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Shag Estuary

Broad Scale Habitat Mapping 2016/17

Prepared for

Otago Regional Council

May 2017

Cover Photo: Shag Estuary, view over the main channel towards the entrance, December 2016.

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by

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Contents

List of Tables

List of Figures

All photos by Wriggle except where noted otherwise.

SHAG ESTUARY - EXECUTIVE SUMMARY

Shag Estuary is a relatively modified, moderate sized (120ha), mesotidal (1.6m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary. It has a single narrow tidal opening that may occasionally be restricted, a central river channel, a large basin in the lower estuary and two smaller basins in the upper estuary. The catchment is dominated by pasture (71%). It is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. This report presents the results of the December 2016 broad scale estuary habitat mapping with broad scale monitoring results, overall estuary condition and issues, and monitoring recommendations summarised below.

BROAD SCALE RESULTS

- Intertidal flats comprised 38% of the estuary, saltmarsh 39%, and subtidal waters 17%.
- Intertidal substrates were dominated by firm muddy sand (60%) with smaller areas of gravel (16%), soft mud (9%), very soft mud (5%), mobile sand (5%), firm sand (2%), soft muddy sand (2%), and rockfield (<1%).
- Sediment mud content measured within mud habitat was high (28-73%).
- Opportunistic macroalgal growth (*Ulva intestinalis* and *Gracilaria chilensis*) was sparse overall (<1% of the available intertidal habitat - an Ecological Quality Rating of "HIGH"), and no gross eutrophic zones were present. However, dense macroalgal growths were present subtidally and stratified areas with high phytoplankton concentrations were recorded (Robertson et al. 2016).
- Seagrass (*Zostera muelleri*) was not present in the estuary.
- Saltmarsh cover was relatively extensive 80ha (45% of the intertidal area) and was dominated by herbfields (96%).
- The 200m terrestrial margin was 71% pasture or unmaintained grassland with 28% densely vegetated buffer.

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. muddiness, eutrophication, and habitat modification), the December 2016 broad scale mapping results show that the estuary supported a variety of substrate types, extensive areas of saltmarsh, but no seagrass. It was expressing symptoms of excessive muddiness, a moderate level of eutrophication, with historical habitat modification also significant. Fine sediment issues were most evident in the relatively sheltered arms in the upper estuary, and along channel banks in the main basin. Eutrophication was evident primarily through dense subtidal macroalgal growths and stratified subtidal water in the upper estuary supporting very high phytoplankton concentrations. There were no intertidal nuisance macroalgal growths. Historical loss of estuary saltmarsh was estimated at ~60ha) with the 200m terrestrial buffer now dominated by grassland. Ongoing pressures are evident in saltmarsh areas.

The combined results place the estuary in a "MODERATE" state overall in relation to ecological health.

RECOMMENDED MONITORING

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

To characterise any issues of change in habitat (e.g. saltmarsh or soft mud extent), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2026) unless obvious changes are observed in the interim.

In conjunction with scheduled fine scale sampling it is recommended that macroalgal growth be quickly assessed, and monitoring implemented if macroalgal cover exceeds 5% in the estuary.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. The Otago Regional Council's "Regional Policy Statement and Regional Plan: Water" demonstrates the Council's determination to maintain estuaries in good condition. In the period 2005-2008 Otago Regional Council (ORC) undertook preliminary (one-off) monitoring of the condition of seven estuaries in its region. In 2016, ORC began a more comprehensive long-term estuary monitoring programme designed to particularly address the key NZ estuary issues of eutrophication and sedimentation within their estuaries, as well as identifying any toxicity and habitat change issues. The estuaries currently included in the programme are; Shag Estuary, Waikouaiti Estuary and Catlins Estuary.

Monitoring of the Shag Estuary began with preliminary broad and fine scale monitoring undertaken in November 2006 and the first year of comprehensive baseline monitoring undertaken in December 2016.

Within NZ, the approach for monitoring estuary condition follows the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a and b). It consists of three components as follows:

1. **Ecological Vulnerability Assessment (EVA**) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has not yet been undertaken on a regional scale for Otago and hence relative vulnerabilities of their estuaries to the key issues have not been formally identified.
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Broad scale intertidal mapping of Shag Estuary was first undertaken in November 2006 (Stewart 2007) and was repeated in December 2016. This latter monitoring is the subject of this report.
3. **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Shag Estuary, was undertaken in a partial form in November 2006 (Stewart 2007), with the first year of baseline monitoring undertaken on 9 December 2016 (Robertson et al. 2017).

Report Structure: The current report presents an overview of key estuary issues in NZ and recommended monitoring indicators (Section 1). This is followed by risk indicator ratings (Section 2) and the sampling methods (Section 3) used in this broad scale assessment. Summarised results of the December 2016 field sampling are then presented and discussed (Section 4) for the following:

- Broad scale mapping of estuary sediment types.
- Broad scale mapping of macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*).
- Broad scale mapping of seagrass (*Zostera muelleri*).
- Broad scale mapping of saltmarsh vegetation.
- Broad scale mapping of the 200m terrestrial margin surrounding the estuary.

To help the reader interpret the findings, results are related to relevant risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 5), and to guide monitoring recommendations (Section 6).

SHAG ESTUARY

The Shag Estuary is a moderate-sized (120ha), shallow, intertidal dominated estuary (SIDE) on the Otago east coast (Figure 1). It comprises a mix of several confined upper estuary river channels, a large central basin, two small side arm basins, and a 600m long sand spit on the southern coastal margin that creates a narrow entrance to the estuary. The tidal estuary extends ~3km up the valley with its margins lined by high-tidal saltmarsh and historically included large areas of estuary or flood plain but which have subsequently been developed for farming. The greatest development has occurred on the southern and western sides of the estuary. The Shag Estuary is listed as a coastal protection area in the Regional Plan: Water (see Section 3.0). The estuary has Kai Tahu cultural and spiritual values, and its estuarine values include large mudflats used as feeding and roosting areas for birds, fish nursery habitat, and whitebait spawning in the upper tidal reaches.

Catchment landuse is dominated by sheep and beef grazing on high and low producing exotic grassland but it also includes significant areas of exotic forest. However, because the catchment is hilly in nature, contains soft rock types, and is primarily grazed, the suspended sediment yield is elevated. As a consequence, the estuary receives excessive inputs of fine sediments and the water is relatively turbid, and the bed muddy except for the very lowest reaches where firm sands/gravels dominate.

