutrient and sediment inputs. Drainage of this land has resulted in reduced access for migratory species through habitat loss and the construction of low stopbanks and flap gates to minimise tidal inundation.

Pockets of scrub/forest buffer are present in narrow strips along many of the steeper parts of the estuary margin, areas generally unsuitable for farming. Cover is predominately gorse or flax, and biodiversity would be greatly enhanced by an increase in native plants and extent. Around Riverton itself, the estuary margin has been extensively modified with roads, artificial seawalls and reclamations along much of the estuary edge. Various industries have established along the foreshore in the south east with very limited natural buffering remaining. There has been no meaningful change in the composition of the terrestrial margin cover since 2003.

Table 11. Summary of the 200m terrestrial margin, Jacobs River Estuary, February 2018.

Dominant 200m terrestrial margin cover	2018 %
Forest	0.1
Scrub/Forest	3.5
Scrub	8.0
Grassland	71.8
Duneland	0.3
Residential	10.8
Commercial	1.7
Industrial	1.0
Artificial structure (Road)	2.8
% Dense vegetated 200m margin	**12%**

Land cover in the wider catchment is shown in Figure 13, highlighting that most native forest is generally located in the upper (steeper) reaches of each catchment, with scrub and exotic forestry on the intermediate slopes, and pasture on the valley floors. Over half of the Pourakino catchment (54%) is indigenous native forest, with 34% high producing grassland; and 7% exotic forest. The Aparima catchment is dominated by high producing grassland 58%, with 11% indigenous native forest; and 12% exotic forest (source LCDBv41, 2012/13).

Compared to the Aparima, the relatively high cover of native forest in the Pourakino catchment means it is at reduced risk from common terrestrial stressors of sediment, nutrients and pathogens, however, due to its relatively small assimilation capacity, and the constriction of flows through the Neck, it readily retains sediments and nutrients.

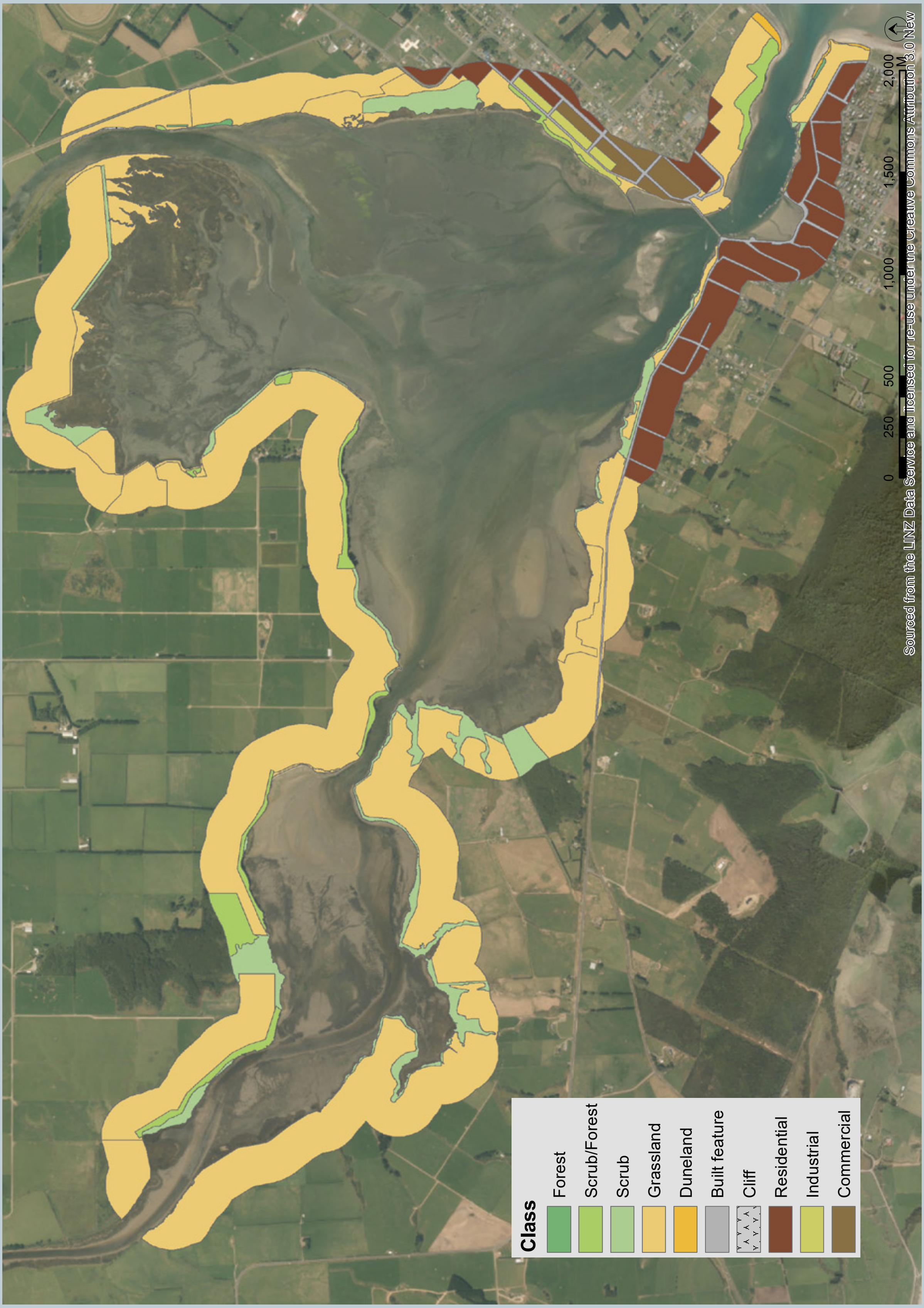
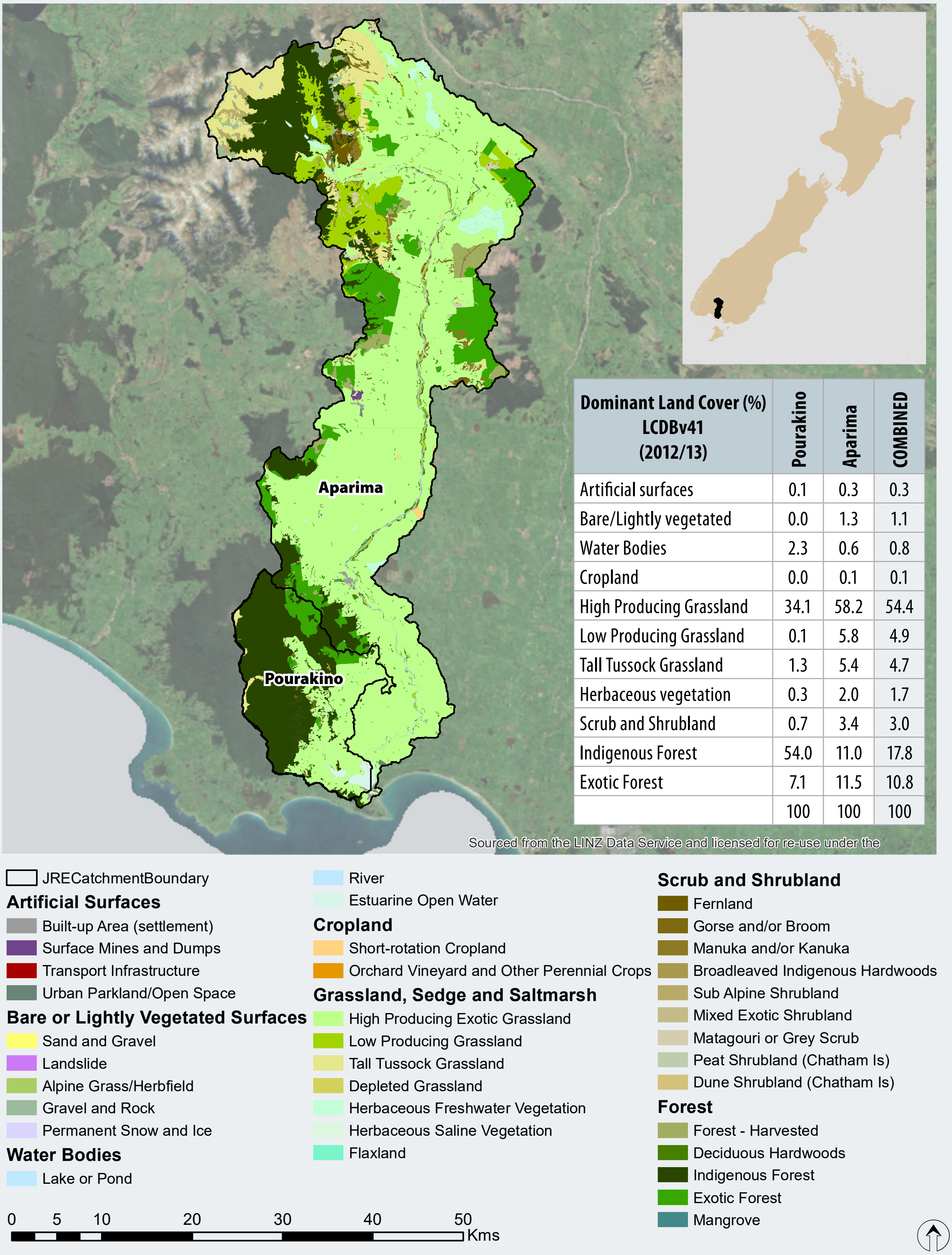


