SALT ECOLOGY

National Estuary Monitoring Protocol for Aotearoa New Zealand: Overarching Guidance

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For the People
Mō ngā tāngata

National Estuary Monitoring Protocol for Aotearoa New Zealand: Overarching Guidance

Prepared by

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for

Ministry for the Environment

June 2025

www.saltecology.co.nz

SALT ECOLOGY

For the environment
Mō te taiao

GLOSSARY

AC	Auckland Council
AMBI	AZTI Marine Biotic Index (macroinvertebrate index)
aRPD	Apparent Redox Potential Discontinuity (assessed visually)
CLUES	Catchment Land Use for Environmental Sustainability (NIWA model)
DPSIR	Driver, Pressure, State, Impact, Response (environmental reporting and management framework)
DSDE	Deep Subtidal Dominated, longer residence time Estuary
ETI	Estuary Trophic Index
EVA	Ecological Vulnerability Assessment
GIS	Geographic Information System
ICOE	Intermittently closed/open estuary
LCDB	Land Cover Data Base
LiDAR	Light Detection and Ranging (remote sensing method)
MfE	Ministry for the Environment
NEMP	National Estuary Monitoring Protocol
NIWA	National Institute of Water and Atmospheric Research
NPS-FM	National Policy Statement for Freshwater Management
SIDE	Shallow Intertidal Dominated Estuary
SLR	Sea Level Rise
SMART	Specific, Measurable, Achievable, Relevant, and Time-bound (monitoring objective)
SOE	State of the Environment (monitoring)
SSRTRE	Shallow, Short Residence-time Tidal River Estuary
WRC	Waikato Regional Council

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TABLE OF CONTENTS

APPENDICES

FIGURES

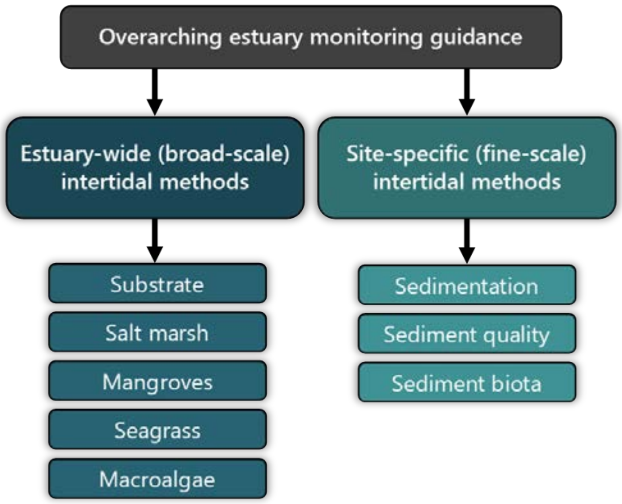
TABLES

SUMMARY

Most councils in Aotearoa New Zealand undertake State of the Environment (SOE) estuary monitoring using methods outlined in the National Estuary Monitoring Protocol (NEMP), originally published in 2002. Since then, regional and temporal differences have resulted from the continued use of methods that existed prior to the NEMP, the inclusion of new indicators as they became available, improvements in technology (e.g., imagery), and *ad hoc* updates to various methods. This update to the NEMP focuses on revisions to broad-scale and fine-scale monitoring methods, and the inclusion of a new sedimentation monitoring method.

Similar to the original NEMP, the update is presented in three documents (see diagram) incorporating:

1. **General overarching guidance**, which addresses the generic components of monitoring that relate to both the broad- and fine-scale methods.
2. **Broad-scale methods** for mapping salt marsh, mangroves, seagrass, macroalgae, and substrate type. See Roberts et al. (2025).
3. **Fine-scale methods** for monitoring sedimentation rate, sediment quality (i.e., grain size, nutrients, organic content, oxygenation, trace metals), and sediment-associated biota including macro-invertebrates, epibiota, epifauna, macroalgae, and microalgae. See Forrest et al. (2025).



Linkages between the three NEMP documents prepared in the current update.

The general overarching guidance (this document) describes key elements of estuary assessment, monitoring goals and objectives, estuary and indicator selection, the use of supporting metrics, programme design considerations, programme review needs, considerations for management, and a brief overview of complementary methods and additional indicators that could be developed for future NEMP updates. Central to this guidance is a tiered monitoring framework:

- **Basic** monitoring represents a relatively low-cost, low-effort option. It uses a desktop broad-scale approach, and a subset of fine-scale indicators, to identify dominant features and determine if any significant problems exist. Regular monitoring helps track coarse temporal change and can signal if more detailed monitoring is needed to improve confidence in the assessment of ecological state, temporal change, and/or responses to management actions.
- **Intermediate** monitoring includes field validation and more detailed broad-scale classification of substrate and vegetation, and quantification of a wider suite of fine-scale indicators. This level of monitoring allows for increasing confidence and a more in-depth understanding of estuary condition, including the extent and progression of any issues.
- **Comprehensive** monitoring builds on the previous tiers to deliver robust high-resolution monitoring capable of detecting changes in habitat and fine-scale indicators with a higher degree of certainty. It includes detailed characterisation of substrate and vegetated habitats, and adds macroinvertebrates and other biota to the fine-scale indicators. While this level provides further confidence in assessing ecological state and/or trends, it requires significantly more time and resources.

The choice of indicators and tier will depend on the specific objective(s) of the monitoring, issues that need to be addressed, and/or regional priorities.

1. INTRODUCTION

1.1 BACKGROUND

Estuaries are tidally-influenced, semi-enclosed coastal bodies of water where freshwater from rivers and streams mixes with saltwater from the ocean. They are dynamic ecosystems and immensely valuable due to their rich biodiversity and ecological functions. They provide essential habitats for a wide range of species, serving as nurseries for fish and a refuge for various birds and invertebrates, perform vital ecosystem services such as filtering contaminants (e.g., sediments, nutrients, metals), protect coastlines from erosion, and contribute to local economies through fisheries, tourism, and recreation. Estuaries hold deep significance for Māori as they connect the whenua (land), awa (river) and moana (ocean), and are an important source of kaimoana (seafood) and other materials (e.g., medicine, weaving, carving) [1] and provide important habitats for taonga species (e.g., tuangi, pātiki, kanakana, tuna). Many estuaries are culturally important because they were historically places where kāinga (villages) were established and they continue to be home to wāhi tapu (sacred sites). Activities on land and in the estuaries can threaten these values by altering hydrology, reducing water and sediment quality, and through direct impacts such as habitat degradation or loss.

To appropriately support ecological condition and guide sustainable management practices, monitoring estuary condition, and the potential drivers of temporal change, is a fundamental requirement. In Aotearoa New Zealand (hereafter New Zealand), most councils monitor estuaries as part of their State of the Environment (SOE) programmes, using a quantitative monitoring framework outlined in New Zealand's National Estuary Monitoring Protocol [NEMP; 2]. The original NEMP involves three main components (Fig. 1):

- A regional prioritisation framework to identify which estuaries to monitor.
- A 'broad-scale' protocol for mapping intertidal habitats (e.g., substrate, salt marsh, seagrass).
- A 'fine-scale' protocol for monitoring estuary sediment quality and sediment-associated biota.

While originally intended as a 'living document' that would be regularly updated to incorporate method improvements and, over time, be extended into other habitats and estuary types, there has been no formal review or update of the NEMP since its first publication. There are however, regional and temporal differences in monitoring, arising from the continued use of methods that existed prior to the NEMP, inclusion of new indicators (e.g., sedimentation), adoption of improvements in technology (e.g., imagery) and *ad hoc* updates to existing methods (e.g., macroalgal cover/ biomass).

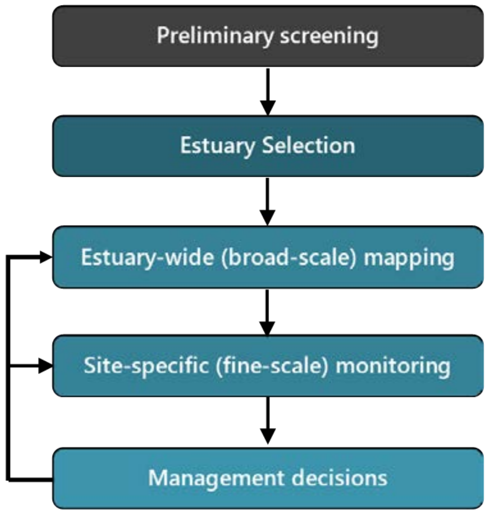


Fig. 1. Sequence of estuary monitoring commonly followed in Aotearoa New Zealand under the NEMP.

To determine whether the NEMP remained 'fit-for-purpose', and collect high-level information on usage, key scientists from regional councils, unitary authorities and research providers (i.e., Cawthron and NIWA) were surveyed in 2023 to summarise NEMP use, strengths, and limitations - see Roberts and Stevens (2023) [3]. Key recommendations were that the NEMP be updated to:

- Standardise field collection methods for current estuary health indicators;
- Provide more detailed method guidance (at the level of individual indicators) to improve consistency across regional councils;
- Provide a more flexible approach to monitoring to allow for variable resourcing across councils, and
- Incorporate new approaches developed since the NEMP's first release.

Broad-scale intertidal mapping, Blueskin Bay, Otago.

1.2 PROJECT OVERVIEW

The scope of this NEMP review has been limited to revision of existing intertidal broad- and fine-scale indicators, and the inclusion of a sedimentation monitoring method (see Table 1). There were a range of additional council needs highlighted in the recommendations of Roberts and Stevens (2023) that remain out of scope in the current update [3]. Some of these have been developed under other MfE contracts, e.g., monitoring of tidal river estuaries [9], whereas others still require development. These include, but are not limited to, the addition of emerging methods (e.g., remote sensing, eDNA), new indicators (e.g., mapping of intertidal macroinvertebrate communities or habitats for ecosystem goods and services), subtidal habitat classification, and a comprehensive analysis of existing data to assess the efficacy of current methods (Table 1). The current update aims primarily to improve alignment between councils in the monitoring of current indicators, with future updates likely to focus the advancement of existing methods, and the inclusion of new indicators and/or emerging technologies.

Table 1. Components included or excluded from this NEMP revision.

Component	In Scope	Out of Scope
Overarching guidance on:		
Selection of representative estuaries for monitoring	✓	
Design considerations for monitoring programmes	✓	
Tiered monitoring approaches	✓	
Indicator selection	✓	
Method consistency/monitoring frequency	✓	
Update broad-scale indicator methods for:		
Salt marsh	✓	
Mangroves	✓	
Macroalgae	✓	
Seagrass	✓	
Substrate	✓	
Update fine-scale sediment indicator methods for:		
Grain size	✓	
Nutrients (TN and TP)	✓	
Organic carbon content	✓	
Oxygenation	✓	
Trace metals	✓	
Macro-invertebrates	✓	
Epibiota	✓	
Include sedimentation method in the fine-scale indicator methods update		
Sediment plate method	✓	
Additional council needs identified in Roberts and Stevens (2023):		
Review of existing datasets to optimise sampling or evaluate current method effectiveness		X
Inclusion of other broad-scale indicators (e.g., mapping ecosystem services)		X
Inclusion of emerging methods (e.g., remote-sensing, eDNA)		X
Inclusion of water quality indicators		X
Development of new indicators or methods		X
Inclusion of human health or cultural health indicators		X
Assessment of the applicability of NEMP methods to different estuary types		X
Guidance on issue-specific investigative monitoring		X
Detailed guidance on data analysis and reporting		X
Recommendations on management actions		X

The target audience for this document includes council, government and research scientists, and other users with background scientific knowledge and experience relating to the NEMP.

