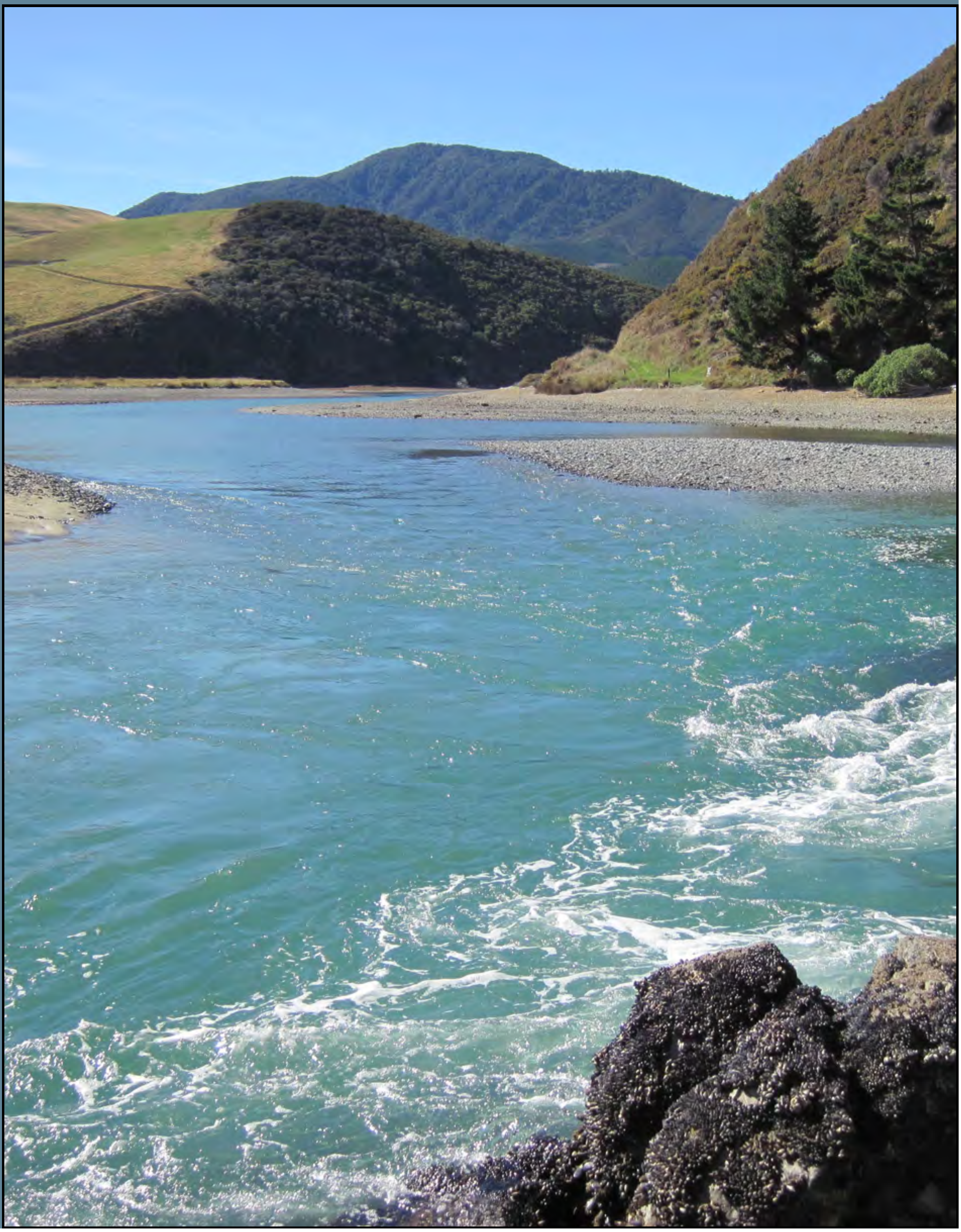
coastalmanagement

Nelson Region Estuaries

Vulnerability Assessment and Monitoring Recommendations



Prepared for

Nelson City Council

September 2017

Cover Photo: Kokorua Inlet entrance - showing low tide channel and mixture of surrounding land use types in the background


Saltmarsh fringing tidal flats, Kokorua Inlet

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Prepared for
Nelson City Council

By

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EXECUTIVE SUMMARY

Understanding the risks to estuarine habitats is fundamental to establishing a defensible and cost effective long-term estuary monitoring programme for the Nelson region. To this end, Nelson City Council (NCC) recently contracted Wriggle Coastal Management to consolidate existing information on the four largest estuaries in the Nelson region (Waimea Inlet, Nelson Haven, Delaware Inlet and Kokorua Inlet) and to use a formalised risk based approach to determine estuary vulnerability, identify key stressors (e.g. excessive sediment, nutrients, pathogens, toxins, or habitat changes), and apply established assessment criteria to determine the likely influence of stressors on estuary condition. From this, monitoring indicators and approaches will be defined for each estuary (along with any data gaps), and recommendations made regarding long term estuarine monitoring.

ESTUARY VULNERABILITY ASSESSMENT METHODS

The Estuary Vulnerability Assessment (EVA) uses an adaptation of a UNESCO methodology (UNESCO 2000) designed to be used by experts to represent how coastal ecosystems are likely to react to the effects of potential "stressors" (the causes of coastal issues - often human activities). The most common stressors in NZ estuaries are excessive inputs of fine muds, nutrients, pathogens, toxicants, and habitat changes, with identified stressors assessed in the current EVA listed to the right.

The vulnerability of each estuary to identified stressors was assessed using defined criteria to determine their potential influence, and combined with existing knowledge of estuary condition and ecological and human use values to determine the likely expression of problems. The 8 key steps involved in the EVA are summarised in the flow diagram in the panel to the right.

The EVA uses a combination of estuary physical characteristics, modelled estimates of nutrient, sediment and pathogen loads, monitoring results (collected using established tools such as the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002), and assessment criteria from established risk assessment frameworks (e.g. Robertson and Stevens 2012) and more recent tools like the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b).

The results are combined and summarised for each estuary using a vulnerability matrix and accompanying narrative that defines the vulnerability of each estuary to key stressors, highlights the key indicators used to assess change, and recommends targeted monitoring appropriate for each estuary.

STRESSORS ASSESSED IN THE CURRENT EVA

Eutrophication (excessive nutrients)
Fine sediment
Disease Risk
Toxicants e.g. Urban runoff, Pesticides, Oil spills
Climate Change (vulnerability to sea level rise)
Structures that Disrupt Sediment Transport
Drainage and Reclamation
Freshwater Abstraction
Harvesting Living Resources
Invasive Species
Off-Road Vehicles
Toxic Algal Blooms (TAB)
Human/Animal Disturbance of Wildlife
Grazing in High-value Habitat

KEY STEPS IN THE EVA PROCESS

Step 1. Map broad scale habitat features
↓
Step 2. Define estuary type
↓
Step 3. Estimate susceptibility to key stressors
↓
Step 4. Rate the stressor influence on estuary habitat
↓
Step 5. Identify and rate stressor influence on human uses and ecological values
↓
Step 6. Rate stressor influence on monitoring indicators and issues
↓
Step 7. Identify priority indicators for monitoring
↓
Step 8. Identify overall vulnerability, key issues and monitoring recommendations

VULNERABILITY TO KEY ISSUES

Vulnerability is the combination of i. susceptibility to stressors (the extent an ecological community would be impacted if exposed to a stressor), and ii. the likelihood or presence of stressors. The susceptibility of estuaries to common stressors is relatively well understood and guidelines have been established to rate susceptibility in a transparent and consistent manner. The existing condition of the estuaries in response to the presence of the stressors is then used to define overall vulnerability.

Executive Summary (continued)

Previous monitoring has been undertaken in all of the estuaries as follows:

- **Broad scale habitat mapping** to document dominant estuary features (e.g. substrate, seagrass, saltmarsh, macroalgae) and monitor changes over time. Broad scale mapping, usually scheduled at 5 yearly intervals, was undertaken in Waimea Inlet in 1990 (Davidson and Moffat 1990), 1999 (Robertson et al. 2002), 2006 (Clarke et al. 2008), and 2014 (Robertson & Stevens 2014a). Historical vegetation cover was also assessed using 1946 and 1985 aerial photographs (Tuckey and Robertson 2003). Nelson Haven and Delaware Inlet were mapped in 2009 (Gillespie et al. 2011a&b; Kokorua Estuary in 2015 (Stevens and Robertson 2015).
- **Fine scale monitoring** measures the condition of representative intertidal sediments (usually the dominant substrate type as well as deposition zones where sedimentation and eutrophication symptoms are first expressed) using a suite of physical, chemical and biological indicators (refer to Table 1 of the main report for further detail). It is commonly undertaken once annually for three consecutive years during the period Nov-Mar (usually at two to three sites) to establish a baseline, and thereafter at 5 yearly intervals. Fine scale intertidal monitoring was undertaken in Waimea Inlet in 2001, 2006, 2011, with a multi-year baseline established from 2014, 2015 and 2016 (see Robertson & Stevens 2014a). Nelson Haven was assessed in 2012 (Gillespie et al. 2012), Delaware Inlet in 2009 (Gillespie et al. 2009), and Kokorua Inlet in 2015 (Stevens and Robertson 2015).
- **Annual sedimentation rate (including grain size) monitoring** measures sedimentation trends within the estuary over time. Sediment plates have been deployed in Waimea Inlet and monitored since 2008 as part of the Tasman District Council estuarine monitoring programme, and historical coring to determine past sediment accrual was also undertaken in Waimea Inlet in 2011 (Stevens and Robertson 2011). Sediment plates were deployed and baseline measurements taken in Kokorua in 2015 (Stevens and Robertson 2015).

The facing page provides a high level summary of existing condition based on key indicators. These results, in combination with the vulnerability assessment undertaken, identified the following values and issues for the four Nelson estuaries assessed:

HUMAN USE AND ECOLOGICAL VALUE	Waimea	Nelson Haven	Delaware	Kokorua
Human use	HIGH	HIGH	HIGH	LOW
Ecological value	MODERATE	MODERATE	MODERATE	HIGH

SUMMARY OF VULNERABILITY RATINGS				
Sedimentation Susceptibility	High	Moderate	High	Moderate
Sedimentation Existing Condition	Moderate	High	High	Very High
Combined Sedimentation (muddiness)	HIGH	HIGH	HIGH	HIGH
Susceptibility to Eutrophication Rating	High	High	Low	High
Existing Condition Eutrophication Rating	Moderate	Low	Low	Moderate
Combined Eutrophication (Nutrient enrichment)	HIGH	MODERATE	MODERATE	HIGH
Bathing Areal FC Loading Rating	Moderate	Moderate	Moderate	Moderate
Shellfish Areal FC Loading Rating	High	High	High	High
Combined Disease Risk	HIGH	HIGH	HIGH	HIGH
Coastal Erosion	LOW	LOW	LOW	LOW
Climate change - pH and temperature	HIGH	HIGH	HIGH	HIGH
Toxicants	MODERATE	MODERATE	LOW-MODERATE	LOW-MODERATE
Marine Oil Spills	MOD-HIGH	HIGH	MOD-HIGH	MODERATE
Saltmarsh (% loss from baseline)	HIGH	HIGH	HIGH	NA
Seagrass (% loss from baseline)	HIGH	HIGH	HIGH	NA
Reclamation	HIGH	HIGH	LOW	VERY LOW
Shoreline Armouring, Structures	MODERATE	MOD-HIGH	MODERATE	LOW
Freshwater Abstraction	MODERATE	MODERATE	MODERATE	MODERATE
Harvesting	MOD-HIGH	MOD-HIGH	MODERATE	LOW
Invasive Species	MODERATE	MOD-HIGH	MODERATE	LOW
Off Road Vehicles	LOW	LOW	LOW	LOW
Wildlife Disturbance	MOD-HIGH	MOD-HIGH	MOD-HIGH	MODERATE
Grazing	LOW	LOW	LOW	LOW
Natural Terrestrial Margin	HIGH	HIGH	HIGH	VERY LOW
OVERALL VULNERABILITY	**HIGH**	**MODERATE-HIGH**	**MODERATE-HIGH**	**MODERATE**

Executive Summary (continued)

EXISTING ESTUARY CONDITION

Results of the latest available estuary monitoring data, presented with "risk ratings" developed to indicate the likely risk of adverse ecological impacts occurring, are as follows:

- Soft and very soft mud cover was moderate-high (9.4-36.2%), predominantly on mid-upper estuary intertidal flats and settlement basins where fine sediment deposition is promoted by physical conditions.
- Gross eutrophic conditions were not widespread - Waimea Inlet (28ha, 2.7% of the intertidal area) and Kokorua Inlet (0.3ha, 0.5% of the intertidal area).
- Intertidal seagrass cover was sparse (<2%) in Waimea, Delaware and Kokorua but was relatively extensive (14%) in Nelson Haven.
- Dense (>50% cover) macroalgae cover was also sparse (<2% of the intertidal area) in Waimea, Nelson Haven and Kokorua but was relatively extensive in Delaware (10%).
- Saltmarsh extent was low in Nelson Haven (largely due to historical reclamation), moderate in Delaware and Waimea Inlets, and relatively high in Kokorua.
- Dense vegetation cover in the 200m terrestrial margin was relatively low in Waimea and Delaware but relatively high in Kokorua. Nelson Haven, not yet assessed formally, is also low.

Fine scale monitoring within dominant unvegetated mid-low tide substrate showed:

- Sediment mud contents were high (>25% mud) in Waimea, Delaware and Kokorua, and relatively lower (<20% mud) in Nelson Haven.
- Sediment oxygenation was considered moderate-poor in Waimea and Kokorua.
- Sediment organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were low-moderate in all four estuaries, except for relatively high total phosphorous contents in Delaware.
- Sediment toxicant indicators (heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn, the metalloid As, and semi-volatile organic compounds) within all four estuaries were at concentrations that were not expected to pose toxicity threats to aquatic life (very low risk).
- Macroinvertebrate communities were in good condition in Waimea but relatively depauperate (mud impacted) in Kokorua.

Risk Ratings Key*: Low | Very Low | Moderate | High | Very High | Not available

*see Robertson & Stevens 2015a&b and Robertson et al. 2016a&b for full details on the Wriggle risk ratings, including their rationale and development).

BROAD-SCALE CONDITION

Broad scale indicator	Soft mud (% of intertidal)	Seagrass (% of intertidal)	Seagrass (% loss since baseline - baseline year in brackets)	Macroalgae (% intertidal in >50% cover)	Gross eutrophic conditions (% of intertidal)	Saltmarsh (% of estuary)	Saltmarsh (% loss since baseline - baseline year in brackets)	200m densely vegetated terrestrial margin (%)
Waimea 2014	36.2	1	41 (1990)	1.8	2	9.1	14 (1946)	22
Nelson Haven 2009	10.5	14.1	58 (1840)	1.8	NA	0.7	99 (1840)	NA
Delaware 2009	9.4	1.4	38 (1983)	10.2	NA	6.3	30 (1983)	19
Kokorua 2015	20	0	NA	0.3	0.5	31.4	NA	73

FINE-SCALE CONDITION

Fine scale indicator	Site	Sediment Mud Content (%)	Sed. Oxygenation (aRPD cm)	TOC (Total Organic Carbon%)[a]	TN (Total Nitrogen mg/kg)	TP (Total Phosphorus mg/kg)	Toxicants[b]	Macroinvertebrates (NZ AMBI)
Waimea 2014	A	42.7	1	0.54	700	437		
	B	25.2	2	0.38	500	493		
	C	26.6	1	0.54	733	370		
	D	50.1	1	0.62	700	530		
Nelson Haven 2009	A	12.3	1-2	0.20	200	416		NA
	B	7.3	1-2	0.24	243	300		NA
	C	16.1	1-2	0.38	383	300		NA
Delaware 2009	A	73.3	1-2	0.68	823	587		NA
	B	3.9	>3	0.42	250	543		NA
	C	18.9	2-3	0.46	313	573		NA
Kokorua 2015	A	24.7	1	0.69	733	490		
	B	69.9	1	1.31	1000	473		

[a] TOC (Total Organic Carbon) values estimated from AFDW (Ash Free Dry Weight) as follows: 1g AFDW as equivalent to 0.2 g TOC (± 100%) based on a preliminary analysis of NZ estuary data. [b]Naturally high levels of Nickel and Chromium and are present in Nelson catchment geologies.

Executive Summary (continued)

MONITORING RECOMMENDATIONS

To maintain the high value of the four surveyed Nelson region estuaries, and to ensure sufficient information is available to manage each in relation to the identified vulnerability to specific issues, long term monitoring is recommended for each estuary below:

- **Broad scale habitat mapping** to document dominant estuary features (e.g. substrate, seagrass, saltmarsh, macroalgae) and monitor changes over time.
- **Fine scale monitoring** measures the condition of representative intertidal sediments (usually the dominant substrate type as well as deposition zones where sedimentation and eutrophication symptoms are more likely to be expressed) using a suite of physical, chemical and biological indicators.
- **Annual sedimentation rate (including grain size) monitoring** measures sedimentation trends within the estuary over time.
- **High level data on dominant changes in catchment land use** to track changes in high risk activities (e.g. land disturbance, point source discharges), and facilitate estimates of changes to naturally occurring catchment inputs of sediment, nutrients and pathogens likely from human influenced land disturbance.
- **Synoptic sampling** of two smaller estuaries located to the northeast of Kokorua Inlet (Omokau and Oananga Bays), and for which no data are currently known to exist, to quickly determine existing state and pressures and determine the need for further monitoring.

The monitoring proposed, based on the NEMP framework, has been successfully applied to establish estuary monitoring priorities throughout NZ, and underpins the NZ ETI. Adopting a nationally consistent approach ensures the Council benefit directly from work undertaken in other regions, as well as from established tools and existing national data, indicators and thresholds.

PROPOSED MONITORING PLAN

COMPONENT	ESTUARY	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Broad scale mapping	Waimea		X					X				
	Nelson Haven			X					X			
	Delaware	X*					X					X
	Kokorua				X					X		
Fine scale monitoring	Waimea				X					X		
	Nelson Haven				X	X	X					X
	Delaware		X	X	X					X		
	Kokorua	X	X	X					X			
Sedimentation rate monitoring (sediment plates)		annual monitoring recommended for each estuary										
Regional State of Environment report						R					R	
Catchment land use changes, sediment/nutrient source tracking						R					R	
Ecological vulnerability assessment	Tasman					R						
	Nelson										R	

X = Proposed long term monitoring schedule (Note Waimea monitoring is linked directly to the TDC long term monitoring plan).

X* = Prioritsed monitoring to capture estuary condition prior to scheduled forest logging in surrounding catchment

R = Recommended high level data collection and reporting

1. INTRODUCTION

AIM AND SCOPE

The Parliamentary Commissioner for the Environment's 2000 report "Setting Course for a Sustainable Future: the Management of New Zealand's Marine Environment" identified that the current knowledge of estuarine life and how such ecosystems work was not yet sufficient to show whether we are sustainably managing New Zealand's coastal biodiversity. In particular NZ would benefit from the integration of measurable impacts into an ecosystem-based framework with explicit biodiversity objectives. The need to gather information to inform the assessment of effects on the environment is implicit in NZ's legislation for sustainable management, and a variety of tools and approaches to better achieve this have been developed in NZ, including the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the recently developed NZ Estuary Trophic Index (ETI) toolbox (Robertson et al. 2016a, 2016b). Information collected through such approaches, and from a variety of other sources, can then be drawn together within an estuary vulnerability assessment framework to consistently and transparently assess the vulnerability of individual estuaries to major issues (see Table 1), identify appropriate monitoring design, and guide management.

