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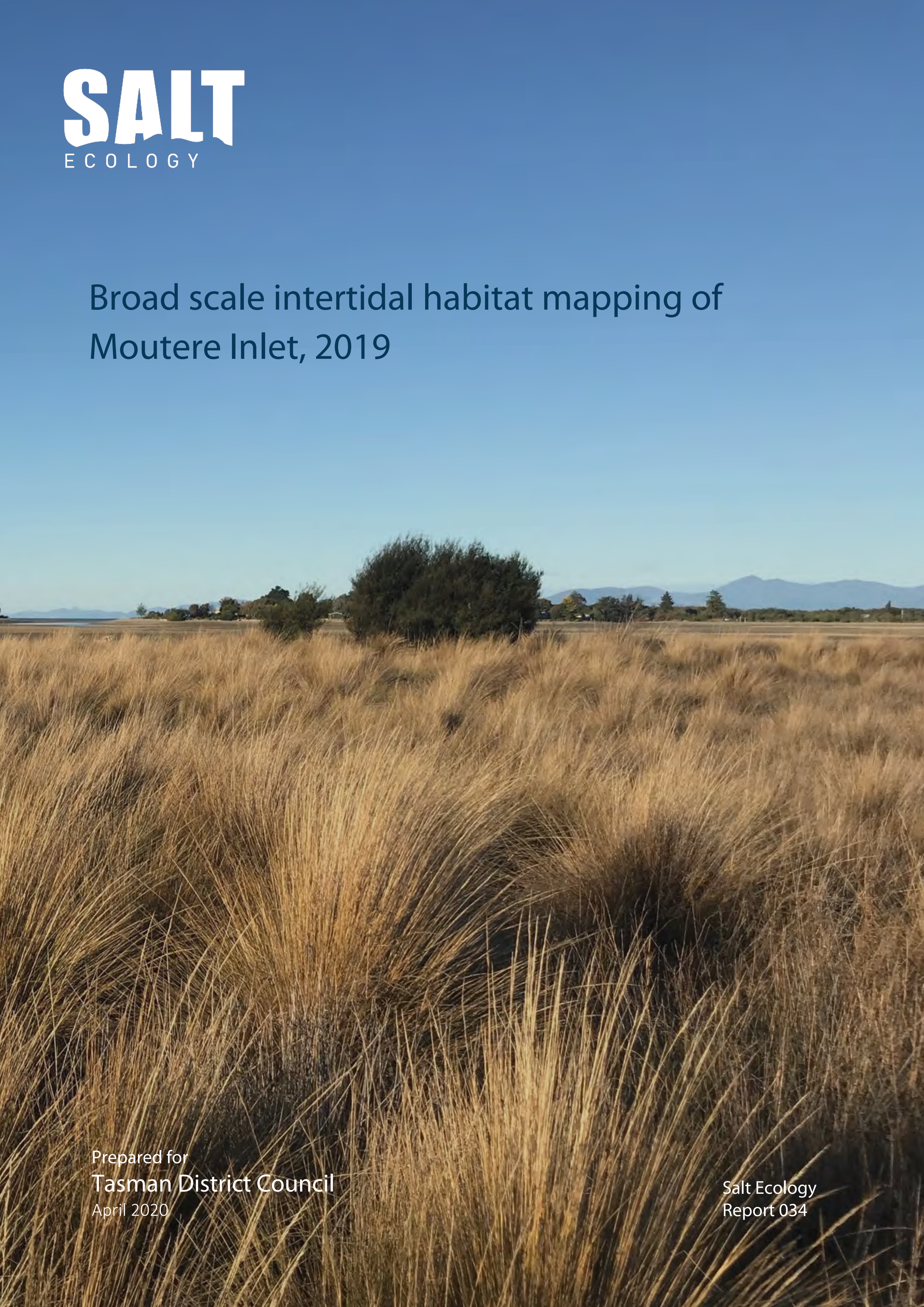

Broad scale intertidal habitat mapping of Moutere Inlet, 2019

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Broad scale intertidal habitat mapping of Moutere Inlet, 2019

Prepared by

Leigh Stevens,
Thomas Scott-Simmonds
and Barrie Forrest

for

Tasman District Council

April 2020

leigh@saltecology.co.nz, +64 (0)21 417 936

www.saltecology.co.nz

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BACKGROUND

This report summarises the results of broad scale habitat mapping of Moutere Inlet conducted in May 2019. Moutere Inlet is a moderate-sized (765ha), well-flushed, shallow, intertidally-dominated estuary located on the western side of Tasman Bay. It is one of several estuaries in Tasman District Council's (TDC's) long-term coastal monitoring programme. The primary purpose of the 2019 survey was to describe and map the dominant substrate and vegetation features present in the estuary including seagrass, salt marsh and macroalgae, based on the framework outlined in New Zealand's National Estuary Monitoring Protocol (NEMP). Mapping results for 1947, 1988, 2004 and 2013 were QAQC checked, and 2004 and 2013 GIS data from the field surveys updated to address errors in geometry or typology and to incorporate improvements in substrate classifications. These updated results were then used to assess temporal changes.

KEY FINDINGS

The following table summarises key broad scale monitoring results and rates them using preliminary criteria for assessing estuary health. Changes to key indicators since 2013 are also noted.

Broad scale indicators	Unit	Value	2019 Rating	Change since 2013
Mud extent	% of estuary	29	Poor	Small ↓, 22ha, 9%
Macroalgae (OMBT)	Ecological Quality Rating	0.53	Fair	Moderate ↓*
Seagrass	% decrease from baseline	0	Very Good	Large ↑, 1.1ha**
Salt marsh extent	% of intertidal area	10.8	Good	No change
Salt marsh loss	% of historical remaining	55	Fair	No change
200m terrestrial margin	% densely vegetated	8.3	Poor	Slight ↓**
High Enrichment Conditions	ha	31	Poor	Large ↓, 29ha
High Enrichment Conditions	% of estuary	4.3%	Good	Large ↓, 48%
NZ Estuary Trophic Index	ETI score	0.69	Fair	Slight ↓ (improvement)

OMBT=Opportunistic Macroalgal Blooming Tool. *Estimated change based on reduction in dense macroalgal cover

**Primarily reflects differences in mapping coverage or classification rather than meaningful change

The extent of mud-dominated substrates is the most significant current issue present in Moutere Inlet, in part as most of the sediment entering the estuary (96%) is predicted to be trapped and retained within it. Most mud is located in the central basin and to the southeast and, to a lesser degree, in the sheltered embayments on the western side of the estuary and north of Wharf Road – ideal settling areas for fine sediment.

The spatial extent of mud is high in both a regional and national context although there appears to have been a recent reduction in mud extent (22ha, 9% since 2013) and an obvious decrease in sediment volume in certain parts of the estuary, most particularly the central basin. The very high mud content of the sediments contributes to reduced sediment oxygenation, which will likely limit sediment macrofauna to a relatively low diversity community dominated by mud-tolerant species.

Despite the high extent of mud-dominated substrates, analysis of sediment plate monitoring (collected by TDC) showed that net rates of measured sediment accumulation (average 0.2mm/yr over the past decade) were well below the 2mm/yr guideline value proposed for New Zealand estuaries, and comparable to the 0.9mm/yr calculated from NIWA's national estuary sediment load estimator. However, in the central basin where deposition appears most pronounced, sediment cores analysed using forensic methods (lead and caesium radioisotopes) estimated mean sediment accrual of ~10mm/yr from 1988 to 2018 This high rate of sediment accrual is rated 'poor'.

The ratio of the current sedimentation rate (CSR) to the natural sedimentation rate (NSR), assessed using rating criteria in the NZ Estuary Trophic Index, placed Moutere Inlet in 'Band C' (fair). Previous studies indicate that the dominant source (~90%) of recent sediment inputs to the estuary at the Moutere River mouth is of pine forest origin (linked to recent harvesting) and possibly also reflects land clearance for rural residential subdivision in the past decade.

Macroalgae were most commonly present in two distinct forms – dense high biomass growths of sediment-entrained *Gracilaria,* and relatively sparse low biomass growths of *Ulva* (sea lettuce), the latter growing mostly along channel edges or as a subdominant growth on *Gracilaria*. Of the two, *Gracilaria* was causing the most significant adverse ecological effects in the estuary, with large smothering beds present in the Wharf Road embayment, several of the western embayments and in mud-dominated substrates in the central basin.

Prolific growths of macroalgae that cause nuisance conditions seldom occur naturally in well-flushed shallow intertidally-dominated estuaries, but can occur when nutrient inputs are significantly elevated. In extreme cases, excessive macroalgal growths can result in persistent High Enrichment Conditions (HECs) developing that lead to sediment degradation. In Moutere Inlet, the extent of HECs has expanded significantly over time, from an estimated ~1ha (0.1% of estuary area) in 1947, to 37ha (5%) in 2004 and to 60ha (8%) in 2013, before decreasing to 31ha (4.1%) in 2019. The large decrease in both macroalgal cover (48ha) and HEC extent (29ha) since 2013 is very positive, although the specific reasons for the changes are unclear. However, despite the near halving of HEC area from 2013 to 2019, the condition rating remains 'poor'.

To assess the overall extent that symptoms of eutrophication are expressed, the NZ Estuary Trophic Index combines macroalgal growth, the presence of HECs and mud extent (as well as several other indicators). The ETI score of 0.69, indicates Moutere Inlet is at the upper (more degraded) end of the 'fair' rating band.

Small seagrass (*Zostera*) beds were present (3.1ha) primarily in the central basin near the Kina entrance, with an apparent increase of 1.1ha since 2013 and 2.2ha since the first reliable baseline in 2004. This increase is rated 'good', although it is attributed more to improved mapping accuracy than a change in actual extent. The remaining beds appear confined to a relatively narrow range, with infilling in many other areas creating perched tidal flats that are exposed for most of the tidal cycle and which, when combined with excessive muddiness, is unfavourable for seagrass growth. While data are not available, the remaining seagrass beds are likely to be very small compared to their pre-human extent.

Salt marsh vegetation remained a prominent feature in 2019 (83ha, 10.8% of the estuary), with no appreciable change from 2004 or 2013. Salt marsh was dominated by rushland (55%) and herbfield (40%) and was most common within estuary embayments and on the northwest and southern tidal flats. Compared to historical extent, there has been an estimated reduction of ~45% since 1947, most losses due to reclamation and drainage. The modification of the estuary margin severely restricts the area available for salt marsh expansion and disrupts the natural connectivity between the land-sea interface, preventing the migration of salt marsh species in response to predicted sea level rise. Without changes in management approaches, the outcome is likely to be a progressive reduction of salt marsh habitat over time.

The 200m wide terrestrial margin bordering the estuary was also highly modified and dominated by residential/industrial development (21.7%), pasture (28.6%) and horticulture (19.5%). Only 16% was densely vegetated, half of which was exotic, resulting in a condition rating of 'poor'.

Overall, despite extensive historical habitat modification, much reduced habitat diversity, and large areas of mud, the estuary retains significant ecological value, although it is currently expressing moderate symptoms of eutrophication and muddiness. Without reductions in current nutrient and sediment loads the estuary is likely to remain in a similar state to its present condition, and salt marsh losses are likely to increase in response to sea level rise.

RECOMMENDATIONS

Moutere Inlet has been identified by TDC as a priority for monitoring because of its high ecological and human use values, and because it is potentially vulnerable to elevated sedimentation and localised eutrophication issues. Based on the 2019 results, the following recommendations are proposed for consideration by TDC.

Broad Scale Habitat Mapping

In order to track changes in the dominant features of the estuary, undertake broad scale habitat mapping at 5-10 yearly intervals; five yearly for habitat features where changes over the past 10 years have been significant (macroalgae and fine sediment) and 10 yearly where habitat features are relatively stable, e.g. terrestrial margin, salt marsh, seagrass. In light of the potential for rapid changes to nuisance macroalgal beds, the extent and state of established and persistent macroalgal beds should be synoptically assessed annually.

Sedimentation Rate Monitoring

Given the consistency of sediment plate results over the past 10 years it is recommended that they be monitored biennially.

To understand the scale of observed change in the central basin, install additional plates at two sites where fine sediments are currently being eroded, and at the sites use for fine scale ecological monitoring, to help interpret future changes in sediment biota.

To determine if sediments are getting muddier in the absence of sediment accretion, consideration should be given to analysing a composite sediment sample for grain size at each sediment plate site to establish a baseline against which future change can be assessed.

Catchment Influences

In addition to the above field-based monitoring, it would be helpful if the council maintained records on the location and scale of known catchment disturbances or land use changes (e.g. forest harvesting, road development, urban subdivision) to assist in the interpretation of monitoring results. Such information will complement high-level national-scale data such as the Landcare Research Land Cover Database (LCDB) assessed from satellite imagery. It would also be prudent to reassess modelled catchment sediment and nutrient load predictions following any significant change in catchment land use, or when national models (e.g. NIWA CLUES model, suspended sediment yield estimator) are updated.

Management and Restoration

There is significant potential for the ecological restoration of Moutere Inlet. It is recommended that TDC develop a strategy to identify and prioritise areas for ecological enhancement and protection, including recommending specific restoration options, e.g. replanting salt marsh, improving tidal flushing, recontouring shorelines, and removing barriers to salt marsh expansion. This would ideally be part of a region-wide planning approach facilitated to assist community and stakeholder initiatives.

A key component of the strategy would be to delineate low-lying areas previously within the estuary, or likely to be impacted by sea level rise, using GIS-based mapping techniques and existing coastal LIDAR data. These outputs can be used to encourage the protection or expansion of salt marsh on private land adjacent to the estuary, and to facilitate planning for the managed retreat of salt marsh in response to predicted sea level rise.

1. INTRODUCTION

1.1 BACKGROUND

Monitoring the ecological condition of estuarine habitats is critical to their management. Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective, easy to use, nationally-applied standard protocol with which they can assess and monitor the ecological status of estuaries in their region. The results provide a valuable basis for establishing a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad-scale monitoring to map estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine-scale monitoring (at selected sites) of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

Tasman District Council (TDC) has in place a long-term SOE monitoring programme for estuaries. The programme is designed to detect and understand changes in key estuaries over time and determine catchment influences, especially those due to the input of nutrients and muddy sediments. The TDC programme includes regular monitoring in five estuaries: Ruataniwha, Motupipi and Waimea, as well as Moutere Inlet and the Motueka River delta. Monitoring at each of these locations has been undertaken periodically for the last 10-20 years – see:

https://www.tasman.govt.nz/my-council/key-documents/more/environment-reserves-and-open-space/environmental-monitoring-reports/?path=/EDMS/Public/Other/Environment/EnvironmentalMonitoring/CoastalMonitoring/Estuaries.

The current report describes the methods and results of the third broad-scale monitoring survey undertaken at Moutere Inlet (Fig. 1) in May 2019, along with a synthesis of the results of surveys from earlier years. A focus of the report is understanding changes in estuary habitat compared to previous broad-scale surveys undertaken in 2004 (Clark et al. 2006) and 2013 (Robertson & Stevens 2013), and to estimates of historical salt marsh and seagrass cover reported for 1947 and 1988 (Clark & Gillespie 2007). As part of the analysis, the report includes a suite of broad-scale indicators that were not part of the original NEMP, but which have been widely adopted since the protocol was developed. These include use of 'sediment plate' monitoring to assess patterns of estuary sedimentation, improved methods for classifying macroalgae and substrate, and development of various metrics for assessing ecological condition.

1.2 BACKGROUND TO MOUTERE INLET

Previous reports (e.g. Gillespie et al. 1995; Clark et al. 2006; Gillespie & Clark 2006; Clark & Gillespie 2007; Robertson & Stevens 2009, 2013; Stevens & Robertson 2013; Stevens & Rayes 2018) all present background information on Moutere Inlet, which is paraphrased (and expanded in places) below.

Moutere Inlet (Fig. 1) is a moderate-sized (764ha), well-flushed, shallow, intertidally-dominated, estuary (SIDE) located near Motueka. The estuary consists of one main basin with a tidal opening at each end of Jacket Island, and several tidal embayments separated from the main estuary basin by causeways. The estuary is shallow (mean depth ~2m) and almost completely drains at low tide. Intertidal habitats are characterised by wide sandflats and mudflats - many perched high in the tidal range - and well flushed, steeply incised drainage channels, particularly near the entrances. These channels contain a variety of cobble, gravel, san d and biogenic (oyster, mussel, tubeworm) habitats, and support localised macroalgal growths. Although significantly reduced from their historical range, small patches of seagrass remain in the lower tidal reaches of the estuary, and salt marsh is present along the upper tidal margins. Background information on the ecological significance of the difference vegetation features is provided in Table 2.

The mean freshwater flow from the Moutere River in the northwestern corner of the estuary is ~2065L/s (TDC data), with secondary inputs from several streams along the western side.

Fig. 1. Location map of Moutere Inlet. The position of sedimentation monitoring sites is shown from which data analysed in this broad-scale survey report are collected. Also shown is the location of survey sites periodically surveyed as part of NEMP fine-scale monitoring.

The surrounding catchment (Fig 2) is highly modified and dominated by pasture (53%), horticulture (15%), exotic forestry (12%) and built up areas (settlements) (2%), including the commercial port and marina located at Port Motueka. Native forest cover is low (2%) (Table 1).

Much of the terrestrial margin immediately adjacent to the estuary (70%) has been reclaimed or modified (seawalls, roads, causeways), which has significantly displaced large areas of salt marsh, and now limits its ability to migrate in response to sea level rise. Despite these changes the estuary remains valued for its aesthetic appeal, rich biodiversity, shellfish collection, swimming, waste assimilation, whitebaiting, fishing, boating, walking and scientific interest. It is recognised as a valuable nursery area for marine and freshwater fish and is regarded as a nationally important coastal area for birdlife (Davidson & Preece 1994, Melville & Shuckard 2013, Shuckard & Melville 2013).

The ecological vulnerability of Moutere Inlet was assessed in 2013 as MODERATE-HIGH, with the key pressures identified as excessive areas of mud-impacted sediment and increasing nutrient related eutrophication (Robertson & Stevens 2012; Stevens & Robertson 2013). The latter included the presence of High Enrichment Conditions (HECs) characterised by dense macroalgae, poor sediment oxygenation, sulphide-rich sediments, and mud accumulation.

Table 1. Summary of catchment land cover (LCDB5 2018), Moutere Inlet.

LCDB5 (2018) Class and Name		Ha	%
1	Built-up Area (settlement)	399	2.1
2	Urban Parkland/Open Space	56	0.3
5	Transport Infrastructure	69	0.4
6	Surface Mine or Dump	1	0.003
10	Sand or Gravel	24	0.1
20	Lake or Pond	76	0.4
21	River	4	0.02
22	Estuarine Open Water	48	0.3
30	Short-rotation Cropland	108	0.6
33	Orchard, Vineyard or Other Perennial Crop	2799	14.9
40	High Producing Exotic Grassland	9882	52.6
41	Low Producing Grassland	125	0.7
45	Herbaceous Freshwater Vegetation	9	0.05
46	Herbaceous Saline Vegetation	49	0.3
50	Fernland	0	0.002
51	Gorse and/or Broom	372	2.0
52	Manuka and/or Kanuka	74	0.4
54	Broadleaved Indigenous Hardwoods	104	0.6
56	Mixed Exotic Shrubland	29	0.2
64	Forest - Harvested	759	4.0
68	Deciduous Hardwoods	19	0.1
69	Indigenous Forest	369	2.0
71	Exotic Forest	3421	18.2
	Grand Total	18795	100

Table 2. Overview of ecological role of various vegetation types

Terrestrial margin vegetation: 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 food source and habitat for a variety of species in waterway riparian zones, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity.

