SALT ECOLOGY

Synoptic overview of the Marlborough District Council estuarine State of the Environment monitoring programme

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Synoptic overview of the Marlborough District Council estuarine State of the Environment monitoring programme

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April 2019

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EXECUTIVE SUMMARY

Marlborough District Council (MDC) recently contracted Salt Ecology to conduct a synoptic overview of their estuarine State of the Environment monitoring programme to assess current data and to better understand future monitoring needs and priorities. The following report provides a synopsis of work undertaken to date using the National Estuary Monitoring Protocol (NEMP), which has consisted of broad-scale habitat mapping of 13 Marlborough estuaries (with repeat surveys in 3), and fine-scale benthic sediment assessment in 6 Marlborough estuaries (with repeat surveys in Havelock). It summarises the key findings and learnings; undertakes an appraisal of whether the NEMP approach is "fit-for-purpose" for MDC's ongoing needs; and recommends the information needs and next steps for determining future priorities.

The review identified that there appears to have been a strong focus on information gathering without a clear purpose beyond a general goal to assess and monitor the state of ecologically significant marine sites as part of a coordinated multi-agency approach. Furthermore, there has been no comprehensive distillation and synthesis of the findings of the monitoring undertaken to date, except for subjective expert judgements regarding changes within estuaries, and inferences about their causes. The review also identified several areas where relatively simple improvements to existing methods, or the adoption of new methods, would improve the consistency and quality of monitoring outputs.

While most of the monitoring undertaken has generally followed the NEMP, there has been obvious variance in the approaches used and reporting undertaken by different providers. Unless efforts are made to standardise existing data sets, it will remain difficult to consistently evaluate change within estuaries over time, and to compare estuaries within the region and nationally. Recommendations made within individual reports are generally appropriate, but have been made by multiple providers working largely in competition with each other, and in isolation from related work programmes including subtidal estuary assessments, sediment source tracking and historical coring, and coastal water quality monitoring. This places a significant onus on MDC, as the coordinator and funder of these programmes, to determine the priority of the various estuary recommendations, and to place them in a wider coastal monitoring context.

Before continuing with ongoing estuary monitoring, recommended to be carried out every 5 years in a MDC 2012 coastal monitoring strategy, it is recommended that MDC undertake or consider the following broad matters:

1. In terms of understanding ongoing monitoring and management priorities, it would be timely to undertake a comprehensive data synthesis and analysis to quantitatively evaluate some of the key changes that have occurred in both broad- and fine-scale indicators, and to investigate the potential causes of any such changes. Such an assessment will require standardisation and aggregation of existing data into a single database.
2. Refine the monitoring approach to address key design gaps in the NEMP, including:

   (i). Developing a "meso-scale" survey approach to address key issues (e.g. using sediment plates along sedimentation gradients) that is intermediate between the present broad- and fine-scale approaches, and which includes field-based measures of sediment state.

   (ii). Ensuring that the survey approaches capture key ecological values of interest (e.g. rare or threatened species, shellfish resources) or, conversely, species of potential concern such as invasive plants and animal pests.
3. In order to ensure that future NEMP (or revised) monitoring is robust, standard operating procedures (SOPs) for broad-scale mapping, fine-scale sampling, new design elements (as above in #2) and reporting outputs should be developed, including QA/QC procedures to ensure data reliability and consistency. Achieving these outcomes will require that the many and various methodological inconsistencies and uncertainties detailed in the main report are addressed. Ideally the NEMP approach should be expanded to include the adoption of improved metrics for assessing macroalgae, as described in the NZ Estuary Trophic Index (ETI).
4. A formal process is needed for prioritising estuaries in the region for monitoring, with a clear focus on: (i) the purpose of the monitoring; (ii) delivery of "fit for purpose" outcomes; (iii) integration and refinement of the current disparate approaches used to assess estuary condition; and (iv) consideration of the wider context of other MDC (or broader) monitoring programmes.

1. INTRODUCTION

Marlborough District Council (MDC) undertakes monitoring of the coastal marine area as part of its coastal State of the Environment monitoring programme. Since 2011, a focus of that monitoring has been on the ecological health of their estuaries. That work has been conducted using methods outlined in a National Estuary Monitoring Protocol (NEMP), which was originally developed in 2001 by Cawthron Institute (Robertson et al. 2002a; Robertson et al. 2002b; Robertson et al. 2002c). The NEMP was intended to provide councils with a standardised approach for assessing the state or condition of estuaries in their regions.

MDC's estuarine monitoring to date has included 'broad-scale' and 'fine-scale' surveys described in the NEMP. Efforts since 2011 have encompassed the region's main estuaries, with some systems having been assessed on multiple occasions. MDC now wishes to conduct a stocktake of these monitoring efforts, to better understand future monitoring needs and priorities. For this purpose, MDC has contracted Salt Ecology to compile a brief report that:

- Provides a synopsis of the NEMP work undertaken to date;
- Summarises the key findings and learnings;
- Undertakes an appraisal of whether the NEMP approach is 'fit-for-purpose' for MDC's ongoing needs; and
- Recommends the information needs and next steps for determining future priorities.

2. NEMP PROGRAMME

2.1 OVERVIEW

The NEMP programme has three main elements. The first part is a coarse screening tool that is intended to enable councils to undertake a preliminary assessment of the condition of estuaries in their region in order to establish monitoring priorities (Robertson et al. 2002a). Once initial priorities are established, the NEMP monitoring approach itself consists of two protocols described in Robertson et al. (2002c), which are as follows:

1. Broad-scale mapping of intertidal habitat characteristics.

The aim of broad-scale habitat mapping is to describe an estuary according to different dominant habitat types based on substrate characteristics (mud, sand, cobble, etc.) and vegetation type (macroalgae, eelgrass, saltmarsh, etc.), and develop a baseline habitat map. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats can then be monitored by repeating the mapping exercise. This procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographical Information System (GIS) technology.

2. Fine-scale assessment of intertidal habitat condition.

Once an estuary has been classified according to its main distinguishing features, and the dominant habitats have been described and mapped on a broad scale, representative habitats can be selected and targeted for fine-scale monitoring. The NEMP advocates monitoring soft sediment (sand/mud) habitat in the mid to low tidal range of priority estuaries. The environmental characteristics assessed in fine-scale surveys incorporate a suite of commonly used benthic indicators, including biological (e.g. macroinvertebrate infauna) and physical (e.g. sediment mud content, heavy metals, nutrients) characteristics.

Using these approaches, the NEMP is intended to provide resource managers with key tools with which they can assess and monitor the ecological status of estuaries in their region. A nationally applied standard protocol provides a valuable basis for establishing a benchmark of estuarine health in order to better understand anthropogenic influences, and against which future comparisons can be made. To achieve these outcomes, the protocol aims to be scientifically defensible, cost-effective, easy to use, and applicable to estuaries throughout New Zealand.

2.2 NEMP BROAD-SCALE METHODOLOGY

Broad-scale NEMP mapping is a method for describing habitats based on the dominant surface features present. It includes a classification scheme to describe dominant vegetation and substrate in a consistent manner; e.g. rock, boulder, cobble, and gravel; with sand and mud substrates divided into subcategories based subjectively on how much a person walking on the sediment sinks. Vegetation is classified in broad structural classes (e.g. rush, sedge, herb, grass, reed, tussock) that are defined based on the individual plant species present.

Site boundaries are commonly set as the seaward edge of tidal deltas or a straight line between enclosing headlands, with the upper boundary set to the extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are ‹0.5ppt).

Mapping combines detailed ground truthing of aerial photography with GIS-based digital mapping tools to record the primary habitat features present. Very simply, the method involves:

- Obtaining recent georeferenced aerial photos of an estuary at low tide for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground truthing) using laminated aerial photos during the period September to May when most plants are still visible and have not died back.
- Digitising ground truthed features evident on aerial photographs into GIS layers (e.g. ArcMap).

Aerial photographs are ideally assessed at a scale of less than 1:5000, as at a broader scale the detail of the estuary may be lost and it will become difficult to accurately determine changes in habitats over time. The georeferenced spatial habitat maps produced subsequently provide a robust baseline of key indicators that can be used to assess estuary condition in response to common stressors, and to assess future change. Changes over time have generally been assessed 5 yearly where significant pressures or changes are expected, or 10 yearly in estuaries where pressures are lower or changes are less likely. An example of a typical broad scale summary substrate map is presented in Fig. 1.

The NEMP represented an important step in the development of a consistent framework for assessing estuary features. However, it was always intended to be a living document that incorporated knowledge gained from its use to refine and improve it. Consequently, since the initial development of the NEMP, there have been a range of complementary broad-scale measures incorporated into estuary assessments to better characterise features. These include validations of substratum classes using laboratory-

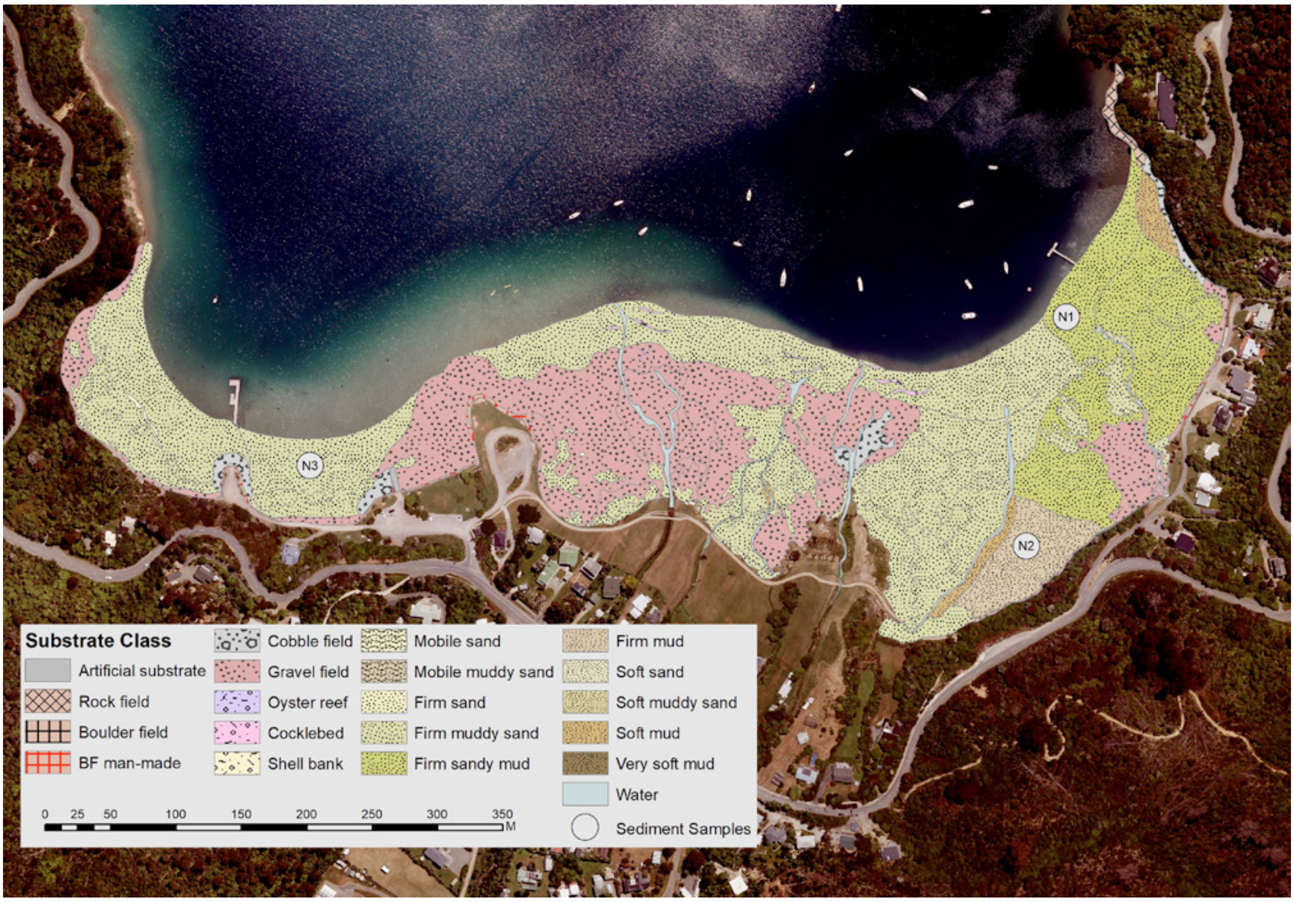

Fig. 1. Example of the dominant broad scale substrate features in Ngakuta Estuary, Queen Charlotte Sound (Stevens 2018a).

based analyses of grain size, and assessment of seagrass and macroalgae using measures of percent cover and density/biomass. Many other broad-scale features have also been variably recorded, including the estimated natural estuary extent (to assess historical habitat loss), barriers to sea level rise (causeways, flood banks), sediment oxygenation, invasive species, shellfish beds, eutrophic (enriched) zones, terrestrial margin vegetation, and catchment land use. The key benefit of these changes has been to improve the metrics used, and the scope and quality of the outputs. However, a significant drawback has been that these developments have not been undertaken within any nationally or regionally coordinated or formally agreed process. Therefore, they have led to a variable use of terms, forms of reporting, and coverages within and between providers.

