SALT
ECOLOGY

Broad scale intertidal habitat mapping of the estuaries of Greville Harbour/Wharariki, D'Urville Island, Marlborough.

Salt Ecology Report 001

PREPARED FOR:
Marlborough District Council
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View of Greville Harbour (14 January 2018) looking over the boulder bank that divides the middle of the harbour towards Smylies and Punt Arms. Camping Bay located to the centre right of the image.

RECOMMENDED CITATION

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PROJECT BRIEF

Marlborough District Council (MDC) recently engaged Salt Ecology to synoptically map the broad scale intertidal habitat features of three estuarine sites (Smylies Arm, Punt Arm and Mill Arm) and two beach sites (Bullock Bay and Camping Bay) in Greville Harbour/Wharariki, D'Urville Island, Marlborough (Figure 2). 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 resource consent decision-making. The following report describes the methods and results of field sampling undertaken on 14 January 2018, and on 18 March 2018.

METHODS

Broad scale habitat mapping comprises a combination of field identification and mapping to characterise broad habitat types (e.g. substrate: mud, sand, cobble, rock; or vegetation: seagrass, macroalgae, salt marsh).

Features evident on aerial photos are verified in the field and subsequently digitised into GIS layers (e.g. ArcMap) to produce maps of the dominant surface features with a horizontal accuracy of 2-5m. The methods are described in the National Estuary Monitoring Protocol (NEMP) Robertson et al. (2002) and subsequent extensions e.g. the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b, Stevens and Robertson 2016). Appendix 1 lists the definitions used to classify substrate and vegetation.

Estuary boundaries for mapping were defined as the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are less than 0.5ppt), and seaward to an imaginary line closing the mouth of the estuary or bay.

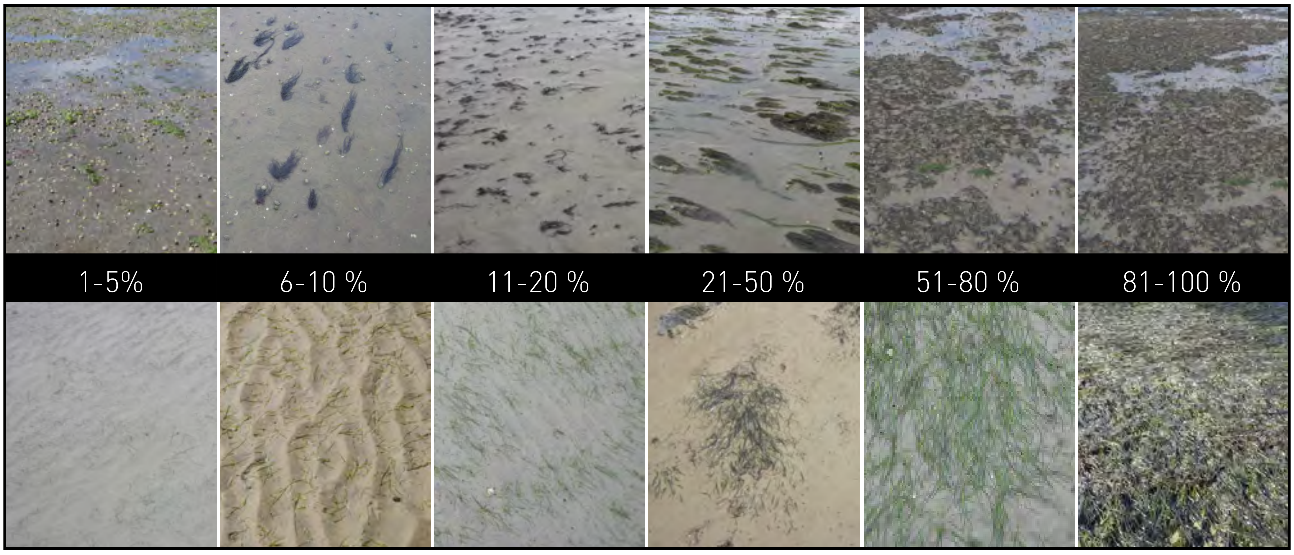
To validate broad scale substrate classifications, samples were also collected from representative fine sediment areas and analysed for grain size (percent mud/sand/gravel - see Appendix 4).

The broad scale results are used to establish a baseline of estuary features and allow initial assessment of estuary condition in response to common stressors such as fine sediment inputs, nutrient enrichment or habitat loss. Ratings, summarised in Table 1, have been developed to guide the assessment of results to determine the need and priority for more detailed investigations.

For the current study MDC supplied unrectified ~0.05m/pixel resolution colour aerial photos flown in 2017 which were laminated (scale of 1:1000) and ground-truthed by experienced scientists to map the spatial extent of dominant vegetation and substrate. 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 1 below).

Broad scale habitat features were subsequently digitised into ArcMap 10.3 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs to produce habitat maps showing the dominant estuary features (substrate, salt

Figure 1. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom).



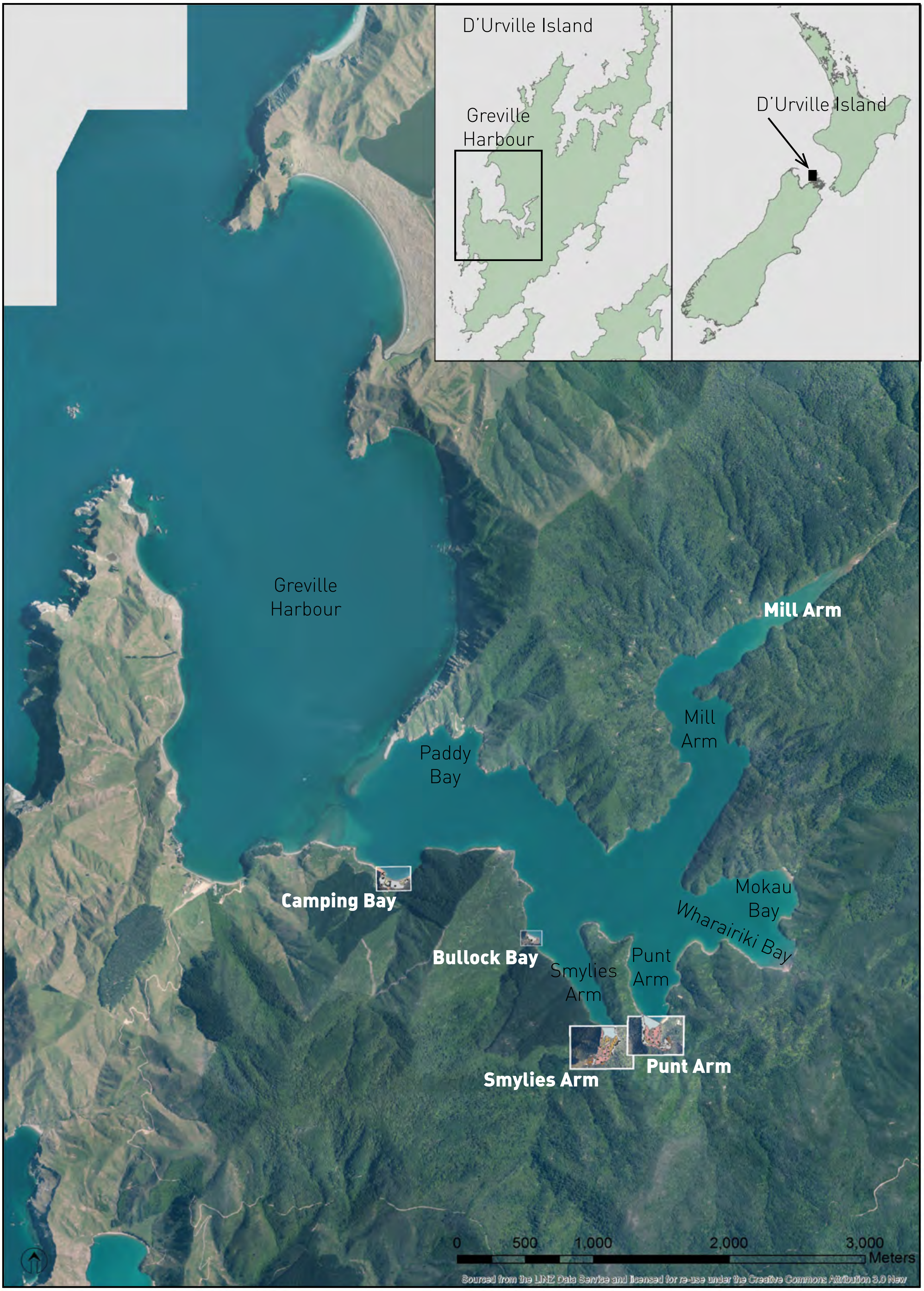


Figure 2. Greville Harbour, D'Urville Island, showing the five sites mapped.

Table 1. Indicator ratings used to assess the risk of adverse ecological impacts.

INDICATOR	ETI Band / Risk	A - Very Good / Very Low	B - Good / Low	C - Moderate / Moderate	D - Poor / High
Soft Mud Extent (% of unvegetated intertidal substrate)		<1%	1-5%	>5-15%	>15%
Sediment Mud Content (% mud)		<5%	5-10%	>10-25%	>25%
Sediment Oxygenation (Apparent Redox Potential Discontinuity)		>2cm (visual assessment unreliable)		0.5-2cm	<0.5cm
Gross Eutrophic Conditions (ha or % of intertidal area)		<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Salt marsh Extent (% of intertidal area)		>20%	>10-20%	>5-10%	0-5%
Salt marsh Extent (% remaining from estimated natural state)		>80-100%	>60-80%	>40-60%	<40%
Densely Vegetated 200m Terrestrial Margin		>80-100%	>50-80%	>25-50%	<25%
NZ ETI score		0-0.25	>0.25-0.5	>0.5-0.75	>0.75-1.0

See Appendix 2 for additional supporting information on indicator ratings.

marsh vegetation, and seagrass). These broad scale results are summarised in the following section, with the 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 and a robust baseline of key indicators against which future change can be assessed.

In addition, to establish a baseline to measure future changes in sedimentation, 4 concrete plates (19cm x 23cm paving stones) were buried 20m apart on a transect located in mud substrate in the middle section of Smylies Arm (Figure 3). Each plate was buried in stable substrate beneath the sediment surface and positioned on a metal rod driven vertically into the sediment to both stabilise the plate and to enable future relocation with a metal detector. Wooden pegs were positioned 5m south-east of each buried plate to mark the transect line.

The depth to each buried plate was then measured to establish a baseline by vertically inserting a measuring probe in the sediment and measuring the depth to the underlying plate with a strait edge used to average out any minor surface height irregularities. Sediment samples were also collected from each plate site and assessed by laboratory analysis of grain size (wet sieving with dispersant, 2mm and 63µm sieves, gravimetry - calculation by difference). These baseline measures can be used in future to assess changes in sediment muddiness, even where there are no changes in sediment depth.