Saltmarsh: Salt marsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important in estuaries 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. Salt marsh generally has the densest cover in sheltered and more strongly freshwater-influenced upper estuary areas, and is relatively sparse in the lower (more exposed and saltwater dominated) parts of an estuary. The tidal limit of salt marsh growth for most species is restricted to above the height of mean high-water neap tide.

Seagrass: Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (particularly if there is a lack of oxygen and production of sulphides).

Opportunistic macroalgae: Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to outcompete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh. Macroalgae that becomes detached (e.g. *Ulva* spp.) can also accumulate and decay in subtidal areas and on shorelines causing oxygen depletion and nuisance odours and conditions. One species in NZ, *Gracilaria chilensis*, can become entrained in sediments (i.e. grow within the sediment matrix) and establish persistent growths that trap fine sediment and lead to surface smothering of habitat. Trapped sediments provide a source of nutrients that facilitate further algal growth, and lead to other changes in the sediment that become difficult to reverse.

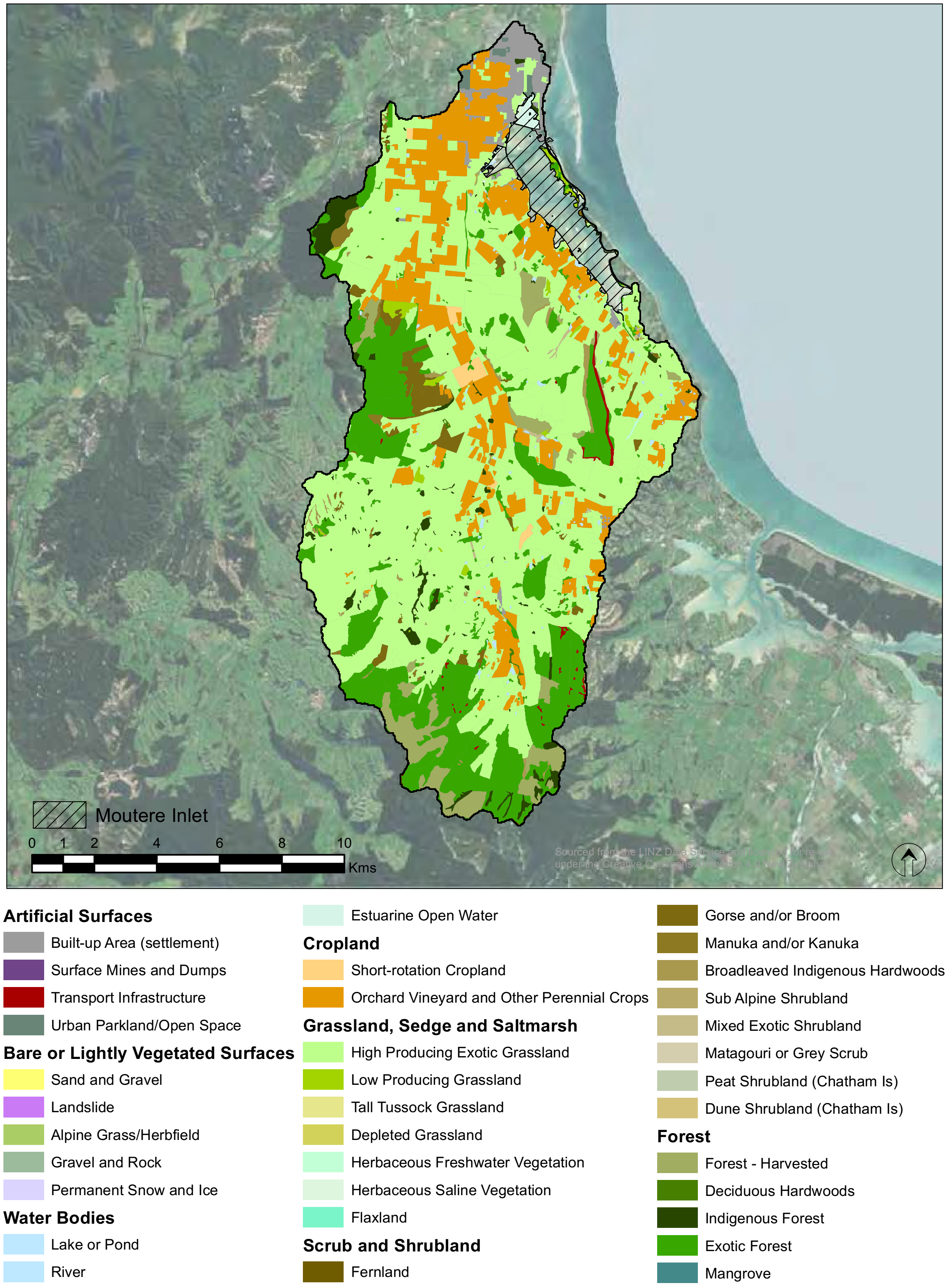

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Fig. 2. Map of catchment land cover (LCDB5 2018).

2. BROAD SCALE METHODS

2.1 OVERVIEW

Broad-scale surveys involve describing and mapping estuaries according to the dominant surface habitat features (substrate and vegetation) present. This procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats, e.g. Table 3 can be monitored by repeating the mapping exercise. Broad-scale mapping is typically carried out during the period September to May when most plants are still visible and seasonal vegetation has not died back. Aerial photographs are ideally assessed at a scale of less than 1:5000, as at a broader scale it becomes difficult to accurately determine changes in habitats over time.

Broad scale mapping of Moutere Inlet in 2019 used 1:3000 colour aerial photographs (~0.03m/pixel resolution) flown for LINZ in early 2019 and supplied by TDC. Ground truthing was undertaken by experienced scientists who walked the estuary in May 2019 to map the spatial extent of dominant vegetation and substrate. In the field these habitat features were drawn onto laminated aerial photographs. The broad scale features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps are produced showing the dominant estuary features (substrate, salt marsh, macroalgae and seagrass) and the vegetation and other features of the terrestrial margin.

Estuary boundaries for mapping purposes were defined as the area between the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt) and seaward to a straight line between the outer headlands where the angle between the head of the estuary and the two outer headlands is <150°.

2.2 HABITAT CLASSIFICATION AND MAPPING

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system defined in the NEMP, whereby dominant estuarine plant species were used to define broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock). Vegetation was coded using the two first letters of the genus and species; e.g. sea rush *Juncus kraussii*, was coded as Jukr. Plants were listed in order of dominance with subdominant species placed in parentheses, e.g. Jukr(Caed) indicates that sea rush was dominant over ice plant *(Carpobrotus edulis)*. A relative measure of vegetation height can be derived from its structural class (e.g. rushland is taller than herbfield). Terrestrial margin vegetation was classified using the Landcare Research LCDB5 numeric codes (see Table 1).

The NEMP approach to estuary substrate classification has been extended to record substrate beneath vegetation (salt marsh, seagrass and macroalgae) to provide a continuous substrate layer for the estuary. Furthermore, the NEMP substrate classifications themselves have been revised to provide a more meaningful classification of sediment based on mud content (Table 3).

Under the original NEMP classification, mud/sand mixtures can have a mud content ranging from 1-100% within the same class, and classes are separated only by sediment firmness (how much a person sinks), with increasing softness being a proxy measure of increasing muddiness. Not only is sinking variable between individuals (heavier people sink more readily than lighter people), but also in many cases the relationship between muddiness and sediment firmness does not hold true. Very muddy sediments may be firm to walk on, e.g. sun-baked muds or muds deposited over gravel beds. In other instances, soft sediments may have low mud contents, e.g. coarse muddy sands. Further, many of the NEMP fine sediment classes have ambiguous definitions making classification subjective, or are inconsistent with commonly accepted geological criteria (e.g. the Wentworth scale).

To address these issues, mud and sand classifications have been revised to provide additional resolution based on the estimated mud content of fine-grained substrates, with sediment firmness used as an independent descriptor (Table 3, Appendix 1).

Lower-case abbreviations are used to designate sediment firmness (f=firm, s=soft, vs=very soft). Mobile substrate (m) is classified separately. Upper-case abbreviations are used to designate four fine unconsolidated substrate classes consistent with existing geological terminology (S=Sand, MS=Muddy Sand, SM=Sandy Mud, M=Mud). These are based on sediment mud content (Table 3) and reflect both biologically meaningful thresholds where key changes in sediment macrofaunal communities occur, and categories that can be subjectively assessed in the field by experienced scientists and validated by laboratory analyses.

In developing the revised classifications, care has been taken to ensure that key metrics such as the area of mud dominated habitat can be assessed using both the NEMP and the revised classifications so that comparisons with existing work can be made.

2.3 FINE SEDIMENT ASSESSMENT

2.3.1 Sediment Muddiness

The primary indicator used in the current broad scale report to assess sediment mud impacts is the area (horizontal extent) of intertidal muddy sediment, with sediment mud content, as determined by laboratory analysis, a supporting indicator.

For Moutere Inlet we derived estimates of the horizontal extent from the broad-scale mapping work described above. To validate the broad scale classifications surface samples (0-20mm) were collected from nine representative areas and analysed for grain size (percent mud/sand/gravel). See Appendix 2 for sample site coordinates and field measurements, and Appendix 3 for laboratory methods and results.

Table 3. Substrate classification codes used in the current report.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.096m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Mobile sand	mS
		Firm shell/sand	fSS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Mobile muddy sand	mMS10
		Firm muddy shell/sand	fSS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Mobile muddy sand	mMS25
		Firm muddy shell/sand	fMSS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Mud (M)	Mud (>90%-100%)	Firm mud	fM90
		Soft muddy sand	sM90
		Very soft mud	vsM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Sabellid field	TUBE
Artifical Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aBF
		Cobble field	aCF
		Gravel field	aGF
		Sand field	aSF

2.3.2 Sedimentation Accumulation

Assessment of the change in depth of sediment overlying buried sediment 'plates' (typically concrete pavers) has become a routine method in many NZ estuaries for obtaining information on sediment accumulation (e.g. Hunt 2019). By measuring the depth of sediment above each plate at regular intervals (annual measurements are recommended as a minimum), sedimentation rates can be determined over the long term. National guidance for estuary sedimentation has recently been proposed to assist in defining appropriate rates of accumulation for NZ estuaries (Townsend & Lohrer 2015, Robertson et al. 2016b). Where significant issues are identified using the sediment plate approach, more comprehensive assessment methods are commonly used, e.g. bathymetric studies or transect-based cross-sectional survey approaches.

In 2008 TDC staff buried a total of 20 concrete paving stones (19cmX23cm) at five sites in Moutere Inlet and measured them annually for 10 years. Two additional sites were added in 2013 (see Fig. 1 for site locations). Over each plate, TDC staff made 4-6 measurements of sediment depth by pushing a probe into the sediment until it hit each plate and measuring the penetration depth to the nearest mm. A 2.5m straight edge was placed over each plate position to average out any small-scale irregularities in surface topography.

2.3.3 Sediment Oxygenation

The apparent Redox Potential Discontinuity (aRPD) layer is a subjective measure of the enrichment state of sediments according to the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). The aRPD depth provides an easily measured, time integrated, and relatively stable measure of the sediment oxygenation conditions that infaunal communities are predominantly exposed to.

As part of broad scale mapping in Moutere Inlet, sediment aRPD was assessed in representative areas by digging into the underlying sediment with a hand trowel to determine whether there were any significant areas where sediment oxygenation was depleted close to the surface. Sediments were considered to have poor oxygenation if the aRPD was consistently <5mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. As significant sampling effort is required to map subsurface conditions accurately, the broad scale approach is intended to be used as a preliminary screening tool to determine the need for additional sampling effort.

Examples of poorly oxygenated muddy sediment with aRPD <5mm (left) and well oxygenated sandy sediment with aRPD >150mm (right). Note the dried surface mud layer evident from a recent flood.

2.4 MACROALGAL ASSESSMENT

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature. Because opportunistic macroalgae is the primary indicator of nutrient enrichment in shallow intertidally dominated estuaries (SIDEs), the NZ ETI (Robertson et al. 2016a,b) has adopted the use of the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) for macroalgal assessment. The OMBT, described in detail in Appendix 4a, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- Percent cover of opportunistic macroalgae throughout soft sediment habitat in an estuary (the spatial extent and density of algal cover providing an early warning of potential eutrophication issues).
- Macroalgal biomass (providing a direct measure of macroalgal growth and enabling estimates of mean biomass to be made within areas affected by macroalgal growth, as well across the total estuary area).
- Extent of algal entrainment into the sediment matrix (highlighting where persistent macroalgal growths have established).

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

Using this approach in Moutere Inlet, macroalgae patches were mapped to the nearest 10% using a 6-category rating scale as a guide to describe percentage cover (see Fig 3). The focus was on opportunistic species associated with nutrient enrichment problems in NZ, namely *Gracilaria chilensis* and *Ulva* spp.

Within these percentage cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the depth of macroalgal entrainment were measured. Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algal material was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale. Macroalgae were defined as entrained when growing >30mm deep within sediments. When sufficient representative patches had been measured to enable biomass to be reliably estimated, additional subjective biomass estimates were made following the OMBT method (WFD-UKTAG 2014).

2.5 SEAGRASS ASSESSMENT

The NEMP provides no guidance on the assessment of seagrass beyond recording its presence when it is a dominant surface feature. To improve on the NEMP method, the mean percent cover of discrete seagrass patches was visually assessed to the nearest 10% based on the 6-category percent cover rating scale presented in Fig. 3.

To assess temporal changes in estuary seagrass, 2019 data where seagrass cover was >50% were compared to data from previous reports. The 50% threshold was used as previous NEMP mapping only recorded seagrass beds when present as a dominant feature (i.e.

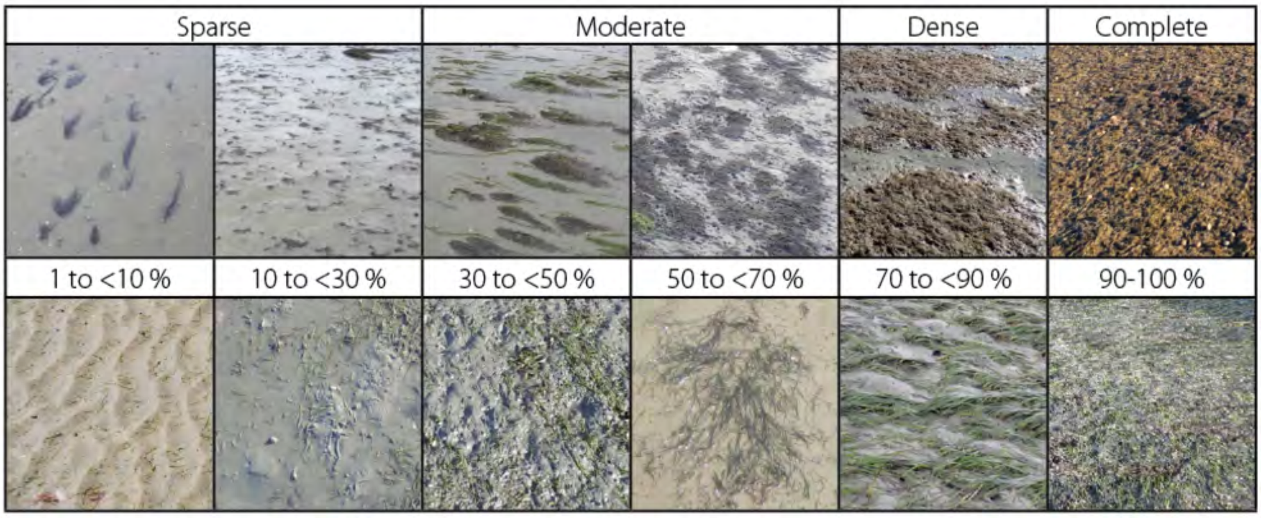


Fig. 3. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

cover >50%), and historical estimates made from aerial photographs become difficult to clearly distinguish when cover is <50%.

2.6 SALT MARSH ASSESSMENT

NEMP methods (Appendix 2) were used to map and categorise salt marsh, with two measures used to assess salt marsh condition: i) intertidal extent (percent cover) and ii) current extent compared to estimated historical extent.

2.7 TERRESTRIAL MARGIN ASSESSMENT

Broad-scale NEMP methods were used to map the 200m terrestrial margin using the dominant land cover classification codes described in the Landcare Research Land Cover Data Base (LCDB) detailed in Appendix 1.

2.8 DATA RECORDING, QA/QC AND ANALYSIS

Broad scale mapping is intended to provide a rapid overview of estuary condition based on the mapping of features visible on aerial photographs. The ability to correctly identify and map features is primarily determined by the resolution of available photos, the extent of ground truthing undertaken to validate features visible on photos, and the experience of those undertaking the mapping. 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 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse seagrass beds, or where there is a transition between features that appear visually similar, e.g. sand, muddy sand, mud. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground truthed, but accuracy is unlikely to be better than ±20-50m for such features when relying on photos alone.

In 2019, field maps with ground truthing notes were scanned and imported into ArcMAP 10.6, and were used with georeferenced field photos for digitising habitat features. Following digitising, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables. Using these same tools, the 2004 (Cawthron) and 2013 (Wriggle) GIS layers were similarly checked for any errors in basic geometry (e.g. overlapping polygons), and updated to fix any identified issues. Where discrepancies were identified between GIS data and hard copy reports, the underpinning GIS data were reanalysed to produce revised summary statistics.

Further, the 2004 and 2013 substrate types were updated to reflect the revised classifications presented in Table 3. The original classification codes have been retained in the GIS attribute tables with any changes shown alongside. In addition, detailed metadata describing data sources and any changes made have been provided with each GIS layer produced and supplied to TDC.

During the field ground truthing, sediment grain size and macroalgal data were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP. Macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template.

2.9 ASSESSMENT OF ESTUARY CONDITION AND TEMPORAL CHANGE

Broad-scale results are used primarily to assess estuary condition in response to common stressors such as fine sediment inputs, nutrient enrichment or habitat loss. In addition to the authors' interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from NZ and overseas (Table 4). These metrics assign different indicators to one of four colour coded 'health status' bands, as shown in Table 4. The condition ratings are primarily sourced from the NZ ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 5. As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HEC) was evaluated. HECs are defined as having sediments with elevated organic content (>1% TOC) and/or dense macroalgal cover (>50%), combined with an elevated mud content (≥25% mud) and low sediment oxygenation (aRPD <10mm). HECs are also referred to alternatively as 'Gross Eutrophic Zones' (GEZs) in the ETI (Zeldis et al. 2017).

In addition to the Table 4 indicators, the percent change from the first measured baseline is used to qualitatively describe broad changes in estuary condition over time. It is assumed that increases in high value habitat such as seagrass, salt marsh, and a densely vegetated terrestrial margin are desirable, and decreases are undesirable. The converse is true for the establishment of degraded conditions, e.g. spatial extent of sediment with elevated mud contents or HECs.

As many of the scoring categories in Table 4 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Table 4. Indicators used to assess results in the current report.