Because the estuary is fed by a relatively small river, the Shag (mean flow ~2.5$m^3.s^{-1}$), the main channel of the upper-mid estuary is poorly flushed during baseflows. As a consequence, this section becomes stratified with a surface layer of lighter, low salinity freshwater flowing over a layer of dense saline water. Because the dense bottom water layer is more stagnant, its water quality can deteriorate, particularly in relation to excessive inputs of nutrients (eutrophication) and fine muds.

Table 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).

Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

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.

Figure 1. Shag Estuary, showing main estuary zones and fine scale monitoring sites.

2. ESTUARY RISK INDICATOR RATINGS

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; Table 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 2 below). 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.

The indicators and interim risk ratings used for the Shag Estuary broad scale monitoring programme are summarised in Table 2, with supporting notes explaining the use and justifications for each indicator in Appendix 2. 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.

Table 2. Summary of estuary condition risk indicator ratings used in the present report.

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
BROAD AND FINE SCALE INDICATORS	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
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)**	Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (RP mV) upper 3cm***	>+100mV	+100 to -50mV	-50 to -150mV	<-150mV
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*	0-0.25	0.25-0.50	0.50-0.75	0.75-1.0

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

3. 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 1 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 ratings to assess estuary condition in response to common stressors, and assess future change.

Estuary boundaries were set seaward from an imaginary line closing the mouth 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 (~0.25m/pixel resolution) flown in 2014/15 were sourced from ESRI online, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in Dec. 2016 to ground-truth the spatial extent of dominant vegetation and substrate types. From representative broad scale substrate classes, 6 grain size samples were analysed to validate substrate classifications (Figure 3, Table 5, methods in Appendix 4). 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 3.

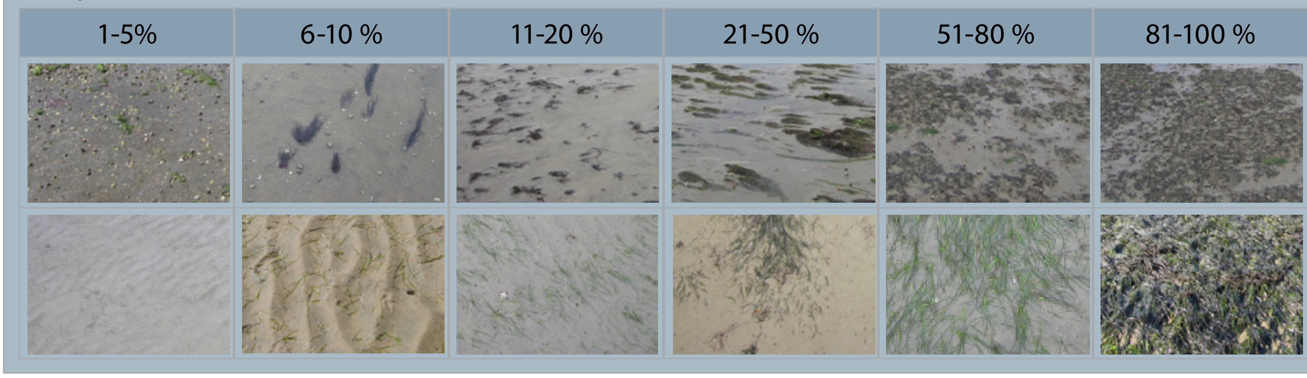
Macroalgae was further assessed by identifying patches of comparable growth and measuring:

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

Where macroalgal cover exceeds 5% of the Available Intertidal Habitat (AIH), a modified Opportunistic Macroalgal Blooming Tool (OMBT) (UK WDF 2014) is used to rate macroalgal condition. 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, 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 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs, to produce habitat maps showing the dominant cover of: substrate, macroalgae (e.g. *Ulva, Gracilaria*), saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse (Figure 4). These broad scale results are summarised in Section 4, 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.

