coastalmanagement

Duncan, Harvey and Tuna Bays

Broad Scale Habitat Mapping 2018

Prepared
for

**Marlborough
District
Council**

**June
2018**

Cover Photo: Harvey Bay, estuarine rushland flanked by bush clad hillsides, March 2018.

Intertidal herbfield and rushland at the head of Harvey Bay, March 2018

Duncan, Harvey and Tuna Bays

Broad Scale Habitat Mapping 2018

Prepared for
Marlborough District Council

by

Leigh Stevens

Wriggle Limited, PO Box 1622, Nelson 7040, Ph 021 417 936, www.wriggle.co.nz

RECOMMENDED CITATION:
Stevens, L.M. 2018. Duncan, Harvey and Tuna Bays: Broad Scale Habitat Mapping 2018. Report prepared by Wriggle Coastal Management for Marlborough District Council. 31p.

Contents

List of Tables

List of Figures

All photos by Wriggle except where noted otherwise.

EXECUTIVE SUMMARY

Duncan, Harvey and Tuna Bay estuaries are three shallow intertidal dominated estuaries (SIDEs) located within the upper tidal reaches of the Tawhitinui Reach of the Pelorus Sound/Te Hoiere, Marlborough. They are relatively unmodified, small sized (14, 16, 25ha respectively), macrotidal (>1.6m spring tidal range), shallow (mean depth ~1m at high water), well-flushed (residence time <1 day), and seawater-dominated. The catchments are dominated by native scrub and forest (92-95%). The estuaries are priorities within Marlborough District Council's (MDC's) long-term coastal monitoring programme. This report presents the results of the March 2018 broad scale estuary habitat mapping, including discussion of estuary condition and issues and monitoring recommendations.

BROAD SCALE RESULTS

All three estuaries are similar in nature and are summarised together below.

- Intertidal substrates were dominated by well oxygenated cobble and gravel (60-79%) with soft mud (0-14%) limited in extent, a risk rating of LOW-MODERATE. Within localised mud habitat, sediment mud content was 52-72%, a risk rating of HIGH.
- Opportunistic macroalgal growth was absent, and no gross eutrophic zones were present, a risk rating of LOW.
- Seagrass (*Zostera muelleri*) was relatively extensive (6-19%), a condition rating of GOOD.
- Saltmarsh cover was relatively extensive 11.4ha (13-17% of the intertidal area), a condition rating of GOOD. It was dominated by rushland (51-69%) and herbfields (24-40%).
- 66-77% of the 200m terrestrial margin was densely vegetated, a risk rating of LOW.

Dominant Estuary Feature	Duncan Bay		Harvey Bay		Tuna Bay	
	ha	%	ha	%	ha	%
Intertidal saltmarsh	1.9	13.4	2.7	16.7	4.0	15.9
Intertidal seagrass (>20% cover)	1.5	10.6	0.9	5.7	4.6	18.5
Intertidal macroalgal beds (>50% cover)	0.0	0.0	0.0	0.0	0.0	0.0
Intertidal substrate (unvegetated)	5.4	38.0	9.5	59.6	10.4	41.5
Intertidal Total	8.8	62.0	13.1	81.9	19.0	75.9
Subtidal Total	5.4	38.0	2.9	18.1	6.0	24.1
Total Estuary	**14.2**	**100**	**16.0**	**100**	**25.0**	**100**

ESTUARY CONDITION AND ISSUES

Broad scale habitat mapping undertaken in March 2018, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification), have been used to assess overall estuary condition. The dominant substrates were well oxygenated cobble and gravel with only small areas of soft mud. Soft muds were concentrated in the lower tidal reaches of the estuary where mud settlement most likely reflects reduced current flows and the presence of sheltered deposition zones. Deeper subtidal habitat just offshore is the most likely settlement area for fine sediments.

The estuaries were not expressing eutrophic symptoms (no significant opportunistic macroalgal growth), with low ETI scores (ratings of Very Good or Good). All had relatively large beds of seagrass, healthy and intact saltmarsh contiguous with native forest at the estuary edge, and native forest dominated catchments. Historical habitat loss and modification has been relatively small in extent. Consequently commonly observed catchment based stressors, particularly excessive inputs of fine sediment and nutrients, were not significant issues in the estuaries.

The combined results place the estuaries in a GOOD state overall in relation to ecological health.

RECOMMENDED MONITORING

Duncan, Harvey and Tuna Bay estuaries have been identified by MDC as priorities within a coastal and estuarine monitoring programme being undertaken throughout the region as they have high ecological and human use values. The following monitoring recommendations are proposed for consideration by MDC:

Broad Scale Habitat Mapping. To characterise any issues of change in habitat (e.g. soft mud extent, saltmarsh or seagrass area), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for consideration in 2028), unless obvious changes are observed in the interim.

Fine Scale Monitoring. The large extent of catchment native forest cover, and the absence of significant estuary issues, suggests little need for intensive fine scale monitoring. However, it is recommended that consideration be given to establishing a long term fine scale monitoring site in Harvey Bay as a reference location against which results from other monitoring in the Marlborough Sounds can be compared. Because of the potential for increased sediment inputs to occur following future forest harvesting adjacent to Tuna Bay estuary, it is recommended that a series of sediment plates be buried in likely deposition areas within both Tuna Bay and Harvey Bay, the latter acting as a reference site.

1. INTRODUCTION

1.1 PROJECT BRIEF

The Marlborough District Council (MDC) coastal monitoring strategy (Tiernan 2012) identifies priorities for long-term coastal and estuarine monitoring in the region including broad scale habitat mapping and fine scale monitoring of intertidal sediments in key estuaries. As part of this work, MDC recently engaged Wriggle Coastal Management to map the broad scale intertidal habitat features of Duncan, Harvey and Tuna Bay estuaries located at the head of Tennyson Inlet in the Tawhitinui Reach of Pelorus Sound, Marlborough (Figure 1). The purpose of the work was to provide MDC with baseline information on the ecological condition of each site for state of the environment monitoring purposes and to help support planning and resource consent decision-making. The following report describes the methods and results of field sampling undertaken on 19 March 2018.

1.2 BACKGROUND

Estuary monitoring in NZ generally comprises three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) to address major issues identified in NZ estuaries (see Appendix 1). The tiered approach includes:

i. Ecological Vulnerability Assessment (EVA) of estuaries to major issues and the design of prioritised and targeted monitoring programmes. This has been partially completed within the MDC coastal monitoring strategy (Tiernan 2012) and in reports documenting ecologically significant marine sites in Marlborough (e.g. Davidson et al. 2011). The specific vulnerability of Duncan, Harvey and Tuna Bay estuaries to key issues has not yet been specifically assessed.

ii. Broad Scale Habitat Mapping (NEMP approach). This component documents the key bio-physical features and habitats within the estuary, enables changes to these habitats to be assessed over time, and is used to define fine scale monitoring needs and management priorities.

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

The current report focuses on detailed broad scale habitat mapping undertaken in March 2018 to assess the current state of the estuaries and uses a range of established broad scale indicators to assess ecological condition. Key indicators are described in Appendix 1 and include mapping and assessment of:

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

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

1.3 REPORT STRUCTURE

The current report presents a brief introduction to the estuaries being assessed (Section 1.4), the sampling methods, monitoring indicators and assessment criteria used (Section 2), and results and discussion of the field sampling (Section 3). To help the reader interpret the findings, results are related to relevant condition or risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 4), and to guide monitoring recommendations (Section 5).

Figure 1. Location of Duncan, Harvey and Tuna Bay estuaries, Tennyson Inlet, Marlborough.

1. INTRODUCTION (CONTINUED)

1.4 STUDY SITES

Duncan, Harvey and Tuna Bay estuaries are located within Tennyson Inlet, ~30km north of the Rai Valley township. All three estuaries are relatively small (14, 16, 25ha respectively) shallow intertidal dominated estuaries (SIDEs) located within the upper tidal reaches of the Tawhitinui Reach of the Pelorus Sound, a 43km long, 435km^2, deep, subtidally dominated estuary (DSDE) (Figure 1).

The estuaries are all very similar with a north-northeast aspect and wide shallow deltas that extend seawards until dropping off sharply into deeper waters. Freshwater inflows are relatively small and can dry up in summer, but respond quickly to catchment rainfall and flows can quickly increase causing the stream channels that cross the estuary deltas to be relatively mobile.

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

The catchments surrounding the estuary areas are steep with erodible geology, but are relatively small, have land cover that is dominated by pristine beech and podocarp forest, and have small freshwater flows. Consequently, the estuarine deltas are relatively small (14-25ha), are dominated by cobble and gravel substrates, and naturally support only small areas of saltmarsh. Fine sediment deposited in intertidal areas is generally re-suspended by localised tidal and wave action and settles in the deeper waters of the subtidal zone - the predominant area of fine sediment deposition in the Marlborough Sounds (see Handley et al. 2017). Once in the deeper sheltered subtidal waters, fine sediments generally accumulate and remain stable on the seabed, but can be re-mobilised and redistributed by current and wave action, particularly in shallower areas. The steep and rocky shorelines further offshore are well flushed and do not readily trap fine sediments.

Land cover in the upper catchment is predominantly native forest (92-95%) with small areas of pastoral farming in the lower catchment. Where valley floors have been developed into pasture there has generally been historical modification of the estuary margins primarily from channelisation and drainage, however saltmarsh is still relatively plentiful.