Similar to the original NEMP, the update has been presented in three documents (Fig. 2):

1. **General overarching guidance** provided in this document, including the selection of estuaries, design considerations for monitoring programmes, indicator selection, tiered approaches, method consistency, and monitoring frequency.
2. **Broad-scale methods** for mapping salt marsh, mangroves, seagrass, macroalgae, and substrate. See Roberts et al. (2025) [4].
3. **Fine-scale methods** for monitoring sedimentation rate, sediment quality (i.e., grain size, nutrients, organic content, oxygenation, trace metals), and sediment-associated biota (macroinvertebrates and epibiota). See Forrest et al. (2025) [5].

This document presents a high-level narrative and rationale for estuary monitoring programmes, with the broad- and fine-scale documents being focused on method detail.

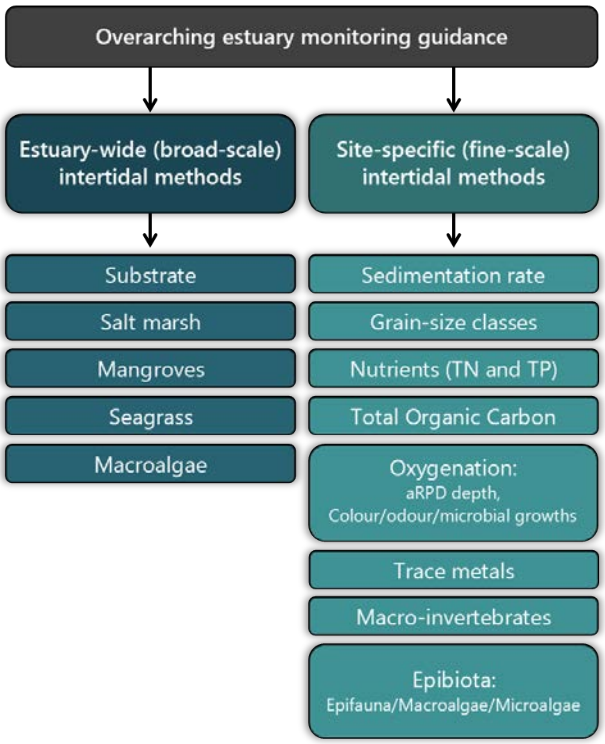


Fig. 2. Linkages between the three NEMP documents, and specific indicators, in the current update.

1.3 STAKEHOLDER ENGAGEMENT AND REVIEW

Each of the three documents in the NEMP review has been prepared by a lead writer and technical expert/s, supported by subject-specific Technical Advisory Groups (TAGs), comprising estuarine monitoring experts working at councils.

Work commenced in December 2023, with invited representatives from the regional council Coastal Special Interest Group (CSIG) and MfE participating in an online workshop. The workshop described the intended NEMP review process, and sought agreement on a 'strawman' of proposed updates based on information gathered from councils in the 2023 NEMP scoping project. TAG participants, comprising subject-specific technical experts were identified at that stage.

Separate draft documents were then prepared on overarching guidance, broad-scale methods, and fine-scale methods. MfE managed TAG engagement, circulated the draft documents for review, collated feedback, and resolved any conflicting feedback among TAG participants. Collated feedback was incorporated by Salt Ecology with any unresolved issues returned to MfE to consult with the TAG before a final decision was incorporated. Draft documents were also sent for external expert (i.e., NIWA) review prior to being finalised.

1.4 DOCUMENT STRUCTURE

In this document, Section 2 describes the key elements of estuary assessment, providing a conceptual understanding of how ecological condition is evaluated. Section 3 presents a generic management framework within which SOE monitoring is embedded, and detail on monitoring goals and objectives. Section 4 provides guidance on selecting estuaries for SOE monitoring. Section 5 summarises the selection of broad- and fine-scale indicators and their links to management, and also describes the use of supporting metrics. Section 6 addresses programme design considerations, including monitoring frequency and application of a tiered (Basic, Intermediate, Comprehensive) monitoring framework that enables councils to tailor monitoring effort based on resourcing and estuary priorities. Section 7 outlines review and evaluation needs to ensure SOE monitoring remains fit-for-purpose over time, and Section 8 presents some future considerations, including complementary methods, additional indicators and recommended method support tools.

2. ESTUARY ASSESSMENTS

In New Zealand, a range of ecological assessment approaches are used to support estuary management, each differing in purpose, scope, and duration. These assessment approaches, summarised in Table 2, contribute to building ecological knowledge and informing management decisions. Recognising the distinctions between them ensures that each assessment is appropriately matched to decision-making needs and management contexts.

SOE monitoring, the focus of the NEMP, is critical due to its long-term, systematic nature. SOE monitoring primarily involves the quantitative assessment of ecological condition and trends across multiple spatial scales, at individual sites within estuaries, at the whole-estuary scale, and across networks of estuaries regionally or nationally over long time periods. Its core functions are to systematically identify emerging environmental issues, support environmental policy and regulation, and inform communities and stakeholders through consistent and repeatable data collection, analysis, and reporting.

While the NEMP focuses solely on SOE monitoring, councils also wanted to understand what other approaches could be used to scope the need for such monitoring, and to track emerging issues between scheduled SOE assessments [3]. Of the assessments listed in Table 2 there are two types that are routinely used for this purpose:

- A **high-level snapshot** is often a qualitative or desktop approach used to evaluate general estuary condition, identify potential stressors or ecologically valuable habitats, and determine whether more detailed monitoring is needed. Underpinning knowledge can also be sourced from mana whenua, local communities and council scientists. This approach can be applied flexibly; as an initial screening tool during estuary or site selection, as a check on estuaries without routine monitoring, or to maintain a watching brief between scheduled SOE monitoring periods. It offers a cost-effective means to detect emerging issues, and to trigger SOE monitoring if required. A suggested approach for undertaking this type of assessment is provided in Appendix 1.
- A **synoptic survey** can mix qualitative and quantitative approaches to assess ecological condition at a single point in time, using a range of indicators and methods tailored to the survey purpose. For example, synoptic data can be collected from multiple sites across a region [e.g., 6] to inform monitoring and management priorities. Alternatively, SOE monitoring may identify areas within an estuary where additional data, beyond the scope of the NEMP, is required (e.g., water quality).

Table 2. Examples of different types of assessment and their general purpose, scope and duration.

Type	Definition/purpose	Scope	Duration
State of the Environment (SOE) Monitoring	To quantitatively assess and report on overall ecological condition and trends, identify issues, support environmental policy, regulation and management, and inform communities/ stakeholders.	Regional monitoring at estuary-wide and/or site scale	Ongoing
High-level Snapshot	To identify stressors or features of ecological interest for scoping monitoring and management needs. Can be desktop or field based.	Variable	Short-term
Synoptic Survey	To provide a broad assessment of ecological condition at a single site, multiple sites or a large geographic area at a single point in time. Used to scope monitoring and management needs.	Variable	Short-term
Targeted Investigation	Focused study that addresses a specific issue, area/s, or stressors/s identified as a concern. Used to inform targeted monitoring and management.	Issue-specific	Short- to medium-term
Research Investigation	To explore scientific questions, test hypotheses, or expand scientific understanding of ecological processes. Expands foundational knowledge which is utilised in other forms of estuary assessment or management.	Variable	Short- to long-term
Regulatory Assessments:			
Baseline	To establish current conditions prior to development/intervention.	Site-specific	Pre-project
Ecological Impact	To detect and evaluate ecological changes from a specific activity/event.	Project-linked	Pre- to post-project
Consent	To assess ecological effects as specifically required by consent conditions.	Site-specific	Project
Compliance	To ensure an activity meets specified legal/ regulatory/ consent requirements.	Broad (legal scope)	Project
Operational	Monitors system/ infrastructure performance, i.e., wastewater treatment.	Facility-specific	Continuous

3. SOE PROGRAMME SCOPE AND OBJECTIVES

3.1 SCOPE

SOE monitoring, as illustrated in Fig. 3, sits within an iterative, cyclical process that supports evidence-based environmental management by systematically tracking estuary condition and trends. This approach extends from setting goals and objectives, to designing monitoring programmes, collecting and analysing data, and determining and implementing management needs and actions. All components are important to ensure effective monitoring and management outcomes. In particular, SOE monitoring data should be analysed as soon as practicable to ensure the results are able to contribute to timely management decision-making, while the wider programme and indicators should be reviewed regularly to ensure that monitoring is optimised and remains fit-for-purpose.

Fig. 3 provides a high-level summary of a generic management framework within which SOE monitoring is embedded. Because most councils in New Zealand have existing estuary SOE monitoring programmes, it is intended primarily as a high-level 'checklist' to assist any councils that may wish to re-evaluate existing programmes, or as a prompt to use if establishing a new SOE programme. Further detail on the various components is provided in the following sections.