Figure 12. Map of 200m terrestrial margin vegetation - Jacobs River Estuary, February 2018.



Dominant Land Cover (%) LCDBv41 (2012/13)	Pourakino	Aparima	COMBINED
Artificial surfaces	0.1	0.3	0.3
Bare/Lightly vegetated	0.0	1.3	1.1
Water Bodies	2.3	0.6	0.8
Cropland	0.0	0.1	0.1
High Producing Grassland	34.1	58.2	54.4
Low Producing Grassland	0.1	5.8	4.9
Tall Tussock Grassland	1.3	5.4	4.7
Herbaceous vegetation	0.3	2.0	1.7
Scrub and Shrubland	0.7	3.4	3.0
Indigenous Forest	54.0	11.0	17.8
Exotic Forest	7.1	11.5	10.8
	100	100	100

Figure 13. Summary of Catchment Land Cover (LCDBv41 2012/13), Jacobs River Estuary.

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 Jacobs River Estuary are presented in Table 12 below using the broad scale monitoring results presented in this report, data in Robertson et al. (2017), and unpublished ES data collected from Site D in the eutrophic Pourakino Arm in February 2018.

ETI Tool 1 rates the nutrient load susceptibility as “HIGH” - note default ETI values from Coastal Explorer have been updated with more accurate field measurements to provide better accuracy.

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

The ETI score places Jacobs River Estuary in the very upper range of possible scoring and highlights the presence of significant eutrophication symptoms in the estuary.

Table 12. Primary and supporting indicator values used to calculate an ETI score for Jacobs River Estuary, February 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	0.245	13
Required	Macroalgal GEZ %	% Gross Eutrophic Zone (GEZ)/Estuary Area	shallow intertidal	30	14
Required	Macroalgal GEZ Ha	Ha Gross Eutrophic Zone (GEZ)	shallow intertidal	144	15
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	-317	14
Required Indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow intertidal	29	14
Required Indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow intertidal	143.5	15
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	1.3	10
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	1333	10
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	4.74	14
Optional Indicators	Muddy sediment	Proportion of estuary area with >25% mud content	shallow intertidal	28	16
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**			15.0
		Final Supporting Indicator Score			13.3
			ETI SCORE	**0.88**	
			ETI BAND	**POOR**	

4. SUMMARY AND CONCLUSION

Broad scale mapping of Jacobs River Estuary was first undertaken in February 2003 and has been repeated in 2008, 2013, 2016 (limited survey) and 2018. Macroalgal mapping was also undertaken in February 2007 and annually from 2008 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 Jacobs River Estuary by matching the 2018 coverage to that mapped in 2003, 2008, 2013 and 2016. 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, Jacobs River 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	-	125*	-	164	33%	-	-	<20	<4%	34.5	baseline
2007	-	125*	-	-	-	-	-	-	-	-	-
2008	-	263	-	165	33%	-	-	20	4%	32.0	-7%
2009	-	162	-	-	-	-	-	-	-	-	-
2010	-	165	-	-	-	-	-	-	-	-	-
2011	-	149	-	-	-	-	-	-	-	-	-
2012	-	156	-	-	-	-	-	-	-	-	-
2013	-	149	-	166	34%	-	-	141	30%	28.3	-18%
2016	0.96	181	0.248	171	35%	145	30%	145	30%	23.8	-31%
2018	0.88	138	0.245	145	29%	144	29%	144	29%	28.6	-19.2%

*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, it is estimated that ~125ha of the estuary supported high density macroalgal cover (i.e. >50% cover), with significant beds established in sheltered settlement areas of the Aparima and Pourakino Arms. Soft mud was also prominent in these areas, and covered 164ha (33%) of the estuary. While not formally assessed at the time, gross eutrophic zones (GEZs) were not a prominent feature in the estuary.
- Repeat broad scale monitoring in 2008 showed a significant expansion of dense macroalgal cover to 263ha, very little change in soft mud extent, but the presence of 20ha of GEZ. Seagrass had declined from 34ha to 32ha due to displacement by dense macroalgal growths.
- Annual monitoring of macroalgal cover between 2009 and 2013, showed consistent and extensive high density cover - 149-165ha, but with increasing biomass evident. Mean biomass measured in 2013 in the GEZ areas was 15,000gm^{-2} wet wgt in Pourakino Arm and 12,000gm^{-2} wet wgt in Aparima Arm.
- By February 2013, the GEZ had increased to 141ha (30%) from 20ha (4%) in 2008, while seagrass had declined by 18% (from 32ha to 28ha), predominately displaced by dense macroalgal growth.
- Monitoring in February 2016 showed very extensive GEZs were still present and slightly larger (145ha), and seagrass had declined to 24ha (a 31% loss since 2003), displaced by dense macroalgae.
- In 2018 there was a small reduction in soft mud and macroalgal cover compared to 2016 within the northern Aparima Arm. Seagrass beds had also increased in area, re-establishing on the eastern flats near the Aparima River in an area previously dominated by macroalgae. However, the extent of GEZs and reduced sediment oxygenation remained very extensive and macroalgal biomass remained very high: ~11,000gm^{-2} wet wgt in Pourakino Arm and ~6,000gm^{-2} wet wgt in Aparima Arm. The 2018 ETI score of 0.88 (Band D) shows the estuary is expressing significant adverse symptoms of nutrient enrichment.

The results for all years highlight the consistent presence of extensive high density (>50% cover) opportunistic macroalgae, 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 currently in a "POOR" condition overall in relation to eutrophication and muddiness, and "MODERATE " in relation to habitat loss.

5. RECOMMENDED MONITORING

Jacobs River Estuary has been identified by Environment Southland as a high priority for monitoring, and is a key part of their coastal monitoring programme being undertaken in a staged manner throughout the Southland region. 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 be undertaken at five yearly intervals (next scheduled for consideration in 2023).

Macroalgae

Because of the significant growth and impact of nuisance macroalgae in the estuary it is recommended that ES continue with the programme of annual broad scale mapping of macroalgae in February/March each year. More accurate assessment of 2003 and 2007 cover based on aerial photos is also recommended to refine estimates of baseline conditions.

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 additional sediment plates be deployed within representative deposition zones so that the sedimentation rate over much larger parts of the estuary can be determined. These plates will also be used to gauge the success of actions taken to reduce sediment inputs.