The estuaries have localised high use and are valued for their aesthetic appeal, bathing, boating, fishing, whitebaiting and beach access. Ecologically they are important for freshwater fish and birds. Duncan Bay is especially popular because it is one of the closest places from Nelson to launch boats in the Marlborough Sounds and is also the trailhead of the popular Nydia Bay walkway.

The estuaries all have relatively low nutrient loads (estimated catchment N areal loading of ~40-60mg N.m^{-2}.d^{-1} which is below the proposed guideline for SIDE estuaries of ~100mgN.m^{-2}.d^{-1}, Robertson et al. 2016), consequently all three estuaries currently have low susceptibility to eutrophication. This is supported by regular observations from Duncan Bay Estuary between 1971 and 2004 which recorded only one macroalgal bloom between Sept. 1980 to Jan. 1981 when 10% of the estuary was covered by *Enteromorpha* (recently renamed *Ulva*) (Bray and Struik 2006).

The ratio of the estimated current suspended sediment load (CSSL) compared to the estimated natural state sediment load (NSSL) is <1.1 in Tuna and Duncan Bays, and 1.3 in Harvey Bay, ETI ratings of very good and good respectively, reflecting the relatively high forest and scrub cover in the catchment. The estuaries are rated as having low vulnerability to muddiness as they are well-flushed, although some sheltered areas are susceptible to localised sediment accumulation and Tuna Bay is vulnerable to increased sediment inputs if exotic forest harvesting in the catchment is not managed appropriately.

2. METHODS

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

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

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

Estuary boundaries were set seaward from a straight line across the enclosing headlands of the intertidal estuary area (as generally defined in the MDC work brief) to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For the current study, LINZ rectified colour aerial photos (~0.1m/pixel resolution) flown in 2017/18 were provided by MDC, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in March 2018 to ground-truth the spatial extent of dominant vegetation and substrate types (see Appendix 6). From representative broad scale substrate types, 6 grain size samples were analysed to validate substrate classifications (Figure 3, Appendix 6). When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2). Notes on sampling, resolution and accuracy are presented in Appendix 5.

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

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

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

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

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

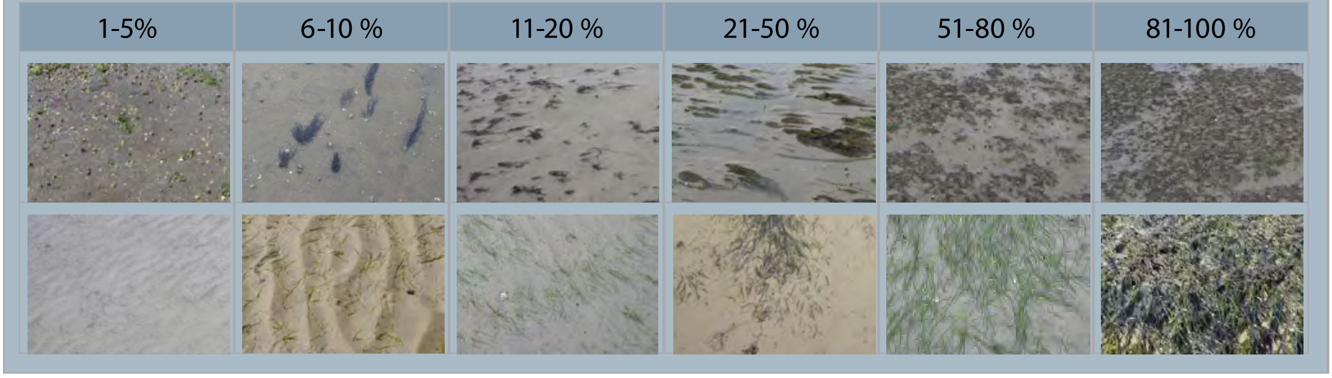


Table 1. Summary of estuary condition and risk indicator ratings used in the present report.

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

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

Native forest contiguous with estuary saltmarsh in Tuna Bay.

3. RESULTS AND DISCUSSION

3.0. BROAD SCALE MAPPING SUMMARY

The 2018 broad scale habitat mapping ground-truthed and mapped intertidal estuary substrate and vegetation as well as the dominant land cover of the 200m terrestrial margin. The dominant estuary features are summarised in Table 2 and shown in Figures 3-8.

All three estuaries are intertidally dominated (62-85%) with extensive unvegetated intertidal flats (38-60%). Saltmarsh (13-14%) was located predominantly at the head of each estuary where valley floors meet the sea. Intertidal seagrass was a relatively significant feature in each estuary (5-15%), and no dense (>50% cover) opportunistic macroalgae was observed. The 200m wide terrestrial margin was dominated by dense vegetation (66-77%), and native forest cover in the surrounding catchments was very high (91-96%).

In the following sections, various factors related to each of these key habitats (e.g. area of soft mud) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification (Table 3). In addition, the GIS files underpinning this written report provide a more detailed spatial record of the key features present throughout each estuary and are intended as the primary supporting tool to help the Council address a suite of estuary issues and management needs, and to act as a baseline to assess future change.

Table 2. Summary of dominant broad scale features, Duncan, Harvey and Tuna Bays, 2018.

Dominant Estuary Feature	Duncan Bay		Harvey Bay		Tuna Bay	
	ha	%	ha	%	ha	%
Intertidal saltmarsh	1.9	13.4	2.7	16.7	4.0	15.9
Intertidal seagrass (>20% cover)	1.5	10.6	0.9	5.7	4.6	18.5
Intertidal macroalgal beds (>50% cover)	0.0	0.0	0.0	0.0	0.0	0.0
Intertidal substrate (unvegetated)	5.4	38.0	9.5	59.6	10.4	41.5
Intertidal Total	8.8	62.0	13.1	81.9	19.0	75.9
Subtidal Total	5.4	38.0	2.9	18.1	6.0	24.1
Total Estuary	**14.2**	**100**	**16.0**	**100**	**25.0**	**100**
200m Terrestrial Margin (densely vegetated)		65.5		75.7		77.0
Catchment native forest cover	736.8	95.3	676.9	91.3	1811.5	95.7

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

Supporting Condition Measures	Duncan Bay	Harvey Bay	Tuna Bay
Catchment Area (Ha)*	773	657	1892
Mean freshwater flow (m^3/s)*	0.21	0.22	0.52
Catchment nitrogen load (TN/yr)*	2.51	2.46	6.03
Catchment phosphorus load (T/Pyr)*	0.49	0.51	1.05
Catchment sediment load (KT/yr)*	3.4898	5.1255	6.7116
Estimated N areal load in estuary ($mg/m^2/d$)	49.2	42.1	66.0
Estimated P areal load in estuary ($mg/m^2/d$)	9.5	8.7	11.5
Intertidal soft mud extent (%)	9.0	14.1	0.0
Macroalgal OMBT EQR score	1	1	1
Saltmarsh (est. natural % remaining)	>80	>80	>80
200m land margin (% densely vegetated)	65.5	75.7	77.0
ETI susceptibility (Tool 1)	LOW	LOW	LOW
NZ ETI score (Tool 2)	0.29	0.29	0.09

*source NIWA Coastal Explorer database and CLUES model output.