Notwithstanding, selected summary data have been able to be used to establish correlative relationships between key habitat features and anthropogenic influences; e.g. mud extent in relation to catchment sediment inputs or macroalgal growth in relation to catchment nutrient loads (e.g. Fig. 2, Robertson et al. 2017).

Such relationships have subsequently been used to derive thresholds at which important changes in the ecological state of estuaries have begun to occur throughout New Zealand. This information is used to help assess current ecological condition, as well as to guide policy decisions and aid in limit setting approaches for catchment-based management (e.g. Robertson et al. 2016b).

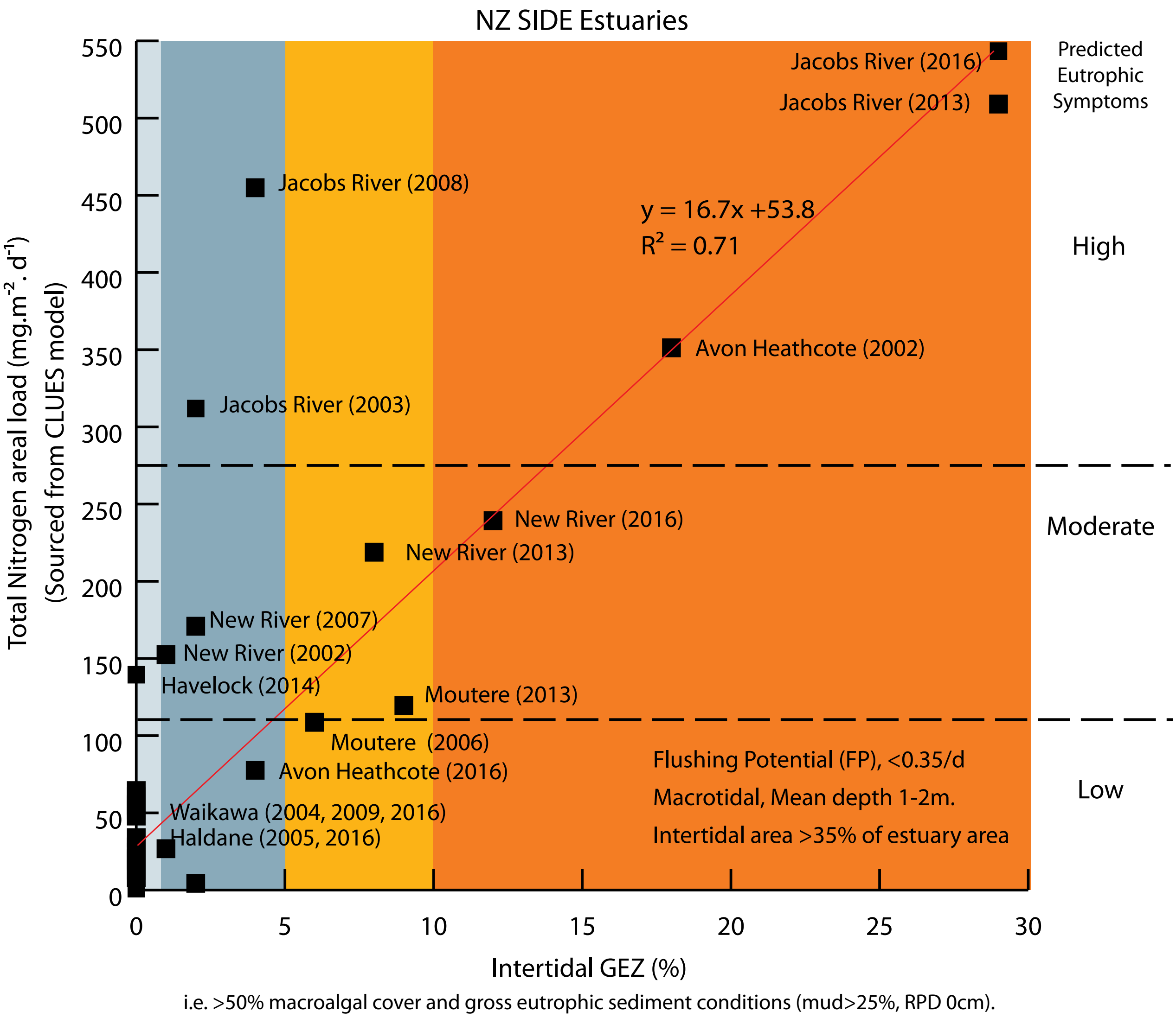

Fig. 2. Relationship between nitrogen (N) areal load and the hectares of intertidal area classified as Gross Eutrophic Zones (GEZ) for 25 New Zealand shallow intertidally dominated (SIDE) estuaries, 2001-2016 (Robertson et al. 2017).

2.3 NEMP FINE-SCALE METHODOLOGY

The NEMP fine-scale sampling procedure is illustrated in Fig. 3. The protocol recommends sampling at 2 to 4 sites per estuary, with sites consisting of unvegetated sand/mud habitat in the mid to low tide zone. Sites should be located away from river mouths (recommended mean salinity of overlying water >20 ppt). The number of sites is determined based on estuary size, the extent of the dominant mud/sandflat habitat, and the number of isolated arms. The NEMP recommends that each site consist of an area of 60 x 30 m subdivided into 12 equal-sized (i.e. 15 x 10 m) plots, with 10 of these plots sampled in a given survey (see detail in Fig. 3).

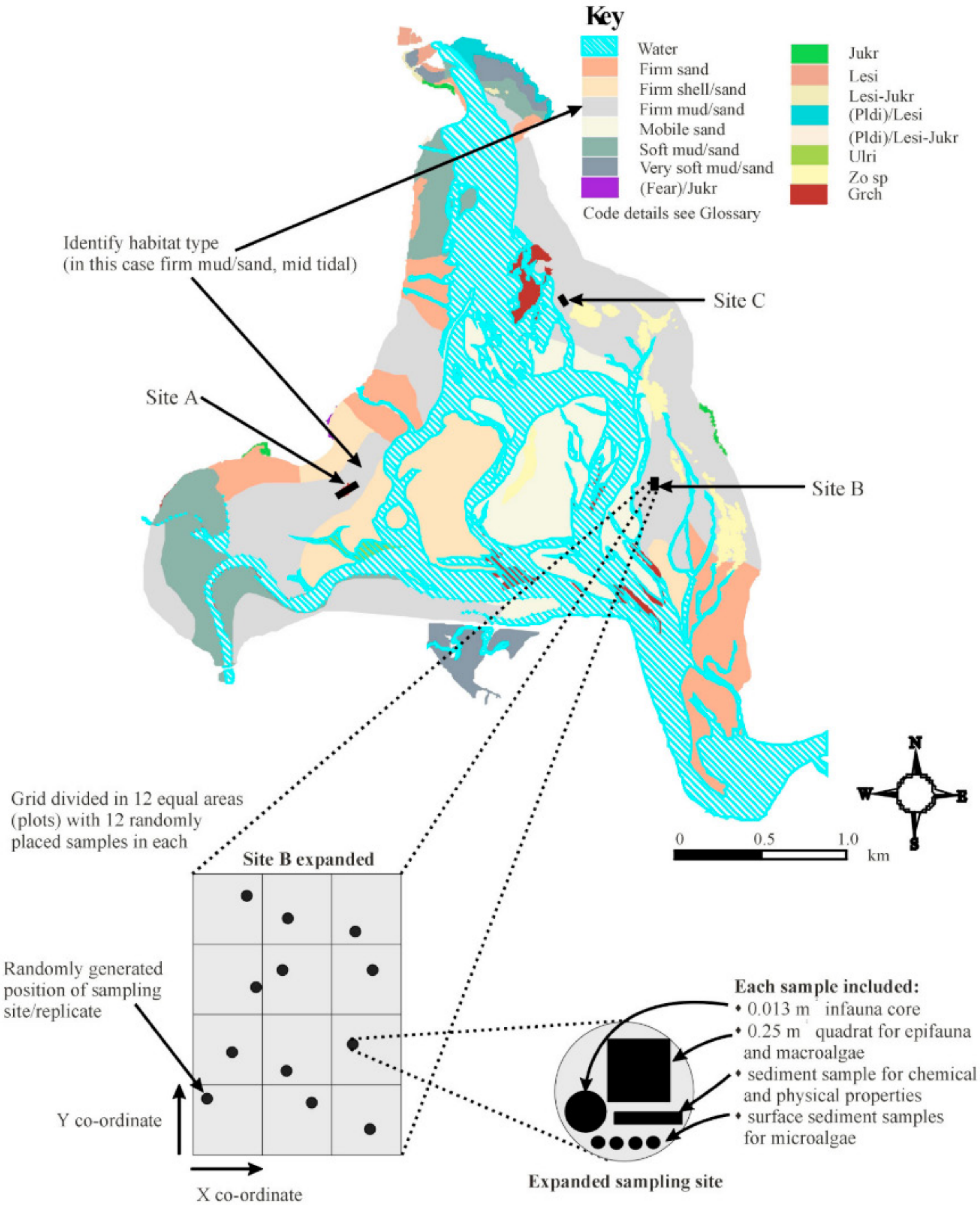

Fig. 3. Example of the NEMP sampling strategy described by Robertson et al. (2002b) (for the Avon-Heathcote Estuary).

Each survey involves sampling or assessment of the benthic health indicators shown in Table 1. In summary, these are:

- Physical and chemical indicators: sediment grain size, organic matter content, nutrients, trace metals.
- Biological indicators: sediment-dwelling infauna, visible epibiota, benthic chlorophyll-a and microalgae.

The selected indicators reflect the types of human-induced pressures that commonly affect many New Zealand estuaries. These are 'muddiness', nutrient and organic enrichment, and toxicity. The chosen indicators integrate point-in-time conditions related to the past history of exposure to stressors, and therefore require a relatively low frequency of monitoring. For example, the structure of the biological community living on and within the sediment is affected by cumulative exposure to both the surrounding sediment and the overlying water, reflecting the wider prevailing conditions.

Table 1. Summary of NEMP fine-scale benthic indicators, rationale for their use, and field sampling method

NEMP benthic indicators	General rationale	Sampling method
Physical and chemical		
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated	1 x surface scrape to 20mm sediment depth for each of 10 plots, retained for lab analysis
Nutrients (nitrogen and phosphorus) and organic matter (ash-free dry weight)	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment	1 x surface scrape to 20mm sediment depth for each of 10 plots, retained for lab analysis
Depth of apparent redox potential discontinuity layer (aRPD)	A subjective measure of the enrichment state of sediments according to the visual transition between oxygenated surface sediments and deeper deoxygenated black sediments	1 x 60mm diameter sediment core for each of 10 plots, split vertically, with depth of aRPD recorded where visible
Trace metals (copper, chromium, cadmium, lead , nickel, zinc)	Common toxic contaminants generally associated with human activities	1 x surface scrape to 20mm sediment depth for each of 10 plots, retained for lab analysis
Biological		
Infauna	The abundance, composition and diversity of macroinvertebrate infauna (i.e. animals living within the sediment matrix) are commonly-used indicators of estuarine health	1 x 130mm diameter sediment core for each of 10 plots, sieved to 0.5mm to retain macrofauna
Epifauna	The abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health	1 x 0.25 m^2 quadrat for each of 10 plots, with all animals observed on the sediment surface identified and counted
Macroalgae	The composition and prevalence of macroalgae are indicators of nutrient enrichment	1 x 0.25 m^2 quadrat for each of 10 plots, with % coverage estimated from 49 equally spaced grid intercepts
Chlorophyll-*a*, phaeopigments and benthic microalgae	Indicators of benthic microalgal extent, and response to nutrient enrichment	4 x composited 15 mm diameter sediment cores (top 5mm) per plot, retained in 50 ml centrifuge tube for lab analysis

3. SUMMARY OF ESTUARY MONITORING IN MARLBOROUGH

3.1 MARLBOROUGH ESTUARIES SURVEYED UNDER THE NEMP PROGRAMME

Havelock Estuary was one of the original national study sites surveyed in 2001 as part of the development of the NEMP. Prior to the NEMP, detailed estuary surveys in Marlborough have also been conducted e.g. Davidson and Brown 2000, Knox et al. 1999, Knox 1983, 1990. Since initiating regular monitoring using the NEMP in 2011, broad-scale surveys and associated reports have been produced for 13 estuaries, tidal flats or lagoon systems in Marlborough (Table 2, Fig. 4). Repeat broad-scale surveys have been undertaken at three of these (Havelock, Okiwa and Ngakuta Bays). Fine-scale surveys have been undertaken in six of these systems, the most studied of which is Havelock Estuary, where four fine scale surveys have now been undertaken (one being the original 2001 survey, the most recent in 2019 for which a report is not yet available). The selection and prioritisation of these estuaries was determined by MDC based on recommendations in Tiernan (2012).