Indicator	Unit	Very Good	Good	Fair	Poor
Broad scale indicators					
Mud extent[1]	% of estuary	< 1	1-5	> 5-15	> 15
Macroalgae (OMBT)[1]	EQR	≥ 0.8 - 1.0	≥ 0.6 - < 0.8	≥ 0.4 - < 0.6	0.0 - < 0.4
Seagrass[2]	% decrease from baseline	< 5	≥ 5-10	≥ 10-20	≥ 20
Salt marsh extent[2]	% of intertidal area	≥ 20	≥ 10-20	≥ 5-10	0-5
Salt marsh loss[2]	% of historical remaining	≥ 80-100	≥ 60-80	≥ 40-60	< 40
200m terrestrial margin[2]	% densely vegetated	≥ 80-100	≥ 50-80	≥ 25-50	< 25
HECs[1]	ha	< 0.5ha or	≥ 0.5-5ha or	≥ 5-20ha or	≥ 20ha or
HECs[1]	% of estuary	< 1%	≥ 1-5%	≥ 5-10%	≥ 10%
NZ ETI[1]	ETI score	0-0.25	>0.25-0.5	>0.5-0.75	>0.75-1.0
Sediment Quality					
Mud content[1]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to < 20	< 10

[1] *General indicator thresholds derived from a New Zealand Estuary Tropic Index, with adjustments for aRPD. See text and Appendix 5 for further explanation of the origin or derivation of the different metrics.*

[2] *Subjective indicator thresholds derived from previous broad scale mapping assessments.*

3. RESULTS AND DISCUSSION

The 2019 broad scale results are summarised in the following sections, with the supporting GIS files (supplied as a separate electronic output) providing a more detailed data set designed for easy interrogation and to address specific monitoring and management questions.

3.1 INTERTIDAL SUBSTRATE

Table 5 and Fig. 4 show intertidal substrate was relatively heterogeneous in 2019, but dominated by sandy sediments (416ha, 58.4%) located predominantly throughout the central parts of the estuary near the two entrances. Sandy sediments were generally firm, with a mud content <25%.

Table 5. Summary of dominant intertidal substrate, Moutere Inlet 2019.

Class	Dominant Substrate	Ha	%
Artificial	Artificial substrate	0.7	0.1
Boulder/ Cobble/ Gravel	Boulder field	3.3	0.5
	Cobble field	6.4	0.9
	Gravel field	56.1	7.9
Sand	Firm sand (0-10% mud)	173.4	24.3
	Firm shell/sand (0-10% mud)	1.6	0.2
	Mobile sand (0-10% mud)	15.2	2.1
	Soft sand (0-10% mud)	1.3	0.2
Muddy Sand	Firm muddy sand (>10-25% mud)	149.0	20.9
	Firm muddy sand (>25-50% mud)	19.5	2.7
	Mobile muddy sand (>10-25% mud)	0.3	0.05
	Mobile muddy sand (>25-50% mud)	1.6	0.2
	Soft muddy sand (>10-25% mud)	27.6	3.9
	Soft muddy sand (>25-50% mud)	27.9	3.9
Sandy Mud	Firm sandy mud (>50-90% mud)	0.2	0.03
	Soft sandy mud (>50-90% mud)	45.5	6.4
	Very soft sandy mud (>50-90% mud)	155.0	21.7
Mud	Firm mud (>90% mud)	20.5	2.9
Zootic	Cocklebed	4.7	0.7
	Oyster reef	0.1	0.02
	Sabellid field	0.7	0.1
	Shell bank	2.5	0.3
Grand Total		**713.1**	**100.0**

Hard substrates (e.g. boulder, cobble and gravel) comprised 65.8ha (9.3%) and were most common near the estuary entrances. The highly flushed channel margins were dominated by gravel beds (56ha, 7.9%) with small pockets of cockle beds (0.7%), sabellid tube worm reefs (0.1%) and oyster reefs (0.02%). Artificial substrate (0.1%) comprised predominantly steep-faced rock and earth margins reclaimed for transport infrastructure (e.g. SH60, Wharf Road, Kina Beach Road).

Mud-dominated habitat (sediment with >50% mud content) comprised 222ha (31%) of the intertidal area of which 28% was classed as soft or very soft and 3% as firm. Mud-dominated sediment was concentrated in the upper tidal reaches of the northwest and southeast parts of the estuary, in natural settlement areas in the central basin, and along the edges of low tide flow channels and within flow-restricted embayments. During sampling in 2019 a significant amount of scouring of soft sandy mud was evident (see photo below).

Scouring of mud in the central basin

The previously uniform estuary surface had become uneven due to variable sediment erosion, with large numbers of crab holes present. While not quantifiable by broad scale mapping, it appears that there has been a widespread reduction in the volume of this type of sediment in the estuary. Despite the apparent reduction in sediment volume there has not been a significant reduction in the spatial extent of mud dominated sediments as the footprint of these areas remain largely unchanged. The reduction since 2013 has been (22ha, 9%), but remains higher than the extent reanalysed for 2004 (199ha).

In some parts of the central basin, the erosion observed has occurred in areas that previously supported extensive nuisance macroalgae beds. Dense macroalgal beds (primarily *Gracilaria*) trap and stabilise muds and can contribute to the rapid accretion of fine sediment. The recent die back of some macroalgal beds may be allowing previously stabilised sediments to more readily erode.

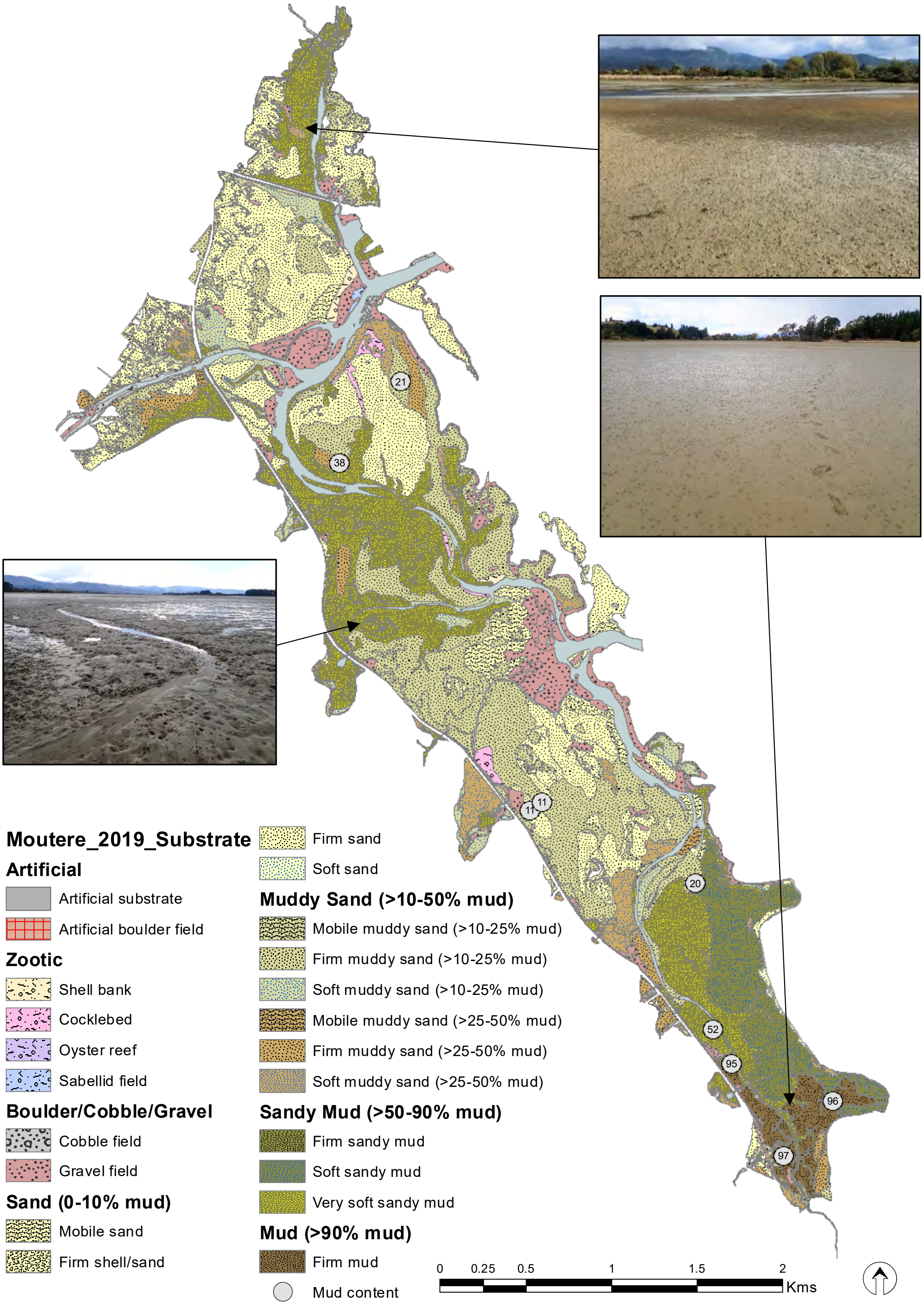


Fig. 4. Map of dominant intertidal substrate types, and sediment mud content measured at nine locations, Moutere Inlet May 2019.

The specific drivers of the fine sediment erosion and macroalgal die-back are unknown but may reflect a combination of flood events during February 2018 (Cyclones Gita and Fehi), or the progressive degradation of sediment conditions within macroalgal beds. At an extreme state of trophic enrichment sediments can become so enriched with toxic sulphides that they are no longer able to support macroalgae growth.

Substrates within vegetated areas were variable. Among herbfields the substrate predominantly consisted of cobble and gravel, while among rushland it was dominated by sandy mud or muddy sand. Within seagrass beds, sand-dominated substrates were present (Section 3.5), whereas within areas of dense macroalgae the most common substrates were soft mud-dominated sediments, particularly in flow restricted areas, e.g. north of Wharf Road.

3.2 FINE SEDIMENT ASSESSMENT

3.2.1 Sediment grain size

Grain size was measured within sand and mud dominated sediments representative of the classes used to characterise the wider estuary. Firm muds near the upper tidal level in the southeast had very high mud contents (94-97%) and were silken when rubbed between the fingers. This type of sediment contains virtually no interstitial space (gaps) among the sediment particles and tends to bake hard over the summer, but becomes soft and slippery at other times of the year. Sandy muds (50-90% mud) were also widespread in the southeast of the estuary and within the constricted embayments north of Wharf Road, along SH60, and in the upper tidal range between the estuary entrances (Fig. 4). Further seaward, mud content decreased to ~20-50% among muddy sands, and dropped to 10-11% in the sand-dominated flats common near both estuary entrances (Fig. 4, Appendix 2). The relatively low incidence of muds around the estuary entrances likely reflects strong tidal flushing, which limits settlement and facilitates the export of fine sediments to Tasman Bay.

Overall, the substrate classifications applied by scientists during field mapping had a relatively high degree of consistency with the sediment grain size results from laboratory analysis (Appendix 2).

3.2.2 Sediment oxygenation

Field assessment found sand, shell and gravel sediments to be generally well oxygenated with the average aRPD depth between ~10-25mm, and often >50mm. This situation appears to be maintained largely as a consequence of open interstitial spaces within the coarse sediment matrix allowing for the free exchange of oxygen from either the atmosphere or from seawater. Other well oxygenated areas included sediments containing cockles, which are very effective bioturbators of sediment and facilitate good oxygen exchange with underlying sediments, and among seagrass beds due to oxygenation through the root systems.

Areas exhibiting the most reduced sediment oxygenation (aRPD depth ~5 to 10mm) were generally located in sediments containing a high mud content (see Fig. 4). Strongly anoxic conditions associated with the breakdown of organic material were only observed in areas with persistent macroalgal growths, most commonly in flow-restricted embayments (e.g. North and Robinsons Road embayments), but also in the central basin of the estuary between the entrances.

Previous fine scale surveys have shown that ecological communities living in muddy oxygen-depleted sediments support a relatively limited number of mud tolerant species and increases in muddiness and organic enrichment contribute to declines in macro-invertebrate abundance and species richness.

3.2.3 Sediment deposition

Results of sediment plate monitoring undertaken by TDC (Fig. 5) show that net rates of measured sediment accumulation were well below the DGV of 2mm/yr proposed by Townsend and Lohrer (2015). While this result is a positive sign, it is noted that significant deposition zones in the central basin were not included in the sediment plate monitoring programme prior to 2013 and thus actual inputs will be underestimated. Since 2013, raw data (not presented) reveal a relatively significant deposition event (~5.7mm) in the central basin between Feb and Aug 2015, followed by subsequent erosion.

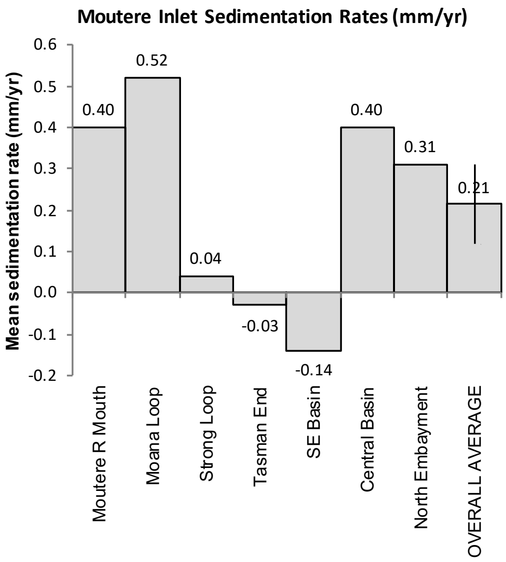


Fig. 5. Summary of sediment deposition rates, Moutere Inlet 2008-2018 (data supplied by TDC).

This change, and similar episodic inputs at other times, have been captured to some extent by the broad scale mapping undertaken in 2004, 2013 and 2019.

Although the sources of fine sediments are not easy to determine with any certainty from the available data, Stevens and Robertson (2013) suggested one likely source was soil loss from the 2007-2008 conversion of forestry to rural-residential land use in catchments draining to the west of the estuary. More recent support for this suggestion is provided by Gibbs and Woodward (2018) who undertook compound specific stable isotope (CSSI) source tracking of sediment. They found almost 90% of the sediment at the Moutere River mouth was of pine forest origin, with the main sources of fine sediment below the Moutere/Gardner Valley confluence reflecting recently harvested pine forest. Although other sources undoubtably contribute sediment to the estuary and coast, the attribution of ~90% of the sediment inputs to a land use activity comprising just 22% of the catchment (Table 1) indicates forestry can at times be a disproportionately high source of catchment sediment entering the system.

3.3 OPPORTUNISTIC MACROALGAE

Table 6 and Fig. 6 summarise macroalgal condition within Moutere Inlet, with further detail on the location of mapped macroalgal patches and measured algal densities presented in Appendix 4b. In May 2019 the opportunistic macroalgal EQR was 0.53 which equates to a rating of 'fair' according to the Table 4 categories.

The majority of the tidal flats had no significant macroalgae growth, likely to be a consequence of being perched high in the tidal range and subjected to long periods of exposure where desiccation is likely to limit macroalgal survival.

Sea lettuce (*Ulva* spp.), a common estuary green alga that often blooms seasonally (i.e. Oct-Apr) was growing along channel edges in low densities and was also regularly found as a subdominant species among (or on) *Gracilaria*.

Dense macroalgal growths were relatively localised in extent within the northern and central estuary (Fig. 6). Macroalgae was dominated by the red alga, *Gracilaria chilensis*, commonly found in soft and poorly oxygenated muds.

Gracilaria itself was relatively localised in its extent, with beds in the central basin, within the Wharf Road embayment and in many of the smaller embayments on the west of the estuary. However, where present it was often at a cover and biomass likely to cause adverse ecological effects due to underlying sediment anoxia.

Extensive *Gracilaria* beds in the Wharf Road embayment

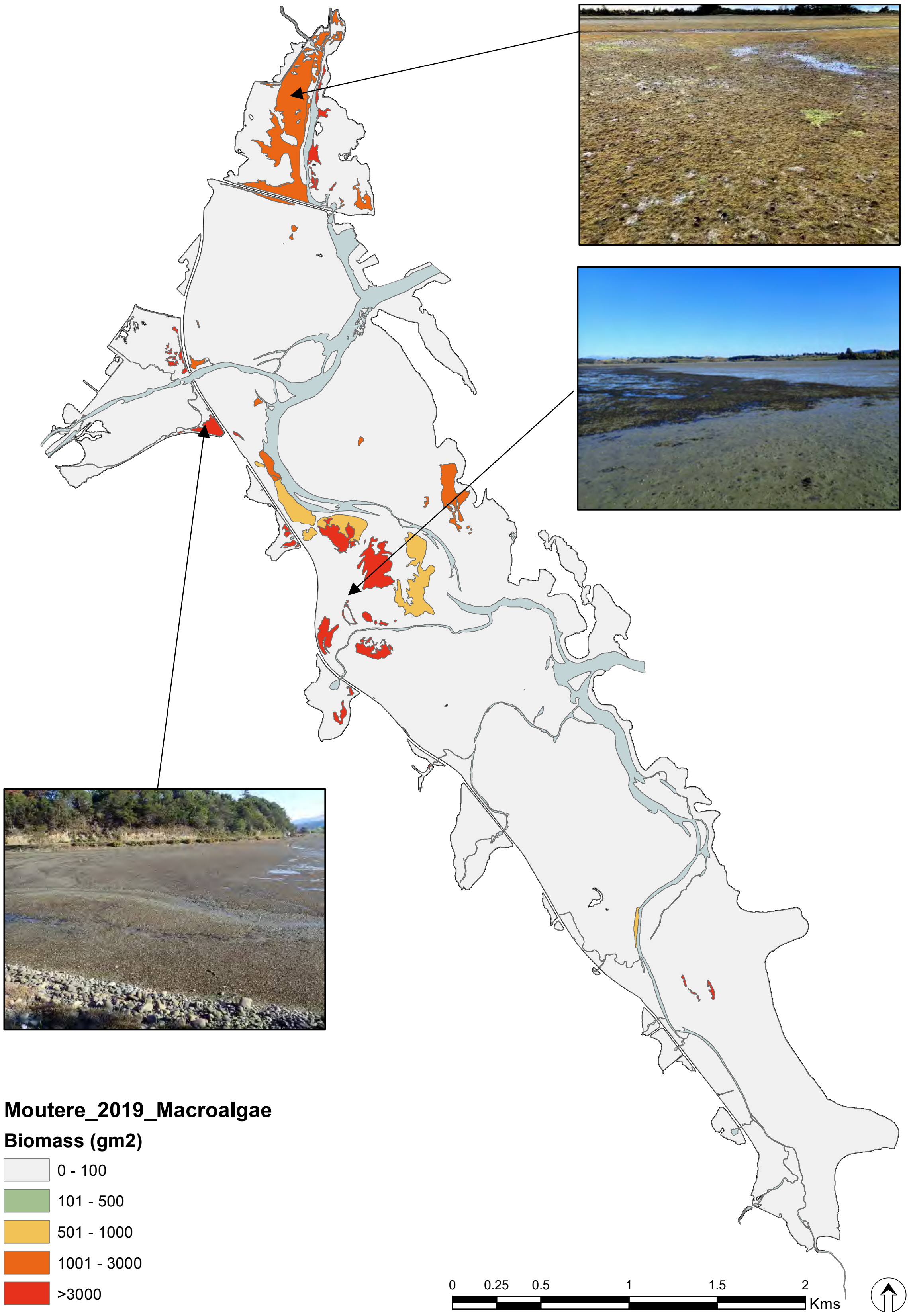


Fig. 6. Map of intertidal macroalgal biomass (g/m^2 wet weight), Moutere Inlet May 2019.