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



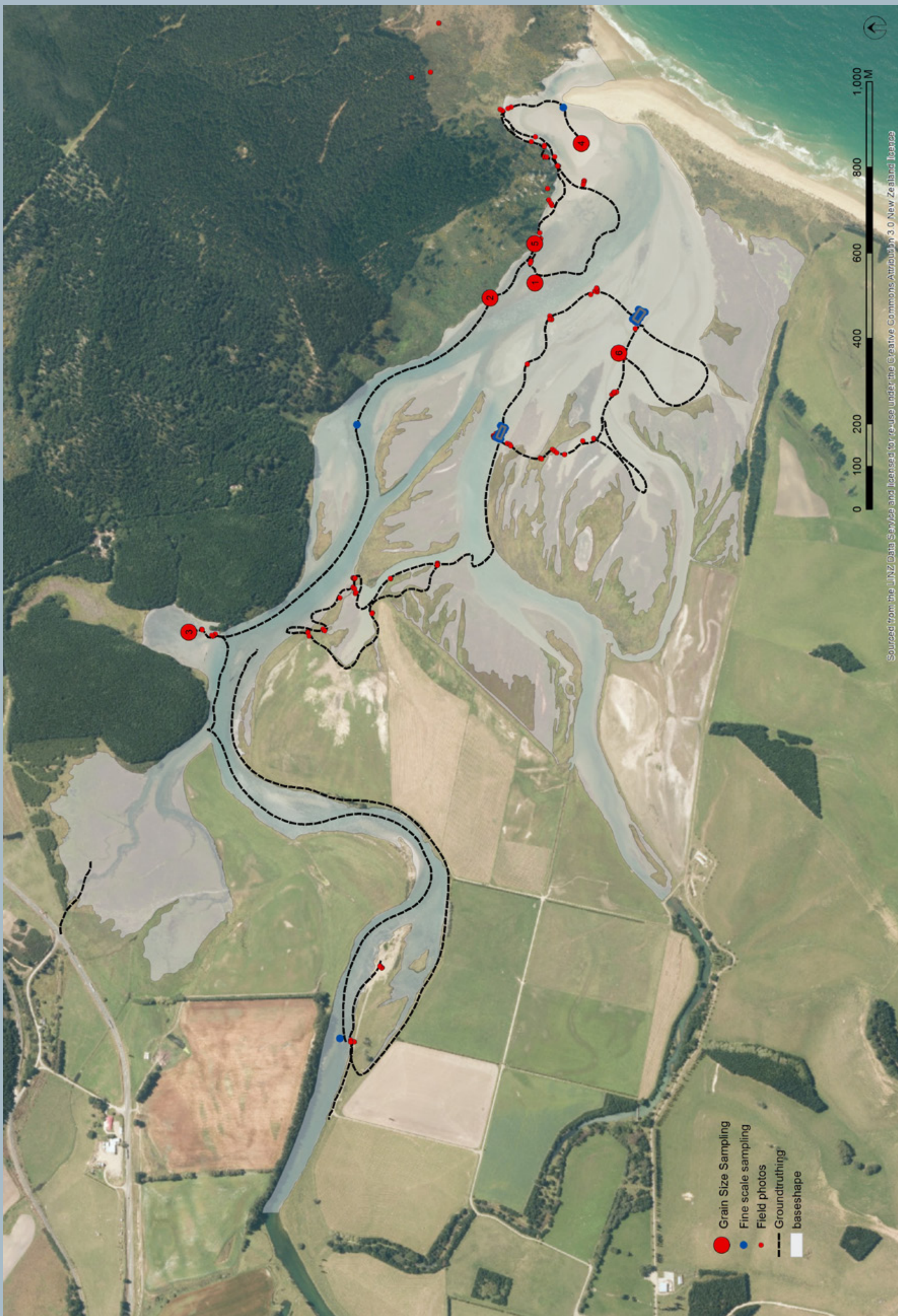


Figure 3. Shag Estuary - mapped estuary extent showing ground-truthing coverage, field photos and location of grain size samples used to validate substrate classifications.

4. RESULTS AND DISCUSSION

4.0. BROAD SCALE MAPPING SUMMARY

The 2016 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the 200m terrestrial margin, with the six dominant estuary features summarised in Table 3 and shown in Figure 4. The estuary comprises a large enclosed tidal basin, two smaller basin areas in the northwest, and freshwater dominated river channels to the east where the tidal influence extends significantly inland from the upper saline limit. There was an equal balance of intertidal flats (38%) and saltmarsh (39%), and a smaller area of subtidal river channel (17%). No intertidal seagrass was observed, while dense (>50% cover) opportunistic macroalgae was very sparse (<1%). The 200m wide terrestrial margin was dominated by pasture and unmanaged grassland (71%) with 28% supporting a densely vegetated (scrub and forest) buffer. The supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuary. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

While mapping of the estuary was previously undertaken in 2006 (Stewart 2007), the supplied GIS files provide only high level summary details, appear to include ~40ha of terrestrial habitat, and exclude subtidal area, all of which limited the extent that detailed comparisons could be made. The 2006 and 2016 results are summarised in Table 3. 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. Summary of dominant broad scale features in Shag Estuary, 2006 and 2016.

Dominant Estuary Feature		2006			2016		
		ha	% intertidal	% estuary	ha	% intertidal	% estuary
1.	Intertidal flats (excluding saltmarsh)	53.4	40.0	33.1	45.5	49.5	38.0
2.	Opportunistic macroalgal beds (>50% cover) [on intertidal flats]	0.7	0.5	0.4	0.20	0.22	0.17
3.	Seagrass (>20% cover) [on intertidal flats]	0	0	0	0	0	0
4.	Saltmarsh	79.9	60.0	49.6	46.3	50.5	38.7
5.	Subtidal waters ([1]not recorded in 2006, 2016 value used)	27.9[1]	-	17.3	27.9	-	17.3
Total Estuary		**161**	**100%**		**120**		**100**
6.	200m wide densely vegetated Terrestrial Margin (e.g. scrub, shrub, forest)						28%

4.1. INTERTIDAL SUBSTRATE (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 5) show substrates on intertidal flats were dominated by firm muddy sand (60%) with smaller areas of gravel (16%), soft mud (9%), very soft mud (5%), mobile sand (5%), firm sand (2%), soft muddy sand (2%), and rockfield (<1%). Strong tidal and freshwater flushing action in the main river channel facilitates the removal of fine material and helps to maintain gravel beds in the upper estuary and sand dominated substrate near the estuary entrance. Muddy sands dominate in more sheltered basin areas (where current flows are less pronounced), while soft and very soft muds are confined largely to the upper tidal reaches.

Table 4. Summary of dominant intertidal substrate, Shag Estuary, 2016.

Dominant Substrate	Ha	%	Comments
Rock field	0.4	0.8	Headlands along the northern side of the estuary near the entrance
Gravel field	7.5	16.4	Upper estuary river margins and by main river channel in central basin
Mobile sand	2.2	4.8	Predominantly near the entrance
Firm sand	1.2	2.6	Small pockets in the main basin near the entrance
Firm muddy sand	27.1	59.7	Within the central basin
Soft muddy sand	0.7	1.6	Channel areas within the central basin
Soft mud	4.2	9.3	Smaller basin areas in the northwest
Very soft mud	2.2	4.8	Sheltered channels in the upper central basin
Grand Total	**45.5**	**100**	