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. The next sampling by ES is scheduled for Feb. 2019. 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

Eutrophication and sediment muddiness have been identified as major issues in Jacobs River Estuary since at least 2007-8 (Robertson and Stevens 2008, Stevens and Robertson 2007, 2008).

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). Guideline criteria should be based on available catchment load/estuary response information from relevant estuaries.
- 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 Jacobs River Estuary, February 2018.

Broad Scale Classification	Site #	% mud	% sand	% gravel	NZTM EAST	NZTM NORTH
Mobile muddy SAND (mms)	A1	5.6	87.6	6.9	1215858	4856498
Firm muddy SAND (fms)	A2	6.8	78.3	14.9	1215795	4856650
Firm muddy SAND (fms)	A3	5.0	93.4	1.6	1215718	4856804
Soft MUD (sm)	A4	22.7	73.7	3.6	1215683	4856877
Soft MUD (sm)	A5	24.2	75.3	0.5	1215607	4857030
Very soft MUD (vsm)	A6	28.3	70.6	1.1	1251439	4857392
Firm muddy SAND (fms)	C1	19.8	70.2	9.9	1214093	4855692
Firm muddy SAND (fms)	C2	9.9	89.5	0.5	1214041	4855665
Firm muddy SAND (fms)	C3	17.2	80.3	2.5	1213997	4855640
Very soft MUD (vsm)	C4	57.4	42.5	0.2	1213905	4855591
Very soft MUD (vsm)	C5	60.6	38.7	0.7	1213816	4855544
Very soft MUD (vsm)	C6	76.4	23	0.6	1213736	4855501

See Figures 2 and 3 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.

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Certificate of Analysis

Client:	Environment Southland	**Lab No:**	1932434 SUPv1
Contact:	Keryn Roberts	**Date Received:**	27-Feb-2018
	C/- Environment Southland	**Date Reported:**	26-Apr-2018
	Private Bag 90116	**Quote No:**	54752
	Invercargill 9840	**Order No:**	4060.1375.412
		Client Reference:	Jacobs River Estuary Sediment Transect on 24-Feb-2018
		Submitted By:	Keryn Roberts

Sample Type: Sediment

	Sample Name:	20180713 24-Feb-2018 4:00 pm	20180714 24-Feb-2018 4:15 pm	20180715 24-Feb-2018 4:30 pm	20180716 24-Feb-2018 4:45 pm
	Lab Number:	1932434.1	1932434.2	1932434.3	1932434.4
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	80	84	77	79
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	6.9	14.9	1.6	3.6
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	87.6	78.3	93.4	73.7
Fraction < 63 µm*	g/100g dry wt	5.6	6.8	5.0	22.7

	Sample Name:	20180717 24-Feb-2018 5:00 pm	20180718 24-Feb-2018 5:15 pm		
	Lab Number:	1932434.5	1932434.6		
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	76	76	-	-
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	0.5	1.1	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	75.3	70.6	-	-
Fraction < 63 µm*	g/100g dry wt	24.2	28.3	-	-

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.

Analyst's Comments

The customer has indicated that the sampling time was recorded as NZ Standard Time (NZST). The sampling time has been reported as supplied in NZST. It should be noted any other times reported by Hill Laboratories will have been corrected for New Zealand Daylight Saving Time (NZDT), where applicable.

The sample temperature on arrival (taken from a randomly selected sample from within the batch) was 12.8 °C.

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			

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Certificate of Analysis

Page 1 of 2

Client:	Environment Southland	**Lab No:**	1939729 SUPv1
Contact:	Keryn Roberts C/- Environment Southland Private Bag 90116 Invercargill 9840	**Date Received:**	08-Mar-2018
		Date Reported:	03-May-2018
		Quote No:	54752
		Order No:	4060.1375.412
		Client Reference:	Jacobs River Estuary Sediment Transect 2 The Narrows on 25-Feb-2
		Submitted By:	Keryn Roberts

Sample Type: Sediment

Sample Name:		20180856 25-Feb-2018 4:00 pm	20180857 25-Feb-2018 4:10 pm	20180858 25-Feb-2018 4:30 pm	20180859 25-Feb-2018 4:45 pm
Lab Number:		1939729.1	1939729.2	1939729.3	1939729.4
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	81	82	81	73
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	9.9	0.5	2.5	0.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	70.2	89.5	80.3	42.5
Fraction < 63 µm*	g/100g dry wt	19.8	9.9	17.2	57.4

Sample Name:		20180860 25-Feb-2018 4:50 pm	20180861 25-Feb-2018 4:55 pm		
Lab Number:		1939729.5	1939729.6		
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	66	61	-	-
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	0.7	0.6	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	38.7	23.0	-	-
Fraction < 63 µm*	g/100g dry wt	60.6	76.4	-	-

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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APPENDIX 6. GROUND TRUTHING

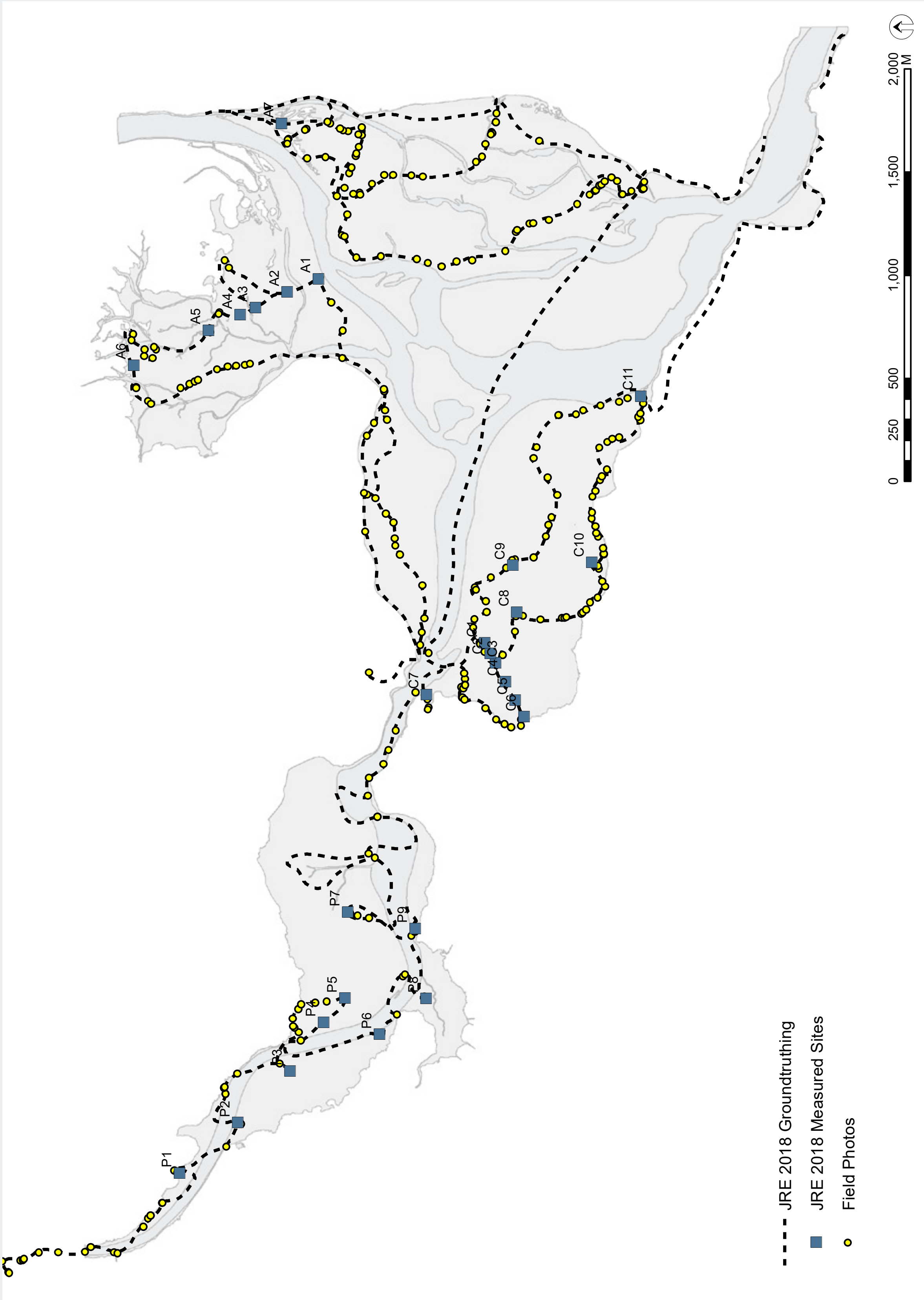

Figure A1. Jacobs River Estuary - showing 2018 ground truthing coverage and location of field photos.