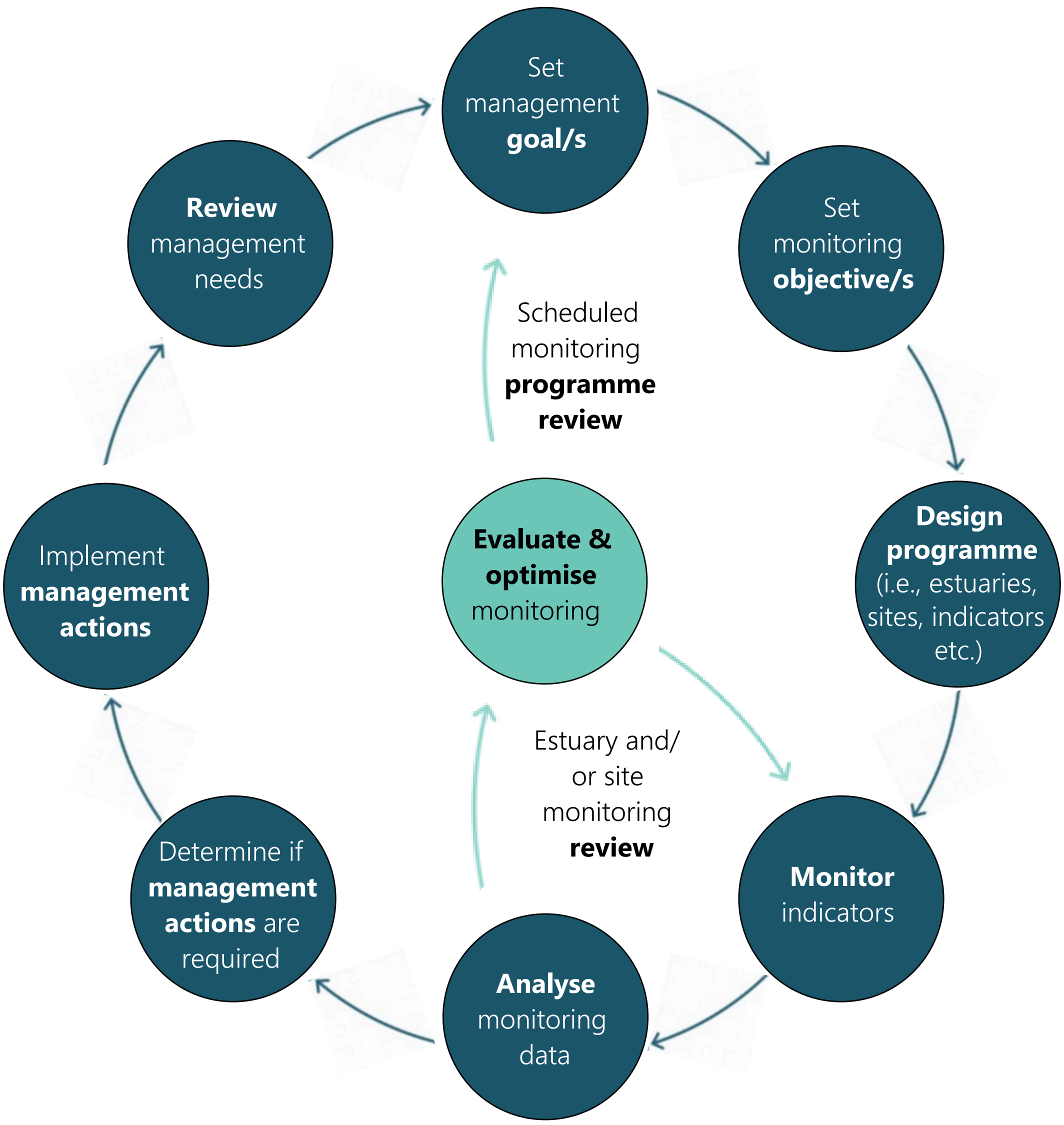


Fig. 3. Generic management framework within which SOE monitoring is embedded. Programme evaluation and optimisation can occur at the estuary and/or site level, where monitoring indicators may be adjusted and monitoring continued. Alternatively, evaluation may take place during a programme review, where goals, objectives and overall design are revisited.

3.2 GOALS AND OBJECTIVES

Under the Resource Management Act (1991; RMA), councils have a duty to gather information and report on the state of the environment to support informed management decisions. In the absence of legislation requiring regional or unitary councils in New Zealand to meet specific monitoring objectives, monitoring approaches will inevitably vary between regions, with objectives often reflecting local, regional or coastal plan requirements, or seek to address specific issues of concern such as habitat loss or impacts from excessive inputs of sediment, nutrients or other contaminants. Although regional variance can lead to difficulties in comparing monitoring results at a national level, this in itself is not an issue at a regional level where goals and objectives are clearly defined.

However, the scoping report [3] identified uncertainty among some councils about the specific monitoring goals and objectives of their estuary SOE programmes, and how their monitoring linked to management. In some instances, this reflected a loss of institutional knowledge that explained the original purpose behind programme establishment, while in others, changes in goals and objectives over time had resulted in monitoring programmes morphing to be used in ways they were not initially intended, and are perhaps not well-suited for (e.g., plan effectiveness monitoring).

To help councils clarify what outcomes they are seeking to address through their estuary SOE monitoring, the following section provides examples of common management goals (what you hope to achieve) and monitoring objectives (what you plan to do) that may be applicable.

A **management goal** is a broad, general statement of intent that provides overall direction and purpose to the monitoring process. It typically focuses on the big picture and is often long-term in nature. A management goal is not necessarily easily measurable but sets the context for more specific actions. Examples of high-level management goals include:

- Protect and/or enhance habitat and ecosystem functioning.
- Maintain capacity to respond to changes in predicted sea level rise (e.g., set aside areas for managed retreat).
- Minimise estuary degradation due to human activities.
- Restore an estuary to its 'natural' state, or a defined historical 'baseline' condition.
- Improve water clarity.
- Ensure waters are safe for recreational activities and/or seafood gathering.
- Engage mana whenua, communities and stakeholders in estuary management activities.
- Reduce the effects of specific estuary stressors (e.g., decrease the extent of muddy habitat, frequency of macroalgal blooms, or contaminant concentrations near stormwater outfalls).
- Improve flushing and/or reinstate natural entrance behaviour (e.g., remove flap-gates to improve salt marsh functioning, minimise culverting and drainage, avoid artificial entrance openings, maintain freshwater flows).
- Maintain or improve an estuary indicator (e.g., increase seagrass or salt marsh extent).
- Achieve a desired indicator state (e.g., a specified indicator threshold; see Stevens et al. 2024 [11]).

A **monitoring objective** is the first step in developing a monitoring programme to address management goals to be achieved in the short or medium term. Objectives that are specific, measurable, achievable, relevant, and time-bound (SMART) facilitate timely data analysis or evaluation [7]. High-level monitoring themes, under which SMART objectives can be built, may include, but are not limited to:

- Monitor flora and fauna diversity and abundance to gauge overall estuary health and ecosystem functioning.
- Monitor concentrations of nutrients, heavy metals, and other pollutants to assess potential risks to marine life and human health.
- Evaluate the condition of key estuarine habitats like seagrass and salt marsh, and track changes over time.
- Evaluate the effectiveness of management actions such as restoration projects, pollution control measures, or changes in catchment land use.
- Assess climate change impacts that can affect estuarine species distribution and habitat quality, e.g., seawater temperature, salinity, and acidification.
- Provide early warnings of potential issues.
- Report progress towards targets, or compliance with regulatory requirements.

For example, relating to an objective to evaluate and track changes in the condition of seagrass and salt marsh, two specific examples of SMART objectives could be:

- Increase the extent of salt marsh by 10% by 2040 through restoration planting and reinstating tidal flows into disconnected areas, to support biodiversity and enhance estuary resilience to sea-level rise.
- Protect seagrass meadows to prevent further loss in extent by 2030, through improved water quality and a reduction in physical disturbance (e.g., vehicles), to maintain an important habitat for nursery fish species.

A well-designed monitoring programme, embedded within a management framework, links monitoring objectives to **management actions** - the specific strategies or activities required to achieve defined goals (e.g., Fig. 3). This requires clear recognition of the connections between human activity, ecological change, and cultural or social consequences. The 'DPSIR' framework is a widely used systems-based model in environmental reporting and management. It links **Drivers** of change to **Pressures** on the environment, their impacts on **State**, the resulting **Impacts** on ecosystems and society, and the **Responses** taken to manage or mitigate those effects.

Drivers are the underlying social, cultural, and economic forces such as agricultural intensification, urban development, forestry, or climate change. These create Pressures, which are the direct stressors on the environment, including sediment runoff, contaminants such as heavy metals and pathogens, and habitat modification. The State reflects the resulting condition of the environment, for example increased turbidity, eutrophication, smothered benthic habitats, degraded seagrass or salt marsh, and poor water quality and/or kaimoana health. The Impact is seen in the effects on ecosystems, human wellbeing, and cultural values, such as loss of biodiversity and resilience, decline in mahinga kai species (including pipi, tuangi, tuna, and īnanga), reduced cultural wellbeing and kaitiakitanga, and decreased recreational and economic values. Finally, Responses are the societal or policy actions taken to address these impacts, including catchment planting and wetland restoration, farm and stormwater controls, regulatory measures under the RMA and NPS-FM, ecological and cultural monitoring, and iwi/hapū partnerships that embed mātauranga Māori.

Effective SOE monitoring measures state variables at appropriate temporal and spatial scales to identify how and when pressures impact estuarine biota or habitats. When monitoring detects a decline in estuary condition, it should trigger an investigation of the cause and assess whether management actions to address adverse impacts are necessary and feasible.

Additional guidance on linking monitored indicators to management objectives is outlined in Section 0. It is also critical to ensure appropriate policy is in place to meet ecological goals and objectives, noting that to date in New Zealand, estuary management has generally been reactive (responding to degradation), rather than proactive (preventing impacts).

Sandfly Bay Estuary, Abel Tasman National Park.

4. SELECTING ESTUARIES FOR SOE MONITORING

Once clear management goals and monitoring objectives have been defined, the next step is to determine which estuaries may require monitoring. A systematic approach to estuary selection is recommended to make the best use of available budgets, ensure overarching management goals are met, and to accommodate any estuary-specific objectives and priorities that are identified during the selection process. Ideally, estuaries will be selected that have good regional spatial coverage, are representative of different ecological conditions, vulnerabilities and pressures, and for which results can be extrapolated to estuaries that are not monitored (or are perhaps monitored less frequently).

The scoping review [3] highlighted that most councils have already selected estuaries for monitoring using a variety of approaches including:

- Local knowledge and expert judgement.
- Considering connectivity with other programmes (e.g., linkages to freshwater).
- Systematic desktop approaches such as the original NEMP decision matrix, or more recent approaches e.g., Ecological Vulnerability Assessment (EVA).
- Systematic desktop approaches combined with preliminary field observations of key features and expert evaluations of susceptibility.
- Snapshot or synoptic field surveys (see Section 2) to provide an assessment of ecological conditions across multiple sites within an estuary or over a large geographic area at a single point in time, to inform the potential suitability of sites or estuaries for systematic long-term monitoring.

For councils that have not yet selected estuaries, or wish to expand SOE programmes, an Ecological Vulnerability Assessment (EVA) framework such as summarised in Appendix 2 [8], provides a useful approach to support decision making. The Appendix 2 example draws on the original NEMP decision-matrix, and illustrates a systematic approach that enables estuaries to be ranked in terms of monitoring or management priorities based on four underpinning categories (Fig. 4):

- Ecological Values: Habitat types, species of ecological or conservation significance, and habitat intactness.
- Pressures: Current/existing natural and anthropogenic pressures on the ecological values.
- Susceptibility: Eutrophication susceptibility based on physical characteristics, and vulnerability to future changes in state due to changes in pressures.
- Condition: Estuary condition with respect to qualitative or quantitative indicators of health.

Note! Cultural values and human health indicators are not considered in the current EVA framework. Where this information is available, and this is important for estuary selection, the framework could be expanded to include these components.

There is also potential to enhance the EVA approach by more explicitly considering climate change adaptation and resilience as part of Susceptibility.

The EVA approach provides a tool to semi-quantitatively score estuaries against criteria within each of these categories, providing councils with a transparent and objective way of identifying and prioritising needs. For example, high-level information on physical properties (e.g., estuary area, depth, flushing and dilution), catchment pressures (e.g., sediment and nutrient loads, land-cover), current state (e.g., salt marsh or seagrass extent, presence of algal blooms or invasive species), and human use (recreational, commercial) are used to determine monitoring priorities.

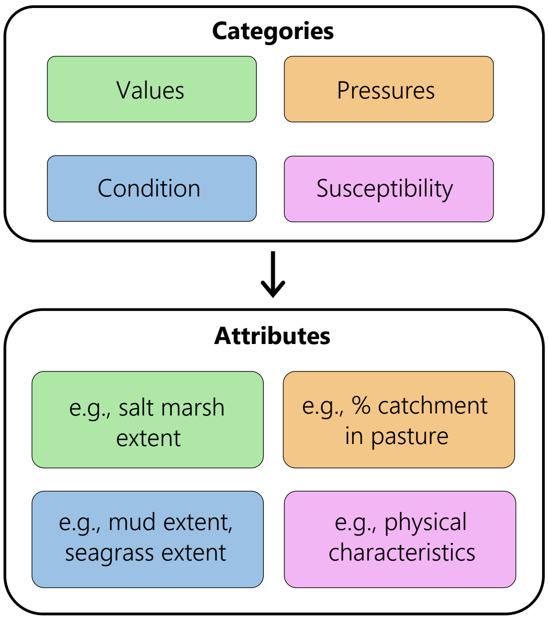


Fig. 4. Conceptual diagram of EVA categories and attributes (see Appendix 2 for further detail).