Recently, Nelson City Council (NCC) contracted Wriggle Coastal Management (Wriggle) to consolidate existing information on the four largest estuaries in the Nelson region (Waimea Inlet, Nelson Haven, Delaware Inlet and Kokorua Inlet - Figure 1) and to use a formalised risk based approach to determine estuary vulnerability, identify key stressors (e.g. excessive sediment, nutrients, pathogens, toxins, or habitat changes), and apply established assessment criteria to determine the likely influence of stressors on estuary condition. From this, monitoring indicators and approaches will be defined for each estuary (along with any data gaps), and recommendations made regarding long term estuarine monitoring. The approach is based on that used recently in coastal vulnerability assessments in the Greater Wellington, Southland, Tasman, and Manawatu-Wanganui regions (Robertson and Stevens 2007a, 2007b, 2007c, 2008, 2012, 2016). It includes the following key components:

- **Estuarine monitoring results:** Results of existing broad scale habitat mapping and fine scale sediment monitoring are summarised for each estuary e.g. extent of soft mud, seagrass, saltmarsh, opportunistic macroalgae, and sediment quality within representative dominant habitat.
- **Vulnerability assessments**: An assessment of the vulnerability and existing condition of estuarine habitats to key estuarine issues, particularly the dominant issues of eutrophication (excessive nutrients) and fine sediment (excessive muddiness), as well as other key issues including disease risk, toxicity, climate change, and habitat loss or disturbance (see Table 1 for further detail).
- **Monitoring priorities:** A recommended monitoring programme designed to track long-term changes in estuary condition and guide appropriate management in relation to these key issues in a staged, cost effective and defensible manner (see Table 1 for further detail).

REPORT STRUCTURE

Section 1 provides an broad overview of the scope and structure of the study.

Section 2 introduces the methods used for assessing vulnerability and establishing monitoring recommendations.

Section 3 provides summary detail for each estuary including their characteristics, values and uses, vulnerabilities to key stressors, existing condition and recommended monitoring. In addition:

- Vulnerability assessments are presented as completed matrices for each estuary.
- Broad scale habitat maps of dominant substrate and saltmarsh are presented for each estuary. These are derived from highly detailed electronic GIS maps held by NCC.
- Detailed summary information on each estuary, on which much of the vulnerability assessment is based, is presented in Appendix 1.

Section 4 summarises the vulnerability assessment results and monitoring recommendations.

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. 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 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,
- direct physical effects e.g. gill abrasion in fish, compromised filter feeding (invertebrates including shellfish, and prey sighting (fish and birds),
- 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
Sedimentation	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 storm-water 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. Microbeads and plastics are a recently recognised concern. 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 shell-fish 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 pollut-ants, 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.

1. Introduction (continued)

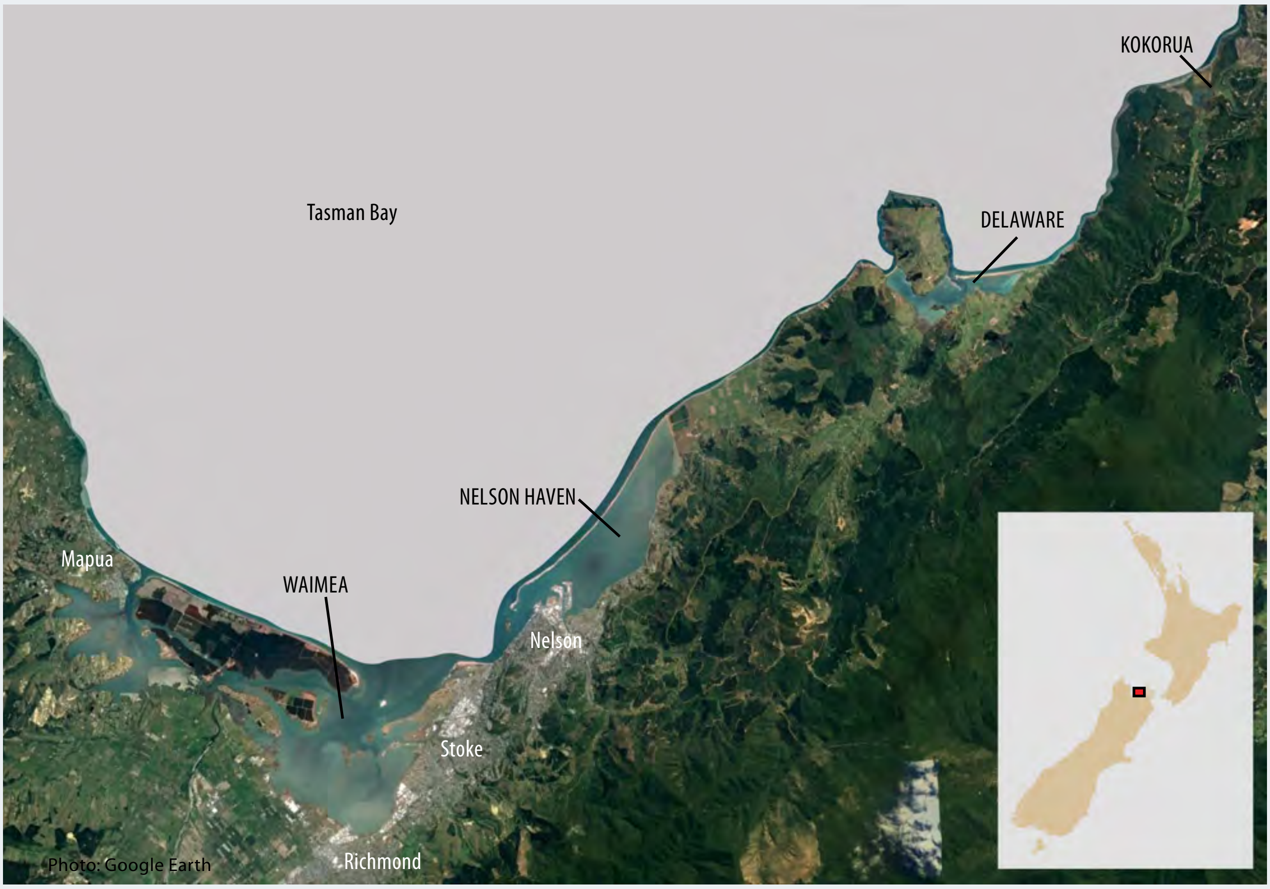


Figure 1. Map showing the location of the four largest estuaries in the Nelson region.

2. METHODS

2.1 ESTUARY VULNERABILITY ASSESSMENT

A summary outline of the approach used for the Nelson region Estuary Vulnerability Assessment (EVA) is presented in Figure 2, with a detailed step-wise outline of the methods and assessment criteria used presented in Section 2.2. An example of the final matrix used for recording the findings for each of the key steps is shown in Table 2. The criteria used to assess the vulnerability of Nelson region estuaries to key stressors were based on those described in detail in the Tasman region coastal EVA (Robertson & Stevens 2012) and are included in summary form in Section 2.2.

The Nelson region EVA also makes extensive use of the recent NZ ETI (Robertson et al. 2016a, 2016b) (see summary inset below), which is designed to be used by experts to represent how estuarine ecosystems are likely to react to the effects of excessive nutrients and fine sediment, and how to monitor and assess their existing level of eutrophication and sedimentation. These reports provide much of the underpinning rationale for the indicators and monitoring approaches recommended.

Summary of the NZ Estuary Trophic Index (ETI) Tool

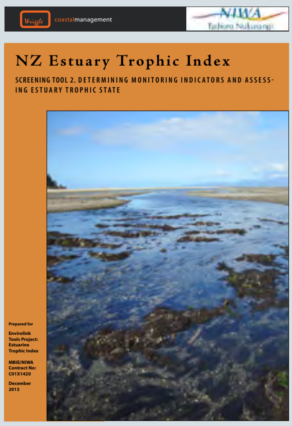
The ETI is a stand-alone, hard-copy methodology that includes two sets of tools that provide screening guidance for assessing where an estuary sits on the eutrophication (and associated sedimentation) gradient, what is required to shift it to a different location in the gradient, and which indicators are required for monitoring. Although the ETI focuses on the issue of eutrophication, it includes relevant thresholds for determining the influence of fine sediments on estuary condition, in particular, sedimentation rate and area (spatial extent) of soft muds.

Screening Tool 1. Physical and Nutrient Susceptibility Tool

This tool is designed to provide a robust and cost effective approach to enable the prioritisation of estuaries for more rigorous monitoring and management. It applies a desktop susceptibility approach that is based on estuary physical characteristics, and nutrient input load/estuary response relationships for key NZ estuary types. The tool produces a single physical susceptibility score that can be used to classify either the ***physical susceptibility*** (i.e. very high, high, moderate, low susceptibility), and/or be combined with nutrient load data to produce a ***combined physical and nutrient load susceptibility*** rating. Nutrient areal load/trophic state bands for each estuary eutrophication type will be developed as a long term goal, with data currently available for some estuary types, but not all as yet. This section also provides guidance on the use of a simple load/response model tool provided in the ETI toolbox, and recommendations for the use of more robust approaches for setting load limits.

Screening Tool 2. Trophic Condition Assessment Tool

This tool is a monitoring approach that characterises the ecological gradient of estuary trophic condition for relevant ecological response indicators (e.g. macroalgal growth, sediment oxygenation), and provides a means of translating these ratings into an overall estuary trophic condition rating/score (the ETI). It provides guidance on which condition indicators to use for monitoring the various estuary types (and why they have been chosen), and on assessing the trophic state based on the indicator monitoring results and their comparison to numeric impairment bands (e.g. very high, high, moderate, low). The latter involves measurement of the expression of both primary (direct) eutrophication symptoms (e.g. macroalgae or phytoplankton) and supporting indicators for secondary (indirect) symptoms of trophic state (e.g. sediment oxygenation).



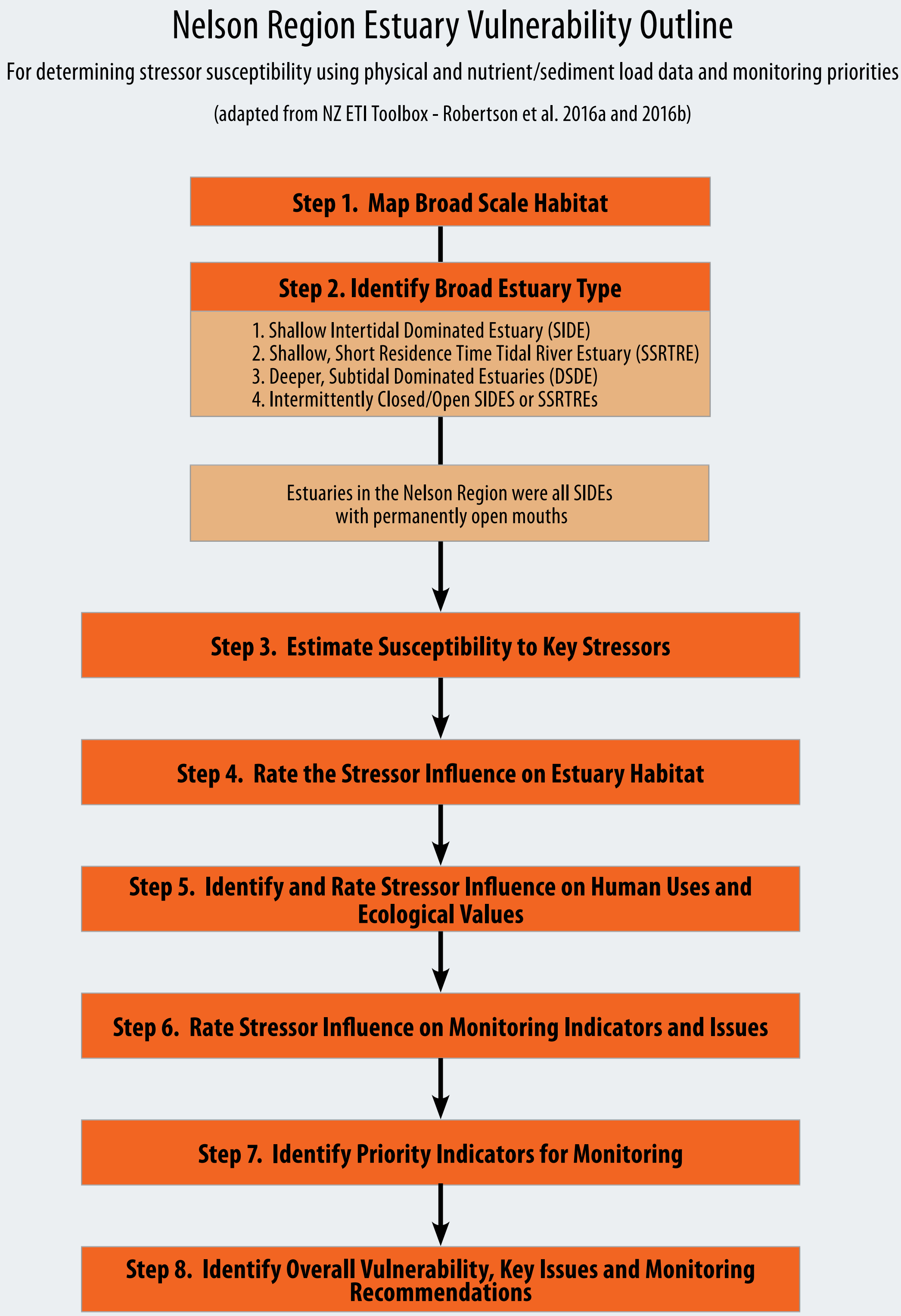
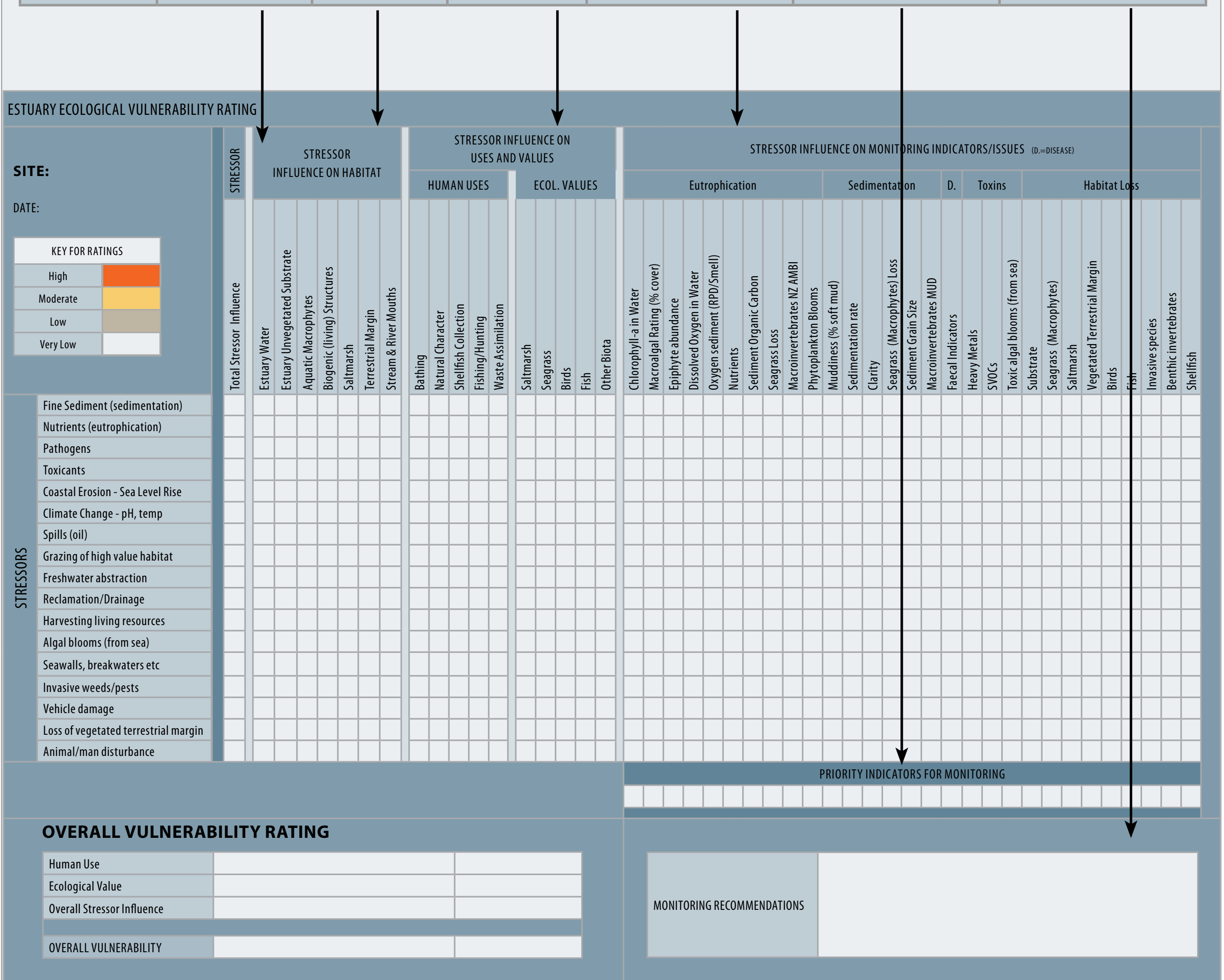


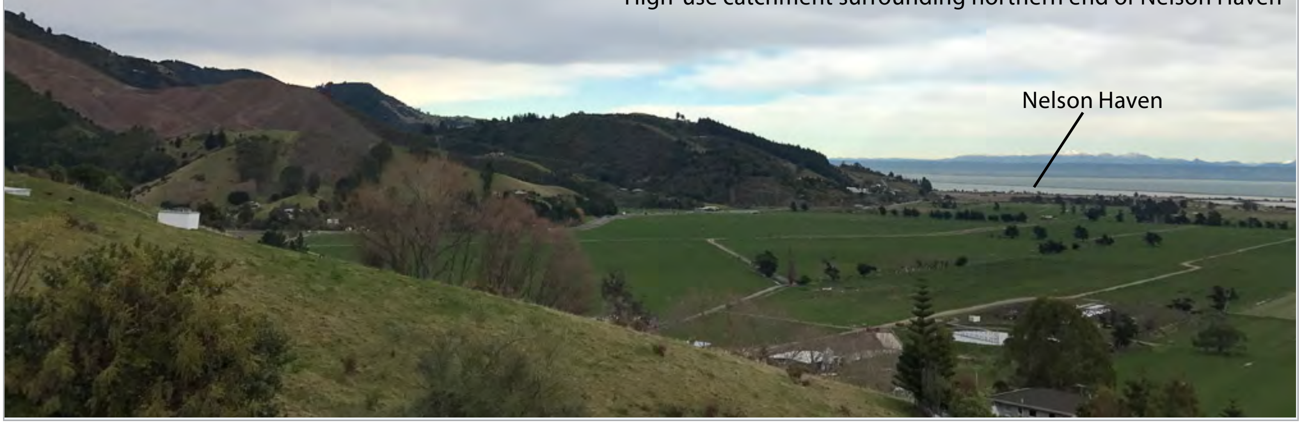
Figure 2. Outline flow diagram of the key steps in assessing estuary susceptibility to key stressors.