Table 6. Summary of OMBT input metrics and calculation of overall macroalgal ecological quality rating, Moutere Inlet, May 2019.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat	713.3		
Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 *where Total % cover = Sum of {(patch size)/100} x average % cover for patch*	4.4	0.824	High
Biomass per AIH (g.m-2) = Total Biomass/AIH *where Total biomass = Sum of (patch size x average patch biomass)*	161	0.769	Good
Biomass of Affected Area (g.m-2) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	2436	0.256	Poor
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	96.7	0.013	Bad
Affected Area (use the lowest of the following two metrics)		0.768	Good
Affected Area, AA (ha) = Sum of all patch sizes (macroalgal cover >5%)	42.2	1.000	Good
Size of AA in relation to AIH (%) = (AA / AIH) x 100	6.6	0.768	Good
Overall Macroalgal Ecological Quality Rating - EQR (Average of FEDS)		0.53	Moderate

Compared to 2013, there has been a 48ha (61%) decrease in dense macroalgae cover. The largest decrease has been in the central basin. In this area sediment conditions appear to have been degraded (i.e. become anoxic) by macroalgal decay to a point where remaining macroalgae can no longer survive. Local flood events during early 2018 (Cyclones Gita and Fehi) may also have directly scoured macroalgae or aided in flushing already decaying macroalgae out of the estuary.

Despite a mean overall decrease in macroalgal cover, there has also been an expansion in some areas, in particular large stable nuisance algal beds in the Wharf Road embayment and the Robinson Road embayment adjacent to SH60 (Fig. 6). The expansion of macroalgal growth in these areas coincides with the presence of soft, poorly oxygenated muds, likely exacerbated by restricted tidal flushing, which results in increased sediment deposition and the retention of sediment bound nutrients.

Ulva growing along the channel edge

Gracilaria entrained in anoxic, soft, mud dominated sediment

3.4 HIGH ENRICHMENT CONDITIONS

The area of Moutere Inlet where persistent High Enrichment Conditions (HECs) have established was significant (31ha, 4.1%), and rated as 'poor' using the criteria in Table 4. Unsurprisingly, Fig. 7 shows that in 2019 these areas were in locations with high biomass macroalgal growths (Fig. 6). These parts of the estuary are highly enriched with consistently poor sediment quality comprising low oxygenation, high organic contents, and sulphide-rich sediments.

Fig. 7 and Table 7 show that there have been some significant increases in this type of habitat over time, although note that estimates presented in Fig. 7 and Table 7 for 1947 and 2004 (sourced from Stevens & Robertson 2013) were based on the assumption that dense macroalgal beds evident on aerial photos would have underlying HECs This is likely to over-estimate the historical extent of HECs. In 2013, HECs were directly mapped and showed a large apparent increase in extent from 2004, although some of this apparent increase may be the result of more detailed mapping and ground truthing. Between 2013 and 2019, there has been a significant reduction in the extent of HEC areas (most evident in the central basin), associated with the decreased macroalgal cover discussed in the previous section. Compared to the assumed historic extent in 1947, the HEC area in 2019 remains high. This result is of genuine concern given that, outside of very localised patches, HECs should not be present in well flushed estuaries like Moutere Inlet.

Table 7. Summary of HEC extent, Moutere Inlet 1947-2019.

Year	Ha	%
1947	1	0.2
2004	37	6
2013	60	9
2019	31	4.3

High enrichment conditions in the central basin of the estuary - dense *Gracilaria* growing in poorly oxygenated soft muds

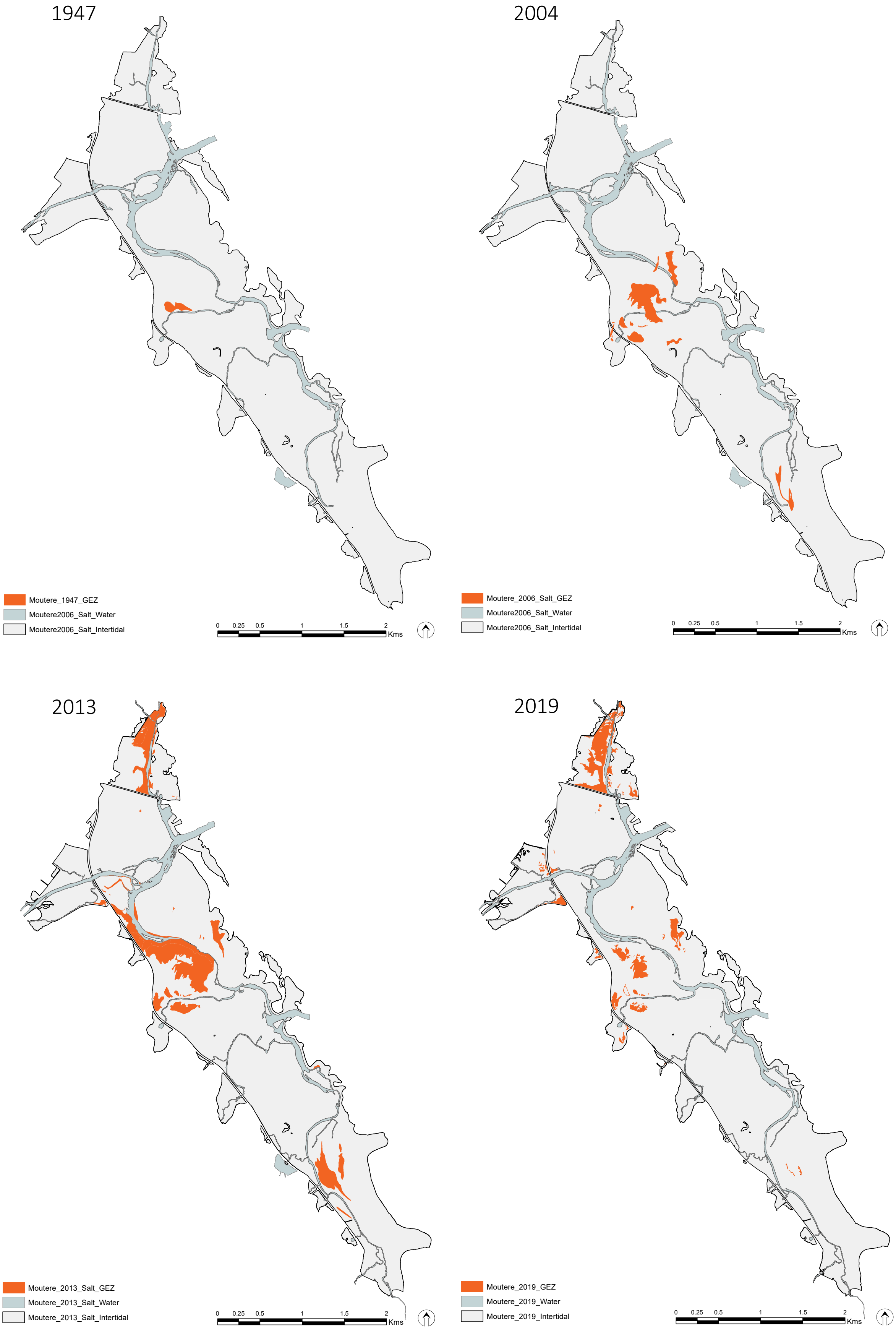


Fig. 7. Areas of High Enrichment Conditions (HECs), Moutere Inlet 1947-2019.

3.5 SEAGRASS

Fig. 8 shows small intertidal seagrass beds in 2019, which were located low in the tidal range, primarily near channels by the Kina entrance, with the majority (3.1ha) present as dense (70-90%) cover (Table 8). The current location of seagrass appears restricted to the eastern arm of the central basin, specifically well flushed lower channels which are dominated by sandy sediments with a relatively low mud content (i.e. <25%). Where present, seagrass beds appeared in a healthy and luxuriant condition.

Table 8. Summary seagrass percent cover by area, Moutere Inlet 2019

Seagrass Class	PctCover	Ha
>30-70% Moderate	50	0.02
>70-90% Dense	80	3.1
Grand Total		3.12

Seagrass appears unable to establish on the perched intertidal flats of the estuary, most likely due to a combination of desiccation (long periods of exposure between tides), excessive muddiness, and poor water clarity.

Clark and Gillespie (2007) report no seagrass in the estuary in 1947, 0.2ha in 1988, and 0.9ha in 2004. However, it is noted that seagrass beds are evident in the 1947 aerial photos in many of the same locations they are currently found in, despite not being identified by Clark and Gillespie (2007). Hence, these beds appear to have remained in the estuary despite major modifications since 1947 (e.g. salt marsh clearance and transport infrastructure development). Historically, because the estuary had already been significantly modified by 1947, seagrass beds are likely to have been far more extensive prior to that time (Stevens & Robertson 2013).

The 2004 survey (Clark et al. 2006) was comprehensively ground truthed and therefore provides the most accurate available baseline against which to make comparisons of more recent changes. In this context, the change from 0.9ha in 2004 to 3.12ha in 2019 represents more than a 3-fold increase in seagrass. While this receives an indicator rating of 'very good' against the criteria in Table 4, it is nonetheless a small overall area relative to the size of the estuary. Although similar in percent cover to other estuaries in the region, (e.g. Waimea, Motupipi, Ruataniwha and Motueka), it is significantly less than the similarly sized, but less muddy, Nelson Haven (135Ha, 15%). In the absence of any comprehensive rating of seagrass extent within NZ estuaries, change from a documented baseline, in this case revised data for 2004, represents the most reliable method for ongoing monitoring of seagrass extent.

Seagrass beds in the central basin of the estuary

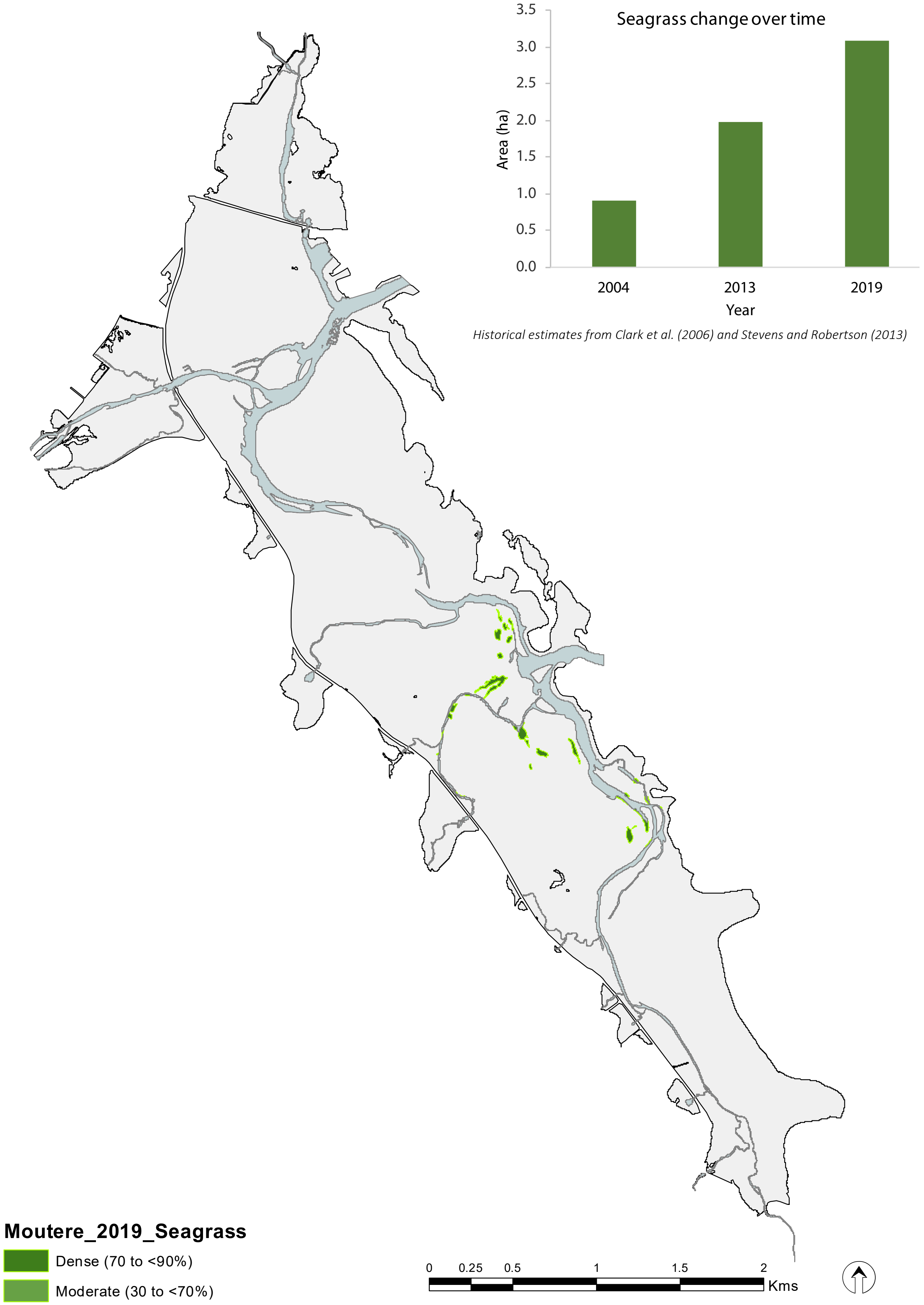


Fig. 8. Map of seagrass percent cover, Moutere Inlet May 2019, with inset chart showing previously mapped seagrass cover >50%.

3.6 SALT MARSH

Table 9 and Fig. 9 summarise the 2019 salt marsh mapping results. The area of remaining salt marsh within the intertidal area (82.9ha, 10.8%) represents a moderate cover. The most extensive salt marsh areas were located in the northwest and southern regions. The western embayments landward and adjacent to SH60 also support pockets of salt marsh. However, the presence of steep seawalls along the margins of most of these areas means there is very little capacity for salt marsh to expand in response to predicted sea level rise. Salt marsh migration in the north of the estuary is similarly impeded due to the urban development around Motueka and Port Motueka.

The dominant cover of salt marsh was rushland (55%), predominantly found in the upper intertidal reaches in the northwest and south of the estuary, and herbfield (40%), which was located throughout the estuary but was most extensive in the north.

Rushland and herbfield in the northwest estuary

Salt marsh species composition on the exposed tidal flats was dominated by low growing salt and desiccation-tolerant herbfield species, namely glasswort (*Sarcocornia quinqueflora*) and sea blite (*Suaeda novaezelandiae*). These species were present in both sand-dominated and gravel substrates, but not common in mud-dominated substrates.

Coastal rushland was dominated by searush (*Juncus kraussii*) with smaller areas of jointed wirerush (*Apodasmia similis*). A localised area of sedgeland (three square, *Schoenoplectus pungens*), was present adjacent to SH60 in the northwest.

Extensive glasswort herbfield in the north of the estuary

At the top of the tidal range in sand and gravel substrates were small pockets of shore tussock (*Stipa stipoides*). Salt marsh ribbonwood (*Plagianthus divaricatus*) was the dominant estuarine shrub, often forming a narrow boundary to the upper estuary margins.

Compared to the historical extent of salt marsh in the estuary, there has been an estimated reduction of ~45% since 1947 (Fig. 9 inset). The vast majority of these losses occurred prior to 1988 as a result of salt marsh reclamation and margin development, in particular the development of the SH60 coastal highway and associated causeways which now divide the western margin from the main estuary.

Little change in salt marsh was evident from 2013 to 2019, and cover has remained consistent over the past decade (Fig. 9 inset). A small increase from 2004 to 2013 was largely attributable to salt marsh planting undertaken as offset mitigation following the NZTA realignment of the coastal highway SH60 (Robertson & Stevens 2013). These plantings are now well established and likely to further develop over time. However, localised losses continue through reclamation and roading modifications (e.g. sea walls on Kina Beach Road), and from the impact of vehicles crossing the estuary to Jackett Island (see photos following). The latter impacts are relatively easily managed through education targeted at those using vehicles and a rationalisation of the existing routes.

Vehicle tracks through salt marsh adjacent to SH60 (left) and salt marsh loss from seawalls constructed along Kina Road (right)

Table 9. Summary of dominant salt marsh cover, Moutere Inlet 2019

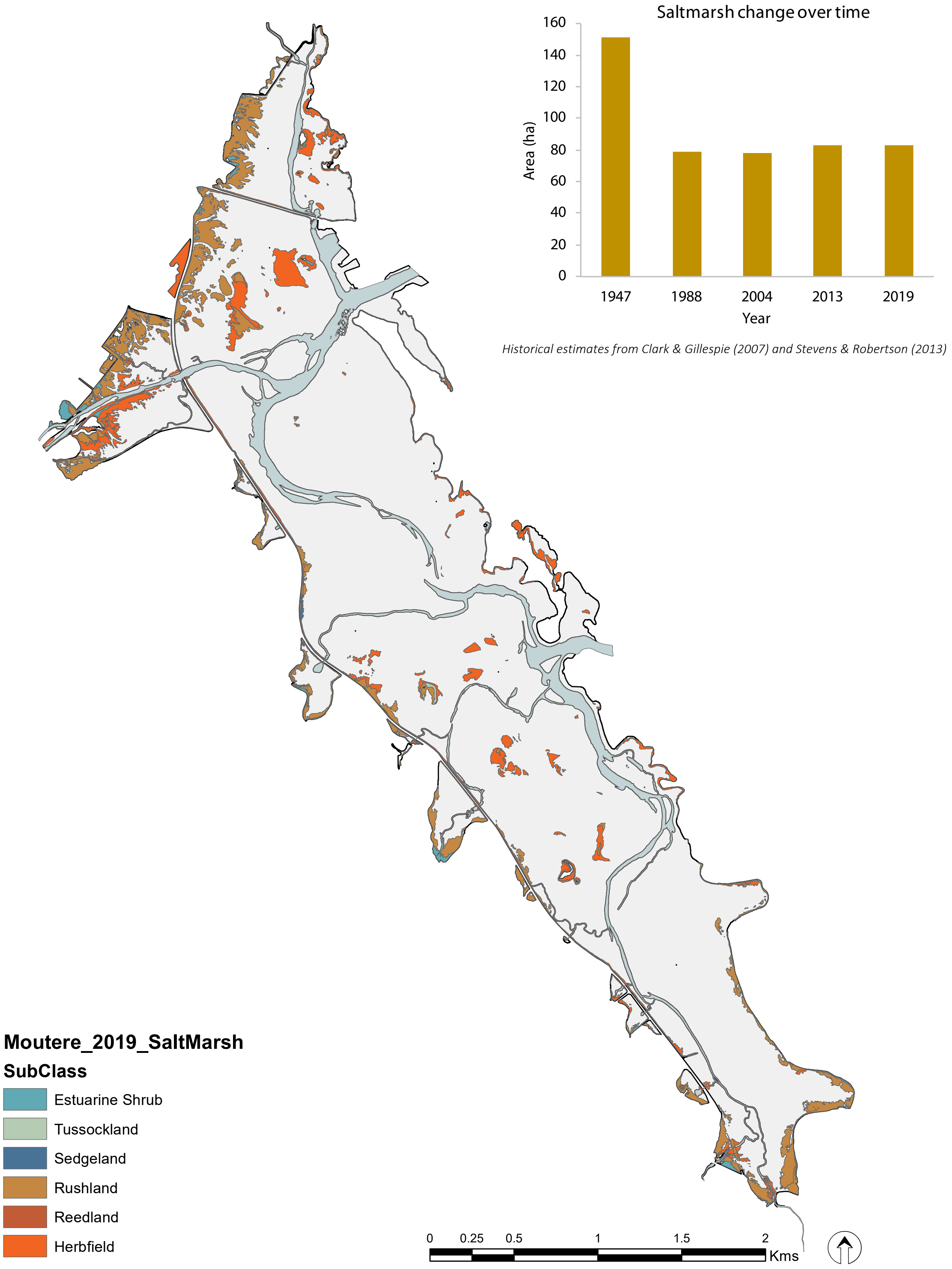
Class, dominant and subdominant species	Ha	%
Estuarine Shrub	3.4	4.1
Plagianthus divaricatus (Salt marsh ribbonwood)	0.4	
Festuca arundinacea (Tall fescue)	1.0	
Ficinia (Isolepis) nodosa (Knobby clubrush)	0.2	
Juncus kraussii (Searush)	1.8	
Stipa stipoides	0.1	
Tussockland	0.3	0.4
Stipa stipoides		
Juncus kraussii (Searush)	0.3	
Sedgeland	0.6	0.7
Schoenoplectus pungens (Three square)	0.6	
Rushland	45.6	55.0
Apodasmia similis (Jointed wirerush)	0.2	
Juncus kraussii (Searush)	0.3	
Samolus repens (Primrose)	0.01	
Ficinia (Isolepis) nodosa (Knobby clubrush)		
Juncus kraussii (Searush)	0.04	
Juncus kraussii (Searush)	13.5	
Apodasmia similis (Jointed wirerush)	5.2	
Festuca arundinacea (Tall fescue)	0.04	
Ficinia (Isolepis) nodosa (Knobby clubrush)	0.5	
Plagianthus divaricatus (Salt marsh ribbonwood)	0.9	
Poa astonii (Blue shore tussock)	0.1	
Sarcocornia quinqueflora (Glasswort)	23.2	
Selliera radicans (Remuremu)	0.1	
Stipa stipoides	1.4	
Herbfield	33.1	39.9
Samolus repens (Primrose)		
Plagianthus divaricatus (Salt marsh ribbonwood)	0.01	
Selliera radicans (Remuremu)	0.00	
Sarcocornia quinqueflora (Glasswort)	14.0	
Carpobrotus edulis (Ice Plant)	0.6	
Festuca arundinacea (Tall fescue)	0.2	
Juncus kraussii (Searush)	4.2	
Plagianthus divaricatus (Salt marsh ribbonwood)	0.01	
Samolus repens (Primrose)	1.2	
Selliera radicans (Remuremu)	0.2	
Stipa stipoides	0.3	
Suaeda novaezelandiae (Sea blite)	12.3	
Selliera radicans (Remuremu)		
Sarcocornia quinqueflora (Glasswort)	0.03	
Suaeda novaezelandiae (Sea blite)	0.1	
Grand Total	82.9	100.0

Salt marsh ribbonwood

Three square

Jointed wire rush

Glasswort



Historical estimates from Clark & Gillespie (2007) and Stevens & Robertson (2013)

Fig. 9. Map of salt marsh extent, Moutere Inlet 2019, with inset chart showing estimated historical salt marsh extent.

