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Havelock Estuary, Marlborough

Broad Scale Habitat Mapping and Ecological Assessment

For Marlborough District Council

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REPORT INFORMATION & QUALITY CONTROL

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Executive Summary

Robertson Environmental Ltd has been engaged by Marlborough District Council (MDC) to undertake the broad scale habitat mapping of Havelock Estuary, a relatively large, shallow, intertidal dominated (SIDE) type estuary situated at the head of Pelorus Sound. It is one of the key estuaries in Marlborough District Council's (MDC's) long-term coastal monitoring programme.

The purpose of the assessment was to characterise the estuary's current ecological condition in relation to several key coastal issues (i.e. eutrophication, sedimentation, and habitat modification), and compare the findings with relevant national standards (NZ Estuary Trophic Index, NZ ETI), to provide recommendations regarding future monitoring and management priorities in the estuary. The survery was undertaken in January 2019, and the results, risk indicator ratings, overall estuary condition, and monitoring recommendations are summarised below.

As summarised in the below table, the 2019 assessment identified the following, with NZ ETI-based risk indicator ratings and previous surveys (2001, 2014) included:

- Intertidal flats comprised 46% of the estuary, saltmarsh 25%, and subtidal waters 29%;
- Intertidal substrata (outside of saltmarsh) were dominated by very soft mud (53%) and soft mud (17.8%), with smaller areas of firm muddy sand (9.8%), gravel (10.2%), cobble (1.9%), firm sand (0.5%), and mobile sand (0.03%);
- Sediment mud content measured within mud habitat was high (34.6-92.8%);
- Opportunistic macroalgal growth was present across 20% of the intertidal flats;
- A relatively small (16 ha, 2.9%) part of the intertidal estuary was adversely impacted by gross eutrophic zones and areas with low sediment oxygenation.

Summary of NZ ETI-based risk ratings, Havelock Estuary, 2001, 2014 and 2019.

Estuary Issue	Indicator	Risk Indicator[1]			Narrative change since 2014
		2001	2014	2019	
Sedimentation	Soft mud (% cover)	High	High	High	No notable change
Eutrophication	Macroalgal Growth (OMBT Index)	Low	Low	Moderate	Increase in the extent of opportunistic macroalgae
	Gross Eutrophic Zones (ha)	Very low	Very low	Moderate	Increase (16 ha, 3%)
	Sediment Oxygenation (ha)	*na*	*na*	High	-
Habitat Modification	Seagrass Change (since baseline)	*na*	Very low	Moderate	Decrease (3 ha, 10%)
	Saltmarsh (% of intertidal area)	Very low	Very low	Very low	No notable change
	200 m Vegetated Terrestrial Margin	Low	Low	Low	No notable change
Overall NZ ETI Rating		*na*	*na*	**Moderate**	-

[1] 2001 and 2014 Risk Ratings from Stevens and Robertson (2014). *na* = not applicable.

- Seagrass beds characterised regions of the lower estuary, but experienced losses (3 ha, 10%) from 2014 to 2019.
- Saltmarsh cover was relatively extensive 197 ha (35% of the intertidal area) and was dominated by rushlands (95%).
- The 200 m terrestrial margin was 53% densely vegetated buffer zone with 38% pasture or unmaintained grassland.
- The majority of the upper tidal reaches of the estuary (~70%) have been modified with the edge hardened or armoured as a consequence of reclamation (e.g. most of the areas flanked by roading, seawalls, or flood control measures) and, to a lesser extent, pasture.

In relation to the key issues addressed by the broad scale monitoring (i.e. muddiness, eutrophication, and habitat modification), the 2019 broad scale mapping results show that the estuary supported a variety of substrata, extensive areas of saltmarsh, and some seagrass. It was expressing symptoms of excessive muddiness, and a moderate level of eutrophication with nuisance macroalgal growths, gross eutrophic zones with very soft muds and poor sediment oxygenation present.

Historically, there has been significant modification and loss of saltmarsh, though much of the 200 m terrestrial buffer remains densely vegetated (53%) but also supports a mix of residential/industrial activities, roading and grassland.

The combined 2019 results place the estuary in a moderate-poor state in relation to ecological health, with an NZ ETI score of 0.67, Band C, reflecting a moderate degree of eutrophic symptoms and a more widespread sediment muddiness/poor oxygenation problem. The most degraded intertidal conditions were largely confined to physically constricted regions of the estuary where flushing potential is low and access to nutrients (from sediments and water column) is high.

In terms of future monitoring and management, Havelock Estuary has been identified by MDC as a priority for monitoring because it is a large sized estuary with moderate-high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation, eutrophication and habitat loss. Broad scale habitat mapping, in conjunction with fine scale monitoring (including sedimentation rate monitoring), provides valuable information on current estuary condition and trends over time. The following broad scale monitoring recommendations are proposed by Robertson Enviro for consideration by MDC:

- Because the estuary is expressing moderate symptoms of eutrophication as well as seagrass decline, it is recommended that macroalgae (including GEZ) and seagrass (including biomass estimates) be synoptically monitored annually (next recommended in 2020), with estuary-wide comprehensive broad scale habitat mapping undertaken every 5 years (next recommended in 2024);
- Sediment muddiness remains a priority issue in the estuary. It is therefore recommended that existing sediment plate depths be measured annually, and a single composite sediment sample be analysed for grain size at each site;
- Fine scale monitoring recommendations are presented in Robertson (2019).

In terms of management, given the ongoing sedimentation issue and more recent establishment of gross eutrophic conditions in the estuary, previous recommendations (e.g. Stevens and Robertson 2014) are reiterated for the prioritised development of catchment nutrient and sediment guideline criteria to derive thresholds protecting against adverse sediment and nutrient impacts. To provide more robust catchment load estimates, it is recommended that future river total nitrogen and suspended sediment load sampling be undertaken during representative lowflow, baseflow and floodflow periods. This would enable local calibration of modelled load estimates thereby strengthening their usefulness for associated management initiatives.

1 Introduction

1.1 Project Brief

The Marlborough District Council (MDC) coastal monitoring strategy (Tiernan 2012) identifies priorities for long-term coastal and estuarine monitoring in the region including broad scale habitat mapping and fine scale monitoring of intertidal sediments in key estuaries. As part of this work, MDC recently engaged Robertson Environmental to map the broad scale intertidal habitat features of Havelock Estuary located at the head of Pelorus Sound, Marlborough (Figure 1). The purpose of the work was to provide MDC with information on the estuary's ecological condition for state of the environment (SoE) monitoring purposes and to help support planning and resource consent decision-making. The following report describes the methods and results of field sampling undertaken on 26th-29th January 2019.

1.2 Background

Estuary monitoring in NZ generally comprises three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) to address major issues identified in NZ estuaries (see Appendix A). The tiered approach includes:

i. Ecological Vulnerability Assessment (EVA) of estuaries to major coastal issues and the design of prioritised and targeted monitoring programmes. This has been partially completed for Havelock Estuary through a preliminary assessment for NZ Landcare Trust (Robertson and Stevens 2009), within the MDC coastal monitoring strategy (Tiernan 2012), and in reports documenting ecologically significant marine sites in Marlborough (e.g. Davidson et al. 2011). The specific vulnerability of Havelock Estuary to key coastal issues has not yet been specifically assessed;

ii. Broad Scale Habitat Mapping (NEMP approach). This component documents the key biophysical features and habitats within the estuary, enables changes to these habitats to be assessed over time, and is used to define fine scale monitoring needs and management priorities. Broad scale mapping of Havelock Estuary was undertaken in 2001 (Robertson et al. 2002) and 2014 (Stevens and Robertson 2014). The current report describes a repeat of broad scale habitat mapping undertaken in early 2019;

iii. Fine Scale Monitoring (NEMP approach). This component monitors physical, chemical and biological indicators within estuary sediments and provides more detailed information on estuary condition.

This report focuses on detailed broad scale habitat mapping undertaken in January 2019 to assess the current state of Havelock Estuary and uses a range of established broad scale indicators to assess ecological condition. Key indicators are described in Table 1 and Appendix A and include mapping and assessment of:

- Substrata types (e.g. mud, sand);
- Sediment oxygenation;
- Macroalgal beds (i.e. *Ulva* spp., *Gracilaria* spp.);
- Seagrass (i.e. *Zostera muelleri*);
- Gross Eutrophic Zones (GEZs - i.e. macroalgal-dominated, organically enriched/poorly oxygenated benthic environment);
- Saltmarsh vegetation;
- 200 m terrestrial margin surrounding the estuary.

Assessment of results uses a suite of indicator ratings developed for nationally standardised estuarine assessment (Table 1), many of which are included in the recently developed NZ Estuary Trophic Index (NZ ETI) (Robertson et al. 2016a,b). The NZ ETI is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness.

1.3 Report Structure

The current report presents a brief introduction to the Havelock Estuary (Section 1.4), 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 and/or risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 4 with conclusions in Section 5), and to guide monitoring recommendations (Section 6).

1.4 Site Details and Previous Investigations

Havelock Estuary is a large (~800 ha, Robertson et al. 2002; Stevens and Robertson 2014) shallow, intertidal dominated (SIDE; NZ ETI classification in Robertson et al. 2016a) type estuary situated at the head of Pelorus Sound, a long, deep, subtidally dominated estuary (DSDE) (Figure 1). Formed by the sediment output from the Kaituna and Pelorus Rivers (mean flows 3.7 and 45 $m^3 s^{-1}$ respectively), the estuary is macrotidal (2.17 m spring tidal range), has one opening, one main basin, and several poorly flushed tidal arms.

Like much of the Marlborough Sounds, Pelorus Sound is a drowned valley system characterised by steep hillsides that slope directly to narrow rocky shorelines. Intertidal estuarine flats are largely confined to the upper tidal reaches of the elongate and narrow arms where sediment deposition from catchment erosion contributes to the natural build up of river and stream deltas (Figure 1). The extent and nature of the intertidal estuarine deltas is determined largely by the combined influences of underlying geology, the size and steepness of the catchment, and the volume of freshwater flowing to the coast. The type of land cover also has a strong influence on substrata composition, particularly as rates of sediment erosion (and subsequent deposition at the coast) are increased where land cover is disturbed either through natural events such as landslides or fires, or more commonly through human activities such as land clearance for farming or forestry. The drainage of wetland areas (which are very effective at trapping terrestrial sediments) can also significantly increase the delivery of fine sediment to coastal areas.

Havelock Estuary has high use and is valued for its aesthetic appeal, biodiversity, shellfish collection, bathing, waste assimilation, whitebaiting, fishing, boating, walking, and scientific appeal. It is recognised as a valuable nursery area for marine and freshwater fish, an extensive shellfish resource, and is very important for birdlife. A small port and marina is located at Havelock near the Kaituna River mouth.

The catchment (1,149 km^2) is partially developed and dominated by native forest (72%), exotic forestry (14%), dairying (4%), other pasture (8%) and scrub (2%) (source LCDB4, 2012/13). Part of the estuary margin is directly bordered by developed urban and rural land, roads, and seawalls.

Despite the catchment being dominated by mixed native and exotic forest/scrub and hard sedimentary rock types which do not readily erode, the terrain is often steep, and therefore erosion can be elevated from developed areas. This erosion is exacerbated by the frequent and high rainfall in the catchments, which in a typical year has several rainfall events that deliver between 50-200 mm of rain in one day. As a consequence, freshwater inputs to Havelock Estuary tend to include intermittent pulses that carry elevated loads of suspended sediments and nutrients, some of which settle in the estuary, promoting a mud-dominated benthic environment (>70% of intertidal flats characterised by soft/very soft muds), with low clarity water, while the remainder settles in the deeper waters of the subtidal zone - the predominant area of fine sediment deposition in the Marlborough Sounds (see Handley et al. 2017). The cloudy waters and muddy bed can lead to the loss of high value seagrass from intertidal and shallow subtidal areas, and reduced phytoplankton production, seabed life and fish communities. However, due to the relatively large area of upper intertidal shallows, the estuary has extensive beds of high value saltmarsh (predominantly jointed wire rush and sea rush), that provide important habitat for birdlife, macroinvertebrates and, at high water, likely fish.

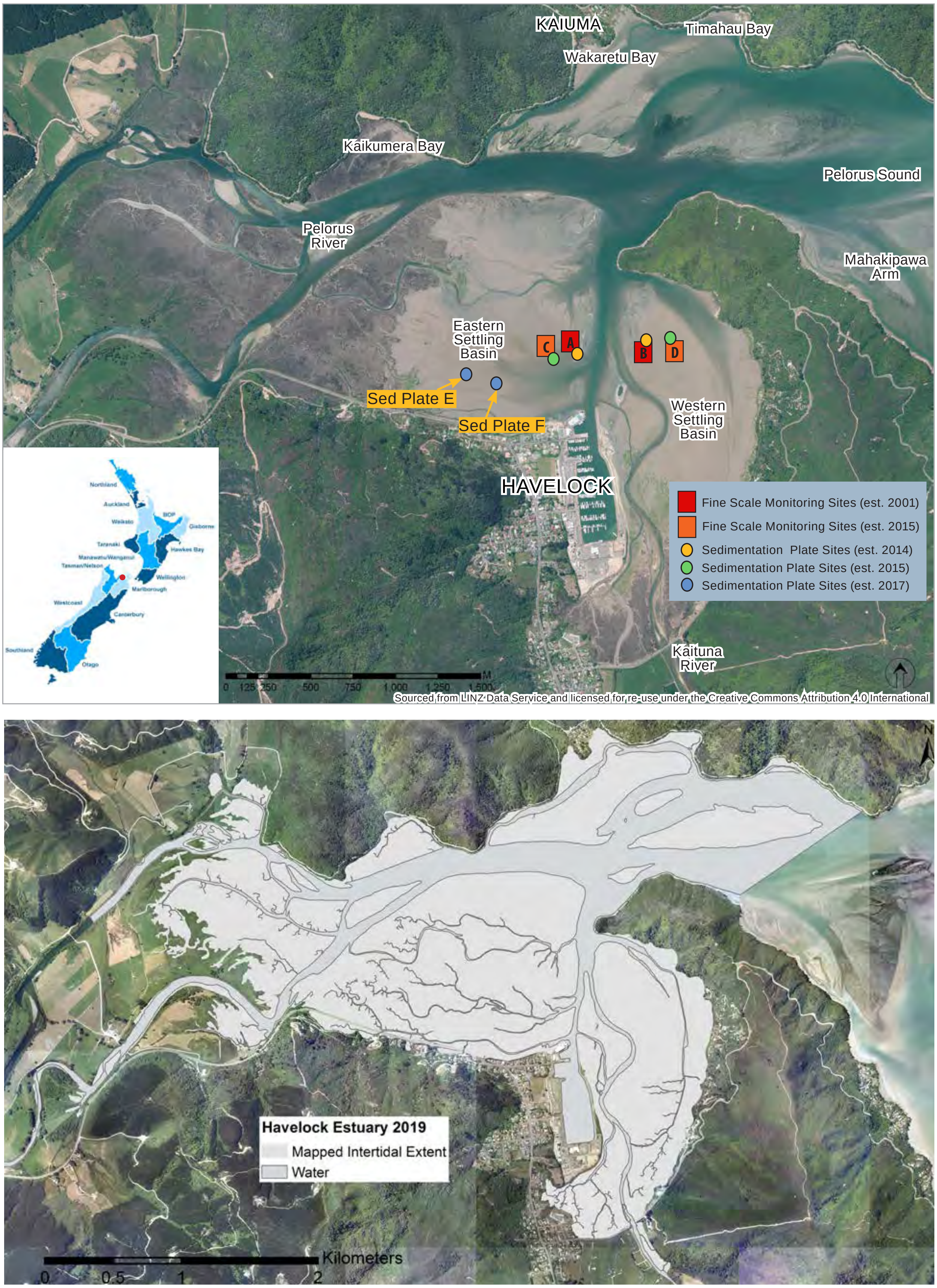


Figure 1. Havelock Estuary, including location of fine scale sampling (A-D) and sediment plate (A-F) monitoring sites and regions presumed vulnerable to sedimentation and/or eutrophication impacts (settling basins). Mapped intertidal extent also shown (bottom map).

The highly elevated mud content of the estuary has also provided ideal habitat for the invasion of opportunists (both plant and animal) such as the introduced cordgrass *Spartina townsendii* and the Pacific oyster (*Crassostrea gigas*), both acting as stabilisers of the mud. Both species established new habitat on unvegetated estuary flats and therefore caused limited displacement of native species. Currently Pacific oyster growth is expanding in the estuary but *Spartina* has been eradicated, releasing an unknown amount of mud and associated nutrients to the water column for redistribution within the estuary (e.g. through erosion of fine sediments previously bound up in root masses) and adjacent sounds.