Broadly, the approach captures the key matters that would be considered when making decisions about monitoring and management in specific estuaries, such as:

- What are the estuary ecological values present?
- What are the main pressures on each estuary system? e.g., diffuse or point sources, direct disturbance, etc.
- How susceptible is the estuary to a change in pressures (e.g., catchment land use change)?
- Do the known or potential pressures justify the cost of investigation or monitoring?
- Is there a recognised issue with estuary state? If so, is it persistent, or of sufficient scale (severity, spatial extent, duration), that it warrants monitoring, or further understanding?
- Are the estuary and its habitats suitable for NEMP intertidal monitoring (i.e., intertidally dominated)?
- Can changes in state be reliably measured given the habitats present? What habitats or indicators are most sensitive to change?
- In view of the values, pressures, and susceptibility, is there a need for an estuary visit to characterise state?
- Are there any key knowledge gaps and uncertainties?

Much of the required input information can be obtained from desktop sources, however, an estuary visit may be necessary to better understand existing state and susceptibility. To this end, as discussed in Section 2, a high-level snapshot (Appendix 1) or synoptic survey can be used to gather preliminary information.

While there are still some limitations to the approach (e.g., data availability, data quality, thresholds under development) the EVA provides a coarse screening tool that enables estuaries to be compared in a consistent manner, and to set priorities for future monitoring and management.

A secondary benefit of undertaking a systematic approach to site prioritisation (e.g., an EVA) is that it incorporates a comprehensive range of supporting indicators that assist not only with the initial desktop assessment, but can also be used later to help plan field surveys and interpret findings, or when reviewing estuary programmes to assess changes in susceptibility and state, and to revisit management goals and monitoring objectives.

Waikouaiti Estuary, Otago, impacted by channelisation, salt marsh drainage, reclamation, grazing, flow abstractions, tidal disconnection and a wastewater treatment plant within the estuary margin.

5. SELECTING SOE MONITORING INDICATORS

5.1 OVERVIEW

Following the selection of priority estuaries, decisions are required on the specific indicators to include in monitoring. This section provides some commentary on the suite of indicators included in the NEMP update, and the selection of which ones to use.

Like estuary selection, the selection of specific indicators should be driven by the defined monitoring objectives and broader management goals (see Section 3.2). A suite of commonly-used broad- and fine-scale indicators are included in this version of the NEMP (see Table 1). These are suited to monitoring shallow intertidal dominated estuaries (SIDEs), and shallow short residence time, tidal river estuaries (SSRTREs) with suitable intertidal areas. However, SSRTREs may be less amenable to routine NEMP monitoring in situations where physical stressors (e.g., flood flows, low salinity) are the dominant forces that dictate ecological condition [9]. Hence, in SSRTREs with limited intertidal area, intermittently closed or open estuaries (ICOEs) and deep subtidal-dominated estuaries (DSDEs), alternative indicators and monitoring approaches may be needed (e.g., [9, 14].

Indicators included in an SOE programme should ideally include a mix of those that are able to individually or collectively characterise current state; identify temporal change in response to stressors; represent different ecosystem elements; and provide advance warning for management action. The initial focus of SOE monitoring should be on broad condition indicators of estuary health as they provide a baseline for assessing current state, and subsequent ecosystem response to common pressures that councils have a mandate to manage. Indicators from outside the estuary will also be needed to assess driver-pressure-state relationships (see Section 5.3). These may include catchment scale indicators (e.g., land use change, forest harvesting, stock intensification, rainfall intensity and frequency) or indicators from other monitoring programmes (e.g., freshwater nutrient concentrations, turbidity, suspended sediment, flow).

The indicator suites included in the NEMP update are summarised in Table 3 and Table 4, along with a rationale for their use. More comprehensive detail and recommended monitoring methods are presented in the broad- and fine-scale method documents [4, 5].

It is noted that not all the indicators included will be relevant to all estuaries (e.g., natural mangrove distribution is limited to the upper North Island), while some indicators may not need to be regularly assessed where estuary-specific issues are absent (e.g., estuaries with low nutrients and no nuisance opportunistic macroalgae). While there is no requirement to include indicators where estuary-specific issues are absent, many programmes may still choose to include them to demonstrate that the absence of an issue is a measured result, and not due to a gap in monitoring.

5.2 INDICATOR SUITES

5.2.1 Estuary-wide (broad-scale) indicators

Estuary-wide (broad-scale) indicators are the spatial mapping indicators described in the NEMP broad-scale document. They characterise the dominant intertidal substrate (e.g., cobble, gravel, sand, mud) and vegetation (e.g., salt marsh, seagrass, mangroves, opportunistic macroalgae) visible on an estuary's intertidal flats (Table 3). Measuring these indicators combines the use of aerial imagery, and digital mapping using Geographical Information System (GIS) technology.

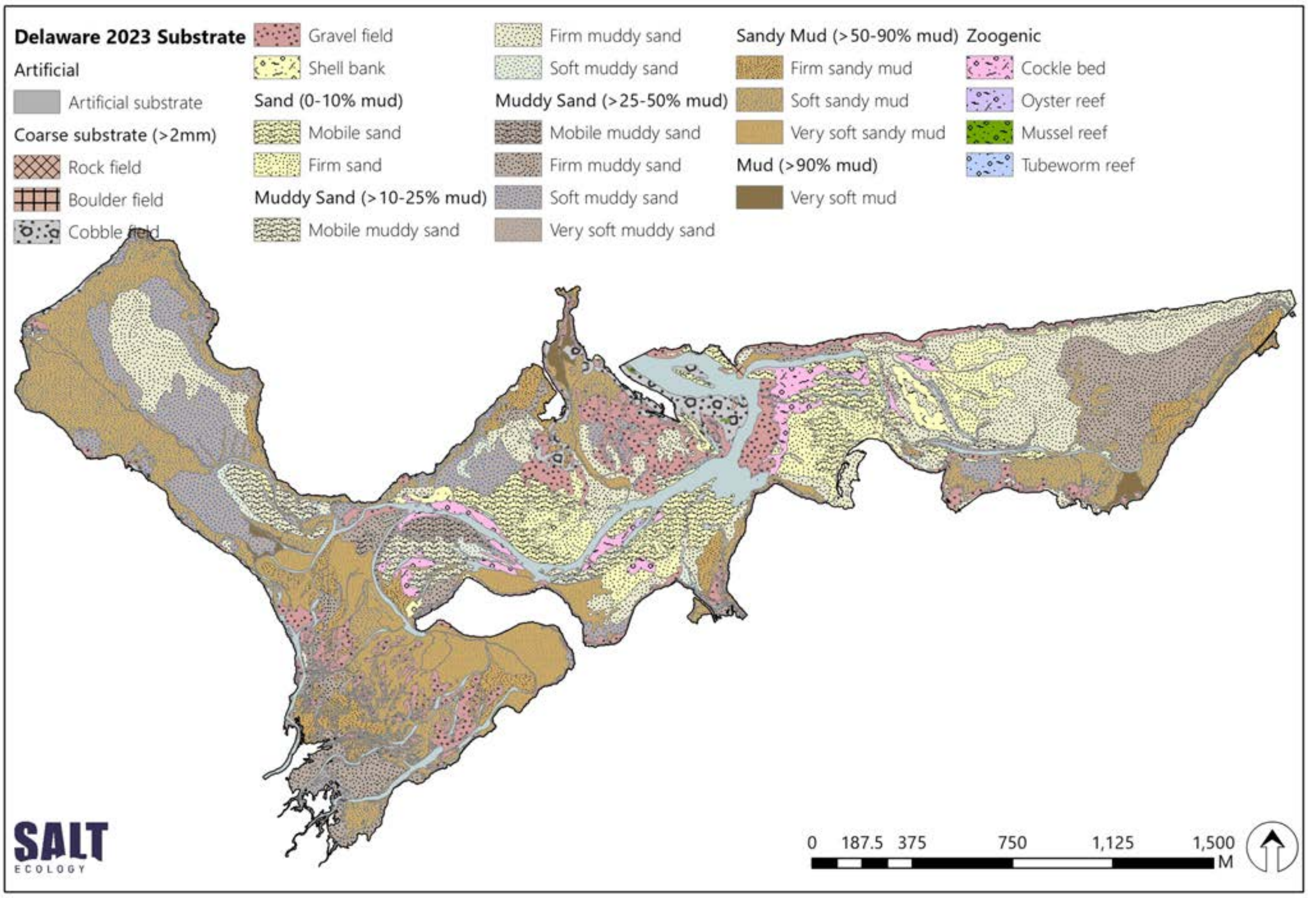
Mapping is commonly supported by ground-truthing to validate key features, with validation data used to extrapolate across comparable habitat features, or to estimate average values for broad-scale indicators that rely on spot measurements (e.g., macroalgal biomass).

The broad-scale method is not intended to provide a comprehensive inventory of everything present in an estuary, but instead focuses on characterising dominant intertidal features, and temporal change in those features, to highlight issues that may warrant more detailed investigation or targeted management.

Broad-scale mapping - field-validating features visible on laminated aerial imagery.

Table 3. Summary of estuary-wide (broad-scale) mapping indicators for intertidal estuaries, and their rationale. Appendix 3 highlights key differences between the original NEMP and the current update.

Indicator	General rationale
Substrate	Substrate type is a key habitat component that shapes habitat diversity and suitability, species composition, nutrient cycling, erodibility and other ecosystem processes. Changes can highlight habitat degradation or loss.
Salt marsh	Salt marshes predominantly grow within the high water spring to neap tide range, and are important biogenic habitats dominated by salt-tolerant plant species present at the land-sea interface. They provide critical habitat for various species (e.g., bird, fish, insects), are highly productive, and offer a wide range of ecosystem services (e.g., sediment stabilisation, erosion mitigation).
Mangroves	Mangroves (*Avicennia marina* subsp. *australasica*) inhabit shores slightly above mean sea level. They perform diverse physical and ecological functions, including contributing organic matter to food webs, providing habitat structure, sequestering carbon, and acting as a natural defence against coastal hazards.
Seagrass	Seagrass (*Zostera muelleri*) grows primarily in the low to mid-intertidal zone, and shallow subtidal zone, and provides shelter and food for other species, is an important nursery habitat for juvenile fish, stabilises the seabed, and influences biogeochemical processes such as nutrient cycling and carbon storage.
Opportunistic macroalgae	Macroalgae (seaweeds) are important primary producers at the base of the food web and provide important habitats for invertebrates, juvenile fish, crabs and other species. However, nuisance blooms of rapidly growing opportunistic species can occur in nutrient-enriched waters when combined with suitable growing conditions.



Example of broad-scale GIS mapping output showing the spatial location and type of dominant intertidal substrates.

5.2.2 Site-specific (fine-scale) indicators

Site-specific (fine-scale) indicators are those described in the NEMP fine-scale document [5]. These are applied within estuaries deemed a priority for the collection of more detailed information to characterise estuary state at one or more fixed sites in stable intertidal areas. Sites commonly represent the dominant habitat type, or specific areas of interest or concern, e.g., sediment deposition zones. Guidance on selecting sites is outlined in the NEMP fine-scale methods report [5].