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.

APPENDIX 7. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

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. JACOBS RIVER ESTUARY 2018 MACROALGAL DATA

Macroalgal cover >5% used in calculating the OMBT EQR (see Figure A2 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)	aRPD depth (cm)	Presence (1) or absence (0) of soft mud
0	grch ulsp	2.4	80	1	4000	94491	1	1
1	ulsp	4.1	50	1	8000	326675	0	1
2	ulsp grch	19.6	90	1	15760	3087416	0	1
3	grch	8.1	70	1	6000	485348	0	1
4	grch ulsp	2.5	100	1	30000	753750	0	1
5	grch ulsp	2.2	50	1	4800	107071	0	1
6	grch	19.2	80	1	15000	2875695	0	1
7	ulsp	12.2	50	1	6500	791316	0	1
8	grch ulsp	3.5	10	1	2000	69725	0	1
9	grch	0.5	80	0	200	1007	5	0
10	ulsp	1.2	50	0	100	1219	5	0
11	ulsp	0.8	20	1	2000	15040	0	1
12	ulsp	1.9	80	1	5000	94253	0	1
13	ulsp	0.4	20	0	150	555	3	0
14	ulsp	0.4	40	0	1000	3997	3	0
15	ulsp grch	0.4	50	1	5000	17661	1	1
16	grch	19.8	75	1	7500	1488135	0	1
17	grch	1.7	75	1	5000	83657	1	1
18	grch	0.8	75	1	800	6745	1	1
19	grch	1.8	10	0	100	1773	3	0
20	ulsp	0.4	75	1	3000	11908	0	1
21	grch	0.5	100	1	10000	53591	0	1
22	grch ulsp	5.4	20	0	2000	107491	0	0
23	ulsp	4.6	10	0	150	6939	1	0
24	grch	1.6	50	0	4000	64427	3	0
25	grch	44.8	5	0	120	53741	3	0
26	grch	9.2	5	0	50	4621	0	0
27	grch	0.4	80	1	2000	8755	0	1
28	grch	0.9	100	1	3000	28157	0	0
29	grch	1.3	20	1	500	6541	1	1
30	grch	0.8	20	0	150	1158	0	0
31	ulsp	3.5	20	0	50	1751	0	0
32	grch	0.4	20	0	50	183	0	0
33	grch	0.9	20	0	150	1343	0	0
34	grch	0.7	25	0	500	3475	0	0
35	grch	102.0	5	0	50	51018	0	0
36	grch	0.6	100	0	10	57	0	0
37	grch	0.3	100	1	3000	8225	0	1
38	grch	1.4	50	0	100	1393	0	0
39	grch	0.8	100	1	1000	8286	1	1
40	grch	1.1	50	1	1500	16197	0	1
41	grch	5.9	80	1	3000	177126	0	1
42	ulsp	9.4	80	1	6000	561263	0	1
43	grch	2.9	100	1	8000	234700	0	1
44	grch	12.3	80	1	6000	736128	0	1
45	grch	2.8	50	1	6000	166927	0	1

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

APPENDIX 8. JACOBS RIVER ESTUARY 2018 MACROALGAL DATA

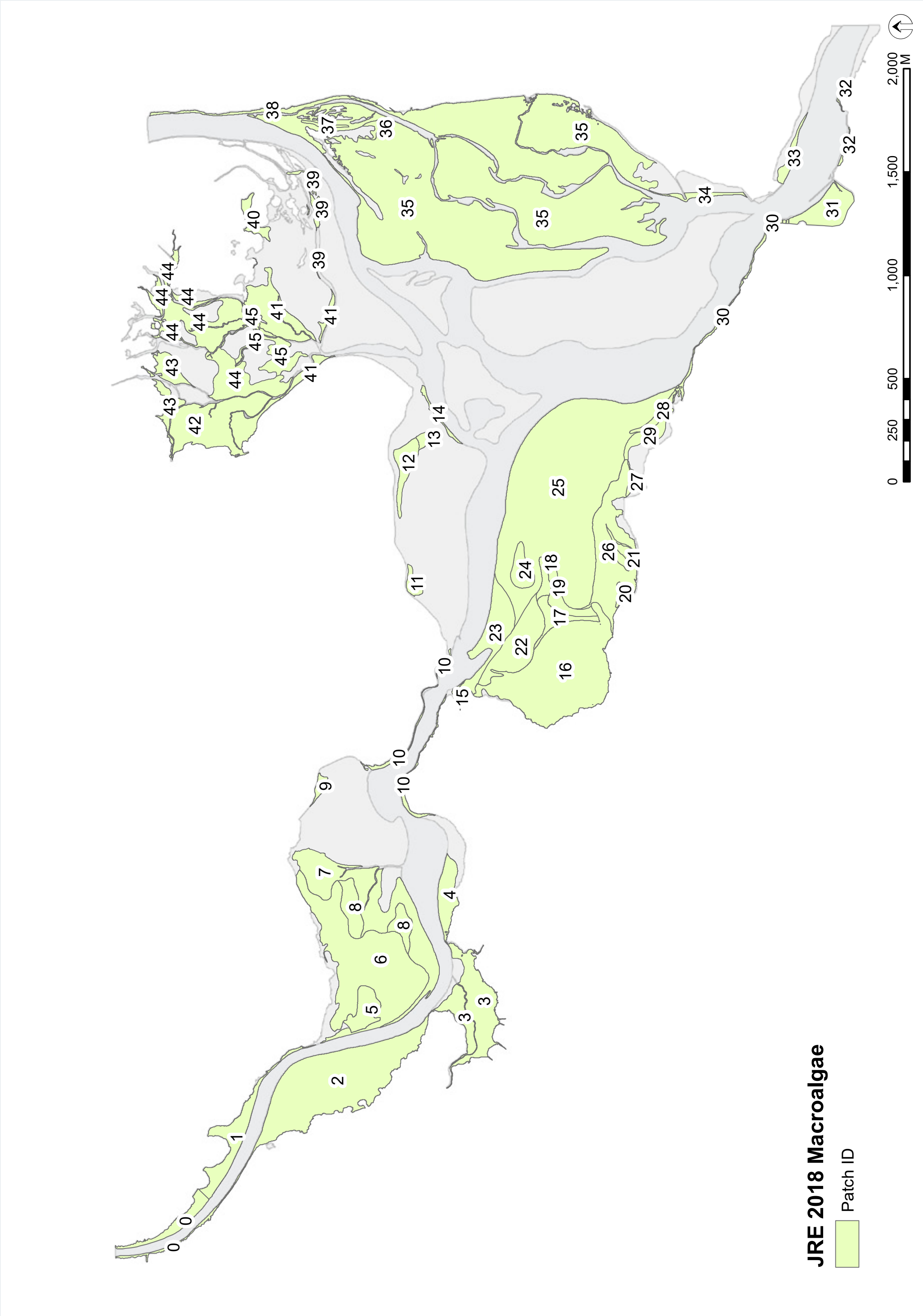
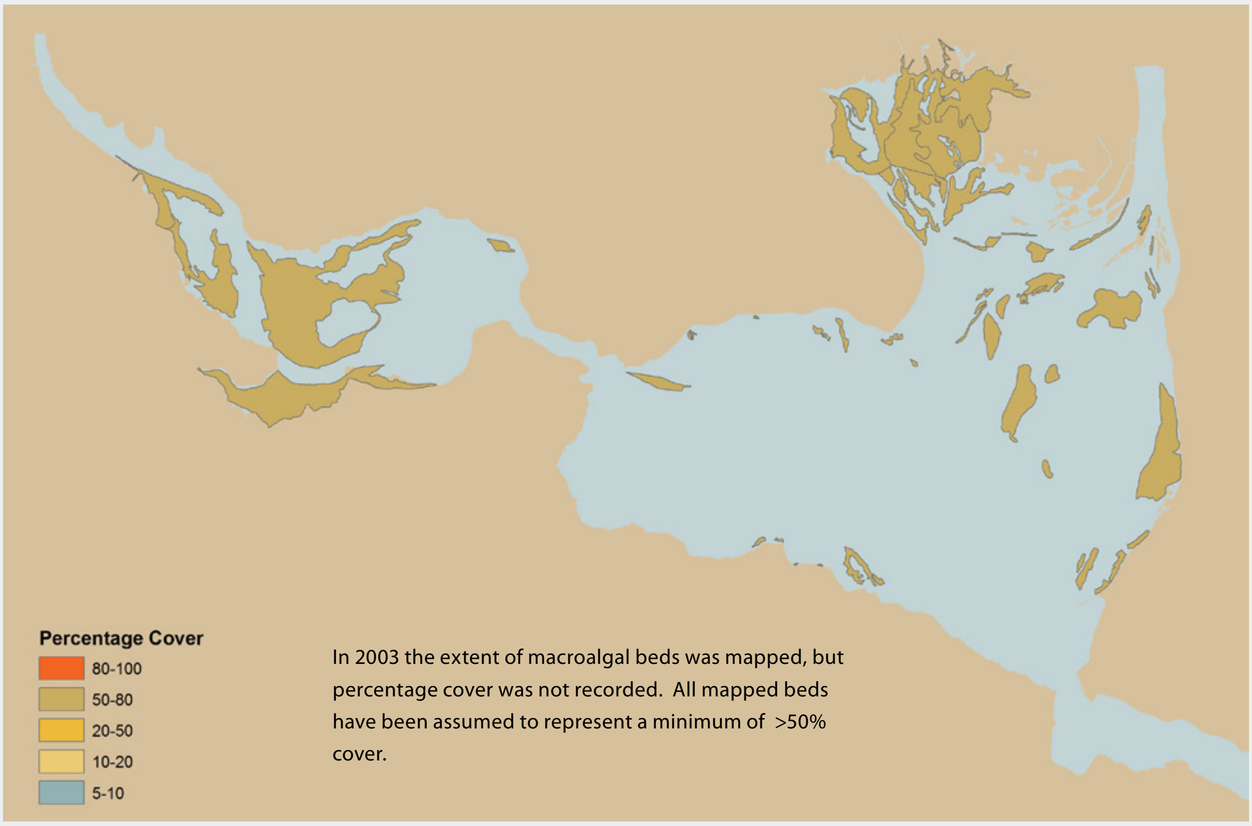