3.2 NEMP BROAD-SCALE MONITORING IN MARLBOROUGH

3.2.1 Overview

A summary of broad-scale indicators and methodologies used for surveys of Marlborough estuaries is provided in Table 3. This is a high-level synopsis of measures made, the response variables derived, and the basic data display approaches used. The purpose in our assessment is primarily to evaluate:

- the extent to which monitoring approaches are consistent with the NEMP and between different providers;
- whether the NEMP monitoring methods used are appropriate and adequate;
- what has been learned; and opportunities for refinement or improvement.

Table 2. Broad- and fine-scale surveys undertaken to date in Marlborough.

Estuary	Broad-scale	Fine-scale	Science Provider	Reference
Havelock	2001	2001	Cawthron	Robertson et al. (2002),
	2014		Wriggle	Stevens & Robertson (2014)
		2014	Wriggle	Robertson & Robertson (2014)
		2015	Wriggle	Stevens & Robertson (2015)
		2017	Wriggle	Stevens (2017)
	2019	2019	Robertson Environmental	In prep.
Greville Harbour	2018		Salt Ecology	Stevens (2018b)
Kaiuma Bay	2017		Wriggle	Stevens and Robertson (2018)
Kenepuru Estuary	2018		SLR	SLR (2018)
Mahakipawa Arm	2017	2017	SLR	Skilton & Thompson (2017)
Ngakuta Bay	2011		Cawthron	Gillespie et al. (2012)
	2018		Wriggle	Stevens (2018a)
Okiwa Bay	2011		Cawthron	Gillespie et al. (2012),
	2018		Wriggle	Stevens (2018a)
Shakespeare Bay	2016	2016	Cawthron	Berthelsen et al. (2016)
Tuna, Harvey & Duncan Bays	2018		Wriggle	Stevens (2018c)
Waikawa Bay	2016		Wriggle	Stevens and Robertson (2016)
		2016	Wriggle	Robertson & Stevens (2016)
Wairau Estuary	2015	2015	Cawthron	Berthelsen et al. (2015)
Whangarae Bay	2016		Wriggle	Stevens and Robertson (2016)
		2016	Wriggle	Robertson & Stevens (2016)
Whatamango Bay	2018		Cawthron	Berthelsen et al. (2018)

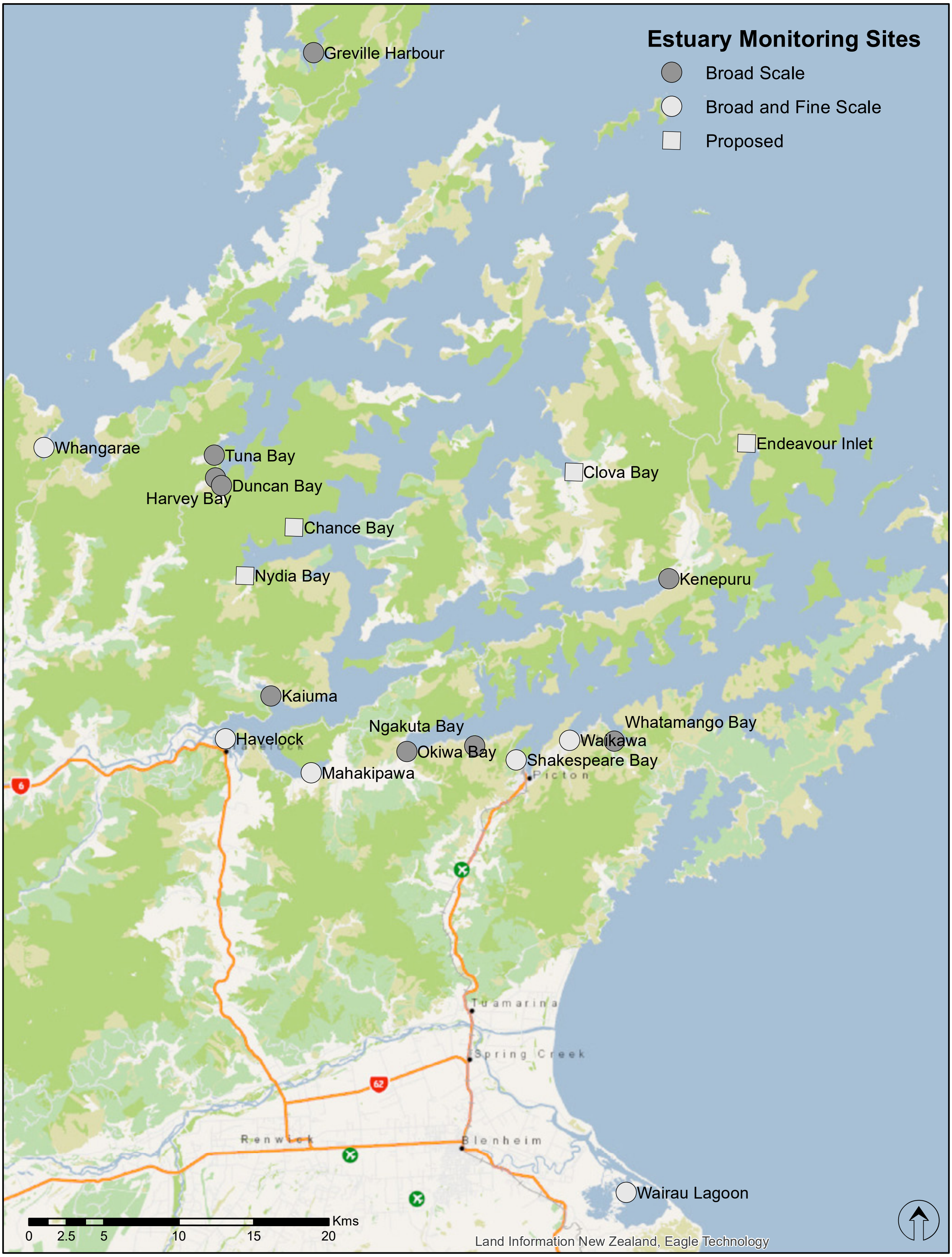

Fig. 4. Location of broad- and fine-scale surveys undertaken to date, and sites proposed for monitoring in Marlborough by MDC.

Table 3. Summary of broad-scale indicators and methodologies used in surveys of Marlborough estuaries.

Estuary	Year	Substrate	Seagrass	Macroalgae	Sediment Oxygenation	Eutrophic Conditions	Saltmarsh	Terrestrial Margin	Catchment Landcover	Analyses and indices
Havelock	2001	Intertidal flats (excluding saltmarsh, seagrass and macroalgae)	Presence when a dominant feature (e.g. >50%)	Presence when a dominant feature (e.g. >50%)	Not assessed	Not assessed	Structural class and dominant species types	No	No	Broad summary data
Havelock	2014	Intertidal flats (excluding saltmarsh)	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Not assessed	Assessed	Structural class and dominant species types	200m boundary	No	Broad summary data. Macroalgal OMBT. Change from 2001 baseline. Comparison with risk ratings
Greville Harbour	2018	Intertidal flats (excluding saltmarsh). Grain size validation of substrate classes. Sediment plates	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types. % remaining from natural extent	200m boundary	No. Modelled nutrient and sediment loads calculated	Broad summary data. Macroalgal OMBT. NZ ETI. Comparison with indicator ratings
Kaiuma Bay	2017	Intertidal flats (including saltmarsh).Grain size validation of substrate classes	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types	200m boundary	Yes	Broad summary data. Macroalgal OMBT. NZ ETI. Comparison with risk ratings. National comparison of mud
Kenepuru Estuary	2018	Intertidal flats (including saltmarsh)	Percent cover bands (30-50, 80-100)	Presence when a dominant feature (e.g. >50%)	Assessed	Assessed	Structural class and dominant species types	200m boundary	No	Broad summary data. Macroalgal OMBT. NZ ETI. Comparison with risk ratings
Mahakipawa Arm	2017	Intertidal flats (including saltmarsh).	Presence when a dominant feature (e.g. >50%)	Presence when a dominant feature (e.g. >50%)	Assessed	Assessed	Structural class and dominant species types	200m boundary	No	Broad summary data. Macroalgal OMBT. NZ ETI. Comparison with risk ratings

Table 3 (continued). Summary of broad-scale indicators and methodologies used in surveys of Marlborough estuaries.

Estuary	Year	Substrate	Seagrass	Macroalgae	Sediment Oxygenation	Eutrophic Conditions	Saltmarsh	Terrestrial Margin	Catchment Landcover	Analyses and indices
Ngakuta Bay	2011	Intertidal flats (excluding saltmarsh, seagrass and macroalgae)	Presence when a dominant feature (e.g. >50%)	Presence when a dominant feature (e.g. >50%)	Not assessed	Not assessed	Structural class and dominant species types	"Supralittoral fringe" mapped (10m wide)	Yes	Broad summary data. Regional comparison of saltmarsh seagrass, mud
Ngakuta Bay	2018	Intertidal flats (excluding saltmarsh). Grain size validation of substrate classes.	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types	200m boundary	Yes	Broad summary data. Macroalgal OMBT. NZ ETI. Change from 2011 baseline. Comparison with risk ratings. Regional comparison of saltmarsh seagrass, macroalgae, mud
Okiwa Bay	2011	Intertidal flats (excluding saltmarsh, seagrass and macroalgae)	Presence when a dominant feature (e.g. >50%)	Presence when a dominant feature (e.g. >50%)	Not assessed	Not assessed	Structural class and dominant species types	"Supralittoral fringe" mapped (10m wide)	Yes	Broad summary data. Regional comparison of saltmarsh seagrass, mud
Okiwa Bay	2018	Intertidal flats (excluding saltmarsh). Grain size validation of substrate classes.	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types	200m boundary	Yes	Broad summary data. Macroalgal OMBT. NZ ETI. Change from 2011 baseline. Comparison with risk ratings. Regional comparison of saltmarsh seagrass, macroalgae, mud
Shakespeare Bay	2016	Intertidal flats (excluding saltmarsh).	Percent cover bands (<20, 20-50, >50)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types	"Supralittoral fringe" mapped	Yes	Broad summary data. Regional comparison of saltmarsh seagrass, macroalgae, mud

Table 3 (continued). Summary of broad-scale indicators and methodologies used in surveys of Marlborough estuaries.