3.7 TERRESTRIAL MARGIN

The results of the 200m terrestrial margin mapping are presented in Table 10 and Fig. 10.

Table 10. Summary of 200m terrestrial margin land cover, Moutere Inlet May 2019.

LCDB Class Number and Name		%
1	Built-up Area (settlement)	21.7
2	Urban Parkland/Open Space	5.6
5	Transport Infrastructure	5.1
10	Sand and Gravel	1.1
20	Lake or Pond	1.1
21	River	0.1
33	Orchard Vineyard and Other Perennial Crops	19.5
40	High Producing Exotic Grassland	1.1
41	Low Producing Grassland	27.5
44	Depleted Grassland	0.9
45	Herbaceous Freshwater Vegetation	0.1
46	Herbaceous Saline Vegetation	0.7
47	Flaxland	0.02
51	Gorse and/or Broom	0.4
52	Manuka and/or Kanuka	1.2
54	Broadleaved Indigenous Hardwoods	0.0
56	Mixed Exotic Shrubland	10.4
64	Forest Harvested	0.0
68	Deciduous Hardwoods	0.2
69	Indigenous Forest	2.0
71	Exotic Forest	1.2
Grand Total		100
Total dense vegetated margin (LCDB classes 45-71)		16.2

The majority of the margin has been highly modified by residential/industrial development (21.7%), pasture (28.6%) and horticulture (19.5%). Only 16.2% of the Moutere Inlet was densely vegetated and this was predominantly located on Jackett Island and Kina Peninsula.

The shrub and scrubland vegetative buffering capacity on land surrounding the estuary, and associated habitat diversity, has been significantly reduced as a consequence of extensive historical drainage of wetland and salt marsh areas, which is ongoing in some areas.

The presence of roads, seawalls and shoreline armouring (e.g. SH60, Wharf Road, Kina Beach Road) further reduces the natural connectivity between the land and sea in most places and greatly restricts opportunities for the natural migration of estuarine plant species in response to predicted sea level rise.

A small area of restorative plantings was present within the urban parkland in the northern estuary; and while valuable, this reflects a small contribution overall to improving the vegetative terrestrial buffer.

Similarly, planting associated with the realignment of SH60 in the south is valuable but has not significantly increased the extent of dense terrestrial vegetative margin cover.

Restoration plantings in the northern arm

Channelised and grassed estuary margins

Eroding and unvegetated road margin

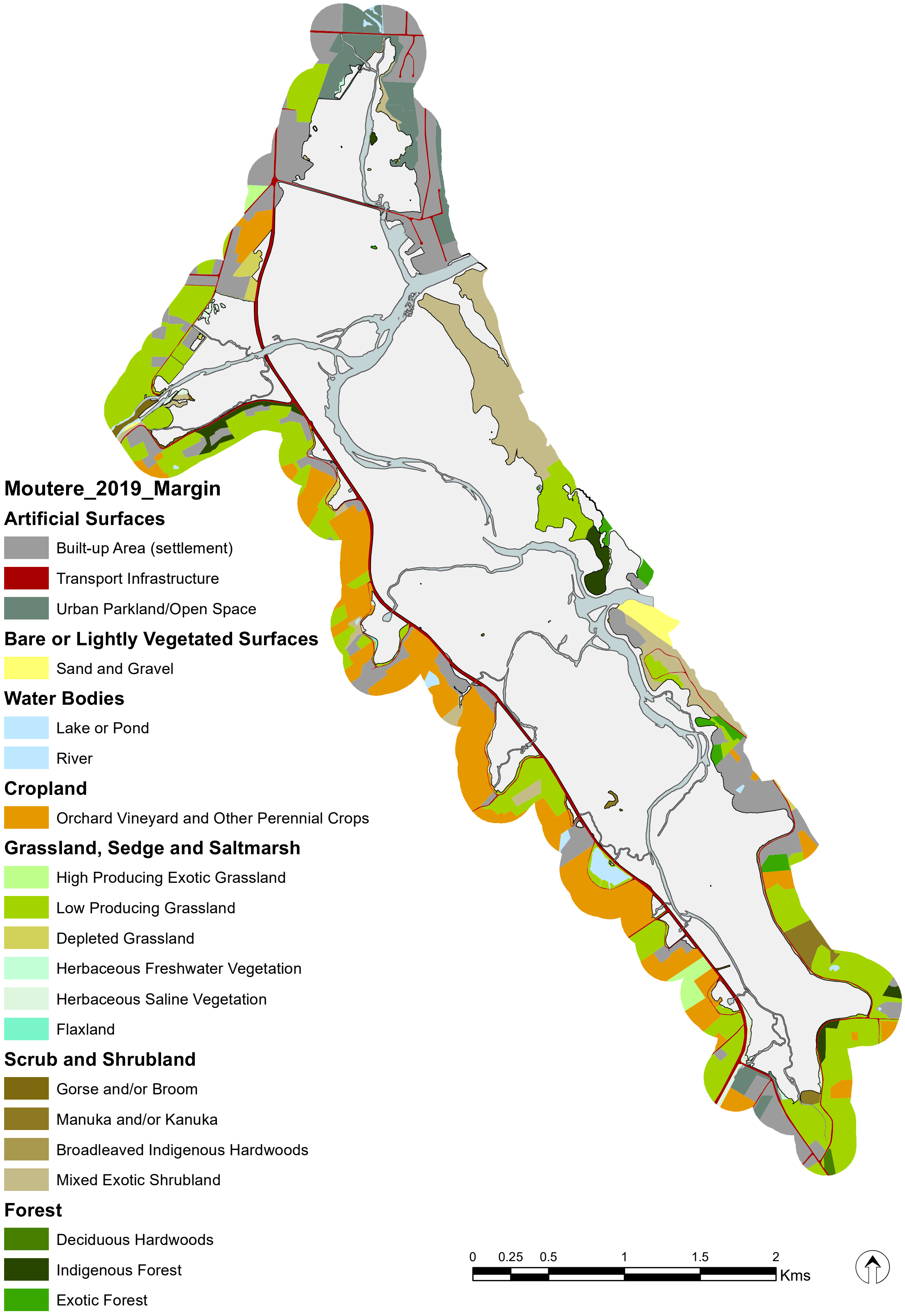


Fig. 10. Map of 200m terrestrial margin land cover, Moutere Inlet 2019.

4. SYNTHESIS AND RECOMMENDATIONS

4.1 SYNTHESIS OF KEY FINDINGS

The dominant features assessed as part of broad scale habitat mapping of Moutere Inlet undertaken in May 2019 are summarised in Table 11. Key broad scale indicator results and ratings are presented in Table 12 and additional supporting data used to assess estuary condition are presented in Table 13.

Table 11. Summary of dominant broadscale features, Moutere Inlet May 2019.

a. Area Summary	ha	%
Intertidal area	713.3	93.3
Subtidal area	51.1	6.7
Total estuary area	**764**	**100**

b. Key intertidal features	ha	%*
Salt marsh	82.9	11.6
Seagrass (>50% cover)	3.1	0.4
Macroalgal beds (>50% cover)	30.6	4.3
Mud-dominated sediment (%)	222.3	31.2

*% of 713.3ha of intertidal area

c. 200m Densely vegetated margin	80.5	16.2

Table 13. Supporting data used to assess estuary ecological condition.

Supporting Condition Measure	
[1] Mean freshwater flow (m^3/s)	2.2
[1] Catchment Area (Ha)	18622
[2] Catchment nitrogen load (TN/yr)	156.1
[2] Catchment phosphorus load (TP/yr)	9.6
[1] Catchment sediment load (KT/yr)	10.6
[2] Estimated N areal load in estuary ($mg/m^2/d$)	56
[2] Estimated P areal load in estuary ($mg/m^2/d$)	3
[1] CSR:NSR ratio	1.6
CSR/NSR ratio with 50% natural wetland attenuation	3.3
[1] Trap efficiency (sediment retained in estuary)	96%
[1] Estimated rate of sed. trapped in estuary (mm/yr)	0.9

[1] Hicks et al. 2019

[2] CLUES version 10.3, Run date: April 2020

With regard to preliminary criteria for assessing estuary health, extensive muddiness, the presence of HECs, and the extent of densely vegetated terrestrial margin were all rated 'poor' (Table 12).

The extent of mud dominated substrates is the most significant current issue present in Moutere Inlet, in part as most of the sediment entering the estuary (96%) is predicted to be trapped and retained within it (Table 13, Hicks et al. 2019). Most mud is located in the central basin and to the southeast and, to a lesser degree, in the sheltered embayments on the western side of the estuary and north of Wharf Road – ideal settling areas for fine sediment.

The spatial extent of mud is high in both a regional

Table 12. Summary of key broadscale indicator results and ratings.

Broad scale indicators	Unit	Value	2019 Rating	Change since 2013
Mud extent	% of estuary	29	Poor	Small ↓, 22ha, 9%
Macroalgae (OMBT)	Ecological Quality Rating	0.53	Fair	Moderate ↓*
Seagrass	% decrease from baseline	0	Very Good	Large ↑, 1.1ha**
Salt marsh extent	% of intertidal area	10.8	Good	No change
Salt marsh loss	% of historical remaining	55	Fair	No change
200m terrestrial margin	% densely vegetated	8.3	Poor	Slight ↓**
High Enrichment Conditions	ha	31	Poor	Large ↓, 29ha
High Enrichment Conditions	% of estuary	4.3%	Good	Large ↓, 48%
NZ Estuary Trophic Index	ETI score	0.69	Fair	Slight ↓ (improvement)

OMBT=Opportunistic Macroalgal Blooming Tool. *Estimated change based on reduction in dense macroalgal cover

**Primarily reflects differences in mapping coverage or classification rather than meaningful change

Very Good	Good	Fair	Poor

and national context (Fig. 11) although there appears to have been a recent reduction in mud extent (22ha, 9%) since 2013, and an obvious decrease of the sediment volume in certain parts of the estuary, most particularly the central basin. The very high mud content of these sediments contributes to reduced sediment oxygenation, which will limit sediment macrofauna to a relatively low diversity community dominated by mud-tolerant species.

As noted in Section 3.2.3, previous studies (Gibbs & Woodward 2018) indicate that the dominant source (~90%) of recent sediment inputs to the estuary at the Moutere River mouth is considered to be of pine forest origin (linked to recent harvesting) and possibly also reflects land clearance for rural residential subdivision in the past decade.

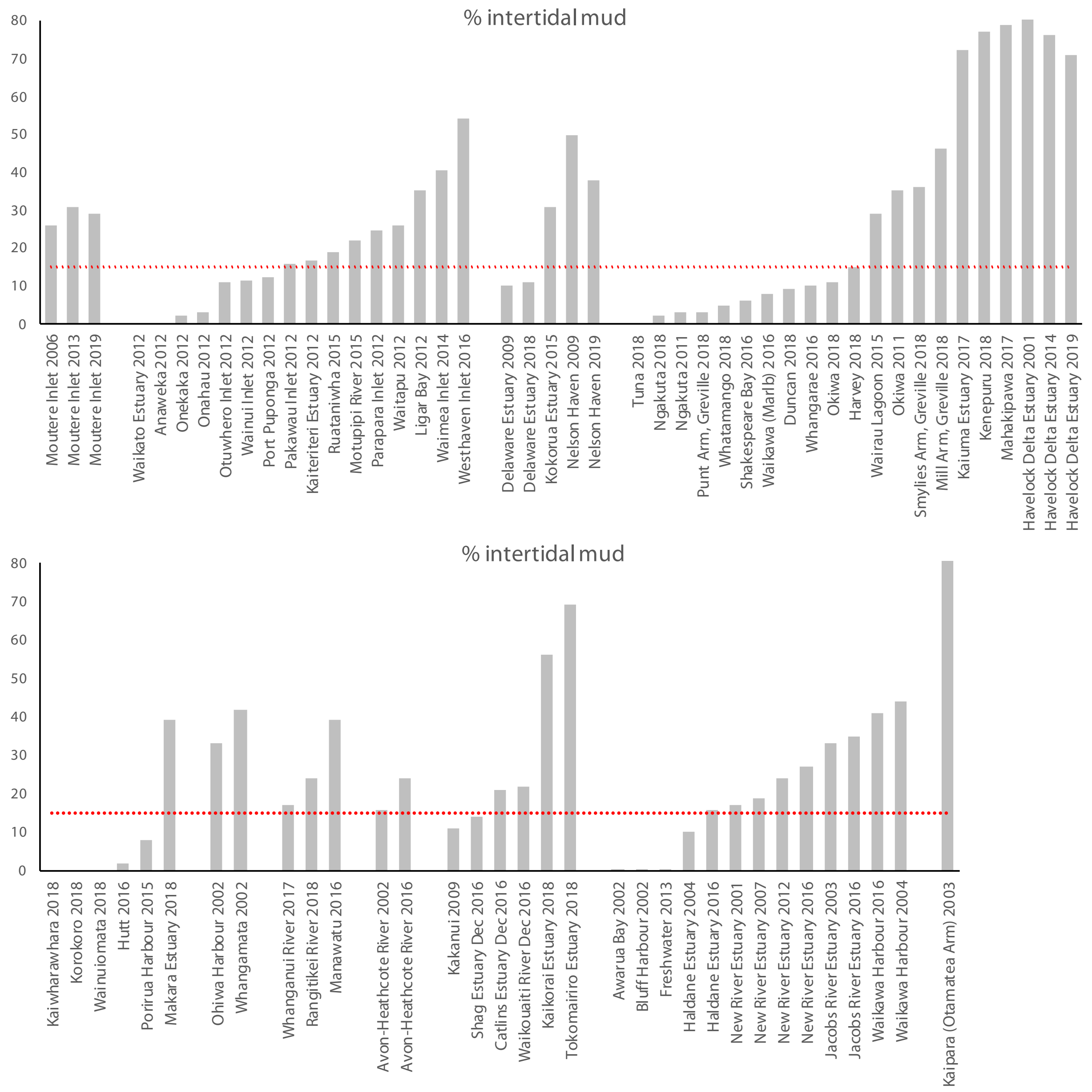


Fig. 11. Percentage of intertidal estuary with soft mud habitat for various NZ tidal lagoon and delta estuaries.

Data from regional council monitoring reports 2006-2019 and Robertson et al. 2002). Red dashed line indicates 'POOR' condition rating threshold.

Although other sources undoubtably contribute sediment to the estuary, the attribution of ~90% of the sediment inputs to a land use activity comprising just 22% of the catchment indicates forestry can at times be a disproportionately high source of catchment sediment inputs.

Despite the high extent of mud-dominated substrates, analysis of sediment plate monitoring data (collected by TDC) showed that net rates of measured sediment accumulation (average 0.2mm/yr over the past decade) were well below the 2mm/yr guideline value proposed for New Zealand estuaries, and comparable to the 0.9mm/yr calculated from NIWA's national estuary sediment load estimator. However, it is noted that some of the greatest deposition in the estuary in recent times has occurred in areas that are not currently monitored with sediment plates, in particular the central basin. High deposition in this area was recently confirmed following analysis of sediment cores using forensic methods (lead and caesium radioisotopes), which estimated mean sediment accrual of ~10mm/yr from 1988 to 2018 (Gibbs & Swales 2019). This high rate of sediment accrual is rated 'poor'. Although the likely source and timing of historical sediment inputs prior to 1988 cannot be readily determined from available data, significant sediment inputs are known to have occurred during the development of horticultural land in the Moutere catchment in the 1960s (Leighs 1977).

The NIWA sediment load estimator allows coarse comparison of the estimated current sedimentation rate (CSR) to the natural sedimentation rate (NSR), noting there are multiple caveats on the accuracy of predictions (see Hicks et al. 2019). The NSR assumes the catchment has 100% native forest cover, but no sediment attenuation in wetlands. Table 13 shows the CSR/NSR ratio is 1.6. This rises to 3.3 if wetland attenuation of 50% is applied, a value considered reasonable to use given the relatively low rolling hill country surrounding the estuary and the likely historic occurrence of significant areas of wetland and salt marsh that are no longer present. The latter ratio, assessed using rating criteria in the NZ Estuary Trophic Index, placed Moutere Inlet in 'Band C' (fair).

Because predicted catchment sediment inputs are currently elevated, and could potentially increase significantly as a consequence of land use changes, maintaining a record of any significant land disturbance activities in the catchment is recommended (e.g. GIS maps, consent monitoring), as is ensuring appropriate land management controls are implemented.

Although large parts of the estuary supported no nuisance algal growths, the OMBT macroalgal ecological quality rating (0.53) was scored as 'fair'. Macroalgae were most commonly present in two distinct forms – dense high biomass growths of sediment-entrained *Gracilaria,* and relatively sparse low biomass growths of *Ulva* (sea lettuce), the latter growing mostly along channel edges or as a subdominant growth on *Gracilaria*. Of the two, *Gracilaria* was causing the most significant adverse ecological effects in the estuary, with large smothering beds present in the Wharf Road embayment, several of the western embayments and in mud-dominated substrates in the central basin. When present, *Gracilaria* tended to be very prolific (biomass >2000g/m^2), with entrainment in sediment indicating that beds are relatively stable and persistent.