RESULTS AND DISCUSSION

Greville Harbour is a large (~1,300 ha) sheltered harbour located on the western side of D'Urville Island at the northern end of New Zealand's South Island

Punt Arm showing the steep hillsides and narrow rocky intertidal zones that dominate the shorelines of Greville Harbour.

(Figure 2). The harbour edge is dominated by narrow and steep cobble, gravel and rock shorelines, with sandy beaches and intertidal estuarine flats generally uncommon and small in area. The largest intertidal estuarine flats are located in the head of Mill Arm (which supports populations of the nationally declining sea sedge Carex litorosa), and in Smylies Arm, Punt Arm and Wharariki Bay. A large boulder spit ~3.5km from the entrance divides the inner and outer harbour near Camping Bay (see inside cover photo), with vessel access possible through a narrow channel. Subtidally, the seabed is dominated by muds although cleaner sands are likely to be present near the narrow entrance due to strong tidal flows. Water clarity is generally good and much of the catchment is covered by native scrub and forest extending to the harbour edge. The harbour overall is listed by Davidson et al. (2011) as a highly ranked and ecologically significant marine site in Marlborough.

Like much of the nearby Marlborough Sounds, Greville Harbour is a drowned valley system characterised by steep hillsides that slope directly to narrow rocky shorelines (see photo on p.3). 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. 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.

Within Greville Harbour, the catchments surrounding the estuary areas assessed are steep with erodible geology, but are relatively small, have land cover that is dominated by native scrub and forest or plantation forestry, include small relatively unmodified freshwater wetlands at the heads of the arms, and have small freshwater flows. Consequently, the estuarine deltas are relatively small (less than ~10ha), are dominated by cobble and gravel substrates, and naturally support only small areas of salt marsh. The intertidal areas are subjected to frequent wind-driven wave action exacerbated by the narrow arms funneling wind, which help to remobilise deposited fine intertidal sediment and relocate it, some into the upper intertidal zone where it is trapped by salt marsh, but most into the water column where sediment settles in the deeper waters of the subtidal zone - the predominant area of fine sediment deposition in the harbour. Once in the deeper sheltered subtidal waters, fine sediments generally accumulate and remain relatively stable on the seabed, but can be remobilised and redistributed by current and wave action, particularly in shallower areas. The steep and rocky shorelines are well flushed and do

Table 2. Summary of dominant broad scale habitat features at five sites in Greville Harbour, Jan/Mar 2018.

Dominant Habitat Features	Smylies Arm		Punt Arm		Mill Arm		Camping Bay		Bullock Bay	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
SALT MARSH (dominant species)	**0.3**	**7.5**	**0.1**	**3.3**	**0.3**	**2.8**			**0.02**	**4.9**
Estuarine Shrub	0.005	0.1	0.004	0.1						
Rushland	0.2	5.8	0.1	62.9	0.2	1.4			0.02	4.9
Sedgeland			0.003	2.5						
Herbfield	0.1	1.6	0.04	31.3	0.1	1.4				
SUBSTRATE (intertidal flats)	**3.5**	**92.5**	**2.5**	**70.4**	**10.6**	**97.2**	**0.4**	**95.1**	**1.2**	**100**
Rock field	0.01	0.3	0.05	1.4			0.08	6.3	0.05	11.6
Boulder field			0.04	1.0					0.03	6.0
Cobble field	0.54	14.5	0.95	26.9	2.79	25.7	0.96	77.6	0.33	74.6
Gravel field	1.09	29.2	1.36	38.6	0.91	8.3			0.01	2.9
Firm muddy sand	0.003	0.1					0.20	16.1		
Firm mud					0.07	0.7				
Soft mud	1.30	34.7	0.09	2.5	0.03	0.3				
Very soft mud	0.04	1.1			4.89	45.0				
SUBTIDAL WATERS	**0.47**	**12.6**	**0.9**	**26.3**	**1.86**	**17.1**	**-**	**-**	**-**	**-**
TOTAL ESTUARY AREA (Ha)	**3.7**		**3.5**		**10.9**		**1.2**		**0.5**	

Table 3. Summary of dominant salt marsh species at five sites in Greville Harbour, Jan/Mar 2018.

Dominant Salt marsh Features	Smylies Ha	Punt Ha	Mill Ha	Camping Ha	Bullock Ha
Estuarine Shrub					
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.005	0.004			
Rushland					
Apodasmia similis (Jointed wirerush)	0.021				
Ficinia (Isolepis) nodosa (Knobby clubrush)		0.002			
Carex litorosa			0.157		
Juncus kraussii (Searush)	0.080	0.001			
Apodasmia similis (Jointed wirerush)	0.061	0.028			
Isolepis cernua (Slender clubrush)					0.022
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.054	0.041			
Sedgeland					
Carex litorosa		0.00003			
Schoenoplectus pungens (Three-square)		0.003			
Herbfield					
Samolus repens (Primrose) Selliera radicans (Remuremu)	0.016		0.091		
Sarcocornia quinqueflora (Glasswort)	0.001				
Selliera radicans (Remuremu)		0.003			
Isolepis cernua (Slender clubrush)	0.006				
Samolus repens (Primrose)	0.038	0.033	0.056		
Total Saltmarsh	**0.3**	**0.1**	**0.3**	**0**	**0.02**

not readily trap fine sediments.

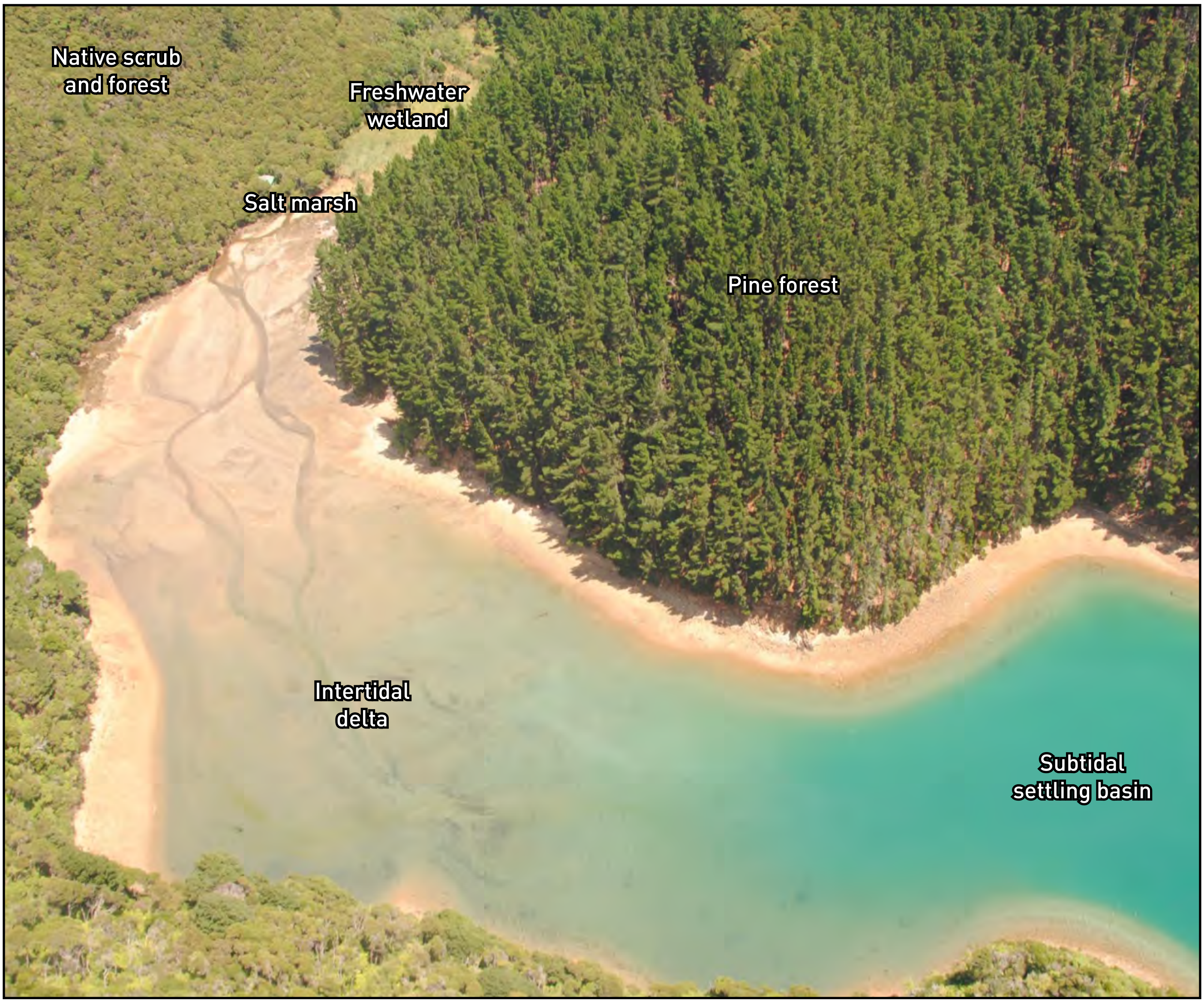
Of the five sites assessed, the upper reaches of Punt, Smylies and Mill Arms are shallow intertidal stream delta estuaries, and Bullock Bay and Camping Bay are cobble dominated beaches. Table 2 summarises the broad scale intertidal substrate and vegetation features at each site, with salt marsh vegetation further detailed in Table 3, and seagrass results presented in Table 4. Habitat maps are presented in Figures 3-7, with additional measures used to assess estuary condition presented in Table 5. The sites are discussed below.

PUNT ARM AND SMYLIES ARM

These adjacent estuaries, while located only ~200m apart as the crow flies, are separated by a narrow peninsula extending ~1km into the harbour (Figure 2). Both have a similar northerly facing aspect, comparable catchment sizes and freshwater flows, and similar intertidal areas. Each estuary supports small areas of salt marsh with a predictable graduated salt marsh vegetation sequence characterised by salt marsh ribbonwood near the upper tidal reaches, progressing through a mix of jointed wire rush and sea rush present in relatively extensive beds along the upper shore, then seaward of this and growing among the rushes, smaller herbfields dominated by remuremu and sea primrose with occasional glasswort growing on the gravel and sand flats. A single plant of the nationally declining sea sedge Carex litorosa was recorded in Punt Arm, but no plants were observed in Smylies Arm. While salt marsh was relatively small in area, it has not been significantly modified and remains within 80-100% of its likely natural extent.