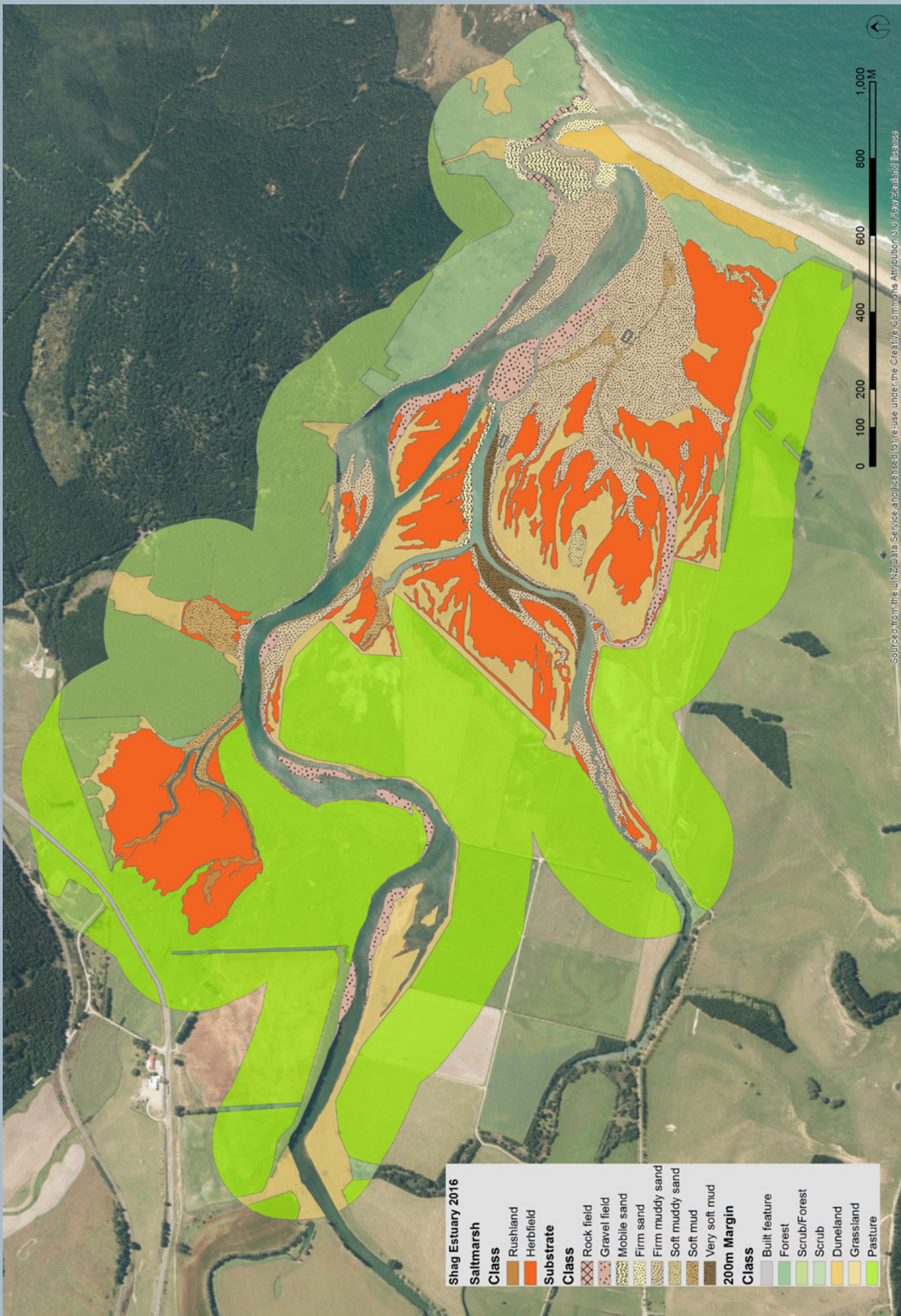


Figure 4. Overview of terrestrial margin and intertidal areas mapped - Shag Estuary, Dec. 2016.

4.2. EXTENT OF SOFT MUD

Where soil erosion from catchment disturbance exceeds the assimilative capacity of an estuary, adverse estuary impacts are expected from increased muddiness and 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. In particular, multiple studies have shown estuarine macroinvertebrate communities to be adversely affected by mud accumulation, both through direct and indirect mechanisms including: 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 2)

ii. **Vertical buildup** (sedimentation rate) - fine scale assessment using 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 - 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. Sediment plates have been established at two fine scale sites to enable future monitoring of vertical buildup (see Robertson et al. 2016 for details).

Figure 5 and Table 4 shows that soft or very soft muds covered 6.4ha (14.1%) of the intertidal area (excluding saltmarsh), a risk indicator rating of MODERATE, and had a mud content measured in representative areas of 30-73%, a supporting risk indicator rating of HIGH. Soft muds were concentrated in the upper tidal reaches of the estuary embayments where mud settlement is thought to predominantly reflect the presence of sheltered deposition zones and, to a lesser extent, salinity driven flocculation. Within the dominant firm sandy mud substrate in the main central basin, grain size reflected a LOW risk rating (5-10% mud content).

The 2016 soft mud extent (6.4ha) was approximately half that reported in 2006 (12.3ha, Stewart 2007), with less mud recorded in the central basin in 2016 than previously recorded.

Table 5. Grain size results from representative sediments, Shag Estuary, 2016.

Broad Scale Classification	Site #	% mud	% sand	% gravel	NZTM East	NZTM North
Mobile Sand	4	0.6	99.3	0.1	1429341	4961495
Firm Muddy Sand	1	8.4	91.1	0.5	1429014	4961603
Firm Muddy Sand	5	8.9	83.6	7.5	1429106	4961604
Firm Muddy Sand/Gravel	2	9.6	28.2	62.1	1428979	4961709
Soft Mud	6	27.8	64	8.2	1428850	4961407
Very Soft Mud	3	72.5	27.4	< 0.1	1428197	4962412

Figure 5. Map of dominant intertidal substrate types - Shag Estuary, Dec. 2016.

4.3. SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are aRPD depth and RP measured at 3cm. These indicators were measured at representative sites throughout the dominant sand and mud substrate types, and from sites where macroalgae was growing. From these measurements, broad boundaries have been drawn of estuary zones where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected (Figure 6). Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

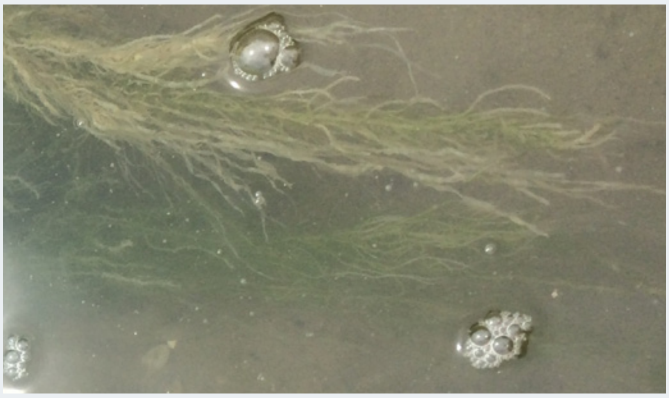
The majority of the estuary sediments appeared well oxygenated with the aRPD depth at 2-5cm and the RP above -150mV at 3cm within sand and gravel sediments that dominated cover in the central basin. However, sediment oxygen was depleted in soft and very soft muds which covered 6.4ha (7%) of the total intertidal area (Figure 6), a NZ ETI risk rating of MODERATE. These areas were located predominantly along channel margins and small settling basins in the upper tidal parts of the estuary. Sediment oxygenation was not recorded in 2006.