Prolific growths of macroalgae that cause nuisance conditions seldom occur naturally in well-flushed shallow intertidally-dominated estuaries, but can occur when nutrient inputs are significantly elevated. Moutere Inlet currently has a predicted nitrogen input of 156mg/m^2/d (excluding point source inputs) which is above the threshold at which most macroalgal problems are evident in similar NZ estuaries (100mg/m^2/d, see Robertson et al. 2016b). Currently the macroalgal growths are contributing in the presence of persistent areas with HECs. HECs are likely to cause significant adverse ecological impacts on sediment-dwelling animals and, once established, are generally slow to recover. The extent of HECs has expanded significantly over time from an estimate of ~1ha (0.1%) in 1947, to 37ha (5%) in 2004 and 60ha (8%) in 2013, before decreasing to 31ha (4.1%) in 2019. The large decrease in both macroalgal cover (48ha) and HEC extent (29ha) since 2013 is very positive, although the specific reasons for the changes are unclear

One explanation for the decrease in HEC area from 2013 to 2019 is that sediment conditions may have become so enriched that macroalgae can no longer survive due to the presence of toxic sulphides. This phenomenon has been previously observed in highly enriched estuaries in Southland (Robertson et al. 2017). A second explanation is the potential influence of two recent cyclones (Gita and Fehi) in Feb 2018, which may have caused macroalgae to be physically washed from the estuary.

Relating to the previous point, the loss of macroalgae from the estuary removes any nutrients within the algal material and, as macroalgae are very effective at binding muds, is likely to also facilitate the erosion of nutrient rich muds from the estuary. When combined with a potential reduction in the input of mud from the catchment (due to reduced land disturbance since the identified inputs in ca 2008), there has potentially been an overall reduction in the retention of nutrients in the estuary, contributing to the improved conditions observed since 2013. However, despite the near halving of HEC area from 2013 to 2019, the condition rating remains 'poor'. A further reduction in nutrient inputs is therefore likely to be required to reduce the currently observed macroalgal growths and HECs and improve estuary quality.

To assess the overall extent that symptoms of eutrophication are expressed, the NZ Estuary Trophic Index combines macroalgal growth, the presence of HECs and mud extent (as well as several other indicators) into an ETI score. The ETI score of 0.69 (see Table 13), indicates Moutere Inlet is at the upper (more degraded) end of the 'fair' rating band. The ETI score had improved slightly from the last assessment which was based on 2013 data (Stevens & Rayes 2018), but the rating remains unchanged.

Small seagrass (*Zostera*) beds were present (3.1ha) primarily in the central basin near the Kina entrance, with an apparent increase of 1.1ha since 2013 and 2.2ha since the first reliable baseline in 2004. This increase is rated 'good', although it is attributed more to improved mapping accuracy than a change in actual extent. The remaining beds appear confined to a relatively narrow range, with infilling in many other areas creating perched tidal flats that are exposed for most of the tidal cycle and which, when combined with excessive muddiness, is unfavourable for seagrass growth. While data are not available, the remaining seagrass beds are likely to be very small compared to their pre-human extent.

Salt marsh vegetation remained a prominent feature in 2019 (83ha, 10.8% of the estuary), a rating of 'good' (for salt marsh extent) with no appreciable change from 2004 or 2013. The most extensive salt marsh areas, dominated by rushland (55%) and herbfield (40%), were located within estuary embayments and on the northwest and southern tidal flats. Compared to the historical salt marsh extent, there has been an estimated reduction of ~45% since 1947. Most of this has been the result of reclamation and drainage including the construction of SH60, expansion of the Motueka township, port and marina, and as a consequence of land development and catchment inputs from horticulture, pastural farming exotic forestry and residential subdivision. These activities have contributed to significant infilling and elevated muddiness of the estuary and modified almost every part of the upper tidal terrestrial margin of the estuary, which is now dominated by a mix of steep-faced concrete seawalls, earth bunds and rock reinforcing.

The modification of the estuary margin severely restricts the area available for salt marsh growth and disrupts the natural connectivity between the land and the estuary, preventing the migration of estuarine species in response to predicted sea level rise. Without changes in management approaches, the likely result is a progressive reduction of salt marsh habitat over time. The cost of this reduction is high. The estimated ecosystem services value of salt marsh is NZ$368,220 per ha per year (Costanza et al. 2014). These values include: habitat and ecological community services, food and water provisioning, filtering of contaminants, erosion control, carbon sequestration, buffering of floods and coastal storm surges, and cultural and recreational services. In virtually all cases, the cost of salt marsh loss greatly exceeds that of retaining existing salt marsh and allowing its natural expansion.

The 200m wide terrestrial margin bordering the estuary was also highly modified and dominated by residential/industrial development (21.7%), pasture (28.6%) and horticulture (19.5%). Only 16% was densely vegetated, much of which was exotic, a condition rating of 'poor'. There was no significant change in the percentage of densely vegetated margin from 2004 to 2019.

Overall, despite extensive historical habitat modification, much reduced habitat diversity, and large areas of mud, the estuary retains significant ecological value, although it is currently expressing moderate symptoms of eutrophication and muddiness. Although there have been recent reductions in mud-dominated substrate, and the extent of dense macroalgal beds and HEC's, maintaining current nutrient and sediment inputs is likely to see the estuary remain in a similar state to present. Reductions in sediment and nutrient loads will be needed to improve estuary condition, and salt marsh losses are likely to increase in response to sea level rise without changes in current management approaches.

4.2 RECOMMENDATIONS

Moutere Inlet has been identified by Tasman District Council as a priority for monitoring because of its high ecological and human use values, and because it is potentially vulnerable to elevated sedimentation and localised eutrophication issues. Based on the 2019 results, the following recommendations are proposed for consideration by TDC.

Broad Scale Habitat Mapping

In order to track changes in the dominant features of the estuary, undertake broad scale habitat mapping at 5-10 yearly intervals; five yearly for habitat features where changes over the past 10 years have been significant (macroalgae and fine sediment) and 10 yearly where habitat features are relatively stable, e.g. terrestrial margin, salt marsh, seagrass. In light of the potential for rapid changes to nuisance macroalgal beds, the extent and state of established and persistent macroalgal beds should be synoptically assessed annually.

Sedimentation Rate Monitoring

Given the consistency of sediment plate results over the past 10 years it is recommended that they be monitored biennially.

To understand the scale of observed change in the central basin, install additional plates at two sites where fine sediments are currently being eroded, and at the sites use for fine scale ecological monitoring, to help interpret future changes in sediment biota.

To determine if sediments are getting muddier in the absence of sediment accretion, consideration should be given to analysing a composite sediment sample for grain size at each sediment plate site to establish a baseline against which future change can be assessed.

Catchment Influences

In addition to the above field-based monitoring, it would be helpful if the council maintained records on the location and scale of known catchment disturbances or land use changes (e.g. forest harvesting, road development, urban subdivision) to assist in the interpretation of monitoring results. Such information will complement high-level national-scale data such as the Landcare Research Land Cover Database (LCDB) assessed from satellite imagery. It would also be prudent to reassess modelled catchment sediment and nutrient load predictions following any significant change in catchment land use, or when national models (e.g. NIWA CLUES model, suspended sediment yield estimator) are updated.

Management and Restoration

There is significant potential for the ecological restoration of Moutere Inlet. It is recommended that TDC develop a strategy to identify and prioritise areas for ecological enhancement and protection, including recommending specific restoration options, e.g. replanting salt marsh, improving tidal flushing, recontouring shorelines, and removing barriers to salt marsh expansion. This would ideally be part of a region-wide planning approach facilitated to assist community and stakeholder initiatives.

A key component of the strategy would be to delineate low-lying areas previously within the estuary, or likely to be impacted by sea level rise, using GIS-based mapping techniques and existing coastal LIDAR data. These outputs can be used to encourage the protection or expansion of salt marsh on private land adjacent to the estuary, and to facilitate planning for the managed retreat of salt marsh in response to predicted sea level rise.

Further, opportunities for creating new habitat or increasing and enhancing the vegetative buffering capacity of the estuary should be explored through existing work wherever possible e.g. requirements to increase the number and size of causeway culverts, avoid or remove unnecessary shoreline barriers, or undertake supplementary planting as part of future road maintenance or protection works.

5. REFERENCES CITED

Atkinson IAE. 1985. Derivation of vegetation mapping units for an ecological survey of Tongariro National Park Nth Island, NZ. NZ Journal of Botany, 23; 361-378.

Clark K, Gillespie P. 2007. Historical broad scale mapping of Moutere Inlet (1947, 1988 and 2004). Prepared for Tasman District Council. Cawthron Report No. 1234. 19p.

Clark K, Stevens L, Gillespie P. 2006. Broad scale mapping of Moutere Inlet. Prepared for Tasman District Council. Cawthron Report No. 1037. 19p.

Costanza R, de Groot R, Sutton P, Sander van der Ploeg S, Anderson SJ. Kubiszewski I, Farber S, Turner K. 2014. Changes in the global value of ecosystem services. Global Environmental Change 26 (2014) 152–158.

Davidson RJ, Preece JR. 1994. Internationally and nationally important coastal areas from Waimea Inlet to Cape Soucis, Nelson, New Zealand: recommendations for protection. Department of Conservation, Nelson/Marlborough Conservancy. Occasional Publication No 15.

Gibbs M, Swales A. 2019. Historical Sediment Source Apportionment in the Waimea Estuary. Continuation of the Waimea and Moutere River Study. NIWA Client Report No 2002012HN. Prepared for Tasman District Council. 44p.

Gibbs M, Woodward B. 2018. Waimea and Moutere Sediment Sources by Land Use. NIWA Client Report No 2018026HN. Prepared for Tasman District Council under Envirolink contract, CO1X1632 1749-7STDC130. 63p.

Gillespie PA, Stark JD, Asher RA. Fenemor, A.D. 1995. Moutere Inlet Ecosystem Investigation. Report prepared for Tasman District Council. Cawthron Report No. 273. 49p.

Gillespie P, Clark K. 2006. Moutere Inlet fine scale benthic baseline 2006. Prepared for Tasman District Council. Cawthron Report No. 1183. 18p.

Hicks M, Semademi-Davies A, Haddadchi A, Shankar U, Plew D. 2019. Updated sediment load estimator for New Zealand. NIWA Client Report No. 2018341CH, prepared for Ministry for the Environment. January 2019. 190p.

Hunt S. 2019. Regional Estuary Monitoring Programme (REMP) intertidal sedimentation measurements, results and review of methodologies. Waikato Regional Council Technical Report 2019/04.

Leighs MJ. 1977. A review of soil and water conservation works in Nelson orchards. November, 1977. Nelson Catchment and Regional Water Board.

Melville DS, Schuckard R. 2013. Effects of Selected Activities on Shorebirds in Tasman District: Management Issues and Options for Sites of International Importance. Prepared for Nelson City Council and Tasman District Council. 47p.

Robertson BM, Gillespie PA, Asher RA, Frisk S, Keeley NB, Hopkins GA, Thompson SJ, Tuckey BJ. 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

Robertson BM, Stevens L 2009. State of the Environment Report, Estuaries of Tasman District. Prepared by Wriggle Coastal Management for Tasman District Council. 54p.

Robertson BM, Stevens L 2013. Moutere Inlet fine scale monitoring 2012/2013. Report prepared for Tasman District Council. 25p.

Robertson BM, Stevens L 2012. Tasman Coast - Waimea Inlet to Kahurangi Point, habitat mapping, risk assessment and monitoring recommendations. Report prepared for Tasman District Council. 167p.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M. 2016a. NZ Estuary Trophic Index Screening Tool 1: Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420. 47p.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M. 2016b. NZ Estuary Trophic Index Screening Tool 2: determining monitoring indicators and assessing estuary trophic state. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

Robertson BM, Stevens LM, Ward N, Robertson BP. 2017. Condition of Southland's Shallow, Intertidal Dominated Estuaries in Relation to Eutrophication and Sedimentation: Output 1: Data Analysis and Technical Assessment - Habitat Mapping, Vulnerability Assessment and Monitoring Recommendations Related to Issues of Eutrophication and Sedimentation. Prepared for Environment Southland. 152p.

Schuckard R, Melville DS. 2013. Shorebirds of Farewell Spit, Golden Bay and Tasman Bay. Prepared for Nelson City Council and Tasman District Council. 81p.

Stevens LM, Rayes C. 2018. Summary of the Eutrophication Susceptibility and Trophic State of Estuaries in the Tasman Region. Report prepared by Wriggle Coastal Management for Tasman District Council. 16p.

Stevens LM, Robertson BM 2013. Moutere Inlet 2013 Broad Scale Habitat Mapping. Report prepared for Tasman District Council by Wriggle Coastal Management. 39p.

Townsend M, Lohrer D. 2015. ANZECC Guidance for Estuary Sedimentation. NIWA Client Report No: HAM2015-096. Prepared for Ministry for the Environment. 45p

WFD-UKTAG. 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Water Framework Directive - United Kingdom Technical Advisory Group. Retrieved from: http://www.wfduk.org/sites/default/files/Media/ Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG MethodStatement.PDF

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

APPENDICES

APPENDIX 1. BROADSCALE HABITAT CLASSIFICATION DEFINITIONS

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP (Robertson et al. 2002) with minor modifications as listed.
Revised substrate classes were developed by Salt Ecology to more accurately classify fine unconsolidated substrate.
Terrestrial margin vegetation was classified using the field codes included in the Landcare Research Land Cover Database (LCDB5) - see following page.

VEGETATION (mapped separately to the substrates they overlie and ordered where commonly found from the upper to lower tidal range).

Estuarine shrubland: Cover of estuarine shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh (density at breast height).

Tussockland: Tussock cover is 20-100% and 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 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.*

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

Grassland[1]: Grass cover (excluding tussock-grasses) is 20-100% and exceeds that of any other growth form or bare ground.

Introduced weeds[1]: Introduced weed cover is 20-100% and exceeds that of any other growth form or bare ground.

Reedland: Reed cover is 20-100% and 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*.

Lichenfield: Lichen cover is 20-100% and exceeds that of any other growth form or bare ground.

Cushionfield: Cushion plant cover is 20-100% and 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.

Rushland: Rush cover (excluding tussock-rushes) is 20-100% and exceeds that of any other growth form or bare ground. A tall grass-like, often hollow-stemmed plant. Includes some species of *Juncus* and all species of *Apodasmia (Leptocarpus).*

Herbfield: Herb cover is 20-100% and 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.

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

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 chlorophyll, 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.

Note NEMP classes of Forest and Scrub are considered terrestrial and have been included in the terrestrial Land Cover Data Base (LCDB) classifications.

[1] Additions to the NEMP classification.

SUBSTRATE (physical and zoogenic habitat)

Sediment texture is subjectively classified as: **firm** if you sink 0-2 cm, **soft** if you sink 2-5cm, **very soft** if you sink >5cm, or **mobile** - characterised by a rippled surface layer.

Artificial substrate: 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. Commonly sub-grouped into artificial: substrates (seawalls, bunds etc), boulder, cobble, gravel, or sand.

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

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

Sand: Granular beach sand with a low mud content 0-10%. No conspicuous fines evident when sediment is disturbed.

Sand/Shell: Granular beach sand and shell with a low mud content 0-10%. No conspicuous fines evident.

Muddy sand (Moderate mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >10-25%). Granular when rubbed between the fingers, but with a smoother consistency than sand with a low mud fraction. Generally firm to walk on.

Muddy sand (HIgh mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >25-50%). Granular when rubbed between the fingers, but with a much smoother consistency than muddy sand with a moderate mud fraction. Often soft to walk on.

Sandy mud (Very high mud content): Mud/sand mixture dominated by mud (i.e. >50%-90% mud). Sediment rubbed between the fingers is primarily smooth/silken but retains a granular component. Sediments generally very soft and only firm if dried out or another component, e.g. gravel, prevents sinking.

Mud (>90% mud content): Mud dominated substrate (i.e. >90% mud). Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out or another component, e.g. gravel, prevents sinking.

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

Table of modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.096m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Firm shell/sand	fSS
		Mobile sand	mS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Firm muddy shell/sand	fSS10
		Mobile muddy sand	mMS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Firm muddy shell/sand	fSS25
		Mobile muddy sand	mMS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Mud (M)	Mud (>90%)	Firm mud	fM90
		Soft or very soft mud	sM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Sabellid field	TUBE
Artifical Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aBF
		Cobble field	aCF
		Gravel field	aGF
		Sand field	aSF

Artificial Surfaces	
1	Built-up Area (settlement)
2	Urban ParklandOpen Space
5	Transport Infrastructure
6	Surface Mines and Dumps
Bare or Lightly Vegetated Surfaces	
10	Sand and Gravel
12	Landslide
14	Permanent Snow and Ice
15	Alpine Grass/Herbfield
16	Gravel and Rock
Water Bodies	
20	Lake or Pond
21	River
Cropland	
30	Short-rotation Cropland
33	Orchard Vineyard & Other Perennial Crops
Grassland, Sedge and Saltmarsh	
40	High Producing Exotic Grassland
41	Low Producing Grassland
43	Tall-Tussock Grassland
44	Depleted Grassland
45	Herbaceous Freshwater Vegetation
46	Herbaceous Saline Vegetation
Scrub and Shrubland	
47	Flaxland
50	Fernland
51	Gorse and/or Broom
52	Manuka and/or Kanuka
54	Broadleaved Indigenous Hardwoods
55	Sub Alpine Shrubland
56	Mixed Exotic Shrubland
58	Matagouri or Grey Scrub
Forest	
64	Forest - Harvested
68	Deciduous Hardwoods
69	Indigenous Forest
71	Exotic Forest

Field codes used in the current report

Salt marsh Class	Species/Category	Code
Estuarine Shrub	Plagianthus divaricatus (Salt marsh ribbonwood)	Pldi
Gorse and/or Broom	Ulex europaeus (Gorse)	Uleu
Grassland	Festuca arundinacea (Tall fescue)	Fear
Tussockland	Phormium tenax (New Zealand flax)	Phte
	Poa astonii (Blue shore tussock)	Poas
	Stipa stipoides	Stst
Sedgeland	Schoenoplectus pungens (Three square)	Scpu
Rushland	Apodasmia similis (Jointed wirerush)	Lesi
	Ficinia (Isolepis) nodosa (Knobby clubrush)	Isno
	Juncus kraussii (Searush)	Jukr
Herbfield	Carpobrotus edulis (Ice Plant)	Caed
	Samolus repens (Primrose)	Sare
	Sarcocornia quinqueflora (Glasswort)	Saqu
	Selliera radicans (Remuremu)	Sera
	Suaeda novaezelandiae (Sea blite)	Suno