On the terrestrial margin, native forest and small freshwater wetland plants surround the head of the estuary, while lower in the tidal flats, salt marsh vegetation gives way to marine species with seagrass (Zostera) growing in variable density patches lower in the tidal range. Seagrass beds are also evident on the shallow subtidal deltas at the seaward edge of the estuaries.

With regard to substrate, cobble and gravel dominate as extensive beds throughout the upper tidal reaches (Figures 3 and 4), with soft muds located primarily near the stream margins low in the tidal zone. There is a significant difference in the extent of muddy substrate present between the estuaries: 36% in Smylies Arm compared to 2.5% in Punt Arm. The reason for the difference is not readily apparent but may reflect variable past land disturbance in the respective catchments, or greater retention and accumulation within Smylies Arm. There is also a noticeable difference in the upper tidal reaches of the estuaries, the stream delta in Punt Arm comprising relatively



Smylies Arm showing the native bush and exotic forest on steep hillsides surrounding the intertidal stream delta.

Smylies Arm, looking towards the head of the estuary showing the transition from salt marsh (jointed wire rush in foreground, sea rush in background) to freshwater wetland, to native scrub and exotic forest.

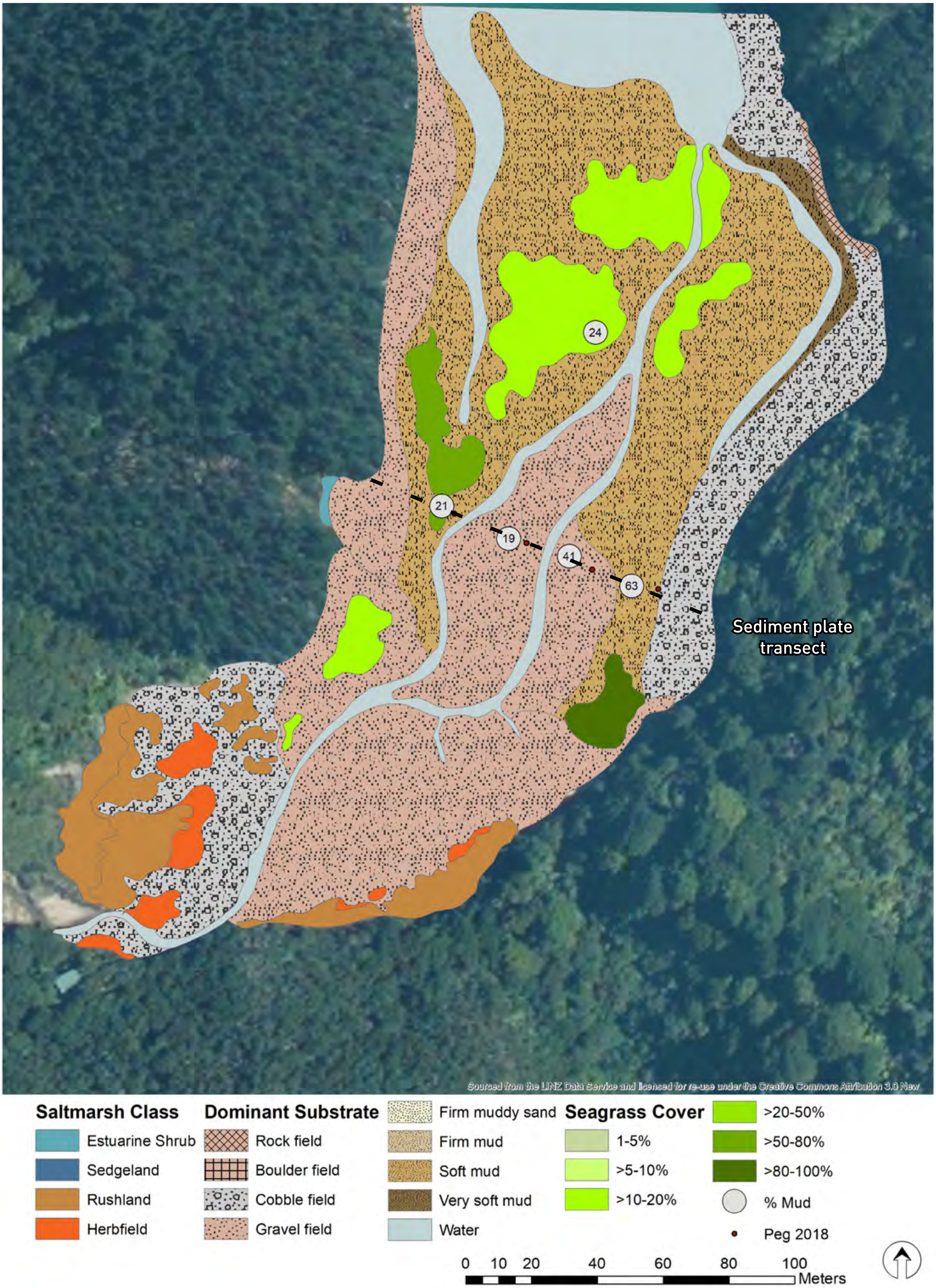


Figure 3. Broad scale habitat features in Smylies Arm, 14 January 2018 .

Punt Arm showing unvegetated coarse cobbles and gravels at the lower edge of the intertidal delta. Small patches of seagrass are present in the shallow subtidal parts of the delta.

Punt Arm showing the native scrub and forest catchment flanking the upper estuary. Sediments are dominated by cobble and gravel with small areas of salt marsh in the upper tidal zone.

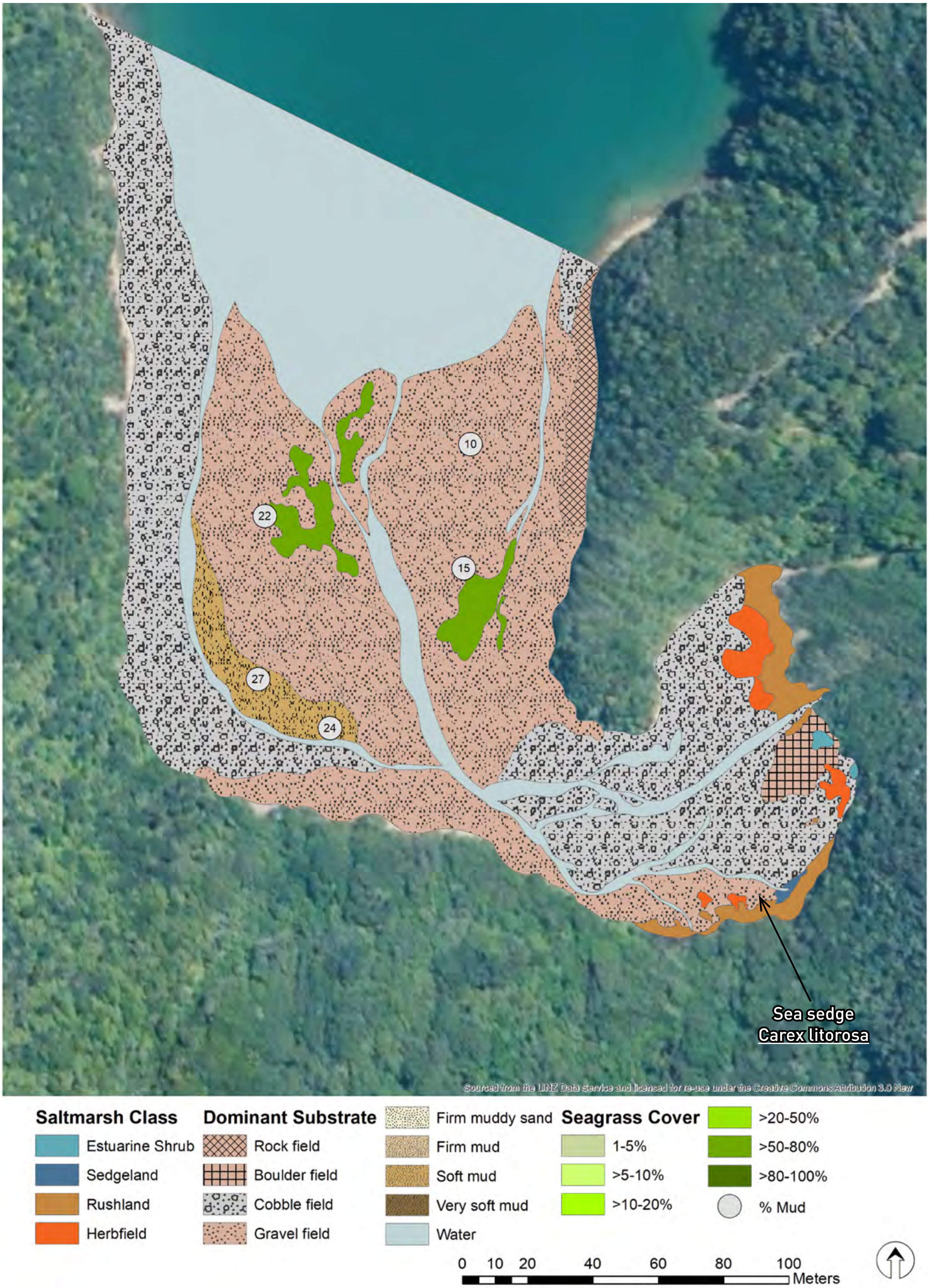


Figure 4. Broad scale habitat features in Punt Arm, 14 January 2018 .

large cobbles and gravels perched higher in the tidal range than occurs in Smylies Arm.

The extent of mud in Punt Arm is low and reflects a relatively undisturbed estuary. The mud extent in Smylies Arm is high and indicates terrestrial sediment has accumulated in the estuary.

These differences in substrate in each estuary are also reflected in the seagrass present (Table 4). While seagrass is highly vulnerable to excessive muddiness, particularly where there is low water clarity or very high rates of deposition, it is also an effective sediment trap. If sediment inputs are not excessive, seagrass beds will assimilate suspended sediment which gets trapped among the fronds and roots creating valuable soft sediment habitat for marine and estuarine animals. Intertidal seagrass beds are relatively rare on the rock-dominated shorelines of the Marlborough Sounds, and have declined significantly from their natural state where fine sediment deposition has been excessive. Their presence on the intertidal flats of both estuaries, and also growing in the shallow sub-tidal edges of the estuary deltas, is a positive sign and indicates current sediment inputs are not displacing seagrass. However, it is noted that seagrass cover in Punt Arm was high density (80-100% cover) compared to the muddier Smylies Arm where 76% of the seagrass was present in low density beds (<25% cover). The lower density beds were located primarily in the lower tidal reaches in soft mud habitat where water clarity is expected to be reduced.

Table 4. Summary of seagrass (<u>Zostera muelleri</u>) cover, Jan. 2018.