Monitoring involves field measurement of sediment oxygenation (e.g., aRPD depth), and systematic sampling and laboratory analyses of an explicit suite of sediment quality indicators (Table 4) that aim to characterise grain size, trophic state (nitrogen, phosphorus, organic carbon), and the presence of anthropogenic chemical contaminants (trace metals). Biotic indicators include benthic infauna (macroinvertebrates) and epifauna, with the former a well-recognised indicator of estuary state (Table 4). The fine-scale indicator suite includes sedimentation rate (measured as accrual over concrete plates) which can influence benthic fauna and flora [10]. Results are generally compared to thresholds of biological health to assess the likelihood of ecological degradation [e.g., 11], and detect change over time from baseline conditions.

Table 4. Summary of site-specific (fine-scale) sedimentation, sediment quality and biotic indicators for intertidal estuaries, and their rationale. Appendix 3 highlights key differences between the original NEMP and the current update.

Indicator	General rationale
Sedimentation	
Sedimentation rate	High sedimentation rates can smother benthic biota, including macroinvertebrates and seagrass. Measures of sediment accrual (or erosion) above buried 'plates' may help to interpret changes in sediment quality and biota at fine-scale sites.
Sediment quality	
Grain size classes	As well as mud itself being a stressor, the contaminant-holding capacity of sediments tends to increase with decreasing particle grain size. Changes in mud content can highlight sediment degradation.
Trophic state and enrichment	Total organic carbon measures sediment organic enrichment which can lead to low sediment oxygen conditions that influence nutrient cycling and habitat suitability for infauna and vegetation, e.g., seagrass.
	Nutrients (total nitrogen and total phosphorus) indicate the potential for sediment eutrophication, algal blooms and other enrichment symptoms (e.g., low sediment oxygen). Sediment nutrient enrichment can alter nutrient cycling and habitat suitability for infauna and vegetation.
	Sediment oxygenation indicates the enrichment response to organic matter loading or sediment mud content. Commonly measured as apparent Redox Potential Discontinuity (aRPD) depth.
	Qualitative colour, odour, and microbial growth indicators can highlight eutrophic sediment enrichment, e.g., a 'rotten egg' odour, intense black colour profile, and/or sulfur-oxidising bacteria or microalgae growths.
Trace metals	Toxic contaminants commonly associated with human activities (e.g., heavy metals) may indicate toxic effects, and a need to investigate other anthropogenic contaminant types (e.g., pesticides, hydrocarbons).
Biota	
Macro-invertebrates	Sediment infauna and epifauna provide an important food source for birds and fish. They indicate estuary health in response to changes in enrichment, contaminants, mud content, physical disturbance, or vegetation.
Macroalgae	Macroalgae can influence infauna and epifauna composition. Further, the composition and prevalence of opportunistic macroalgae (especially species of *Gracilaria* and *Ulva*) can indicate nutrient enrichment.
Microalgae	Microalgae (microphytobenthos) can influence macroinvertebrate communities and grow conspicuously, e.g., bright yellow or green on sediment surface) under enriched conditions.

5.2.3 Linking NEMP indicators to management

International monitoring programmes prioritise indicators (such as those listed in Tables 3 and 4) that have a direct relationship to pressures (e.g., sediment and contaminant loads), ensuring that the data collected can tangibly inform management actions [e.g., 12, 13]. While this linkage seems obvious, there has been limited effort historically in New Zealand to ensure condition indicators are linked to pressures or management endpoints.

The Estuary Trophic Index (ETI) project [14] described the first national-scale example of an approach linking eutrophic condition indicators (e.g., macroalgae and phytoplankton) to a specific pressure (i.e., eutrophication caused by high nutrient loads). The pressure-state-response concept has also been discussed in other estuary-related reports commissioned by MfE [15, 9, 16].

Despite these developments, the lack of clear guidance, or the difficulty in translating impacts into effective policy, has often resulted in councils collecting data that are under-utilised in management decisions. To support more effective use of monitoring data, Table 5 provides a high-level overview of how various indicators relate to assessing overall estuary health or targeting specific stressors, issues, or management questions. To assist with indicator selection, the utility of each indicator is subjectively rated, based on the monitoring objective (Table 5). Targeted selection of indicators is particularly important when resources are limited, and it is important to consider the management endpoint to ensure that monitoring is fit-for-purpose.

Further, some estuary types (e.g., SSRTREs) or sites within estuaries can exhibit high natural variability. Therefore, it is important to select indicators with a high signal-to-noise ratio (i.e., anthropogenic change to natural change) to effectively link monitoring results to management outcomes [17, 18], and to adequately characterise natural variability under baseline conditions. For example, macroinvertebrates can be used to describe infaunal communities in SSRTREs, but may be a poor long-term monitoring indicator. In these systems, the community tends to be resilient due to strong physical drivers such as substrate mobility and recurrent freshwater pulses, which can mask potential effects due to anthropogenic pressures (e.g., increased catchment sediment loads).

Table 5. Illustration of the utility of different indicators in relation to the assessment of general ecological state, some key pressures or stressors, key values, or regulatory needs (e.g., limit setting). Indicator utility is subjectively rated as: critical (***), useful (**), or potentially useful (*). Blank cells imply an indicator is likely to be unnecessary.

	Historic habitat modification	General ecological state	Limit setting (e.g., NPSFM)	Eutrophication & algal blooms	Sedimentation & erosion	Toxic contaminant pollution	Invasive species and pests	Biodiversity
Estuary-wide (broad-scale) mapping								
Substrate type	**	***	**	**	***	**	*	*
Salt marsh	***	***	***	*			***	***
Mangroves	***	***	**	*	***		***	***
Seagrass	***	***	***	*	*			***
Opportunistic macroalgae (seaweeds)	**	***	***	***			***	***
Site-specific (fine-scale) monitoring								
Sedimentation rate	*	*	**		***	*		
Grain size classes		**	**	**	***	***	**	**
Total organic carbon		**	**	***		***	**	**
Nutrients (TN and TP)		**	**	***		***	**	**
aRPD		*		***		*	*	**
Colour, odour & microbial growths		*		*		*		
Trace metals		**	**			***	*	*
Macroinvertebrates (infauna)		**		*	*	**	***	***
Macroinvertebrates (epifauna)		*		*	*		***	***
Microalgae		*		*				

5.3 SUPPORTING METRICS

Additional data are often needed to interpret estuary condition and the pressures that influence it. For example, water residence time (i.e., estuary flushing) can affect nutrient retention, which in turn may influence eutrophication indicators such as macroalgal growth. Accordingly, Table 6 lists supporting indicators that can aid in interpreting monitoring data or enable more meaningful comparisons between estuaries with similar characteristics. While relationships between supporting and monitored indicators are not necessarily causal, they can help identify where more targeted investigations are required to improve confidence in pressure-state-response relationships.

Table 6. Supporting indicators that could assist with the interpretation of estuary condition. These are primarily desktop, except where noted.

Supporting Indicators	Data Type	Description and Information Sources
Bathymetry	Desktop and/or field observations	Estuary bathymetry can be used to determine intertidal extent, inundation periods of fine-scale sites, upper estuary boundaries, predicted areas of inundation under sea level rise, and temporal changes in estuary-wide sedimentation. LiDAR (intertidal) or hydrographic survey (subtidal) data available from councils and LINZ Data Service.
Catchment land-use activities (e.g., discharges)	Regulatory	Enables assessment of regulated contaminant pressures. Sourced from council consent data, e.g., point-source discharges, permitted activities.
Catchment land-use types	Satellite/ Regulatory/ Industry	Enables assessment of pressures. Sources include Landcare Land Cover Data Base (LCDB), finer scale council data, industry data (e.g., exotic forest harvest records, farm stocking densities), and other sources (e.g., MfE forestry harvest data).
Estuary flushing	Modelled	Facilitates estimates of pollution/ eutrophication susceptibility. National data in Plew et al. (2018) [19].
Entrance status	Desktop and/or field observations	An open, closed or flow-restricted entrance can affect estuary state. Opening status can be assessed from aerial/satellite imagery (including historic), on-ground checks, council records, and council LiDAR data (see bathymetry above).
Historic maps of estuary boundary, salt marsh and intertidal seagrass	Historic	Useful for determining habitat loss and potential causes. Information sources include aerial photos and satellite images from council records, LINZ Data Service, and Retrolens (retrolens.co.nz), oral histories, paintings, and written narratives.
Meteorological station climate records	Measured	Data typically held in council records, and also the National Climate Database (https://cliflo.niwa.co.nz/)
Nutrient loads	Measured/ modelled	Enables assessment of eutrophication pressures. Measured (e.g., council records) or modelled (e.g., CLUES [20], Snelder et al. 2020 [21] or regional/local models).
River flow and abstraction	Measured/ modelled	Particularly in small estuaries, river flow can have a significant influence on flushing time. Measured (e.g., council records) or modelled river flows, e.g., CLUES [20].
Sediment loads	Measured/ modelled	Enables assessment of sediment pressures. Sourced from measurements or modelled data, e.g., CLUES [20], Hicks et al. (2019) [22], regional/local models.
Sediment trapping efficiency	Estimated	Can assist understanding sediment pressures, although estimates such as in Hicks et al. (2019) [22] should be treated with caution given caveats around the approach [23].
Terrestrial margin vegetation	Desktop and/or field observations	A modified margin is likely to reflect estuarine habitat loss, decreased biodiversity, barriers to migration, and a potential increase in sediment and nutrient inputs. Information can be sourced from LCDB, aerial imagery or field surveys.
Tide data	Measured/ modelled	Tidal heights vary across the lunar cycle and affect seawater intrusion, intertidal inundation periods and the intertidal extent exposed. Data available from LINZ Data Service and NIWA tide forecaster.
Water temperature (ongoing and historic)	Measured	National databases of sea surface temperature, upstream or estuary high-frequency monitoring records, international satellite data (e.g., NOAA, Copernicus) and/or proxy meteorological records (e.g., cliflo.niwa.co.nz) can be useful to determine whether estuarine habitats have been exposed to heat stress (e.g., seagrass loss).

6. SOE PROGRAMME DESIGN CONSIDERATIONS

6.1 OVERVIEW

Following estuary and indicator selection, there are several key considerations in designing or reviewing a monitoring programme. The programme must align with management goals and monitoring objectives (Section 3.2) while also being scientifically robust. However, programme design is often constrained by council budgets and staff resourcing, highlighting the need for a practical approach, clear prioritisation, and a realistic understanding of the programme's limitations.

In general, monitoring can be adapted to align with available resourcing in three main ways:

- **Monitoring effort** - varying the level of monitoring effort (as described in Section 6.2 on tiered monitoring) across estuaries and/or sites, while maintaining the same monitoring frequency.
- **Monitoring frequency** - maintaining the same level of monitoring effort but applying it at a higher frequency at high-priority or sentinel estuaries and/or sites.
- **A combination of both** - adjusting both monitoring frequency and effort to align with monitoring objectives and resource availability.