Substrate Class	Category	Code
Artificial	Artificial substrate	aS
	Artificial boulder field	aBF
	Earth bund	Bund
	Seawall	Wall
Transport Infrastructure	Walkway	walk
Bedrock	Rock field	RF
Boulder/Cobble/Gravel	Cobble field	CF
	Gravel field	GF
	Shell bank	shel
Sand	Mobile sand (0-10% mud)	mS
	Firm shell/sand (0-10% mud)	fSS
	Firm sand (0-10% mud)	fS
	Soft sand (0-10% mud)	sS
Muddy Sand	Mobile muddy sand (>10-25% mud)	mMS10
	Firm muddy sand (>10-25% mud)	fMS10
	Soft muddy sand (>10-25% mud)	sMS10
	Mobile muddy sand (>25-50% mud)	mMS25
	Firm muddy sand (>25-50% mud)	fMS25
	Soft muddy sand (>25-50% mud)	sMS25
Sandy Mud	Firm sandy mud (>50-90% mud)	fSM
	Soft sandy mud (>50-90% mud)	sSM
	Very soft sandy mud (>50-90% mud)	vsSM
Mud	Firm mud (>90% mud)	fM90
Zootic	Cocklebed	CKLE
	Mussel reef	MUSS
	Oyster reef	OYST
	Sabellid field	TUBE

APPENDIX 2. SUBSTRATE CLASSIFICATION VALIDATION RESULTS

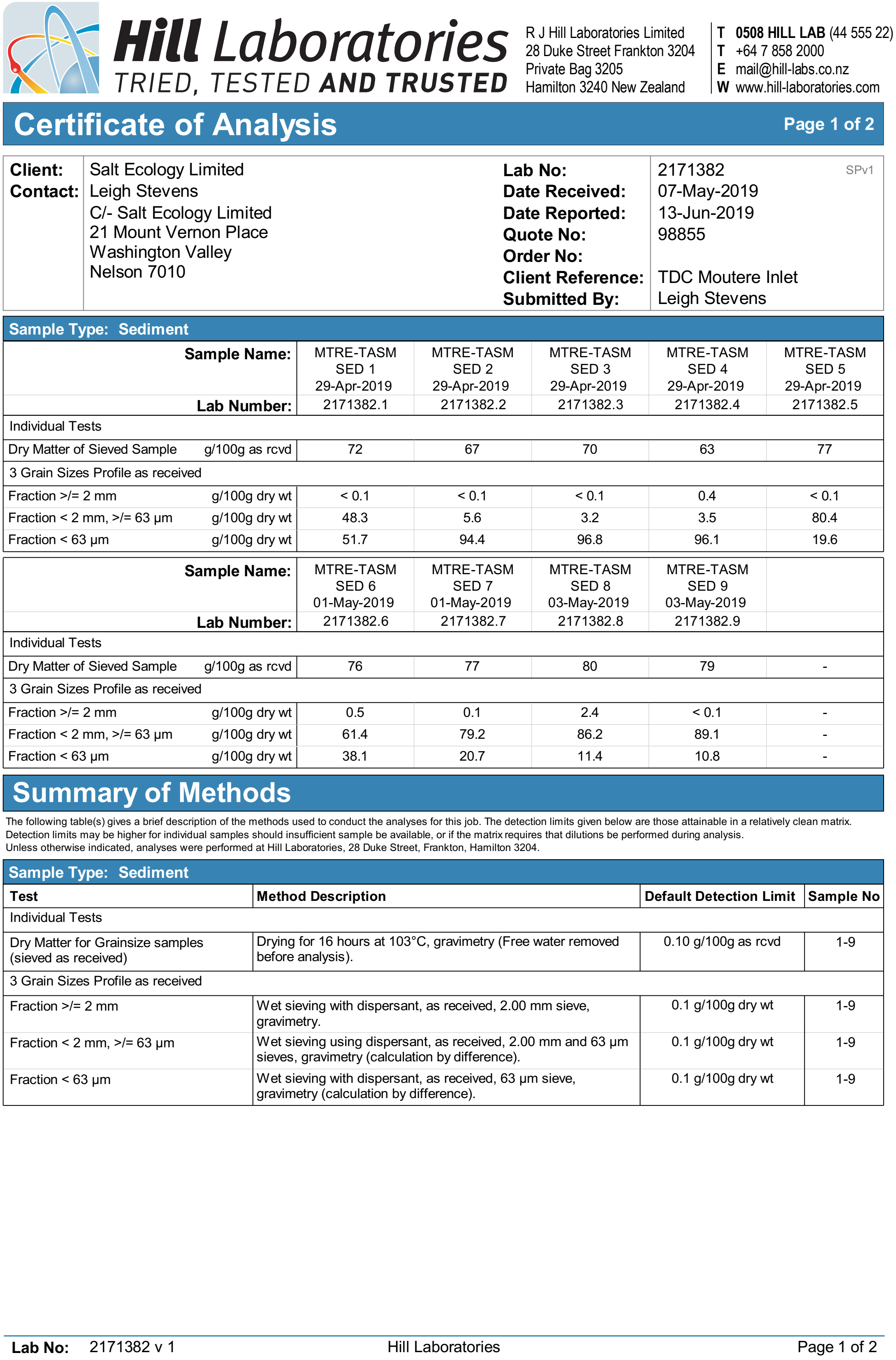
Sampling locations (May 2019) and supporting data for the validation of substrate classifications are presented in the following Table.

Sediment samples were collected from fine unconsolidated substrates representative of the wider estuary and classified in the field based on the criteria described in Appendix 1 (Field Code in table below). Samples corresponding to these classes were subsequently analysed for grain size (Appendix 3) to provide validation of the classification applied. There was generally a high level of concordance between the field code applied and the measured sediment grain size.

Field Code	MudPct	aRPD (mm)	Station	NZTM East	NZTM North
fS	11	20	Sed8	1602675	5442709
fMS10	11	200	Sed9	1602747	5442758
fMS10	20	15	Sed5	1603642	5442284
fMS10	21	25	Sed7	1601923	5445213
fMS25	38	10	Sed6	1601565	5444740
vsSM	52	5	Sed1	1603743	5441428
fM90	94	5	Sed2	1603854	5441227
sM90	96	3	Sed4	1604448	5441011
fM90	97	5	Sed3	1604159	5440691

Refer to Fig. 4 for site locations

APPENDIX 3. LABORATORY METHODS AND RESULTS



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R J Hill Laboratories Limited
28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand

T **0508 HILL LAB** (44 555 22)
T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

Certificate of Analysis

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Client:	Salt Ecology Limited	**Lab No:**	2171382	SPv1
Contact:	Leigh Stevens C/- Salt Ecology Limited 21 Mount Vernon Place Washington Valley Nelson 7010	**Date Received:**	07-May-2019	
		Date Reported:	13-Jun-2019	
		Quote No:	98855	
		Order No:		
		Client Reference:	TDC Moutere Inlet	
		Submitted By:	Leigh Stevens	

Sample Type: Sediment

Sample Name:		MTRE-TASM SED 1 29-Apr-2019	MTRE-TASM SED 2 29-Apr-2019	MTRE-TASM SED 3 29-Apr-2019	MTRE-TASM SED 4 29-Apr-2019	MTRE-TASM SED 5 29-Apr-2019
Lab Number:		2171382.1	2171382.2	2171382.3	2171382.4	2171382.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	72	67	70	63	77
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	< 0.1	< 0.1	< 0.1	0.4	< 0.1
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	48.3	5.6	3.2	3.5	80.4
Fraction < 63 µm	g/100g dry wt	51.7	94.4	96.8	96.1	19.6

Sample Name:		MTRE-TASM SED 6 01-May-2019	MTRE-TASM SED 7 01-May-2019	MTRE-TASM SED 8 03-May-2019	MTRE-TASM SED 9 03-May-2019	
Lab Number:		2171382.6	2171382.7	2171382.8	2171382.9	
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	76	77	80	79	-
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	0.5	0.1	2.4	< 0.1	-
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	61.4	79.2	86.2	89.1	-
Fraction < 63 µm	g/100g dry wt	38.1	20.7	11.4	10.8	-

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			
Dry Matter for Grainsize samples (sieved as received)	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-9
3 Grain Sizes Profile as received			
Fraction >/= 2 mm	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-9
Fraction < 2 mm, >/= 63 µm	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-9
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-9

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.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 4a. OPPORTUNTISTIC MACROALGAL BLOOMING TOOL

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

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

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

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

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

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

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

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

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

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

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

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool.

All the metrics are equally weighted and combined within the multimetric, in order to best describe the changes in the nature and degree of opportunist macroalgae growth on sedimentary shores due to nutrient pressure.

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

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

Derivation of Threshold Values.

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

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

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

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

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

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

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

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

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

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

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 categories in Table A1:

The EQR calculation process is as follows:

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

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

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

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

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

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

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

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

References

DETR, 2001. Development of ecological quality objectives with regard to eutrophication. Final report, unpublished.

Foden, J., Wells, E., Scanlan, C., Best M.A. 2010. Water Framework Directive development of classification tools for ecological assessment: Opportunistic Macroalgae Blooming. UK TAG Report for Marine Plants Task Team, January 2010, Publ. UK TAG.

Hull, S.C., 1987. Macroalgal mats and species abundance: a field experiment. Estuar. Coast. Shelf Sci. 25, 519-532.

Lowthion, D., Soulsby, P.G., and Houston, M.C.M. 1985. Investigation of a eutrophic tidal basin: 1. Factors affecting the distribution and biomass of macroalgae. Marine Environmental Research 15: 263–284.

Raffaelli, D., Hull, S., Milne, H., 1989. Long-term changes in nutrients, weedmats and shore birds in an estuarine system. Cah. Biol. Mar. 30, 259–270.

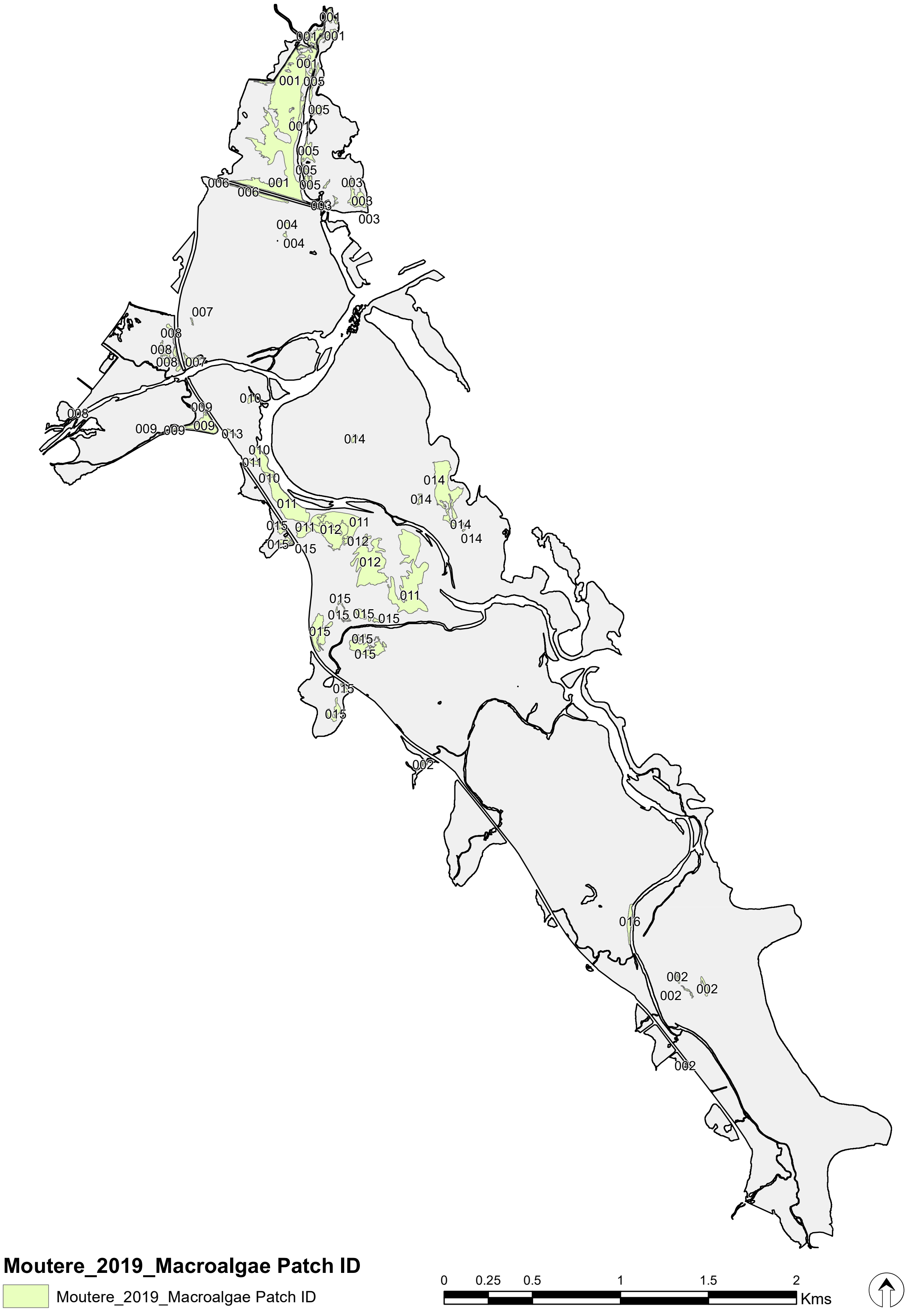
WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group) 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Retrieved from http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

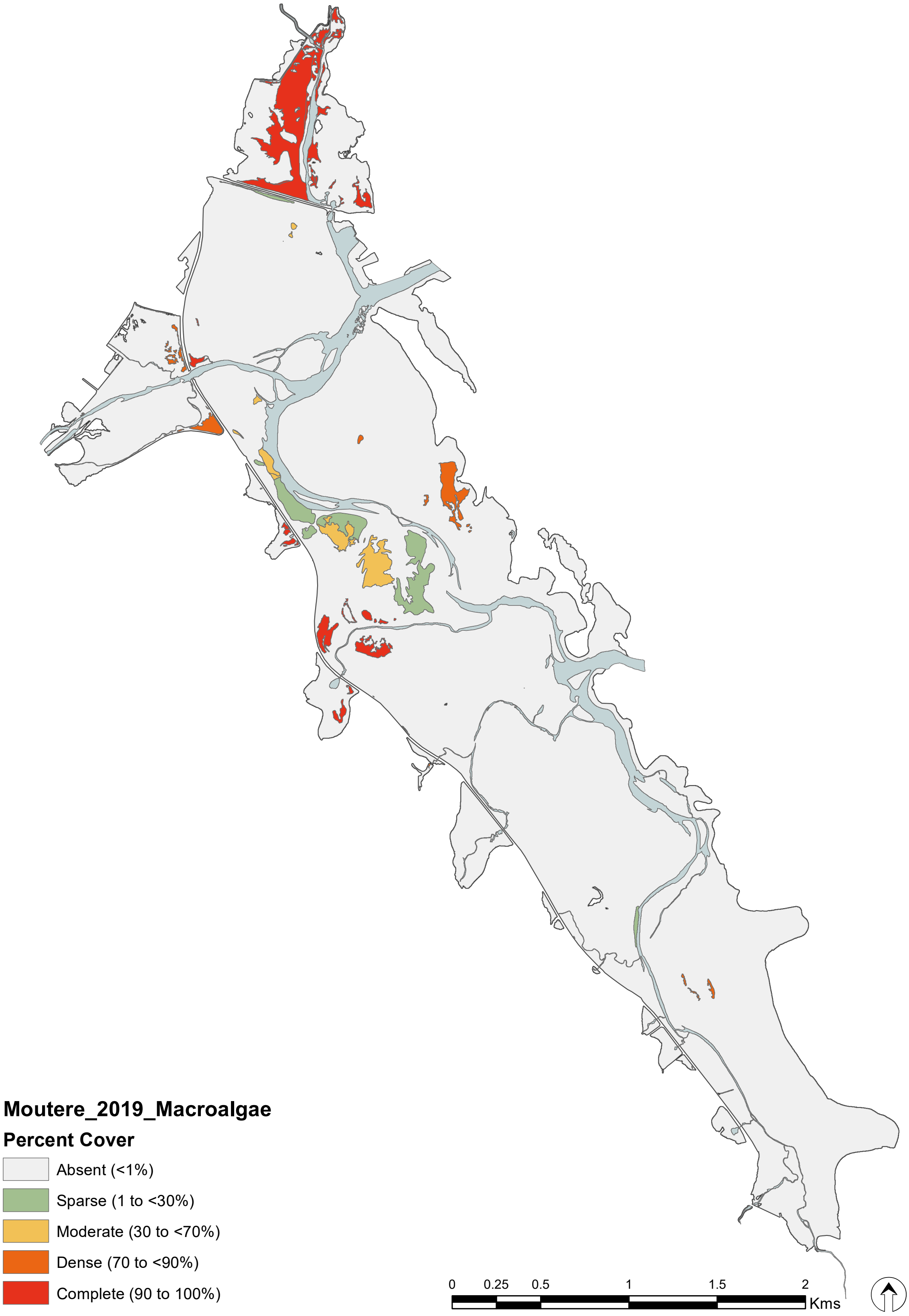
Wither, A., 2003. Guidance for sites potentially impacted by algal mats (green seaweed). EC Habitats Directive Technical Advisory Group report WQTAG07c.