4.4. OPPORTUNISTIC MACROALGAE

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

If the estuary supports <5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), overall quality status is reported as HIGH with no further sampling required. If there is >5% cover, opportunistic macroalgal growth is assessed by mapping the spatial spread and density in the AIH, and calculating an OMBT "Ecological Quality Rating" (EQR) (WFD UKTAG, 2014). Intertidal macroalgal cover was very low in December 2016 (0.2ha, <1%), and was confined to two small areas near the entrance dominated by the green alga *Ulva intestinalis* (Figure 7). The macroalgae quality status was therefore HIGH, and the risk rating LOW. Previous sampling (Stewart 2007) also recorded low intertidal macroalgal cover (0.7ha) in the estuary.

The general absence of intertidal opportunistic macroalgal is supported by the fine scale sampling results which indicated low nutrient concentrations in sediments (Robertson et al. 2017). However, high concentrations of phytoplankton indicated eutrophication issues were present in stratified areas of the water column in the upper estuary (Robertson et al. 2017) and dense beds of macroalgae were noted as subtidal growths in channels in the lower estuary. These latter two findings suggest elevated nutrient concentrations are sufficient to fuel nuisance algal growth in the estuary.



4. RESULTS AND DISCUSSION (CONTINUED)

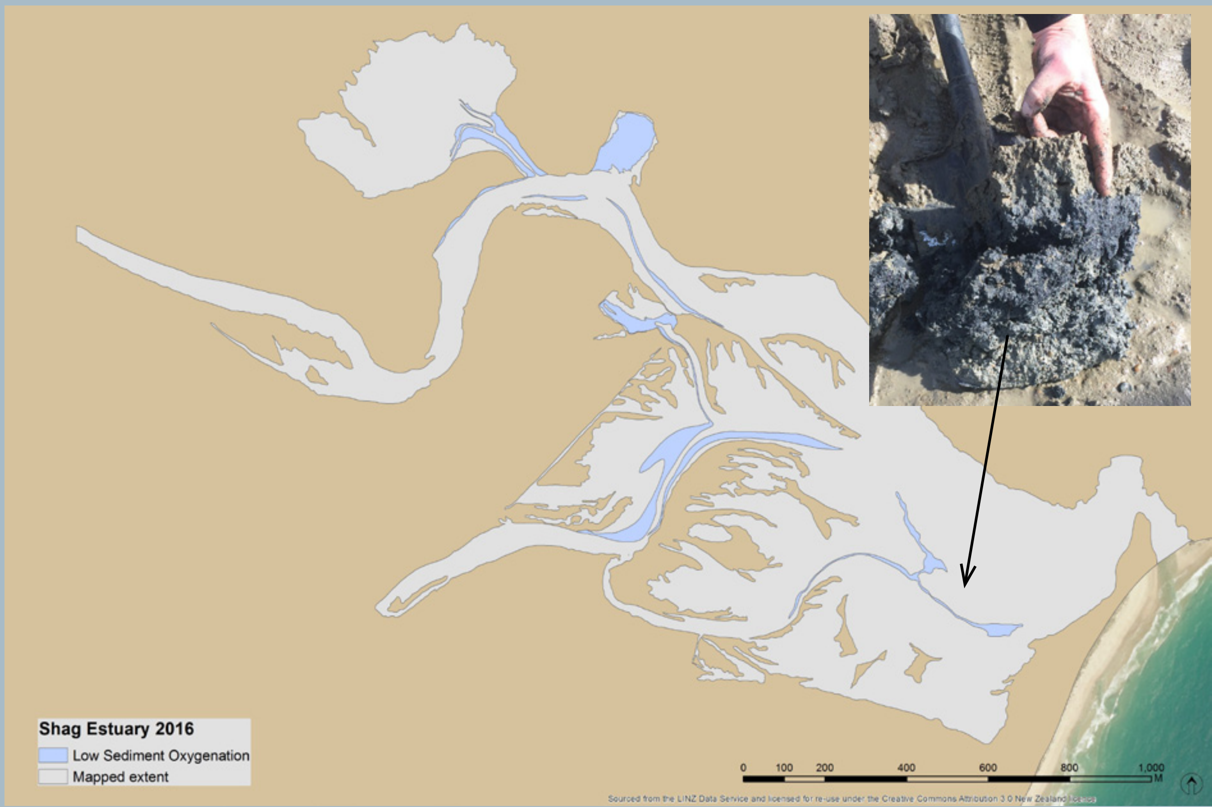
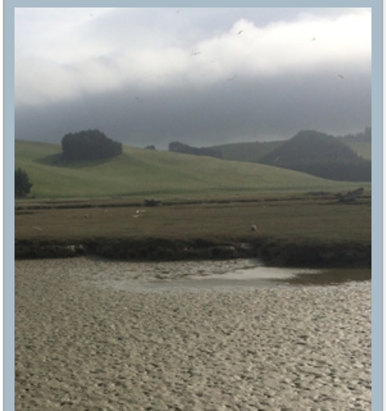


Figure 6. Map of areas with low sediment oxygenation - Shag Estuary, Dec. 2016.

Figure 7. Map of intertidal opportunistic macroalgal biomass (g.m^{-2}) - Shag Estuary, Dec. 2016.

4.5. 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 relatively sparse cover 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 6 and Figure 8 summarise the 2016 results and show saltmarsh was present across 46.3ha (51%) of the intertidal estuary area, a risk indicator rating of LOW. Saltmarsh was dominated by herbfields (97%) located in extensive beds in the upper central basin. Glasswort was the dominant cover, commonly mixed with primrose, and remuremu, (see sidebar photos) with introduced weeds and grasses common in the upper tidal range, particularly at the edges of estuary reclamation or where natural drainage has been modified (channelised). There were only small areas dominated by rushland (1.3%) predominantly jointed wire rush and some searush in the upper estuary (Figure 8, lower sidebar photo).