Seagrass Cover	Smylies Arm Ha	Punt Arm Ha	Camping Bay Ha
20%	0.29		
80%	0.05	0.08	
100%	0.04		0.05
TOTAL (Ha)	0.38	0.08	0.05
% of intertidal	11.0	2.3	4.0

Macroalgae, particularly potential nuisance species like <u>Ulva</u> and <u>Gracilaria</u> that grow prolifically in the presence of elevated nutrients, were not present in either estuary at densities greater than 5%, indicating nutrient related nuisance growth was not a problem. This is further supported by the relatively low intertidal areal loads of nitrogen and phosphorus estimated for each estuary (Table 5).

The terrestrial margins of both estuary arms were largely unmodified, and a dense cover of native bush and forest dominated the catchment, including the presence of freshwater wetlands at the head of each estuary. Estuaries where native forest is contiguous with estuarine salt marsh and wetland are rare both regionally and nationally and represent a very important ecological gradient worthy of protection. Away from the tidal deltas, forest cover extends directly to the intertidal margin. No significant impacts are expected from these areas if forest cover remains

Table 5. Supporting data used to assess ecological condition at five sites in Greville Harbour, Jan/Mar 2018.

Supporting Condition Measures	Smylies Arm	Punt Arm	Mill Arm	Camping Bay	Bullock Bay
Catchment Area (Ha)*	305	240	1670	78	141
Mean freshwater flow (m^3/s)*	0.082	0.065	0.39	0.02	0.03
Catchment nitrogen load (TN/yr)*	0.848	0.657	4.3	0.216	0.394
Catchment phosphorus load (T/Pyr)*	0.098	0.07	0.46	0.026	0.053
Catchment sediment load (KT/yr)*	0.582	0.21	1.139	0.073	na
Estimated N areal load in estuary ($mg/m^2/d$)	62.8	51.4	108.1	na	na
Estimated P areal load in estuary ($mg/m^2/d$)	6.6	5.5	11.3	na	na
Intertidal soft mud extent (%)	36	2.5	45	0	0
Macroalgae (Ha with density >50% cover)	0	0	0	0	0
Seagrass (Ha with density >50% cover)	0.9	0.08	0	0.05	0
Seagrass (% with density >50% cover)	23.0	100	0	100	0
Salt marsh (est. % remaining from natural state)	80-100	80-100	80-100	80-100	80-100
200m land margin (% densely vegetated)	80-100	80-100	80-100	50-80	80-100
NZ ETI score	0.5	0.2	0.5	na	na

*source NIWA Coastal Explorer database and CLUES model output.
na = not available or not appropriate.

Dense native forest contiguous with estuarine salt marsh - no longer a common feature in many NZ estuaries.

Mature pine forest growing to the edge of Smylies Arm estuary.

intact, but there is a high likelihood of sediment release should the forest cover be disturbed, given its proximity to the coast and estuary. Should land cover change, the most likely areas to be impacted from sediment deposition are the deeper subtidal areas within Greville Harbour where fine sediments are expected to accumulate.

Overall, both Punt Arm and Smylies Arm represent small relatively unmodified shallow intertidally dominated stream delta estuaries. Salt marsh and seagrass are present in both and in good condition. Fine sediment is currently not an issue in Punt Arm, but is more prominent in Smylies Arm. The source of this sediment is unknown, but its presence means the estuary in a vulnerable condition to further inputs, particularly seagrass which is intolerant of prolonged high mud conditions.

MILL ARM

Mill Arm, located on the east site of Greville Harbour, is a long (850m) narrow (150m) arm with a south-west facing aspect. Substrate is a mix of cobble and gravel present in a narrow strip along the shoreline and across the upper tidal flats of the estuary stream delta, while the lower estuary is covered in extensive beds of mud (Figure 5).

The head of the estuary supports small areas of salt marsh characterised by remuremu and sea primrose herbfields with occasional glaswort growing on the gravel and sand flats in the upper tidal reaches. Jointed wire rush and sea rush are present in small patches among herbfields, with the nationally declining sea sedge Carex litorosa present as a subdominant cover throughout the areas where salt marsh grows (see photo on page 12). Salt marsh has not been significantly modified and remains within 80-100% of its likely natural extent. No seagrass was observed in Mill Arm.

The terrestrial margin comprises native forest with freshwater wetland plants common near the stream delta at the head of the estuary. The forest cover extends directly to the rock and cobble dominated seaward edge of the lower estuary.

There was a sparse and patchy presence of potential nuisance macroalgae Gracilaria in the lower estuary muds. Overall both percent cover (<5%), and density (estimated biomass <250g.m^2 wet weight) was low and nuisance growth was not a problem. However, rather than growing attached to hard substrates or shells (where it seldom causes adverse ecological impacts), the Gracilaria roots were growing >3cm deep in sediments. Such sediment entrainment allows the macroalgae to utilise both sediment bound nutrients as well as dissolved nutrients present in the water, and can lead to relatively rapid increases in macroalgal cover because the plants have a near continuous supply of nutrients available for growth rather than being exposed to nutirents only when covered by tidal waters. Because of the relatively low areal loads of nitrogen and phosphorus estimated for the estuary (Table 5), and the native forest catchment surrounding the estuaary, it is considered unlikely that the Gracilaria observed will reach nuisance levels.

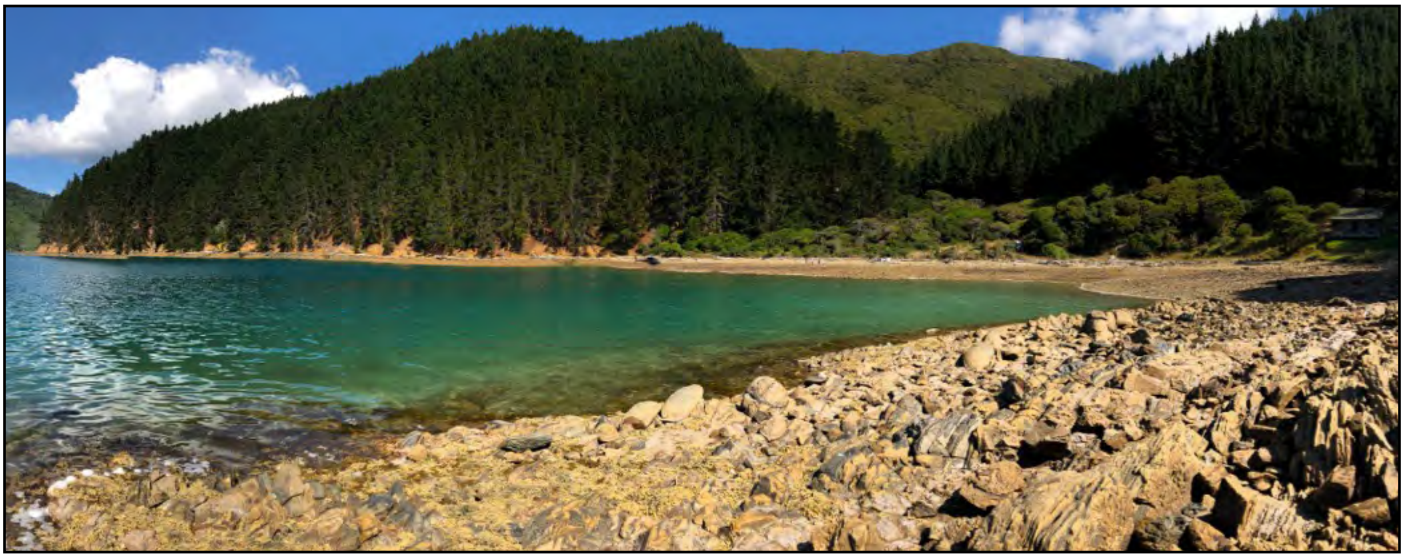
The NZ ETI ratings for the estuaries were "good" or "very good", based on the low influence of eutrophication drivers present in the estuaries.

Sparse growth of Gracilaria entrained in sediment in lower Mill Arm.

Mill Arm showing coarse cobbles and gravels at the estuary edge and the dominant cover of unvegetated soft muds in the lower intertidal flats.

Mill Arm showing the nationally declining pale green sea sedge Carex litorosa growing among herbfield plants in cobble and gravel in the upper tidal zone, flanked by native forest flanking growing to the upper estuary margin.

Figure 5. Broad scale habitat features in Mill Arm, 18 March 2018 .



Camping Bay showing the rock dominated shoreline at the western end of the beach, with a boulder and cobble beach adjacent to plantation forestry at the eastern end.

BULLOCK BAY AND CAMPING BAY

These two sites are located on the south western shoreline of inner Greville Harbour and are relatively narrow open beaches dominated by rock, cobble and gravel shorelines. Bedrock underlies the dominant cobble substrate at both sites. Freshwater inputs are small.

Neither site has intertidal mudflats, and there was no nuisance macroalgae present. Bullock Bay supports a small area of intertidal salt marsh (0.02Ha) along the central part of the upper shore (Figure 6), dominated by sea rush but including the same sequence of small herbfield plants and sedges recorded from the estuary sites (see photo on page 15). The terrestrial margin is densely vegetated, comprising a mix of native and exotic scrub (regenerating after previous land clearance), and a small area of pine forest. Camping Bay is very similar but lacks fringing salt marsh along the upper shore. This most likely reflects its more exposed location nearer the harbour entrance. Although still within the protection of the mid-harbour boulder bank, it was obvious during the site visit that significant wave energy reaches the upper shoreline and likely precludes the establishment of salt marsh. In the lower shore, two areas of firm muddy sand were present. A large bed of dense and healthy seagrass was present at the eastern end of the beach (Figure 7). Aerial photographs indicate this bed has been stable and well established over many years. The terrestrial margin, like Bullock Bay, comprises a mix of regenerating native and exotic scrub, pine forest, and a small area of grassland around the dwelling. Water clarity at both sites was very good, and there was no evidence of mud accumulating in the shallow subtidal zone. Both sites appeared to be in good ecological condition with no obvious impacts related to excess sediment, nutrients or habitat loss.

Bullock Bay showing the rock dominated shoreline at the western end of the beach.

Bullock Bay showing the native bush and a narrow strip of salt marsh rushland and herbfield growing in cobble and gravel along the upper shoreline near the center of the beach.