2. Methods (continued)

Table 2. Steps in filling out the vulnerability matrix

Steps 1 & 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Broad scale mapping and definition of estuary type	Rate estuary susceptibility and stressor influence	Rate the stressor influence on habitat	Identify and Rate Human Uses and Ecological Values	Rate the stressor influence on monitoring indicators and hence issues	Identify priority indicators for monitoring	Determine the overall ratings, and monitoring recommendations





High-use catchment surrounding northern end of Nelson Haven

2. Methods (continued)

2.2 SUMMARY OF THE STEPS USED IN THE NELSON REGION ESTUARY VULNERABILITY ASSESSMENT

Step 1. Assess existing estuary data including broad scale habitat maps and fine scale monitoring results

In order to characterise the physical structure, habitats and condition of Nelson's estuaries, the following existing information was used:

Waimea

- A detailed vulnerability assessment in 2010 (Stevens & Robertson 2010).
- Region-wide ecological risk assessment of the Tasman coastline in 2012 (Robertson & Stevens 2012).
- Broad scale habitat mapping: 1946 and 1985 (Tuckey and Robertson 2003), 1990 (Davidson and Moffat 1990), 2001 (Robertson et al. 2002), 2006 (Clarke et al. 2008), and 2014 (Robertson & Stevens 2014a).
- Fine scale benthic sampling in 2001 (Robertson et al. 2002), 2007 (Gillespie et al. 2007), 2011 (Robertson & Stevens 2012) and 2014 (Robertson & Stevens 2014).
- Monitoring of sediment/mud deposition undertaken annually at 10 sites since 2008 as part of the TDC estuarine monitoring programme (data held by TDC).

Nelson Haven

- Preliminary assessment of environmental status in 2008 (Gillespie 2008a).
- Broad scale habitat mapping in 2009 (Gillespie et al. 2011a), seagrass mapping of 1840, 1931, 1979, 2009 (Gillespie et al. 2011a), and macroalgal mapping in 2010 (Stevens and Robertson 2010a).
- Fine scale sediment sampling in 2012 (Gillespie et al. 2012).

Delaware

- Preliminary assessment of environmental status in 2008 (Gillespie 2008b).
- Broad scale habitat mapping in 1983 and 2009 (Gillespie et al. 2011b).
- Fine scale sediment sampling in 2009 (Gillespie et al. 2009).

Kokorua

- Preliminary assessment of environmental status in 2013 (Gillespie 2013).
- Broad scale habitat mapping in 2015 (Stevens & Robertson 2015).
- Fine scale sediment sampling in 2015 (Robertson & Stevens 2015).

Relevant information from each source was incorporated in this report to assess the ecological condition of each estuary, with both system-wide (broad scale) and site-specific (fine scale) spatial scales. Fine scale data were used to characterise, for example, the state of benthic macroinvertebrate communities and sediment nutrient/toxicant levels at representative sites within dominant substrate, whereas the broad-scale habitat maps provided an estuary-wide insight into the extent of muddiness and eutrophication symptoms, as well as habitat diversity and quality e.g. substrate composition, sediment oxygenation, seagrass, saltmarsh. These details were then used to inform the vulnerability of each Nelson region estuary to key estuarine stressors as follows:

Step 2. Identify estuary eutrophication type

Susceptibility to the key estuary issues of eutrophication and sedimentation, and to a lesser extent toxicity and disease risk, is influenced by specific physical modifying characteristics including dilution, flushing, residence time, depth and intertidal extent. The ETI adopted a simple four category typology (described further in Table 3) specifically suited to the assessment of estuarine eutrophication susceptibility in NZ (an adaptation of the more detailed New Zealand Coastal Hydrosystems Typology, Hume 2016), as follows:

1. Shallow intertidal dominated estuaries (SIDEs)
2. Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs)
3. Deeper subtidal dominated, longer residence time estuaries (DSDEs)
4. Intermittently closed/open lake and lagoon estuaries (ICOLLs) - sub types of SIDEs and SSRTREs.

The four Nelson region estuaries assessed are all SIDEs with mouths permanently open to the sea.

Table 3. Main estuary categories used in eutrophication susceptibility analysis

1. Shallow, Intertidal Dominated Estuaries (SIDEs)

For NZ's dominant estuary types (i.e. shallow, short residence time (<3 days), and predominantly intertidal, tidal lagoon estuaries and parts of other estuary types where extensive tidal flats exist e.g. Firth of Thames, Kaipara Harbour, Freshwater Estuary - Stewart Island), flushing is too strong for significant retention of dissolved nutrients. Nevertheless, retention can still be sufficient to allow for retention of fine sediment and nutrients (particularly if these are excessive), deleterious for healthy growths of seagrass and saltmarsh, and promoting nuisance growths of macroalgae in at-risk habitat. In this estuary type, assessment of the susceptibility to eutrophication must focus on the quantification of at-risk habitat (generally mid-upper estuary tidal flats), based on the assumption that the risk of eutrophication symptoms increases as the habitat that is vulnerable to eutrophication symptoms expands. Nitrogen (N) has been identified as the element most limiting to algal production in most estuaries in the temperate zone and is therefore the preferred target for eutrophication management in these estuaries (Howarth and Marino 2006).

Susceptibility to Nutrient Loads: Moderate to High

Major Primary Producers: Macroalgae

Freshwater Estuary (Stewart Island): high susceptibility pristine estuary

2. Shallow, Short Residence Time Tidal River, and Tidal River with Adjoining Lagoon, Estuaries (SSRTREs)

NZ also has a number of shallow, short residence time (<3 days) tidal river estuaries (including those that exit via a very well-flushed small lagoon) that have such a large flushing potential (freshwater inflow/estuary volume ratio >0.16) that the majority of fine sediments and nutrients are exported to the sea. Tidal rivers with mouth restrictions or closure periods of days rather than months and high freshwater inflows (e.g. Lake Onoke) can also fit in this category. In general, these estuary types have extremely low susceptibilities and can often tolerate nutrient loads an order of magnitude greater than shallow, intertidal dominated estuaries. These shallow estuary types are generally N limited.

Susceptibility to Nutrient Loads: Low to Very Low

Major Primary Producers: Macroalgae, but low production, especially if freshwater inflow high

Waimatuku Estuary (Southland)

3. Deeper, Subtidal Dominated, Estuaries (DSDEs)

Mainly subtidal, moderately deep (>3m to 15m mean depth) coastal embayments (e.g. Firth of Thames) and tidal lagoon estuaries (e.g. Otago Harbour) with moderate residence times >7 to 60 days, can exhibit both sustained phytoplankton blooms, and nuisance growths of opportunistic macroalgae (especially *Ulva* sp. and *Gracilaria* sp.) if nutrient loads are excessive. The latter are usually evident particularly on muddy intertidal flats near river mouths and in the water column where water clarity allows. Deeper, long residence time embayments and fiords are primarily phytoplankton dominated if nutrient loads are excessive. Outer reaches of such systems which sustain vertical density stratification can be susceptible to oxygen depletion and low pH effects (Sunda and Cai 2012, Zeldis et al. 2015). In both cases, it is expected that the US ASSETS approach will adequately predict their trophic state susceptibility. These deeper estuary types are generally N limited.

Susceptibility to Nutrient Loads: Moderate to Low

Major Primary Producers: Macroalgae (moderately deep) and phytoplankton (deeper sections)

Pelorus Sound (Marlborough)

4. Intermittently Closed/Open Estuaries (SIDEs and SSRTREs)

Shallow tidal lagoon and tidal river type estuaries (<3m deep) that experience periodical mouth closure or constriction have the highest susceptibility to nutrient retention and eutrophication, with the most susceptible being those with closure periods of months (e.g. Waituna Lagoon, Southland) rather than days (e.g. Lake Onoke, Wellington). In general, the tidal rivers have shorter periods of mouth closure (unless they are very small) than the more buffered tidal lagoons. The high susceptibility arises from reduced dilution (absence of tidal exchange at times) and increased retention (through both enhanced plant uptake and sediment deposition). Excessive phytoplankton and macroalgal growths and reduced macrophyte growth are characteristic symptoms of eutrophication in mouth restricted or closed estuaries. In such situations, which vary between marine and close to freshwater salinities, a co-limiting situation between N and P is expected, and as a consequence nutrient load/estuary response relationships should consider both N and P.

Susceptibility to Nutrient Loads: Very High

Major Primary Producers: Both Macroalgae and Phytoplankton

Waituna Lagoon (Southland): high susceptibility intermittently open/closed estuary

2. Methods (continued)

Step 3. Assess key stressor influence based on susceptibility and existing condition

The following four pages summarise the key stressors assessed in the current work and the criteria used to assess their influence. The data used to determine ratings are presented in Appendix 1.

Nutrients (eutrophication) and fine sediment (muddiness) are the two most significant stressors of the ecological condition of Nelson region estuaries. Eutrophication of NZ SIDEs is a process driven by the enrichment of water and sediment by nutrients, especially compounds of nitrogen (N) and, to a lesser extent, phosphorus (P) that results in excessive primary production of macroalgae and/or phytoplankton. Because fine sediments often contain elevated nutrient concentrations, the two issues of eutrophication and sediment muddiness are generally strongly interlinked. Catchment inputs are the primary source of both nutrients and fine sediments and, if individually present in excess, they result in ecological degradation, which is exacerbated when they occur together (e.g. muddy, nutrient-rich sediments leads to lower pore water exchange, increased sediment bound nutrients, increased organic matter, reduced sediment oxygenation, elevated toxic sulphide levels).

Stressor	Guideline used to assess estuary susceptibility to stressor
Nutrients (Eutrophication)	See below

Stressor: Nutrients (Eutrophication)

Combined physical and nutrient load susceptibility to eutrophication (expressed as primary production of macroalgae)
This was assessed using the ETI nutrient load thresholds for SIDEs as follows:

Physical Susceptibility	N load Susceptibility (Areal N load $mg/m^2/d$)			
	Very High >250	High >50-250	Moderate 10-50	Low <10
High	Band D Very High	Band C High	Band C High	Band B Moderate
Mod	Band D Very High	Band C High	Band B Moderate	Band A Low
Low	Band C High	Band B Moderate	Band B Moderate	Band A Low

Areal N load = Total N estuary load ($mg.N.d^{-1}$)/estuary area (m^2). For the Nelson region estuaries, total N load estimates were derived using the NIWA CLUES model (Version 10.3, released May 2016 default setting using REC2 and LCBB3 (2008/2009) land cover), (Elliot et al. submitted, Semadeni-Davies et al. 2011). Physical susceptibility was determined using the ETI Tool 1 approach where Flushing Potential [i.e. freshwater inflow ($m^3.d^{-1}$) divided by estuary volume (m^3) and adjusted for tidal height (m)] and Dilution Potential [i.e. 1 ÷ estuary volume (ft^3)} are combined in a matrix. Input data for the Nelson estuaries, and combined N load were as follows:

Estuary	Physical susceptibility	Areal N load ($mg.N.m^{-2}.d^{-1}$)	Combined physical and N load susceptibility
Waimea	High	38.0	Band C High
Nelson Haven	High	8.1	Band B Moderate
Delaware	Moderate	19.2	Band B Moderate
Kokorua	Moderate	120.8	Band C High

Current eutrophication condition
The current trophic state of the Nelson region estuaries was assessed using the ETI Tool 2 approach. This approach requires data or expert opinion for at least one primary indicator and one supporting indicator. For the Nelson region estuaries macroalgal cover data or expert opinion was used for the primary indicator and redox potential for the supporting indicator to develop an ETI trophic state score (note that other indicator data are also presented where available in order to provide additional support).

Stressor: Sediment change

The susceptibility of estuaries to the accumulation of fine sediments is related both to the suspended sediment input load and the physical sediment trapping characteristics of each estuary. Currently, there is insufficient information to identify robust sedimentation susceptibility thresholds for NZ estuaries, but for screening level purposes it is appropriate to use the Current State Sediment Load (CSSL)/Natural State Sediment Load (NSSL) ratio as a means of identifying catchments with excessive sediment loads. For the Nelson region estuaries, the chosen CSSL/NSSL ratio thresholds were those described in the ETI Tool 2 approach. Catchment sediment load estimates were derived from the NIWA CLUES model (Version 10.3, released May 2016)[1].

[1] CSSL estimated using CLUES (default setting of REC2 and LCBB3 (2008/2009) land cover) (Elliot et al. submitted, Semadeni-Davies et al. 2011). NSSL estimated by setting CLUES land cover to native forest, with a further 75% reduction applied to account for high expected sediment retention in wetlands in the catchment under natural state.

	Current State Sediment Load (CSSL)/Natural State Sediment Load (NSSL) ratio			
Estuary Category	CSSL = 1 to 1.1 x NSSL	CSSL = 1.1 to 2 x NSSL	CSSL = 2 to 5 x NSSL	CSSL > 5 x NSSL
SIDE Estuaries	Very Low Susceptibility	Low Susceptibility	Moderate Susceptibility	High Susceptibility

Current sediment condition
ETI thresholds for the percentage of estuary area dominated by soft mud substrate (i.e. sediment mud content >25%) were used to assess the current sedimentation (or muddiness) of the Nelson region estuaries as follows: low 1%, moderate 1-5%, high >5-15%, very high >15%.

Stressor: Overall eutrophication and sediment vulnerability

This step combines the susceptibility and current condition ratings to get an overall vulnerability rating for each stressor. If the estuary was assessed for condition during reasonable worst case times, then the existing condition rating is used as the final rating. However, if there is considerable uncertainty around the condition rating, then the more conservative susceptibility rating (or combination) is used.

2. Methods (continued)

Step 3. Assess key stressor influence (continued)

The likely influence of the other key stressors (e.g. disease risk, toxicants, climate change, etc.) was assessed using the guideline criteria summarised in the tables below (and on the following two pages), and included the use of estuary data presented in Appendix 1. A detailed rationale and description for each stressor and the criteria used is presented in Robertson and Stevens (2012) which, for brevity, is not repeated here.

Stressor | **Guideline used to assess estuary susceptibility to stressor**

Disease Risk

Vulnerability to Bathers	Low	Moderate	HIGH
Areal FC Loading (FC/m²/day)	<10,000	10,000 - 1 million	> 1 million

Vulnerability to Shellfish Consumers	Low	Moderate	HIGH
Areal FC Loading (FC/m²/day)	<1,000	1,000-100,000	> 100,000

Various Toxicants

Urban runoff / Contaminant spills

Vulnerability to Toxicants from Urban Runoff and Contaminant Spills e.g. roads, industrial spills, wastewater.	VERY LOW Receives runoff from unmodified catchments.	LOW Light urban or industrial development of catchment.	MODERATE Moderate urban or industrial development of catchment..	HIGH Extensive urban or industrial development of catchment.

Naturally occurring inputs of heavy metals

Vulnerability to Naturally Occurring Inputs of Heavy Metals	VERY LOW No toxicant-rich mineral belt in catchment.	LOW Small area of toxicant-rich mineral belt in catchment.	MODERATE Moderate area of toxicant-rich mineral belt in catchment.	HIGH Large area of toxicant-rich mineral belt in catchment.

Pesticides

Vulnerability to Pesticides	VERY LOW Receives runoff from unmodified catchments.	LOW Runoff from significant areas of pastoral and forestry in catchment.	MODERATE Runoff from small areas of intensive horticulture	HIGH Runoff from large areas of intensive horticulture, both historical and recent.

Marine oil spills

The two key elements of risk here are: the probability of an oil spill occurring and the consequences of the spill should it occur.

	Rating	VERY LOW	LOW	MODERATE	HIGH
PROBABILITY OF SPILL OCCURRING	Proximity to offshore drilling platform	None	Low	Moderate	Within trajectory
	Proximity to shipping/vessel route	Very low numbers of boats	Recreational/commercial boats present	Small port nearby	Large port nearby servicing oil tankers.
	Proximity to land runoff source	Very remote	Semi-remote	Small communities nearby	Large town/city nearby
	OVERALL PROBABILITY	NEGLIGIBLE	SLIGHT	MODERATE	HIGH
POTENTIAL MAGNITUDE OF IMPACT	Habitat Sensitivity	Exposed subtidal	Rip-rap man-made, subtidal embayment	Rocky shore, reef.	Saltmarsh, tidal flats, sand/gravel beach, seagrass. High biodiversity habitats with high potential to retain oil.
	Recovery Time	<1yr	1-3yrs	3-6yrs	>6yrs or irreversible
	OVERALL MAGNITUDE OF IMPACT	NEGLIGIBLE	SLIGHT	MODERATE	SEVERE

2. Methods (continued)

Step 3. Assess key stressor influence (continued)

Stressor	Guideline used to assess estuary susceptibility to stressors

Coastal erosion (physical vulnerability to sea level rise)

	Rating	VERY LOW 1	LOW 2	MODERATE 3	HIGH 4	VERY HIGH 5
a	Geomorphology	Rocky cliffs, fiords	Medium cliffs, indented coasts	Low cliffs, glacial drift, alluvial plains	Cobble beaches, subtidal estuary, low cliffs.	Sand beaches, salt-marsh, tidal flats, deltas, mangroves.
b	Erosion (-)/Accretion (+) Rate (m/yr)	>2.0	1.0 to 2.0	-1.0 to 1.0	-2.0 to -1.0	>-2.0
c	Coastal Slope %	>1.2%	1.2-0.9%	0.9-0.6%	0.6-0.3%	<0.3%
d	Sea Level Change (mm/yr)	<1.8	1.8-2.5	2.5-3.0	3.0-3.4	>3.4
e	Wave Height (m)	<0.55	0.55-0.85	0.85-1.05	1.05-1.25	>1.25
f	Tidal Range (m)	>6	4-6	2.4	1-2	<1

*Once each section of coastline is assigned a vulnerability value for each specific data variable (table above), the coastal vulnerability index (CVI; in right table) is calculated as the square root of the product of the ranked variables divided by the total number of variables;

Physical CVI = √{(a.b.c.d.e.f)/6}

where, a = geomorphology, b = shoreline erosion/accretion rate, c = coastal slope, d =relative sea-level rise rate, e = mean wave height, and f = mean tide range.