Supporting measures also used are percent saltmarsh remaining compared to estimated natural state cover, and loss compared to an established baseline. While the historical extent of the estuary has not been specifically mapped as part of the current work, it is evident that extensive areas in the upper estuary have been historically drained and converted to pasture. It is estimated that ~60ha of saltmarsh has been lost from the estuary, a supporting risk rating of MODERATE, with 34ha less saltmarsh recorded in 2016 compared to 2006, a supporting risk rating of HIGH. However, it is recognised that potentially much of the reported change since 2006 could relate to the inclusion of terrestrial grassland in the 2006 estimates. The combined overall saltmarsh risk rating was assessed as MODERATE recognising that while historical losses have been extensive (and appear to be ongoing), saltmarsh remains a significant feature of the estuary, albeit one dominated by low herbfields and lacking the expected level of natural diversity provided by a mixed assemblage including common rush, sedge, tussock, and estuarine shrub species.

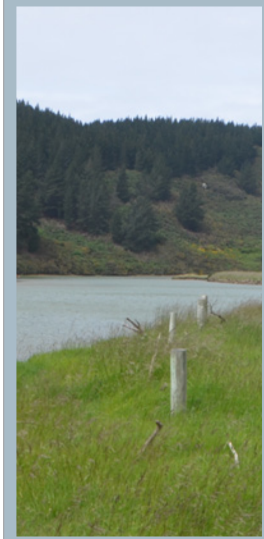
Table 6. Summary of dominant saltmarsh cover, Shag Estuary, 2016.

Class	Dominant Species	Primary subdominant species	Area (ha)	Percentage
Rushland			1.3	2.7%
	Apodasmia similis (Jointed wirerush)		1.24	
	Juncus kraussii (Searush)		0.02	
Herbfield			45.1	97.3%
	Sarcocornia quinqueflora (Glasswort)	*Sarcocornia quinqueflora (Glasswort)*	31.5	
		Samolus repens (Primrose)	0.2	
		Selliera radicans (Remuremu)	13.4	
Total (Ha)			**46.3**	

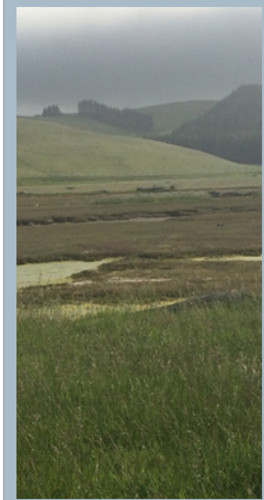
Figure 8. Map of dominant saltmarsh cover - Shag Estuary, Dec. 2016.

4. RESULTS AND DISCUSSION (CONTINUED)

4.6. 200m TERRESTRIAL MARGIN



Grassland, scrub and forest bordering estuary margins



Grassland bordering estuary margins

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 (Table 7 and Figure 9) showed:

- 71% was pasture or unmaintained grassland.
- 28% was densely vegetated (18% pine trees, 10% mixed native and exotic cover).

A similar pattern is evident on a catchment wide scale with 71% of the catchment developed grassland (Figure 10).

The 200m terrestrial margin risk indicator rating is therefore MODERATE, although it is noted that there is virtually no remaining terrestrial vegetation between the farmland surrounding the south and west of the estuary. These areas have historically been modified through reclamation, drainage and conversion to pasture, with recent ongoing conversion evident. Consequently, there is limited buffering against adverse ecological degradation (e.g. localised sediment and nutrient inputs, introduced weeds), and poor natural ecological connectivity between the estuary and surrounding natural habitats.

Table 7. Summary of 200m terrestrial margin land cover, Shag Estuary, 2016.

Class	Dominant features	Percentage
Forest	Mixed native and exotic trees, predominately *Pinus radiata* (pine trees) along the northern edge of the estuary and with tree lupin (*Lupinus arboreus*) dominant as scrub cover near the spit at the entrance to the estuary	0.3
Scrub/Forest		17.7
Scrub		9.7
Duneland	Marram grass (*Ammophila arenaria*) on the coastal spit at entrance	1.5
Grassland	Developed pasture surrounding most of the southern and eastern sides of the estuary and unmaintained grassland near and within saltmarsh	14.5
Pasture		56.0
Built feature	Road	0.3
Total		**100**

Developed pasture to estuary margins with pine trees and rolling hill pasture in the background (left) and trees and unmanaged grassland along river channels in the upper estuary (right).

Figure 9. Map of 200m Terrestrial Margin - Dominant Land Cover, Shag Estuary, Dec. 2016.

LCDB4 (2012)	%
Forest	1.0
Exotic (Plantation) Forest	11.1
Shrub/Scrub	4.2
Gorse and/or Broom	2.5
Tussockland	8.4
Wetland	0.1
Saltmarsh	0.1
Short-rotation Cropland	0.6
High Producing Exotic Grassland	47.9
Low Producing Grassland	22.6
Urban Parkland/Open Space	0.1
Urban/roading	0.2
Unvegetated	0.9