Estuary	Year	Substrate	Seagrass	Macroalgae	Sediment Oxygenation	Eutrophic Conditions	Saltmarsh	Terrestrial Margin	Catchment Landcover	Analyses and indices
Tuna, Harvey & Duncan Bays	2018	Intertidal flats (excluding saltmarsh). Grain size validation of substrate classes.	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types	200m boundary	Yes	Broad summary data. Macroalgal OMBT. NZ ETI. Comparison with risk ratings. National comparison of mud, seagrass, saltmarsh
Waikawa Bay	2016	Intertidal flats (excluding saltmarsh). Grain size validation of substrate classes)	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types	200m boundary	No	Broad summary data. Comparison with risk ratings
Wairau Estuary & Lagoon	2015	Intertidal flats (excluding saltmarsh). Grain size validation of substrate classes)	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	Presence when a dominant feature (e.g. >50%)	Not assessed	Assessed	Structural class and dominant species types. % remaining from natural extent.	"Supralittoral fringe" mapped	No	Broad summary data
Whangarae Bay	2016	Intertidal flats (excluding saltmarsh). Grain size validation of substrate classes	Percent cover bands (1-5, 5-10, 10-20, 20-50, 50-80, >80)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types. % remaining from natural extent.	200m boundary	No	Broad summary data. Macroalgal OMBT. NZ ETI. Comparison with indicator ratings
Whatamango Bay	2018	Intertidal flats (excluding saltmarsh).	Percent cover bands (<20, 20-50, >50)	OMBT EQR, % cover, biomass, degree of entrainment, affected area, dominant species	Assessed	Assessed	Structural class and dominant species types	200m boundary	Yes	Broad summary data. Macroalgal OMBT. Regional comparison of saltmarsh seagrass, macroalgae, mud

3.2.2 Comparison and evaluation of broad-scale methods and reporting

Broad-scale estuary monitoring in Marlborough has largely followed the NEMP, although departures from the protocol, and variability among studies, is evident. Although it was beyond the present scope to explore these issues in detail, Table 4 reveals that there are methodological inconsistencies or issues with many of the NEMP indicators. However, the most significant ones to address going forward, are the following:

Substrate classes: The NEMP provides a list of substrate classes that allow for the broad classification of dominant substrate types. The definition of each class is not always clear and involves subjective assessment in the field. Some measures (e.g. mobile sand, firm sand, firm mud/sand) are variably used by different providers to describe ostensibly the same substrate. Substrate classes should ideally be standardised across estuaries to enable consistent recording and comparison. For example, separating empirical and subjective classes; e.g. grain size and softness; is recommended, as is applying internationally consistent terminology e.g. FGDC (2012): "mud substrate" = no trace of Gravel and is composed of 90% or more Mud (particles less than 0.0625 mm in diameter); the remainder (<10%) is composed of Sand (particles 0.0625 mm to <2 mm in diameter.

Substrate within vegetation: The NEMP does not record substrate beneath vegetation (saltmarsh, seagrass or macroalgae). However, this is a key indicator of habitat quality (e.g. high mud contents can compromise seagrass health), as well as an early indicator of changes (increasing sediment muddiness can precede the loss of certain species). It is recommended that substrate underlying vegetation be recorded.

Macroalgal cover: Macroalgae are only recorded by the NEMP where they are a dominant feature, with little additional information provided other than species composition or percent cover. In recognising that macroalgae are a better indicator than benthic microalgae of eutrophication in shallow intertidally dominated estuaries, far more comprehensive measurements are now regularly taken based primarily on the UK WDF (2014) Opportunistic Macroalgal Blooming Tool (OMBT), which incorporates measures of percentage cover, entrainment (growth within sediment), biomass, and affected area within available habitat. This tool represents one of the most significant advances to the methods described in the NEMP and underpins the New Zealand Estuarine Trophic Index (ETI). It is recommended that macroalgae be assessed using this method.

ETI metrics: If MDC propose to use the ETI, then it will require the measurement of specific metrics to support it. Many of the fine scale indicators used in the ETI require measurements to be taken from deposition zones reflecting the "worst" 10% of the estuary. These are almost always in different locations to those included in NEMP fine scale monitoring programmes undertaken to date. Broad scale indicators include the extent of eutrophic (enriched) areas, as well as the extent of substrate with poor sediment oxygenation. For the latter there is a need to define appropriate methods for assessment (visual aRPD is recommended over ORP mV measures; see Section 3.3.2). Sampling effort (spatial coverage, replication) should reflect the level of confidence required for the results. It is noted that monitoring effort will be vastly different depending on the outcomes required – for example, much more effort will likely be needed for catchment management and/or compliance or threshold/limit setting purposes than for general ecological condition assessment purposes.

Aerial photos: Many of the past assessments have noted that broad scale mapping accuracy has been compromised by the absence of recent high quality aerial photography. Ensuring that mapping activities are supported by the provision of recently flown georeferenced aerial photography will ensure higher resolution and more accurate outputs.

3.2.3 What have the broad-scale surveys revealed?

The broad scale assessments undertaken have provided a robust baseline of estuaries in the Marlborough region but lack a consistent and defensible way to record, present and interpret monitoring data in order to rate and/or rank estuaries in terms of their ecological health. This makes it difficult to readily compare outputs from different estuaries and surveys, and to analyse key estuary features. Condition has been assessed subjectively by some providers (e.g. judgements of condition such as 'good', 'moderate' or 'bad' i.e. Berthleson et al. 2015, Berthleson et al. 2016, Stevens and Robertson 2017), while other providers have used more systematic means of categorising estuary condition using interim "risk rating" or "condition rating" categories defined for selected indica-

Table 4. Comparison of estuary monitoring methods and issues that need further consideration.

INDICATOR	METHODOLOGICAL DIFFERENCES AND ISSUES FOR FURTHER CONSIDERATION
Substrate classes	The NEMP provides a list of substrate classes that allow for the broad classification of dominant substrate types. As the definition of each class is not always clear and requires subjective assessment in the field, some measures (e.g. mobile sand, firm sand, firm mud/sand) are variably used by different providers to describe ostensibly the same substrate. Some providers also record only dominant substrate classes, whereas others detail both dominant and sub-dominant features. Additional classes have been included by some providers to give better resolution of substrate type (e.g. firm mud, sandy mud, muddy sand), with narrative descriptions describing the look and texture of sediment, as well as ranges for percent mud content reflecting thresholds of known biological change. Some NEMP classes mix subjective measures such as extent of sinking (e.g. 2-5cm = soft mud, >5cm = very soft mud) which can lead to inconsistency in recorder classifications due to variable interpretations of sinking extent (which vary depending on body weight, foot size, walking technique), as well as physical influences such as interstitial water and drying (sun-baked mud is firm to walk on), or the presence of secondary habitat features such as gravel or cobble which can prevent sinking in muds. Grain size measures from representative soft sediments have sometimes been collected to support the substrate classifications ascribed. The relationship between extent of sinking and particle grain size has been inconsistent at best, generally lacks supporting data, and where supporting data exist, there has been little or no analysis of it. Other classes have been included, such as features of the overlying sediment (e.g. driftwood, pine debris). Method refinements as described above have been developed outside of formally agreed protocols and thus require consensus for consistent use. Consequently, placing sediments into these classes remains subjective and is likely to result in relatively high inter-provider variation.
Substrate within vegetation	The NEMP does not record substrate beneath vegetation (saltmarsh, seagrass or macroalgae). However this is a key indicator of habitat quality (e.g. high mud contents can compromise seagrass health), as well as an early indicator of changes (increasing sediment muddiness can precede the loss of certain species). It is particularly important when assessing macroalgal growths as persistent nuisance conditions commonly only develop after sediments become mud-dominated. Consequently it seems an oversight that this feature is not included in the NEMP and is not consistently recorded. Due to variability in this feature being recorded, care is needed when interpreting metrics provided by different providers (e.g. soft mud % of estuary area) as the metrics will vary depending on whether they refer to total estuary area or unvegetated substrate only.
Macroalgal cover	At the time of its development the NEMP proposed the use of benthic microalgae as the primary indicator of eutrophic (highly enriched) conditions. Macroalgae are only recorded using the NEMP where they are a dominant feature, with little additional information provided other than species composition or percent cover. In recognising that macroalgae are a better indicator than benthic microalgae of eutrophication in shallow intertidally dominated estuaries, far more comprehensive measurements are now regularly undertaken based primarily on the UK WDF (2014) Opportunistic Macroalgal Blooming Tool (OMBT), which incorporates measures of percentage cover, entrainment, biomass and affected area within available habitat. This represents one of the most significant advances to the methods described in the NEMP and underpins the New Zealand Estuarine Trophic Index (ETI). However, the assessment and enumeration of macroalgae remains highly variable between providers.
Seagrass cover	The NEMP does not record substrate beneath seagrass, and does not record seagrass density or biomass. Density, biomass and substrate are all very important measures when assessing the broad scale condition, and change over time, in seagrass. These aspects are variably measured by providers with no standard density classes applied, or only recorded where seagrass is a dominant feature.

Table 4 (continued). Comparison of estuary monitoring methods and issues that need further consideration.

INDICATOR	METHODOLOGICAL DIFFERENCES AND ISSUES FOR FURTHER CONSIDERATION
Mapping extent	It is clear that there is variation in the mapped extent of estuaries. For example, saltmarsh measures from different providers indicate there is a variable recording of supratidal vegetation, terrestrial plants and saltmarsh species. This inconsistency makes it difficult to assess of change within estuaries over time, between estuaries, and between providers. There is also obvious variance around the inclusion of coastal duneland and variation in the mapped estuary boundaries; e.g. measured salinity thresholds vs upstream extent of tidal influence, seaward boundaries to enclosing headlands, intertidal margins, or arbitrary cut-offs. It is recommended that set boundaries be applied to define estuary extent and to enable consistent comparison of data.
Sediment oxygenation	This component is addressed as part of the fine scale monitoring but has relevance as it is also used as a key broad scale spatial measure in the ETI. The NEMP advocated visual assessment of the apparent Redox Potential Discontinuity (aRPD) zone in the sediment profile (see Table 8), which is a time-integrated measure of sediment condition. Quantitative measurements of oxidation-reduction potential (ORP) have been undertaken in some studies, and included in the ETI as a method under development. The utility of ORP as used in the NEMP context is yet to be demonstrated, and its relationship with aRPD is unclear (but would be of value to better understand).
Terrestrial margin	Mapping the land cover surrounding estuaries is sometimes included to indicate the localised extent of terrestrial margin vegetation. This is not described in the NEMP and is variable in the way it is undertaken.
Catchment land cover	Catchment based management is a key component of Council policy and planning initiatives. Reporting land cover is useful when developing predictive tools to indicate the likely state an estuary is in, and how it may alter following land use changes. It is closely linked to catchment load estimates of key stressors like sediments or nutrients, which are often key targets of management actions. At present there is no prescribed methodology standardising the inclusion of such information.
Assessment metrics	There is a wide variation in the type of assessment metrics used, and the analysis of broad scale mapping outputs. Many of the NEMP based outputs simply provide summary data (e.g. saltmarsh, seagrass, soft mud %). Some providers include subjective ratings of "condition" or "risk" to aid in the assessment of results, with other formal metrics recently developed or applied in New Zealand variably reported e.g. NZ ETI (Robertson et al. 2016a,b), OMBT (UK-WDF 2014). Definition of a minimum set of agreed metrics should be provided. Ideally GIS outputs should use a standard set of styles and terms for consistency of mapping.
Values at risk	The NEMP broad scale mapping approach misses several key estuary components and potentially at-risk features at the current scale/scope of mapping. These include rare species, invasive species, subtidal habitats, cultural and human use components, as well as quantification measures such as habitat intactness, restoration potential, extent of change, susceptibility, and resilience. It is beyond the scope of the current work to address these components, but such aspects should be considered when evaluating Council information needs.
Assessment scale	MDC has a variety of estuary types. The Marlborough Sounds comprise relatively large, subtidally-dominated estuaries with long residence times which are sensitive to subtidal sedimentation, nutrient enrichment, and water quality fluctuations. Within the larger estuaries there are many smaller intertidally dominated areas where direct pressures may come from margin development, reclamation, invasive species (e.g. Pacific oysters, Spartina) or displacement of high value habitat (e.g. seagrass or saltmarsh). Ensuring monitoring programmes collect intertidal and subtidal information in a coordinated and complementary way is necessary to manage at appropriate scales within different estuary types.

tors (Berthleson et al. 2018, SLR 2018, Stevens 2018, Stevens 2018b). While the latter approach has merit and intuitive appeal, there is considerable scope to improve the overall framework and condition scoring categories (see Section 4.2).

Where metrics have been standardised, summary information can be used to compare different estuaries, and changes within estuaries over time; e.g. Fig. 5 and Table 5 (Stevens 2018a). This summary indicates that overall many of the estuaries in the region have significant remaining areas of seagrass and saltmarsh. Fine muds are a significant issue in many of the larger estuaries, and seagrass is less frequent in estuaries with a large mud extent. Growths of intertidal macroalgae are generally sparse and do not appear to be resulting in degraded conditions, suggesting that nutrient inputs are not causing widespread intertidal impacts in Marlborough. The ability to compare and utilise data from different estuaries could be vastly improved by establishing an integrated data set using standardised terms, coverages and reporting metrics.