Rating*	CVI Value
LOW	<13.7
MODERATE	13.7 to 15
HIGH	15 and 17
VERY HIGH	above 17

Structures that Disrupt Sediment Transport

Rating	VERY LOW	LOW	MODERATE	HIGH
Seawall/Breakwater	Absent	Length of structure small compared with beach length.	Length of structure moderate compared with beach length.	Length of structure greater than 1/10th of beach length.
Groyne	Absent	Groyne extends less than 1/4 width of beach.	Groyne extends 1/4 to 1/2 half width of beach.	Groyne extends half to full width of beach.
Exposure	Sheltered	Semi-sheltered	Semi-exposed	Exposed

Drainage and Reclamation

Rating	VERY LOW	LOW	MODERATE	HIGH
Percentage or area affected	<1%	1-5%	5-10%	>10%
Ecological state prior to reclamation	Unvegetated habitat	Unvegetated muddy habitat	Unvegetated sandy habitat	Vegetated sandy habitat
Water and sediment quality	LOW	GOOD	GOOD	GOOD

Freshwater Abstraction

Rating	VERY LOW	LOW	MODERATE	HIGH
Susceptibility	Estuaries with little or no freshwater inflows.	Estuaries with low-moderate freshwater/marine water inflow ratios.	Estuaries with high freshwater/marine water inflow ratios.	Estuaries with one or more of; mouth often closed, poorly flushed lagoon or upper estuary, upper estuary bottom water stagnation, degraded water/sed quality.
Magnitude	Zero	<1% of mean flow	1-20% of base flow	>20% of base flow

Harvesting Living Resources

Rating	VERY LOW	LOW	MODERATE	HIGH
Harvestable Resource Presence	None	Low	Moderate	High
Proximity to Human Population	Very remote	Semi-remote	Small communities nearby	Large town/city nearby

2. Methods (continued)

Step 3. Assess key stressor influence (continued)

Stressor	Guideline used to assess estuary susceptibility to stressors				
Invasive Species	**Rating**	VERY LOW	LOW	MODERATE	HIGH
	Pathway (aquatic only)	Remote from boating and shipping activity	Local recreational vessels present but passing through only.	National and local vessels visit: anchorage, marina, launching ramp, jetty, aquaculture area etc.	Major shipping port - international and national. Intentional release.
	Existing Presence of Invasive Species	Invasive species absent.	Invasive species possible but not surveyed.	Invasive species present.	Invasive species well-established.
Off-Road Vehicles	**Rating**	VERY LOW	LOW	MODERATE	HIGH
	Vehicles on Beaches, Dunes and Tidal Flats	Absent	Small number (1 per mth) and limited to small area	Moderate number (1-5 per month), over large area	High numbers (>1/ day).
	Damage	NONE	SLIGHT	MODERATE	SEVERE
Toxic Algal Blooms (TAB)	**Rating**	VERY LOW	LOW	MODERATE	HIGH
	Risk of TAB occurring	No previous TABs; no seed stock (up stream or in estuary); unfavourable growth conditions.	No previous TABs; potential seed stock (up stream or in estuary); potentially favourable growth conditions.	Previous TABs; potential seed stock (up stream or in estuary); favourable growth conditions.	Previous TABs; known seed stock (up stream or in estuary); favourable growth conditions.
	Risk to ecology if TAB occurred	No at-risk species (e.g. shellfish/fish)	Low abundance of at-risk species	Moderate abundance of at-risk species	High abundance of at-risk species
	Risk to humans if TAB occurred	No human interaction (e.g. human consumption of estuarine resources)	Low human interaction	Moderate human interaction	High human interaction
Human/Animal Disturbance of Wildlife	**Rating**	VERY LOW	LOW	MODERATE	HIGH
	Presence of vulnerable wildlife	None	Low	Moderate	High
	Proximity to Human Population Centres	Very remote	Semi-remote	Small communities nearby	Large town/city nearby
	Access to vulnerable wildlife habitat	Closed	Restricted	Limited	Easy
Grazing in High-value Habitat	**Rating**	VERY LOW	LOW	MODERATE	HIGH
	Presence of Grazing Animals	None	Rare	Occasional	Common
	Density of Grazing Animals	None	Low (<1/ha)	Moderate (1-5/ha)	High (>5/ha)

2. Methods (continued)

Step 4. Rate the stressor influence on habitat

The influence of key stressors on the ecological condition of each listed estuarine habitat type is rated based on the results of Steps 1-3.

Step 5. Identify and rate stressor influence on human uses and ecological values

Human uses and ecological values were also identified and their presence assessed using four broad rating categories (Very Low, Low, Moderate, High) based on a UNESCO (2000) methodology. Expert judgement is used to provide an overall rating for stressor influence on each use as follows:

1. Human Uses and Values. The information used to rate human uses and values of estuarine habitat is based on local knowledge and available information. The estimated number of people involved are used to guide the rating:

Human usage	Rating
<10 per year.	VERY LOW
10 to 50 per year (<30 per day in summer).	LOW
>30 per day (may be only in summer) but <200 per day.	MODERATE
>200 per day (any time during year).	HIGH

2. Ecological Values. Ecological value defines an ecosystem's natural riches (generally interpreted as habitat diversity and biodiversity). It can be supposed that the richer and more diversified an ecosystem is, the greater the losses will be in the event of a disruption. The ecological richness component is divided into four subcategories; birds, vegetation, fish, and other biota. The information used to rate the ecological value will be drawn from local knowledge, available reports and information, and expert opinion.

Step 6. Rate stressor influence on monitoring indicators and issues

Monitoring indicators that can be used to assess the influence of stressors are identified. For each, a rating is applied based on the extent that each monitoring indicator is likely to be affected by the stressor influence that was estimated in Step 3. Because each monitoring indicator is assigned into an appropriate issue category, then it is straightforward to assess which issues are likely to arise and what should be monitored. In this section, the overall stressor influence rating for each indicator is also determined using an appropriate weighting for each stressor.

Step 7. Identify priority indicators for monitoring

Combine the results of Steps 4 and 6 to determine the priority indicators for monitoring.

Step 8. Identify overall vulnerability, key issues, monitoring recommendations

Finally, determine overall vulnerability by combining total stressor influence, total human use rating and total ecological values rating. Identify key issues for monitoring. Make monitoring recommendations based on priority monitoring indicators.

Shoreline armouring displacing herbfield habitat, Waimea Inlet

3. RESULTS

WAIMEA INLET (2014)

Estuary Type/Area	SIDE (Barrier Island)/3,910ha
Intertidal/Subtidal	3,308ha/602ha
Catchment Area	913km^2
FW Inflow	Mean annual 21m^3.s^{-1}
Saltmarsh, Seagrass	303ha, 34ha
Intertidal Soft Mud	1,137ha
Macroalgae	59ha (>50% cover)
Dairy Cows	2085
Susp. Sed. Load	147 kt/yr
Nitrogen Load	463.4 t/yr
Faecal c. Load	4.39 x 10^{15}/yr
Landuse: 36% native forest, 33% exotic forest, 20% high producing pasture, 4% crop, 2% urban.	
Geology: Post glacial alluvium.	
Human Use	HIGH
Ecological Value	MODERATE
Stressor influence	MOD-HIGH
ISSUES	
Sedimentation	HIGH
Eutrophication	HIGH
Disease Risk	HIGH
Habitat Loss	HIGH
Toxicity	MODERATE
OVERALL VULNERABILITY	
HIGH	

Waimea Inlet is a large (3,910ha), shallow, well-flushed, seawater-dominated, tidal lagoon type estuary with two tidal openings, two main basins, and several tidal arms. Tidal flats are dominated by sands (49%) and soft muds (38%), with sand dominant near the entrances. The catchment is heavily modified, with exotic forest occupying 33% and prime pastoral 20%. Much of it is located in geologically nickel and chromium enriched soil and rock types and therefore terrestrial sediment has elevated Ni and Cr contents (Robinson et al. 1996; Rattenbury et al. 1998). The ecological vulnerability of Waimea Inlet was assessed in the present study based on information from a previous vulnerability assessment (Stevens and Robertson 2010) and more recent broad and fine scale monitoring reports (Stevens and Robertson 2014, Robertson and Stevens 2014).

Uses and Values: High use - it is valued for its aesthetic appeal, assimilation of wastes, biodiversity, shellfish collection, bathing, duck shooting, whitebaiting, fishing, boating, walking, and scientific appeal. It is a focal point for users of the bordering cycle trail, and a small but historically significant port is located at Mapua.

Ecological Values: Ecologically, habitat diversity is high with a variety of substrate types including cobble gravel, shell, oyster reef, cockle beds, sand and mud; moderate areas of saltmarsh (8% of estuary), a small amount of seagrass (1% of the estuary), and a small subtidal sponge-dominated community (by Rough Island). The estuary has low-moderate levels of organic enrichment and toxicity (apart from naturally elevated Ni and Cr levels).

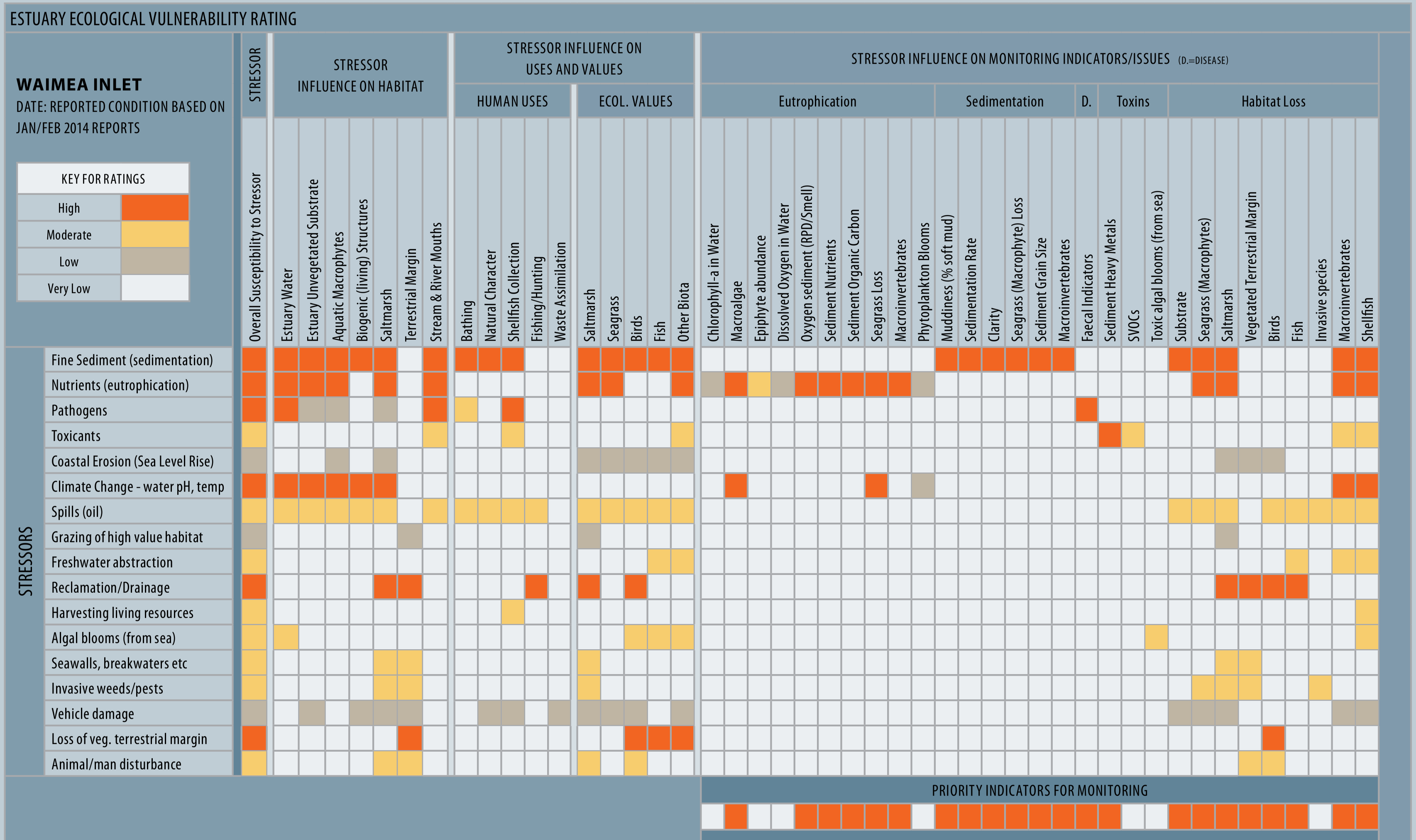
The spatial extent of soft mud habitat has remained relatively consistent since ~1990, but monitoring results indicate it has become progressively muddier since 1999 (i.e. mud content has increased). Increased muddiness is known to displace high-value mud sensitive benthic organisms (i.e. pipi) - Robertson and Stevens 2014), and seagrass which has declined by 41% since 1990 (Stevens and Robertson 2014). In localised areas (2.7% of the intertidal area), nuisance macroalgal growths (*Gracilaria* and *Ulva*) have established in soft muds. Since 1946, at least 83ha of saltmarsh has been reclaimed and developed with most of the natural vegetated margin also developed (Stevens and Robertson 2014). The invasive cord grass *Spartina anglica,* introduced to promote reclamation and stabilisation of soft muds entering from the catchment, previously occupied large areas of the estuary in the 1980's (40-50ha in 1985) but was eradicated in the early 1990s. Despite the large extent of muddy sediments, the inlet provides high value habitat for marine and freshwater fish, shellfish and is very important for bird life.

Issues and Stressors

- Excessive muddiness and elevated disease risk (bathing and shellfish) caused primarily by catchment runoff from intensive land use in the lower catchment, exotic forestry (muddiness only), and to a lesser extent the Bells Island wastewater discharge. Climate change (increased storms) is expected to exacerbate these issues. The estuary is generally safe for bathing, although disease risk indicators are elevated following rainfall, and shellfish consumption is not recommended. The Bells Island WWTP and occasional sewage overflows contribute to localised risk.
- Localised toxicity and eutrophication at urban stream mouths caused by urban stormwater, including waters discharging from specific sub-catchments. Notably, recently measured toxicant and nutrient levels in waters at lowland sites within Stoke's streamways, which empty into the eastern arm of Waimea Inlet exceeded ANZECC lowland guideline criteria for levels of nitrogen and phosphorous (McArthur 2016) and have contributed to localised eutrophication symptoms (Stevens and Robertson 2014). However, nutrient inputs from these streams only constitute <5% of the total nutrient loads entering the system.
- Loss of high value saltmarsh/seagrass habitat caused primarily by historical reclamations or infrastructure maintenance e.g. 2012 Bells Island sewerage upgrade. Natural gravel supply to stream deltas is frequently interrupted by retention structures (ponds or traps) that get cleaned out after floods as well as through manual extraction, reducing saltmarsh habitat and (short-term) protection against sea level rise. To maintain existing habitat in the face of impending sea level rise, inland migration of remnant (or re-established) saltmarsh will need to be facilitated.
- Shifts in biological communities as a result of climate-related changes to sea pH and temperature.
- Other lesser stressors include; a highly modified terrestrial margin, the presence of seawalls (limiting saltmarsh habitat and potential retreat in response to sea level rise), causeways and flapgates, increased population pressure and margin encroachment (wildlife disturbance, predator introductions, habitat loss), and invasive species (e.g. Pacific oyster, iceplant).

Issues	Monitoring/Investigations	Management
• Excessive muddiness. • Local eutrophication and toxicity. • Elevated disease risk. • Habitat loss. • Climate change.	• Continue scheduled estuary habitat mapping and fine scale monitoring (5 yearly), and sedimentation rate (plates) annually. • If localised issues arise (e.g. at Stoke stream mouths), monitor river and stream specific nutrient, SS and FC loads (high and low flows) to determine annual loads. • Map catchment nutrient, sediment and FC sources (5 yearly). • Model catchment nutrient, SS and FC loads with BMP's in place. • Monitor shellfish and bathing disease risk.	• Limit SS inputs to estuary (e.g. mean <2mm/yr, no expansion of existing mud habitat). • Maintain/restore high value seagrass and saltmarsh habitat. • Allow saltmarsh to migrate inland as sea level rises. • Reduce FC inputs to meet bathing and shellfish standards. • Limit stream specific nutrient, SS, and toxicant inputs. • Limit nutrient inputs to 50mg.N.m^{-2}.d^{-1} (areal loading). • Ensure sediment toxicity guidelines met 50m from stormwater outfalls.

3. Results (continued)



OVERALL VULNERABILITY RATING - WAIMEA INLET

		KEY ISSUES
Human Use	High	Sedimentation, eutrophication, disease risk, climate change, reclamation of high value habitat, loss of natural terrestrial margin.
Ecological Value	Moderate	
Overall Stressor Influence	Mod-High	
OVERALL VULNERABILITY	Mod-High	

MONITORING RECOMMENDATIONS

- Continue scheduled estuary broad scale habitat mapping and fine scale monitoring (5 yearly), and sedimentation rate (plates) annually.
- If localised issues arise (e.g. at Stoke stream mouths), monitor river and stream specific nutrient, SS and FC loads (high and low flows) to determine annual loads.
- Map catchment nutrient, sediment and FC sources (5 yearly).
- Model catchment nutrient, SS and FC loads with BMP's in place.
- Monitor shellfish and bathing disease risk.

3. Results (continued)

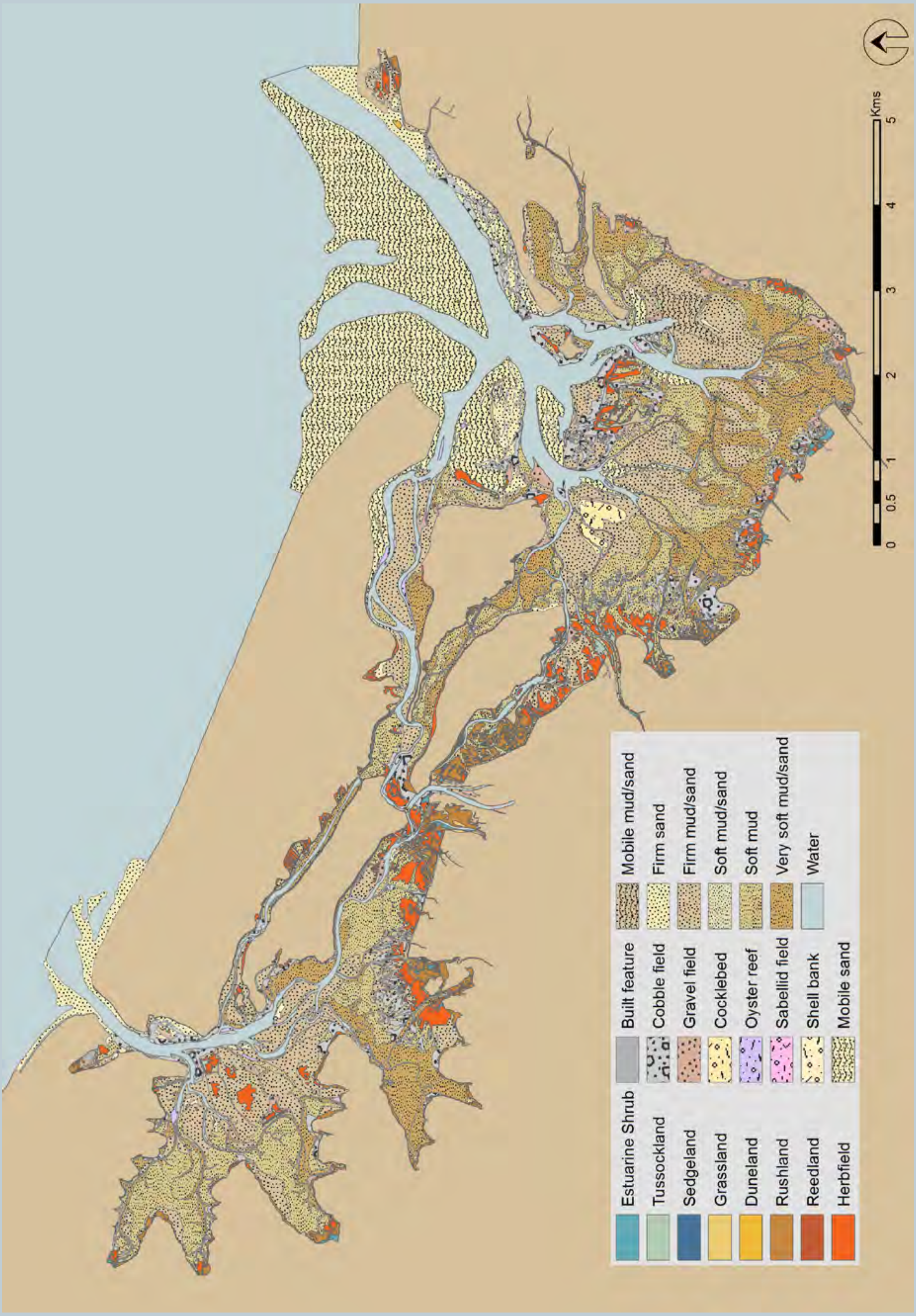


Figure 3. Broad scale map of dominant substrate and saltmarsh, Waimea Inlet, 2014.
Source: Wriggle Coastal Management (Stevens and Robertson 2014)

3. Results (continued)

NELSON HAVEN (2009)

Estuary Type/Area	SIDE/1,242ha
Intertidal/Subtidal	892ha/391ha
Catchment Area	129km^2
FW Inflow	Mean annual 2.4m^3.s^{-1}
Saltmarsh, Seagrass	9ha, 119ha
Soft Mud	89ha
Macroalgae	16.1ha >50% cover
Dairy Cows	1270
SS Load	11.4 kt/yr
Nitrogen Load	36.6 t/yr
Faecal c. Load	1.1 x 10^{15}/yr
Landuse: 54% native forest, 33% exotic forest, 3.4% high producing pasture, 0% crop, 4.2% urban.	
Geology:	
Human Use	HIGH
Ecological Value	MODERATE
Stressor Influence	MODERATE-HIGH
ISSUES	
Muddiness	MODERATE
Eutrophication	LOW-MODERATE
Disease Risk	HIGH
Habitat Loss	HIGH
Toxicity	MODERATE
OVERALL VULNERABILITY	
MODERATE-HIGH	

Nelson Haven is a large (1,242ha), shallow, well-flushed, seawater-dominated, tidal lagoon type estuary with two tidal openings (divided by Haulashore Island), and one main basin. It is situated directly in front of Nelson City and is separated from Tasman Bay by the iconic Boulder Bank. Over the past 160 years, the estuary has undergone considerable modification through extensive land reclamation (estimated to be >500ha) and the development of port and roading infrastructure. The catchment is dominated by native (54%) and exotic (33%) forest, and is geologically characterised by nickel and chromium enriched soil and rock types (Robinson et al 1996; Rattenbury et al 1998), with a relatively small urban component (4.2%). The ecological vulnerability of Nelson Haven is assessed in the present study based on information from previous reports (Stevens and Robertson 2010; Gillespie et al. 2011a, 2012).