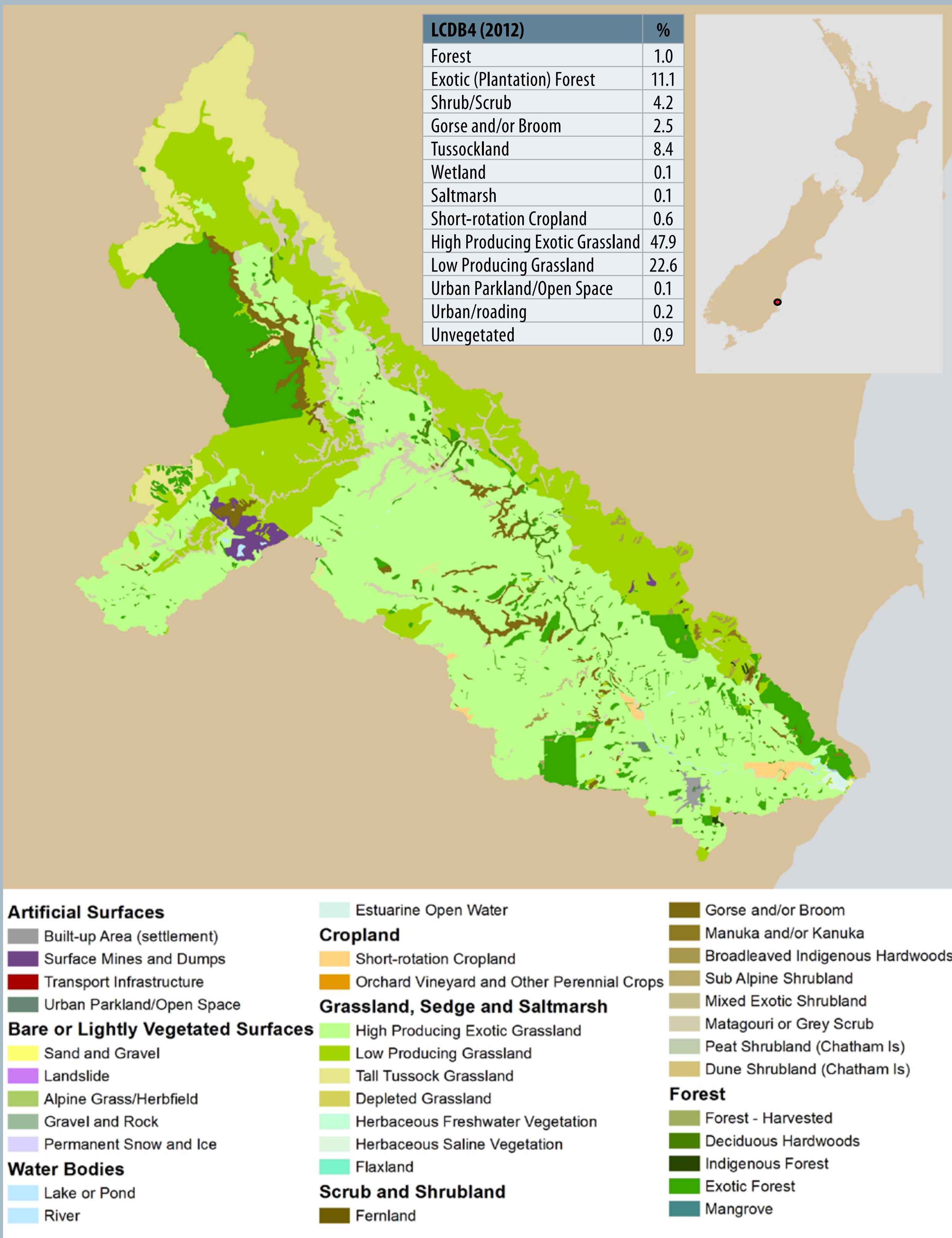


Figure 10. Summary of Catchment Land Cover (LCDB4 2012), Shag Estuary.

4. RESULTS AND DISCUSSION (CONTINUED)

4.7. NZ ESTUARY TROPHIC INDEX

The recently developed 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. A key part of the ETI output has been the development of an integrated calculator that enables easy calculation of 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.

From the current broad scale monitoring (this report) and fine scale monitoring (Robertson et al. 2017), Table 8 presents the indicators used to derive an ETI score for the estuary.

The physical and nutrient load susceptibility of Shag Estuary has been determined as HIGH based on catchment estimates of nutrient loads derived from NIWAs CLUES model, estuary characteristics sourced from the Coastal Explorer database, and ecological value. The overall ETI score for the estuary in December 2016 is 0.35, a risk rating of LOW for eutrophic symptoms.

Table 8. Primary and supporting indicator values used to calculate an ETI score for Shag Estuary, December 2016.

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	0.9
	Macroalgal GEZ/Estuary Area	% Gross Eutrophic Zone (GEZ)		0
	Macroalgal GEZ	Ha Gross Eutrophic Zone (GEZ)		0
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	<1*
	Cyanobacteria (if issue identified)			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	-152
		% of estuary with Redox Potential <-150mV at 3cm		7
		Ha of estuary with Redox Potential <-150mV at 3cm		6.4
		% of estuary with apparent Redox Potential Depth <1cm		7
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		0.35
	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		620
	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area		4.3
		% of estuary with AMBI >4.3		not yet developed
		TBI (if toxicity an issue)		not yet developed
Optional Indicators	Dissolved oxygen	7 day mean, 7 day mean minimum, 1 day minimum (mg/m^3)	water column	not yet developed
	TN and TP concentration	mg/l - 7 day mean, 7 day mean minimum, 1 day minimum		not yet developed
	Water Clarity	Secchi or black disc (m)		not yet developed
	Sediment Sulphur	Requires development	shallow inter-tidal	not yet developed
	Soft mud	% estuary area with soft mud (>25% mud content)		14
		% mud content (mean of whole estuary area)		not yet developed
	Sedimentation Rate	Ratio of current annual mean relative to Natural Sed. Rate (NSR)		4.1
		% Estuary Area with Sedimentation Rate >5xNSR		baseline estab.
	SAV (Seagrass)	Extent (% of ENSC)	all habitat	-
		% change from measured baseline		baseline estab.
NZ ETI Score				**0.35**

*surface and bottom measurements at 3 sites collected on 9/12/17 (Robertson et al. 2017).

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in December 2016, 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.

Muddiness

Soft or very soft muds covered 6.4ha (14.1%) of the intertidal area (excluding saltmarsh), a risk indicator rating of MODERATE, and had a mud content measured in representative areas of 30-73%, a supporting risk indicator rating of HIGH. 6.4ha (7%) of the intertidal area (including saltmarsh) had sediment oxygenation depleted to a level where adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, an ETI risk indicator rating of MODERATE. Soft muds were located predominantly along channel margins and small settling basins in the upper tidal parts of the estuary. The lower estuary and main river channel habitat were in relatively good condition with limited accumulation of muds and generally good sediment oxygenation.

Eutrophication

The NZ ETI combines a range of broad and fine scale indicators (see also Robertson et al. 2017) to provide an overall assessment of eutrophic expression in the estuary, including primary productivity through macroalgal growth and phytoplankton, and supporting indicators of sediment muddiness, oxygenation, organic content, nutrients, macroinvertebrates, and the presence of gross eutrophic zones (a combined presence of dense macroalgal growth, muds and poor sediment oxygenation). The overall ETI score for the estuary in December 2016 was 0.35, a risk rating of LOW for eutrophic symptoms.

Intertidal nuisance macroalgal growths were not evident and there were no gross eutrophic zones present in the estuary. However fine scale sampling did identify stratification in the upper estuary with very high phytoplankton growth, and dense subtidal macroalgal growths indicating that nutrient inputs to the estuary are sufficient to fuel localised primary production to high levels and consequently at times the estuary will shift to a more degraded state.