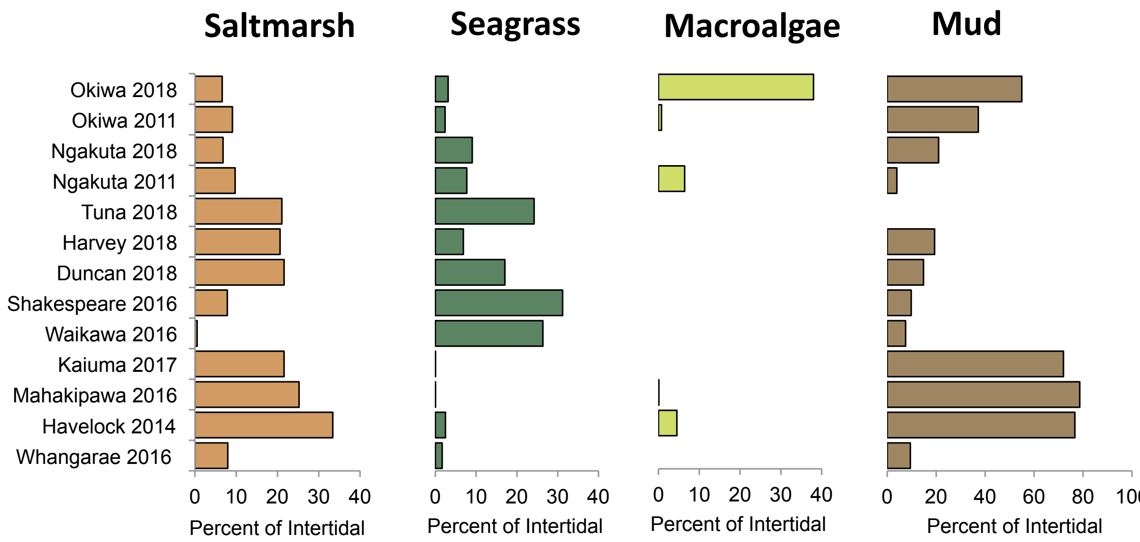

Fig. 5. Example of some key features (% of intertidal area) of estuaries in Marlborough (source: Stevens 2018a).

Table 5. Percent of intertidal area of saltmarsh, seagrass, macroalgae and mud in selected Marlborough estuaries (source: Stevens 2018a).

Dominant Intertidal Estuary Feature (%)	Ngakuta[1]	Ngakuta[9]	Okiwa[1]	Okiwa[9]	Whangarae[2]	Havelock[3]	Mahakipawa[4]	Kaiuma[5]	Waikawa[6]	Shakespeare[7]	Duncan[8]	Harvey[8]	Tuna[8]
	2011	2018	2011	2018	2016	2014	2016	2017	2016	2016	2018	2018	2018
Saltmarsh	9.6	7.4	8.5	6.2	8.0	33.4	25.2	21.6	0.5	7.9	21.6	20.6	21.1
Seagrass (›20% cover)	7.6	8.8	2.3	3.0	1.7	2.5	0.0	0.0	26.4	31.2	17.0	6.9	24.2
Macroalgal beds (›50% cover)	6.4	0.0	0.7	38.4	0.0	4.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mud (e.g. mud content ›25%)	3.9	21.0	37.2	55.0	9.5	76.7	78.7	72.0	7.5	9.8	14.8	19.4	0.0

1. Gillespie et al. (2012), 2. Stevens and Robertson (2016), 3. Stevens and Robertson (2014), 4. Skilton and Thompson (2017), 5. Stevens and Robertson (2017), 6. Stevens and Robertson (2016a), 7. Berthelsen et al. (2016), 8. Stevens (2018c), 9. Stevens (2018a).

3.2.4 Recommendations from broad-scale reports

The monitoring and management recommendations that have emerged from the broad-scale work are summarised for each estuary in Table 6, with Table 2 citing the source report for each estuary. General methodological recommendations include:

- Use up-to-date aerial photos for mapping.
- Standardise broad scale reporting methodologies.
- Track and map catchment land use change.
- Use citizen science to provide additional supporting information on estuary changes over time.

More specific recommendations include:

- Use of specific sites as long-term reference sites (Shakespeare Bay, Harvey Bay).
- Sediment load model and historical coring where fine sediment has been identified as a particular issue (Havelock 2014).
- Drone monitoring of target habitats (Wairau lagoon/estuary).
- Targeted monitoring of potential future stressors (Tuna Bay, Whatamango Bay).
- Assessment of historic aerial photographs and deep sediment cores to understand longer-term changes in estuaries (Wairau, Havelock).
- Installation of sediment plates (Whangarae, Tuna Bay, Harvey Bay).
- Inclusion of subtidal mapping and reference sites (Wairau).
- Targeted assessment of potential problem macroalgae (Wairau).
- Include an iwi monitoring programme (Shakespeare Bay, Wairau).
- The investigation of seagrass wasting disease (Shakespeare Bay, Okiwa, Ngakuta).

Management recommendations primarily focus on high level generic issues such as:

- Ensure strict sediment controls for any relevant activities within the catchment and estuary (Cawthron).
- Determine relative sediment inputs from dominant catchment land uses, identify "target" estuary conditions with stakeholders, and define sediment input load criteria required to meet specified targets (Wriggle).
- Apply a holistic approach to consider habitats, communities and processes over a wide range of spatial and temporal scales and that incorporates research carried out over all levels of ecological organisation (SLR).
- Manage anthropogenic fine sediment and nutrients (SLR).
- Plant margin and catchment with native vegetation (Cawthron)
- Undertake a CVA (Coastal Vulnerability Assessment) to identify monitoring and management priorities throughout Marlborough; (this need and potential approaches are discussed in Section 4.2 of the present report).

At face value, all of the above recommendations make sense and are probably quite useful, and in fact are likely to be relevant to most of the estuaries surveyed (i.e. not just the estuaries referred to). However, what priority they should be afforded (relative to each other) cannot be determined without a more systematic evaluation of monitoring findings to date, to better understand what present monitoring is telling us and whether the general approach and monitoring methods are fit-for-purpose.

Table 6. Summary of issues and recommendations identified from broad-scale NEMP surveys of Marlborough estuaries.

Estuary	Year	Issues identified	Overall condition status*	Monitoring Frequency	Monitoring Recommendations	Management-related recommendations
Havelock	2001	Not reported	Not reported	5 yearly	None	No management recommendations
Havelock	2014	Increasing mud since 2001. Little nuisance macroalgae. Saltmarsh loss (Spartina eradication)	Variable	Repeat 5 yearly for sediment, 10 yearly for saltmarsh and terrestrial margin habitat (next scheduled for consideration in 2019 and 2024 respectively)	Install additional sediment plates to assess fine sediment deposition. Track and map catchment land use change (5 yearly)	Sediment source monitoring
Greville Harbour	2018	Fine sediment (Smylies and Mill arms). Relatively unmodified sites, low eutrophication.	Good	None recommended	None recommended. Sediment plates established in Smylies Arm.	No management recommendations
Kaiuma Bay	2017	Extensive fine sediment. Mud area increased since 2006, little seagrass, low eutrophication	Moderate	Repeat 5-10 yearly (next scheduled for consideration in 2022)	Monitor sediment plates annually	Determine relative sediment input from dominant catchment land uses. Identify “target” estuary condition Define sediment input load criteria
Kenepuru Estuary	2018	Extensive mud habitat, widespread Pacific oysters. Potential localised nutrient source from stream draining residential area, little seagrass, low eutrophication	Unclear	Repeat 5-yearly (next scheduled for consideration in 2023)	Establish fine scale site at same time broad scale sampling is repeated.	MDC consider classifying this estuary as an ecologically significant marine site within the Marlborough Sounds. Apply a holistic approach to consider habitats, communities and processes over a wide range of spatial and temporal scales and that incorporates research carried out over all levels of ecological organization.
Mahakipawa Arm	2017	Extensive mud habitat, little seagrass, low eutrophication	Unclear	Repeat 5-yearly (next scheduled for consideration in 2022)	Consider more frequent monitoring of specific indicators to track spatial and temporal changes	Decrease fine sediment and encourage seagrass growth. Apply a holistic approach to consider habitats, communities and processes over a wide range of spatial and temporal scales and that incorporates research carried out over all levels of ecological organization.
Ngakuta Bay	2011	Seagrass fungal wasting disease, coastal armouring	Unclear	Repeat 5-yearly	Consider complimentary fine scale assessment at same time as broad scale sampling.	Coordinate with community or iwi monitoring initiatives. Further investigation of seagrass wasting disease.
Ngakuta Bay	2018	Sand and gravel dominated, extensive seagrass, healthy saltmarsh, low eutrophication, extensive coastal armouring	“Good”	Repeat 10 yearly (next scheduled for consideration in 2028)		No management recommendations
Okiwa Bay	2011	Seagrass fungal wasting disease, coastal armouring	Unclear	Repeat 5-yearly	Consider complimentary fine scale assessment at same time as broad scale sampling.	Coordinate with community or iwi monitoring initiatives. Further investigation of seagrass wasting disease

Table 6 (Continued). Summary of issues and recommendations identified from broad-scale NEMP surveys of Marlborough estuaries.

Estuary	Year	Issues identified	Overall condition status*	Monitoring Frequency	Monitoring Recommendations	Management-related recommendations
Okiwa Bay	2018	Historical saltmarsh loss. Extensive macroalgal beds, relatively high mud content (40%) in firm mud/sand habitat	"Moderate"	Repeat 5 yearly (next scheduled for consideration in 2023)	Seek local knowledge of macroalgal growth from 2011 to 2018. Incorporate citizen science to maintain watching brief.	No management recommendations
Shakespeare Bay	2016	Low muddiness and eutrophication, extensive seagrass, healthy saltmarsh. Exotic plants and man-made structures in supralittoral zone.	"Good"	Repeat 5-yearly (next scheduled for consideration in 2021)	Further targeted monitoring of ecological indicators e.g. seagrass	Use as regional reference site. Manage anthropogenic fine sediment and nutrients. Consider incorporation of an iwi monitoring programme.
Tuna, Harvey & Duncan Bays	2018	Relatively unmodified estuaries. Low eutrophication, extensive seagrass, healthy saltmarsh. Potential for localised forest harvesting impacts in Tuna Bay.	"Good"	Repeat 10 yearly (next scheduled for consideration in 2028)	Initiate sediment grain size and accrual measurements to assess potential forest harvesting impacts in Tuna Bay.	Because of high catchment native forest extent and low degree of modification, consider Harvey Bay for use as a long term fine scale reference site for monitoring.
Waikawa Bay	2016	Extensive seagrass, low eutrophication. Extensive historical modification	"Moderate"	Repeat 5-10 yearly (next scheduled for consideration in 2021)		Identify "target" estuary condition with stakeholders. Encourage saltmarsh restoration
Wairau Estuary & Lagoon	2015	Limited connectivity of intertidal vegetation and main estuary habitat. Absence of eelgrass beds. Abundance of exotic grassland in margin. Presence of nuisance macroalgae. Extensive interiidal mud habitat.	"Fair to compromised"	Repeat 5-yearly (next scheduled for consideration in 2020)		Literature review, iwi consultation and historic aerial to better understand historic intertidal, lagoon, habitat & margin changes etc. Use drones for target areas? Include water quality & shellfish quality monitoring. More work on salinity changes over tidal cycles. More work on cover of potential problem macroalgae. Subtidal mapping and reference sites (using DIDSON). Deep sediment cores to assess historic sedimentation rates. Include an iwi monitoring programme
Whangarae Bay	2016	Localised muddiness likely due to historical land clearance	"Good"	Repeat 10 yearly (next scheduled for consideration in 2026)	Complete fine scale baseline	Identify "target" estuary condition with stakeholders. Develop management strategies to achieve targets.
Whatamango Bay	2018	Low eutrophication, extensive seagrass, healthy saltmarsh, predominantly native forest margin.	"Good"	Repeat 10 yearly (next scheduled for consideration in 2028)	Standardise broad scale reporting methodologies. Initiate fine scale monitoring. Future broad scale mapping use up-to-date aerial photos. Carry out regular (5-yearly) high resolution seagrass mapping.	Ensure strict sediment controls for any relevant activities within the catchment and estuar.y Plant margin and catchment with native vegetation

*Overall condition status is the condition reported for each estuary. It is based on either the use of a defined systematic approach (such as risk or condition ratings), or expert judgement.