In terms of catchment loading rates, the estuary receives a relatively moderate nutrient load (estimated catchment total nitrogen (N) areal loading of ~70 mg N m^{-2} d^{-1} which is approaching the proposed guideline for SIDE estuaries of ~100 mg N m^{-2} d^{-1}, Robertson et al. 2016b; Robertson 2018; Robertson & Savage in review), and consequently currently has moderate susceptibility to eutrophication. This is supported by previous surveys of Havelock Estuary which identified early signs of highly localised eutrophication (i.e. excessive macroalgal blooms restricted to poorly flushed upper estuary habitat) as a primary catchment-related issue in the estuary.

Estimated current suspended sediment load (CSSL) compared to the estimated natural state sediment load (NSSL) equates to a ratio of 2.4 (see details in Appendix F), an NZ ETI rating of moderate, indicating that the current sedimentation rate is likely to exceed the natural state sedimentation rate and therefore contribute to sedimentation issues in the estuary, despite the relatively high forest/scrub cover in the catchment.

A 2009 synoptic catchment impact assessment (Robertson and Stevens 2009) and subsequent broad scale survey (Stevens and Robertson 2014) identified excessive muddiness, highly localised macroalgal issues, and moderate disease risk as the most significant catchment-related issues in the estuary.

Havelock Estuary is currently being monitored every five years and the results will help determine the extent to which the estuary is affected by major estuary issues (Appendix A), both in the short and long term.

2 Sampling Methodology

2.1 Broad Scale Habitat Mapping and GIS Analyses

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrata: 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 C lists the definitions used to classify substrata 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 risk indicators (Table 1) to assess estuary condition in response to common stressors, and assess future change.

While the transitional estuarine waters of Havelock Estuary extend well into Pelorus Sound, the extent mapped in 2014 and the present study applied an arbitrary seaward boundary based on that of Robertson et al. (2002). The mapped extent (Figure 1) includes the extensive intertidal margins of the upper estuary, as well as the deltas present at the confluence of the Pelorus and Kaituna River deltas. For the current study, LINZ rectified colour aerial photos (~0.1-0.3 m per pixel resolution) flown in 2017/18 were provided by MDC, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in January 2019 to ground-truth the spatial extent of dominant vegetation and substrata types (see Appendix C). From representative broad scale substrata types, 9 grain size samples were analysed to validate substrata classifications (Appendix D and G). When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Appendix D). Notes on sampling, resolution and accuracy are presented in Appendix D, and field photos are presented in Appendix H.

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) is 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.

Broad scale habitat features were digitised into ArcMap 10.5, and combined with field notes and georeferenced photos to produce habitat maps showing the dominant cover of: substrata, macroalgae (e.g. *Ulva* spp., *Gracilaria* spp.), seagrass, saltmarsh vegetation, and the 200 m 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 NZ ETI condition and risk indicator ratings used in the present report. * NZ ETI (Robertson et al. 2016b), ** Hargrave et al. (2008), Keeley et al. (2012) - Refer to Appendix B for further information.

NZ ETI Condition Bands and Risk Indicator Ratings (indicate risk of adverse ecological impacts)				
Broad and Fine Scale Indicators — NZ ETI Condition Rating*	Very Good (Band A)	Good (Band B)	Moderate (Band C)	Poor (Band D)
Risk Rating	Very Low	Low	Moderate	High
Sediment Oxygenation (aRPD <0.5 cm or RP@3 cm<-150 mV)*	<0.5 ha or <1%	0.5-5 ha or 1-5%	6-20 ha or >5-10%	>20 ha 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
Gross Eutrophic Zones (ha or % of intertidal area)	<0.5 ha or <1%	0.5-5 ha or 1-5%	6-20 ha or >5-10%	>20 ha or >10%
Soft mud (% of unvegetated intertidal substrata)*	<1%	1-5%	>5-15%	>15%
Sediment Mud Content (% mud)*	<5%	5-10%	>10-25%	>25%
Apparent Redox Potential Discontinuity (aRPD)**	>2 cm (Good or Very Good)		0.5-2 cm	<0.5 cm
Saltmarsh Extent (% of intertidal area)	>20%	>10-20%	>5-10%	0-5%
Vegetated 200 m Terrestrial Margin	>80-100%	>50-80%	>25-50%	<25%
Percent Change from Monitored Baseline	<5%	5-10%	>10-20%	>20%
NZ ETI score*	**0 - 0.25**	**0.25 - 0.50**	**0.50 - 0.75**	**0.75 - 1.0**

3 Results and Discussion

3.1 Broad Scale Habitat Mapping Summary

The 2019 broad scale habitat mapping ground-truthed and mapped all intertidal estuary substrata and vegetation including the dominant land cover of the terrestrial (200 m) margin, with the five dominant estuary features summarised in Table 2 and shown in Figures 2-10. This report does not include any mapping/description of subtidal substrata or vegetation.

Estuarine habitat was characterised by extensive intertidal flats (46% of estuary), saltmarsh (24.6%). Seagrass and dense (>50% cover) opportunistic macroalgae comprised ~5% and ~6% of the intertidal area, respectively. The mapping also showed that 53% of the 200 m wide terrestrial margin was densely vegetated, and mixed native and exotic forest/scrub cover in the surrounding catchments was relatively high (39%).

- In the following sections, various factors related to each of these habitats (e.g. area of soft mud) are used to apply risk ratings (Table 1) to assess key estuary issues of sedimentation, eutrophication, and habitat modification. As appropriate, general (non-statistical) trends in broad scale features have been assessed based on the most relevant of either estimates of natural state cover or previous broad scale mapping results for 2001 and 2014;
- In addition, the supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuary. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

Table 2. Summary of dominant broad scale features in Havelock Estuary, 2019.

Dominant Estuary Feature		Area (ha)	% of Intertidal	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	368	65%	46%
2.	Macroalgal beds (>50% cover) [included in 1. above]	21	4%	3%
3.	Seagrass (>20% cover) [included in 1. above]	19	3%	2%
4.	Intertidal saltmarsh	197	35%	25%
5.	Subtidal waters	236	-	29%
	Total Estuary	**801**	**100%**	**100%**

3.2 Intertidal Substrata (Excluding Saltmarsh)

Results (summarised in Table 3 and Figure 2) show the dominant intertidal substrata was very soft mud (53%) and soft mud (17.8%). These muddy substrata were all generally poorly oxygenated (aRPD <1 cm), reflecting the lack of tidal flushing in such regions of both estuary arms. Other prominent habitats included firm muddy sands (9.8%), cobble and gravel fields (12.1%) and oyster beds (6.8% - indicating a 4.8 ha expansion since 2014). Firm sands (1.8%) and rock and boulder features were relatively uncommon. In general terms, mud-dominated substrata and oyster reefs tended to be most common in the mid/upper intertidal basins and embayments (Figure 2) where salinity driven flocculation zones are located. The decaying root systems of the introduced cordgrass *Spartina*, which has been progressively eradicated from the estuary since 2003, were associated with soft muds, as was the case in 2014 (Stevens and Robertson 2014). Gravel, cobble and sand features were predominantly located in the lower reaches of the estuary and adjacent to channels that have a high degree of flushing from river and tidal flows.

Table 3. Summary of dominant intertidal substrata, Havelock Estuary, 2019.

Dominant Substrata	Area (ha)	Percentage	Comments
Cobble field	7.2	1.9%	Shorelines near Havelock township, Kaiuma and Shag Point.
Gravel field	37.6	10.2%	Predominantly within the Pelorus River channel and delta.
Mobile sand	0.1	0.03%	Pelorus River channel and delta, and Kaiuma channel.
Firm sand	1.8	0.5%	Small patches within the Pelorus River channel and delta.
Firm muddy sand	35.9	9.8%	Near the well flushed tidal delta of the Kaituna River and the lower estuary.
Soft mud	65.3	17.8%	Settling areas in the lower estuary and Timahau Bay, and on flats adjacent to Kaituna River.
Very soft mud	194.6	53.0%	Within intertidal settling basins east and west of Kaituna River and in Wakaretu Bay.
Oyster reef	25.0	6.8%	Predominantly in muddy low tide reaches of the main settling basins and lower estuary.
Total Intertidal	**368**	**100%**	

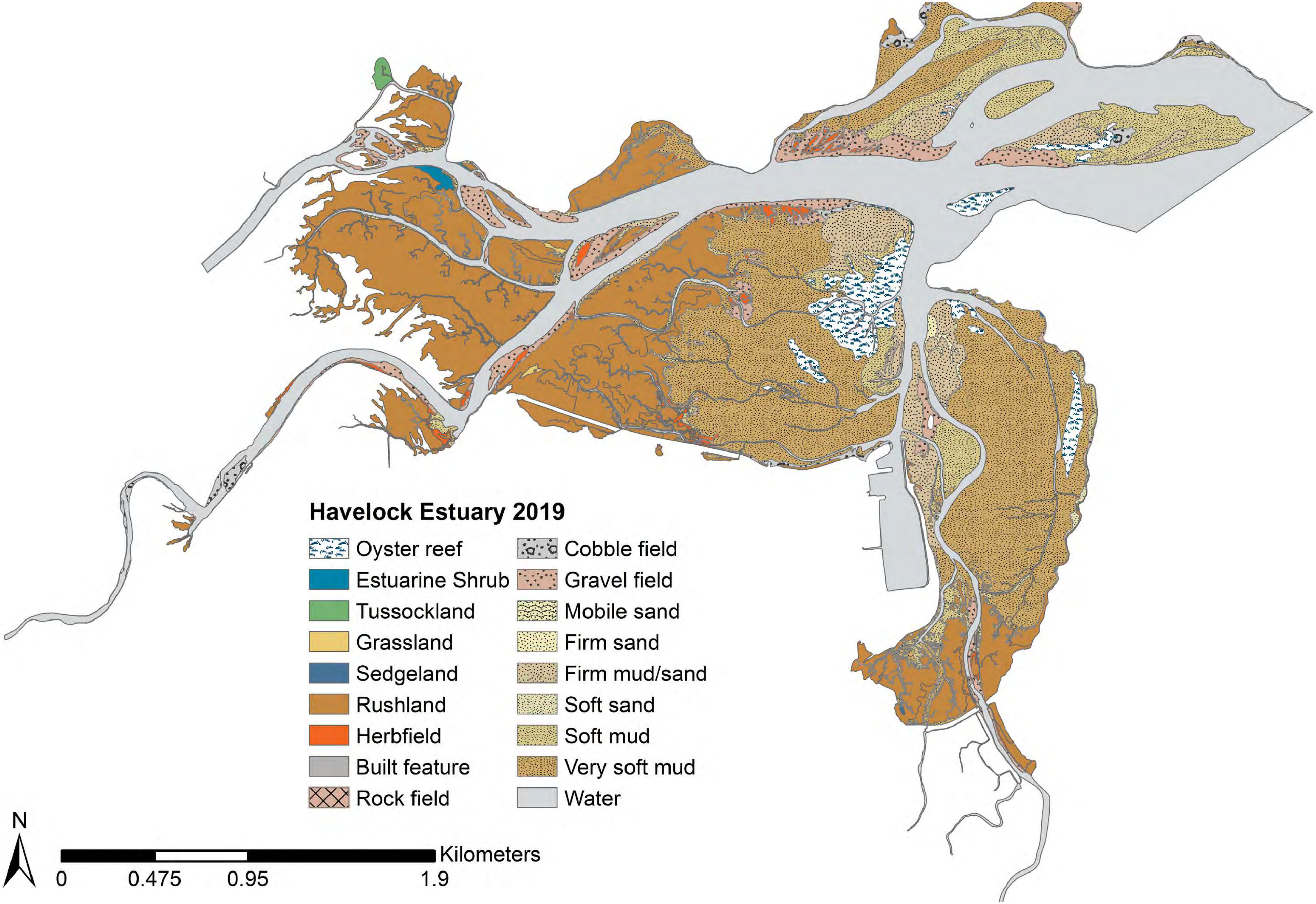


Figure 2. Intertidal substrata (including saltmarsh), Havelock Estuary, January 2019.

3.3 Extent of Intertidal Soft Mud	NZ ETI Condition Rating	Poor
	Risk Rating	High

Adverse impacts are commonly encountered when estuaries receive excessive inputs of fine sediment (mud), often resulting in shallowing, elevated turbidity, nutrients, 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 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/very soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Table 3 and Figure 2 shows that soft mud habitat was concentrated in Havelock Estuary throughout the intertidal flats of both arms, along the banks of the Pelorus and Kaituna Rivers, and the edges of smaller streams entering the estuary. This corresponds to a risk rating of high, based on the large area of soft mud relative to the intertidal habitat area (260 ha, 71%).

The most extensive areas of very soft mud were in the less well flushed eastern, western and northern settling basins (Figure 2). This is thought to predominantly reflect a hydrodynamic boundary, with the settlement of fine sediments promoted in these areas by changes in freshwater flow velocities, combined with salinity driven flocculation.

Compared to other estuaries in the Marlborough Sounds and around NZ, the extent of soft mud was relatively high (Figure 3), a likely reflection of the catchment's relatively large size and steep nature, despite its relatively high cover of native forest. Within soft mud and very soft mud habitat in the estuary, the measured mud contents were 34.6-92.8%, which is well within the high risk indicator rating band (>25%).

There appears to have been a small (17.6 ha, 6%) reduction in the area of the intertidal estuary characterised by soft mud between 2014-19. While this reduction in mud extent potentially shows the estuary has some capacity to naturally flush muds from the intertidal flats, it is more likely to reflect more accurate mapping in 2019. This is supported by the sedimentation rate monitoring undertaken by MDC that shows sediment levels in representative estuary deposition zones (locations in Figure 1) have increased since baseline years at an across-site average of 2.7 mm yr^{-1} (Robertson 2019). Overall soft muddiness remains a key ecological issue for Havelock Estuary in 2019.

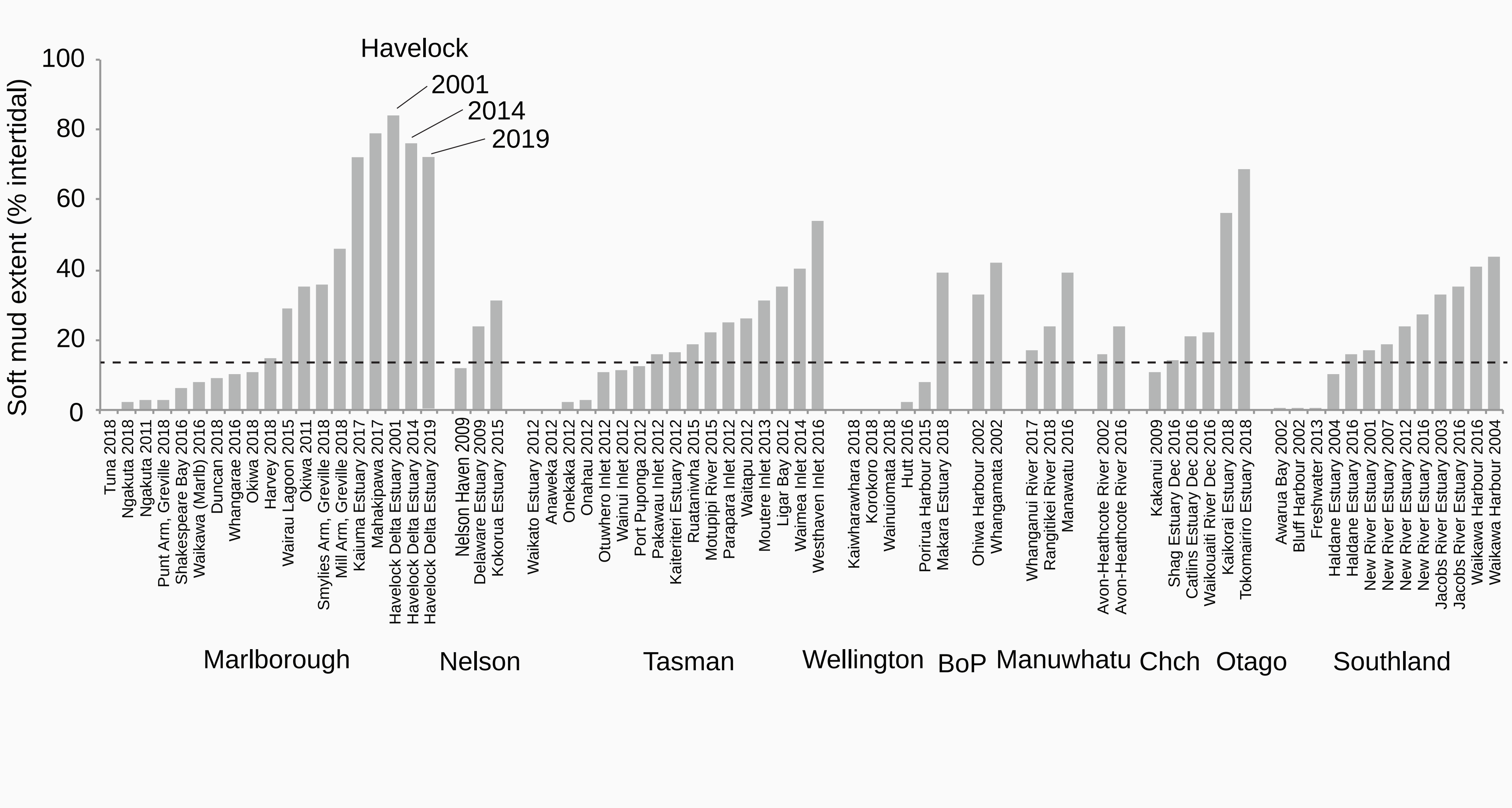


Figure 3. Percentage of intertidal estuary with soft mud habitat for various NZ tidal lagoon and delta estuaries (shallow, intertidal dominated, residence time <3 days - data from Robertson Environmental database). Dashed line represents moderate/high risk threshold (Table 1).