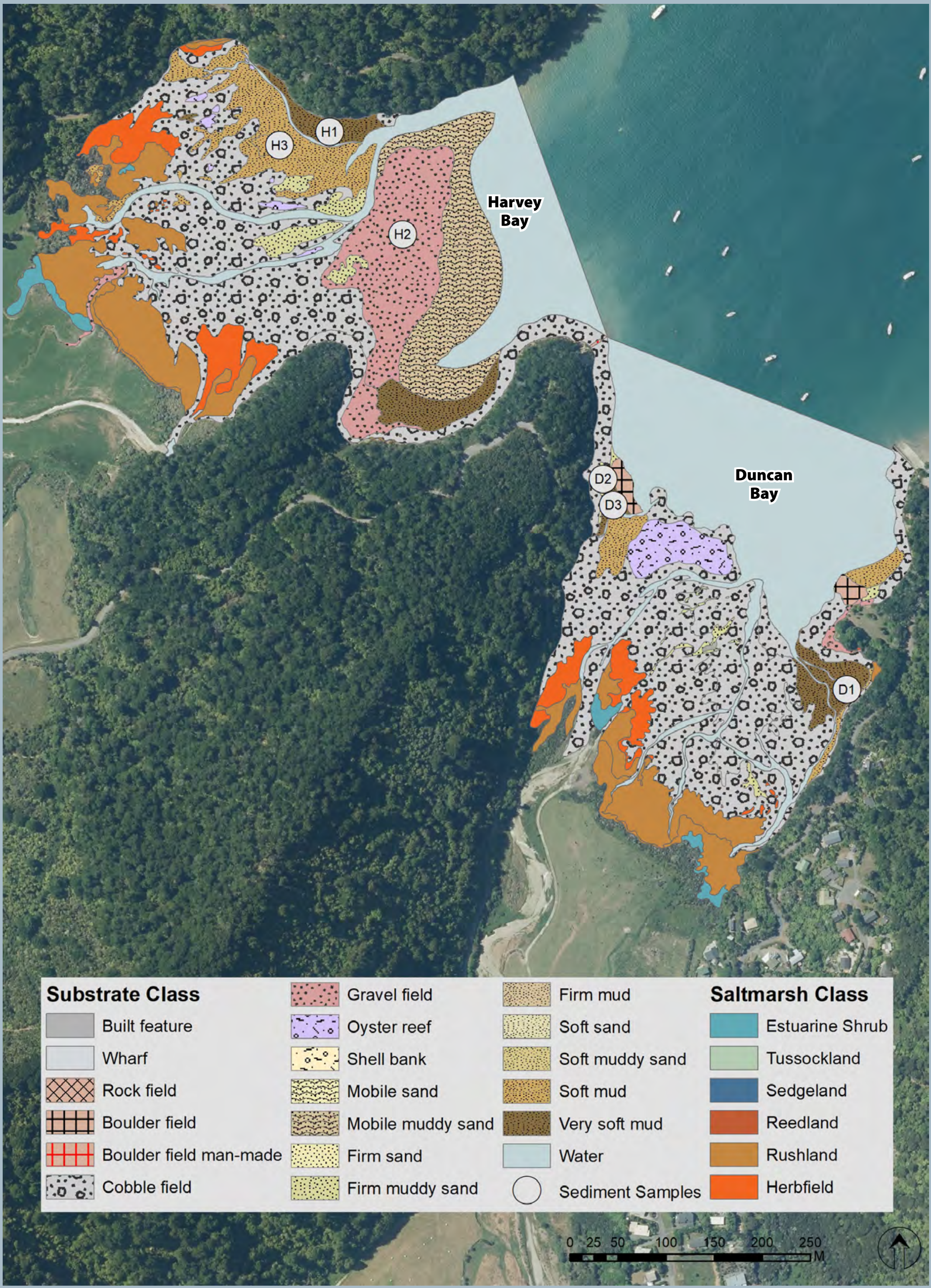
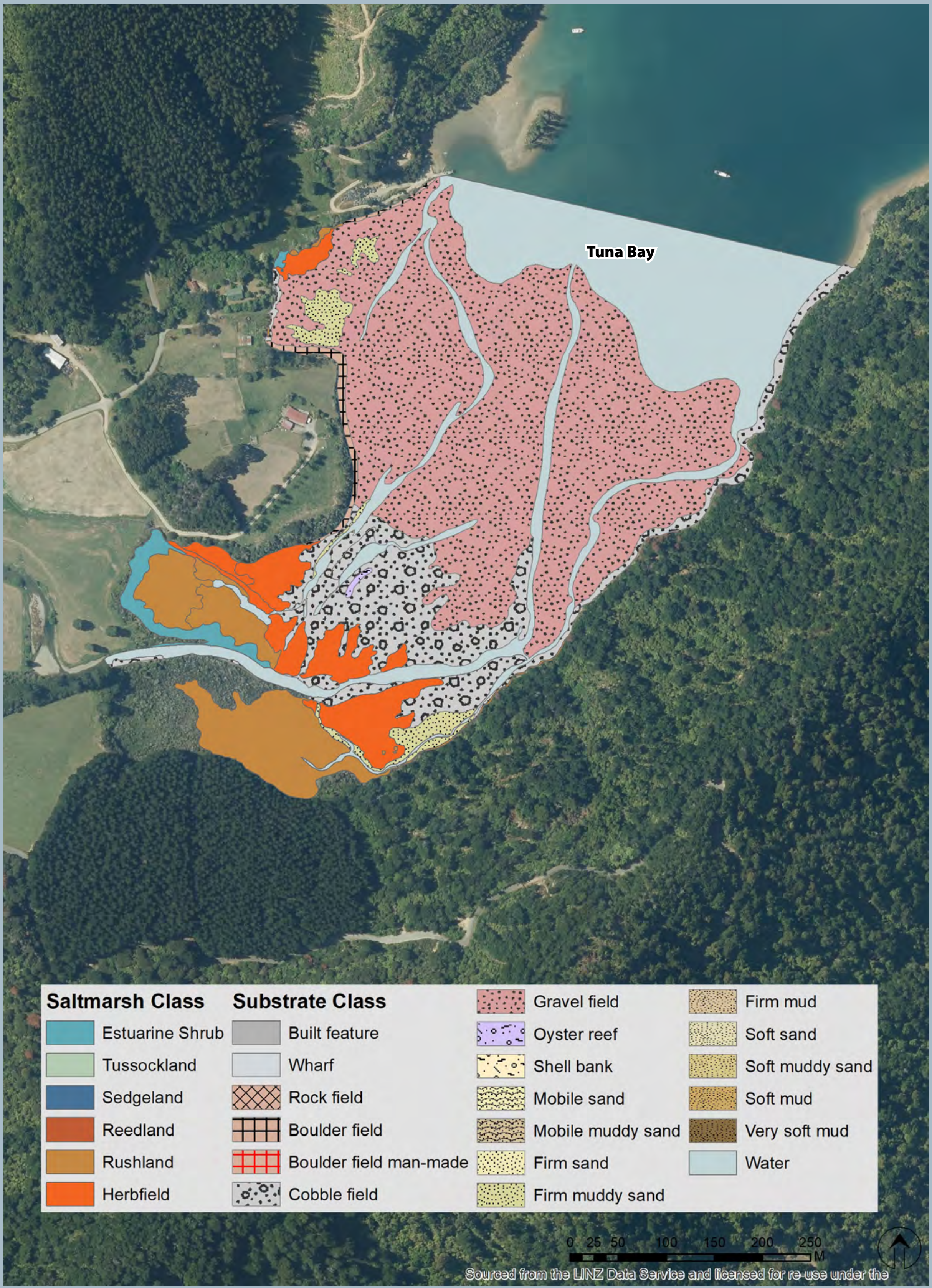


Figure 3. Map of dominant intertidal saltmarsh and substrate - Duncan and Harvey Bay estuaries, March 2018.



Sourced from the LINZ Data Service and licensed for re-use under the

Figure 4. Map of dominant intertidal saltmarsh and substrate - Tuna Bay estuary, March 2018.

3. RESULTS AND DISCUSSION (CONTINUED)

3.1. INTERTIDAL SUBSTRATE

Results summarised in Table 4 and Figures 3 and 4 show intertidal substrate was dominated by cobble/gravel fields (76%, 60% and 79% respectively at Duncan, Harvey and Tuna Bays). This hard substrate was present throughout the upper intertidal zone, often as a perched but mobile delta around stream margins, and with cross-shore zonation evident with cobbles dominating the upper shoreline, and finer substrates more common on the lower shoreline.

While mud dominated habitat was not particularly widespread, it did overlay buried cobble fields on the lower shoreline and accumulated within Pacific oyster beds, although these were not very common. Infilling of interstitial spaces with sand and muds was most common in the lower third of the tidal range, and most evident in small settlement basins on the true left and true right of each bay (e.g. Figure 3). Soft muds were also evident in the shallow subtidal zone with regular tidal and wave action likely to mobilise fine material from the intertidal zone and deposit it in the subtidal zone where it settles and is retained.

The seaward edge of the Harvey Bay tidal delta had the largest extent of intertidal substrate dominated by finer sediments (mobile muddy sands). This substrate is the most similar to that commonly included in fine scale state of the environment monitoring programmes undertaken using the NEMP and may thus be a useful potential reference site within the Marlborough Sounds for comparing differences to existing monitoring sites impacted by land use change e.g. Havelock, Mahakipawa and Kaiuma estuaries.

Within vegetated areas, substrate among herbfields was predominantly cobble and gravel dominated, while substrate among rushland was dominated by firm mud or muddy sand. Seagrass beds, which were present in all three estuaries, were growing in sand and mud substrates, often located in small depressions among cobble beds.

Small beds of Pacific oyster were noted in Duncan and Harvey Bays. These beds were not extensive and appeared to be healthiest in the lower tidal reaches. Dead oyster shells indicated that more extensive beds existed previously, but have subsequently died back to remnant areas. No beds of mussels or other biogenic habitats e.g. tube worm reefs, were noted.

Table 4. Summary of dominant intertidal substrate in Duncan, Harvey and Tuna Bays, 2018.

Dominant Estuary Feature	**Duncan Bay**		**Harvey Bay**		**Tuna Bay**	
	ha	**%**	**ha**	**%**	**ha**	**%**
Intertidal substrate within saltmarsh						
Cobble field	-	-	1.11	8.5	0.57	3.0
Gravel field	1.33	15.1	0.23	1.8	0.31	1.6
Firm muddy sand	0.57	6.5	1.16	8.8	3.11	16.4
Soft mud	-	-	0.16	1.3	-	-
Intertidal substrate outside of saltmarsh						
Boulder field	0.16	1.8	-	-	0.21	1.1
Boulder field man-made	0.00	0.0	-	-	-	-
Cobble field	5.28	60.1	4.51	34.4	3.06	16.1
Gravel field	0.06	0.6	1.99	15.2	11.11	58.6
Oyster reef	0.44	5.0	0.08	0.6	0.02	0.1
Mobile muddy sand	-	-	1.68	12.8	-	-
Firm muddy sand	0.15	1.7	0.35	2.6	0.58	3.0
Soft mud	0.36	4.0	1.20	9.2	-	-
Very soft mud	0.44	5.0	0.64	4.9	-	-
Grand Total	**8.8**	**100**	**13.1**	**100**	**19.0**	**100**

3.2. EXTENT OF SOFT MUD

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

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

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

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

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

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Table 3 shows that no areas within Tuna Bay were classified as being dominated by soft muds, compared to 9% and 15% of the habitat in Duncan and Harvey Bays, a risk rating of MODERATE. In both of the latter bays the deposition zones were away from the main stream flow paths in the central bay and in relatively low-lying quiescent zones where cobble and gravel sediment had not built up. There were also areas of soft mud accumulation within hollows among cobble and gravel beds, areas that also commonly supported seagrass growth. Compared to other estuaries in the Marlborough Sounds, the extents of soft mud were relatively low (Figure 5), a likely reflection of the relatively small and native forest dominated catchments. Within very soft mud habitat in the estuaries, the measured mud contents were 52-72%, which is well within the HIGH risk indicator rating band (>25%). Overall soft mud issues appear to be relatively localised within each estuary and are unlikely to deteriorate if the native forest cover in the catchment remains intact. Because of the potential for increased sediment inputs to occur following future forest harvesting adjacent to Tuna Bay estuary, it is recommended that a series of sediment plates be buried in likely deposition areas within both Tuna Bay and Harvey Bay, the latter acting as a reference site.