Habitat modification

There has been significant historical modification of the estuary margin primarily through drainage, reclamation and conversion to pasture. This has greatly altered the ecological composition of the estuary and reduced the natural ecological connectivity between the estuary and surrounding natural habitats. Despite this, extensive herbfield-dominated saltmarsh remained in the estuary (47ha, 51% of the intertidal area). The estuary supported no intertidal seagrass beds in 2016. The 200m terrestrial margin had also been highly modified with 71% pasture or unmaintained grassland, but 28% remained as a densely vegetated buffer.

The combined risk indicators (remaining saltmarsh extent, saltmarsh loss compared to natural cover, change from measured saltmarsh baseline, densely vegetated 200m margin) were rated MODERATE.

Comparison with 2006 results

A comparison of the 2006 (Stewart 2007) and 2016 results was possible for some indicators, but limited by the 2006 report only providing high level summary details, and the likely inclusion of ~40ha of terrestrial habitat. The results show a potential improvement in the estuary from a decrease in the area of soft mud (from 12ha in 2006 to 6ha in 2016), but a significant decrease in saltmarsh (80ha to 46ha). Future monitoring will determine if these results reflect ongoing trends in broad scale features of the estuary or relate more to differences in the mapping and monitoring approaches used in the two surveys.

The combined results place the estuary in a MODERATE state overall in relation to ecological health. Fine sediment issues are evident in the relatively sheltered settlement zones, and water column phytoplankton and subtidal macroalgal growth indicate excessive nutrients are present in the estuary. The modification and loss of estuary saltmarsh and a densely vegetated buffer zone have been historically significant and ongoing pressures are evident in these areas.

6. MONITORING RECOMMENDATIONS

Shag Estuary has been identified by ORC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of ORC's coastal monitoring programme being undertaken throughout the Otago region. Broad scale habitat mapping and the first year of baseline fine scale sampling have now been undertaken (December 2016).

In order to assess ongoing long-term trends in the condition of such 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), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the broad scale component of the long term programme. The recommendation for ongoing monitoring to meet this requirement for the Shag Estuary is as follows:

Broad Scale Habitat Mapping

To characterise any issues of change in habitat (e.g. saltmarsh or seagrass area, soft mud extent), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2026) unless obvious changes are observed in the interim.

In conjunction with scheduled fine scale sampling it is recommended that macroalgal growth be quickly assessed, and monitoring implemented if opportunistic macroalgal cover exceeds 5% in the estuary.

Fine Scale Monitoring

To complete the fine scale baseline in Shag Estuary, it is recommended that the remaining 3 consecutive years of annual summer (i.e. December-February) fine scale monitoring of intertidal sites (including sedimentation rate measures), be undertaken in 2017, 2018 and 2019 (preferably during a summer, low flow period).

To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a summer, prolonged low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 5-6 sites in the main channel of the estuary.

To characterise the potential for excessive sedimentation, it is recommended that sedimentation rates be assessed annually, using appropriately placed sediment plates, and the areal extent of muddy sediments be assessed at 5-10 yearly intervals (the latter assessed in broad scale monitoring).

7. ACKNOWLEDGEMENTS

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APPENDIX 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).

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.

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.

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.

APPENDIX 2. NOTES SUPPORTING RISK INDICATOR RATINGS (TABLE 2)

NOTES to Table 2: 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.

Redox Potential (Eh). For meter approaches, Eh measurements represent a composite of multiple redox equilibria measured at the surface of a redox potential electrode coupled to a millivolt meter (Rosenberg et al. 2001) (often called an ORP meter) and reflects a system's tendency to receive or donate electrons. The electrode is inserted to different depths into the sediment and the extent of reducing conditions at each depth recorded (RPD is the depth at which the redox potential is ~0mV, Fenchel and Riedl 1970, Revsbech et al. 1980, Birchenough et al. 2012, Hunting et al. 2012). The Eh rating bands reflect the presence of healthy macrofauna communities in sediments below the aRPD depth.

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.

APPENDIX 3. 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 6. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

In addition, at selected sampling sites redox potential (RP) was measured with an oxidation-reduction potential meter at 0, 1, 3, 6 and 10cm depths below the substrate surface, and the aRPD depth and substrate type recorded. These results have been used to generate broad scale maps showing areas where sediment oxygenation is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected i.e. where RPD at 3cm <-150mV or aRPD <1cm (Robertson et al. 2016b).

Sampling resolution and accuracy

Estimates of error for different measurements have been made based on the field data collected to date. Initial 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 accuracy of mapping is therefore primarily determined by the resolution of the available photos, and secondarily by the extent of groundtruthing. In most instances features with readily defined edges such as saltmarsh beds, rockfields etc. can be accurately mapped to within 1-2m of their boundaries. The largest area for potential error is where boundaries are not readily visible on photographs e.g. where firm muddy sands transition to soft muds. These boundaries require field validation. Extensive mapping experience has shown that it is possible to define such boundaries to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Because broad scale mapping necessitates the grouping of variable and non-uniform patches (which introduces a certain amount of variation) overall broad scale accuracy is unlikely to exceed ±10% for boundaries not readily visible on photographs.

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 uses transect or grid based grain size sampling.

For specific broad scale seagrass and macroalgae features that are spatially and temporally variable, the overall spatial extent, and boundaries between different percentage cover and density areas, are considered accurate to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Accuracy declines when assessed remotely e.g. from aerial photographs, and particularly so when assessing lower density (<50%) cover which is commonly not visible on aerial coverages. As previously, the most accurate measures are obtained with increasing field time (and cost).

Within mapped boundaries, broad scale estimates of percentage cover and density, due to the grouping of variable and non-uniform patches, are considered accurate to ±10%. These however can be assessed to a much higher degree of accuracy using fine scale quadrat based approaches such as the OMBT which can also be increased by applying fine scale approaches estuary-wide if a very high degree of accuracy is considered important.

For the OMBT, a methodology for calculating a measure of the confidence of class (CofC), has been developed (Davey, 2009) that defines the specific accuracy of the measures undertaken. Called CAPTAIN ('Confidence And Precision Tool Aids aNalysis') it calculates CofC at three levels: i. metric, ii. survey (single sampling event), and iii. water body over the reporting period (potentially several surveys). The upper and lower 90% Confidence Intervals for the SE of the EQR are presented in this report.

APPENDIX 4. DETAILS OF ANALYTICAL METHOD

Sediment Indicator	Laboratory	Method	Detection Limit
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference)	0.1 g/100g dry wgt