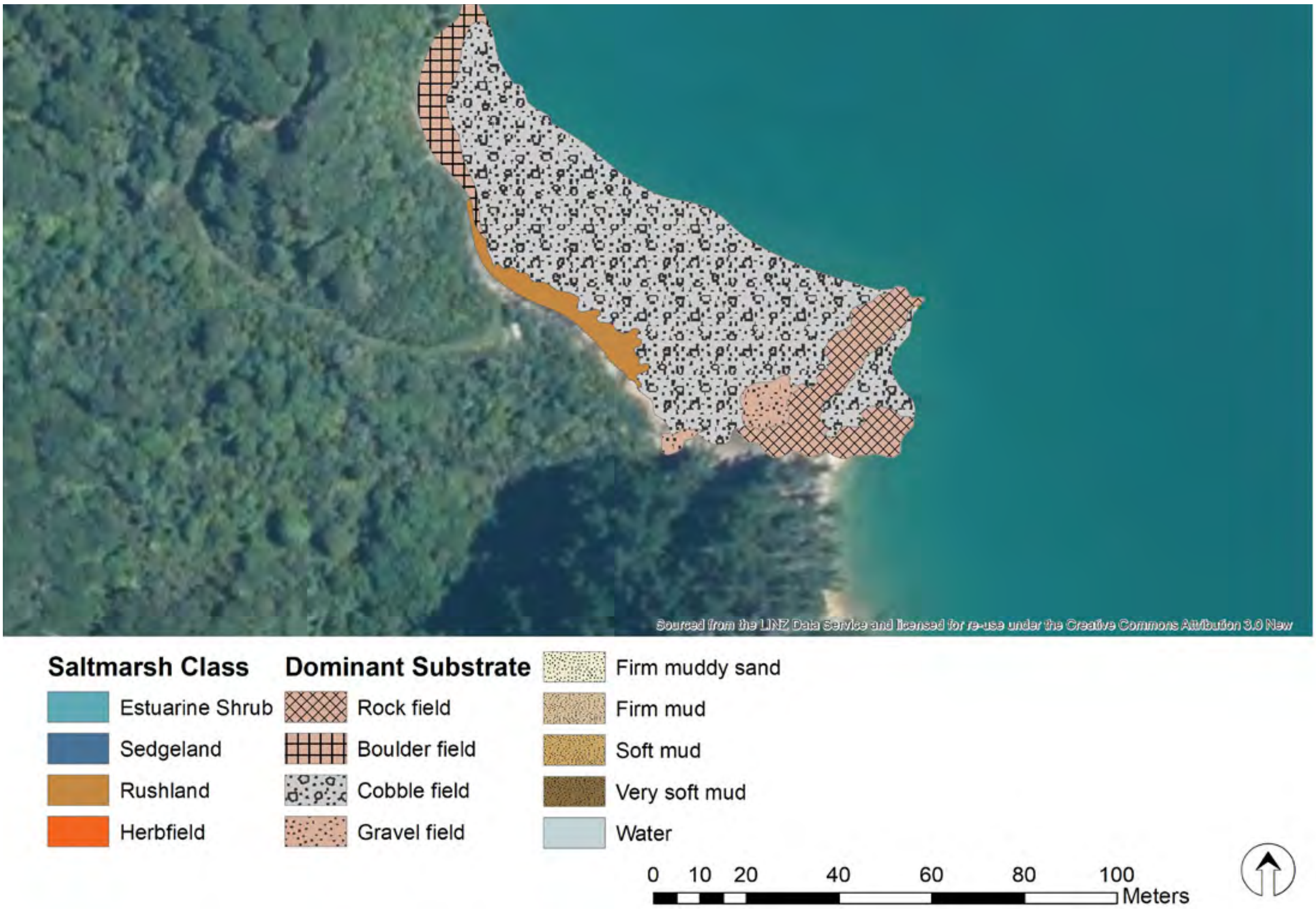


Figure 6. Broad scale habitat features in Bullock Bay, 14 January 2018 .

Camping Bay showing seagrass growing in firm muddy sands at the lower shoreline at the eastern end of the beach, with a boulder and cobble upper shoreline adjacent to plantation forestry.

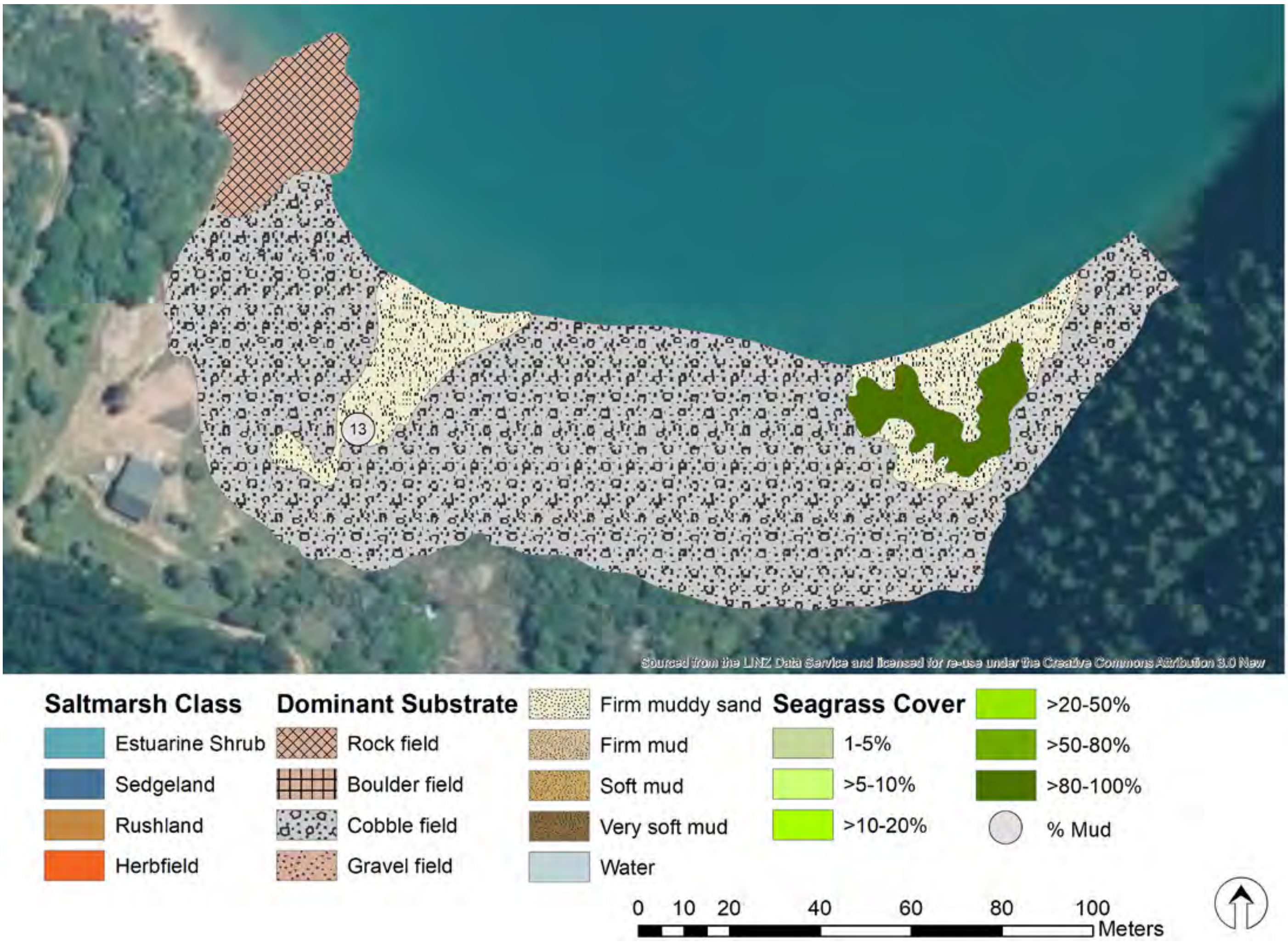


Figure 7. Broad scale habitat features in Camping Bay, 14 January 2018 .

SUMMARY AND CONCLUSIONS

The five sites assessed within Greville Harbour/ Wharariki all reflect the high ecological values previously identified by Davidson et al. (2011). The three estuary sites are in good ecological condition and represent relatively rare regional and national habitat features of estuarine salt marsh contiguous with native forest and fresh-water wetlands. Punt and Smylies Arms support high value seagrass habitat and have largely intact salt marsh vegetation that has changed little from its natural extent. Mill Arm, while lacking seagrass, supports populations of the nationally declining sea sedge Carex litorosa as a subdominant salt marsh cover.

Intertidal muddy sediments are uncommon in Punt Arm but are relatively widespread in Smylies Arm, and extensive in Mill Arm, a likely consequence of the accumulation of inputs from historical land disturbance. Most fine sediment is predicted to accumulate in the shallow sub-tidal areas seaward of the estuary deltas.

The beach sites at Bullock Bay and Camping Bay are both well flushed, dominated by coarse gravel, cobble and rock and are free of sediment. Small areas of seagrass and salt marsh are present in Camping and Bullock Bay respectively.

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.

Birchenough, S., Parker N., McManus E. and Barry, J. 2012. Combining bioturbation and redox metrics: potential tools for assessing seabed function. Ecological Indicators 12: 8-16.

Davidson R. J., Duffy C.A.J., Gaze P., Baxter, A., du Fresne S., Courtney S. and 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.

Fenchel, T. and Riedl, R. 1970. The sulphide system: a new biotic community underneath the oxidized layer of marine sand bottoms. Mar Biol 7: 255-268.

Hunting, E.R. and Kampfraath, A.A. 2012. Contribution of bacteria to redox potential (E h) measurements in sediments. International Journal of Environmental Science and Technology, 10(1): 55-62.

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.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., Thompson, S.J. and 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.

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.

Rosenberg, R., Nilsson, H.C. and Diaz, R.J. 2001. Response of benthic fauna and changing sediment redox profiles over a hypoxic gradient. Estuarine Coast Shelf Science 53: 343-350.

Stevens, L.M. and Robertson, B.M. 2016. Waikawa Estuary (Marlborough): Broad Scale Habitat Mapping 2016. Report prepared by Wriggle Coastal Management for Marlborough District Council. 27p.

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.

APPENDICES

1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

2. ADDITIONAL NOTES SUPPORTING INDICATOR RATINGS (TABLE 1)

3. SEDIMENT GRAIN SIZE RESULTS AND SEDIMENT PLATE SITE LAYOUT

4. LABORATORY RESULTS

5. MAP SHOWING LOCATION OF FIELD PHOTOS, SEDIMENT SAMPLING SITES AND EXTENT OF GROUND-TRUTHING

1. 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.

2. ADDITIONAL NOTES SUPPORTING INDICATOR RATINGS (TABLE 1)

Soft Mud Percent Cover

Soft mud (greater than 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 greater than 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 greater than 25%.

Sedimentation Mud Content

Sediments with mud contents of 20-30% 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 (greater than 3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to less than 1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. 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 WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014, Robertson et al. 2016a,b), 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.