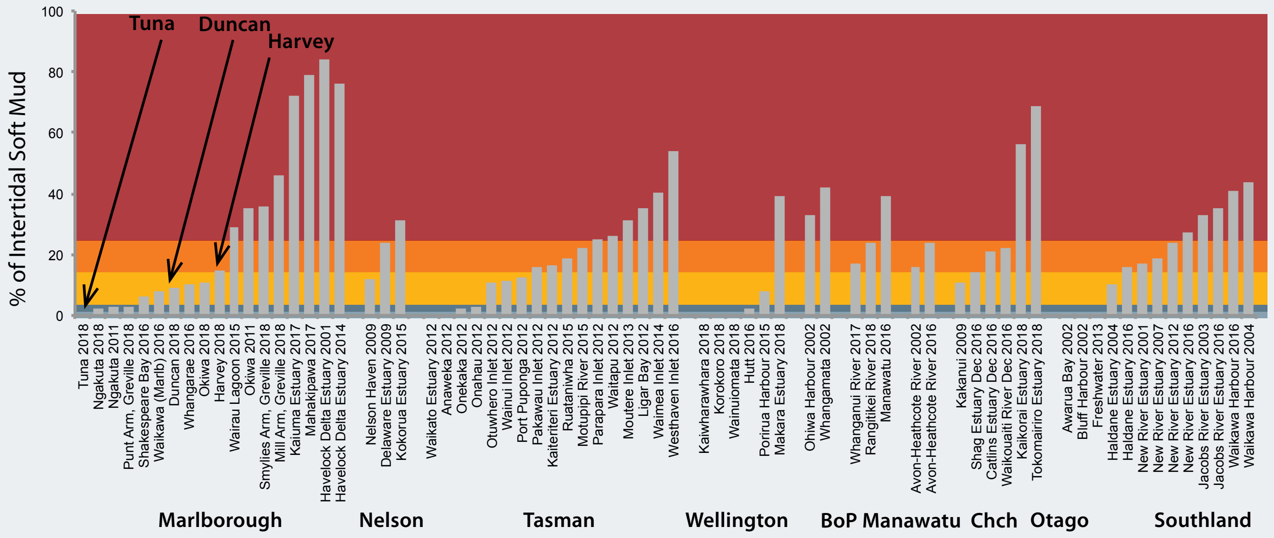


Figure 5. Percentage of intertidal estuary with soft mud habitat for various NZ tidal lagoon and delta estuaries (shallow, intertidal dominated, residence time <3 days - data from Wriggle monitoring reports 2006-2018 and Robertson et al. 2002).

3. RESULTS AND DISCUSSION (CONTINUED)

Duncan Bay: Dominant cobble and gravel habitat.

Harvey Bay: Mobile muddy sands and with Pacific oysters in the lower tidal reaches.

Tuna Bay: Extensive gravel and cobble sediments on the estuary delta.

3.3. SEDIMENT OXYGENATION

The primary indicator used to assess sediment oxygenation was the visually apparent aRPD depth. This indicator was measured within representative intertidal sediments throughout the estuaries and results used to assess which parts of the estuary had sediment oxygen depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) might be expected. Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that reduced oxygen zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

The broad scale field measurements found the dominant sand and gravel sediments in the estuaries to be generally well oxygenated with the aRPD depth at ~2-5cm. This appears to be maintained largely as a consequence of open interstitial spaces within the sediment matrix allowing for the free exchange of oxygen from either the atmosphere or from seawater. The only areas indicating reduced sediment oxygenation were within relatively small areas of soft muds (Figure 3). Where muds supported seagrass, oxygen levels were good, but in unvegetated muds the average aRPD depth was ~0.5 to 1cm equating to a measured RP of -50 to -150mV at 1cm. However, as mud-dominated habitat appeared to have low levels of organic enrichment and was confined to relatively small areas in the estuaries, a LOW risk rating for this indicator has been applied.

3.4. OPPORTUNISTIC MACROALGAE

Intertidal macroalgal cover was absent in March 2018 and consequently the macroalgae quality status is HIGH, and the risk rating LOW with no further enumeration needed. When present, opportunistic macroalgae are a primary symptom of estuary eutrophication because they are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species. At nuisance levels they can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Macroalgae that becomes detached can also accumulate and decay in subtidal areas and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the subsequent impacts.

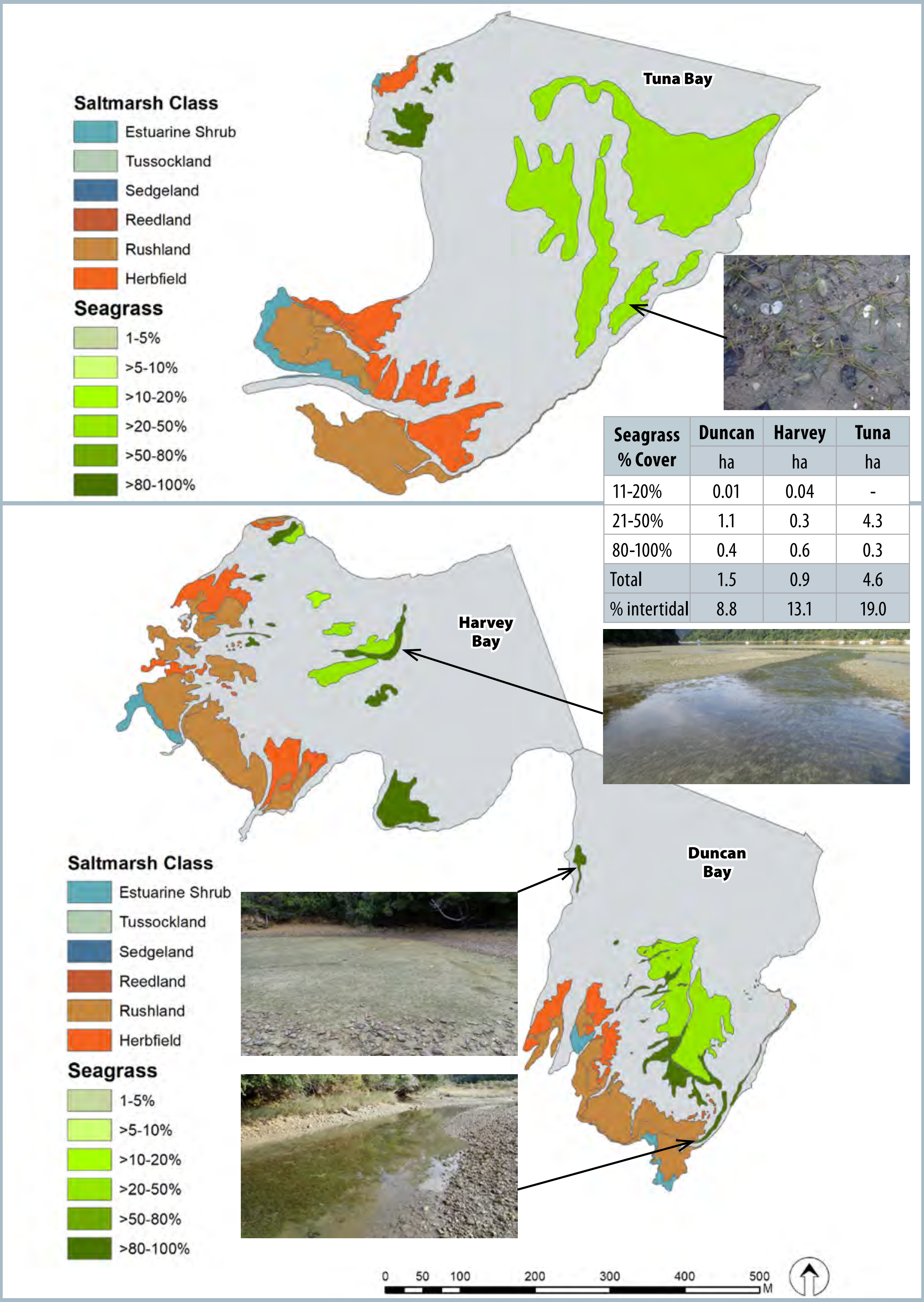
If there is >5% cover, opportunistic macroalgal growth is assessed by mapping the spatial spread and density in the Available Intertidal Habitat (AIH) and calculating an OMBT “Ecological Quality Rating” (EQR) (WFD UKTAG, 2014). If the estuary supports <5% opportunistic macroalgal cover within the AIH, overall quality status is reported as HIGH with no further sampling required.