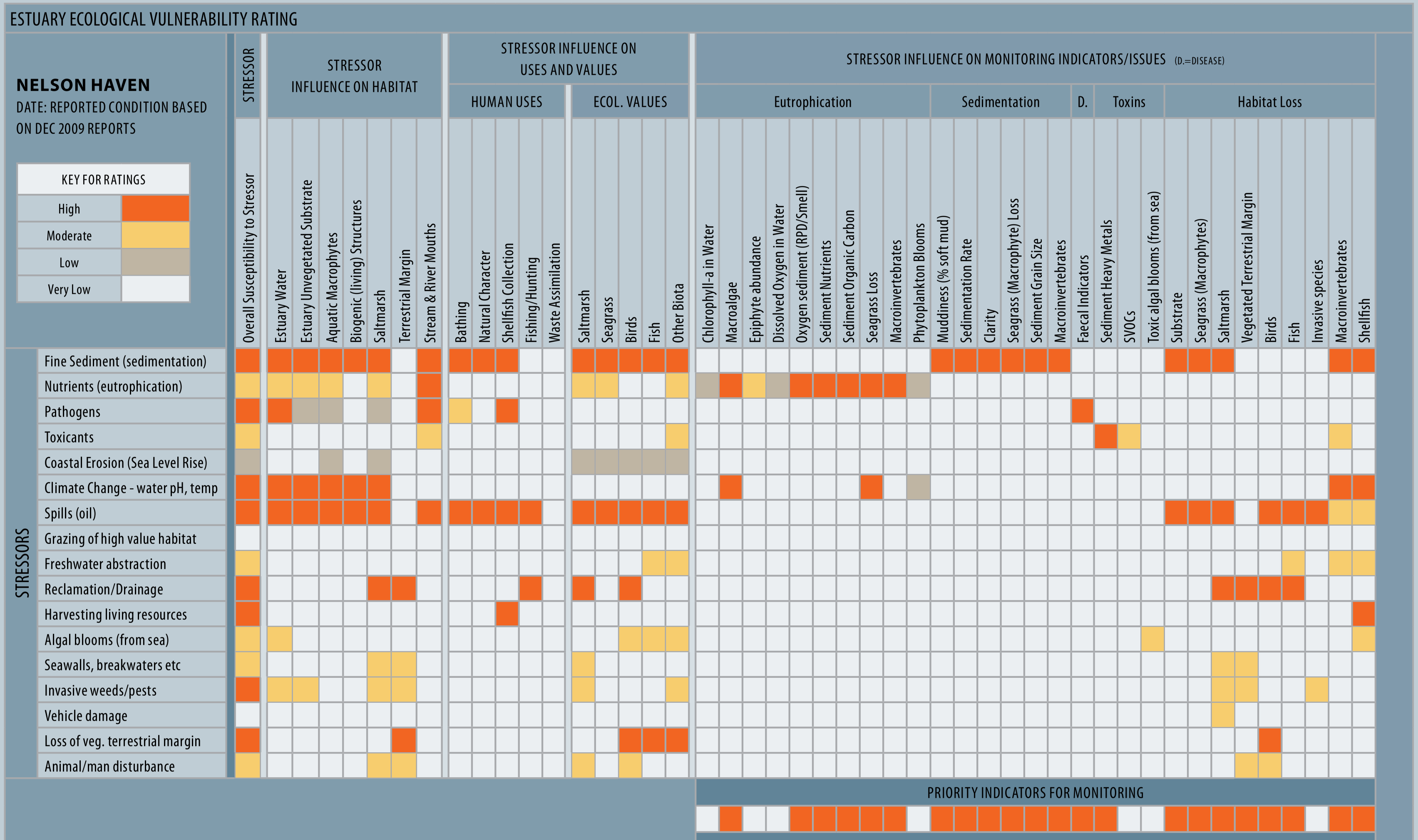
Uses and Values: High use - it is valued for its aesthetic appeal, its rich biodiversity, shellfish collection, bathing, waste assimilation, fishing, boating, walking, and scientific appeal. A large commercial port and marina is located near the estuary entrance.

Ecological Values: Ecologically, habitat diversity is moderate due to significant areas of high value habitat being lost over time. Between 1840 and 2009, an estimated 164ha (58%) of seagrass meadow and 300ha (99%) of saltmarsh was lost from the system (Gillespie et al. 2011a). In addition, the natural vegetated margin has been replaced by infrastructure (port, roading, flood control, etc). Monitoring results for the period 2009 to 2012 revealed that >40% of the unvegetated tidal flats were sandy (Gillespie et al. 2011a), nuisance macroalgal cover was low (Stevens and Robertson 2010), nutrient and toxicant (heavy metals) indicators were low (apart from naturally elevated Ni and Cr concentrations), and that sediment-based macrofaunal communities were considered to be in a "relatively healthy" state (Gillespie et al. 2012). The estuary is recognised as a valuable nursery area for marine and freshwater fish, an extensive shellfish resource, and is very important for birdlife. Community wetland restorations initiatives are underway in the northern part of the estuary.

Issues and Stressors

- Elevated muddiness and disease risk (bathing and shellfish) caused primarily by catchment runoff from urban and rural landuse and exotic forestry. Climate change (increased storms) is expected to exacerbate these issues. The estuary is generally safe for bathing, although disease risk indicators are elevated following rainfall, and shellfish consumption is not recommended. Occasional sewage overflows contribute to localised risk.
- Localised sediment toxicity and eutrophication at urban stream mouths from urban stormwater. Recently measured toxicant and nutrient levels in waters at lowland sites within the Maitai River, which discharge into central Nelson Haven, were found to be below those known to pose toxicity threats to aquatic life (McArthur 2016). There is uncertainty around the connectivity of storm drains discharging into the estuary (mainly in the north), which may contribute nutrient, sediment and toxicant loads to the estuary.
- Loss of high value saltmarsh and seagrass habitat caused primarily by historical reclamations and catchment land use changes. To maintain existing habitat in the face of impending sea level rise, inland migration of remnant (or re-established) saltmarsh will need to be facilitated.
- Shifts in biological communities as a result of climate changes to sea pH and temperature.
- Other lesser stressors include; the extensive presence of seawalls, causeways and flapgates; invasive species (e.g. Pacific oyster, *Undaria*, Mediterranean fan worm), spill risks from Port Nelson, and occasional sewage overflows. Increased population pressure will exacerbate margin encroachment (inc. wildlife disturbance, predator introductions, habitat loss).

Issues	Monitoring/Investigations	Management
• Elevated muddiness. • Elevated disease risk. • Habitat loss. • Climate change. • Local eutrophication and toxicity.	• Estuary habitat mapping (5 yearly), • Fine scale monitoring (5 yearly after 3 year baseline), • Sedimentation rate (plates) annually. • If localised issues arise (e.g. at stream mouths), monitor specific nutrient, SS and FC loads (high and low flows) to determine annual loads. • Map catchment sediment and FC sources (5 yearly). • Model catchment nutrient, SS and FC loads with BMP's in place. • Monitor shellfish and bathing disease risk.	• Limit SS inputs to estuary (e.g. mean <2mm/yr, no expansion of existing mud habitat). • Prevent loss of important habitat, particularly seagrass. • Allow saltmarsh to migrate inland as sea level rises. • Reduce FC inputs to meet bathing and shellfish standards. • Limit stream specific nutrient, SS and toxicant inputs. • Limit overall nutrient inputs to 50mgN.m^{-2}.d^{-1} (areal loading). • Ensure sediment toxicity guidelines met 50m from stormwater outfalls.



OVERALL VULNERABILITY RATING - NELSON HAVEN

Human Use	High	KEY ISSUES
Ecological Value	Moderate	Sedimentation, eutrophication, disease risk, climate change, reclamation of high value habitat, loss of natural terrestrial margin.
Overall Stressor Influence	Mod-High	
OVERALL VULNERABILITY	Mod-High	

MONITORING RECOMMENDATIONS

- Broad scale habitat mapping every 5 years.
- Fine scale sediment monitoring every 5 years after 3yr baseline.
- Sedimentation rate monitoring annually.
- Shellfish and bathing disease risk monitoring.
- Map catchment nutrient, sediment and FC sources 5 yearly.
- Model catchment nutrient, SS and FC loads with BMP's in place.
- Monitor river nutrient, FC and SS loads (high and low flows) to determine annual loads.
- If localised issues arise (e.g. at Wakapuaka stream mouths), monitor river and stream specific nutrient, SS, and FC loads (high and low flow) to determine annual loads.

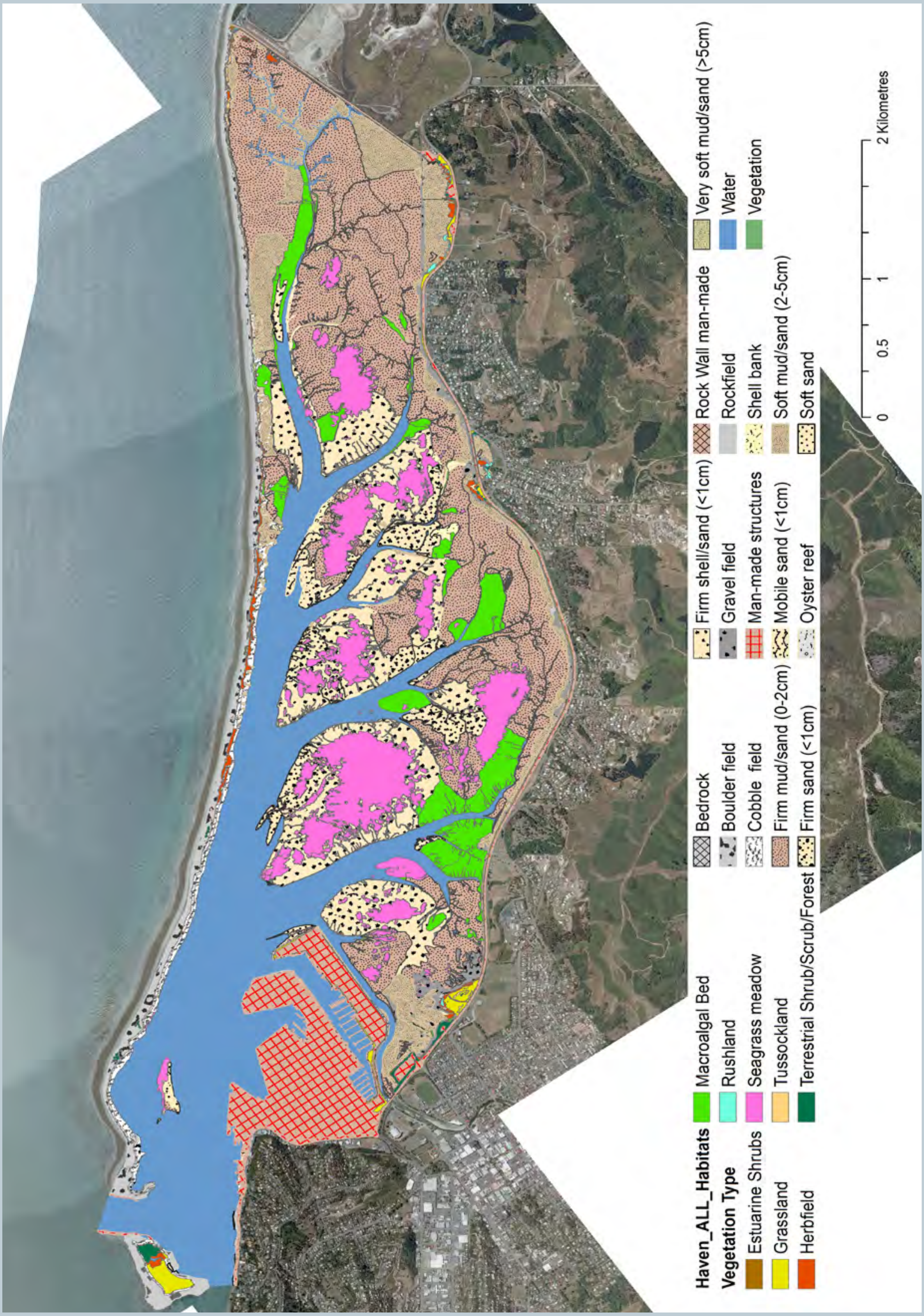


Figure 4. Broad scale map of dominant substrate and saltmarsh, Nelson Haven, 2009.
Source: Cawthron Institute (Gillespie et al. 2009)

DELAWARE INLET (2011)

Estuary Type/Area	SIDE (barrier island)/353ha
Intertidal/Subtidal	331ha/22ha
Catchment Area	93.4km^2
FW Inflow	Mean annual 1.34m^3.s^{-1}
Saltmarsh, Seagrass	22ha, 4.2ha
Soft Mud	31ha
Macroalgae	33.7ha >50% cover
Dairy Cows	189
SS Load	9.6 kt/yr
Nitrogen Load	24.8 t/yr
Faecal c. Load	0.7 x 10^{15}/yr
Landuse: 37% native forest, 42% exotic forest, 13.9% high producing pasture, 0% crop, <1% urban.	
Geology:	
Human Use	HIGH
Ecological Value	MODERATE
Stressors	MODERATE-HIGH
ISSUES	
Muddiness	MODERATE-HIGH
Eutrophication	MODERATE
Disease Risk	HIGH
Habitat Loss	HIGH
Toxicity	Low-Moderate
OVERALL VULNERABILITY	
MODERATE-HIGH	

Watercolour of Delaware Inlet painted by John Gully in 1882

Delaware Inlet is a relatively moderate sized (336ha), shallow, well-flushed, seawater-dominated, tidal lagoon type estuary with a single tidal opening, and two major intertidal arms. Although situated at the foot of an extensively modified and relatively steep catchment (42% exotic forest), with much of it located in geologically nickel and chromium enriched soil and rock types (Robinson et al. 1996; Rattenbury et al. 1998), the inlet has been described as a 'relatively pristine', high-value estuary containing complex intertidal habitats of high biodiversity, with sediments dominated by sands (apart from the muddier upper western arm) (Gillespie 2009; Gillespie et al. 2011b). The ecological vulnerability of Delaware Inlet is assessed in the present study based on information from previous reports (Gillespie 2009; Gillespie et al. 2011b). Further historical detail is available in Stanton et al. (1977) and Franko (1988).

Uses and Values: High use - it is valued for its aesthetic and cultural appeal, biodiversity, shellfish collection, bathing, duck shooting, whitebaiting, fishing, kayaking, walking, access to a world class surf break (at the estuary mouth), and scientific appeal.