Salt marsh

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

Vegetated Margin

The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the salt marsh and estuary. This buffer is sensitive to a wide range of pressures including land reclamation, 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 less than 50% of the estuary with a densely vegetated margin.

Change from Baseline Condition

Where natural state conditions for high value habitat of seagrass, salt marsh, 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=less than 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.

3. SEDIMENT GRAIN SIZE RESULTS AND SEDIMENT PLATE SITE LAYOUT

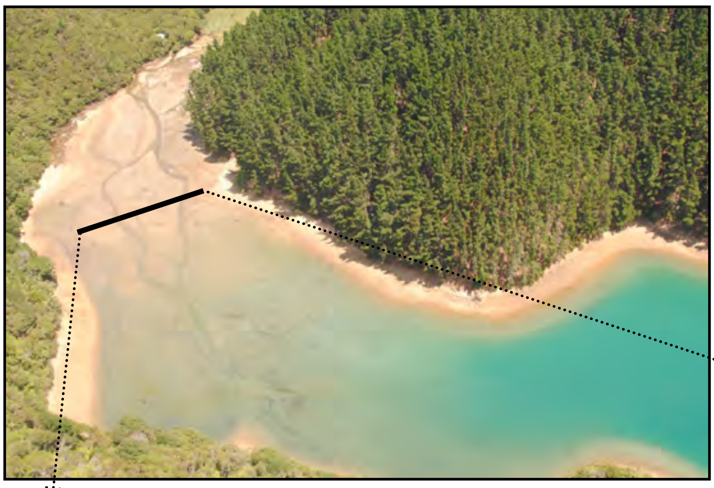
Sediment grain size results used to validate substrate classifications. Laboratory analytical sheets included in Appendix 3 and site locations shown in Appendix 4.

Broad Scale Classification	Site		NZTM East	NZTM North	% mud	% sand	% gravel	Date
firm muddy sand (fms)	Camping	C1	1668177	5476631	12.8	81.1	6.2	14/01/18
gravel field/firm muddy sand (gf fms)	Punt	P5	1670175	5475546	9.9	20.5	69.6	14/01/18
gravel field/firm sandy mud (gf fsm)	Punt	P4	1670173	5475508	14.6	13.5	72.0	18/03/18
gravel field/firm sandy mud (gf fsm)	Mill	M3	1671277	5478795	18.9	27.1	54.0	18/03/18
gravel field/soft mud (gf sm)	Smylies	S2	1669818	5475407	40.7	33.8	25.4	18/03/18
gravel field/soft mud (gf sm)	Smylies	S3	1669799	5475413	19.3	22.3	58.3	18/03/18
gravel field/soft mud (gf sm)	Smylies	S4	1669779	5475422	21.3	35.7	43.1	18/03/18
gravel field/soft mud (gf sm)	Smylies	S5	1669826	5475475	23.8	31.6	44.6	18/03/18
firm mud/gravel field (fm gf)	Mill	M4	1671599	5478933	28.7	60.8	10.5	18/03/18
soft mud/gravel field (sm gf)	Punt	P1	1670112	5475524	22.1	50.9	27.0	14/01/18
soft mud/gravel field (sm gf)	Punt	P2	1670110	5475474	27.0	38.1	34.8	18/03/18
soft mud/gravel field (sm gf)	Punt	P3	1670132	5475459	23.8	20.8	55.3	14/01/18
very soft mud (vsm)	Smylies	S1	1669837	5475398	63.3	23.7	13.0	18/03/18
very soft mud (vsm)	Mill	M1	1671412	5478788	70.7	28.6	0.8	18/03/18
very soft mud (vsm)	Mill	M2	1671275	5478685	48.7	51.1	0.2	18/03/18

Sediment grain size results from buried sediment plate sites in Smylies Arm. Laboratory analytical sheets included in Appendix 3 and site locations shown in Appendix 4.

Sediment plate site	Plate depth (mm)	NZTM East	NZTM North	% mud	% sand	% gravel	Date
Plate 1 (S1)	55	1669837	5475398	63.3	23.7	13.0	18/03/18
Plate 2 (S2)	56	1669818	5475407	40.7	33.8	25.4	18/03/18
Plate 3 (S3)	34	1669799	5475413	19.3	22.3	58.3	18/03/18
Plate 4 (S4)	38	1669779	5475422	21.3	35.7	43.1	18/03/18

Sediment plate sites layout in Smylies Arm. Site locations shown in Appendix 4.



Peg	Height (mm)	NZTM East	NZTM North
1	75	1669845	5475397
2	75	1669825	5475403
3	75	1669805	5475411
4	75	1669783	5475420

4. LABORATORY RESULTS

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	1911213	SPv1
Contact:	Leigh Stevens	**Date Received:**	20-Jan-2018	
	C/- Salt Ecology Limited	**Date Reported:**	05-Mar-2018	
	21 Mount Vernon Place	**Quote No:**		
	Washington Valley	**Order No:**		
	Nelson 7010	**Client Reference:**	MDC Greville	
		Submitted By:	Leigh Stevens	

Sample Type: Sediment

	Sample Name:	P2 14-Jan-2018	P4 14-Jan-2018	P5 14-Jan-2018	C1 14-Jan-2018	
	Lab Number:	1911213.7	1911213.9	1911213.10	1911213.11	
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	69 [#1]	63 [#2]	76 [#1]	72	-
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	34.8 [#1]	72.0 [#2]	69.6 [#1]	6.2	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	38.1	13.5	20.5	81.1	-
Fraction < 63 µm*	g/100g dry wt	27.0	14.6	9.9	12.8	-

Analyst's Comments

[#1] It should be noted that there was insufficient sample to complete the Grainsize_3 analysis at the default quantity required of 100g. The analysis was proceeded using approximately 50g of sample. This should be kept in mind when interpreting these results.

[#2] It should be noted that there was insufficient sample to complete the Grainsize_3 analysis at the default quantity required of 100g. The analysis was proceeded using approximately 30g of sample. This should be kept in mind when interpreting these results.

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	7, 9-11
3 Grain Sizes Profile*		0.1 g/100g dry wt	7, 9-11
3 Grain Sizes Profile			
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	7, 9-11
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	7, 9-11

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.

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Carole Rodgers-Carroll

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

ilac-MRA IANZ ACCREDITED LABORATORY

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

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	1950153
Contact:	Leigh Stevens	**Date Received:**	23-Mar-2018
	C/- Salt Ecology Limited	**Date Reported:**	05-Apr-2018
	21 Mount Vernon Place	**Quote No:**	90036
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Greville Harbour
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		Smylies S1 18-Mar-2018	Smylies S2 18-Mar-2018	Smylies S3 18-Mar-2018	Smylies S4 18-Mar-2018	Smylies S5 18-Mar-2018
Lab Number:		1950153.1	1950153.2	1950153.3	1950153.4	1950153.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	60	67	78	76	74
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	13.0	25.4	58.3	43.1	44.6
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	23.7	33.8	22.3	35.7	31.6
Fraction < 63 µm*	g/100g dry wt	63.3	40.7	19.3	21.3	23.8

Sample Name:		Punt P1 18-Mar-2018	Punt P3 18-Mar-2018	Mill 1 18-Mar-2018	Mill 2 18-Mar-2018	Mill 3 18-Mar-2018
Lab Number:		1950153.6	1950153.7	1950153.8	1950153.9	1950153.10
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	69	76	59	64	75
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	27.0	55.3	0.8	0.2	54.0
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	50.9	20.8	28.6	51.1	27.1
Fraction < 63 µm*	g/100g dry wt	22.1	23.8	70.7	48.7	18.9

Sample Name:		Mill 4 18-Mar-2018				
Lab Number:		1950153.11				
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	73	-	-	-	-
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	10.5	-	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	60.8	-	-	-	-
Fraction < 63 µm*	g/100g dry wt	28.7	-	-	-	-

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	1-11
3 Grain Sizes Profile*		0.1 g/100g dry wt	1-11
3 Grain Sizes Profile			
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-11
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	1-11

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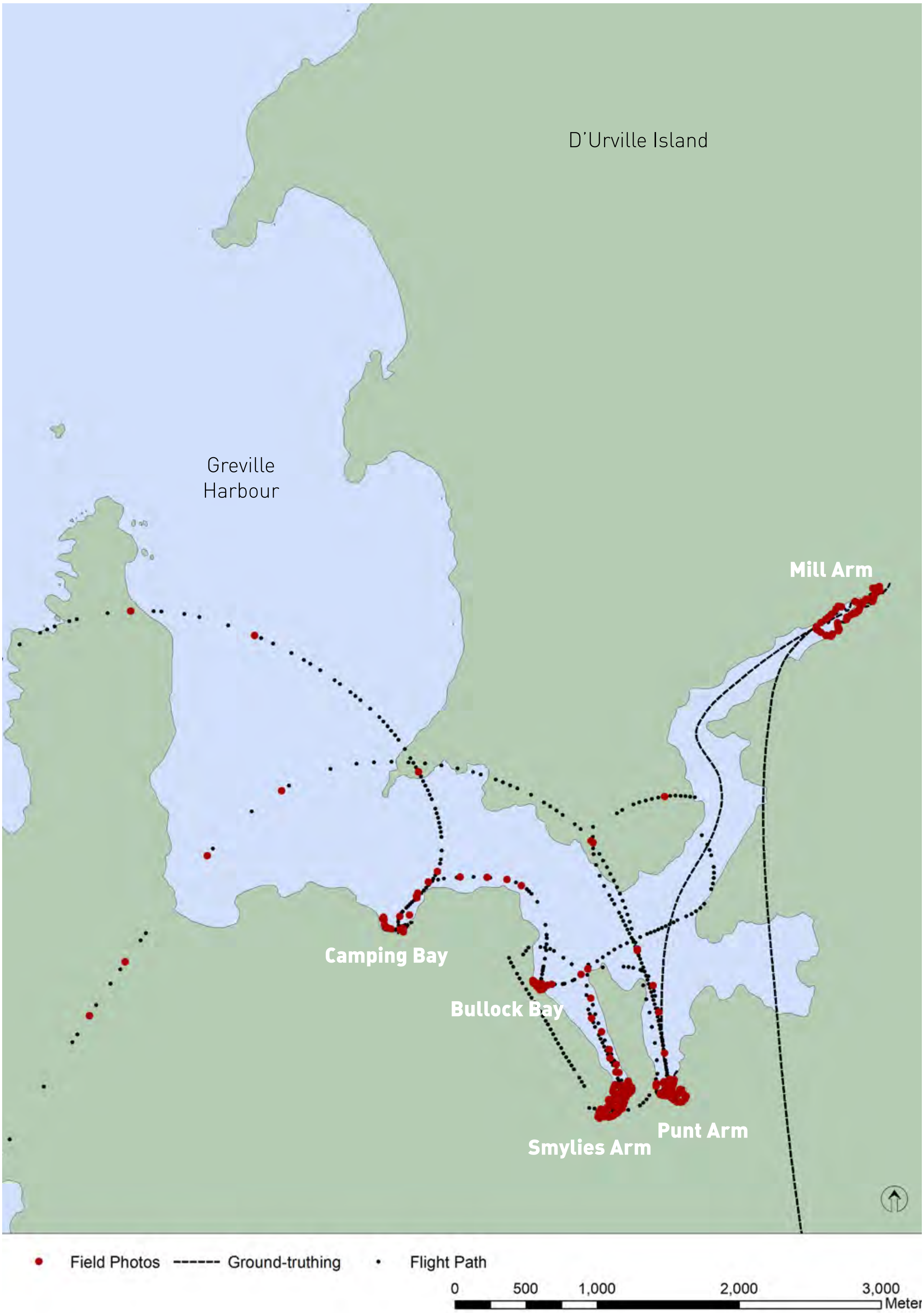
Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-11