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

Figure 6 shows intertidal seagrass beds were present in all three estuaries. Seagrass was relatively widespread with the highest density (80-100%) growing in submerged channels regularly flushed by freshwater inputs. On the open flats, which are subjected to longer periods of drying and reduced flushing, seagrass was patchier in distribution and density was generally lower (20-40% cover). Most beds were nestled within depressions in cobble and gravel habitat and growing in sand and muddy sand. Beds in the low tide zone were often covered in a fine layer of mud making them hard to distinguish visually during field mapping and on aerial photographs.

In the absence of any comprehensive rating of seagrass extent within NZ estuaries, which can be highly variable in the extent of seagrass that they support, changes from a documented baseline currently represent the most reliable method for monitoring seagrass extent and assessing change. The current study has provided baseline maps of seagrass extent for this purpose. Based on the presence of healthy seagrass in each estuary, the absence of macroalgae growing on beds, and no evidence of seagrass wasting disease, a condition rating of GOOD has been applied.



Seagrass % Cover	Duncan	Harvey	Tuna
	ha	ha	ha
11-20%	0.01	0.04	-
21-50%	1.1	0.3	4.3
80-100%	0.4	0.6	0.3
Total	1.5	0.9	4.6
% intertidal	8.8	13.1	19.0

Figure 6. Map of intertidal saltmarsh and seagrass (*Zostera muelleri*) - Duncan, Harvey and Tuna Bay estuaries, March 2018.

3. RESULTS AND DISCUSSION (CONTINUED)

3.6. SALTMARSH

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

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 5 and Figure 6 summarise the 2018 results. Saltmarsh areas were relatively small (1.9-4.0ha) but comprised 13-17% of the intertidal area, a condition rating of GOOD. Saltmarsh was dominated by rushland comprising searush and jointed wire rush in relatively wide beds at the head of each estuary, and also in narrow strips and as isolated beds along the edges. Herbfields were also prominent, commonly growing seaward of the rushland beds and also as a subdominant cover among rushland. Primrose and remuremu were the dominant species, and formed a dense turf community among gravel beds. Saltmarsh ribbonwood was the other dominant saltmarsh class in the upper estuary, often with a mix of terrestrial grasses and weeds and native shrubs at the terrestrial edge. Page 15 presents photos of representative saltmarsh growing throughout the three estuaries. A small population of the nationally declining sea sedge *Carex litorosa* was present in the small bay in the north west of Tuna Bay on a gravel stream fan. It was not recorded from Duncan or Harvey Bays.

A supporting measure for saltmarsh is estimated loss compared to expected natural state cover. While assumptions need to be made regarding likely historical extent, the current saltmarsh extent appears to be relatively unmodified other than small losses from upper estuary areas historically drained and converted to pasture. It is estimated that <20% of saltmarsh has been lost from the estuaries, a supporting risk rating of VERY LOW. The combined overall risk rating was assessed as LOW recognising that saltmarsh remains a significant and relatively unmodified feature within each estuary.

Table 5. Summary of dominant saltmarsh cover, Duncan, Harvey and Tuna Bays, 2018.

Saltmarsh Class, Dominant and subdominant species	Duncan Bay		Harvey Bay		Tuna Bay	
	ha	%	ha	%	ha	%
Estuarine Shrub	0.134	7.0	0.1	5.5	0.4	9.3
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.13		0.01		0.37	
Juncus kraussii (Searush)			0.14			
Rushland	1.31	68.8	1.8	66.66	2.0	50.9
Apodasmia similis (Jointed wirerush)	0.13				0.06	
Juncus kraussii (Searush)			0.06			
Samolus repens (Primrose)	0.01					
Juncus kraussii (Searush)	0.48		0.20		1.97	
Apodasmia similis (Jointed wirerush)	0.12					
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.25		0.35			
Samolus repens (Primrose)	0.06		1.02			
Selliera radicans (Remuremu)	0.26		0.15			
Sedgeland					0.0005	0.01
Carex litorosa					0.0005	
Herbfield	0.46	24.2	0.7	27.8	1.6	39.7
Samolus repens (Primrose)	0.02		0.04			
Selliera radicans (Remuremu)	0.00		0.31		0.07	
Carex litorosa					0.12	
Isolepis cernua (Slender clubrush)	0.00					
Juncus kraussii (Searush)	0.44		0.40		1.39	
Grand Total	**1.90**	**100**	**2.7**	**100**	**4.0**	**100**

3. RESULTS AND DISCUSSION (CONTINUED)

Duncan Bay: Extensive herbfield and searush growing in cobbles and gravels.

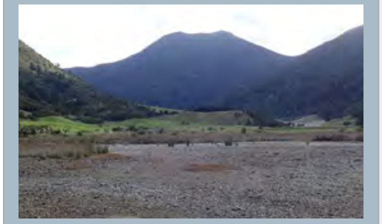
Harvey Bay: Herbfield growing in cobble and searush in mud habitat in the upper tidal range.

Tuna Bay: Herbfield and rushland in the sheltered upper reaches of the estuary.

Tuna Bay: *Carex litorosa* in cobble and gravel habitat in the north west of the estuary.

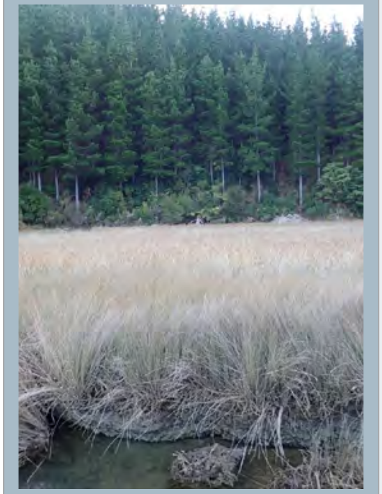
3.7. 200m TERRESTRIAL MARGIN

Native forest growing to the estuary edge in Duncan Bay.



Developed pasture in the valley floor of Harvey Bay.

Native forest growing to the estuary edge in Harvey Bay.



Exotic forest adjacent to the estuary, Tuna Bay.

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity. The results of the 200m terrestrial margin mapping of the estuary are presented in Table 6 and Figure 7 and show all three estuaries had a large proportion of the margin densely vegetated (65-77%), a risk indicator rating of LOW (i.e. good condition). The ecological value of the margin areas is significantly enhanced by the adjoining stands of terrestrial native forest on the steep hillsides flanking the seaward edges of each estuary. This particularly helps to buffer the estuary against localised sediment inputs and introduced weeds, and supports regionally rare ecological connectivity between the estuary and surrounding natural habitats. A small area of residential development is present in Duncan Bay.

The greatest area of margin modification is in the valley floors where land has been cleared and converted largely to pasture. Historically these areas would have supported lowland wetlands which apart from their high ecological value, are also very effective at assimilating catchment derived nutrient and sediment inputs. Consequently there is likely to be an increased delivery of sediment and nutrients to the estuaries compared to natural state conditions, however, this is expected to be small given the dominance of native forest cover in the wider catchment.

This is clearly evident in Figure 8 which shows the Duncan, Harvey and Tuna Bay catchments respectively comprise 95, 92, and 95% indigenous native forest and scrub; 3, 8, and 3% high producing grassland; and 0, 0, and 1% exotic forest (source LCDB4, 2012/13). The high cover of native forest and scrub is a strong factor mitigating against adverse effects commonly associated with elevated inputs of sediment, nutrients and pathogens from farming and forestry activities. Harvesting of exotic forestry on the steep hillsides in the lower catchment surrounding the Tuna Bay estuary represents the highest potential for future sediment inputs to the estuary.

Table 6. Summary of 200m terrestrial margin land cover, Duncan, Harvey and Tuna Bays, 2018.

Class	Duncan Bay	Harvey Bay	Tuna Bay
Indigenous Forest	65.5	75.7	42.1
Exotic Forest	0.0	0.0	18.7
Scrub/Forest	0.0	0.0	2.9
Scrub	0.0	0.0	11.3
Estuarine Shrub	0.0	0.0	2.0
High Producing Exotic Grassland	17.4	24.3	21.6
Low Producing Grassland	0.0	0.0	1.5
Built-up Area (settlement)	17.1	0.0	0.0
Total	**100**	**100**	**100**
% Dense vegetated margin	**65.5**	**75.7**	**77.0**