3.3 NEMP FINE-SCALE MONITORING IN MARLBOROUGH

3.3.1 Overview

A summary of fine-scale benthic indicators and methodologies used for surveys of Marlborough estuaries is provided in Table 7. As for the broad-scale, this is a high-level synopsis of measures made, the response variables derived, and the basic data display and analytical approaches used. The purpose in our assessment is primarily to evaluate:

- the extent to which monitoring approaches are consistent with the NEMP and consistent among different providers;
- whether the monitoring methods used are appropriate;
- what has been learned; and
- opportunities for refinement or improvement.

3.3.2 Comparison and evaluation of fine-scale methods and reporting

Table 7 suggests that estuary monitoring in Marlborough has broadly followed the NEMP, although departures from the protocol, and variability among studies is evident, as follows:

- Some fine scale studies have included vegetated (eelgrass) habitat sites where this is the primary soft sediment habitat present in the estuary (e.g. Waikawa), or is considered to be an important feature useful for monitoring (e.g. Shakespeare Bay).
- Some studies have added new sites over time where the sites initially chosen have been deemed unrepresentative of the dominant habitat (e.g. Havelock Estuary). This may reflect changes in the focus and purpose of the monitoring over time, but could possibly be circumvented with a more careful screening (e.g. by pilot survey) at the initial site selection stage.
- There is reasonably high variability in baseline sediment grain size across sites within and among estuaries, with classes ranging from predominantly sand to predominantly mud. Ideally baseline site selection would aim to standardise the major sediment class type if the primary aim of the monitoring was to compare site differences between and within estuaries.
- Tidal elevation is not reported in any of the studies. Although site selection criteria in the NEMP specify "mid to low" tidal elevation, it is unclear that this is always the case for MDC estuaries. A record of actual tidal elevation for each fine-scale site would be a valuable ancillary variable to include in analyses that make comparisons within or among estuaries, given that species composition is likely to relate to tolerance to tidal exposure.

The above and other habitat differences will need to be accounted for in any comparisons made within and among estuaries. Irrespective of the chosen monitoring habitats and sites, it is evident that NEMP methods have "evolved" since their initial inception in 2002. While this is very much in line with the "living document" philosophy espoused in the NEMP, there has been no formal change or update to the protocol. In Table 8 we briefly outline some of the methodology differences and departures from the NEMP. We also provide a brief appraisal of potential methodological issues that have arisen; although it was beyond present scope to explore these issues in detail. Table 8 reveals that there are issues relating to methodology with many of the NEMP indicators. However, the most significant ones to address going forward, as outlined in the Table, are the following:

Grain size analysis: The NEMP is based on sampling of surficial sediments (to 20mm depth). This makes sense in terms of understanding recent deposition and contaminant accumulation but does not necessarily reflect the habitat within which many infauna live, and may not be consistent over the depth routinely included in macrofauna sampling and enumeration (150mm). It would be possible to address this relatively simply by including a narrative description (either free-form or according to predefined criteria) of the general grain size and core composition from representative areas of fine scale sites.

AFDW vs TOC: The NEMP recommended organic content be assessed by measuring Ash Free Dry Weight (AFDW) with results then converted into an estimate of Total Organic Content (TOC). While AFDW was the most cost effective analysis available at the time, the direct measurement of TOC has subsequently become a routine, reliable and cheap lab. method and should be used in preference to AFDW.

Redox assessment: The utility of instantaneous oxidation-reduction potential (ORP) measurements, and their relationship with time-integrat-

Table 7. Summary of fine-scale benthic indicators and methodologies used in surveys of Marlborough estuaries.

Estuary	Year	Site type(s)	Salinity	aRPD	ORP	Sediments	Epibiota	Macrofauna	Analyses and indices
Havelock	2001	2 x mid-low tide unvegetated	Overlying water at low tide	Core	-	Surface 20mm	NEMP	Cores 130 diam, 150mm deep, sieved to 0.5mm	Macrofauna S, N, main taxa; Epibiota #, % Grain size, aRPD, nutrients, AFDW/TOC, metals Stats: MDS, cluster analysis, PCA, BIO-ENV for spec-env relationships
Havelock	2014	2 x mid-low tide unvegetated	Overlying water at low tide	100mm core	-	Composite surface 20mm	SACFOR, no microalgae sampling	Cores 130 diam, 150mm deep, sieved to 0.5mm	Macrofauna S, N, AMBI & WEBI No epibiota data presented Grain size, aRPD, nutrients, TOC, metals Stats: PCO & vector overlays Condition risk ratings
Havelock	2015	4 x mid-low tide unvegetated	Overlying water at low tide	100mm core	-	Composite surface 20mm	SACFOR, no microalgae sampling	Cores 130 diam, 150mm deep, sieved to 0.5mm	Data only for: Macrofauna S, N Epibiota SACFOR Grain size, aRPD, nutrients, TOC, metals
Havelock	2017	4 x mid-low tide unvegetated	Overlying water at low tide	100mm core	-	Composite surface 20mm	SACFOR, no microalgae sampling	Cores 130 diam, 150mm deep, sieved to 0.5mm	Data only for: Macrofauna S, N Epibiota SACFOR Grain size, aRPD, nutrients, TOC, metals
Mahakipawa Arm	2017	2 x mid-low tide unvegetated	Interstitial water sample	150mm core split	Meter, upper 30mm	Composite surface 20mm	NEMP, no microalgae sampling	Cores 130 diam, 150mm deep, sieved to 0.5mm	Macrofauna S, N, H, J, NZ-AMBI, main taxa, trophic groups Epibiota # (no macroalgae) Grain size, aRPD, nutrients, TOC, metals Stats: GLM (univariate diffs in phys-chem across sites), PERMANOVA (multivariate diffs across sites), MDS with SIMPER & vector overlay, BEST & DISTLM for spec-env relationships
Shakespeare Bay	2016	1 x firm mud/sand, 1 x seagrass	Interstitial water sample	150mm core	Meter	Composite surface 25mm	NEMP + seagrass cover classes & biomass	Cores 130 diam, 100mm deep, sieved to 0.5mm	Macrofauna S, N, H, J, NZ-AMBI Grain size, aRPD, nutrients, TOC, metals, SVOC screen Epibiota #, %, seagrass biomass Stats: MDS
Waikawa Bay	2016	1 x mid-low seagrass	Overlying water at low tide	100mm core	-	Composite surface 20mm	NEMP + SACFOR, no microalgae sampling	Cores 130 diam, 150mm deep, sieved to 0.5mm	Macrofauna S, N, H, J, NZ-AMBI Grain size, aRPD, nutrients, TOC, metals, SVOC screen Epibiota #, %, SACFOR; Condition risk ratings

ed visual assessment of the aRPD, is unclear. There are a range of potential methodological limitations with ORP assessment that need to be further evaluated, to better understand its usefulness as an indicator, especially given that measuring ORP greatly adds to field time/cost.

Infaunal taxonomy: Taxonomic accuracy and resolution differences within and among providers needs to be further explored, including an assessment of differences within each provider across different years (e.g. to gauge whether indeterminate taxa such as Amphipoda sp.1, sp.2, etc, are recorded consistently). At present, the only way to address the issue for data analysis purposes would be to aggregate macrofauna species to comparable general groups (Berthelsen et al. 2018a), with the concomitant loss of power to detect changes.

Epibiota: The utility of quantitative sampling of epibiota needs further evaluation. With respect to macrofauna and macroalgae, our view is that site-level ordinal ranking methods like SACFOR are sufficient to capture an overall "impression" of epibiota status (i.e. useful for the purpose of site characterisation and measurement of gross change). By contrast, high variability in epibiota abundance or percent cover (e.g. due to patchiness) is likely to undermine the utility of quantitative assessment methods for monitoring purposes.

A final consideration for MDC's NEMP surveys relates to the data analysis and reporting undertaken (see Table 7). While not necessarily problematic, it is evident that major differences in analysis and reporting approaches exist. Where full reporting is undertaken (some reports are interim 'data only'), there is a vast difference in the extent of data mining and analysis undertaken, ranging from basic data displays of simple response metrics, to comprehensive univariate and multivariate statistical analyses.

3.3.3 Sedimentation assessment

One of the more recent additions to the fine-scale work, which is not formally part of the NEMP, has been the installation of buried concrete plates along the boundary of fine-scale sites, or nearby. This addition is intended primarily to help interpret changes that may be observed at fine scale sites (i.e. recent sediment deposition or scouring). Change in sediment depth over the buried plates also provides information on pat-

Table 7 (Continued). Summary of fine-scale benthic indicators and methodologies used in surveys of Marlborough estuaries.

Estuary	Year	Site type(s)	Salinity	aRPD	ORP	Sediments	Epibiota	Macrofauna	Analyses and indices
Wairau Estuary & Lagoon	2015	3 x mid-low unvegetated	Interstitial water sample	150mm core split	-	Composite surface 25mm	NEMP, no microalgae sampling	Cores 130 diam, ≥100mm deep, sieved to 0.5mm	Macrofauna S, N, H, NZ-AMBI Grain size, aRPD, nutrients, TOC, metals, SVOC screen Epibiota #, % Stats: MDS
Whangarae Bay	2016	2 x mid-low tide unvegetated	Overlying water at low tide	100mm core	-	Composite surface 20mm	SACFOR, no microalgae sampling	Cores 130 diam, 150mm deep, sieved to 0.5mm	Macrofauna S, N, H, main taxa, NZ-AMBI; Grain size, aRPD, nutrients, TOC, metals, SVOC screen Epibiota SACFOR Condition risk ratings

Table 8. Comparison of estuary monitoring methods and issues that need further consideration.

INDICATOR	METHODOLOGICAL DIFFERENCES AND ISSUES FOR FURTHER CONSIDERATION
Physical/chemical	
Salinity	This variable has been measured by different methods; i.e. overlying ponded water (as per NEMP) and interstitial water, or not at all. Salinity measures may not be particularly useful or reliable irrespective of method; values will depend on tidal elevation, amount of flow from any adjacent freshwater inputs, and environmental conditions on the day of sampling (e.g. hot conditions and high evaporation vs rainfall).
Sediment grain size	The NEMP is based on sampling of surficial sediments (to 20mm depth). This makes sense in terms of understanding recent deposition and contaminant accumulation, but does not reflect the 'habitat' available to infauna (e.g. situations where event-driven muddy sediments have accumulated on top of otherwise coarse-textured sands and gravels.
AFDW/TOC	The NEMP recommended organic content be assessed by measuring Ash Free Dry Weight (AFDW) with results then converted into an estimate of Total Organic Content (TOC). The direct measurement of TOC has subsequently become a routine, reliable and cheap lab. method and should be used.
Redox conditions	Redox conditions: Quantitative measurements of oxidation-reduction potential (ORP) have been undertaken in some studies, but were not part of the original NEMP. The NEMP advocated visual assessment of the apparent Redox Potential Discontinuity (aRPD) zone in the sediment profile, which is a time-integrated measure of sediment condition. The utility of ORP as used in the NEMP context is yet to be demonstrated, and its relationship with aRPD is unknown (but would be of value to better understand). Further considerations for ORP measurement include the following: • ORP is likely to be subject to short-term variation (e.g. over a tidal cycle). For example, it is difficult to reliably measure ORP in free-draining sandy sediments, and results will depend on whether ORP is measured in situ or in extracted cores, and how long the probes are left to 'stabilise' (in reality ORP values typically 'drift'). • Absolute values of ORP may not reliably indicate redox conditions, relative to the actual RPD. Of greatest importance is the rapid transition (if evident) in ORP down a sediment profile (Forrest and Creese 2006). The ORP transition should correspond to the aRPD unless, although may be confounded where processes such as bioturbation disturb the sediment profile. • NEMP studies using ORP have measured across scales of c. 2-4 cm, hence are too coarse to reliably quantify the actual depth of the RPD. As such, ORP may not reliably detect spatial or temporal changes in trophic status except where major system events have occurred.
Biological	
Macro-fauna	Macroinvertebrate infauna are a key NEMP indicator. Sampling in most surveys has generally followed the NEMP, although some studies have taken shallower cores (e.g. 100mm) than the 150mm protocol depth, which may affect the density and composition of macrofauna recorded. Macrofaunal taxonomy issues are not assessed in this report, but taxonomic resolution is likely to differ among providers. Additionally, unidentified species in certain taxa that are designated as sp. A, B, etc, will not be consistent among providers. As such, any future analyses that compare survey results, would need to undertake an appropriate level of taxonomic aggregation to ensure consistency, or seek to resolve current uncertainty by standardising existing data. Establishing a formal QAQC procedure and maintaining a regional collection of reference species would facilitate improved consistency should MDC continue to use multiple providers for taxonomic services.
Epibiota	Epifaunal and macroalgal sampling has been based on the quantitative NEMP methods in some cases (i.e. quadrat or point-intercept counts), and ordinal ranking scales (SACFOR) in others. Quantitative approaches i.e. quadrat counts will be of little value (i.e. subject to considerable site-level variation) for epibiota with clumped/patchy distributions (e.g. the mudflat whelk Cominella glandiformis). Only two surveys have quantified microalgae using the small-scale sampling approach described in the NEMP. The NEMP is unclear regarding the extent to which microalgae can be used as an indicator of trophic state. Unlike macroalgae, the link between anthropogenic changes in estuaries and changes in microalgal assemblages do not appear to be well understood. This limits the utility of microalgae as a robust or useful indicator until sufficient research has been undertaken to demonstrate clear cause-effect linkages.

terns of sediment accretion and erosion over time; for example, in relation to catchment sediment inputs (incremental or event-related) and estuarine sedimentation patterns, although this type of sampling typically requires sites to be located throughout representative parts of each estuary. Sediment grain size measurements (based on composite sampling) typically accompany sediment plate assessment as grain size can alter in the absence of deposition due to infilling of interstitial spaces.