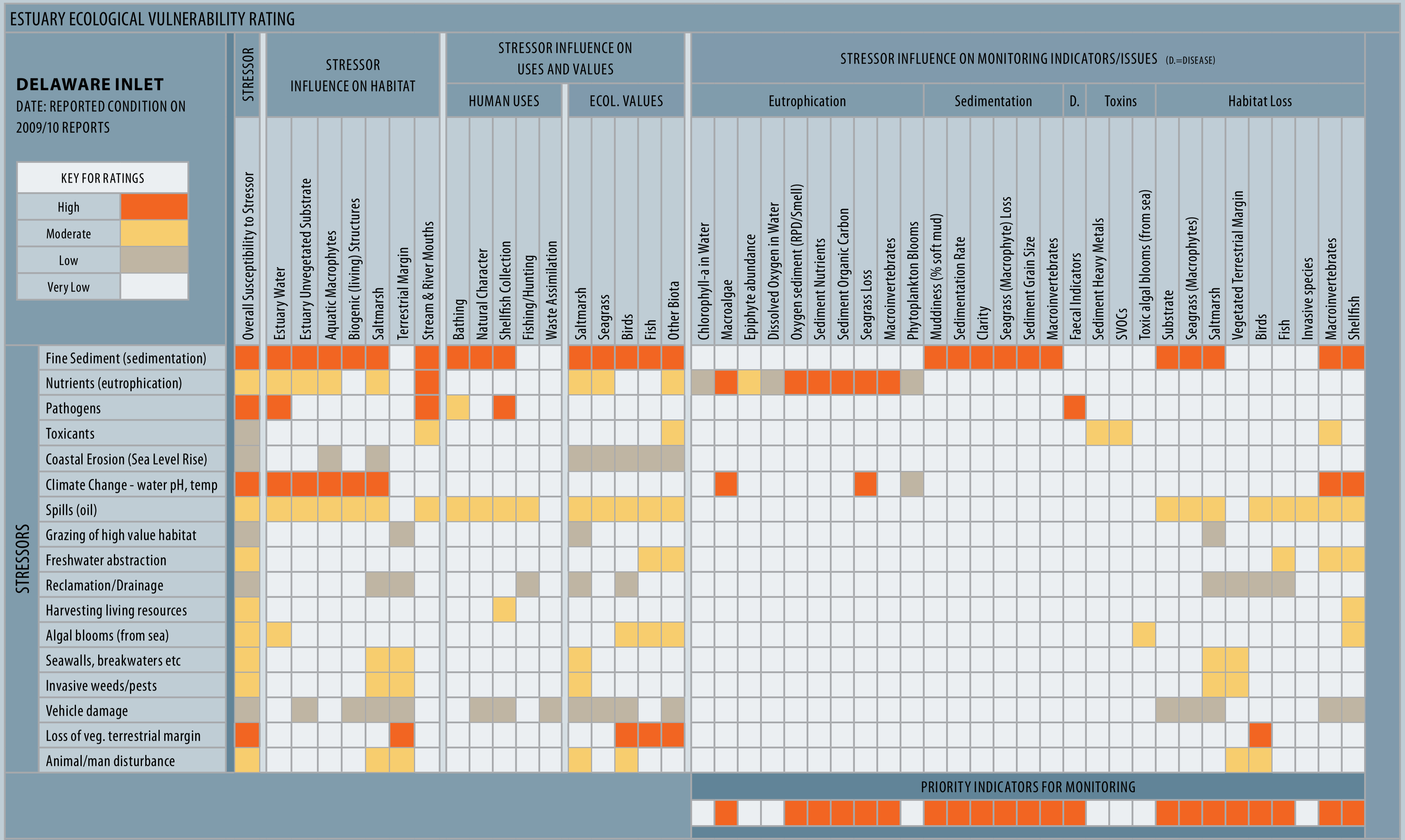
Ecological Values: Ecologically, habitat diversity is high with a variety of substrate types e.g. cobble, gravel, oyster reef, shell, sand and mud, and a moderate cover of both saltmarsh (6.2%) and seagrass (1.2%). Dense (>50% cover) macroalgae also covers 9.5% the estuary's intertidal flats. Much of the natural vegetated margin has been developed for grazing and roading. Broad scale mapping results indicated a significant reduction in seagrass (~2.6ha, 38%) and saltmarsh (25-35%) between 1983 and 2009 (Gillespie et al. 2011b). In 2009, beds of the exotic Pacific oyster (*Crassostrea gigas*) occupied ~1ha of intertidal habitat (Gillespie et al. 2011b). According to Gillespie (2009), sediment nutrient and toxicant (heavy metals) levels were low (apart from naturally elevated Ni and Cr concentrations), and benthic macroinvertebrate communities were well balanced. The estuary is considered an important nursery area for marine and freshwater fish, and birds.

Issues and Stressors

- Elevated muddiness and disease risk (bathing and shellfish) caused primarily by catchment runoff from intensive landuse (lower catchment) and exotic forestry (results in muddiness only). Climate change (increased storms) is expected to exacerbate these issues. The estuary is generally safe for bathing, although disease risk indicators are elevated following rainfall, and shellfish consumption is not recommended.
- Loss of high value saltmarsh/seagrass habitat caused primarily by historical reclamations and catchment land use changes. To maintain existing habitat in the face of impending sea level rise, inland migration of saltmarsh will need to be facilitated There are wetland planting initiatives currently underway at the estuary margin.
- Shifts in biological communities as a result of climate changes to sea pH and temperature.
- Other lesser stressors include; boat launching impacts in the eastern arm, a highly modified terrestrial margin, the presence of seawalls (limiting saltmarsh habitat and potential retreat in response to sea level rise), causeways and flapgates, increased population pressure and margin encroachment (wildlife disturbance, predator introductions, habitat loss), and invasive species (e.g. Pacific oyster, iceplant); localised toxicity and eutrophication at river mouths, though it is noted that recently measured toxicant and nutrient levels in waters at lowland sites within the Wakapuaka River, which discharge into the western arm of Delaware Inlet, were generally below ANZECC (2000) trigger limits known to pose toxicity threats to aquatic life (McArthur 2016).

Issues	Monitoring/Investigations	Management
• Elevated muddiness. • Elevated disease risk. • Habitat loss. • Climate change. • Local eutrophication and toxicity.	• Estuary habitat mapping (5 yearly), • Fine scale monitoring (5 yearly after 3 year baseline). • Sedimentation rate (plates) annually. • Map catchment sediment and FC sources (5 yearly). • Model catchment nutrient, SS and FC loads with BMP's in place. • Monitor river nutrient, SS and FC loads (high and low flows) to determine annual loads. • Monitor shellfish and bathing disease risk.	• Limit SS inputs to estuary (e.g. mean <2mm/yr, no expansion of existing mud habitat). • Restore important degraded habitat, particularly seagrass and saltmarsh. • Allow saltmarsh to migrate inland as sea level rises. • Reduce FC inputs to meet bathing and shellfish standards. • Limit stream specific nutrient, SS, and toxicant inputs. • Limit nutrient inputs to 50mgN.m^{-2}.d^{-1} (areal loading). • Ensure sediment toxicity guidelines met 50m from stormwater outfalls.

3. Results (continued)



OVERALL VULNERABILITY RATING - DELAWARE INLET

		KEY ISSUES
Human Use	High	Sedimentation, disease risk, climate change, reclamation of high value habitat, loss of natural terrestrial margin.
Ecological Value	Moderate	
Overall Stressor Influence	Mod-High	
OVERALL VULNERABILITY	Mod-High	

MONITORING RECOMMENDATIONS

- Broad scale habitat mapping every 5 years.
- Fine scale sediment monitoring every 5 years after 3yr baseline.
- Sedimentation rate monitoring annually.
- Shellfish and bathing disease risk monitoring.
- Map catchment nutrient, sediment and FC sources 5 yearly.
- Model catchment nutrient, SS and FC loads with BMP's in place.
- Monitor river nutrient, FC and SS loads (high and low flows) to determine annual loads.

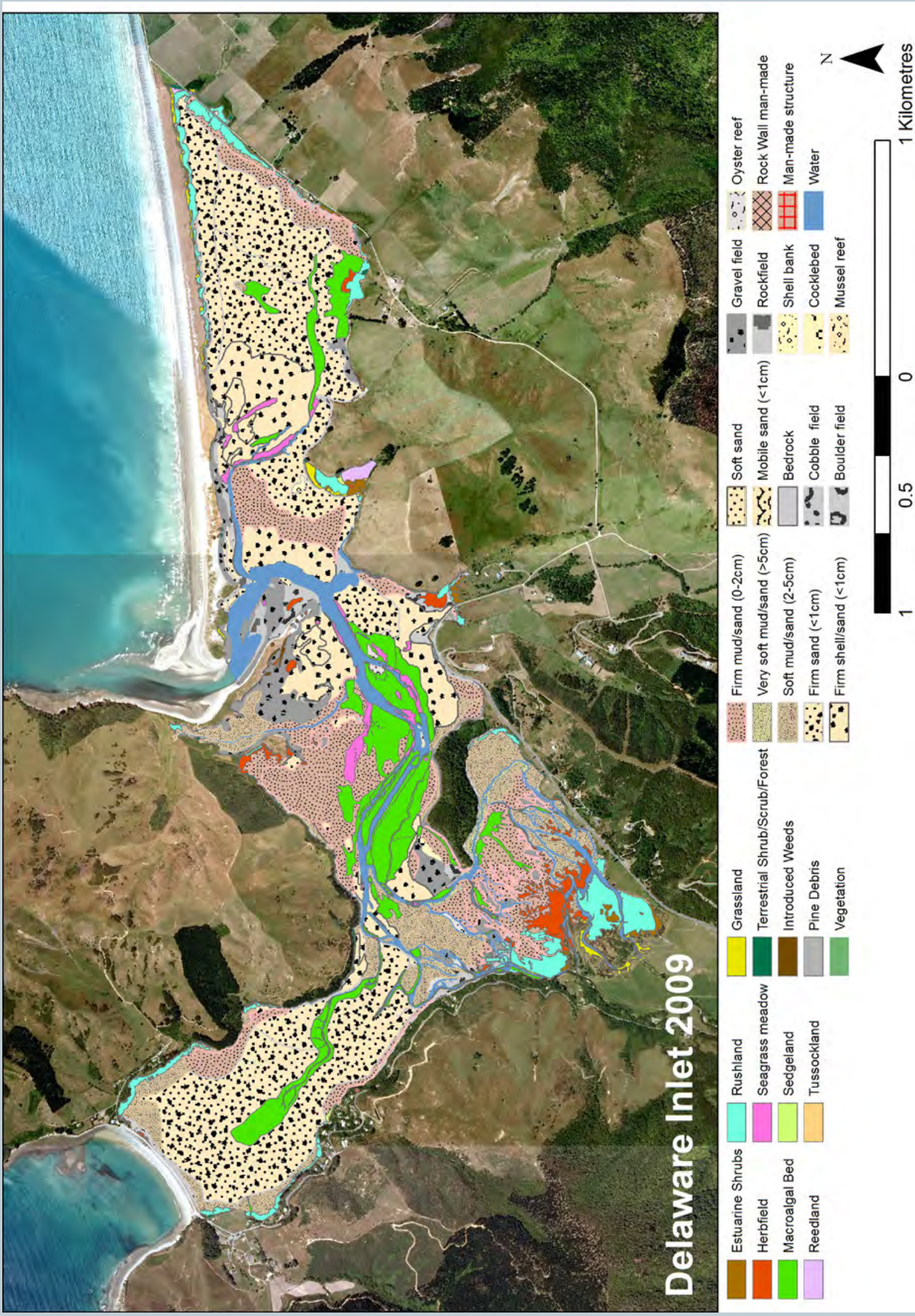


Figure 5. Broad scale map of dominant substrate and saltmarsh, Delaware Inlet, 2009.
Source: Cawthron Institute (Gillespie et al. 2009)

3. Results (continued)

KOKORUA INLET (2015)

Estuary Type/Area	SIDE/68.2ha
Intertidal/Subtidal	61ha/7ha
Catchment Area	95.3km^2
FW Inflow	Mean annual 2.5m^3.s^{-1}
Saltmarsh, Seagrass	21.4ha, 0ha
Intertidal Soft Mud	12.2ha
Macroalgae	0.2ha >50% cover
Dairy Cows	369
SS Load	15.7 kt/yr
Nitrogen Load	30.1 t/yr
Faecal c. Load	0.2 x 10^{15}/yr
Landuse: 51% native forest, 45% exotic forest, 4% high producing pasture.	
Geology:	
Human Use	LOW
Ecological Value	HIGH
Stressors	MODERATE
ISSUES	
Muddiness	HIGH
Eutrophication	HIGH
Disease Risk	HIGH
Habitat Loss	LOW-MODERATE
Toxicity	LOW-MODERATE
OVERALL VULNERABILITY	
MODERATE	

The Kokorua Inlet is situated on the eastern side of Tasman Bay between Delaware Inlet and Cape Soucis. It is a relatively small (61ha), shallow, well-flushed, tidal lagoon type estuary, with a moderate freshwater inflow from the Whangamoa River, and minor contributions from Frenchmans and Toitoi streams and a number of smaller localised waterways. Sediments are dominated by sand (20.7ha, 52%) and mud (12.2ha, 31%). The upper estuary tidal flats show fine mud accrual from the relatively steep surrounding catchment - dominant land use: 45% exotic forest, 4% pasture, 51% native forest. The catchment is also geologically nickel and chromium enriched (Robinson et al. 1996; Rattenbury et al. 1998). The ecological vulnerability of Kokorua Inlet is assessed in the present study based on information from recent monitoring reports (Robertson and Stevens 2015; Stevens and Robertson 2015).

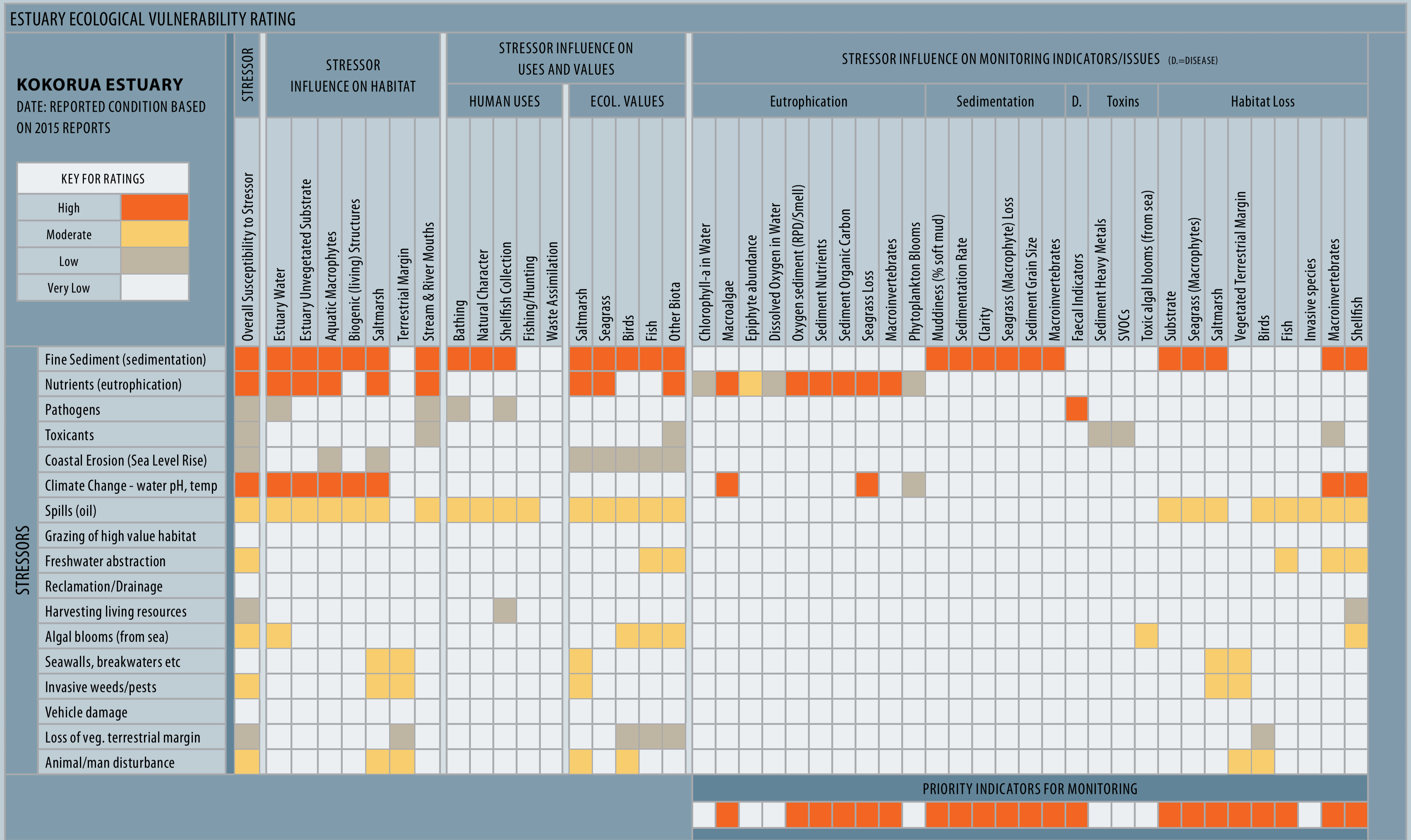
Uses and Values: Low use - primarily due to restricted public access; it is nevertheless valued for its aesthetic and cultural appeal, biodiversity, and scientific appeal.

Ecological Values: Habitat diversity is moderate with a variety of substrate types, particularly extensive cobble and gravel beds in the lower estuary, and firm muddy sands and soft muds, a relatively extensive cover of intact rushland and herbfield (21ha, 31%), but no seagrass (likely limited by muds and low clarity). Soft mud covered (12.2ha, 31%) of the unvegetated intertidal habitat, and was concentrated mostly in the upper northeast and southeast arms of the estuary. At fine-scale sites, sediments had high mud contents, low nutrient and toxicant (heavy metals) concentrations (apart from naturally elevated Ni and Cr concentrations), moderate-poor oxygenation, and an impaired macroinvertebrate community (reflecting mud/organic enrichment related impacts). Opportunistic macroalgal growth was very sparse (some around stream mouths) and no gross eutrophic zones were present. The densely vegetated 200m margin cover (forest, scrub, reed and duneland) of the estuary was high (73%), with pockets of mature native forest adjacent to the estuary, and native dune plants on the barrier spit, both regionally rare features.

Issues and Stressors

- Excessive muddiness, with evidence of recent inputs likely to derive from the dominant land disturbance activity in the catchment (exotic forestry). Climate change (increased storms) is expected to exacerbate sediment inputs from disturbed land.
- High eutrophication risk due to high areal loading (relatively large catchment with small estuary).
- Elevated disease risk (bathing and shellfish) primarily because catchment runoff discharges into a relatively small confined estuary. Although disease risk will be elevated following rainfall, the estuary is likely safe for bathing most of the time due to pastoral farming comprising 4% of the catchment and being relatively low intensity.
- To maintain existing habitat in the face of impending sea level rise, inland migration of saltmarsh will need to be facilitated.
- Shifts in biological communities as a result of climate changes to sea pH and temperature.
- Other lesser stressors include; wetland and saltmarsh drainage, invasive species (e.g. Pacific oyster, iceplant); toxicants (natural sources of Ni and Cr). Recently measured toxicant and nutrient levels in waters at lowland sites within the Whangamoa River, which discharge into the western arm of Kokorua Inlet, were generally below ANZECC (2000) trigger limits known to pose toxicity threats to aquatic life (McArthur 2016).

Issues	Monitoring/Investigations	Management
• Excessive muddiness. • High eutrophication risk. • High disease risk. • Habitat loss. • Climate change. • Low toxicity.	• Estuary habitat mapping (5 yearly). • Fine scale monitoring (5 yearly after 3 year annual baseline). • Sedimentation rate (plates) annually. • Map catchment sediment sources (5 yearly). • Model catchment nutrient, SS and FC loads with BMP's in place to determine annual loads and to assess shellfish and bathing disease risk.	• Limit SS inputs to estuary (e.g. mean <2mm/yr, no expansion of existing mud habitat). • Protect against loss of important habitat, particularly saltmarsh and duneland. • Allow saltmarsh to migrate inland as sea level rises. • Reduce FC inputs to meet bathing and shellfish standards. • Limit nutrient inputs to 50mgN.m^{-2}.d^{-1} (areal loading).



OVERALL VULNERABILITY RATING - KOKORUA INLET

		KEY ISSUES
Human Use	Low	Sedimentation, eutrophication, disease risk, climate change, reclamation of high value habitat, loss of natural terrestrial margin.
Ecological Value	High	
Overall Stressor Influence	Moderate	
OVERALL VULNERABILITY	Moderate	

MONITORING RECOMMENDATIONS

- Broad scale habitat mapping every 5 years.
- Fine scale sediment monitoring every 5 years after 3yr baseline.
- Sedimentation rate monitoring annually.
- Map catchment nutrient, sediment and FC sources 5 yearly.
- Model catchment nutrient, SS and FC loads with BMP's in place to determine annual loads.