Adjusting monitoring effort and frequency inevitably involves trade-offs. These may include a reduced ability to detect long-term trends, lower spatial resolution, data quality versus quantity, and cost versus monitoring coverage. Inconsistent monitoring effort or frequency across estuaries can also limit the ability to compare results regionally or nationally, creating challenges for higher-level reporting and policy evaluation (although there are no current national attributes or targets for estuaries). Nonetheless, even limited monitoring can provide valuable insight into estuary condition and is generally preferable to the absence of data altogether, particularly where estuaries are at-risk and councils need to implement management actions.

To accommodate the need for councils to have a flexible monitoring approach, a tiered monitoring framework, incorporating varying degrees of effort is presented in the broad- and fine-scale method documents. This approach, along with considerations related to monitoring frequency and programme design, are discussed below.

6.2 TIERED APPROACH TO MONITORING

Three levels of effort (tiers) are presented in the broad-scale and fine-scale method documents, and are summarised in Table 7 and Table 8, respectively. The monitoring tiers are briefly described below:

- **Basic** monitoring represents a relatively low-cost, low-effort option, using a desktop approach for broad-scale (Table 7) and a subset of indicators for fine-scale (Table 8) monitoring, to provide a general understanding of estuary condition and the occurrence of any obvious problems. Regular monitoring at this tier helps track coarse changes in condition and can signal the need for management action or more detailed monitoring.
- **Intermediate** monitoring requires field validation of broad-scale features, and includes more detailed classification of substrate and vegetation (Table 7), and quantification of a wider suite of fine-scale sediment quality indicators, e.g., metals, nutrients, organic matter (Table 8). This level of monitoring allows for more confident characterisation of estuary condition, including the extent and progression of any issues.
- **Comprehensive** monitoring builds on the previous tiers to deliver high-resolution monitoring capable of detecting changes in habitat and fine-scale indicators with a higher degree of certainty. It includes detailed characterisation of substrate and vegetated habitats in the broad-scale assessment (Table 7) and expanded fine-scale indicators, including macroinvertebrates (Table 8). While this level requires significantly more time and resources, it provides the most comprehensive basis for assessing ecological condition and trends.

The choice of indicators and monitoring tier will depend on regional priorities and the specific issues that need to be addressed.

Whangarae Estuary on the outer Marlborough coast.

Table 7. Example of a tiered broad-scale monitoring approach, allowing a flexible 'mix and match' approach where different tiers can be selected for each indicator.

Indicator	Basic	Intermediate	Comprehensive
Key elements of each tier	Desktop assessment	Ground-truthing of aerial or satellite imagery	Ground-truthing of aerial or satellite imagery, plus detailed characterisation of indicators
Substrate	Visible extent (e.g., hard vs soft substrate)	Ground-truthed extent of substrate types classified into broad substrate classes (e.g., boulder, cobble, gravel), and classification of unconsolidated sand and mud based on qualitative assessment of texture and mud content. Limited validation of substrate type with grain size samples.	As for intermediate tier, plus systematic sediment sampling to validate qualitative sand and mud classifications, and to more quantitatively delineate substrate boundaries.
Salt marsh	Visible extent	Ground-truthed extent of salt marsh classified into broad salt marsh sub-classes (e.g., rushland, herbfield).	As for intermediate tier, plus composition of dominant salt marsh species (e.g., species with cover ≥20%).
Mangroves	Visible extent	Ground-truthed extent of mangrove patches and classification into structural sub-classes (tree, sapling, seedling, pneumatophore).	As for intermediate tier, plus assessment of percent cover within each structural sub-class patch.
Seagrass	Visible extent	Ground-truthed extent of seagrass patches and assessment of percent cover within each patch.	As for intermediate tier, plus assessment of the percent cover of visually obvious stressors on seagrass health (e.g., percentage of sediment smothering across a patch).
Macroalgae	Visible extent	Ground-truthed extent of macroalgae patches and assessment of percent cover within each patch.	As for intermediate tier, plus collection of data on biomass and sediment entrainment for each patch.

Broad-scale mapping in Kokorua Estuary, Nelson.

Table 8. Example of a tiered fine-scale (FS) monitoring approach, illustrating the expansion of indicators from Basic to Comprehensive. Effort additive to a previous tier is indicated with a plus (+).

Site-specific indicators		Basic	Intermediate	Comprehensive
Key elements of each tier		Grain size & qualitative FS site indicators	+ Quantitative FS sediment quality & sedimentation	+ Quantitative macroinvertebrate cores and other biota indicators
Sedimentation				
Sediment plates		*Not sampled*	✓	✓
Sediment quality				
Qualitative enrichment[1]		✓	✓	✓
aRPD		✓	✓	✓
Grain size (%mud, sand & gravel)		✓	✓	✓
TOC		*Not sampled*	✓	✓
TN & TP[2]		*Not sampled*	✓	✓
Toxicants (e.g., metals)[3]		*Not sampled*	✓	✓
Sediment biota				
Macroinvertebrates		*Not sampled*	*Not sampled*	✓
Epifauna	SACFOR[4]	*Not sampled*	✓	✓
	Quadrats (optional)[5]	*Not sampled*	*Not sampled*	✓
Macroalgae	SACFOR[4]	✓	✓	✓
	Quadrats (optional)[5]	*Not sampled*	*Not sampled*	✓
Microalgae	SACFOR[4]	✓	✓	✓
	Cores[6]	*Not sampled*	*Not sampled*	✓

[1] Qualitative enrichment status assessed based on sediment colour, odour & micro-organism growth, as per methods in Section 5.4.2.

[2] Total Phosphorus (TP) may be dropped from long-term monitoring if results show high collinearity with Total Nitrogen (TN) or Total Organic Carbon (TOC).

[3] Toxicants can be added as relevant to the estuary context (e.g., semivolatile organic compounds could be included in urban environments).

[4] SACFOR is a site-wide ordinal classification method for epibiota abundance or cover, as described in Section 5.5.2.

[5] Field-based quadrat assessment of epifauna abundance, and percent cover of macroalgae, is included as an optional method. For macroalgae, photoquadrats can also be taken for post-field percent cover quantification.

[6] Core sampling for microalgae is for analysis of chlorophyll-*a* and phaeopigments. Microalgae extent in eutrophic systems can also be assessed using qualitative enrichment criteria (as per footnote 1).

Undertaking fine-scale sampling in Chaslands/Waipati Estuary, Otago.

6.3 MONITORING FREQUENCY

The focus of the broad- and fine-scale documents is on providing consistent methods for individual estuary surveys. While the method documents provide guidance on monitoring frequency, this is a consideration that is inherently linked to monitoring purpose and programme design. Frequency is also dictated by the extent of natural variability in monitoring indicators, and the time-scales over which changes in pressures are expected.

For example, relatively stable features like salt marshes in low-pressure areas may only require assessment every 5–10 years, whereas dynamic features such as nuisance macroalgal blooms or sedimentation may warrant annual monitoring to support timely management actions. Monitoring frequency can be adapted within the programme design to align within monitoring objectives and remain within resource constraints.

Current monitoring frequency employed by councils varies considerably across and within regions in New Zealand [3], largely due to differences in management goals, monitoring objectives, and resource constraints.

For councils with severely constrained estuary budgets, broad- and fine-scale monitoring is typically undertaken at intervals of ~5 years. In this situation, assessment of estuary health relies primarily on interpreting indicator values against condition thresholds such as described in Stevens et al. (2024) [11]. In this way, the state of an estuary can be assessed, however a picture of temporal change may only emerge over decadal time-scales. A drawback of infrequent monitoring is that important determinants of estuary health may change across shorter time-scales and therefore not be captured well by infrequent monitoring. These include anthropogenic influences such as sediment release from forestry logging [24], storm or flooding events, and climatic phenomena such as marine heatwaves and the El Niño Southern Oscillation [25]. Furthermore, where changes in estuary health are subtle and unlikely to be apparent from a state assessment alone, necessary management interventions may be delayed.

Accordingly, councils that invest more in estuary monitoring tend to undertake state assessments relatively frequently, often annually (e.g., annual monitoring of sedimentation and fine-scale or other site-specific indicators), or even more often. The focus of this type of work has primarily been on trend detection. For example, to detect trends and tipping points with macroinvertebrates, monitoring at least twice per year (up to six times per year) for 15 years was recommended by Hewitt [25] based on experience in Auckland estuaries. In the Waikato region, a time-series of ~10-years of annual monitoring was recommended for trend detection for sedimentation and macroinvertebrate indicators [26, 27]. A few other councils with estuary SOE programmes have also shown the benefits of regular (annual or near-annual) sampling in terms of trend detection [28-30]. However, there appears to have been much less effort to quantitatively establish the drivers of trends, which is of critical importance if the purpose of monitoring is to clearly link monitoring findings to management actions (see Section 5.2.3).

Broad-scale mapping in Owāhanga Estuary, Manawatu/Wanganui.

6.4 PROGRAMME DESIGNS TO OPTIMISE MONITORING

There are several design approaches that can be applied to balance scientific rigour with practical constraints like budget and staff resourcing discussed above. This section briefly describes some common monitoring design frameworks that could be applied in either initial programme setup or programme review by adjusting both effort and monitoring frequency.

In practice, these design frameworks are often used together to maximise spatial representativeness, minimise costs, and ensure that both estuary condition and trends are detected in a way that informs management actions.

6.4.1 Risk-based design

A risk-based design focuses monitoring resources in estuaries where there is a high likelihood of degradation and where the potential consequences of that degradation are severe and/or irreversible. For example, monitoring may target estuaries in moderate condition and at risk of 'tipping' into an irreversibly degraded state. In contrast, reference estuaries may be considered low-risk, while highly degraded estuaries may have already passed key ecological thresholds and offer limited opportunity for management action.

Risk-based monitoring can also be applied to specific indicators. For example, if sediment is a significant stressor within a region or estuary, sedimentation monitoring may be prioritised over other types of broad- and fine-scale indicators.

6.4.2 Sentinel site monitoring

A sentinel site is an estuary or fine-scale site that is strategically selected in high priority systems to provide early warning or representative information about environmental changes or emerging issues. These estuaries or sites are typically monitored comprehensively (see Section 6.2) at a consistent frequency over time to detect long-term trends. This approach is often used where comprehensive monitoring across a whole region or estuary is impractical. Sentinel sites are most useful where the sites are representative of multiple estuaries or sites within estuaries and can be used as a proxy for assessing broader regional issues.

Depending on the monitoring goals and objectives, a sentinel site may be a reference (undisturbed) estuary used to track natural variability, or it may be an estuary at risk of degradation from regionally common stressors such as sedimentation, nutrient enrichment and other contaminants.

6.4.3 Temporal nesting design (rotating sampling)

A temporal nesting design involves monitoring a subset of sites across different years on a repeat cycle. This approach increases spatial coverage over time and allows for the detection of trends while balancing cost and resourcing. It is typically implemented following a period of intensive sampling to characterise natural variability and ensure that reduced sampling frequency will not compromise the effectiveness of the programme. Auckland Council apply this method in their fine-scale monitoring programme with sentinel sites monitored comprehensively and frequently, and rotational sites monitored periodically [e.g., for 2-years every 5 years; 31].

6.4.4 Stratified design

Estuaries within a region are grouped into categories based on shared characteristics, such as estuary type (e.g., SIDE, SSRTRE), stressors (e.g., land use), geographic area, or ecological zones (for fine-scale monitoring). By stratifying estuaries in this way, targeted sampling can be designed for each sub-group, ensuring representative coverage of each estuary type and stressor gradient. Comparing estuaries within stratified sub-groups (e.g. SIDES) also reduces variability in the dataset, improving the ability to detect trends at the sub-group scale. Results can be extrapolated to infer condition and/or trends within each sub-group.