3.3.4 What have the fine-scale surveys revealed?

A summary of ecological issues identified from the MDC fine-scale survey work, along with recommendations from the reports produced, is provided in Table 9.

As for the broad-scale surveys, most of the fine-scale surveys have identified muddy sediment inputs as being the key stressor for MDC estuaries. For two estuaries, high contaminant levels were identified, which reflected either natural catchment inputs (Whangarae) or historic anthropogenic inputs (Waikawa). For Havelock Estuary, where fine-scale effort has been greatest, reports to date conclude that there has been an increase in mud habitat and 'muddiness' since the 2001 survey that was conducted as part of the NEMP development.

As noted above for the broad-scale assessment, a key missing element of the NEMP fine-scale reports is a consistent and defensible way to interpret the monitoring data in order to rate and/or rank estuaries in terms of their ecological health. Condition has been assessed subjectively by some providers (e.g. judgements of condition such as "good" or "bad" i.e. Berthleson et al. 2015, Berthleson et al. 2016, Stevens and Robertson 2017), while other providers have used more systematic means of categorising estuary condition using interim "risk rating" categories for selected indicators (Robertson and Robertson 2014, Skilton and Thompson 2017, SLR, 2018). While the latter approach has merit and intuitive appeal, there is considerable scope to improve the overall framework and condition scoring categories (see Section 4.2).

3.3.5 Recommendations from fine-scale reports

The management recommendations that have emerged from the fine-scale worked are summarised for each estuary in Table 9, with Table 2 citing the source report for each estuary. These include recommendations for research and investigation where degraded situations have been identified, in particular:

- Sediment load model and historical coring where fine sediment has been identified as a particular issue (Havelock 2014).
- Targeted assessment of potential problem macroalgae (Wairau).
- Improved and expanded methodological approaches such as drone monitoring of target habitats (Wairau lagoon/estuary).
- Targeted monitoring of potential future stressors.
- Assessment of historic aerial photographs and deep sediment cores to understand longer-term changes in estuaries (Wairau, Havelock).
- Expansion of monitoring scope to include water quality and shellfish quality monitoring (Wairau).
- Inclusion of subtidal mapping and reference sites (Wairau).
- Installation of sediment plates (Whangarae).
- Include an iwi monitoring programme (Shakespeare Bay, Wairau).

More generic recommendations include:

- Development of goals for ecological and other uses/values and for a target estuary condition.
- Undertake a CVA (Coastal Vulnerability Assessment) to identify monitoring and management priorities throughout Marlborough.

As noted for the broad-scale assessment, all of the above recommendations make sense and are probably quite useful, and in fact are likely to be relevant to most of the estuaries surveyed (i.e. not just the estuaries referred to). However, what priority they should be afforded (relative to each other) cannot be determined without a more systematic evaluation of monitoring findings to date, to better understand what present monitoring is telling us and whether the general approach and monitoring methods are fit-for-purpose. As these questions were also raised in our assessment of broad-scale monitoring conducted under NEMP, they are considered in subsequent sections for the NEMP as a whole.

Table 9. Summary of issues and recommendations identified from fine-scale NEMP surveys of Marlborough estuaries.

Estuary	Year	Report type	Issues identified	Overall condition	Monitoring recommendations			Management-related recommendations
					FS Frequency	Sediment plates	Sites	
Havelock	2001	Full	Not reported	Not reported	Repeat 5-yearly	-	Not recommended	No management recommendations
Havelock	2014	Full	Increased fine sediment	Variable. Increasing mud since 2001	Repeat for 3 years, with 2 years data only	Annual	Establish 2 extra FS and sediment plate sites	CVA to identify monitoring & management priorities throughout Marlborough Sediment load model Sediment deep coring
Havelock	2015	Data only	Increased fine sediment		Repeat in 2017 with multi-year data analysis in 2019	Annual	No changes recommended	No management recommendations
Havelock	2017	Data only	Increased fine sediment		Repeat in 2019, with a multi-year data analysis	Annual	Establish 2 extra sediment plate sites	No management recommendations
Mahakipawa Arm	2017	Full	High fine sediment	Unclear	Repeat 5-yearly, but more frequent with target indicators if funds allow	Not assessed	No changes recommended	Develop goals for ecological and other uses/values
Shakespeare Bay	2016	Full	Perhaps minor effect of nutrients and sediments	"Good health"	Repeat 5-yearly	Not assessed	No changes recommended	Develop goals for ecological and other uses/values Manage future stressors, with targeted monitoring Include an iwi monitoring programme Location a useful reference
Waikawa Bay	2016	Limited analysis	Legacy contaminants >ISQG-L	Unclear	Repeat 5-yearly	Not assessed	No changes recommended	More comprehensive analysis after baseline established. Develop goals for target estuary condition
Wairau Estuary & Lagoon	2015	Full	Macroalgae?	"Fair to compromised"	Repeat 5-yearly EMP, but annual summer monitoring of macroalgae	Not assessed & not recommended	Establish 1 extra site more like typical EMP site (sandier)	Literature review, iwi consultation and historic aerial to better understand historic intertidal, lagoon, habitat & margin changes etc Use drones for target areas? Include water & shellfish quality monitoring More work on salinity changes over tidal cycles More work on cover of potential problem macroalgae Subtidal mapping and reference sites (DIDSON) Deep sediment cores to assess historic rates Include an iwi monitoring programme
Whangarae Bay	2016	Full	Natural contams, mud from historic land clearance	Unclear	Repeat EMP to get a 3-yr baseline, thereafter every 5-10 years	Annual	No changes recommended	Confirm that muddiness not increasing (i.e. sediment plates). More comprehensive analysis after baseline established

3.4 SYNTHESIS AND INTEGRATION OF BROAD- AND FINE-SCALE APPROACHES

The two key questions relating to both broad- and fine-scale survey approaches and their interaction, which we briefly address below, are as follows:

- What do the monitoring results tell us?
- Are the approaches "fit for purpose"?

3.4.1 What do the monitoring results tell us?

The most immediate question is, what do the results collectively tell us and is the monitoring actually useful? To date, there appears to have been a strong focus on information gathering without a clear purpose beyond a general goal to assess and monitor the state of ecologically significant marine sites with the help of a coordinated multi-agency approach (Tiernan 2012). Furthermore, there has been no comprehensive distillation and synthesis of the findings, except for subjective expert judgements regarding changes within estuaries, and inferences about their causes. In terms of understanding monitoring and management priorities, it would be timely to undertake a comprehensive data synthesis and analysis to quantitatively evaluate some of the key changes that have occurred in both broad- and fine-scale indicators, building on preliminary summaries such as described in Fig. 5 and Table 5 above. The types of questions that could be investigated in detail include:

- Where does seagrass occur, how extensive is it, and in what condition? Has any been lost since monitoring began?
- How is the percentage and area of soft mud changing, if at all? Are the sediment plates located in appropriate locations, are there sufficient to provide reliable measurements, and what are they telling us?
- Where important spatial or temporal changes exist, can they be related to potential explanatory drivers (e.g. catchment activities and differences in mass loads of sediments, nutrients, etc).
- Can sampling design and sampling be optimised? For example, is it necessary to collect 10 infaunal cores for each fine-scale survey, given the associated cost.
- Is the current sampling frequency appropriate.

3.4.2 Are the monitoring approaches "fit for purpose"

Clearly, the approach taken to monitoring to date (i.e. in terms of frequency, locations, indicators, etc.) and its usefulness will be better understood if there is a data analysis and synthesis such as suggested above, and if the purpose of the monitoring is clearly defined. Both of these factors will help determine gaps in the current monitoring programme with respect to MDC's current and future priorities. In the meantime, there are some general points that can be made regarding the NEMP approach, and some general ideas that we suggest by way of improvement.

Firstly, it is apparent that the broad- and fine-scale survey approaches operate at scales, and use methods, that are poles apart, but there is scope for some simple improvements. The broad-scale approach relies on coarse resolution mapping, and subjective classifications of estuarine habitat (e.g. discrimination of soft mud vs very soft mud, and muddy sand vs sandy mud) and estuarine "condition" (e.g. trophic state). As noted above, there is therefore a high likelihood that different observers or providers will obtain different results and reach different conclusions. By contrast, the fine-scale approach is highly forensic, and based on reasonably objective measures of state, but as revealed above, there is nonetheless scope to achieve improved consistency.

The sediment plate addition to the fine-scale work appears to be a potentially useful direction for the monitoring programmes, especially considering that fine sediment inputs have been identified as a key potential driver of change in estuaries in Marlborough and elsewhere in New Zealand. Sediment plate assessment is a rapid and low-cost field technique that requires no specialist expertise. There is scope to expand the sediment plate work to achieve a scale of assessment that is intermediate between the present broad- and fine-scales, accompanied by measures of sediment state that are reasonably inexpensive and objective. A revised approach could include the following:

- Sediment plates could be installed along gradients of change within estuaries, and at habitat transition areas (e.g. between "muddy" and "sandy" sediment zones). Examples exist where this approach has been adopted in New Zealand, most notably in the eutrophic and muddy Fortrose (Toetoes) Estuary in Southland (Stevens 2018).

- Field-based measures of sediment state could be adopted that are rapid, more objective than the expert assessment required for broad-scale mapping, but considerably less expensive than the laboratory grain-size analysis used in the fine-scale protocol. Key potential measures would be the use of a cone penetrometer and/or torsional shear vane to provide proxy quantitative measures of sediment firmness and textural characteristics. For example, a customised field shear vane was used in Mahurangi Harbour (Auckland) to characterise changes in sediment textural properties due to sedimentation from intertidal aquaculture (Forrest and Creese 2006).

Final considerations for the purposes of the present report are the extent to which the NEMP captures all of the key ecological values of interest (e.g. rare or threatened species) or, conversely, species of potential concern. It is also relevant for MDC to consider how much attention should be given to broader matters (e.g. tangata whenua priorities, human use and human health risk). Arguably, the programme does not meet such needs adequately. For example, from an ecological perspective, at least two additional considerations are the following:

- Although the broad-scale mapping captures the nature and extent of habitats such as seagrass, the presence of resources such as shellfish beds are not determined. While areas of shell habitat are determined, the programme does not measure the attributes that characterise the value and state of any associated shellfish populations (e.g. species, density, population size structure).
- The survey approach gives no attention to the occurrence of invasive plant and animal pests. Of 11 species currently designated as marine pests by the Ministry for Primary Industries (MPI 2015), most are capable of inhabiting estuarine systems. Although there is a national programme for target marine pest surveillance, the Marine High-Risk Site Surveillance programme (see: https://www.mpi.govt.nz/dmsdocument/19004/send), it is limited to shipping ports and areas adjacent. MDC by itself, and as part of the Top of the South Marine Biosecurity Partnership, has a biosecurity programme that focuses on vessel surveillance and target pests in vessel hubs such as marinas. Adding a formalised pest surveillance element into the estuary monitoring would greatly enhance these efforts at little extra cost.

Beyond these NEMP design and methodology considerations, it is also timely to consider ongoing priorities in terms of the estuaries surveyed, and the links between NEMP surveys and other MDC (or broader) monitoring programmes. This broader overview is covered in the next Section.