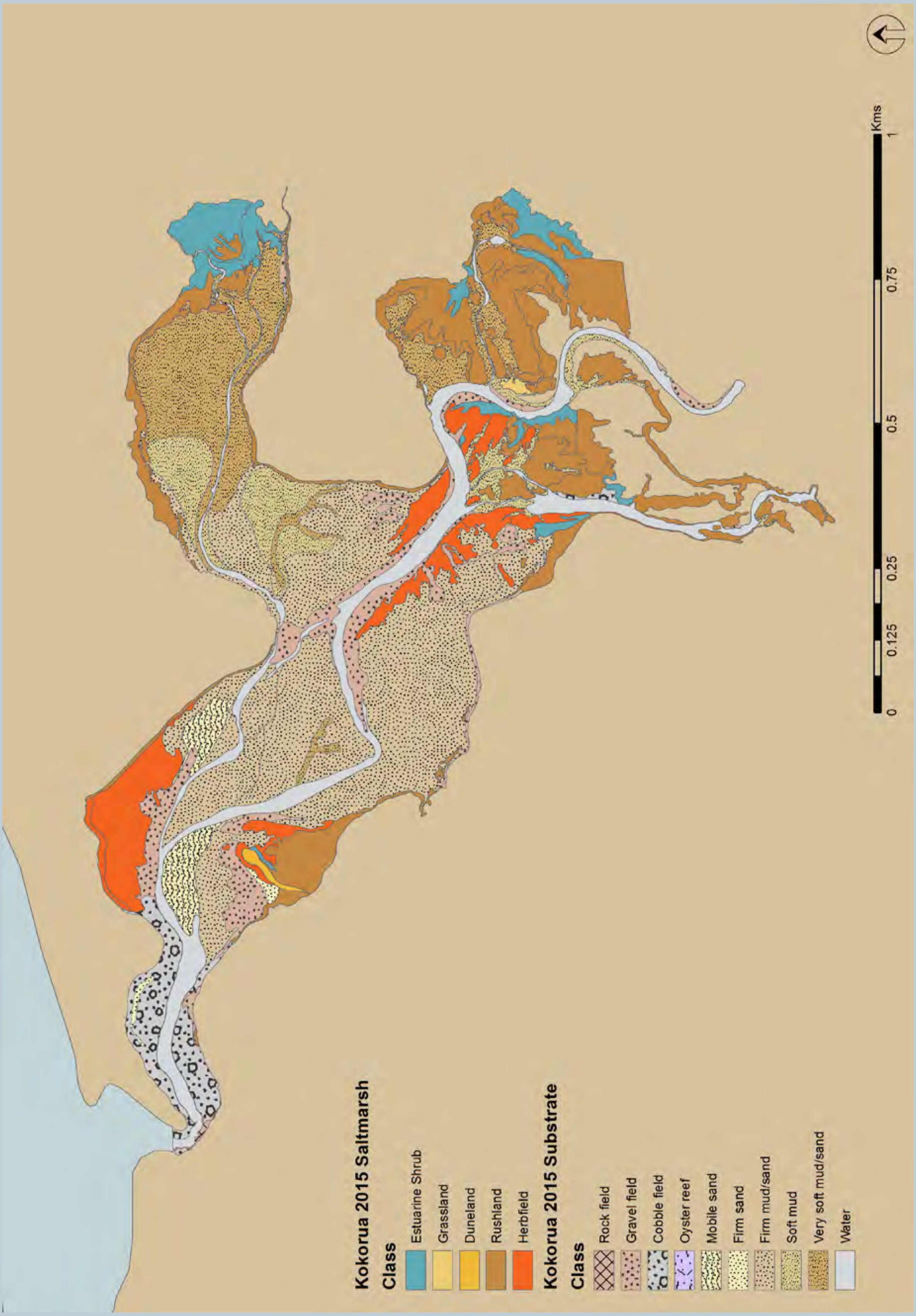


Figure 6. Broad scale map of dominant substrate and saltmarsh, Kokorua Inlet, 2015.
Source: Wriggle Coastal Management (Stevens and Robertson 2015)

4. SUMMARY AND RECOMMENDATIONS

SUMMARY

The four Nelson region estuaries assessed were all shallow, intertidal dominated estuaries (SIDEs), each variable in size and partially separated from the sea by a range of physical features, including barrier islands (Waimea and Delaware), sand bars (Kokorua) and boulder banks (Nelson Haven and Delaware). These estuaries are places of high biological diversity and high cultural, human use, and economic value, although in many instances the ecological value of the estuaries has been diminished as a consequence of human activities including land disturbance impacts (e.g. fine muds, nutrients, and disease causing organisms) and habitat loss (e.g. saltmarsh drainage and reclamation, shoreline armouring). Maintaining the health and productivity of such coastal habitats is a cornerstone of the region's quality of life and vibrant economy, from recreational fishing to shellfish production to tourism. Tables 4 and 5 below summarise the key values and issues identified in the vulnerability assessment, and rate vulnerability for each estuary in relation to specific issues. Key issues are discussed further in general terms on the following pages.

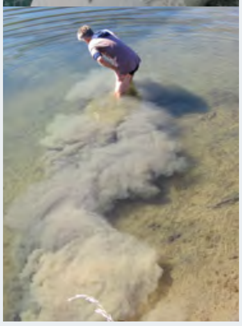
Table 4. Summary of human use and ecological value of Nelson region estuaries.

	Waimea	Nelson Haven	Delaware	Kokorua
Human use	HIGH	HIGH	HIGH	LOW
Ecological value	MODERATE	MODERATE	MODERATE	HIGH

Table 5. Summary of ratings used to assess vulnerability of Nelson region estuaries.

VULNERABILITIES	Waimea	Nelson Haven	Delaware	Kokorua
Sedimentation Susceptibility	High	Moderate	High	Moderate
Sedimentation Existing Condition	Moderate	High	High	Very High
Combined Sedimentation (muddiness)	HIGH	HIGH	HIGH	HIGH
Susceptibility to Eutrophication Rating	High	High	Low	High
Existing Condition Eutrophication Rating	Moderate	Low	Low	Moderate
Combined Eutrophication (Nutrient enrichment)	HIGH	MODERATE	MODERATE	HIGH
Bathing Areal FC Loading Rating	Moderate	Moderate	Moderate	Moderate
Shellfish Areal FC Loading Rating	High	High	High	High
Combined Disease Risk	HIGH	HIGH	HIGH	HIGH
Coastal Erosion	LOW	LOW	LOW	LOW
Climate change - pH and temperature	HIGH	HIGH	HIGH	HIGH
Toxicants	MODERATE	MODERATE	LOW-MODERATE	LOW-MODERATE
Marine Oil Spills	MOD-HIGH	HIGH	MOD-HIGH	MODERATE
Saltmarsh (% loss from baseline)	HIGH	HIGH	HIGH	NA
Seagrass (% loss from baseline)	HIGH	HIGH	HIGH	NA
Reclamation	HIGH	HIGH	LOW	VERY LOW
Shoreline Armouring, Structures	MODERATE	MOD-HIGH	MODERATE	LOW
Freshwater Abstraction	MODERATE	MODERATE	MODERATE	MODERATE
Harvesting	MOD-HIGH	MOD-HIGH	MODERATE	LOW
Invasive Species	MODERATE	MOD-HIGH	MODERATE	LOW
Off Road Vehicles	LOW	LOW	LOW	LOW
Wildlife Disturbance	MOD-HIGH	MOD-HIGH	MOD-HIGH	MODERATE
Grazing	LOW	LOW	LOW	LOW
Natural Terrestrial Margin	HIGH	HIGH	HIGH	VERY LOW
OVERALL VULNERABILITY	**HIGH**	**MODERATE-HIGH**	**MODERATE-HIGH**	**MODERATE**

4. Summary and Recommendations (continued)

1. Muddiness (excessive fine sediment inputs)

Although sedimentation is a natural process and provides a number of important functions (e.g. supplying nutrients, and buffering coastal erosion), environmental problems occur when the rate at which fine sediment is being transferred to, and deposited within, estuarine and coastal regions exceeds their capacity to assimilate them. This has the potential to profoundly alter the structure and function of estuarine and embayment ecosystems in particular. Specific sedimentation-related criteria in the recently developed ETI tool (Robertson et al. 2016a, 2016b) were combined with reported estuary condition to determine the overall vulnerability of Nelson's estuaries to muddiness impacts.

The assessment found that Waimea and Kokorua have a high risk of muddiness impacts, and Delaware and Nelson Haven moderate risk. Waimea and Kokorua also had the largest areas affected (36% and 20% of the intertidal area dominated by soft muds respectively). Within these areas sediment mud content was also elevated (25-70% mud) . Nelson Haven and Delaware had significantly less mud dominated habitat (9-11%), but Delaware had the highest sediment mud content (73% mud at Site A). Within the Nelson/Tasman region, the major sources of sediment to the estuaries were previously identified as intensive pastoral, urban and exotic forestry inputs (Robertson and Stevens 2012). Sediment risks associated with exotic forestry will increase following harvesting and remain high for ~5 years.


2. Eutrophication (excessive nutrient inputs)

Because fine sediments often contain elevated nutrients, the two issues of eutrophication and sedimentation are generally interlinked. Catchment inputs are the primary source of nutrients and fine sediments and, if individually present in excess, they result in ecological degradation, which is exacerbated when they occur together. In SIDEs, eutrophication symptoms (i.e. dense benthic macroalgal beds underlain by muddy, nutrient-rich sediments with low oxygenation and elevated toxic sulphide levels) are most often expressed in mid-upper estuary regions where fine sediment deposition occurs. Here, opportunistic macroalgae can grow using nutrients in the overlying water as well as those stored in underlying sediments (Robertson et al. in prep). Once established, these nuisance macroalgae beds (and associated degraded sediment conditions) are likely to persist until both water column and sediment nutrient sources become limiting. Nuisance growths may also be constrained by localised conditions such as tidal scouring, wave action temperature, or water clarity. Based on an assessment of SIDEs throughout NZ (Robertson et al. 2016a, 2016b; Robertson & Savage in prep.) an areal nitrogen load threshold of $<50mg.N.m^{-2}.d^{-1}$ is recommended to protect against the establishment of persistent nuisance macroalgal growths.

Based on current nitrogen load estimates, Kokorua Inlet has a high risk of eutrophication, Waimea and Delaware Inlet moderate, and Nelson Haven low. When physical susceptibility (flushing and dilution) is factored in, these ratings increase to high for Kokorua and Waimea, and moderate for Delaware and Nelson Haven.

3. Elevated disease risk

Runoff from farmland, urban areas and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the coastal environment, can survive for some time. The major sources of faecal bacterial are runoff from intensive pastoral farming, particularly dairying, animal faeces (including dogs and birds), and sewage spills or treated discharges. 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. 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 in the region. While risk assessment criteria indicate Nelson's estuaries all have a high potential disease risk, this is most likely to be as an elevated disease risk associated with bathing and shellfish consumption for short periods following heavy rain in the catchments. At other times there is likely to be a relatively low risk of disease from bathing.

4. Summary and Recommendations (continued)

4. Coastal erosion through sea level rise

Sea level is predicted to increase up to 7mm/year or more in the next 100 years. A U.S. Geological Survey Coastal Vulnerability Index (CVI) was used to evaluate the potential vulnerability of the Nelson estuaries to shoreline erosion. In general, the CVI approach identifies the most vulnerable areas as shorelines that have soft sediments, low gradients, are eroding, exposed to strong wave action and have a low tidal range. Estuarine systems with low tidal ranges that are exposed to waves are the most vulnerable to erosion, and vulnerability to habitat loss increases wherever barriers prevent the landward migration of coastal habitats (particularly saltmarsh) in response to sea level rise. Note the CVI approach only provides a relative regional vulnerability rating and not a description of the actual impact of sea level rise on each coastal section or habitat. The Nelson region estuaries all fit in the low risk category based on the CVI because of their limited wave exposure and relatively large tidal range.

5. Ecological change through climate induced sea temperature and pH change

Australian research, where the most relevant research to NZ is being undertaken, indicates that future increases in ocean temperatures are likely to result in range shifts of habitat forming macroalgae and associated species, with local extinctions to be expected for some species, particularly at their range extremities. Experimental evidence also suggests that ocean acidification will result in significant negative effects on calcifying algae and animals e.g. shellfish, paua. A lack of long-term observational data means direct evidence of changes attributable to climate impacts is unavailable in Nelson, but the experimental evidence indicates that all shoreline habitats (including estuaries) bathed by ocean waters in the Nelson region are at high and ongoing risk from predicted climate induced increases in ocean acidity and temperature.

6. Saltmarsh loss

Saltmarsh is one of the most productive environments on earth, serves as an important nursery ground and wildlife habitat, and provides tremendous additional benefits for humans including flood and erosion control, water quality improvements, opportunities for recreation, and for atmospheric gas regulation - estuaries tend to be "carbon sinks," since carbon dioxide is absorbed in the photosynthesis carried out by the prolific plant growth. Tidal saltmarshes have the ability to respond rapidly to physical stressors, and their condition is often a dynamic balance between relative sea level rise, sediment supply and the frequency/duration of inundation. However, if sea level rises too much or too fast, or the sediment supply or inundation through flooding is excessive, then the balance can be upset and the saltmarsh is lost or its condition deteriorates. This balance varies between different types of estuaries but their response centres around how each reacts to sediment inputs and inundation (the latter is particularly important in face of predicted accelerated sea level rise through global warming assuming that "natural evolution" of the coastline is allowed to occur through erosion). The reclamation of high value saltmarsh habitat severely lowers the biodiversity and natural assimilative capacity of estuaries contributing to decreased sediment trapping and reduced habitat quality.

Historical saltmarsh losses have been high in Waimea, Delaware and particularly Nelson Haven, and estimated as moderate in Kokorua. While no further significant losses though reclamation are expected to occur, remaining saltmarsh is commonly confined on the landward margin by armouring from seawalls and reclamations, constraining its ability to migrate in response to sea level rise. Terrestrial weeds are also common in the upper tidal reaches. As such it has a high vulnerability rating.

7. Seagrass loss

Seagrass (*Zostera*) is a marine plant of high ecological value that grows in the estuaries and shallow embayments of the Nelson region. It flowers and produces seeds, unlike seaweed, and grows quickly in the spring and summer. Seagrass is important because it provides food and habitat for birds, fish, crabs, shellfish and other marine organisms. It also dampens wave energy and traps sediment thereby protecting shorelines from erosion, and contributes to improved water quality.

Zostera and other seagrass species are used as indicators of estuarine health throughout the world because they respond sensitively to many natural and human-caused environmental factors that affect water quality and shoreline sedimentation. Changes in the abundance or distribution of seagrass are likely to reflect changes in environmental conditions, particularly increased sediment loads and eutrophication. They are also likely to affect many other species that depend on seagrass habitat.

Across all of the Nelson estuaries, there has been significant seagrass loss (38-58% from measured baselines). The most extensive remaining cover is in Nelson Haven (14%, 120ha) with Waimea, Delaware and Kokorua now support less than 2% seagrass (34, 6, 0ha respectively). Historical losses and ongoing reductions result in a high vulnerability rating.

8. Loss of natural vegetated terrestrial margin buffer through development

Coastal shoreline habitats function best with a natural vegetated margin which acts as a buffer from development and "coastal squeeze". This buffer protects against introduced weeds and grasses, naturally filters sediment and nutrients, and provides valuable ecological habitat. The assessment found that >70% of the natural vegetated terrestrial 200m margin buffer that historically bordered shorelines of Nelson's estuaries have been highly modified, mainly by roading, intensive pastoral grazing, residential properties, and forestry - modification often extending a long distance inland from the coast. Waimea Inlet and Nelson Haven have incurred the largest losses, both with only a remnant (<5%) natural vegetated margin remaining. Development within this coastal buffer margin results in decreased resilience of the coast in the face of physical forces, and reduced biodiversity, aesthetics, heritage and landscape values, and public access.

The most significantly affected estuaries were Waimea and Nelson Haven, followed by Delaware and Kokorua, but some reversal of impacts is underway with planting initiatives in Waimea, Nelson Haven and Delaware estuaries.

9. Additional stressors

In all of the estuaries there were a number of more other stressors identified including: shellfish harvesting, the presence of invasive species, off-road vehicles, human disturbance of wildlife, grazing of high value habitats, flapgates and causeways, flow reductions. While exerting a lesser degree of influence than the main stressors of sediments, nutrients and pathogens, the cumulative impact of multiple stressors presents an ongoing threat to healthy estuary functioning.

All of the estuaries have had various assessments undertaken to assess their condition (see following section), with the Waimea Estuary currently included within Tasman District Council's scheduled long-term estuary monitoring programme. However, monitoring of the other estuaries has often been ad hoc and outside of a coordinated monitoring programme. In order to appropriately assess and track changes in the Nelson estuaries in relation to the issues identified, a comprehensive monitoring programme has been proposed based on the National Estuary Monitoring Protocol approach being used by regional councils throughout NZ. It targets the key stressors identified in each estuary and includes a range of cost effective indicators that enable the overall vitality of the estuaries to be assessed, management priorities to be defined, and a cycle of monitoring that enables estuary changes to be reliably tracked. The recommended monitoring for each estuary is outlined on the following page, followed by a possible long-term monitoring schedule.

PREVIOUS MONITORING

Previous monitoring has been undertaken in all of the estuaries as follows:

- **Broad scale habitat mapping** to document dominant estuary features (e.g. substrate, seagrass, saltmarsh, macroalgae) and monitor changes over time. Broad scale mapping, usually scheduled at 5 yearly intervals, was undertaken in Waimea Inlet in 1990 (Davidson and Moffat 1990), 1999 (Robertson et al. 2002), 2006 (Clarke et al. 2008), and 2014 (Robertson & Stevens 2014a). Historical vegetation cover was also assessed using 1946 and 1985 aerial photographs (Tuckey and Robertson 2003). Nelson Haven and Delaware Inlet were mapped in 2009 (Gillespie et al. 2011a&b; and Kokorua Inlet in 2015 (Stevens and Robertson 2015).
- **Fine scale monitoring** measures the condition of representative intertidal sediments (usually the dominant substrate type as well as deposition zones where sedimentation and eutrophication symptoms are first expressed) using a suite of physical, chemical and biological indicators (refer to Table 1 for further detail). It is commonly undertaken once annually for three consecutive years during the period Nov-Mar (usually at two to three sites) to establish a baseline, and thereafter at 5 yearly intervals. Fine scale intertidal monitoring was undertaken in Waimea Inlet in 2001, 2006, 2011, with a multi-year baseline established from 2014, 2015 and 2016 (see Robertson & Stevens 2014a). Nelson Haven was assessed in 2012 (Gillespie et al. 2012), Delaware Inlet in 2009 (Gillespie et al. 2009), and Kokorua Inlet in 2015 (Stevens and Robertson 2015). Multi-year baselines have not been established in these latter estuaries and fine scale sites in Nelson Haven and Delaware Inlet may not adequately target deposition zones where sedimentation and eutrophication symptoms are first expressed.
- **Annual sedimentation rate (including grain size) monitoring** measures sedimentation trends within the estuary over time. Sediment plates have been deployed in Waimea Inlet and monitored annually since 2008 as part of the Tasman District Council estuarine monitoring programme. Historical coring to determine past sediment accrual was also undertaken in Waimea Inlet in 2011 (Stevens and Robertson 2011). Sediment plates were deployed and baseline measurements taken in Kokorua in 2015 (Stevens and Robertson 2015). Sedimentation rate measures have yet to be undertaken in Nelson Haven or Delaware Inlet.