6.4.5 Spatial nesting design

The NEMP is fundamentally designed as a nested monitoring framework, in which data are collected at multiple, hierarchically-organised spatial scales (Fig. 5). For example, regional-level comparisons are made across multiple estuaries within a broad geographic area; broad-scale monitoring is undertaken at the whole-estuary level; and fine-scale monitoring targets sites within an estuary with the most intensive monitoring focused on tracking the response to priority stressors.

Importantly, a spatial nested design can also be applied within the broad- and fine-scale frameworks. For example, the Basic tier could be implemented in multiple estuaries to provide broad regional surveillance, with a subset (e.g., sentinel sites) monitored at a 'Comprehensive' tier. A key advantage of this design is the efficient and strategic use of monitoring resources, allowing monitoring effort to be tailored to management priorities.

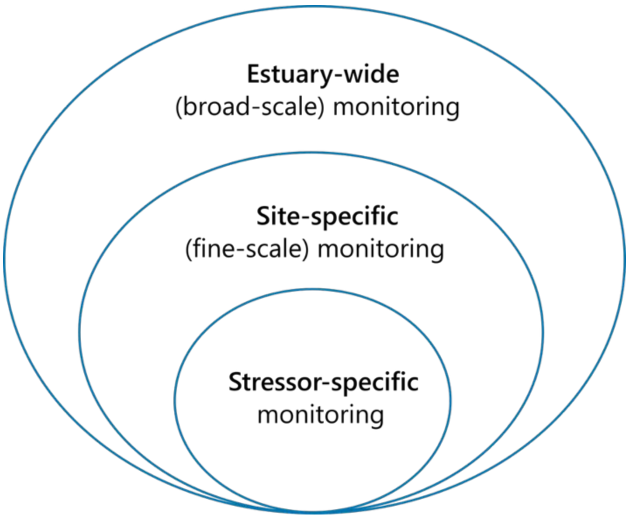


Fig. 5. Conceptual diagram of how broad- and fine-scale methods can be adapted to a nested design.

6.4.6 Example of a regional monitoring design following a programme review

Marlborough District Council (MDC) undertook a review of its estuary monitoring programme following the assessment of baseline conditions in several estuaries, and more comprehensive monitoring in one estuary (Havelock) since 2001 [32]. MDC sought a programme design that would address gaps in the SOE programme, within the constraints of limited budget and staff resourcing, while also meeting political and stakeholder expectations.

The revised programme (summarised in Table 9) grouped 57 estuaries into three levels of priority: high, medium, and low. Five high priority estuaries (i.e., sentinel estuaries that covered a range of estuary types and pressure gradients) are monitored comprehensively for both broad- and fine-scale indicators at ~5-10 yearly intervals. Fifteen medium priority estuaries are monitored for broad-scale indicators at 10-yearly intervals, while 37 low priority estuaries receive monitoring akin to a 'high-level snapshot' (see Section 2) approximately every 5-10 years. Because sedimentation is an issue in several estuaries, targeted sediment plate monitoring is undertaken annually in key sites across both high and medium priority estuaries.

As discussed, adjusting monitoring effort and frequency inevitably involves trade-offs. In this case, MDC opted for greater spatial coverage rather than high-frequency monitoring in one estuary, due to budget constraints. This example of a monitoring programme design incorporates tiered levels of effort, sentinel site monitoring, and stratified, spatial nested and risk-based designs.

Table 9. Example of a regional SOE monitoring schedule for quantitative long-term NEMP-type monitoring, Marlborough District Council. The table shows broad- and fine-scale monitoring at five representative high-priority estuaries (~5 yearly), broad-scale monitoring in 15 medium-priority estuaries (~10 yearly), and annual monitoring of priority stressors (i.e., sedimentation) in seven at-risk estuaries. In addition, monitoring akin to a 'high-level snapshot is scheduled in another 37 low priority estuaries (~5-10 yearly).

		Estuary	Interval	2000/01		2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32		2032/33	2033/34	2034/35	2035/36	2036/37	2037/38
Sentinel Sites	Broad scale mapping	Motuweka (Havelock)	5-yr	✓				✓					✓					✓					✓				10-yr programme review		✓				
		Ōkiwa Bay	5-yr			✓						✓							✓					✓						✓			
		Anakoha Bay	5-yr																✓					✓						✓			
		Whangarae Estuary	10-yr							✓							✓											✓					
		Wairau Lagoon	5-yr						✓						✓						✓	✓									✓		
	Fine scale monitoring	Motuweka (Havelock)	5-yr	✓				✓	✓		✓		✓					✓					✓						✓				
		Ōkiwa Bay	5-yr																✓	✓	✓^					✓						✓	
		Whangarae Estuary	5-yr							✓							✓					✓						✓					✓
At-risk estuaries	Sediment plate monitoring in at-risk estuaries	Motuweka (Havelock)	1-yr					✓	✓			✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
		Okiwa Bay	1-yr																	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
		Kaiuma Bay	1-yr								✓				T		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
		Kenepuru Estuary	1-yr												T		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
		Mahakipawa Arm	1-yr												T		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
		Ohinetaha	1-yr												T		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
		Whangarae Estuary	*							✓							✓					✓						✓					✓
Medium priority estuaries	Broad scale mapping	QCS - Ahuriri Bay	~10-yr											✓											✓		10-yr programme review						
		QCS - Shakespeare Bay	~10-yr							✓										✓											✓		
		QCS - Waikawa Bay	~10-yr							✓										✓											✓		
		QCS - Whatamango Bay	~10-yr									✓													✓								
		QCS - Ngakuta Bay	~10-yr			✓						✓									✓											✓	
		Pelorus - Broughton Bay	~10-yr											✓											✓								
		Pelorus - Ohinetaha Bay	~10-yr											✓											✓								
		Pelorus - Crail Bay	~10-yr											✓												✓							
		Pelorus - Kaiuma Bay	~10-yr								✓												✓										
		Pelorus - Kenepuru Estuary	~10-yr									✓														✓							
		Pelorus - Mahakipawa Arm	~10-yr								✓													✓									
		Pelorus - Tennyson Inlet	~10-yr									✓													✓								
		Pelorus - Nydia Bay	~10-yr															✓											✓				
		Pelorus - Clova Bay	~10-yr																		✓											✓	
		D'Urville - Mill, Smylies, Punt	~10-yr									✓														✓							

^Review data from year 1 and 2 to determine whether a third fine-scale baseline year is required.
*Due to the remote location, monitoring frequency depends on the capacity of the council.
#10-year programme review built into the monitoring plan.

7. SOE PROGRAMME REVIEW

7.1 OVERVIEW

A critical component of any successful estuary monitoring programme is regular review, evaluation and refinement (see Fig. 3). Intermittent reviews ensure that:

- Monitoring methods continue to provide the required level of data quality;
- Results are effectively informing management decisions;
- The programme remains responsive to emerging environmental pressures, new scientific insights, and evolving policy needs; and
- There are mechanisms within the programme for updating methods, sites, and indicators as needed.

7.2 ROUTINE AND PERIODIC REVIEWS

While periodic checks should be built into routine reporting cycles, detailed programme reviews are recommended following:

- Major changes in estuary condition or pressures;
- The development of new monitoring technologies or methods;
- A standard monitoring cycle (e.g., every 5–10 years); or
- Completion of an initial baseline dataset for an estuary or multiple estuaries within a programme.

Routine reporting should include a quantitative synthesis and analysis of the monitoring data, aiming to evaluate the spatial and/or temporal patterns in ecological condition and pressures. This synthesis is an opportunity to refine programme design based on actual performance, scientific progress, and practical experience (see Fig. 3 & Section 6.4.6).

7.2.1 Key questions addressed in a review

Programme reviews should consider the following types of questions:

- Does the programme achieve the monitoring objectives?
- Have management goals or regulatory requirements changed?
- Does the programme appropriately balance cost and effort with scientific rigour and council needs?
- Are there any emerging risks, pressures, or knowledge gaps that require attention?
- Does the programme adequately represent regional priorities for estuaries? Are sentinel sites still representative? Do more estuaries require monitoring?
- Do current indicators and the frequency of monitoring reliably detect change (i.e., are indicators sensitive enough to distinguish anthropogenic ecological change from natural variability)?
- If management actions informed by monitoring data have been implemented, can the programme detect ecological improvement? Or are new indicators or methods required?
- Is site-specific monitoring occurring in optimal locations, and is spatial coverage sufficient to detect meaningful change?
- Where changes in habitat or condition have occurred, can these be statistically or qualitatively linked to potential drivers, such as changes in land use, mass loads of sediments or nutrients, or climate-related factors? Is there adequate data on drivers to make these assessments?
- Can detected changes be linked to any management actions? If not, was the programme designed with the management goals and objectives in mind? Noting this may not be relevant for reference sites or sites designed for early detection of change (i.e., where management action may not be required).
- Is the current fine-scale sampling effort justified? For example:
    - If contaminant concentrations (e.g., trace metals) are consistently below detection limits, can sampling frequency or parameters be adjusted?
    - Can the number of macroinvertebrate cores be reduced without compromising statistical power or monitoring objectives?
- Are sampling events aligned with key seasonal or episodic processes (e.g., algal blooms, storm runoff events)?

7.2.2 Recommendations and iteration

Findings from the review should be clearly documented and communicated to stakeholders. Where necessary, adjustments to the programme should be planned and implemented, including updates to:

- Monitoring design (e.g., frequency, spatial coverage, site selection),
- Methodologies (e.g., field or lab protocols),
- Reporting structures, and
- Management integration strategies.

Programme review is a crucial component of any effective monitoring programme. However, if changes are made to the programme design, indicators, or methods, it is important to consider the influence they will have on the long-term dataset, particularly where the programme has been designed to detect trends. Changing lab protocols, for example, may require a period of paired sampling to minimise artificial step-changes in the dataset. Ultimately, taking these factors into consideration, monitoring programmes must be adaptive - capable of evolving in step with scientific knowledge, estuarine dynamics, and management priorities. Programme reviews are a vital tool for ensuring the monitoring is responsive and maintains long-term relevance.

8. BROADER CONSIDERATIONS AND FUTURE DIRECTIONS

8.1 RECOMMENDED NEMP METHOD SUPPORT TOOLS

The NEMP approach and methods have been updated, within a confined scope, to standardise data collection for key indicators. However, additional supporting tools could further strengthen both the broad- and fine-scale protocols. In particular, the development of visual field guides would be valuable to assist field teams nationally to conduct NEMP surveys consistently. Three key guides are recommended, to address potential issues arising from qualitative estimation and variance among observers:

1. A visual guide for the assessment of seagrass, macroalgae, and mangrove percent cover.
2. A visual guide and criteria for the assessment of sediment oxygenation (aRPD depth).
3. A visual guide to support consistent substrate classification.

Field training in the application of all three guides is also recommended.