4. DIRECTIONS AND PRIORITIES FOR FUTURE ESTUARY MONITORING

As part of the scope of this report, MDC asked for guidance on how to assess risk and vulnerability of estuaries, and how to ensure that estuarine monitoring was representative and captured the "important" estuaries. A process for ranking of estuaries within Marlborough that accounted for such factors would provide a basis for setting priorities for long-term monitoring. Some discussion of these matters is presented below, bearing in mind the point made earlier that, integral to the understanding of priorities, are a definition of clear goals for the monitoring and a comprehensive synthesis of the monitoring data collected to date.

4.1 STOCKTAKE OF ESTUARIES NOT COVERED BY EXISTING OR PLANNED PROGRAMMES

Estuarine areas exist in the heads of most bays in the Marlborough Sounds and along the coast of the region including within Port Underwood and D'Urville Island. While it would be ideal to have baseline information on each one, this is likely to be beyond the scope of the current MDC monitoring programme. MDC have identified Chance, Nydia and Clova Bays, Lake Grassmere, Endeavour Inlet and Port Hardy as larger estuaries to be included in future monitoring programmes. These larger estuaries certainly have important ecological values but may not be the most vulnerable or ecologically significant estuarine areas in the region yet to be monitored. In light of the previous discussion, it would seem prudent to review monitoring data, goals and priorities, prior to embarking on further monitoring (see following section).

4.2 PRIORITISATION FRAMEWORK AND ESTUARY SELECTION CRITERIA

4.2.1 Existing approaches to assessing and prioritising estuaries

The original NEMP work outlined a screening-level Decision Matrix as a framework that could be applied to determine and rank specific estuaries to determine their priority for monitoring or management. A summary of the criteria used and their rationale is provided in Table 10. The approach loosely followed a "pressure-state-response" model advocated by the Ministry for the Environment, and considered estuaries under four broad attributes:

1. Existing physical and biological characteristics.
2. Natural character and values.
3. Characteristics that indicate a potential for an adverse impact.
4. Characteristics that indicate an existing impact.

Assessment criteria were developed for each of these themes, together with some subjective categories for scoring each criterion on a 1-3 (low, medium, high) scale. It was intended that the ranking system could be tailored to incorporate specific issues or priorities, with practitioners assigning weighting factors for each criterion to place emphasis on those characteristics of particular relevance to regional stakeholders. The NEMP authors emphasised that the intent was not to provide a "magic" number that would represent the condition of an estuary, but to provide a flexible tool (the "Decision Matrix") to quickly capture a broad overview of the status of an estuary.

Since that initial work, some practitioners following the NEMP have further developed the assessment criteria and scoring systems (Robertson and Stevens 2006, 2009, Robertson et al. 2017, Stevens 2018d, Stevens and Robertson 2010) and included other recently-developed estuarine

Table 10. Estuary assessment criteria proposed as part of a Decision Matrix in the NEMP study (Robertson et al. 2002a).

A. Existing Estuary Physical and Biological Characteristics	
1	Area of Estuary (ha)
2	Diversity of intertidal habitat
3	Diversity of subtidal habitat
4	Flushing time (days)
5	Freshwater input (m^3/s)/ Area of estuary (ha) ratio
6	Extent of mangrove and saltmarsh habitat
7	Extent of fish/shellfish resources
B. Natural Character and Values	
8	Wetland and wildlife status
9	Recreational use
10	Cultural significance
11	Commercial use
12	Perceived value by the communities in the region
13	Potential for rehabilitation
C. Characteristics that Indicate a Potential for an Adverse Impact	
14	Proportion of urban/industrial land-use in the estuary catchment
15	Proportion of agricultural land-use in the estuary catchment
16	Proportion of exotic forest land-use in the estuary catchment
17	Proportion of unmodified estuary catchment
18	Estuary margin alteration (e.g. reclamation)
19	Point Source effluents
20	Aquaculture licences
21	Extent of biosecurity risk
22	Extent of risk of accidental spills
D. Characteristics that Indicate an Existing Impact	
23	Extent of nuisance macro and micro-algal blooms
24	Extent of invasive species
25	Extent of modification of estuary hydrodynamic characteristics
26	Extent of water clarity problems
27	Suitability for human contact
28	Extent of faecal contamination problems
29	Extent of nuisance odour problems
30	Extent of toxicity problems
31	Solid waste

ecological "health" indices in the overall scoring. These include the Estuarine Trophic Index (Robertson et al. 2016a,b; Stevens and Rayes 2018) and Macroalgal EQR (UK-WDF 2014), which themselves integrate various quantitative and categorical state and response metrics that reflect different aspects of estuarine condition.

4.2.2 Limitations of existing approaches

The key issues with the different existing approaches for assessing estuary health relate primarily to inconsistency in terms of terminology, specific methods and their application. This has led to a range of ways that estuary health or state has been determined or expressed in NEMP studies from Marlborough (e.g. see Table 9) and other regions. Some of the specific limitations and issues with the existing situation include:

- Ecological and non-ecological criteria are not always clearly discriminated, and the latter are not always internally consistent or exhaustive.
- Some approaches do not clearly discriminate pressure, state and response variables in relation to above attribute #3 (potential for an adverse impact) and #4 (existing impacts).
- Concepts of pressure and vulnerability to that pressure are often unclear, and the concept of remediation is not always included.
- There is duplication in some of the assessment criteria; for example, the inclusion of integrative indices (e.g. ETI) as well as some of their constituent metrics (e.g. area of soft mud).
- Criterion weightings, although advocated in the NEMP study, do not appear to have been used in practice.
- All approaches advocate calculating averaged or summed scores across all assessment criteria to provide a single numeric score or categorical descriptor (e.g. "good" or "poor" condition). This approach fails to:
    - Discriminate among the main attributes (e.g. values, pressures, current state/condition).
    - Capture the variance or range of scores across the assessment criteria within or among main attributes.
    - Identify the outliers that may require special consideration for monitoring, further assessment, or management.
- Related to the previous point, it is evident that different practitioners have used different numbers of scoring categories, and inconsistent rankings (e.g. a score of 1 may mean good or bad, depending on the system used).
- Some of the criteria are easily assessed, whereas some may be highly subjective or require consultation (e.g. community perception, cultural values), or scientific or ecological knowledge and investigation.

4.2.3 Improvements to existing frameworks

Given the above issues, we consider that there is a need to revisit and reassess the disparate approaches that have been undertaken, to ensure that they are fit-for-purpose in a Marlborough context. While it is beyond our present scope to undertake such as exercise, to develop a more robust framework would involve a relatively modest effort. MDC would then have a defensible approach for prioritisation of estuaries for further monitoring or investigation, and for identifying where management actions were necessary. This type of tool would also give MDC the ability to consider how priorities and needs might change under future scenarios. These could include anthropogenic changes in pressures, for example due to catchment land-use (e.g. logging, dairying) or coastal activities (e.g. aquaculture, shipping-mediated pest or disease introduction), as well as changes due to natural processes relating to climate change.

As well as optimising the existing assessment criteria, there is a need to place the criteria into a more unified and logical framework that has a transparent and integrated scoring system. For example, we suggest that the four high-level attributes described for the NEMP study (see above) could be revised to the following five attributes and their interactions:

- **Values:** Estuarine values potentially at risk, clearly partitioning different core values (ecological, economic, social, cultural) from each other as appropriate.
- **Pressures:** Natural and anthropogenic pressures on those values.
- **State:** Current estuary condition with respect to qualitative or quantitative indicators of health or state measures
- **Susceptibility:** Vulnerability to future changes in state, without and without changes to

pressures.

- **Management:** Potential to avoid emerging or impending problems, remediate degraded conditions, or restore to a more natural state.

The latter attribute has not been well developed in existing approaches, but is arguably a critical driver of priorities. For example, a degraded estuary that cannot feasibly be improved through management intervention would perhaps be regarded as a low priority for monitoring. Hence, a key consideration would be a way to integrate the above attributes in a way that accounted for these types of intricacies, and made more sense than the summing or averaging approaches applied to date. For this purpose, examples of risk-based decision support tools exist from other disciplines, which account for uncertainty and include considerations of benefit/cost, which could be adapted to MDC's needs (Forrest et al. 2006; Sinner et al. 2009; Forrest and Sinner 2016).

4.2.4 Broader considerations

There are some additional criteria and concepts that might be considered important for setting monitoring priorities, which are not represented in present frameworks, but are useful to include in a wider discussion. Examples include:

- Representativeness of the estuary for specific purposes or end-points. For example, in a monitoring design context, it may be possible to identify examples of:
    - Estuaries potentially affected by catchment issues such as logging and run-off to the aquatic environment.
    - "Unimpacted" reference estuaries or sentinel estuaries against which monitoring of specific pressures could be compared.
- Connectivity of the estuary to:
    - Significant terrestrial or subtidal habitats (e.g. reserves)
    - Other coastal locations where monitoring is conducted.
- Scope for integrating and coordinating coastal environmental monitoring (and even freshwater monitoring) in Marlborough, such as discussed in a recent overview report for MDC (Forrest et al. 2016), with a working example being the integrated regional water quality monitoring conducted by MDC (SOE monitoring) and New Zealand King Salmon (consent-related environmental monitoring).
- The importance of estuaries vs priorities for other coastal habitats. For example, the dominant intertidal and shallow subtidal habitats in the Marlborough Sounds are rocky (mainly cobble). It may be appropriate to consider estuary monitoring alongside these other high value habitats, and/or to monitor these habitats where they occur adjacent to priority estuaries.

5. RECOMMENDATIONS

This synoptic report has provided an overview of the NEMP programme in Marlborough, identifying issues and needs that relate to the purpose of the monitoring, the methods used, the interpretation and application of results for management purposes, and future priorities. The review identified that there appears to have been a strong focus on information gathering without a clear purpose, beyond a general goal to assess and monitor the state of ecologically significant marine sites with the help of a coordinated multi-agency approach. Furthermore, there has been no comprehensive distillation and synthesis of the findings, except for subjective expert judgements regarding changes in estuaries, and inferences about their causes. While most of the monitoring undertaken has generally followed the NEMP, there has been obvious variance in the approaches used, and reporting undertaken, by different providers. Unless efforts are made to standardise existing data sets, it will remain difficult to consistently evaluate change within estuaries over time, and to compare estuaries within the region and nationally.

Recommendations made within individual reports are generally appropriate, but have been made by multiple providers working largely in competition with each other, and in isolation from related work programmes including subtidal estuary assessments, sediment source tracking and historical coring, and coastal water quality monitoring. This places a significant onus on MDC, as the coordinator and funder of these programmes, to determine the priority of the various estuary recommendations, and to place them in a wider coastal monitoring context.

Before continuing with ongoing estuary monitoring, recommended to be carried out every 5 years in a MDC 2012 coastal monitoring strategy, it is recommended that MDC undertake or consider the following broad matters:

1. In terms of understanding ongoing monitoring and management priorities, it would be timely to undertake a comprehensive data synthesis and analysis to quantitatively evaluate some of the key changes that have occurred in both broad- and fine-scale indicators, and to investigate the potential causes of any such changes. Such an assessment will require standardisation and aggregation of existing data into a single database.
2. Refine the monitoring approach to address key design gaps in the NEMP, including:

   (i). Developing a "meso-scale" survey approach to address key issues (e.g. using sediment plates along sedimentation gradients) that is intermediate between the present broad- and fine-scale approaches, and which includes field-based measures of sediment state.

   (ii) Ensuring that the survey approaches capture key ecological values of interest (e.g. rare or threatened species, shellfish resources) or, conversely, species of potential concern such as invasive plants and animal pests.
3. In order to ensure that future NEMP (or revised) monitoring is robust, standard operating procedures (SOPs) for broad-scale mapping, fine-scale sampling, new design elements (as above in #2) and reporting outputs should be developed, including QA/QC procedures to ensure data reliability and consistency. Achieving these outcomes will require that the many and various methodological inconsistencies and uncertainties detailed in the main report are addressed. Ideally the NEMP approach should be expanded to include the adoption of improved metrics for assessing macroalgae, as described in the NZ Estuary Trophic Index (ETI).
4. A formal process is needed for prioritising estuaries in the region for monitoring, with a clear focus on:

   (i) the purpose of the monitoring;

   (ii) delivery of "fit for purpose" outcomes;

   (iii) integration and refinement of the current disparate approaches used to assess estuary condition; and

   (iv) consideration of the wider context of other MDC (or broader) monitoring programmes.

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