3.4 Intertidal Opportunistic Macroalgae	NZ ETI Condition Rating	Moderate
	Risk Rating	Moderate

Opportunistic macroalgae are a primary indicator used to diagnose symptoms of estuary eutrophication. This is because they are highly effective at utilising excess nutrients (primarily nitrogen both from water column and sediment sources; Robertson 2018, Robertson and Savage 2018), enabling them to out-compete other seaweed and macrophyte 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. Decaying macroalgae can also accumulate subtidally 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 consequent impacts.

Opportunistic macroalgal growth in Havelock Estuary (Figures 4 and 5) was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT) described in Appendix E. The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and relates to a quality status threshold band (i.e. bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change.

The overall opportunistic macroalgal EQR score for Havelock Estuary in January 2019 was 0.43 (see Appendix E for detailed results), a quality status of moderate and indicates that the estuary overall is expressing moderate symptoms of eutrophication. The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change. These range from high to moderate, the overall moderate score reflecting only small areas in the relatively poorly flushed mid-upper estuary having issues. The macroalgae present was dominated by green alga *Ulva* spp. and red alga *Gracilaria chilensis*. The latter tended to have a relatively low biomass (<20 g wet weight m^{-2}) and was most common on muds, the decaying roots of old *Spartina* beds, and rocks in the lower estuary. In many areas *G. chilensis* was growing as a sparse cover among *Ulva* spp. beds.

Ulva spp. was present throughout the estuary, but was most obvious in relatively low biomass (<1000 g ww m^{-2}) beds in the soft mud deposition zone in the upper Kaituna Arm, and along the banks of the Pelorus River near Wakaretu Bay. The threshold at which significant adverse impacts from excessive macroalgal growth become apparent has been determined from multiple studies in NZ and internationally to be >1450 g ww m^{-2} (e.g. Robertson et al. 2016b, Robertson 2018). It is clear from Figure 5 that, while this threshold is not being exceeded, moderate biomass areas are now common throughout the upper reaches and poorly flushed channel regions of Havelock Estuary.

Compared to 2014, while average macroalgal biomass in the estuary remains comparable (~528 g ww m^{-2} in 2014, 455 g ww m^{-2} in 2019), there has been an appreciable increase in the amount of available intertidal habitat characterised by opportunistic (>5% cover) macroalgae (from 10.6% of the available intertidal habitat in 2014 to 20% in 2019). Although possibly attributable to differences in mapping accuracy between 2014 and 2019, this latter result was primarily responsible for the deterioration in EQR quality status from good (2014) to moderate (2019).

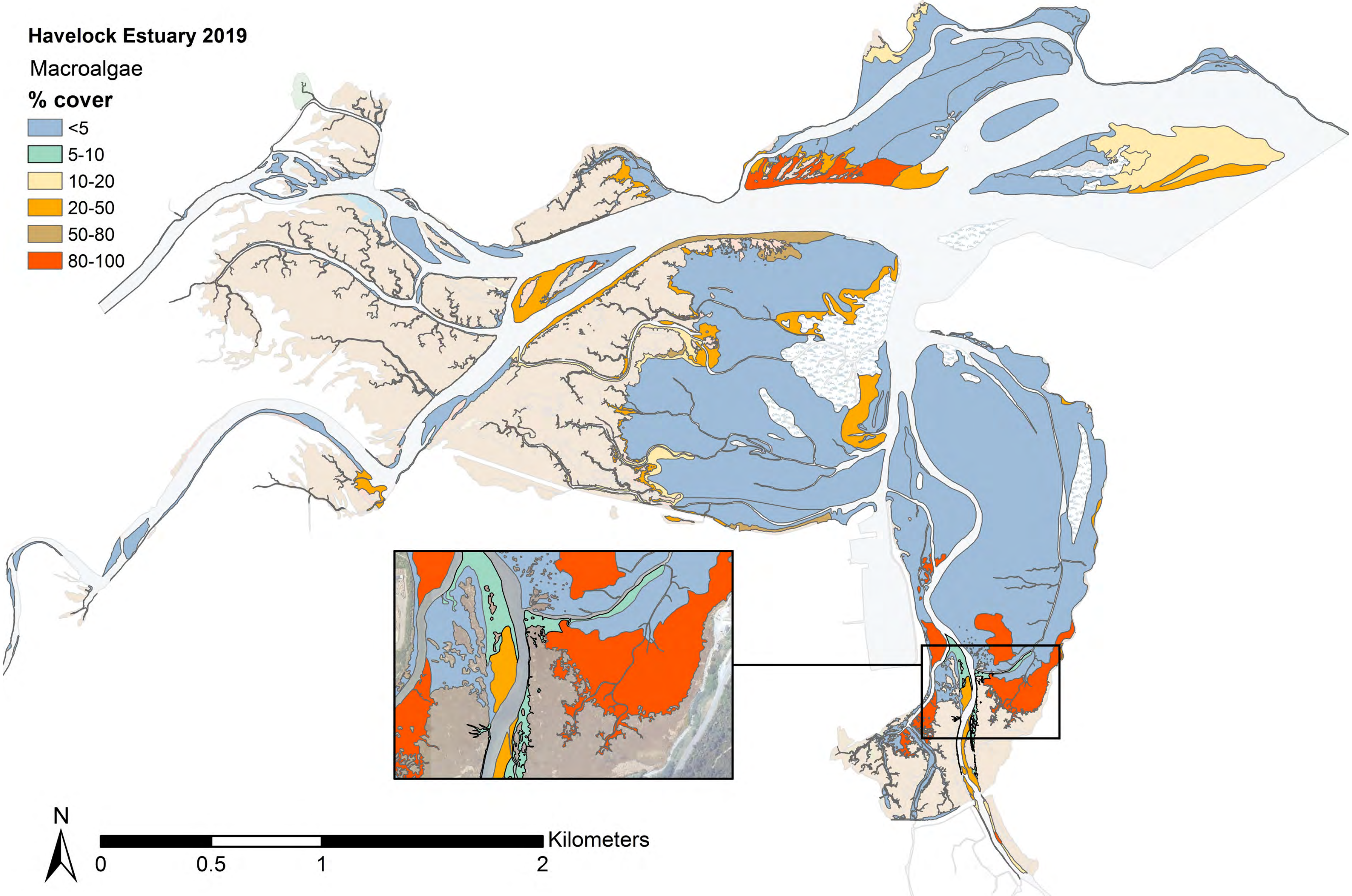


Figure 4. Extent and location of intertidal benthic macroalgae (percentage cover), Havelock Estuary, January 2019.

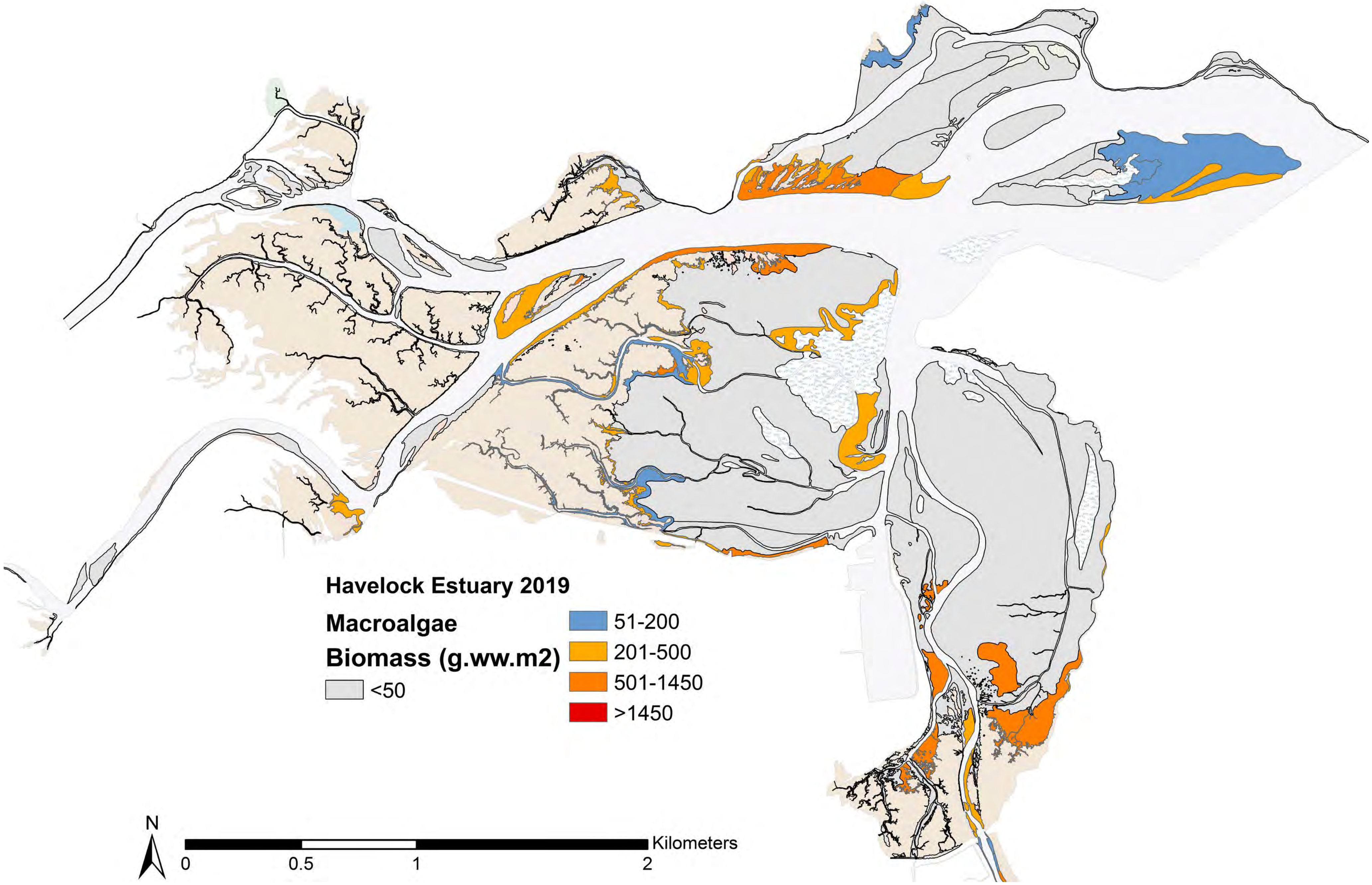
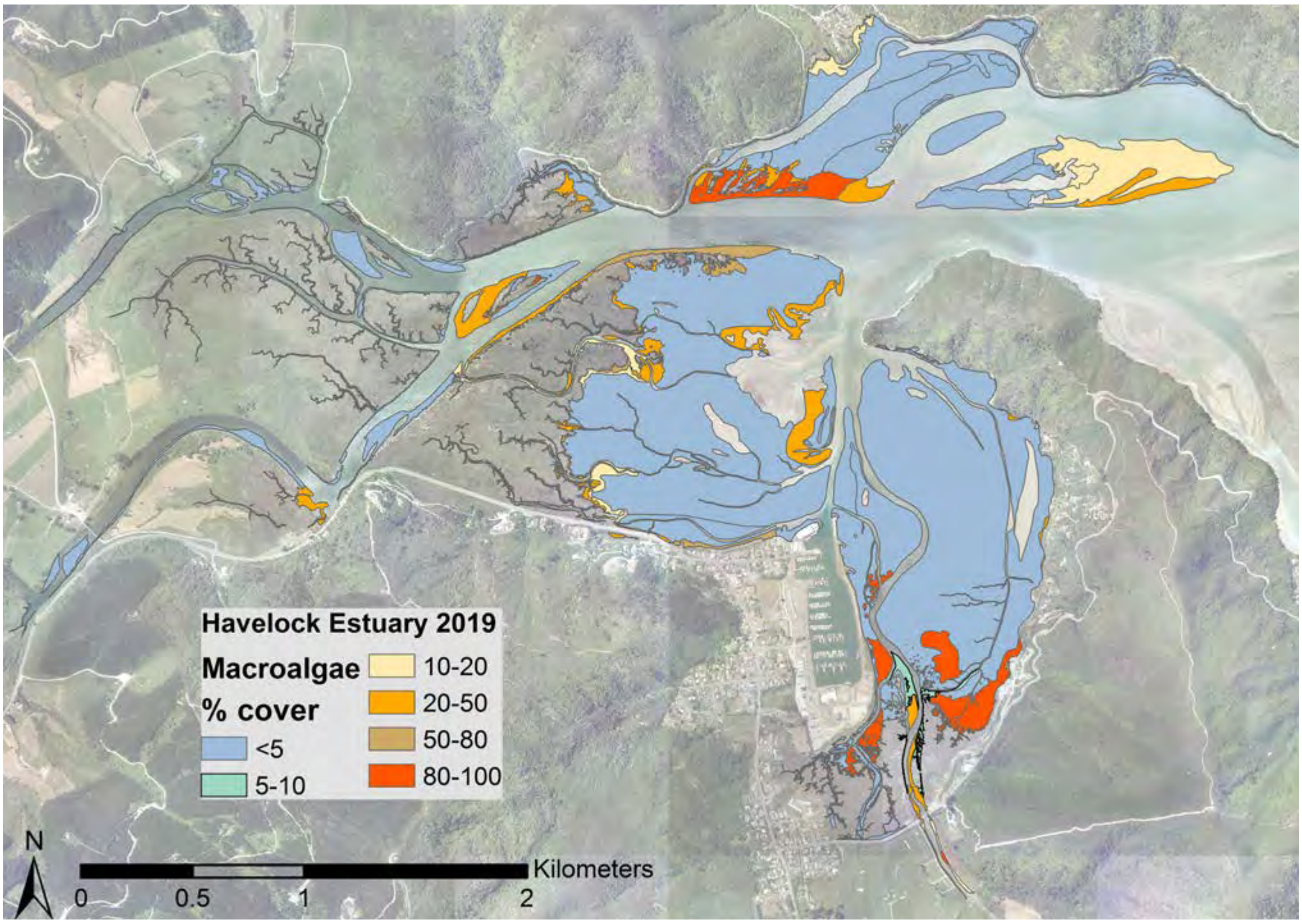


Figure 5. Intertidal opportunistic macroalgae expressed in biomass (grams wet weight per m^2), Havelock Estuary, 2019.