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

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

APPENDIX 4b. PATCH LOCATION AND DATA USED IN THE OMBT, MOUTERE INLET 2019




Moutere_2019_Macroalgae
Percent Cover
Absent (<1%)
Sparse (1 to <30%)
Moderate (30 to <70%)
Dense (70 to <90%)
Complete (90 to 100%)
0
0.25
0.5
1
1.5
2
Kms

PatchID	FieldCode	Pct_Cover	TotPctCov	CrsPctCov	Biomassgm2	CrsBiomass	DomHab	SubDom1	Area_ha	SubstratFC
1	Grch	100	100	Complete (>90%)	2680	>1000-3000	Gracilaria chilensis		0.04	vsSM
1	Grch	100	100	Complete (>90%)	2680	>1000-3000	Gracilaria chilensis		0.06	fS
1	Grch	100	100	Complete (>90%)	2680	>1000-3000	Gracilaria chilensis		0.23	vsSM
1	Grch	100	100	Complete (>90%)	2680	>1000-3000	Gracilaria chilensis		0.25	vsSM
1	Grch	100	100	Complete (>90%)	2680	>1000-3000	Gracilaria chilensis		0.44	vsSM
1	Grch	100	100	Complete (>90%)	2680	>1000-3000	Gracilaria chilensis		0.47	vsSM
1	Grch	100	100	Complete (>90%)	2680	>1000-3000	Gracilaria chilensis		12.41	vsSM
2	Grch	80	80	Dense (70 to <90%)	4560	>3000	Gracilaria chilensis		0.01	vsSM
2	Grch	80	80	Dense (70 to <90%)	4560	>3000	Gracilaria chilensis		0.02	vsSM
2	Grch	80	80	Dense (70 to <90%)	4560	>3000	Gracilaria chilensis		0.06	vsSM
2	Grch	80	80	Dense (70 to <90%)	4560	>3000	Gracilaria chilensis		0.07	vsSM
2	Grch	80	80	Dense (70 to <90%)	4560	>3000	Gracilaria chilensis		0.17	vsSM
3	Grch Ulva	82 16	98	Complete (>90%)	1952	>1000-3000	Gracilaria chilensis	Ulva	0.01	fMS10
3	Grch Ulva	82 16	98	Complete (>90%)	1952	>1000-3000	Gracilaria chilensis	Ulva	0.03	fS
3	Grch Ulva	82 16	98	Complete (>90%)	1952	>1000-3000	Gracilaria chilensis	Ulva	0.04	vsSM
3	Grch Ulva	82 16	98	Complete (>90%)	1952	>1000-3000	Gracilaria chilensis	Ulva	0.70	vsSM
4	Grch Ulva	47 15	62	Moderate (30 to <70%)	1220	>1000-3000	Gracilaria chilensis	Ulva	0.04	vsSM
4	Grch Ulva	47 15	62	Moderate (30 to <70%)	1220	>1000-3000	Gracilaria chilensis	Ulva	0.09	vsSM
5	Grch Ulva	70 30	100	Complete (>90%)	4240	>3000	Gracilaria chilensis	Ulva	0.04	fS
5	Grch Ulva	70 30	100	Complete (>90%)	4240	>3000	Gracilaria chilensis	Ulva	0.05	vsSM
5	Grch Ulva	70 30	100	Complete (>90%)	4240	>3000	Gracilaria chilensis	Ulva	0.05	vsSM
5	Grch Ulva	70 30	100	Complete (>90%)	4240	>3000	Gracilaria chilensis	Ulva	0.16	vsSM
5	Grch Ulva	70 30	100	Complete (>90%)	4240	>3000	Gracilaria chilensis	Ulva	0.23	vsSM
5	Grch Ulva	70 30	100	Complete (>90%)	4240	>3000	Gracilaria chilensis	Ulva	0.23	vsSM
5	Grch Ulva	70 30	100	Complete (>90%)	4240	>3000	Gracilaria chilensis	Ulva	0.52	vsSM
6	Grch	5	5	Sparse (1 to <30%)	1500	>1000-3000	Gracilaria chilensis		0.41	sMS10
7	Grch	100	100	Complete (>90%)	2720	>1000-3000	Gracilaria chilensis		0.03	vsSM
7	Grch	100	100	Complete (>90%)	2720	>1000-3000	Gracilaria chilensis		0.30	vsSM
8	Grch	80	80	Dense (70 to <90%)	3040	>3000	Gracilaria chilensis		0.01	vsSM
8	Grch	80	80	Dense (70 to <90%)	3040	>3000	Gracilaria chilensis		0.02	vsSM
8	Grch	80	80	Dense (70 to <90%)	3040	>3000	Gracilaria chilensis		0.03	vsSM
8	Grch	80	80	Dense (70 to <90%)	3040	>3000	Gracilaria chilensis		0.05	vsSM
8	Grch	80	80	Dense (70 to <90%)	3040	>3000	Gracilaria chilensis		0.18	vsSM
8	Grch	80	80	Dense (70 to <90%)	3040	>3000	Gracilaria chilensis		0.27	vsSM
9	Grch	80	80	Dense (70 to <90%)	4800	>3000	Gracilaria chilensis		0.003	vsSM
9	Grch	80	80	Dense (70 to <90%)	4800	>3000	Gracilaria chilensis		0.005	vsSM
9	Grch	80	80	Dense (70 to <90%)	4800	>3000	Gracilaria chilensis		0.01	vsSM
9	Grch	80	80	Dense (70 to <90%)	4800	>3000	Gracilaria chilensis		0.02	vsSM
9	Grch	80	80	Dense (70 to <90%)	4800	>3000	Gracilaria chilensis		0.96	vsSM
10	Grch Ulva	10 20	30	Moderate (30 to <70%)	1280	>1000-3000	Gracilaria chilensis	Ulva	0.11	fS GF CKLE
10	Grch Ulva	10 20	30	Moderate (30 to <70%)	1280	>1000-3000	Gracilaria chilensis	Ulva	0.13	fS
10	Grch Ulva	10 20	30	Moderate (30 to <70%)	1280	>1000-3000	Gracilaria chilensis	Ulva	0.70	vsSM
11	Grch Ulva	4 3	7	Sparse (1 to <30%)	760	>500-1000	Gracilaria chilensis	Ulva	0.11	vsSM
11	Grch Ulva	4 3	7	Sparse (1 to <30%)	760	>500-1000	Gracilaria chilensis	Ulva	0.40	vsSM
11	Grch Ulva	4 3	7	Sparse (1 to <30%)	760	>500-1000	Gracilaria chilensis	Ulva	2.06	vsSM
11	Grch Ulva	4 3	7	Sparse (1 to <30%)	760	>500-1000	Gracilaria chilensis	Ulva	2.34	vsSM
11	Grch Ulva	4 3	7	Sparse (1 to <30%)	760	>500-1000	Gracilaria chilensis	Ulva	4.97	vsSM
12	Grch	50	50	Moderate (30 to <70%)	4320	>3000	Gracilaria chilensis		0.01	vsSM
12	Grch	50	50	Moderate (30 to <70%)	4320	>3000	Gracilaria chilensis		1.84	vsSM
12	Grch	50	50	Moderate (30 to <70%)	4320	>3000	Gracilaria chilensis		3.50	vsSM
13	Grch Ulva	50 10	60	Moderate (30 to <70%)	4000	>3000	Gracilaria chilensis	Ulva	0.02	fS
13	Grch Ulva	50 10	60	Moderate (30 to <70%)	4000	>3000	Gracilaria chilensis	Ulva	0.07	fS GF CKLE
14	Grch Ulva	75 7	82	Dense (70 to <90%)	1360	>1000-3000	Gracilaria chilensis	Ulva	0.01	vsSM
14	Grch Ulva	75 7	82	Dense (70 to <90%)	1360	>1000-3000	Gracilaria chilensis	Ulva	0.01	vsSM
14	Grch Ulva	75 7	82	Dense (70 to <90%)	1360	>1000-3000	Gracilaria chilensis	Ulva	0.02	vsSM
14	Grch Ulva	75 7	82	Dense (70 to <90%)	1360	>1000-3000	Gracilaria chilensis	Ulva	0.09	vsSM
14	Grch Ulva	75 7	82	Dense (70 to <90%)	1360	>1000-3000	Gracilaria chilensis	Ulva	0.10	vsSM
14	Grch Ulva	75 7	82	Dense (70 to <90%)	1360	>1000-3000	Gracilaria chilensis	Ulva	2.73	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.01	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.01	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.01	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.02	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.02	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.03	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.06	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.08	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.08	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.09	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.09	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.16	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.16	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.23	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		0.39	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		1.19	vsSM
15	Grch	100	100	Complete (>90%)	3200	>3000	Gracilaria chilensis		1.24	vsSM
16	Grch	20	20	Sparse (1 to <30%)	800	>500-1000	Gracilaria chilensis		0.37	vsSM

APPENDIX 5. ADDITIONAL NOTES SUPPORTING TABLE 3 RATINGS

Sedimentation Mud Content

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

Soft Mud Percent Cover

Sediments with >25% mud content have been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and an excessive mud content decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are sinks for sediments, the presence of large areas of soft mud are likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, the widespread presence of sediments dominated by fine mud indicates where changes in land management may be needed. In most instances sediments with >25% mud content are soft and can be identified using the NEMP protocols based on how much a person sinks when walking (Robertson et al. 2002). If an estuary is suspected of having >25% mud content but has substrate that remains firm to walk on (e.g. dried muds, presence of underlying gravels), it is recommended that particle grain size analyses of relevant areas be used to determine the extent of the estuary with sediment mud contents greater than 25%.

Apparent Redox Potential Discontinuity (aRPD)

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

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

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

Opportunistic Macroalgae

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

Seagrass

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

The assessment metric used is the percent change from baseline measurements.

Salt marsh

Salt marshes 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 salt marsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Salt marsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest salt marsh 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, salt marsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to Mean Sea Level (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 salt marsh metric for NZ. As an interim measure, the % of the intertidal area comprising salt marsh is used to indicate salt marsh condition, with a supporting metric proposed of % loss from Estimated Natural State Cover. This assumes that a reduction in natural state salt marsh cover corresponds to a reduction in ecological services and habitat values. The interim condition ratings proposed for these ratings are Very Good 80-100%, Good 60-80%, Fair 40-60%, and Poor <40%. The "early warning trigger" for initiating management action/further investigation is a trend of a decreasing salt marsh area.

Vegetated Margin

The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the salt marsh and estuary. This buffer is sensitive to a wide range of pressures including land reclamation and drainage, margin development, flow regulation, sea level rise, grazing, and weed invasion. A dense buffer 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 less than 50% of the estuary with a densely vegetated 200m terrestrial margin. Land cover at a catchment-wide scale is also a very valuable metric. Landcare Research provide regular national-scale GIS layers (Land Cover Data Base - LCDB) which can be used to develop relationships between estuary state and land cover type, and changes in catchment land cover over time.

REFERENCES

Jørgensen, N. and Revsbech, N.P. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. Limnology and Oceanography 30:111-122.

Nelson, Walter G. (ed.) 2009. Seagrasses and Protective Criteria: A Review and Assessment of Research Status. Office of Research and Development, National Health and Environmental Effects Research Laboratory, EPA/600/R-09/050.

Robertson B, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B 2002. Estuarine Environmental assessment and monitoring: A national protocol part A. Development of the monitoring protocol for New Zealand estuaries. Introduction, rationale and methodology. Sustainable Management Fund Contract No. 5096, Cawthron Institute, Nelson, New Zealand. 93p.

Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016a, b. NZ Estuary Trophic Index. Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data (47p). Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State (68p). Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420.

Robertson, B.P., Gardner, J.P.A. and Savage, C., 2015. Macrobenthic – mud relations strengthen the foundation for benthic index development : A case study from shallow, temperate New Zealand estuaries. Ecological Indicators, 58, pp.161–174. Available at: http://dx.doi.org/10.1016/j.ecolind.2015.05.039.

Robertson, B.P., Savage, C., Gardner, J.P.A., Robertson, B.M. and Stevens, L.M. 2016. Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. Ecological Indicators, 69, pp.595–605.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group) 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool.http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

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

APPENDIX 6. NZ ESTUARY TROPHIC INDEX

The NZ ETI (Robertson et al. 2016a,b) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness. An integrated online calculator is available to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary)

[https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/]

as well as trophic expression based on key estuary indicators

[https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]

The more indicators included, the more robust the ETI score becomes. Where established ratings are not yet incorporated into the NIWA ETI online calculator they are included via spreadsheet calculator. Because the default values in the ETI database have been sourced from high level national data with limited field validation e.g. the Coastal Explorer database, key inputs such as estuary area, depth, volume, tidal prism and flow have been updated using specific estuary measurements and field observations.

The indicators used to derive an ETI score for the estuary are presented below using the broad scale monitoring results (this report) and available fine scale monitoring results (Robertson & Stevens 2013). The input values used in the online calculator are presented on the following page.

ETI Tool 1 rates the physical and nutrient load susceptibility of Moutere Inlet as MODERATE.

ETI Tool 2 (spreadsheet calculator) scores the estuary 0.69, Band C, a rating of 'fair' for eutrophic symptoms.

Primary Indicators for Shallow Intertidal Dominated Estuaries*				**Value**	**Score**
Required	Opportunistic Macroalgae	OMBT EQR	shallow intertidal	0.53	10
	Macroalgal GNA %	% Gross Nuisance Area (GNA)/Estuary Area		31	14
	Macroalgal GNA Ha	Ha Gross Nuisance Area (GNA)		4.3	8
Optional	Phytoplankton biomass	Chl- a (summer 90 percentile, µg/L or mg/m^3)	water column	NA	-
	Cyanobacteria (if issue identified) NOTE ETI rating not yet developed			NA	-
Supporting Indicators for Shallow Intertidal Dominated Estuaries*				Value	Score
Required	Sediment Oxygenation	Mean Redox Potential (RPmV) at 1cm depth in most impacted sediments and representing at least 10% of estuary area	shallow intertidal	-100	10
		% of estuary with aRPD <1cm or RP <-150mV at 3cm		NA	-
		Ha of estuary with aRPD <1cm or RP <-150mV at 3cm		NA	-
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		1	9
	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		250	5
	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area		2.2	6
Optional	Muddy sediment	Proportion of estuary area with >25% mud content	shallow intertidal	0.31	16
	Sedimentation Rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL)		3.3	10
NZ ETI Score				**0.69**	
				FAIR	

*Must include at least 1 Required Indicator

NZ ETI Tool 1 Input details	Calculator Heading	Unit	Input Value
Estuary Name	Est_name		11650
Estuary Number	Est_no		Moutere Inlet
Regional Council	Reg_Council		Tasman-Nelson
Island	Island		South Island
NZCHS geomorphic code	NZCHS_code		9
NZCHS geomorphic class	NZCHS_class		Shallow drowned valley
ETI Class	ETI_class		SIDE
Latitude	LAT	decimal degrees	-41.1574773
Longitude	LON	decimal degrees	173.0396767
Freshwater inflow	Qf	m^3/s	1.5
Annual river total nitrogen loading	TNriver	T/yr	88.2
Annual river total phosphorus loading	TPriver	T/yr	6.8
Volume	V	m^3	10050000
Tidal Prism	P	m^3	9930000
Return flow fraction	b	unitless	NA
ACExR fitted exponent	A	unitless	0
ACExR fitted constant	B	unitless	0
Ratio NO3	R_NO3	unitless	0.8
Ratio DRP	R_DRP	unitless	0.7
Ocean salinity	OceanSalinity_mean	ppt	34.5
Ocean nitrate concentration	NOcean	mg/m^3	16.0
Ocean DRP concentration	POcean	mg/m^3	7.5
Intertidal area	Intertidal	%	76.5
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_m^2	m^2	10050000
Mean depth	mean_depth	m	1
Tidal height	tidal_height	m	3.6274
Estuary Area at low tide	LOWTIDEest_area_m2	m^2	
Mean depth at low tide	LOWTIDEmean_depth	m	
Estuary volume at low tide	LOWTIDEvolume	m^3	

NZ ETI Tool 2 Input details	Calculator Heading	Unit	Input Value
Name of estuary	estuary_name		Moutere Inlet 2019
Phytoplankton Biomass	CHLA	mg/m^3	NA
Macroalgal GNA/Estuary Area	macroalgae_GNA_percent	%	31
Macroalgal GNA	macroalgae_GNA_ha	ha	4.3
Opportunistic Macroalgae	macroalgae_EQR	OMBT EQR	0.53
Dissolved Oxygen (DO)	DO	mg/m^3	NA
Sediment Redox Potential (RP) @1cm*	REDOX	mV	-100
Total Organic Carbon (TOC)*	TOC	%	1
Total Nitrogen (TN)*	TN	mg/kg	250
Macroinvertebrates*	AMBI	NZ AMBI	2.2
Area of soft mud	soft_mud	Proportion	0.31
Estuary type	estuary_type		SIDE
ICOE status	isICOE	TRUE/FALSE	FALSE
CSSL to NSSL ratio (50% wetland attenuation)		Ratio	3.3

*data from fine scale Site A (Robertson & Stevens 2013)

APPENDIX 7. SUMMARY OF HISTORICAL DATA

Summary data extracted from GIS files provided by TDC and modified following QAQC checks, or directly from Clark et al. (2006) and Robertson & Stevens (2013). A breakdown of substrate types is included on the following page.

Key Estuary features (ha)						Change : 2006-2019		Change : 2013-2019	
Year	1947	1988	2006	2013	2019	ha	%	ha	%
Estuary Area	805	766	760	767	765	4.9	1	-2	0
Intertidal area	-	-	702	715	713	10.9	2	-2	0
Subtidal	-	-	57	52	51	-6.1	-11	0	-1
Saltmarsh Extent	136	74	78	82.8	82.9	4.9	6	0	0
Estuarine Shrub	14.6	5.7	3	4.8	3.4	0.4	13	-1	-29
Tussockland	1.6	1.3	0.3	0.1	0.3	0	0	0	200
Sedgeland	-	0.06	0.2	0.6	0.6	0.4	200	0	0
Reedland	-	-	0	0.2	0	0	0	0	-100
Rushland	82.3	40.8	42.2	45.5	45.6	3.4	8	0	0
Herbfield	52.4	31.4	32.4	31.6	33.1	0.7	2	2	5
Seagrass (>50% cover)	-	0.2	0.9	2	3.1	2.2	244	1	55
Macroalgal beds (>50% cover)	3.4	18.6	20.2	78.9	30.6	10.4	51	-48	-61
Macroalgal beds (>20% cover)	-	-	41.4	82.3	31.9	-9.5	-23	-50	-61
HECs	1	-	20.1	62.4	30.4	10.3	51	-32	-51
Mud-dominated sediment	-	-	198.7	244.2	222.3	23.6	12	-22	-9

Key Estuary features (% of estuary)					
Year	1947	1988	2006	2013	2019
Saltmarsh Extent	16.9	9.6	10.3	10.8	10.8
Estuarine Shrub	1.8	0.7	0.4	0.6	0.4
Tussockland	0.2	0.2	0.0	0.0	0.0
Sedgeland	-	0.01	0.0	0.1	0.1
Reedland	-	-	0.0	0.0	0.0
Rushland	10.2	5.3	5.6	5.9	6.0
Herbfield	6.5	4.1	4.3	4.1	4.3
Seagrass (>50% cover)	-	0.03	0.1	0.3	0.4
Macroalgal beds (>50% cover)	0.4	2.4	2.7	10.3	4.0
Macroalgal beds (>20% cover)	-	-	5.5	10.7	4.2
HECs	0.1	-	2.6	8.1	4.0
Mud-dominated sediment	-	-	26.2	31.8	29.1

Source:
1947, 1988 Clark & Gillespie (2007) - review of aerial photos indicates data may be unreliable
2006 Clark et al. (2006) - revised following QAQC of Cawthrobn GIS files supplied by TDC
2013 Stevens & Robertson (2013) - revised following QAQC of GIS files

		2006		2013		2019	
Substrate (intertidal flats)		Ha	%	Ha	%	Ha	%
Artificial	Artificial substrate	-	-	0.2	0.03	0.7	0.1
Bedrock	Rock field	-	-	0.1	0.02	-	-
Boulder/ Cobble/ Gravel	Artificial boulder field	-	-	1.6	0.2	3.5	0.5
	Cobble field	23.9	3.4	4.8	0.7	6.4	0.9
	Gravel field	22.8	3.2	52.7	7.4	56.1	7.9
Sand	Mobile sand (0-10% mud)	18.9	2.7	6.2	0.9	15.2	2.1
	Firm shell/sand (0-10% mud)	-	-	-	-	1.6	0.2
	Firm sand (0-10% mud)	225.5	32.1	224.3	31.4	173.4	24.3
	Soft sand (0-10% mud)	-	-	-	-	1.3	0.2
Muddy Sand	Mobile muddy sand (>10-25% mud)	-	-	-	-	0.3	0.05
	Firm muddy sand (>10-25% mud)	176	25.1	126.5	17.7	149.6	21
	Soft muddy sand (>10-25% mud)	-	-	29.2	4.1	27.6	3.9
	Mobile muddy sand (>25-50% mud)	-	-	-	-	1.6	0.2
	Firm muddy sand (>25-50% mud)	35.6	5.1	7.7	1.1	17.8	2.5
	Soft muddy sand (>25-50% mud)	-	-	15.6	2.2	27.9	3.9
Sandy Mud	Firm sandy mud (>50-90% mud)	97.5	13.9	2	0.3	9.7	1.4
	Soft sandy mud (>50-90% mud)	74.3	10.6	71.1	9.9	46.6	6.5
	Very soft sandy mud (>50-90% mud)	26.9	3.8	157.8	22.1	155	21.7
Mud	Soft/very soft mud (>90% mud)	-	-	3.7	0.5	-	-
	Firm mud (>90% mud)	-	-	9.6	1.3	10.9	1.5
Zootic	Cocklebed	1.1	0.2	-	-	4.7	0.7
	Oyster reef	-	-	0.1	0.02	0.1	0.02
	Sabellid field	-	-	0.9	0.1	0.7	0.1
	Shell bank	0.02	0.003	1.1	0.2	2.5	0.3
Grand Total		702.4	100	715.3	100	713.3	100

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