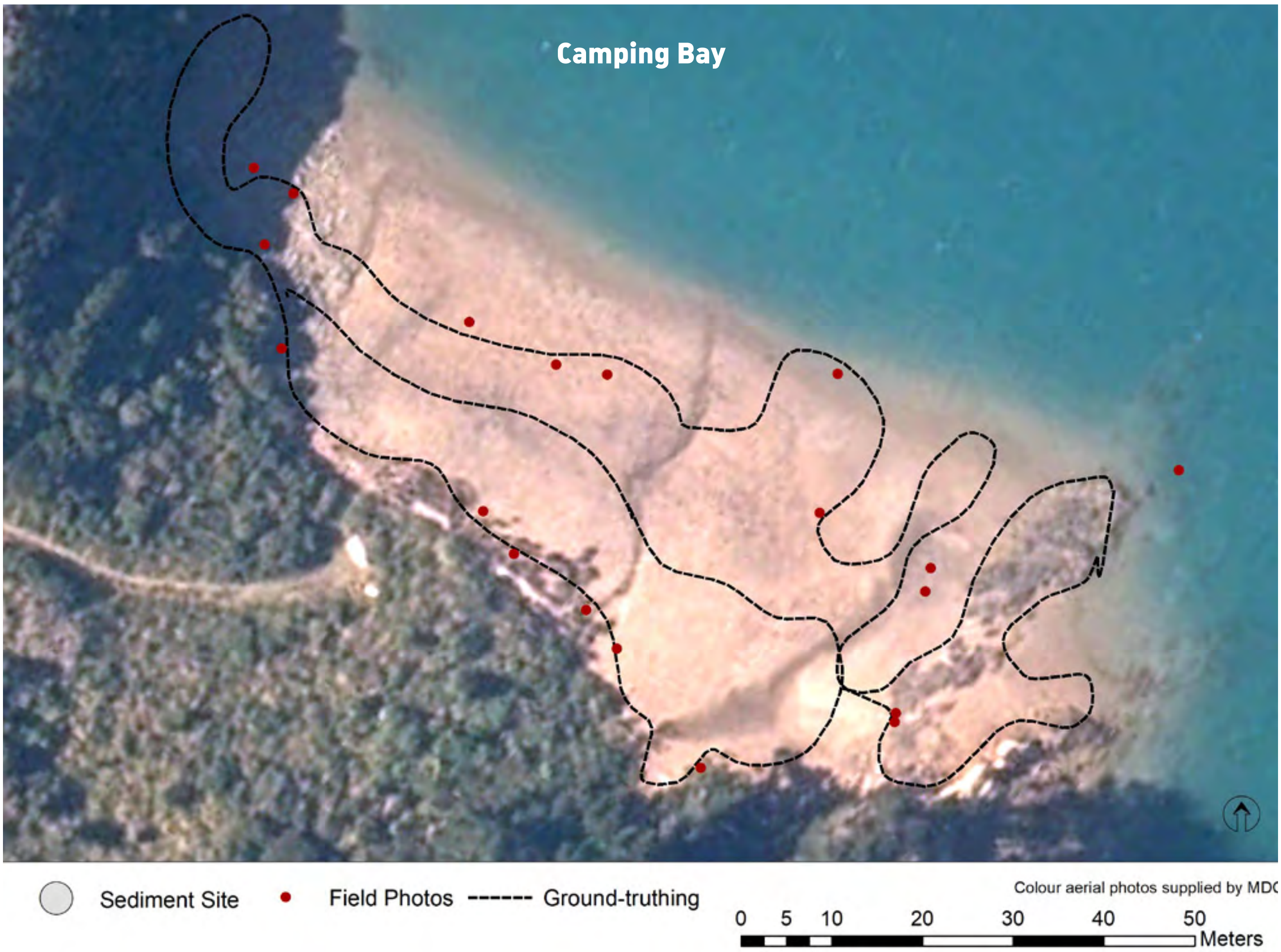
These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

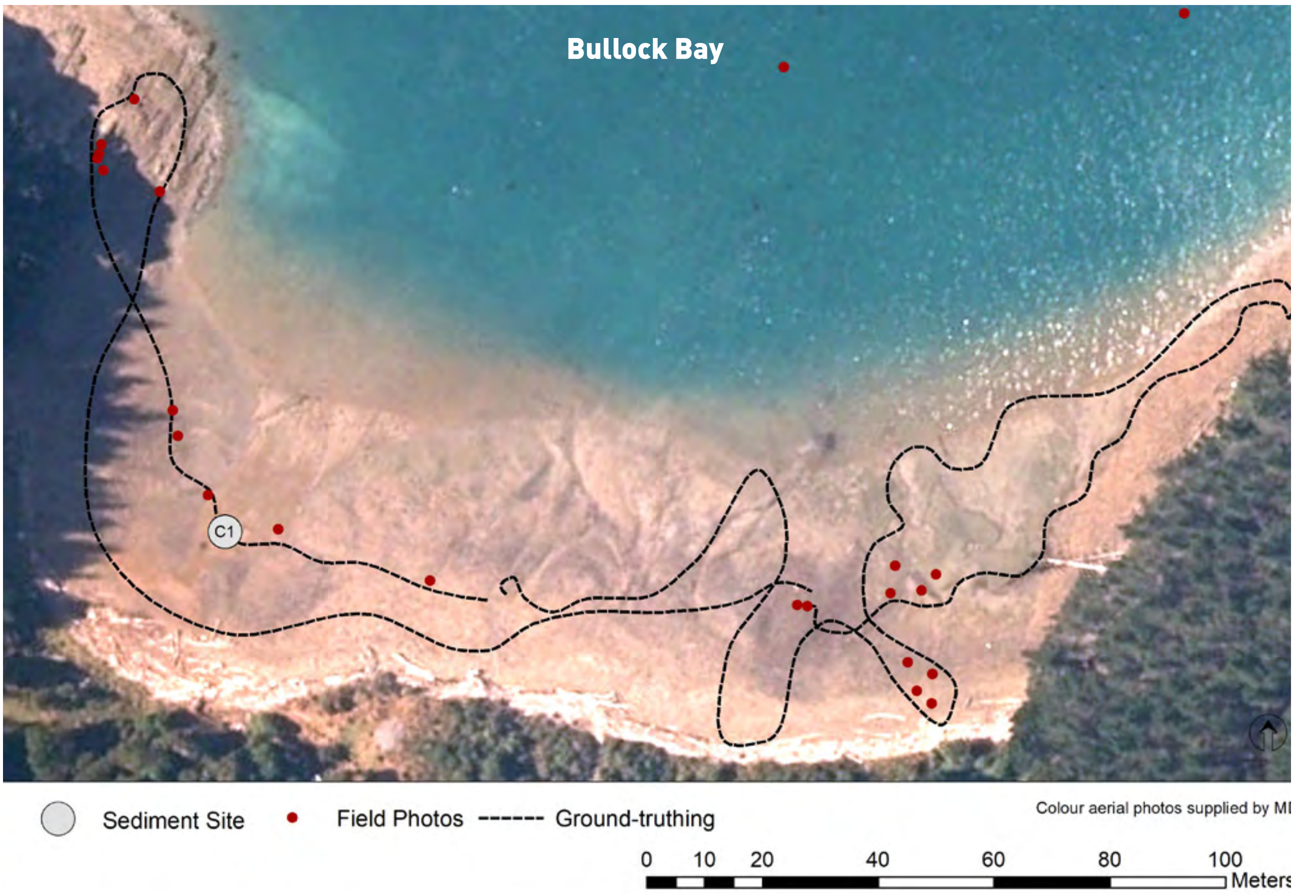
Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

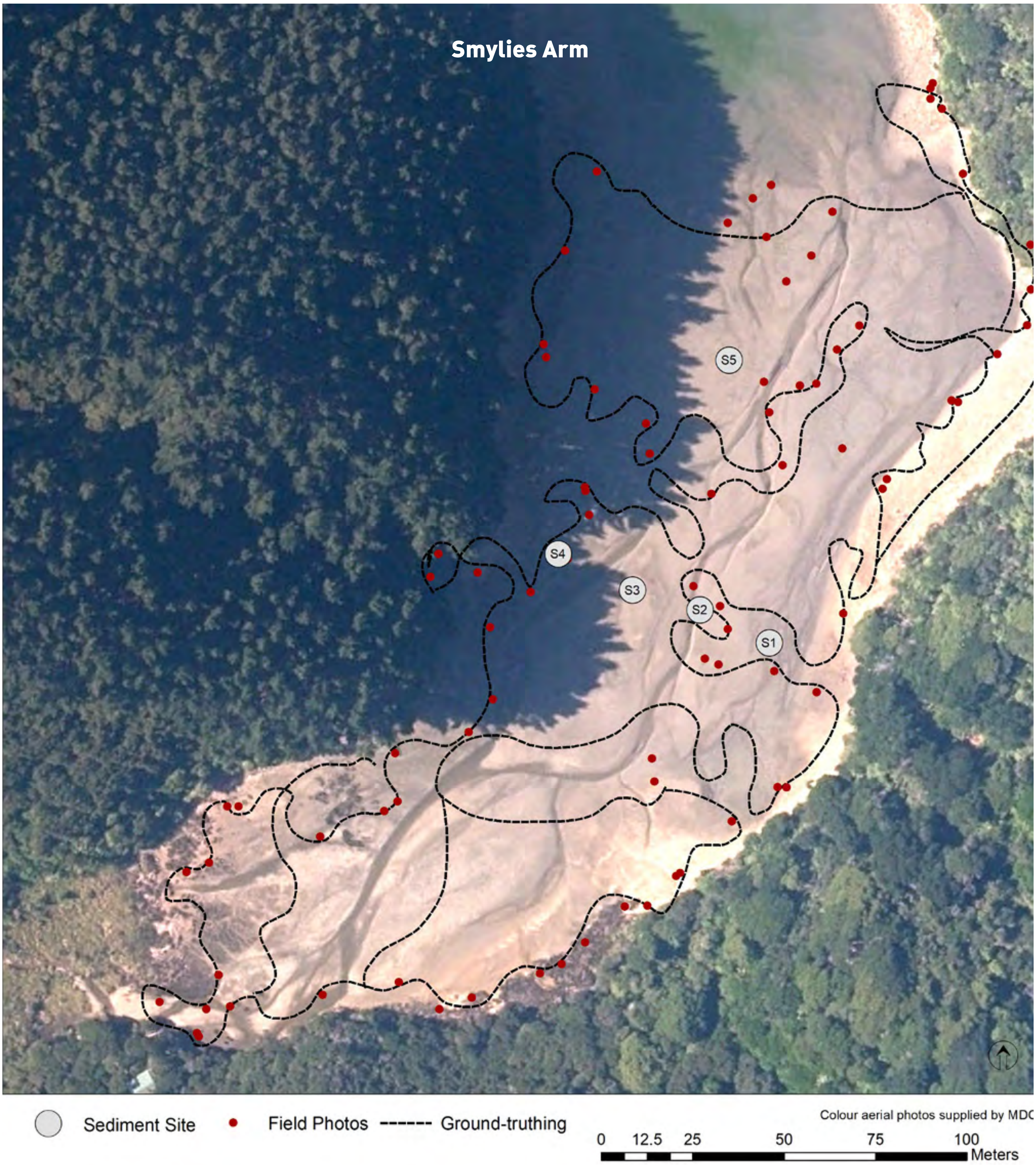
Graham Corban MSc Tech (Hons)
Client Services Manager - Environmental