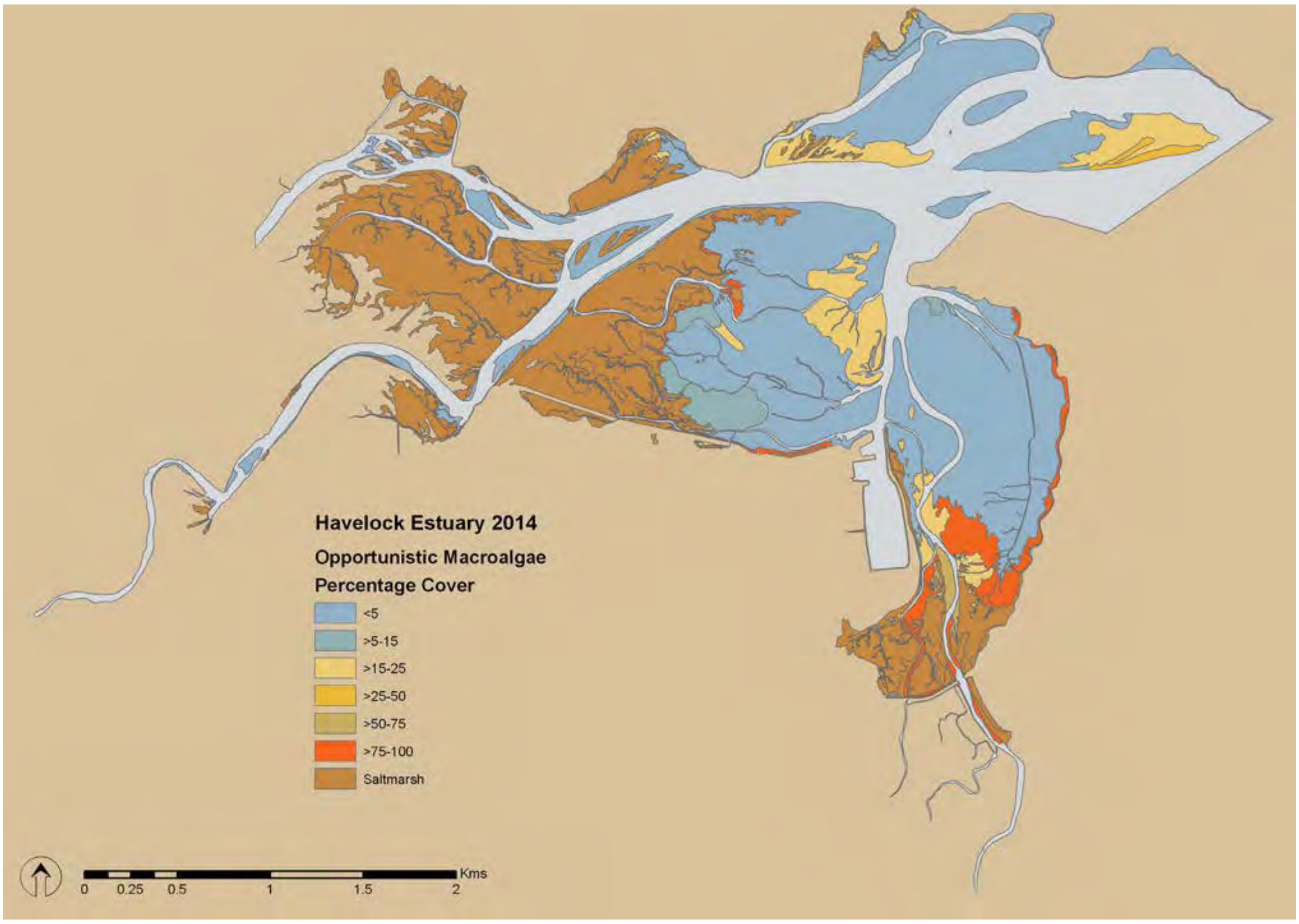


Figure 6. Intertidal macroalgae (% cover), Havelock Estuary, January 2019 (top) compared to March 2014 (bottom - from Stevens and Robertson 2014).

3.5 Gross Eutrophic Conditions	NZ ETI Condition Rating	Moderate
	Risk Rating	Moderate

When sediments are characterised by a combination of high mud content, a shallow RPD, elevated nutrient and organic concentrations, and high macroalgal growth (>50% cover), they represent gross eutrophic conditions (Robertson et al. 2016b). These conditions will kill or displace most estuarine animals and shellfish, and also release nutrients previously bound in the sediments. In extreme cases sediment condition may deteriorate to such an extent that macroalgae can no longer survive, although this has yet to be formally validated in the case of NZ estuaries. Released nutrients will predominantly be in the form of ammonia, which is much more readily available to fuel macroalgal growth (Robertson and Savage 2018), supporting a cycle of increasing habitat deterioration that is likely to be difficult to reverse. Gross eutrophic conditions should not occur in short residence time tidal lagoon estuaries (like Havelock), with their presence providing a clear signal that the assimilative capacity of the estuary for nutrients is being exceeded.

In Havelock Estuary, these conditions are confined to the poorly flushed banks of the Pelorus River near Wakaretu Bay where access to riverine nutrients at relatively high concentrations is likely to be relatively frequent, and among the decaying roots of old *Spartina* beds and associated areas in the sheltered tidal flats of the upper Kaituna Arm (Figure 7).

In 2014, although these same regions of the estuary were characterised by opportunistic (>50% cover) macroalgae, underlying sediment conditions were not reported to be symptomatic of advanced eutrophication. However, in 2019, 16 ha (2.9% intertidal area excluding saltmarsh) were expressing symptoms of advanced eutrophication and classified as being in a significantly ecologically degraded state, reflecting the often gradual decline in sediment quality once opportunistic macroalgae become established and threshold levels are exceeded.

Overall, these results confirm that the estuary is expressing localised symptoms of eutrophication. Studies on other NZ SIDE type estuaries indicate mud-dominated systems are more susceptible to rapid degradation caused by eutrophication stress, therefore ongoing monitoring of associated change is recommended (refer to 'Monitoring Recommendations' for specific details).

3.6 Sediment Oxygenation	NZ ETI Condition Rating	Poor
	Risk Rating	High

The primary indicators used to assess sediment oxygenation are apparent Redox Potential Discontinuity (aRPD) depth and Redox Potential (RP mV) measured at 3 cm. These indicators were measured at representative sites throughout the dominant sand and mud substrata types. From these measurements, broad boundaries have been drawn of estuary zones where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected (Figure 7). Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

These results show that there is a large part (194.6 ha, 53%) of the total intertidal area identified as having depleted sediment oxygen (i.e. aRPD <0.5 cm or RP@3 cm<-150 mV), a NZ ETI rating of poor. This was largely confined to very soft muds located throughout the main settlement basins in the each arm of the estuary. While sediments in these areas had a relatively low level of organic enrichment (based on fine scale monitoring results; Robertson 2019), those in underlying GEZ often exhibited surface anoxia and strong hydrogen sulphide odours indicating anaerobic degradation was occurring.

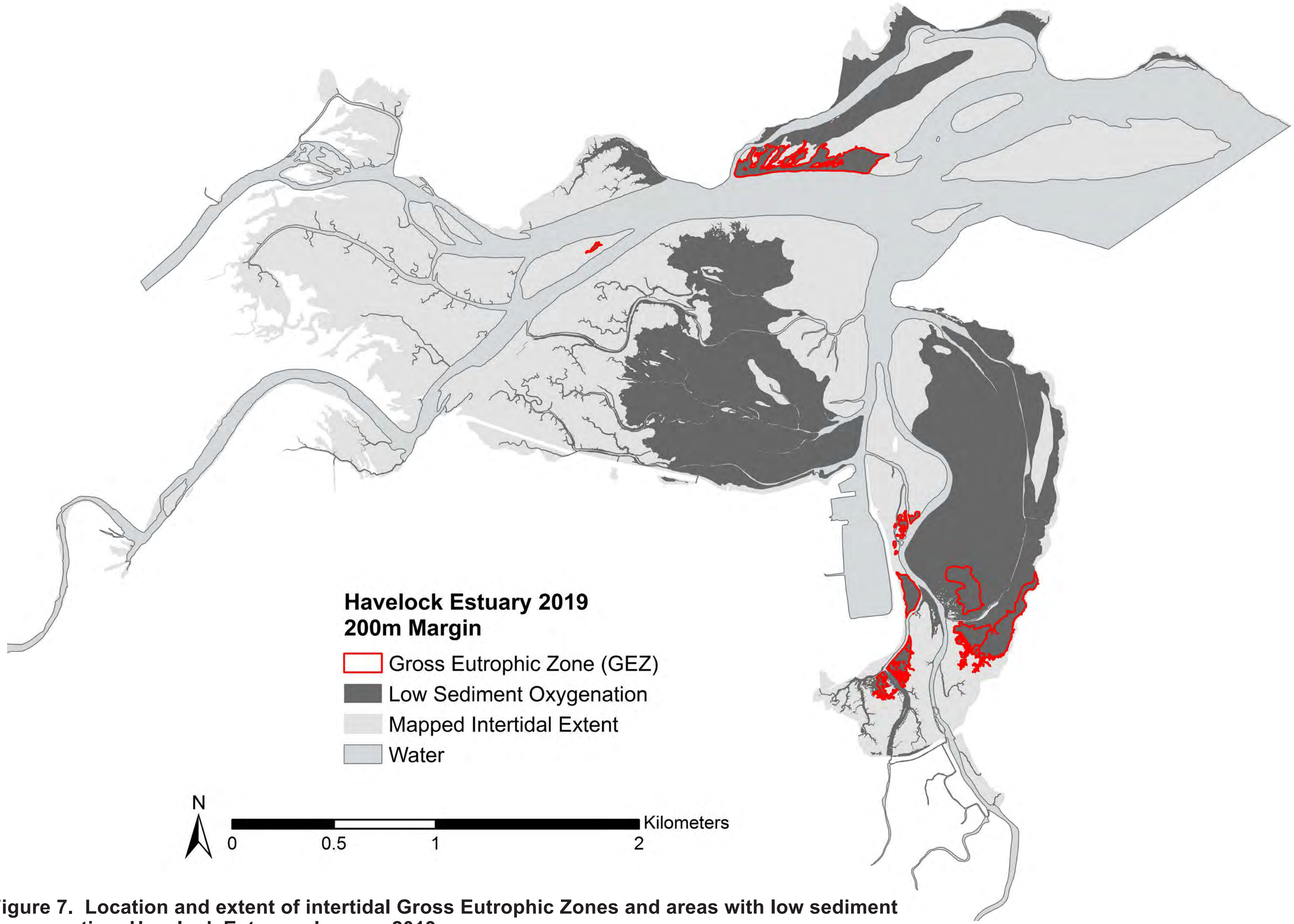


Figure 7. Location and extent of intertidal Gross Eutrophic Zones and areas with low sediment oxygenation, Havelock Estuary, January 2019.

Elsewhere the majority of the estuary sediments are well to moderately well oxygenated and appeared in good (healthy) ecological condition, with the aRPD depth at 2-5 cm and the RP above -150 mV at 3 cm in most sand dominated sediments in the lower estuary and among saltmarsh where oxygen exchange through plant roots contributed to good but variable sediment oxygenation.

Sediment oxygenation was not recorded outside of fine scale sites in 2001 or 2014 so the broad scale patterns of sediment oxygenation cannot be determined from these earlier studies.

3.7 Intertidal Seagrass	NZ ETI Condition Rating	Moderate
	Risk Rating	Moderate

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. Though tolerant of a wide range of environmental conditions, seagrass is vulnerable to excessive nutrients, fine sediments in the water column, and sediment quality (particularly if there is a lack of oxygen and production of toxic compounds e.g. sulphides).

Table 4 and Figure 8 summarise the results of the 2019 survey of the available seagrass habitat (mapped intertidal estuary area minus saltmarsh) as follows:

- The vast majority of the intertidal estuary area (95%) had no seagrass growing;
- 17.8 ha of seagrass beds with >10% cover were present primarily near the well flushed lower estuary channels;
- When present, seagrass beds appeared in relatively good condition, although in January 2019, most of the seagrass beds in the lower estuary were overlain with soft mud. Such observations were also made in 2014 (Stevens and Robertson 2014);
- Seagrass within estuary deposition zones was scarce and appeared highly stressed, most likely due to a combination of excessive muddiness and associated poor water clarity;
- A small patch of previously unmapped, high density (>80% cover) seagrass was recorded in the northernmost embayment adjacent to Shag Point;
- Localised patches of the submerged macrophyte (seagrass) *Ruppia megacarp*a remained present in flow restricted embayments adjacent to the state highway along the estuary's southern edge.

Seagrass cover, first mapped in 2001 (Robertson et al 2002), provided a preliminary baseline against which recent changes could be measured, and there was no significant change in dense seagrass beds evident between 2001 and 2014. However, since 2014 a relatively large (10.1%, 3 ha) reduction in the extent of lower density beds (<50% cover) was recorded in the lower estuary (Figure 8). This was likely to be associated to changes in the substrata of the lower estuary where soft muds present in 2014 had been either eroded, or overlain by fresh sediment deposits between 2014 and 2019. Such physical disturbance is highly likely to account for the seagrass extent changes evident.

In the absence of any comprehensive rating system for seagrass extent within NZ estuaries, which can be highly variable in the extent of seagrass that they support (Robertson 2018), changes from a documented baseline currently represent the most reliable method for monitoring seagrass extent and assessing change. Based primarily on the documented loss of seagrass habitat from the estuary during the 2014-2019 period, a condition/risk rating of moderate has been applied.

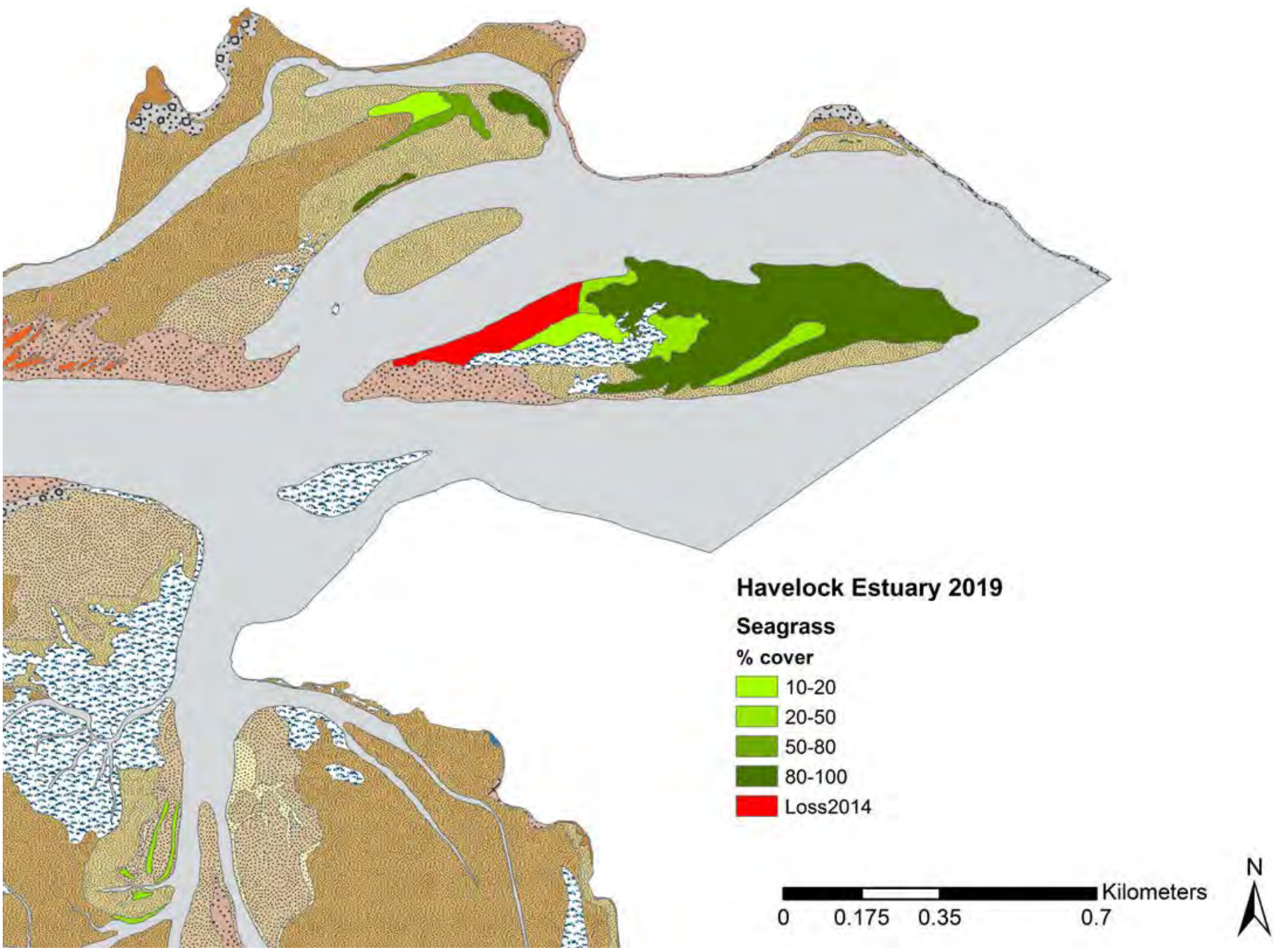


Figure 8. Location and extent of intertidal seagrass cover, including that lost between 2014 and 2019 (Loss2014), Havelock Estuary, 2019.

Table 4. Summary of seagrass (*Z. muelleri*) cover, Havelock Estuary, 2014 and 2019.