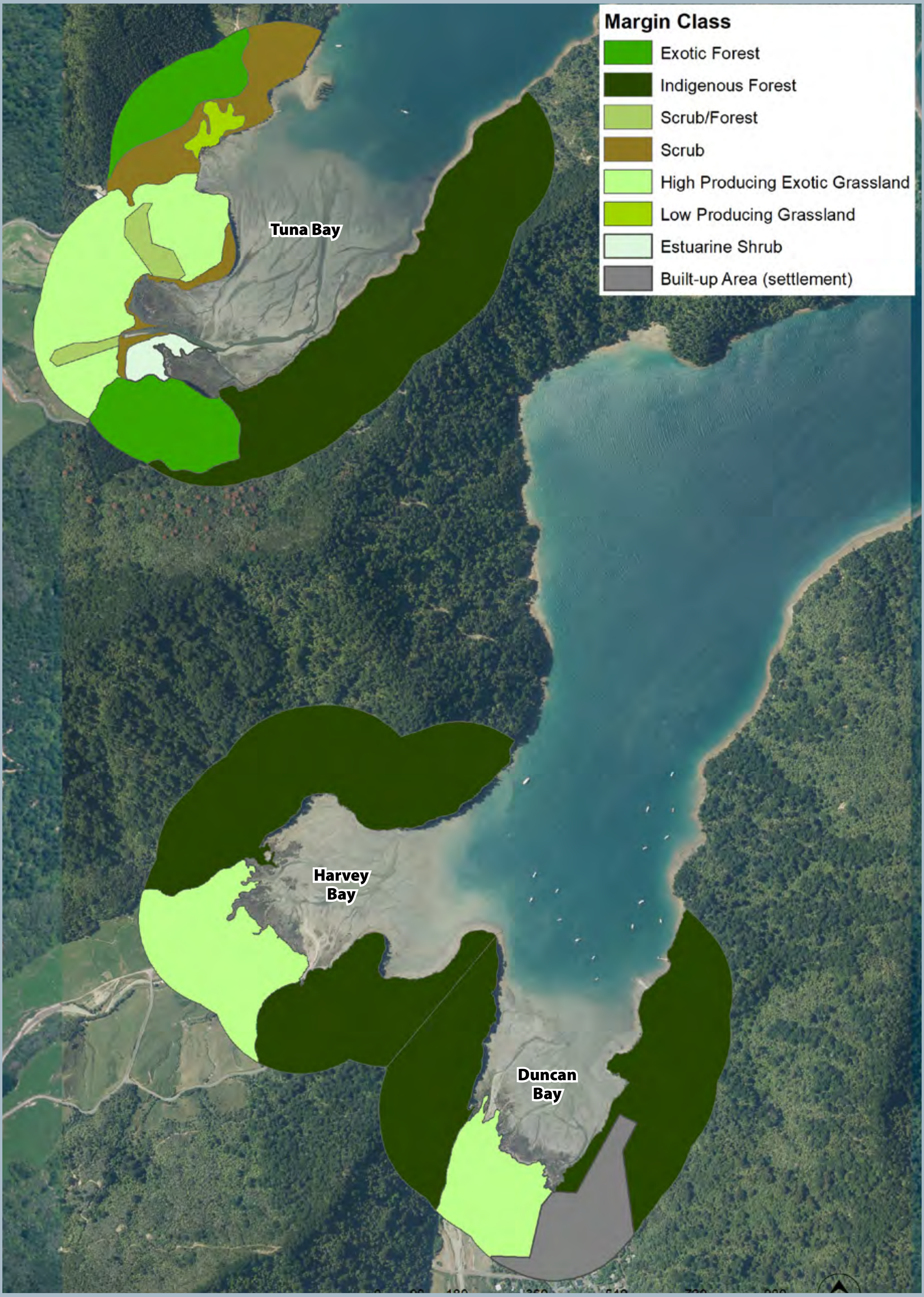
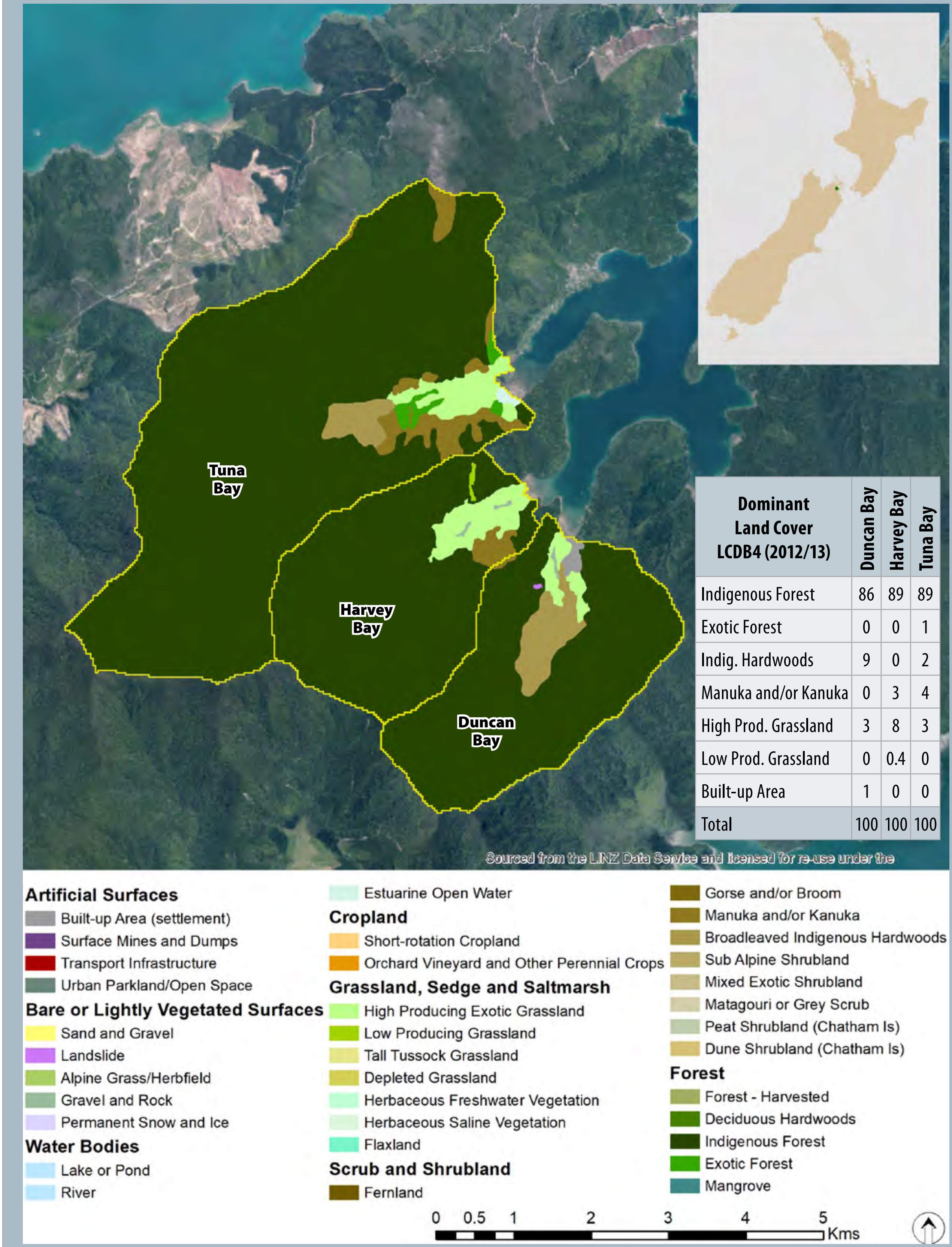


Figure 7. Map of 200m Terrestrial Margin - Dominant Land Cover, Duncan, Harvey and Tuna Bay estuaries, March 2018.



Dominant Land Cover LCDB4 (2012/13)	Duncan Bay	Harvey Bay	Tuna Bay
Indigenous Forest	86	89	89
Exotic Forest	0	0	1
Indig. Hardwoods	9	0	2
Manuka and/or Kanuka	0	3	4
High Prod. Grassland	3	8	3
Low Prod. Grassland	0	0.4	0
Built-up Area	1	0	0
Total	100	100	100

Sourced from the LINZ Data Service and licensed for re-use under the

Figure 8. Summary of Catchment Land Cover (LCDB4 2012/13), Duncan, Harvey and Tuna Bays.

3.8. NZ ESTUARY TROPHIC INDEX

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

The indicators used to derive an ETI score for the estuary are presented below using the broad scale monitoring results presented in this report.

ETI Tool 1 rates the physical and nutrient load susceptibility of all three estuaries as "LOW".

ETI Tool 2 rates eutrophic symptoms scores for the estuaries as either VERY GOOD (Tuna Bay) or GOOD (Duncan and Harvey Bays) indicating that there are no significant issues related to nutrient enrichment evident. In the absence of macroalgal growth, estuary muddiness is the main driver of the score.

Table 7. Primary and supporting indicator values used to calculate an ETI score for Duncan, Harvey and Tuna Bays, 2018.

ETI scoring summary for Duncan, Harvey and Tuna Bays, March 2018.				Duncan	Harvey	Tuna
PRIMARY SYMPTOM INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES **(AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)**				**Primary Symptom Value**		
Required	Opportunistic Macroalgae	OMBT EQR	shallow inter-tidal	1	1	1
	Macroalgal GEZ %	% Gross Eutrophic Zone (GEZ)/Estuary Area		0	0	0
	Macroalgal GEZ Ha	Ha Gross Eutrophic Zone (GEZ)		0	0	0
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	-	-	-
	Cyanobacteria (if issue identified) NOTE ETI rating not yet developed			-	-	-
SUPPORTING INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES **(MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)**				**Supporting Indicator Value**		
Required Indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal			
		% of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm		9	14	0
		Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm		0.8	1.9	0
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area				
	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area				
	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area				
Optional Indicators	Muddy sediment	Proportion of estuary area with >25% mud content	shallow inter-tidal	9	14	0
	Sedimentation Rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL)		1.1	1.3	1.1
	Dissolved oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) ($mg.m^3$)	water column			
NZ ETI Score				**0.31**	**0.31**	**0.09**
				Good	Good	Very Good

4. SUMMARY AND CONCLUSION

Broad scale habitat mapping undertaken in March 2018, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification) have been used to assess overall estuary condition. The dominant substrates were well oxygenated cobble and gravel with only small areas dominated by soft muds. Soft muds were concentrated in the lower tidal reaches of the estuary where mud settlement most likely reflects reduced current flows and the presence of sheltered deposition zones. Deeper subtidal habitat just offshore is the most likely settlement area for fine sediments.