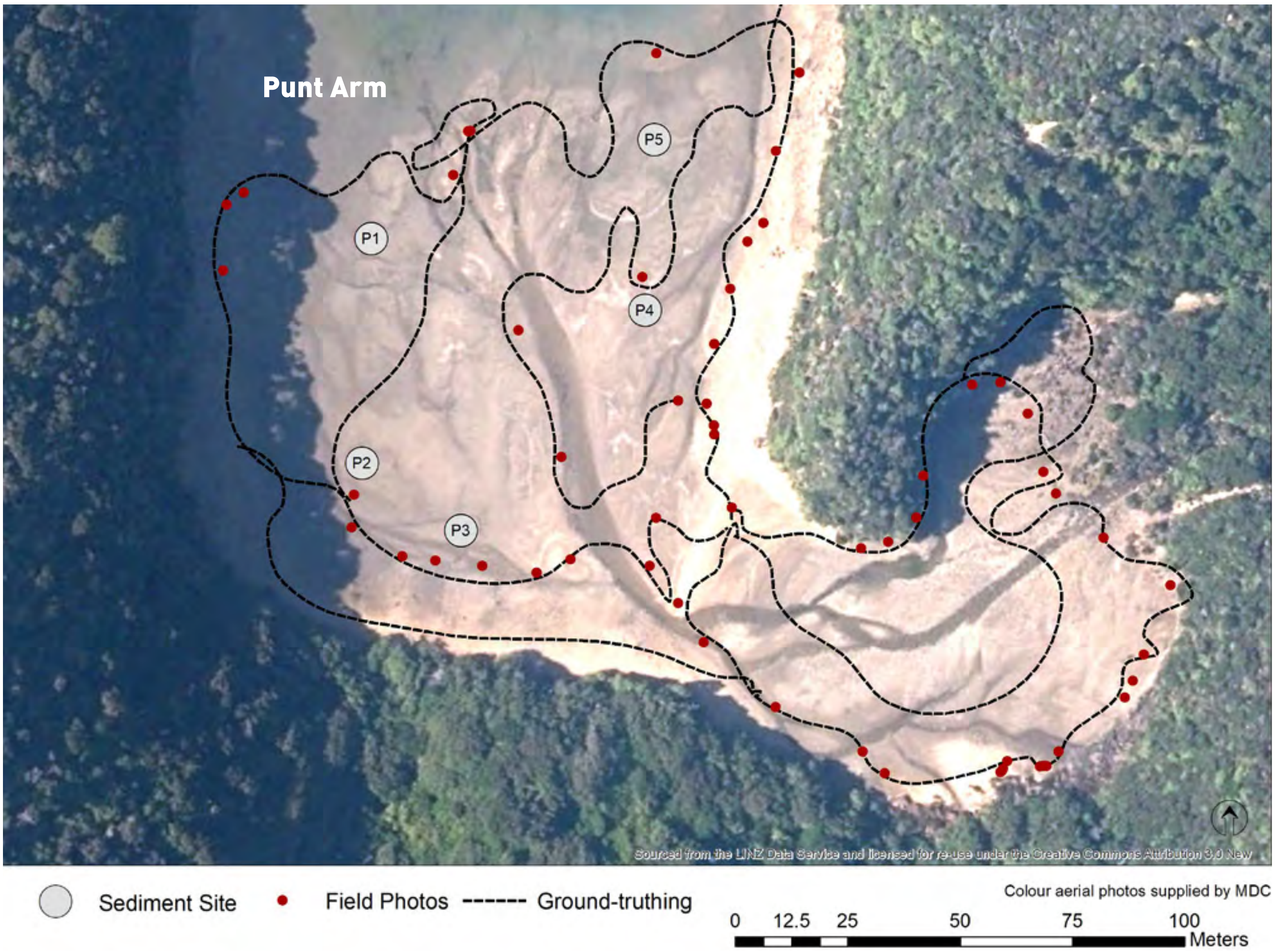
5. MAP SHOWING LOCATION OF FIELD PHOTOS, SEDIMENT SAMPLING SITES AND EXTENT OF GROUND-TRUTHING

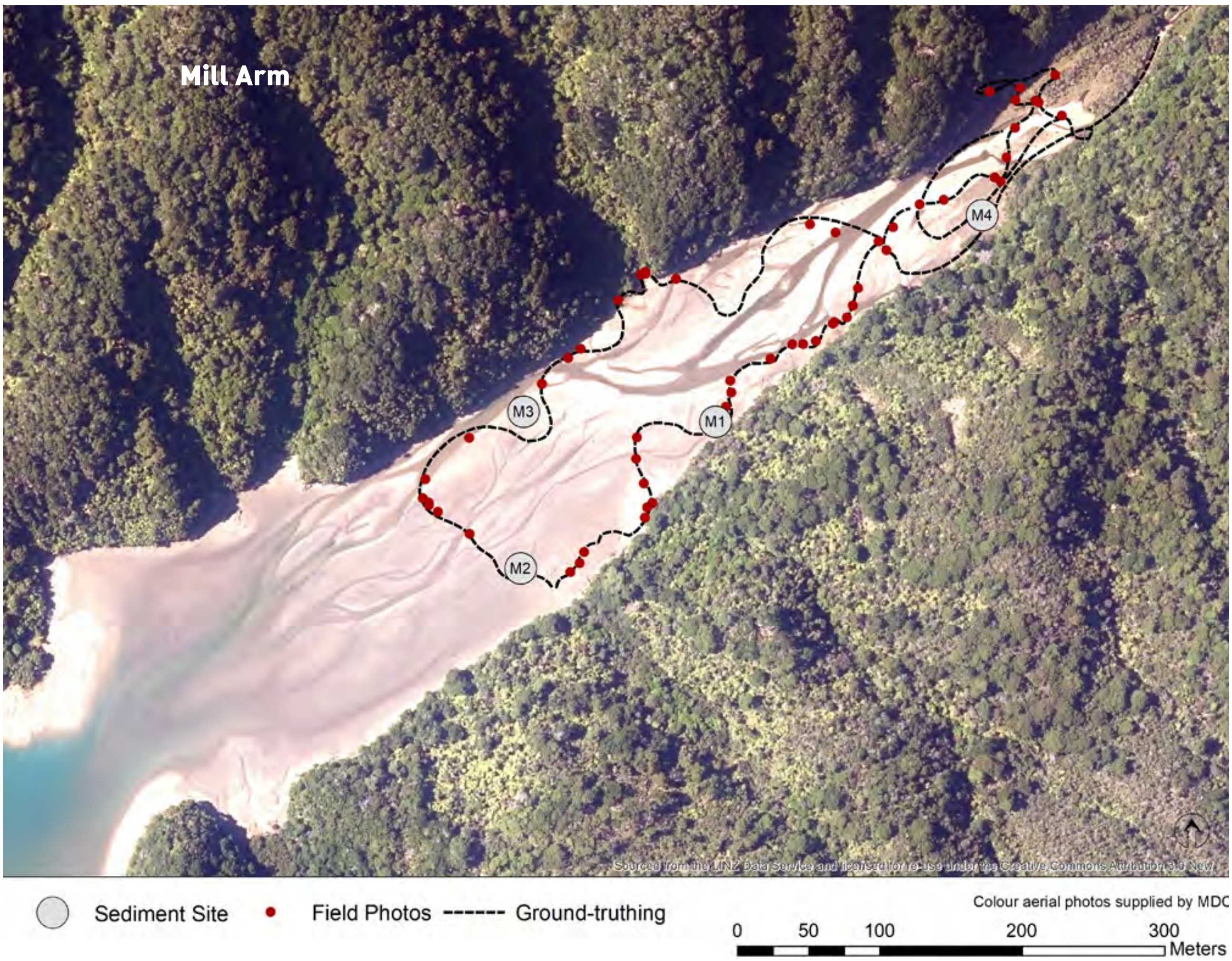



Camping Bay
Sediment Site
Field Photos
Ground-truthing
Colour aerial photos supplied by MDC
0
5
10
20
30
40
50
Meters


Bullock Bay
C1
Sediment Site
Field Photos
Ground-truthing
Colour aerial photos supplied by MI
0
10
20
40
60
80
100
Meters


Smylies Arm
S1
S2
S3
S4
S5
Sediment Site
Field Photos
Ground-truthing
Colour aerial photos supplied by MDC
0
12.5
25
50
75
100
Meters


Punt Arm
P1
P2
P3
P4
P5
Sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 3.0 New
Sediment Site
Field Photos
Ground-truthing
Colour aerial photos supplied by MDC
0 12.5 25 50 75 100
Meters


Mill Arm
M1
M2
M3
M4
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Sediment Site
Field Photos
Ground-truthing
Colour aerial photos supplied by MDC
0 50 100 200 300
Meters

Notes on 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. 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 grouping variable or non-uniform patches or estimating boundaries not readily visible on photographs, 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.