Seagrass Habitat	2014		2019		Change since 2014	
Percentage Cover	**Area (ha)**	**% inter-tidal**	**Area (ha)**	**% inter-tidal**	**Area (ha)**	**% change**
0 (unvegetated inter-tidal)	340	94	347.5	95		
1-5%	0	0	0	0	0	0%
5-10%	0	0	0	0	0	0%
10-20%	3.3	0.9	1.7	0.5	-2	48% reduction
20-50%	3.2	0.9	2.6	0.7	-1	19% reduction
50-80%	0.8	0.2	0.8	0.2	0	0%
>80%	14.4	4	14.4	3.9	0	0.%
Overall Seagrass Habitat	**21.7**	**100%**	**19.5**	**100%**	**-3 ha**	**-10.1%**

3.8 Intertidal Saltmarsh	NZ ETI Condition Rating	Very Good
	Risk Rating	Very Low

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 relatively sparse cover in the lower (more exposed and saltwater dominated) parts of the estuary, with the lower limit of saltmarsh growth limited for most species to above the height of mean high water neap.

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 5 and Figure 9 summarise the 2019 results and show saltmarsh was present across 197 ha (65%) of the intertidal estuary area, an NZ ETI condition rating of very good and risk indicator rating of very low. Saltmarsh, most prominent in the upper river deltas of the Pelorus and Kaituna Rivers, was dominated by rushland (95%), predominantly a balanced combination of searush and jointed wirerush sometimes mixed with ribbonwood. Herbfields were also present (3.6%) and dominated by primrose and remuremu, commonly mixed with and slender clubrush, located in beds in throughout the estuary but most prolific bordering rushland in the upper estuary (Figure 9). There were relatively smaller sized areas of sedgeland (~0.1%, comprising mainly three-square) and reedland (~0.02%, comprising mainly raupo), in the upper estuary. Elsewhere, channelling of the main rivers, or steep edges to reclaimed or drained estuary margins, restricted saltmarsh to a relatively narrow strip along the upper tidal reaches. Recolonisation of ex-*Spartina* beds located in the eastern and western Kaituna basins by native saltmarsh remained to be seen in 2019.

Stevens and Robertson (2014) concluded that modification and loss of estuary saltmarsh (~170 ha, including the aforementioned manually eradicated *Spartina* beds), and a densely vegetated buffer zone has been historically significant. Since 2014, reclamation within the terrestrial margin areas appears to have been negligible, with the slight difference in saltmarsh between the 2014 (203 ha) and 2019 (197 ha) surveys likely to reflect more accurate delineation of habitat borders in 2019 (see detailed insets in Figure 9), as opposed to an actual loss of saltmarsh from the estuary over that six year period. This latter assumption was supported through visual comparison of the 2014 GIS data and relevant aerial photographs.

Notwithstanding, it is important that future monitoring initiatives accurately account for (1) an expected gradual transition to more terrestrial species in the terrestrial margin areas, including an increase in weed species among rushland and estuarine shrub habitat as a result of reduced tidal emersion; and (2) margin drainage and infilling, an ecologically undesirable practise as predicted sea level rise will force saltmarsh inland, and if it is unable to migrate into suitable areas, then the saltmarsh which buffers the estuary from sediment and nutrients, provides high value wildlife habitat, and mitigates flooding impact, will be displaced.

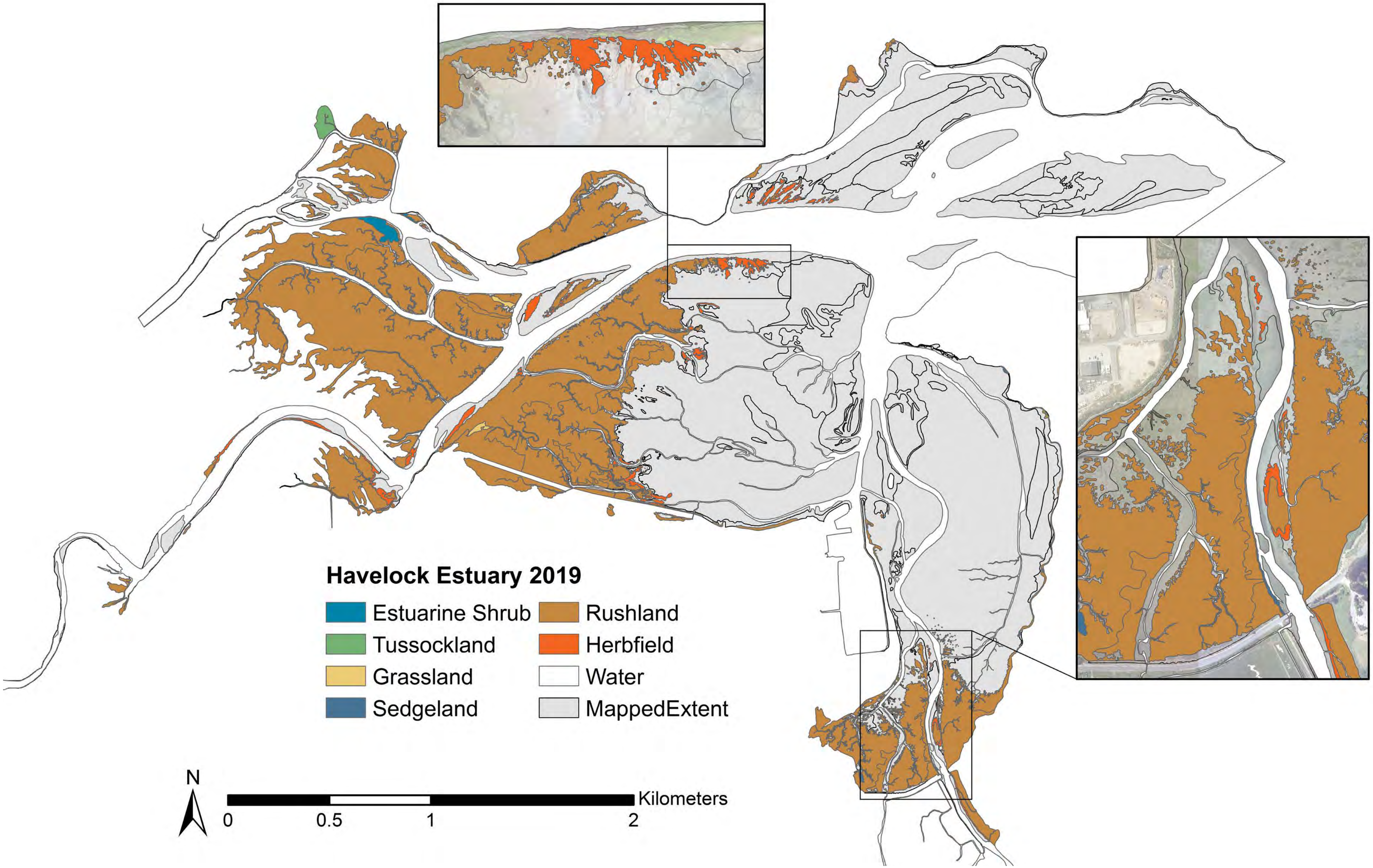


Figure 9. Location and extent of dominant saltmarsh cover - Havelock Estuary, 2019.

Table 5. Summary of dominant saltmarsh cover, Havelock Estuary, 2019.

Class	Dominant Species	Primary subdominant species	Area (ha)	% Saltmarsh
Estuarine Shrub			1.26	0.64
	Plagianthus divaricaus (Saltmarsh ribbonwood)	*Juncus kraussii* (Searush)	1.26	
Tussockland			1.10	0.56
	Cortaderia sp. (Toetoe)		1.10	
Sedgeland			0.19	0.09
	Schoenoplectus pungens (Three-square)	*Juncus kraussii* (Searush)	0.14	
	Isolepis cernua (Slender clubrush)	*Schoenoplectus pungens* (Three-square)	0.04	
	Carex litorosa (Estuary sedge)	*Schoenoplectus pungens* (Three-square)	0.01	
Grassland			0.50	0.25
	Festuca arundinacea (Tall fescue)	*Juncus kraussii* (Searush)	0.50	
Rushland			186.79	95
	Juncus kraussii (Searush)	*Apodesmia* (Leptocarpus) *similis* (Jointed wirerush)	6.20	
	Apodesmia (Leptocarpus) *similis* (Jointed wirerush)	*Juncus kraussii* (Searush)	87.49	
	Juncus kraussii (Searush)	*Plagianthus divaricaus* (Saltmarsh ribbonwood)	93.10	
Reedland			0.03	0.02
	Typha orientalis (Raupo)	*Juncus kraussii* (Searush)	0.03	
Herbfield			7.18	3.65
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	7.15	
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	0.03	
		Total	**197**	**100%**

3.9 Terrestrial Margin	NZ ETI Condition Rating	Good
	Risk Rating	Low

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, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity. The results of the 200 m terrestrial margin mapping of the estuary, presented in Table 6 and Figure 10, showed:

- Dense buffering vegetation comprised a mix of native and exotic scrub and forest (50%), most located on the steeper lower estuary hillsides beside the two arms;
- Plantation forestry (3%) was present in the upper Pelorus;
- The remaining 200 m wide terrestrial margin buffer was dominated by grassland, predominantly high productivity pasture (36%) growing around the upper estuary river areas on flood plain, and small areas of residential (5%), commercial (2.4%), roads (1%) and industrial development (0.3%) were centred around Havelock township;
- In addition, much of the estuary edge (~70%) has been modified through steepening and edge hardening or armouring as a consequence of reclamation (e.g. along most of the estuary edges flanked by pasture), and to a lesser extent, roading and flood control measures.

Remaining areas of the estuary margins had extensive development in the form of roading or infrastructure, and associated erosion protection measures, along the southern estuary margin. These have resulted in a steepened and hardened estuary margin, often with a steep or vertical face along the edge of past reclamations, and around which very little buffering vegetation remains. This, combined with associated drainage of wetland and saltmarsh areas, channelisation of streams, and the restriction of tidal flows to smaller embayments in the estuary significantly compromises the estuary's natural capacity to respond to climate change related sea level rise and to assimilate and buffer against inputs of sediment and nutrients.

Overall, a risk rating of low has been applied based on 53% of the 200 m terrestrial margin of the estuary having a densely vegetated cover, and because there has been no significant change in the terrestrial margin cover since 2001 based on assessment of relevant aerial photographs.

Despite significant past amenity planting initiatives along parts of the developed estuary margin near Havelock marina, most of the low lying estuary fringes, where there was once a gentle natural transition from the estuarine to terrestrial habitat, remain significantly modified by human development. Therefore, any initiative aimed at improving the quality of the estuary's margin, particularly the planting of native trees and creation of bird roosting islands and protection of saltmarsh on private land, should continue to be encouraged wherever possible.

Table 6. Summary of 200 m terrestrial margin land cover, Havelock Estuary, 2019.

Class	Dominant Cover	Area (ha)	Percentage
Exotic Forest	*Pinus radiata* (Pine tree)	22	3%
Scrub/Forest	Mixed native and exotic	247	39%
Scrub	Mixed native and exotic	69	11%
Estuarine Shrub	*Plagianthus divaricatus* (Saltmarsh ribbonwood)	0.4	0.1%
Pasture		230	36%
Unmanaged Grassland		10	2%
Roads		9	1%
Commercial		15	2.4%
Industrial		2	0.3%
Residential		32	5%
	Total 200 m margin	**636**	**100%**

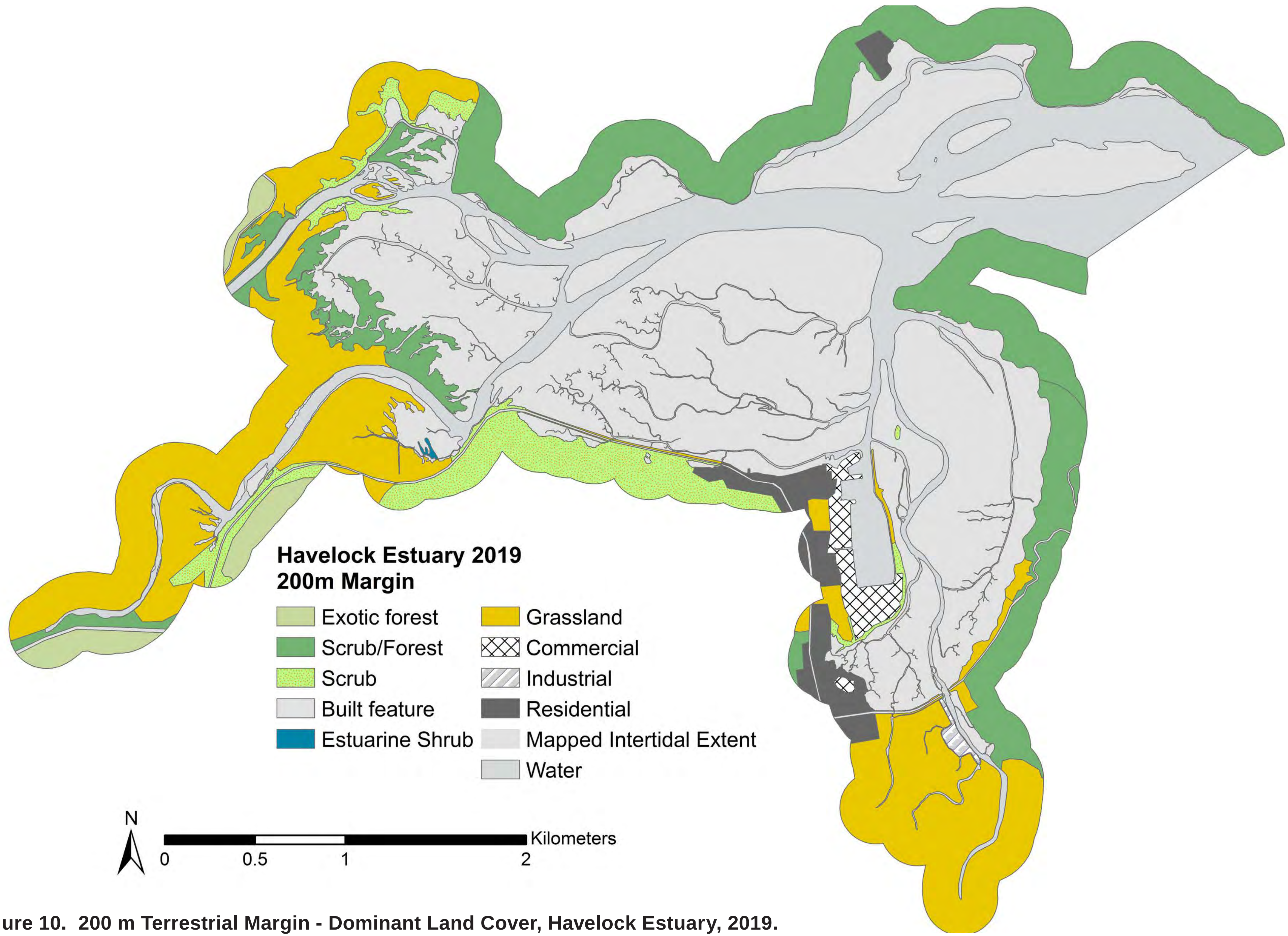


Figure 10. 200 m Terrestrial Margin - Dominant Land Cover, Havelock Estuary, 2019.

4 Summary

Habitat mapping undertaken in January 2019, combined with risk indicator ratings, in relation to the key estuary issues (i.e. sedimentation, eutrophication and habitat modification), and wherever possible changes from baseline conditions (Table 7), have been used to assess overall estuary condition.

Sedimentation (Muddiness)

Sedimentation within estuaries is a natural process but excessive sedimentation can lead to poor ecological health. Soft or very soft muds covered 260 ha (71%) of the intertidal area, a risk indicator rating of high. Soft muds were concentrated in the central estuary where mud settlement is facilitated by a lack of tidal flushing and, to a lesser extent, salinity driven flocculation. 71% of the estuary had a mud content measured in representative areas of 52-93%, an NZ ETI rating of high. To inform the broad scale report recommendations, the current state/natural state sediment load (CSSL/NSSL) ratio and the mean annual rate of sediment deposition have been estimated. The CSSL/NSSL ratio is estimated as 2.4 (see Appendix F for details), an NZ ETI rating of moderate, indicating that the current sedimentation rate is likely to exceed the natural state sedimentation rate and therefore contribute to the observed sedimentation issue in the estuary.

Within the dominant sandy substrata of the lower and central estuary, grain size reflected a moderate risk rating (12.1-14.3% mud content). Associated with the presence of very soft muds, 194.6 ha (53%) of the intertidal area (excluding saltmarsh) had sediment oxygenation depleted to a level where adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, a risk rating of high.

Table 7. Summary of broad scale risk indicator ratings for Havelock Estuary, 2019, and changes from previous surveys. *na* = not applicable.