The estuaries were not expressing eutrophic symptoms (no significant opportunistic macroalgal growth), with low ETI scores (ratings of Very Good or Good). All had relatively large beds of seagrass, healthy and intact saltmarsh contiguous with native forest at the estuary edge, and native forest dominated catchments. Historical habitat loss and modification has been relatively small in extent. Consequently commonly observed catchment based stressors, particularly excessive inputs of fine sediment and nutrients, were not significant issues in the estuaries.

The combined results place the estuaries in a GOOD state overall in relation to ecological health.

5. RECOMMENDED MONITORING

Duncan, Harvey and Tuna Bay estuaries have been identified by MDC as priorities for inclusion within a coastal and estuarine monitoring programme being undertaken throughout the region. In order to assess ongoing long-term trends in the condition of estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth or high sedimentation rates), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the inaugural broad scale mapping component of the long term programme. The recommendations for ongoing monitoring for the Duncan, Harvey and Tuna Bay estuaries are as follows:

Broad Scale Habitat Mapping

To characterise any issues of change in habitat (e.g. soft mud extent, saltmarsh or seagrass area), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for consideration in 2028), unless obvious changes are observed in the interim.

Fine Scale Monitoring

The large extent of native forest cover in the catchments surrounding the estuaries, and the absence of significant impacts within them, suggests that there is little direct need for intensive fine scale monitoring. However, because of this very situation, it is recommended that consideration be given to establishing a long term fine scale monitoring site in Harvey Bay as a reference location against which results from other monitoring in the Marlborough Sounds can be compared. This would enable inferences to be made about the potential significance of changes within catchments subjected to higher inputs of sediment and nutrients, or habitat loss. Such information will help support management actions relating to sediment and nutrient inputs that may be considered by MDC.

Because of the potential for increased sediment inputs to occur following future forest harvesting adjacent to Tuna Bay estuary, it is recommended that a series of sediment plates be buried in likely deposition areas within both Tuna Bay and Harvey Bay, the latter acting as a reference site. It is recommended that measurements of sediment accrual and sediment grain size be collected annually for 5 years prior to scheduled harvesting, with a matching frequency post harvesting, to assist MDC in defining the likely impact of this specific land disturbance activity on the estuary.

6. ACKNOWLEDGEMENTS

This survey and report has been undertaken with the support and assistance of Steve Urlich (Coastal Scientist, MDC). His review of this report was much appreciated. I am also very grateful to Sally O'Neill (Wriggle) for help with the field sampling.

7. REFERENCES

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

Bray, J.R. and Struik, G.J. 2006. Fish populations in a tidal estuary in Marlborough Sounds, New Zealand from 1971 to 2004. 749. ISBN 0-473-11195-0. http://www.oceansatlas.org

Davidson R. J., Duffy C.A.J., Gaze P., Baxter, A., du Fresne S., Courtney S., Hamill P. 2011. Ecologically significant marine sites in Marlborough, New Zealand. Co-ordinated by Davidson Environmental Limited for Marlborough District Council and Department of Conservation.

Ellis, J., Cummings, V., Hewitt, J., Thrush, S., Norkko, A. 2002. Determining effects of suspended sediment on condition of a suspension feeding bivalve (Atrina zelandica): results of a survey, a laboratory experiment and a field transplant experiment. Journal of Experimental Marine Biology and Ecology, 267, 147–174.

Handley, S., Gibbs, M., Swales, A., Olsen, G., Ovenden, R., and Bradley, A. 2017. A 1,000 year history of seabed change in Pelorus Sound/Te Hoiere, Marlborough. NIWA Report prepared for Marlborough District Council, Ministry of Primary Industries and the Marine Farming Association. 136p.

Hargrave, B.T., Holmer, M. and Newcombe, C.P. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Marine Pollution Bulletin, 56(5), pp.810–824.

Keeley, N.B. et al. 2012. Exploiting salmon farm benthic enrichment gradients to evaluate the regional performance of biotic indices and environmental indicators. Ecological Indicators, 23, pp.453–466.

Lohrer, A., Thrush, S., Hewitt, J., Berkenbusch, K., Ahrens, M., Cummings, V. 2004. Terrestrially derived sediment: response of marine macrobenthic communities to thin terrigenous deposits. Marine Ecology Progress Series, 273, 121–138.

Mannino, A. and Montagna, P. 1997. Small-Scale Spatial Variation of Macrobenthic Community. Estuaries, 20, 159–173.

Norkko, A., Talman, S., Ellis, J., Nicholls, P. and Thrush, S. 2002. Macrofaunal Sensitivity to Fine Sediments in the Whitford Embayment. Auckland Regional Council, Technical Publication, 158, 1–30.

Peeters, E., Gardeniers, J., Koelmans, A. 2000. Contribution of trace metals in structuring in situ macroinvertebrate community composition along a salinity gradient. Environmental Toxicology and Chemistry, 19, 1002–1010.

Rakocinski, C., Brown, S., Gaston, G., Heard, R., Walker, W. and Summers, J. 1997. Macrobenthic Responses to Natural and Contaminant-Related Gradients in Northern Gulf of Mexico Estuaries. Ecological Applications, 7, 1278–1298.

Robertson, B.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., Thompson, S.J., Tuckey, B.J. 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, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and 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, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016b. NZ Estuary Trophic Index. Screening Tool 2. 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.

Sakamaki ,T., Nishimura, O. 2009. Is sediment mud content a significant predictor of macrobenthos abundance in low-mud-content tidal flats? Marine and Freshwater Research, 60, 160.

Thrush, S.F., Hewitt, J., Norkko, A., Nicholls, P., Funnell, G. and Ellis, J. 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progress Series 263, 101–112.

Tiernan, F. 2012. Coastal Monitoring Strategy, Marlborough. MDC Report No 12-101.

Wehkamp, S., Fischer, P. 2012. Impact of hard-bottom substrata on the small-scale distribution of fish and decapods in shallow subtidal temperate waters. Helgoland Marine Research, 67, 59–72.

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.

References for Appendix 1

Abrahim, G. 2005. Holocene sediments of Tamaki Estuary: characterisation and impact of recent human activity on an urban estuary in Auckland, NZ. PhD Thesis, University of Auckland, Auckland, NZ, p 361.

Anderson, D., Gilbert, P. and Burkholder, J. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25, 704–726.

Ferreira, J., Andersen, J. and Borja, A. 2011. Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science 93, 117–131.

Gibb, J.G. and Cox, G.J. 2009. Patterns & Rates of Sedimentation within Porirua Harbour. Consultancy Report (CR 2009/1) prepared for Porirua City Council. 38p plus appendices.

IPCC. 2007. Intergovernmental Panel on Climate Change web site. https://www.ipcc.ch/publications_and_data/ar4/wg1/ (accessed December 2009).

IPCC. 2013. Intergovernmental Panel on Climate Change web site. https://www.ipcc.ch/report/ar5/wg1/ (accessed March 2014).

Kennish, M.J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation 29, 78–107.

National Research Council. 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. Ocean Studies Board and Water Science and Technology Board, Commission on Geosciences, Environment, and Resources. Washington, DC: National Academy Press. 405p.

Painting, S.J., Devlin, M.J., Malcolm, S.J., Parker, E.R., Mills, D.K., Mills, C., and Winpenny, K. 2007. Assessing the impact of nutrient enrichment in estuaries: susceptibility to eutrophication. Marine pollution bulletin 55(1-6), 74–90.

Robertson, B.M. and Stevens, L.M. 2007. Waikawa Estuary 2007 Fine Scale Monitoring and Historical Sediment Coring. Prepared for Environment Southland. 29p.

Robertson, B.M. and Stevens, L.M. 2010. New River Estuary: Fine Scale Monitoring 2009/10. Report prepared by Wriggle Coastal Management for Environment Southland. 35p.

de Salas, M.F., Rhodes, L.L., Mackenzie, L.A., Adamson, J.E. 2005. Gymnodinoid genera Karenia and Takayama (Dinophyceae) in New Zealand coastal waters. New Zealand Journal of Marine and Freshwater Research 39,135–139.

Stewart, J.R., Gast, R.J., Fujioka, R.S., Solo-Gabriele, H.M., Meschke, J.S., Amaral-Zettler, L.A., Castillo, E. Del., Polz, M.F., Collier, T.K., Strom, M.S., Sinigalliano, C.D., Moeller, P.D.R. and Holland, A.F. 2008. The coastal environment and human health: microbial indicators, pathogens, sentinels and reservoirs. Environmental Health 7 Suppl 2, S3.

Swales, A., and Hume, T. 1995. Sedimentation history and potential future impacts of production forestry on the Wharekawa Estuary, Coromandel Peninsula. Prepared for Carter Holt Harvey Forests Ltd. NIWA report no. CHH004.

Valiela, I., McClelland, J., Hauxwell, J., Behr, P., Hersh, D., and Foreman, K. 1997. Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. Limnology and Oceanography 42, 1105–1118.

Wade, T.J., Pai, N., Eisenberg, J.N.S., and Colford, J.M., 2003. Do U.S. Environmental Protection Agency Water Quality Guidelines for Recreational Waters Prevent Gastrointestinal Illness? A Systematic Review and Meta-analysis. Environmental Health Perspective 111, 1102–1109.