MONITORING RECOMMENDATIONS

To maintain the high value of the four surveyed Nelson region estuaries, and to ensure sufficient information is available to manage each in relation to the identified vulnerability to specific issues, long term monitoring is recommended for each estuary below (see Table 5 for a summary of previous monitoring and a proposed schedule of future monitoring). It is also recommended that high level data be collated (or gathered) on dominant changes in catchment land use e.g. national data sets like the Landcare Land Cover Data Base (LCDB), supported by local detail on potential sources from high risk activities (e.g. land disturbance, point source discharges), as well as regularly estimating changes to naturally occurring catchment inputs of sediment, nutrients and pathogens likely from human influenced land disturbance e.g. using the NIWA CLUES catchment model, or predicted yields based on specific land use activities.

Waimea Inlet

Continue with the programmed long-term broad and fine scale monitoring scheduled on a 5 yearly cycle. Particular emphasis to be placed on fine mud inputs, in particular defining the spatial extent of mud dominated habitat, maintaining annual sediment plate measurements, monitoring seagrass extent and condition, and quantifying the presence of nuisance macroalgal growth. Saltmarsh change to be monitored 5-10 yearly depending on available resources. Fine scale sampling to maintain three existing long-term sites monitored and reported on 5 yearly. Continue with annual bathing water and shellfish sampling. Due to the regional boundary running through the middle of the estuary, ensure that NCC monitoring is coordinated with that of TDC, and in particular that the influence of NCC inputs to the estuary are able to be related back to catchment sources as much as practicable. Regularly (e.g. 5 yearly) undertake a SOE report that combines all available monitoring information and data on the estuary including consent monitoring, river water quality data and estuary monitoring results to provide an overall summary of condition and review monitoring and management needs.

Table 5. Summary of previous monitoring and proposed future monitoring time-line for Nelson region estuaries.

COMPONENT	ESTUARY	1990	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Broad scale mapping	Waimea	✓	✓							✓								✓					X					X				
	Nelson Haven												✓	*										X					X			
	Delaware												✓									X*					X					X
	Kokorua																		✓						X					X		
Fine scale monitoring	Waimea				✓					✓					✓			✓	✓	✓					X					X		
	Nelson Haven															✓									X	X	X					X
	Delaware												✓										X	X	X					X		
	Kokorua																		✓			X	X	X					X			
Sediment plates	Waimea											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Annual monitoring recommended for each estuary										
	Nelson Haven																															
	Delaware																															
	Kokorua																		✓													
Regional State of Environment report																										R					R	
Catchment land use changes, sediment/nutrient source tracking																										R					R	
Ecological vulnerability assessment	Tasman															✓										R						
	Nelson																				✓										R	

✓ = monitoring undertaken

* = macroalgal mapping only

X = Proposed long term monitoring schedule

X* = Prioritsed monitoring to capture estuary condition prior to scheduled forest logging in surrounding catchment

R = Recommended high level data collection and reporting

Note, historical estimates of saltmarsh and seagrass cover based on aerial photos or maps are available for Waimea (1946, 1985), Nelson Haven (1840, 1931, 1985), and Delaware (1983).

4. Summary and Recommendations (continued)

Nelson Haven
Initiate a programme of long-term broad and fine scale monitoring scheduled on a 5 yearly cycle. Emphasis to be placed on fine mud inputs, in particular defining the spatial extent of mud dominated habitat, establishing annual sedimentation rate measurements, monitoring seagrass extent and condition (including recording of underlying substrate), and quantifying the presence of nuisance macroalgal growth. Saltmarsh change to be monitored 5-10 yearly following a review of existing data which currently excludes extensive saltmarsh in the north (i.e. the Wakapuaka Wildlife reserve where tidal flows are restricted by flapgates).

Fine scale sampling to maintain a total of three existing long-term sites monitored and reported on 5 yearly after a 3 year annual baseline established. This monitoring to include a new site in the mud-dominated upper estuary to provide sufficient data for the recently developed NZ ETI to be used. Continue with annual bathing water monitoring.

Regularly (e.g. 5 yearly) undertake a SOE report that combines all available monitoring information and data on the estuary including consent monitoring, river water quality data and estuary monitoring results to provide an overall summary of condition and review monitoring and management needs.

Delaware Inlet
Initiate a programme of long-term broad and fine scale monitoring scheduled on a 5 yearly cycle. Emphasis to be placed on fine mud inputs, in particular defining the spatial extent of mud dominated habitat, establishing annual sedimentation rate measurements, and monitoring seagrass extent and condition (including recording of underlying substrate). Broad scale monitoring also to record and quantify the presence of nuisance macroalgal growth and exotic species, in particular Pacific oyster. Priority to be given to establishing a robust baseline of mud measures prior to the commencement of pending forest harvesting in the near future.

Saltmarsh change to be monitored 5-10 yearly. Fine scale sampling to maintain the three existing long-term sites monitored and reported on 5 yearly after a 3 year annual baseline established.

Regularly (e.g. 5 yearly) undertake a SOE report that combines all available monitoring information and data on the estuary including consent monitoring, river water quality data and estuary monitoring results to provide an overall summary of condition and review monitoring and management needs.

Kokorua Inlet
Initiate a programme of long-term broad and fine scale monitoring scheduled on a 5 yearly cycle. Emphasis to be placed on fine mud inputs, in particular defining the spatial extent of mud dominated habitat and annual monitoring sedimentation rates. Priority to be given to mud measures following recent forest harvesting in the catchment.

Saltmarsh change to be monitored 5-10 yearly. Fine scale sampling to maintain the two existing long-term sites, monitored and reported on 5 yearly after a 3 year annual baseline established.

Regularly (e.g. 5 yearly) undertake a SOE report that combines all available monitoring information and data on the estuary including consent monitoring, river water quality data, sediment source tracing, and estuary monitoring results to provide an overall summary of condition and review monitoring and management needs.

Omokau Bay and Oananga Bay estuaries
There are two smaller estuaries located to the north east of Kokorua which were not included in this assessment and for which no data are currently known to exist. It is recommended that these be synoptically assessed to determine existing state and pressures.

In addition, some variance was noted in the methods and spatial coverage of key features assessed by different science providers. It is recommended that existing data be reviewed and standardised, and that future monitoring ensures the most recent improvements to national monitoring criteria are adopted wherever possible.

5. ACKNOWLEDGEMENTS

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APPENDIX 1. ESTUARY CHARACTERISTICS

Category	Characteristic	Waimea	Nelson Haven	Delaware	Kokorua
Catchment General	Estuary Type	SIDE	SIDE	SIDE	SIDE
	Catchment Area (km^2)	913	129	93.4	95.3
	Mean Freshwater Inflow (l/s)	21000	2400	1344	2535
	Landuse (% NSF, ESF, HPP/LPP,Urb,Crop, Bare)	36, 33, 20/0, 2, 4, 4	54, 33, 3.4/0.6, 4.2, 0, ?	37, 42, 13.9/0.1, 0, 0, 0.02	51, 45, 3/0.2, 0.3, 0, 0.3
	Geology - dominant rock type	Sst Grv (Mel)	Sst Grv (Ls)	Sst Grv (Ls)	Sst Grv
	No. Dairy Cows, Ha, Cows/Ha	1645, 91300, 0.02	1270, 777, 1.6	189, 2116, 0.1	369, 2253, 0.2
CLUES Model Estimates	N Load (t/y)	463.4	36.6	24.8	30.1
	TP (t/y)	56.8	4.4	4.6	5.2
	SS (kt/yr)	162.0	11.4	9.6	15.8
	E. coli load (x10^{15}/yr)	5.107	1.1	0.7	0.2
	Input mean TN (ug/l)	169	203.5	201.2	172.3
	Input Mean TP (ug/l)	9.4	14.4	28.2	28.3
	N Areal Load (mg/m^2/d)	38.0	8.1	19.2	120.8
	P Areal Load (mg/m^2/d)	4.7	1.0	3.6	21.1
	SS Areal Load (g/m^2/d)	13.3	2.5	7.4	63.3
	E. coli Areal Load (FCx10^6/m^2/d)	418310	245993	542845	828466
Consent Monitoring Data	Point Source N load (t/yr)	98.2			
	Point Source P load (t/yr)	28.1			
	Point Source SS load (t/yr)	134			
	Point Source E. coli. load (Fcx10^{15}/yr)	0.13			
	Point Source Toxicants (high, moderate, low)	low	low	low	low
Estuary General	Estuary area (ha)	3345	1242	353	68
	Shoreline Length (km)	101.0			
	Mean Depth at HW (m)	1.4	1.4	1.3	1.3
	Estuary Volume @ HW = mean depth x area = (m^3)	46,689,360	17,238,960	4,740,119	905,014
	Flushing Potential = FW(m^3/d)/EV(m^3) = (days)	0.038	0.012	0.024	0.235
	Spring Tidal Range MHW (m)	3.6	3.6	3.6	3.6
	Dominant sediment type	SM	FMS	FS/FMS	FMS
Habitat Indicators	Intertidal area	3308	851	331	61.0
	Intertidal Soft mud (ha)	1197	89	31	12.2
	Saltmarsh Baseline Extent (ha, year)	352 (1946)	~300 (1840)	~35 (1983)	21.4 (2015)
	Saltmarsh Extent (ha)	303 (2014)	9 (2009)	22 (2009)	21.4 (2015)
	Seagrass Baseline Extent (ha, year)	58 (1990)	284 (1840)	8.9 (1983)	0 (2015)
	Seagrass Extent (ha)	34 (2014)	120 (2009)	6.3 (2009)	0 (2015)
	Macroalgae (ha with cover >20%)	77.2			
	Macroalgae (ha with cover >50%)	59.2	16.1	33.7	0.2
	Gross Eutrophic Nuisance (ha)	28	0.0	-	0.3
	Natural Terrestrial Margin (%)	2		19	73
	Terrestrial Margin (% Gra, Resi, Hort, Indu)	63, 7, 3, 16	27,40,0,28	25_,_,_	24, 0, 0, 0
	Chlor-a Benthic mg/m^2	19			
	Mean Chlor-a surface water mg/m^3				
	Dominant RPD Depth (cm)	1-3	1-3	1-3	1-3

APPENDIX 2. ESTUARY VULNERABILITY RATINGS

Stressor	Subcomponent	Waimea	Nelson Haven	Delaware	Kokorua
Sedimentation	Sediment load kt/y CLUES All Forest 2015 LCDB3 2008/9 75% wetland attenuation	29.4	2.4	1.9	3.7
	Sediment load kt/y CLUES 2015 LCDB3 2008/9	162.0	11.4	9.6	15.8
	Current State Sediment Load (CSSL)/Natural State Sediment Load (NSSL) ratio	5.5	4.8	5.2	4.3
	Presence of Poorly Flushed Habitat	yes	yes	yes	yes
	Sedimentation Susceptibility Rating	**High**	**Moderate**	**High**	**Moderate**
	% of estuary with soft mud (>25% mud content)	36	10	9	20
	Sedimentation Existing Condition Rating	**Very High**	**High**	**High**	**Very High**
	Overall Sediment Rating	**High**	**High**	**High**	**High**
Eutrophication	Flushing Potential = FW(m^3/d)/EV(m^3) = (days)	0.038	0.012	0.024	0.235
	Dilution potential = 1 ÷ estuary volume (ft^3)	6.06494E-10	1.64261E-09	5.97386E-09	3.12888E-08
	Export potential (physical susceptibility)	High	High	Moderate	Moderate
	Combined nutrient load and physical susceptibility	High	Moderate	Moderate	High
	Susceptibility to Eutrophication Rating	**High**	**Moderate**	**Moderate**	**High**
Primary Indicators	Chl a	na	na	na	na
	Macroalgal GEZ (%)	0.8	0	0	0.4
	Macroalgal GEZ (ha)	28	0	0	0.3
	Macroalgae (EQR)	0.55	0.716	na	0.68
Supporting indicators	1. Dissolved Oxygen (1 day minimum) (mg/m3)	na	na	na	na
	2. Sediment Redox Potential (mV) measured at 1cm depth[1]	-100	-10	-50	na
	2a. % of estuary with Sediment Redox Potential <150mV at 3cm	na	na	na	na
	2b. Ha of estuary with Sediment Redox Potential <150mV at 3cm	na	na	na	na
	2c. % of estuary with apparent Sediment Redox Potential <1cm	na	na	na	na
	3. TOC (%) measured at 0-2cm depth area)	na	na	na	1.3
	4. TN (mg/kg) measured at 0-2cm depth[1]	na	na	na	1000
	5. NZ AMBI[1]	na	na	na	3
	6. % Total Estuary Area with Soft Muds (>25% mud) ex. saltmarsh	40	11	10	31
	7. CSR to NSR ratio.	5.5	4.8	5.2	4.3
	8. % Total Est. Area with CSR > 5x NSR (mm.yr^{-1})	na	na	na	na
	9. Seagrass Change from measured baseline (%)	-41	-58	-49.6	na
	Existing Condition Eutrophication Rating (primary and secondary indicators)	**Moderate**	**Low**	**Low**	**Moderate**
Eutrophication	**Overall Eutrophication Rating**	**High**	**Moderate**	**Moderate**	**High**
Disease Risk	Bathing Areal Faecal indicator Bacteria Loading Rating	Moderate	Moderate	Moderate	Moderate
	Shellfish Areal Faecal indicator Bacteria Loading Rating	High	High	High	High
	Timing of Disease Risk	Floods	Floods	Floods	Floods
	Overall Disease Risk Rating	**High**	**High**	**High**	**High**
Toxicants	Urban Runoff / Contaminant Spills	Moderate	Moderate	Low	Low
	Naturally Occurring Inputs of Heavy Metals	Moderate	Moderate	Moderate	Moderate
	Pesticides	Moderate	Low	Low	Low
	Overall Toxicant Rating	**Moderate**	**Moderate**	**Low**	**Low**
Marine Oil Spills	Proximity to offshore drilling platform	High	High	High	High
	Proximity to vessel path	High	High	High	Moderate
	Proximity to land runoff source	High	High	Moderate	Low
	Overall Probability of spill occurring	Mod-High	High	Moderate	Low
	Habitat Sensitivity	High	High	High	High
	Recovery Time	Moderate	Moderate	Moderate	Moderate
	Overall Magnitude of Impact	Mod-High	Mod-High	Mod-High	Mod-High
	Overall Oil Spill Rating	**Mod-High**	**High**	**Mod-High**	**Moderate**

[1] indicator must represent most impacted sediments and at least 10% of estuary area

APPENDIX 2. ESTUARY VULNERABILITY RATINGS

Stressor	Subcomponent	Waimea	Nelson Haven	Delaware	Kokorua
Toxic Algal Blooms	Previous TABs	Low	Low	Low	Low
	Seed Source local	Moderate	Moderate	Moderate	Moderate
	Seed Source up-current	Moderate	Moderate	Moderate	Moderate
	Conditions favourable for blooms	Low-Moderate	Low-Moderate	Low-Moderate	Low-Moderate
	Overall Risk in Area	Low-Moderate	Low-Moderate	Low-Moderate	Low-Moderate
	Presence of at-risk local species	Mod-High	Mod-High	Mod-High	Mod-High
	Presence of humans who eat shellfish/fish	High	High	High	High
	Overall Human Risk of Eating Infected Species.	High	High	High	High
	Overall TAB Rating	**Moderate**	**Moderate**	**Moderate**	**Moderate**
Coastal Erosion(Sea Level Rise)	a. Geomorphology	5	5	5	5
	b. Erosion/Accretion Rate (m/yr)	3	2	2	2
	c. Slope (%)	5	5	5	5
	d. Rel. Sea Level Rise Rate (mm/yr)	5	5	5	5
	e. Mean Wave Height (m)	1	1	1	1
	f. Mean Tidal Range	3	3	3	3
	Physical CV = √{(a.b.c.d.e.f)/6}	13.7	11.2	11.2	11.2
	Overall Coastal Erosion Rating	**Low**	**Low**	**Low**	**Low**
Reclamation	Area of affected area as a %age of whole	High	High	Low	Very Low
	Ecological value of area prior to reclamation	High	High	Low	Very Low
	Overall Reclamation Rating	**High**	**High**	**Low**	**Very Low**
Freshwater Abstraction	Susceptibility	Low	Low	Low	Low
	Magnitude	High	High	Moderate	Moderate
	Overall Freshwater Abstraction Rating	**Moderate**	**Moderate**	**Moderate**	**Moderate**
Harvesting Living Resources	Presence of Harvestable Living Resource	Moderate	Moderate	Moderate	Moderate
	Proximity to Human Population Centres	High	High	Moderate	Very Low
	Overall Harvesting Rating	**Mod-High**	**Mod-High**	**Moderate**	**Low**
Invasive Species	Pathway	Moderate	High	Low	Very Low
	Existing Presence	Moderate	Moderate	Moderate	Moderate
	Overall Invasive Species Rating	**Moderate**	**Mod-High**	**Moderate**	**Low**
Shoreline Armouring, Structures	Seawall/Breakwater/Causeway	Moderate	High	Moderate	Low
	Groyne	Low	Moderate	Low	Low
	Exposure	Low	Low	Low	Low
	Overall Structures Rating	**Moderate**	**Mod-High**	**Moderate**	**Low**
Off Road Vehicles	Vehicles on Beaches, Dunes and Tidal Flats	Low	Low	Low	Low
	Presence of Damage	Low	Low	Moderate	Low
	Overall Off Road Vehicle Rating	**Moderate**	**Low**	**Moderate**	**Low**
Wildlife Distur-bance	Presence of vulnerable wildlife	High	High	High	High
	Proximity to Human Population Centres	High	High	Low	Very Low
	Access to vulnerable areas	Moderate	Moderate	Moderate	Moderate
	Overall Disturbance Rating	**Mod-High**	**Mod-High**	**Mod-High**	**Moderate**
Dune Overstabi-lisation	Presence of exotic forest on duneland	NA	NA	NA	NA
	Presence residential/industrial dwellings on duneland	NA	NA	NA	NA
	Presence of developed pasture on duneland	NA	NA	NA	NA
	Presence of seawalls in front of duneland	NA	NA	NA	NA
	Presence of marram/weeds on duneland	NA	NA	NA	NA
	Overall Dune Overstabilsation Rating	**NA**	**NA**	**NA**	**NA**
Grazing	Presence of grazing animals in high value habitat	Low	Low	Low	Low
	Overall Grazing Rating	**Low**	**Low**	**Low**	**Low**
Natural Terres-trial Margin	% non-natural cover of 200m wide margin	High	High	High	Very low
	Overall Natural Terrestrial Margin Rating	**High**	**High**	**High**	**Very low**
Lowland river nutrients[2]	SIN (Soluble inorganic nitrogen) exceed ANZEEC criteria?	Yes	No	No	No
	DRP (dissolved reactive phosphorous) exceed ANZEEC criteria?	Yes	No	No	No

[2] data sourced from McArthur (2016) and assessed using ANZECC lowland (2000) trigger limits.

APPENDIX 3. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

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 an adult sinks 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 an adult sinks 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 an adult sinks >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.