Estuary Issue	Indicator	Risk Indicator[1]			Narrative change since 2014
		2001	2014	2019	
Sedimentation	Soft mud (% cover)	High	High	High	No notable change
Eutrophication	Macroalgal Growth (OMBT Index)	Low	Low	Moderate	Increase in the extent of opportunistic macroalgae
	Gross Eutrophic Zones (ha)	Very low	Very low	Moderate	Increase (16 ha, 3%)
	Sediment Oxygenation (ha)	*na*	*na*	High	-
Habitat Modification	Seagrass Change (since baseline)	*na*	Very low	Moderate	Decrease (3 ha, 10%)
	Saltmarsh (% of intertidal area)	Very low	Very low	Very low	No notable change
	200 m Vegetated Terrestrial Margin	Low	Low	Low	No notable change
Overall NZ ETI Rating		*na*	*na*	**Moderate**	-

[1] 2001 and 2014 Risk Ratings from Stevens and Robertson (2014).

Eutrophication

Key broad scale indicators used to assess eutrophic expression in the estuary are primary productivity through macroalgal growth, and supporting indicators of sediment muddiness, oxygenation, and the presence of gross eutrophic zones (a combined presence of dense algal growth, muds and poor sediment oxygenation). Fine scale indicators, reported in Robertson (2019), include sediment organic content, nutrients, macroinvertebrates, and mud content.

The Opportunistic Macroalgal Blooming Tool EQR score was 0.4, and a relatively small part (16 ha 2.9%) of the total intertidal area exhibited gross eutrophic conditions, a risk indicator rating of moderate. The total catchment-derived nitrogen areal load is estimated as ~70 mg N m^{-2} d^{-1}, which is getting close to the 100 mg N m^{-2} d^{-1} threshold where advanced eutrophic symptoms commonly occur in open-mouthed SIDE estuaries in NZ (Robertson et al. 2016a; Robertson and Savage under review). The above results highlight that part of the estuary, although relatively small and largely confined to poorly flushed regions of the upper estuary, is currently eutrophic, and that nutrient inputs to the estuary are sufficient to fuel nuisance algal growths that often degrade underlying sediment conditions.

Habitat modification

Despite significant historical saltmarsh losses (Stevens and Robertson 2014), extensive herbfield and rushland remained in the estuary (197 ha, 35% of the intertidal area). The presence of such a large area of saltmarsh is very positive, a risk indicator of very low. The 200 m terrestrial margin had been modified, although 53% supported a densely vegetated buffer of rushland, scrub and forest, with 36% in pasture or grassland and 8.7% developed (residential/commercial/road), a risk indicator of low. Seagrass beds, mainly confined to the more well flushed regions of the lower estuary, populated only a relatively small intertidal area (19.5 ha, 5%).

Comparison with 2001 and 2014 results

Although mapped estuary boundaries were similar (if not identical) in previous years, it is difficult to compare the current results directly with the preliminary assessments undertaken in 2001 and to a lesser extent 2014, primarily due to variability in the features included (e.g. seagrass and sediment oxygenation extent) and perceived accuracy of the field mapping. However, there appears to have been a small (17.6 ha, 6%) reduction in the area of the intertidal estuary characterised by soft mud between 2014-19, despite the estimated sediment inputs to Havelock Estuary being relatively high (341.9 Kt yr^{-1}; NIWA CLUES model). While this reduction in mud extent potentially shows the estuary has some capacity to naturally flush muds from the intertidal flats, it is more likely to reflect more accurate mapping in 2019. This is supported by (1) the sedimentation rate monitoring undertaken by MDC that shows sediment levels in representative estuary deposition zones (locations in Figure 1) appear to have increased since baseline years at an average of ~2.7 mm yr^{-1} (Robertson 2019), and (2) the discovery of previously unmapped seagrass habitat in a relatively accessible part of the lower estuary.

A relatively small area of gross eutrophic conditions had established since 2014, but was spatially limited to poorly flushed regions of the mid-upper estuary. There was little change in seagrass habitat in the estuary over the 2001-14 period, but a considerable reduction (3 ha, 10%) was observed between 2014 to 2019, a risk rating of moderate. The extent of the introduced Pacific Oyster habitat as a dominant cover (which overlies soft mud habitat) had increased by ~10 ha between 2001 to 2014, and a further 4.8 ha from 2014 to 2019. Although not present in large numbers in their preferred habitat (i.e. hard or rocky surfaces in shallow or sheltered waters), Pacific Oyster were present as relatively large and expanding patches in soft mud habitat in several regions of the estuary, reflecting their ability to proliferate and grow in clumps to form oyster reefs. There appears to have been no significant change in the extent of rushland dominated saltmarsh between 2001 and 2019, a very positive sign attributable to the lack of any major reclamation or environmental disturbance to that part of the estuary. Future monitoring will determine if results reflect ongoing trends in broad scale estuary features.

5 Conclusions

Based on the combined results from the January 2019 survey, the estuary is considered to be in a moderate-poor state in relation to broad scale ecological features. Extensive areas of saltmarsh remain in good condition, but there has been loss of high value seagrass habitat and there are sediment muddiness/poor oxygenation issues evident throughout the intertidal estuary. Eutrophication issues are now apparent through the presence of areas of excessive macroalgal growth/enriched and oxygen depleted sediments within several physically constricted zones of the estuary. The NZ Estuary Trophic Index (NZ ETI) score has been calculated using available broad scale and fine scale indicators (details summarised in Appendix F). The NZ ETI score for Havelock Estuary in 2019 was 0.67, reflecting a moderate degree of eutrophic symptoms and a more widespread sediment muddiness/poor oxygenation issue.

6 Recommendations

Havelock Estuary has been identified by MDC as a priority for monitoring because it is a large sized estuary with moderate-high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation, eutrophication and habitat loss. Broad scale habitat mapping, in conjunction with fine scale monitoring (including sedimentation rate monitoring), provides valuable information on current estuary condition and trends over time. The following broad scale monitoring recommendations are proposed by Robertson Environmental Ltd for consideration by MDC:

- Because the estuary is expressing moderate symptoms of eutrophication as well as seagrass decline, it is recommended that macroalgae (incluidng GEZ) and seagrass (including biomass estimates) be synoptically monitored annually (next recommended in 2020), with estuary-wide comprehensive broad scale habitat mapping undertaken every 5 years (next recommended in 2024);
- Sediment muddiness remains a priority issue in the estuary. It is therefore recommended that existing sediment plate depths be measured annually, and more deployed in line with methods outlined in Hunt (2019), and a single composite sediment sample be analysed for grain size at each site;
- Fine scale monitoring recommendations are presented in Robertson (2019).

In terms of management, given the ongoing sedimentation issue and more recent establishment of gross eutrophic conditions in the estuary, previous recommendations (e.g. Stevens and Robertson 2014) are reiterated for the prioritised development of catchment nutrient and sediment guideline criteria to derive thresholds protecting against adverse sediment and nutrient impacts. To provide more robust catchment load estimates, it is recommended that future river total nitrogen and suspended sediment load sampling be undertaken during representative lowflow, baseflow and floodflow periods. This would enable local calibration of modelled load estimates thereby strengthening their usefulness for associated management initiatives.

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8 Limitations

This document does not include any assessment or consideration of ecological conditions within the subtidal environment of Havelock Estuary, and grainsize and sediment oxygenation (aRPD and RP mV) sampling was carried out at a site-specific scale only. Regarding the latter, from a technical perspective, the benthic environment outside of areas sampled may present substantial uncertainty. It is a heterogeneous, complex environment, in which small surface features or changes in geologic conditions can have substantial impacts on associated physicochemical conditions and biology. Robertson Environmental's professional opinions are based on its professional judgement, experience, and training. These opinions are also based upon data derived from the monitoring and analysis described in this document, with the support of relevant national standards (e.g. NZ ETI; Robertson et al. 2016a,b). It is possible that additional testing and analyses might produce different results and/or different opinions. Should additional information become available, this report should be updated accordingly. Robertson Environmental Ltd has relied upon information provided by the Client to inform parts of this document, some of which has not been fully verified by Robertson Environmental Ltd. This document may be transmitted, reproduced or disseminated only in its entirety.

Appendix A:

Major Issues facing NZ Estuaries

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 Indicator(s)	Method
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 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Sedimentary changes influence the ecology of estuaries. Because they are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were most likely dominated by sandy sediments and had low sedimentation rates (e.g. <1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, NZ'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 2007a, 2010b, 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 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;
- making the water unappealing to swimmers.

Recommended Indicators	Method
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 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Habitat Loss impacts estuaries and their 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 Indicators	Method
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 substrata types.
Sea level	Measure sea level change.
Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

Toxic Contamination has become an issue in the last 60 years, as 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 Indicators	Method
Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring. Note disease risk indicators on the Marlborough coast are assessed separately in MDC's recreational water quality monitoring programme.
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 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Appendix B:

Support Information (Table 1)

The estuary monitoring approach used by Robertson Environmental Ltd 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 A), 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 and/or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 1). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk 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, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- 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 (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. 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; and
    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 tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing. See Robertson et al. (2016a, 2016b) and Robertson (2018) 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 substrata 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 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 (>3 cm) 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 <1 cm (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 3.4 and Appendix E), with results combined with those of other indicators to determine overall condition.

Seagrass: Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent is likely to indicate an increase in these types of pressures. Thresholds used to assess this indicator are derived from the changes from a measured baseline, with results combined with those of other indicators to determine overall condition.

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. Two supporting metrics are also proposed: i. % 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; ii. % of available habitat supporting saltmarsh. This assumes that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. The interim risk ratings proposed for these ratings 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 or saltmarsh growing over <80% of the available habitat.

***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 C:

Broad Scale Habitat Classifications

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. rush-land, scrub, forest).

Vegetation (mapped separately to the substrata 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 ≥10 cm 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 >10 cm 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* spp..

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 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 substrata. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and are mapped separately to the substrata 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 substrata they overlie.

Substrata (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 substrata 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 (>200 mm 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.

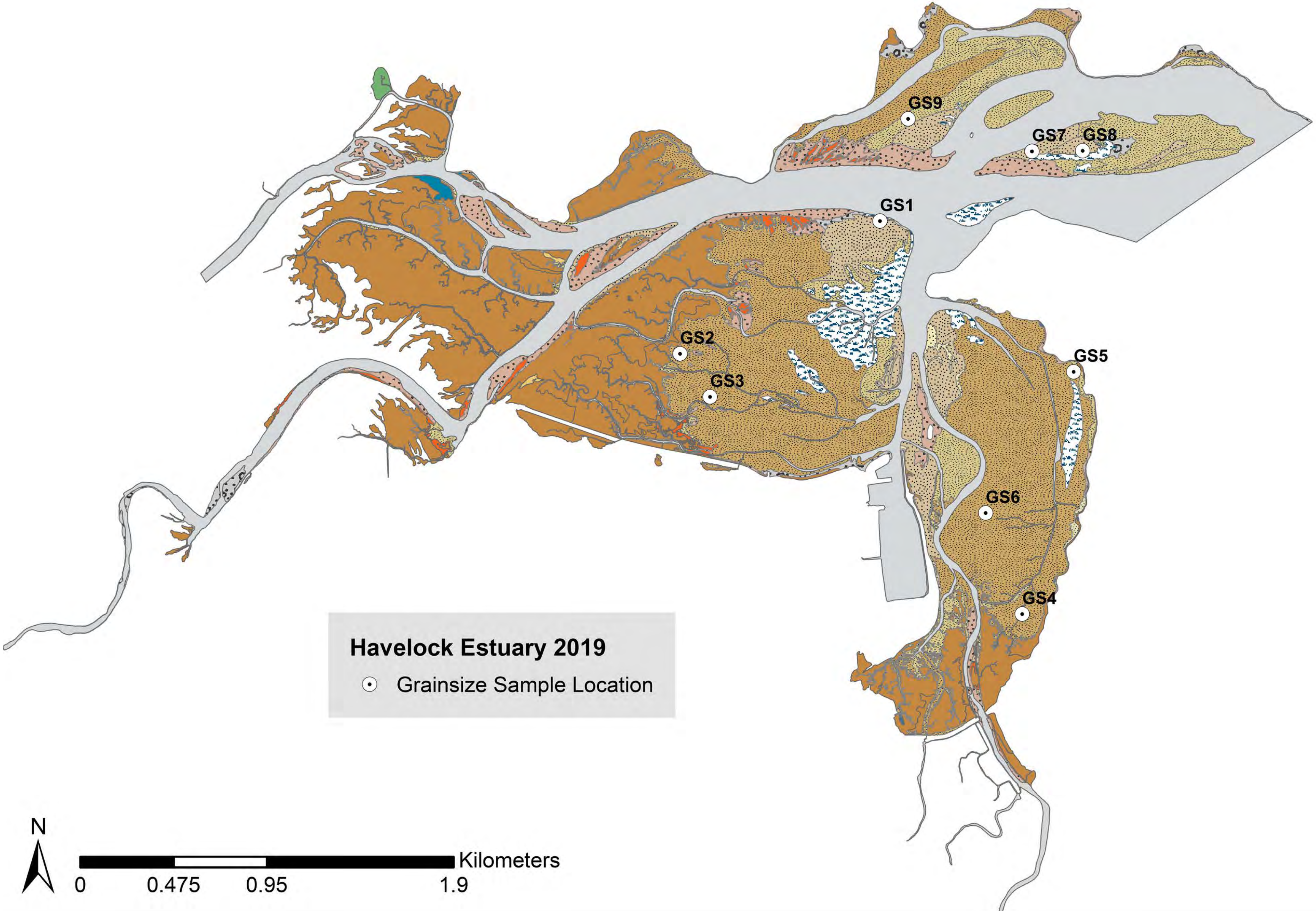
Cockle bed/Mussel reef/Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.

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

Shell bank: Area that is dominated by dead shells.

Appendix D:

Sampling, Resolution and Accuracy

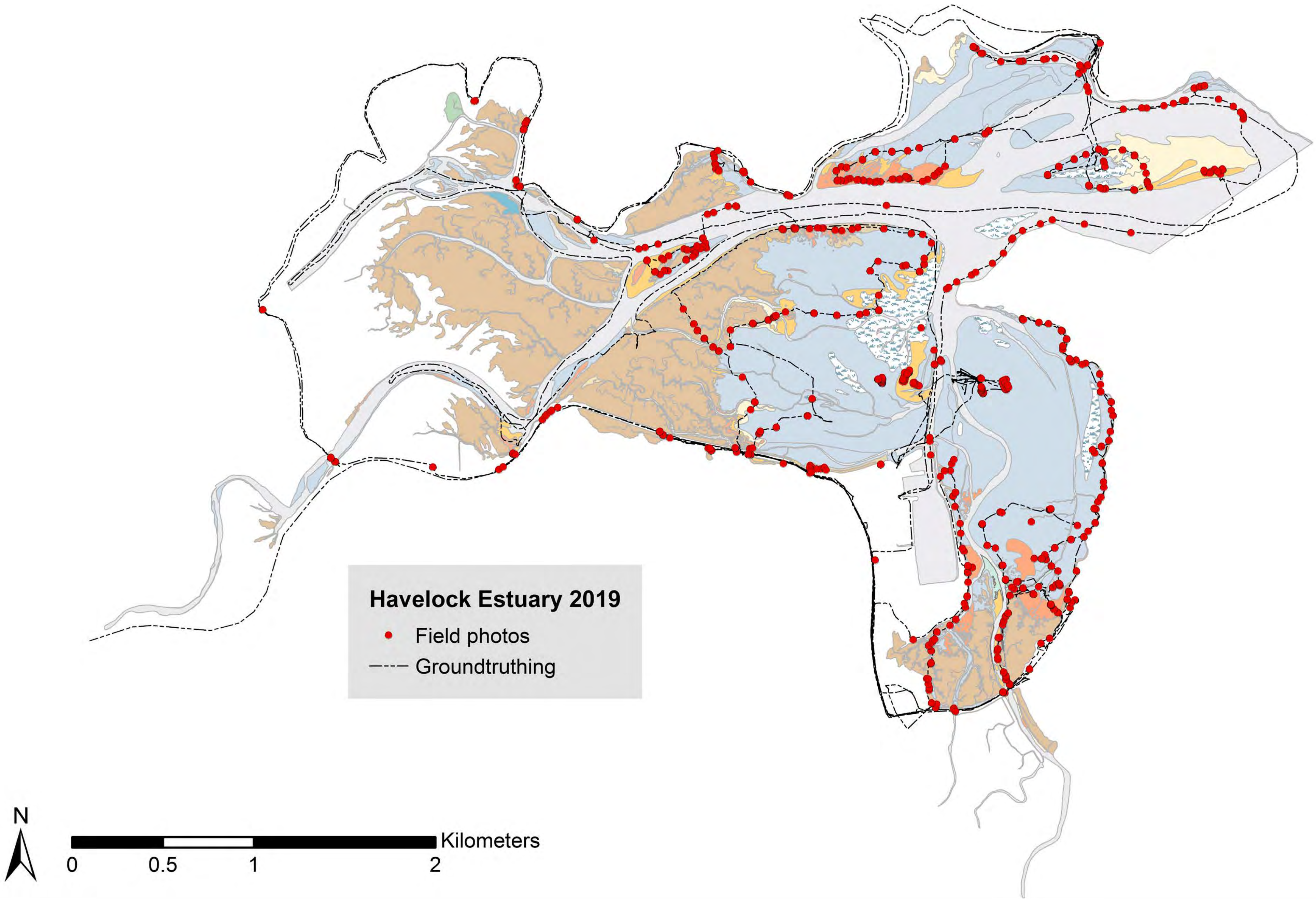


Location of grain size samples used to validate substrata classifications, Havelock Estuary, 2019. See associated data overleaf.