Figure A2. Location of macroalgal patches (>5% cover) used in assessing Jacobs River Estuary, Feb. 2018.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018



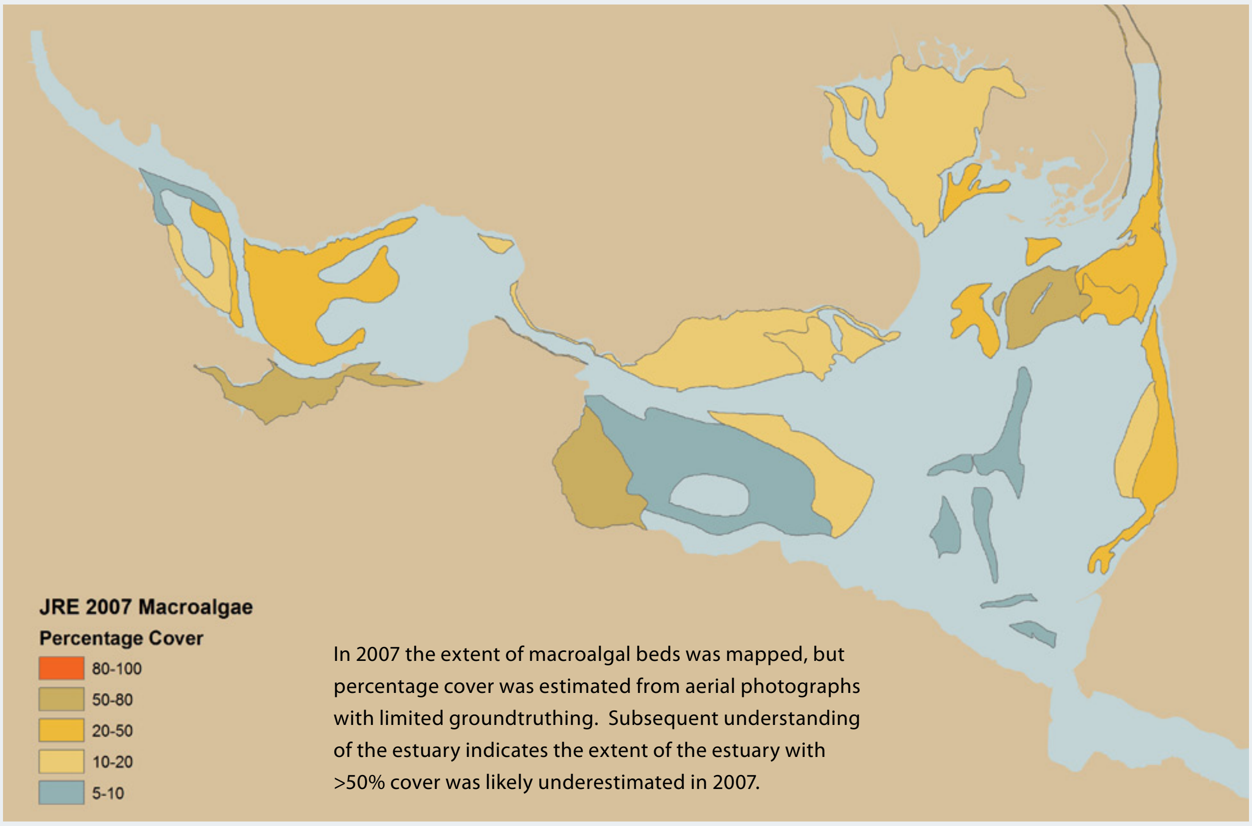
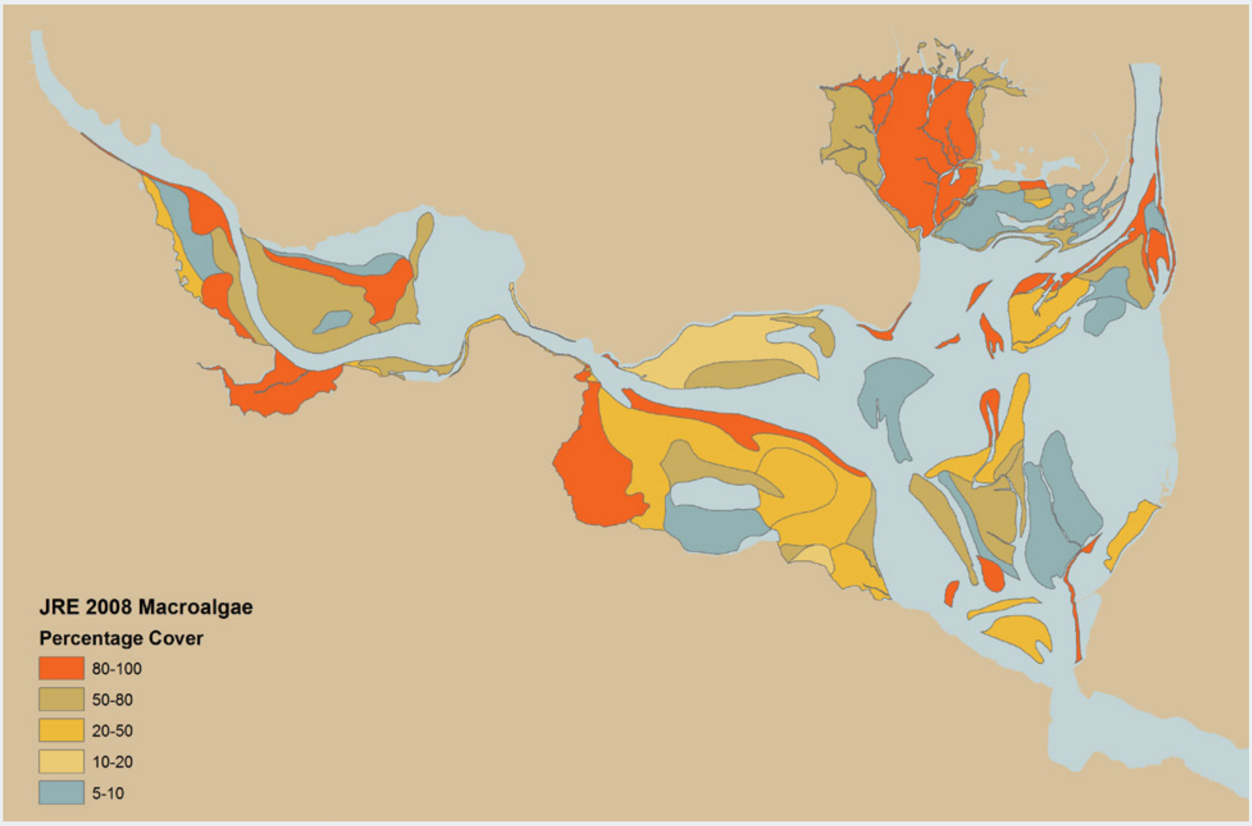