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

1. Sediment Changes

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

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

Recommended Key Indicators:

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

2. Eutrophication

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

Recommended Key Indicators:

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

3. Disease Risk

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

APPENDIX 2. NOTES SUPPORTING INDICATOR RATINGS (TABLE 1)

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

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

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

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

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

Sedimentation Mud Content. Below mud contents of 20-30% sediments are relatively incohesive and firm to walk on. Above this, they become sticky and cohesive and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon concentrations, which typically increase with mud content, as do the concentrations of sediment bound nutrients and heavy metals. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, and on intertidal flats of estuaries can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready resuspension of fine muds, impacting on seagrass, birds, fish and aesthetic values.

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

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

In sandy porous sediments, the aRPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

Opportunistic Macroalgae. The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 3 and Appendix 2), with results combined with those of other indicators to determine overall condition.

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

As a baseline measure of seagrass presence, a continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: ***SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100.*** Because estuaries are likely to support variable natural seagrass extents, the SC rating is intended to highlight estuaries with low seagrass cover for further evaluation (i.e. estimate natural seagrass cover to determine current state), and to provide an estuary specific metric against which future change can be assessed. It is not intended that the SC be used to directly compare different estuaries. The "early warning trigger" for initiating management action is a trend of decreasing SC.

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. Two supporting metrics are also proposed: i. % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. ii. % of available habitat supporting saltmarsh. This assumes that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. The interim risk ratings proposed for these ratings are Very Low=>80-100%, Low=>60-80%, Moderate=>40-60%, and High=<40%. The "early warning trigger" for initiating management action/further investigation is a trend of a decreasing saltmarsh area or saltmarsh growing over <80% of the available habitat.

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

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

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.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. Available at: http://dx.doi.org/10.1016/j.ecolind.2016.04.003.

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. 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, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016b. NZ Estuary Trophic Index. Screening Tool 2. 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.

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.

APPENDIX 3. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

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

VEGETATION (mapped separately to the substrates they overlie).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SUBSTRATE (physical and biogenic habitat)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Shell bank: Area that is dominated by dead shells.

APPENDIX 4. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

Sediment sampling and analysis

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

Sampling resolution and accuracy

Broad scale mapping is intended to provide a rapid overview of estuary condition based on the mapping of features visible on aerial photographs, supported by ground-truthing to validate the visible features.

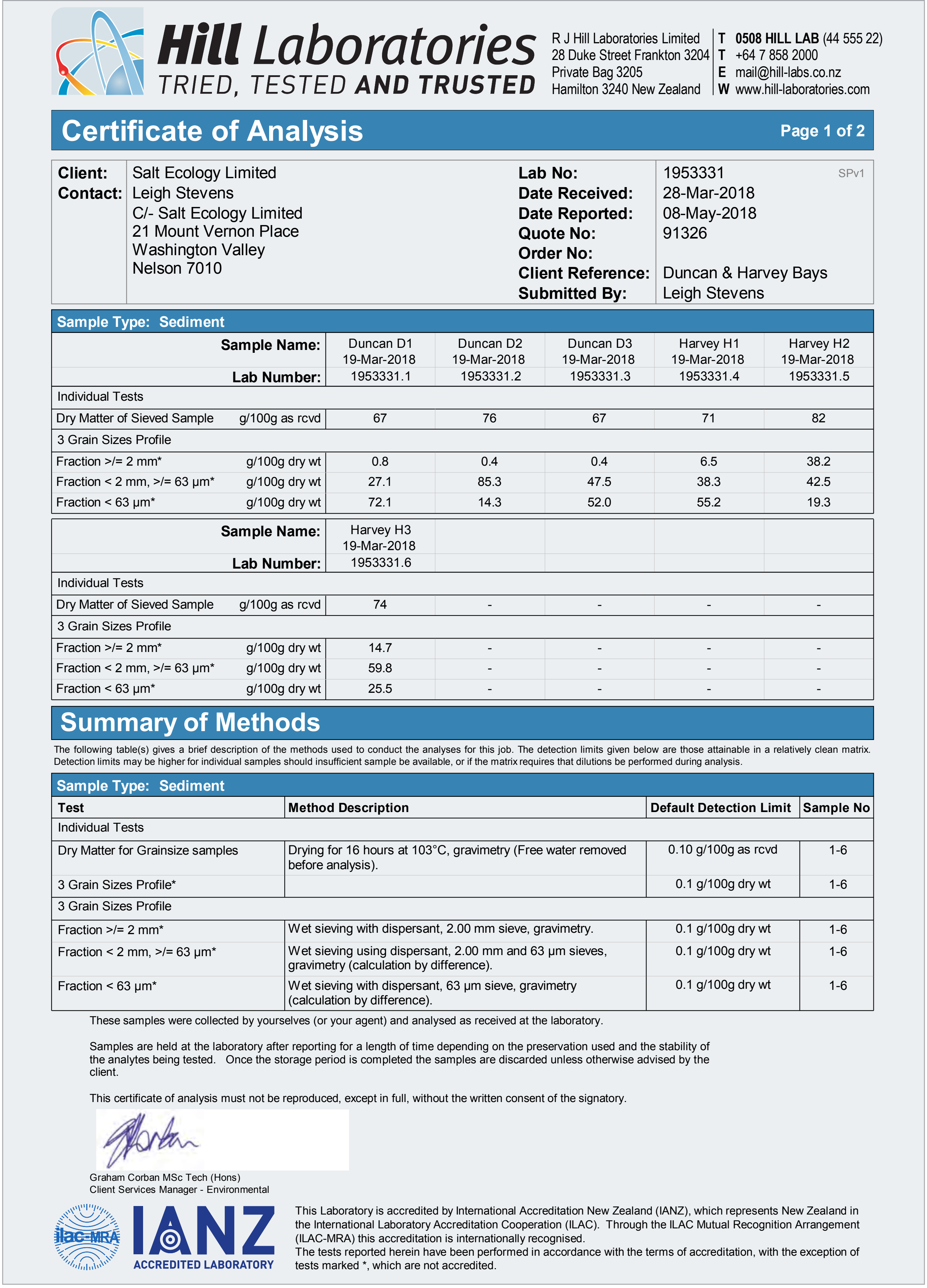
The ability to correctly identify and map features is primarily determined by the resolution of the available photos, the extent of groundtruthing undertaken, and the experience of those undertaking the mapping.

The spatial accuracy of the subsequent digital maps is determined largely by the photo resolution and accuracy of the orthorectified imagery. In most instances features with readily defined edges such as rushland, rockfields, dense seagrass etc. can be mapped at a scale of ~1:2000 to within 1-2m of their boundaries. The largest area for potential error is where boundaries are not readily visible on photographs e.g. sparse seagrass beds, or where there is a transition between features, e.g. where firm muddy sands transition to soft muds across a continuum. Defining such boundaries requires field validation. Extensive mapping experience has shown that such boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed using NEMP classifications.

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

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

APPENDIX 5. ANALYTICAL RESULTS



Hill Laboratories
TRIED, TESTED AND TRUSTED

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

Page 1 of 2

Client:	Salt Ecology Limited	**Lab No:**	1953331 SPv1
Contact:	Leigh Stevens C/- Salt Ecology Limited 21 Mount Vernon Place Washington Valley Nelson 7010	**Date Received:**	28-Mar-2018
		Date Reported:	08-May-2018
		Quote No:	91326
		Order No:	
		Client Reference:	Duncan & Harvey Bays
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		Duncan D1 19-Mar-2018	Duncan D2 19-Mar-2018	Duncan D3 19-Mar-2018	Harvey H1 19-Mar-2018	Harvey H2 19-Mar-2018
Lab Number:		1953331.1	1953331.2	1953331.3	1953331.4	1953331.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	67	76	67	71	82
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	0.8	0.4	0.4	6.5	38.2
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	27.1	85.3	47.5	38.3	42.5
Fraction < 63 µm*	g/100g dry wt	72.1	14.3	52.0	55.2	19.3

Sample Name:		Harvey H3 19-Mar-2018				
Lab Number:		1953331.6				
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	74	-	-	-	-
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	14.7	-	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	59.8	-	-	-	-
Fraction < 63 µm*	g/100g dry wt	25.5	-	-	-	-

Summary of Methods

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

Sample Type: Sediment

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

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.

Graham Corban MSc Tech (Hons)
Client Services Manager - Environmental

ilac-MRA IANZ ACCREDITED LABORATORY

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

This laboratory summary has been edited to fit onto a single page.

APPENDIX 6. SAMPLING DETAILS

Duncan and Harvey Bays - showing ground-truthing coverage, field photos, and location of grain size samples used to validate substrate classifications.

APPENDIX 6. SAMPLING DETAILS

Grain size results from representative sediments, Duncan and Harvey Bay estuaries, 2018.

Broad Scale Classification	Site #	% mud	% sand	% gravel	NZTM EAST	NZTM NORTH
Very Soft Mud	D1	72.1	27.1	0.8	1664125	5447943
Firm Muddy Sand	D2	14.3	85.3	0.4	1663872	5448161
Very Soft Mud	D3	52.0	47.5	0.4	1663882	5448134
Very Soft Mud	H1	55.2	38.3	6.5	1663587	5448521
Soft Mud / Gravel	H2	19.3	42.5	38.2	1663663	5448415
Very Soft Mud	H3	25.5	59.8	14.7	1663536	5448508

See Figure 6 for site locations.

Tuna Bay - showing ground-truthing coverage, field photos, and location of grain size samples used to validate substrate classifications.