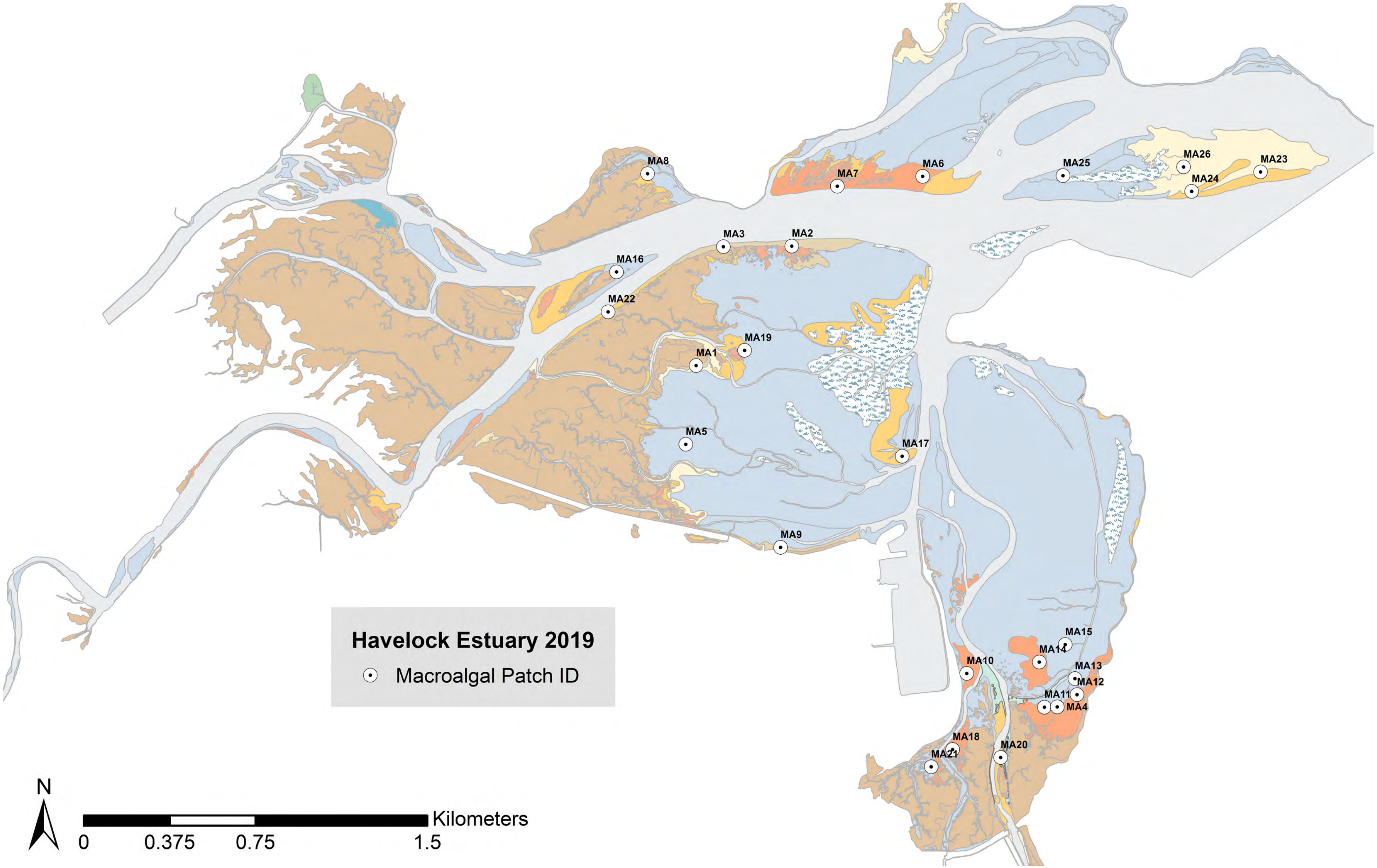
Grain size results from representative sediments, Havelock Estuary, 2019.

			Gravel	Sand					Mud			
		Dry Matter of Sieved Sample	Fraction >/= 2 mm	Fraction < 2 mm, >/= 1 mm	Fraction < 1 mm, >/= 500 µm	Fraction < 500 µm, >/= 250 µm	Fraction < 250 µm, >/= 125 µm	Fraction < 125 µm, >/= 63 µm	Fraction < 63 µm			
Sample ID*	Broadscale Classification	g/100g as rcvd	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	NZTM East	NZTM North	aRPD depth (cm)
GS1	Firm muddy sand	75	5.1	0.4	3	42.2	33.9	3.3	12.1	1664466	5431729	2
GS2	Very soft mud	60	1	1.2	2.6	4.9	8.1	9.5	72.7	1663448	5431054	0.5
GS3	Very soft mud	62	0.5	1.4	4.1	15.2	19.1	8	51.7	1663601	5430835	0.5
GS4	Very soft mud	52	0.1	0.2	0.6	1.3	1.4	5.1	91.3	1665190	5429729	0
GS5	Very soft mud	55	< 0.1	0.2	0.5	1.2	1.1	4.2	92.8	1665453	5430963	0.5
GS6	Very soft mud	62	< 0.1	0.2	0.3	0.5	1.2	11.1	86.6	1665005	5430244	0.5
GS7	Firm muddy sand	79	4.7	3.1	10.9	33.7	26.4	9.2	12.1	1665240	5432084	2
GS8	Firm muddy sand	76	2.4	1.2	5.8	33.8	29.2	13.2	14.3	1665498	5432086	2
GS9	Soft mud	72	6.2	5.3	10.8	20.1	13	10.1	34.6	1664609	5432249	1

*Refer to Appendix G for laboratory outputs.



Ground-truthing coverage and location of field photos, Havelock Estuary, 2019.



Location of macroalgal patches (>5% cover) used in assessing macroalgae in Havelock Estuary, 2019.

Sediment sampling and analysis

Grain size samples were collected from representative mud and sand habitats (to validate substrata classifications) by sampling a composite of the top 20 mm of sediment (approx. 500 g 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 to R.J. Hill Laboratories for grain size analysis (% mud, sand, gravel). Details of lab methods and detection limits are presented in Appendix G. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

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 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 ~1:2000 to within 1-2 m 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 between features, e.g. where firm muddy sands transition to soft muds across a continuum. Defining such boundaries requires field validation. Extensive mapping experience has shown that such boundaries can be mapped to within ±10 m 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.

Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom) in this report.

1-5%	6-10%	11-20%	21-50%	51-80%	81-100%
					
					

Appendix E:

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.

Summary of intertidal OMBT/EQR Score calculation, Havelock Estuary, January 2019.			
Metric	Face Value	Final Equi-distant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	344		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 where Total % cover = Sum of {(patch size) / 100} x average % cover for patch	11	0.46	Good
Biomass of AIH (g ww m^{-2}) = Total biomass / AIH where Total biomass = Sum of (patch size x average patch biomass)	96	0.39	High
Biomass of Affected Area (g ww m^{-2}) = Total biomass / AA where Total biomass = Sum of (>5% cover patch size x average patch biomass)	455	0.37	Good
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	5	0.70	Good
Affected Area (use the lowest of the following two metrics)		0.21	Moderate
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	69	0.21	Moderate
Size of AA in relation to AIH (%) = (AA / AIH) x 100	20	0.64	Moderate
Overall macroalgal Ecological Quality Rating - EQR (Average of FEDS)		0.43	Moderate

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 ww 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 ww m^{-2}): Mean biomass of Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.
5. Presence of Entrained Algae (percent of quadrats): Algae are considered entrained in muddy sediment when they are found growing >3 cm 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. Buildup 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 surfacesediment 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.

In terms of 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.

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 (see below Table).

- 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 50 ha 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 10 ha. 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 <100 g ww m^{-2}. 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 ww m^{-2} was an acceptable level above the reference level of <100 g ww m^{-2}. In Good status only slight deviation from High status is permitted so 500 g ww 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 ww m^{-2} but less than 1,000 g ww m^{-2} would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1000 g ww m^{-2} 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.

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 (modified from 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 ww m^{-2}) of AIH	≥0 - 100	≥100 -200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g ww m^{-2}) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae >3 cm 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.

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Appendix F:

Sediment Loads & NZ ETI Details

Catchment-derived sediment load predictions:

Currently, there is insufficient information to identify robust sedimentation susceptibility thresholds for NZ estuaries, but in order to provide a tentative desktop estimate of the potential for ongoing sedimentation, the magnitude of modelled estimates of the Current State Sediment load (CSSL) can be compared with estimates of the historic Natural State Sediment Load (NSSL). The NSSL can be estimated by assuming a native forest land cover and the presence of sufficient catchment wetlands to retain 50 % of the load. In effect, such a ratio of CSSL/NSSL indicates whether appropriate soil conservation practices are currently undertaken in the catchment (e.g. a high ratio indicating further effort is required). Natural state sediment loads (NSSL) were estimated with all landuse set at native forest cover and corrected for wetland attenuation. Final NSSL = NFL x NSWA where NFL is Native forest load (kt yr^{-1}) and NSWA is the estimated natural state wetland attenuation for suspended sediment. In this case, NSWA is estimated as 0.5, indicating a mean wetland removal efficiency of ~50%. This assumption is based on the following study results:

- A wetland complex, draining suburban catchments in Wisconsin USA, attenuated ~71%, 21%, and 13% of the annual loads of SS, TP and TN respectively over a four year period (Kreiling et al., 2013).
- Previous studies in New Zealand (McKergow et al. 2007; Tanner et al. 2010) and around the world (Kadlec & Wallace 2009; Mitsch & Grosslink 2007) have identified the need for wetland areas of 1-5% of the contributing catchment to provide reasonable levels of nutrient attenuation in humid-climate agricultural landscapes. Depending on the specific attributes of suspended solids, smaller wetland areas in the range of 0.1-1% of contributing catchment can often achieve satisfactory suspended sediment removal.
- The average stormwater suspended sediment removal efficiency for a large number of both NZ and international wetlands showed a mean of 58% (International BMP Database 2007, as presented in Semadeni-Davies 2009).

For the Havelock Estuary, the chosen CSSL/NSSL ratio thresholds were as follows: low 1-1.1, moderate 1.1-2, high 2-5, very high >5. Catchment sediment load estimates were derived from the NIWA CLUES modelling system[1]. The load threshold ratings were then combined (using the matrix below) with ratings for the likelihood of sediment trapping based on the assumption that high susceptibility SIDEs estuaries are physically susceptible to fine sediment accumulation.

[1] CSSL estimated using CLUES (default setting of REC2 and LCBB3 (2008/2009) land cover), NSSL estimated by setting CLUES land cover to native forest, with a further 50% reduction applied as per the points above.

	Current State Sediment Load (CSSL)/Natural State Sediment Load (NSSL)			
Estuary Category	CSSL = 1 to 1.1 x NSSL	CSSL = 1.1 to 2 x NSSL	CSSL = 2 to 5 x NSSL	CSSL > 5 x NSSL
SIDEs with extensive areas of poorly flushed habitat	Very Low Susceptibility	Low Susceptibility	Moderate Susceptibility	High Susceptibility

NZ ETI calculation and outputs:

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 issues. 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 NZ ETI score becomes. Where established ratings are not yet incorporated into the NIWA NZ ETI online calculator they are included via spreadsheet calculator. The indicators used to derive an NZ ETI score and determine trophic state for the Havelock Estuary at the time the 2019 monitoring was undertaken (26th-29th January) are presented below using both the fine scale monitoring results (Robertson 2019) and broad scale monitoring results (this report). The input values used in the online calculator are presented overleaf. NZ ETI Tool 1 rates the physical and nutrient load susceptibility of Havelock Estuary as moderate. NZ ETI Tool 2 online calculator scores the estuary 0.67, Band C, a rating of moderate. This is driven primarily by the presence of GEZ in localised regions and a more widespread sediment muddiness/poor oxygenation problem.

NZ ETI scoring summary for Havelock Estuary, January 2019.			
Primary Symptom Indicators for Shallow Intertidal Dominated Estuaries (At least 1 primary symptom indicator required)			Primary symptom value
Required	Opportunistic Macroalgae	Macroalgal Ecological Quality - Opportunistic Macroalgal Blooming Tool (OMBT) coefficient*	0.4
Required	Macroalgal Gross Nuisance Zone (GNA) %	% Gross Nuisance Area (GNA)/Estuary Area*	2.9
Required	Macroalgal GNA (ha)	Gross Nuisance Area (GNA) (ha)*	16.0
Optional	Phytoplankton biomass	Chl a (summer 90 pctl, mg m^{-3})	-
Optional	Cyanobacteria (if issue identified) - NOTE NZ ETI rating not yet developed		-
Supporting Indicators for Shallow Intertidal Dominated Estuaries (Must include a minimum of 1 required indicator)			Supporting Indicator Value
Required indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1 cm depth in most impacted sediments and representing at least 10% of estuary area**	-268.0
Required indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*	53.0
Required indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*	194.6
Required indicators	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area**	1.2
Required indicators	Sediment Total Nitrogen	Mean TN (mg kg^{-1}) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area**	100.0
Required indicators	Macroinvertebrates	Mean NZ AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10% of estuary area**	2.4
Optional	Sediment muddiness	% estuary area with soft mud (>25 % mud content)*	70.7
Optional	Sedimentation rate***	Ratio of mean estimated annual Current State Sediment Load (CSSL) relative to mean estimated annual Natural State Sediment Load (NSSL)	2.5
Optional	Dissolved Oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case condtions) (mg m^{-3})	-
Overall NZ ETI Score			**0.67**
			Moderate

* Based on 2019 broad scale findings (this report).
** Based on 2019 fine scale findings (Robertson 2019).
***Sediment loads estimated from NIWA's CLUES modelling system.

Input values used in the NZ ETI online calculator (April 2019). See the NIWA online tool metadata spreadsheets for full explanation of terms and abbreviations.

NZ ETI Tool 1 Input details	Calculator Headings	Unit	Input Value
Estuary Number	Est_no		11222
Estuary Name	Est_name		Havelock Estuary
Regional Council	Reg_Council		MDC
Island	Island		South Island
NZCHS geomorphic code	NZCHS_code		9
NZCHS geomorphic class	NZCHS_class		Deep drowned valley
ETI Class	ETI_class		SIDE
Latitude	LAT	decimal degrees	-41.1659
Longitude	LON	decimal degrees	173.46
Freshwater inflow	Qf	m3/s	48.7
Annual river total nitrogen loading	TNriver	T/yr	426.5*
Annual river total phosphorus loading	TPriver	T/yr	112.1*
Volume	V	m3	24000000
Tidal Prism	P	m3	11246995
Return flow fraction	b	unitless	NA
ACExR fitted exponent	A	unitless	-0.55
ACExR fitted constant	B	unitless	128.23
Ratio NO3	R_NO3	unitless	0.86
Ratio DRP	R_DRP	unitless	0.79
Ocean salinity	OceanSalinity_mean	ppt	34.82
Ocean nitrate concentration	NOcean	mg/m3	16.30
Ocean DRP concentration	POcean	mg/m3	7.65
Intertidal area	Intertidal	%	71.00
Typical closure length	Tl	days	NA
ICOE class	isICOE	one of: TRUE, FALSE	FALSE
Closure length	closure_length	one of: days, months	days
Estuary Area	est_area_m2	m2	8007000
Mean depth	mean_depth	m	3
Tidal height	tidal_height	m	2.2

NZ ETI Tool 2 Input details			
Name of estuary	estuary_name		
Phytoplankton Biomass (Chlorophyll a)	CHLA	mg/m3	NA
Macroalgal GNA	macroalgae_GNA_ha	ha	16
Macroalgal GNA/Estuary Area	macroalgae_GNA_percent	%	2.9
Opportunistic Macroalgae	macroalgae_EQR	OMBT EQR	0.41
Dissolved Oxygen (DO)	DO	mg/m3	NA
Sediment Redox Potential (RP)	REDOX	mV	-268
Total Organic Carbon (TOC)	TOC	%	1.2
Total Nitrogen (TN)	TN	mg/kg	100
Macroinvertebrates	NZ AMBI	NZ Hybrid RI AMBI	2.4
Area of soft mud	soft_mud	Proportion	0.7
Estuary type	estuary_type		SIDE
ICOE status	isICOE	TRUE/FALSE	FALSE

* Loads derived using CLUES Model.