Figure A3. Map of Macroalgal Percentage Cover - Jacobs River Estuary, Feb. 2003 and 2007.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018



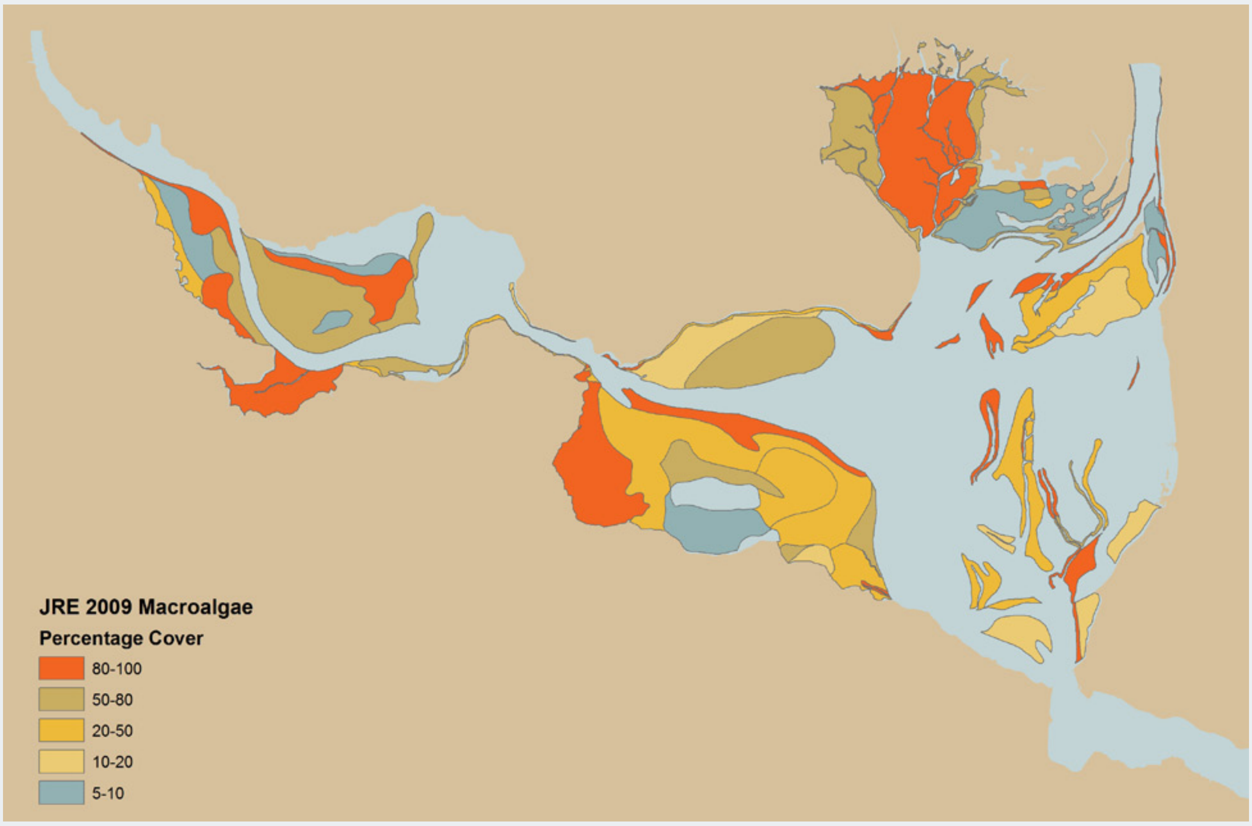
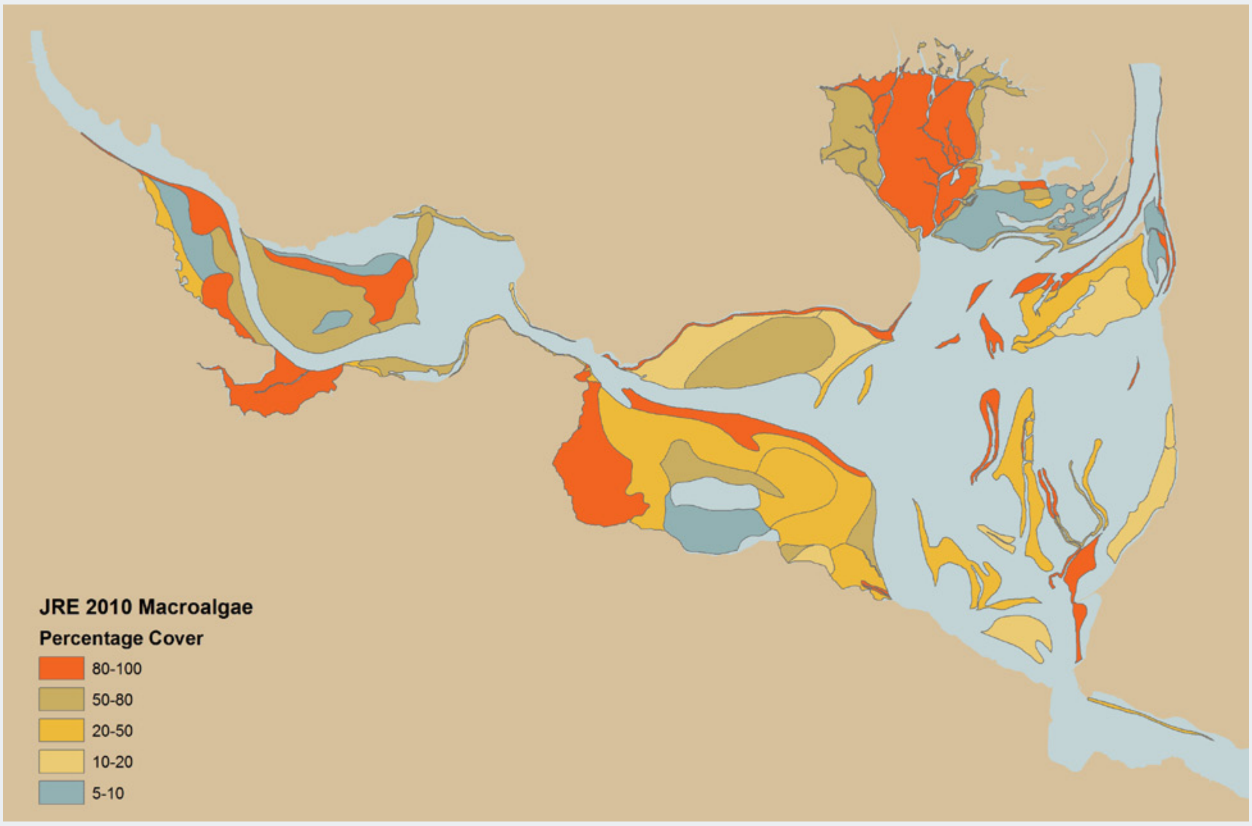


Figure A4. Map of Macroalgal Percentage Cover - Jacobs River Estuary, Feb. 2008 and 2009.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018



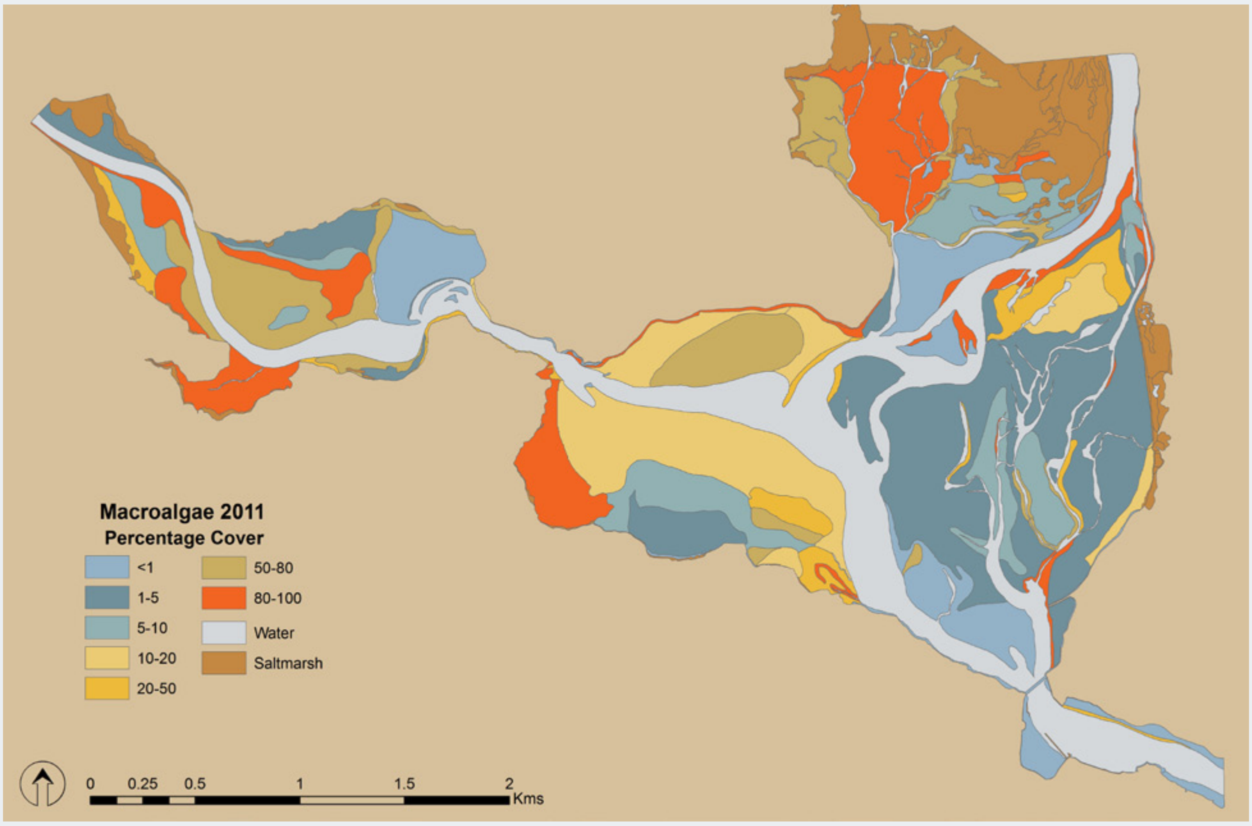
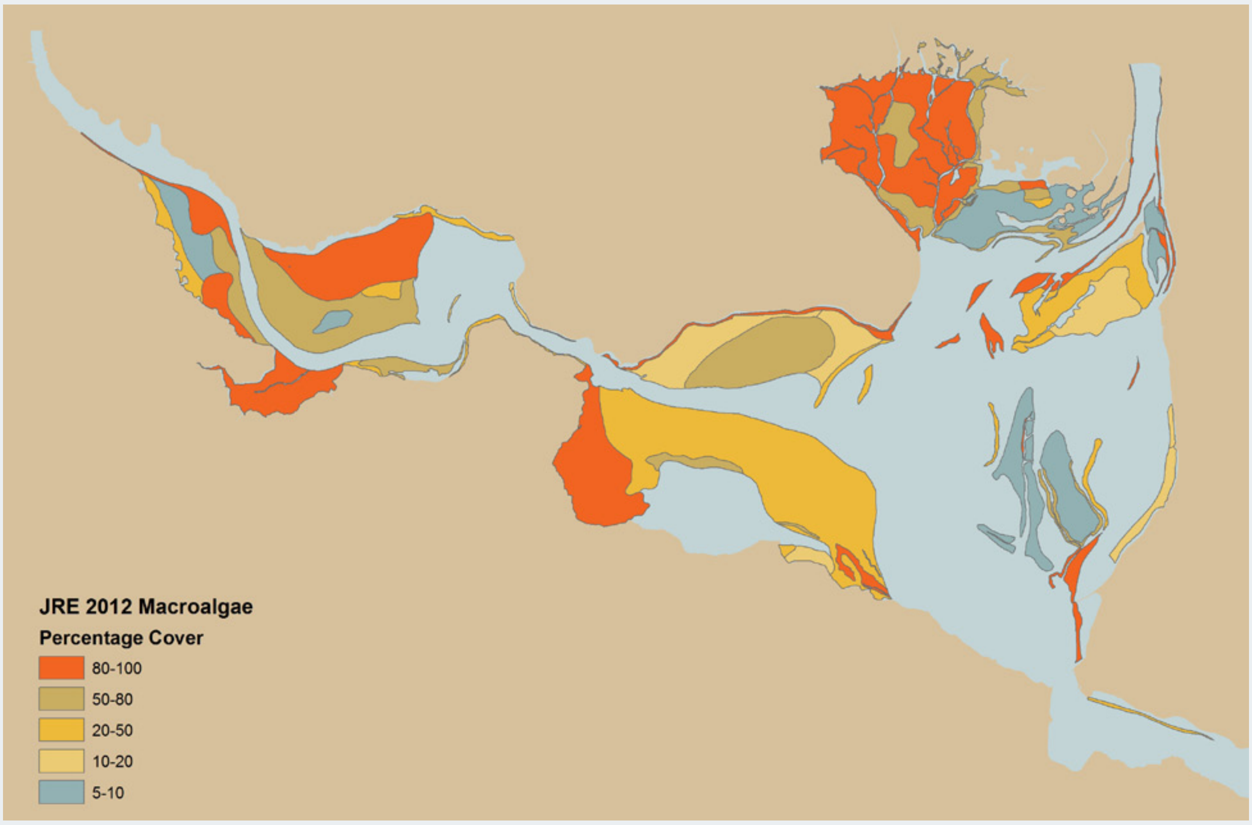