Appendix G:

Analytical Results

Hill Laboratories
TRIED, TESTED AND TRUSTED

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Private Bag 3205
Hamilton 3240 New Zealand

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W www.hill-laboratories.com

Certificate of Analysis

SPv1

Client:	Robertson Environmental	**Lab No:**	2137591
Contact:	Ben Robertson	**Date Received:**	07-Mar-2019
	C/- Robertson Environmental	**Date Reported:**	04-Apr-2019
	108 Glen Road	**Quote No:**	96814
	RD 1	**Order No:**	
	Nelson 7071	**Client Reference:**	Havelock Estuary - Marlborough
		Submitted By:	Ben Robertson

Sample Type: Sediment

Sample Name:		HAVFS_A-1 24-Jan-2019 5:00 pm	HAVFS_A-2 24-Jan-2019 5:00 pm	HAVFS_A-3 24-Jan-2019 5:00 pm	HAVFS_B-1 24-Jan-2019 5:00 pm	HAVFS_B-2 24-Jan-2019 5:00 pm
Lab Number:		2137591.1	2137591.2	2137591.3	2137591.4	2137591.5
Individual Tests						
Total Recoverable Phosphorus	mg/kg dry wt	410	400	390	210	192
Total Nitrogen*	g/100g dry wt	0.07	0.06	0.06	< 0.05	< 0.05
Total Organic Carbon*	g/100g dry wt	0.58	0.55	0.62	0.26	0.21
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	4.1	3.9	4.1	1.5	1.4
Total Recoverable Cadmium	mg/kg dry wt	0.050	0.041	0.042	0.021	0.021
Total Recoverable Chromium	mg/kg dry wt	51	50	53	16.9	18.0
Total Recoverable Copper	mg/kg dry wt	10.2	10.8	10.8	5.9	5.4
Total Recoverable Lead	mg/kg dry wt	5.8	5.8	5.9	3.6	3.3
Total Recoverable Mercury	mg/kg dry wt	0.04	0.04	0.04	< 0.02	< 0.02
Total Recoverable Nickel	mg/kg dry wt	39	40	42	13.6	15.6
Total Recoverable Zinc	mg/kg dry wt	45	43	45	23	22
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	76	74	73	76	76
Fraction >/= 2 mm*	g/100g dry wt	0.7	2.3	4.1	0.2	0.4
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	2.2	1.8	1.9	0.2	0.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	8.6	7.7	6.9	0.3	0.3
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	19.4	20.3	16.3	0.5	0.6
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	24.1	24.3	19.7	15.5	15.4
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	17.7	16.0	19.9	66.1	63.5
Fraction < 63 µm*	g/100g dry wt	27.3	27.6	31.2	17.2	19.7

Sample Name:		HAVFS_B-3 24-Jan-2019 5:00 pm	HAVFS_C-1 24-Jan-2019 5:00 pm	HAVFS_C-2 24-Jan-2019 5:00 pm	HAVFS_C-3 24-Jan-2019 5:00 pm	HAVFS_D-1 24-Jan-2019 5:00 pm
Lab Number:		2137591.6	2137591.7	2137591.8	2137591.9	2137591.10
Individual Tests						
Total Recoverable Phosphorus	mg/kg dry wt	177	420	430	420	310
Total Nitrogen*	g/100g dry wt	< 0.05	0.11	0.11	0.10	0.07
Total Organic Carbon*	g/100g dry wt	0.24	1.25	1.30	1.19	0.67
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	1.3	4.1	4.8	4.3	2.5
Total Recoverable Cadmium	mg/kg dry wt	0.019	0.045	0.044	0.039	0.026
Total Recoverable Chromium	mg/kg dry wt	16.2	66	68	66	23
Total Recoverable Copper	mg/kg dry wt	5.4	14.8	15.6	14.9	8.7
Total Recoverable Lead	mg/kg dry wt	3.3	7.6	8.0	7.8	4.9
Total Recoverable Mercury	mg/kg dry wt	< 0.02	0.06	0.07	0.05	< 0.02
Total Recoverable Nickel	mg/kg dry wt	12.9	51	53	52	17.3

Sample Type: Sediment						
Sample Name:		HAVFS_B-3 24-Jan-2019 5:00 pm	HAVFS_C-1 24-Jan-2019 5:00 pm	HAVFS_C-2 24-Jan-2019 5:00 pm	HAVFS_C-3 24-Jan-2019 5:00 pm	HAVFS_D-1 24-Jan-2019 5:00 pm
Lab Number:		2137591.6	2137591.7	2137591.8	2137591.9	2137591.10
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Zinc	mg/kg dry wt	21	49	51	49	30
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	76	61	62	61	73
Fraction >/= 2 mm*	g/100g dry wt	0.1	< 0.1	< 0.1	< 0.1	1.7
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.1	0.3	< 0.1	< 0.1	0.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	0.2	0.7	0.5	0.4	0.4
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	0.5	2.3	1.9	2.0	0.6
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	17.3	5.9	5.9	5.7	1.6
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	63.0	29.9	32.7	30.2	50.3
Fraction < 63 µm*	g/100g dry wt	18.7	61.0	59.0	61.7	45.3

Sample Name:		HAVFS_D-2 24-Jan-2019 5:00 pm	HAVFS_D-3 24-Jan-2019 5:00 pm	HAVSP-A 24-Jan-2019 5:00 pm	HAVSP-B 24-Jan-2019 5:00 pm	HAVSP-C 24-Jan-2019 5:00 pm
Lab Number:		2137591.11	2137591.12	2137591.13	2137591.14	2137591.15
Individual Tests						
Total Recoverable Phosphorus	mg/kg dry wt	360	330	-	-	-
Total Nitrogen*	g/100g dry wt	0.07	0.06	-	-	-
Total Organic Carbon*	g/100g dry wt	0.86	0.73	-	-	-
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	3.0	2.6	-	-	-
Total Recoverable Cadmium	mg/kg dry wt	0.035	0.031	-	-	-
Total Recoverable Chromium	mg/kg dry wt	26	23	-	-	-
Total Recoverable Copper	mg/kg dry wt	10.6	10.2	-	-	-
Total Recoverable Lead	mg/kg dry wt	6.0	5.3	-	-	-
Total Recoverable Mercury	mg/kg dry wt	< 0.02	0.02	-	-	-
Total Recoverable Nickel	mg/kg dry wt	19.6	18.0	-	-	-
Total Recoverable Zinc	mg/kg dry wt	35	32	-	-	-
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	71	72	70	75	63
Fraction >/= 2 mm*	g/100g dry wt	0.1	1.1	2.1	2.5	< 0.1
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.2	0.3	1.7	0.1	0.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	0.4	0.5	7.2	0.2	0.8
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	0.6	1.0	16.8	0.7	3.3
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	1.4	10.9	23.6	16.1	7.6
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	45.4	35.3	17.4	60.1	32.4
Fraction < 63 µm*	g/100g dry wt	51.8	50.9	31.3	20.3	55.6

Sample Name:		HAVSP-D 24-Jan-2019 5:00 pm	HAVSP-E 24-Jan-2019 5:00 pm	HAVSP-F 24-Jan-2019 5:00 pm	HAVBS_GS-1 26-Jan-2019 6:00 pm	HAVBS_GS-2 26-Jan-2019 6:00 pm
Lab Number:		2137591.16	2137591.17	2137591.18	2137591.19	2137591.20
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	73	60	61	75	60
Fraction >/= 2 mm*	g/100g dry wt	0.2	< 0.1	0.1	5.1	1.0
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.3	0.5	0.6	0.4	1.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	0.4	1.7	1.7	3.0	2.6
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	0.8	5.8	5.2	42.2	4.9
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	2.1	6.2	8.1	33.9	8.1
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	51.0	7.6	11.0	3.3	9.5
Fraction < 63 µm*	g/100g dry wt	45.4	78.1	73.2	12.1	72.7

Sample Name:		HAVBS_GS-3 26-Jan-2019 6:00 pm	HAVBS_GS-4 26-Jan-2019 6:00 pm	HAVBS_GS-5 26-Jan-2019 6:00 pm	HAVBS_GS-6 26-Jan-2019 6:00 pm	HAVBS_GS-7 26-Jan-2019 6:00 pm
Lab Number:		2137591.21	2137591.22	2137591.23	2137591.24	2137591.25

Sample Type: Sediment						
Sample Name:		HAVBS_GS-3 26-Jan-2019 6:00 pm	HAVBS_GS-4 26-Jan-2019 6:00 pm	HAVBS_GS-5 26-Jan-2019 6:00 pm	HAVBS_GS-6 26-Jan-2019 6:00 pm	HAVBS_GS-7 26-Jan-2019 6:00 pm
Lab Number:		2137591.21	2137591.22	2137591.23	2137591.24	2137591.25
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	62	52	55	62	79
Fraction >/= 2 mm*	g/100g dry wt	0.5	0.1	< 0.1	< 0.1	4.7
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	1.4	0.2	0.2	0.2	3.1
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	4.1	0.6	0.5	0.3	10.9
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	15.2	1.3	1.2	0.5	33.7
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	19.1	1.4	1.1	1.2	26.4
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	8.0	5.1	4.2	11.1	9.2
Fraction < 63 µm*	g/100g dry wt	51.7	91.3	92.8	86.6	12.1

Sample Name:		HAVBS_GS-8 26-Jan-2019 6:00 pm	HAVBS_GS-9 26-Jan-2019 6:00 pm			
Lab Number:		2137591.26	2137591.27			
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	76	72	-	-	-
Fraction >/= 2 mm*	g/100g dry wt	2.4	6.2	-	-	-
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	1.2	5.3	-	-	-
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	5.8	10.8	-	-	-
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	33.8	20.1	-	-	-
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	29.2	13.0	-	-	-
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	13.2	10.1	-	-	-
Fraction < 63 µm*	g/100g dry wt	14.3	34.6	-	-	-

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.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-12
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt	1-12
7 Grain Sizes Profile			
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-27
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-27
Fraction < 2 mm, >/= 1 mm*	Wet sieving using dispersant, 2.00 mm and 1.00 mm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 1 mm, >/= 500 µm*	Wet sieving using dispersant, 1.00 mm and 500 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 500 µm, >/= 250 µm*	Wet sieving using dispersant, 500 µm and 250 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 250 µm, >/= 125 µm*	Wet sieving using dispersant, 250 µm and 125 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 125 µm, >/= 63 µm*	Wet sieving using dispersant, 125 µm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27

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

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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

Carole Rodgers-Carroll BA, NZCS
Client Services Manager - Environmental

Appendix H:

Field Photographs

Photo 1-6: Dense macroalgae (*Ulva* spp.) underlain by muddy gravel/anoxic substrata within GEZ and associated herbfield mixed with rushland on the northern edge of the Pelorus River channel near Wakaretu Bay.

Photo 7-10: Mud-dominated channels flanked by rushland in the upper Kaituna Arm adjacent to Havelock Township.

Photo 11-12: GEZ conditions, harbouring a relatively dense macroalgal canopy associated with poorly oxygenated very soft muds, Kaituna Arm opposite Havelock marina.

Photo 13-18: Firm muddy sand substrata, patchy herbfields and rushland, western Kaituna Arm opposite Havelock marina.


Photo 19-20: Low density seagrass patches in middle estuary nearby Fine Scale Site A.




Photo 21-24: Oyster beds among predominantly non-vegetated, soft muddy intertidal flats in the middle estuary.

Photo 25-27: Seagrass habitat in the lower estuary, including the boundary between where seagrass was lost between 2014 and 2019 (bottom right photo).

Photo 28-29: Previously unmapped seagrass patches within embayment nearby Shag Point.

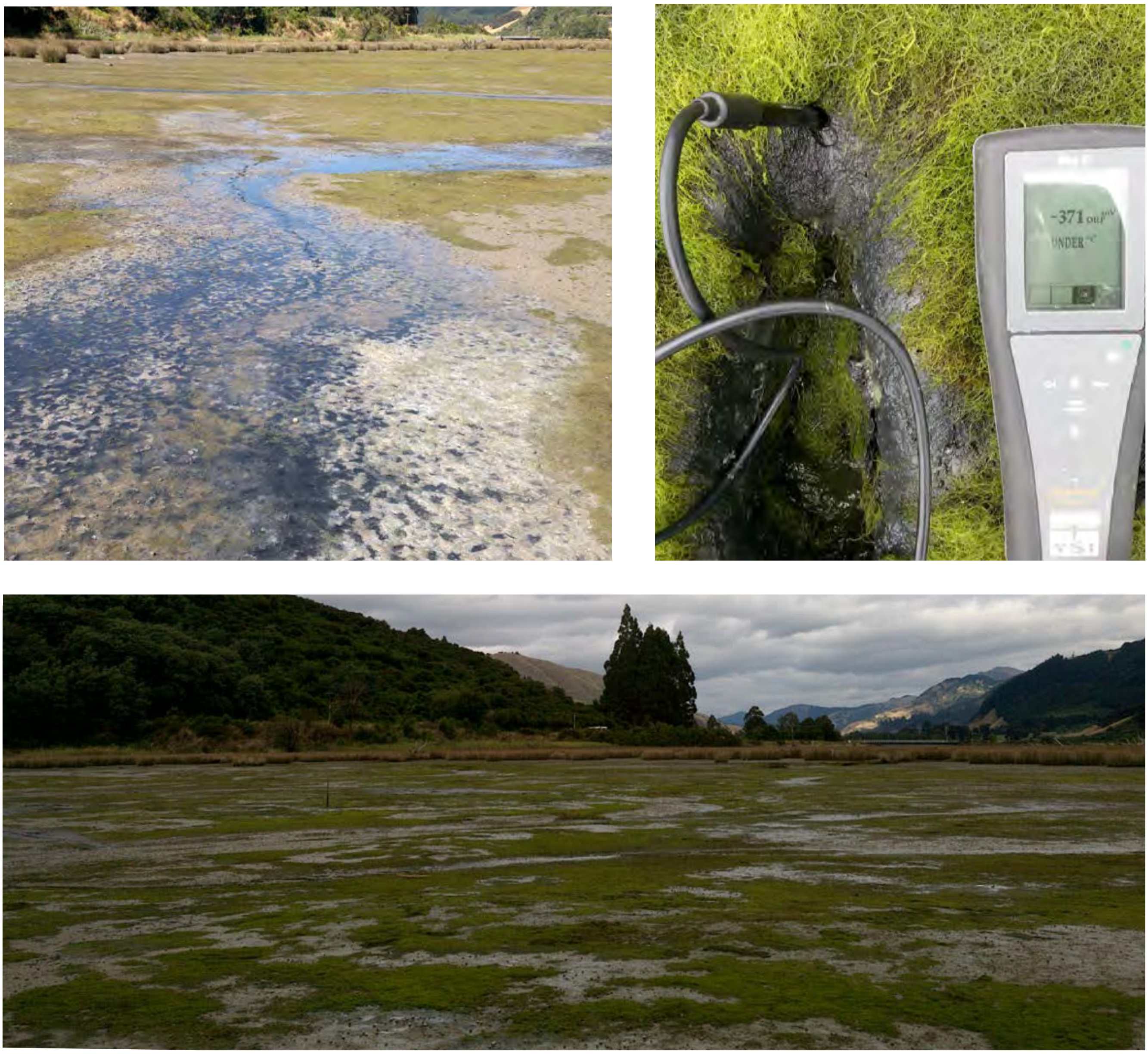

Photo 30-32: Gross eutrophic conditions (GEZ) with highly reducing (poorly oxygenated) sediments in the upper Kaituna Arm where *Spartina* was previously eradicated.

Photo 33-34: Boundary between *Ulva*-dominated GEZ and predominantly non-vegetated, relatively poorly oxygenated soft muds, upper Kaituna Arm.





Photo 35-39: Scientists ground-truthing substrata and vegetation types in the eastern settling basin and surrounding habitat.

Photo 40-44: Saltmarsh and fringing terrestrial margin, upper Pelorus Arm.

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