Figure A5. Map of Macroalgal Percentage Cover - Jacobs River Estuary, Feb. 2010 and 2011.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018



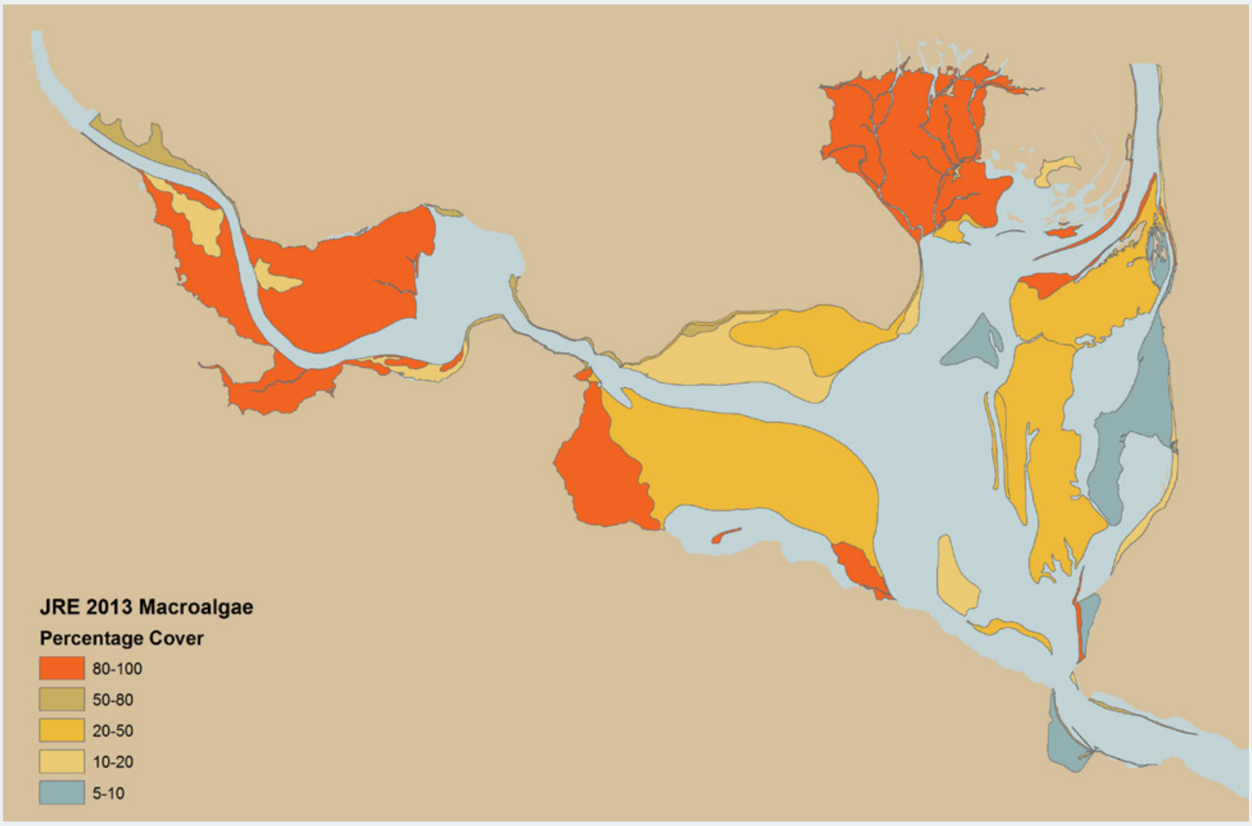


Figure A6. Map of Macroalgal Percentage Cover - Jacobs River Estuary, Feb. 2012 and 2013.

APPENDIX 9. MAPS OF MACROALGAL PERCENTAGE COVER 2003-2018

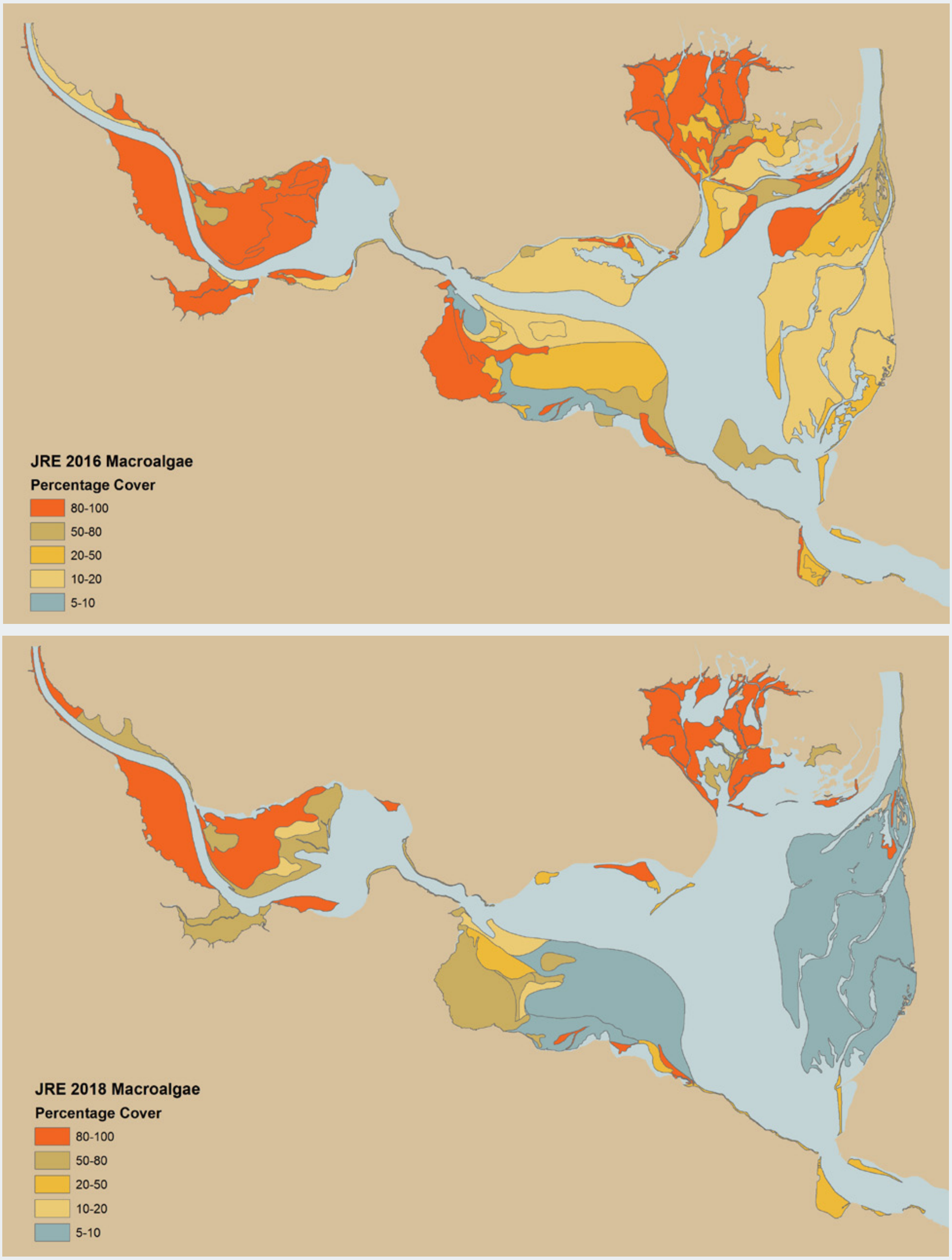


Figure A7. Map of Macroalgal Percentage Cover - Jacobs River Estuary, Feb. 2016 and 2018.