8.2 COMPLEMENTARY APPROACHES AND SAMPLING METHODS

8.2.1 Meso-scale monitoring

A key gap in the original NEMP, that remains in the current revision, was the disconnect between broad- and fine-scale monitoring, highlighting a potential need for 'meso-scale' methods [3]. NEMP methods could be modified to help 'fill the gaps' by collecting targeted information at intermediate spatial scales. For example, fine-scale indicators such as sedimentation rate and grain size could be adapted to meso-scale applications using flexible configurations, including:

- Spot measurements across a broad area.
- Transects across habitat or substrate transitions.
- Focused measurements at specific sites.

These approaches may be used to:

- Improve certainty of habitat/substrate boundaries.
- Provide validation data for mapping.
- Track temporal variability in sediment accumulation and mud content.

Similarly, fine-scale indicators such as sediment quality and macroinvertebrates can be adapted to characterise ecological communities across a range of substrate types and habitats [e.g., 33, 34, 35]. For example, in Mangonui Estuary, McCartain and Hewitt [34] expanded the spatial coverage of fine-scale sampling to 17 sites across a 600ha intertidal estuary, each with triplicate macroinvertebrate and a single composite sediment chemistry sample, providing a meso-scale understanding of macroinvertebrate communities across a range of substrate types.

This approach could also be applied in a pilot study prior to establishing long-term fine-scale sites. It would facilitate:

- Identification of degraded areas (e.g., with elevated contaminant levels or signs of nutrient enrichment);
- Identification of the best habitats for monitoring (e.g., sites that support diverse and abundant macroinvertebrate communities); and
- Informed decisions on monitoring frequency and the appropriate monitoring tier.

Monitoring methods could also be modified depending on the level of detail required. For instance, coarse sieves (e.g., 20mm) could be used to assess shellfish presence, high-level macroinvertebrate abundance and richness could be rapidly assessed by sieving and sorting in the field, or be more rigorously quantified by collecting a smaller number of sediment cores for standard laboratory analysis.

8.2.2 Other methods

Many other estuary sampling approaches have been developed and applied in New Zealand, expanding the range of tools available for ecological assessment beyond those described in the NEMP. These include:

- Remote sensing and LiDAR-based mapping of intertidal vegetation using classification algorithms [36-38].
- Drone surveys combined with field validation to assess substrate, vegetation, and habitat types [39].
- Seagrass health assessment methods [40].
- Integrated approaches combining broad-scale ecological habitat classification and extensive fine-scale sampling, with statistical methods used to interpolate between fine-scale sampling sites [e.g., 41, 42].

These examples demonstrate the diversity of monitoring scales and methods available, each providing different types of ecological information and levels of confidence.

8.3 ADDITIONAL INDICATORS

There are a range of additional indicators that could be developed for future NEMP updates. Recommendations on a range of estuary-wide and site-specific indicators suited for use with developed or developing thresholds are provided in the MfE-commissioned *Advice on Indicators, Thresholds and Bands for Estuaries in Aotearoa New Zealand* [11] and are not repeated here.

In addition, the following suggestions (in no specific order) are made for future consideration, along with brief explanations of potential relevance and application. Data for some of the suggested components are already collected under SOE or other monitoring or research programmes, or can be derived from existing data (e.g., perimeter hardening).

Habitat Change and Climate Adaptation

1. <u>Estuary perimeter hardening extent:</u> Map and quantify artificial structures (e.g., seawalls, revetments) around estuary margins to identify areas where inland habitat migration (e.g., of salt marshes) is restricted due to armouring. Useful for climate change adaptation planning.
2. <u>Future salt marsh migration zones:</u> Map landward areas adjacent to existing salt marshes with potential to support migration under sea-level rise. Highlights conflicts with infrastructure and opportunities for managed retreat or restoration.
3. <u>Predicted salt marsh loss areas:</u> Identify current salt marsh at risk of displacement from sea-level rise inundation. A key input for assessing estuary vulnerability and prioritising protective measures.
4. <u>Historic estuary extent and habitat reconstruction:</u> Compare current extent of intertidal flats, salt marsh, and seagrass with historic (natural state) conditions to quantify habitat loss and guide restoration baselines.

Hydrological and Physical Connectivity

5. <u>Riparian disturbance:</u> Map land use within a defined buffer (e.g., 100m) around estuaries as an indicator of margin pressure.
6. <u>Tidal exchange barrier inventory:</u> Identify structures (e.g., culverts, causeways, flap-gates) that reduce or alter tidal flow. Important for understanding hydrological fragmentation, flushing, and potential restoration priorities.

Biological Communities and Habitat Types

7. <u>Rocky/hard habitat community characterisation:</u> Inventory the flora and fauna of non-soft sediment habitats (e.g., rock, cobble, gravel) to broaden ecological scope beyond mud- and sand-dominated systems.
8. <u>Fish community composition:</u> Monitor fish diversity, abundance, and nursery habitat function. Important for holistic ecosystem assessment.
9. <u>Bird habitat usage and roosting patterns:</u> Monitor and map shorebird and wader feeding, roosting, and nesting sites. Crucial for species protected under national and international agreements (e.g., Ramsar).
10. <u>Shellfish distribution and biomass:</u> Monitor culturally and ecologically important bivalves (e.g., cockles, pipi), including size-class and density. Can indicate both ecosystem health and human harvest sustainability.
11. <u>Biological habitat type classification (vs substrate type classification):</u> Differentiate habitats by biological structure and community, (e.g., dense cockle or pipi beds) as opposed to sediment class (e.g., sand, muddy sand, sandy mud). Adds ecological nuance beyond basic substrate maps and expands beyond physical characteristics to include biological roles, e.g., filtration by shellfish

beds, oxygenation by burrowing macro-invertebrates, or erosion control by vegetation.

12. Invasive species mapping: Target the identification of invasive taxa (e.g., *Spartina* spp., Asian date mussel, Pacific oyster) and map spatial distribution and expansion. Helps guide eradication and biosecurity efforts.
13. Sub-tidal substrate and habitat mapping: characterise subtidal habitats to provide a more holistic picture of estuary health.

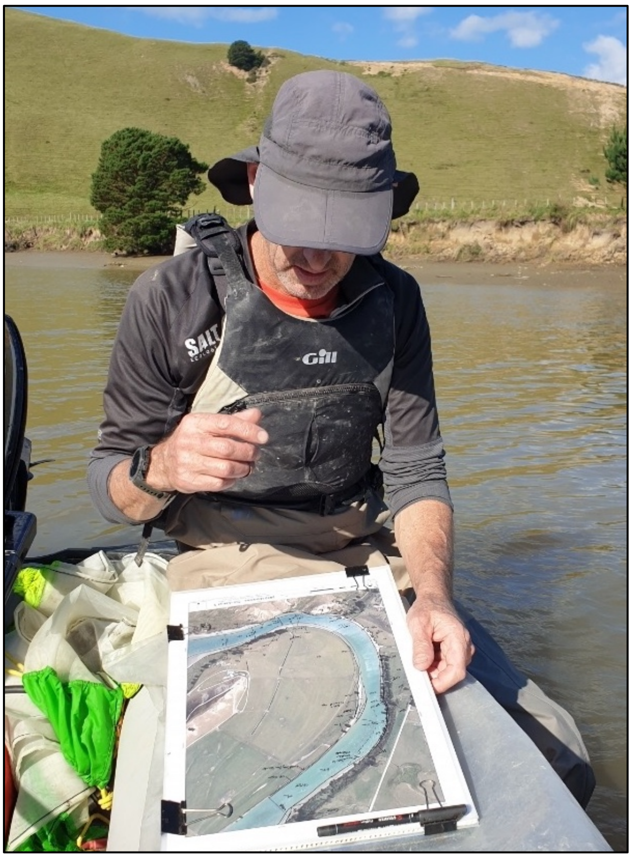
Habitat Quality and Ecosystem Health

14. Habitat quality indices: Integrate factors such as organic enrichment, anoxia, vegetation condition, and faunal diversity into a single quality score per habitat patch.
15. Trophic state indices: Review the Estuary Trophic Index [ETI; 14] to evaluate whether combining individual indicators provides an enhanced measure of estuary-wide trophic state.
16. Macroinvertebrates indices: To support national application of indices widely-used in fine-scale data analysis (e.g., Benthic Health Model, AMBI), undertake further development and refinement such as recommended by Stevens et al. (2024) [11].
17. Eutrophic habitats: Define and map areas indicating extreme levels of organic or nutrient enrichment, e.g., sediments depleted in (or devoid of) oxygen, which have a very shallow aRPD (e.g., <5mm), an intense black colour in the sediment profile, and typically have a strong hydrogen sulfide (i.e., rotten egg) smell.

Environmental Parameters

18. Water clarity: Monitor water clarity. While spatially and temporally variable, clarity is a primary constraint on photosynthesis.
19. Water quality indicators: In sub-tidally dominated estuaries monitor water quality indicators, noting that many councils already monitor estuary water quality following methods laid out in National Environmental Monitoring Standards.

The above indicators would support a more holistic and forward-looking approach to estuary monitoring in New Zealand, particularly in the context of climate change, ecological restoration, and biodiversity protection. Their development could be phased in as new technologies, capacity, and resources become available, and would ideally align with Māori cultural values such as ki uta ki tai and mauri ora.



Recording broad-scale mapping details on aerial photos, Owāhanga Estuary, Manawatu/Wanganui.

Sediment plate monitoring Porirua Harbour, Wellington.

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APPENDIX 1. HIGH-LEVEL SNAPSHOT ASSESSMENT

A high-level snapshot assessment of broad-scale indicators can be done via a desktop review of aerial or satellite imagery, or a field-based estuary walkover, both offering a qualitative overview of estuary health which may assist when setting monitoring priorities. High-level snapshots can be used to check estuary condition and/or explore coarse spatial changes over time. Key indicators include areas of nuisance macroalgae, (e.g., *Gracilaria* spp.), seagrass (if present), physical damage to habitats, potential barriers to habitat migration in response to sea level rise, areas of mud deposition, nutrient enrichment, and/or obvious point-source discharges. Because sparse to moderate (1% to <50%) covers of macroalgae or seagrass are often hard to detect on imagery, field-based methods are preferable when assessing estuaries which are at risk of macroalgal blooms or seagrass loss.

Seagrass change in Whanganui Inlet showing extensive 2004 cover (top) and near complete loss in 2022 (bottom) (photo source: TDC).

DESKTOP REVIEW OF IMAGERY

1. **Source imagery.** Most councils have access to high resolution aerial imagery. If not, free imagery can often be sourced from LINZ Data Service or through research organisations or universities, or purchased from satellite imagery providers (e.g., Apollo Mapping, Planet Labs, Critchlow Geospatial). Lower resolution (~15m/pixel) imagery can be sourced from Google Earth. For temporal comparisons, historic imagery can be sourced from retrolens.co.nz or Google Earth History.

Vehicle damage (right of image) in salt marsh herbfield in New River Estuary (image source: Google Earth).

2. **Conduct a visual inspection of the imagery** to identify any clear signs of habitat degradation or change, e.g., seagrass loss (see upper right photos), salt marsh loss or damage (middle photo), changes in nuisance macroalgae (lower right photos), and/or mangrove loss or expansion.
3. **Assess outcomes and options**:
   a) <u>If no temporal change, pressures, or impacts are identified,</u> further monitoring is unlikely to be necessary unless detailed characterisation of estuary features is required.
   b) <u>If a change or impact has occurred</u>, cross-reference observed changes with known environmental data (e.g., freshwater flows, temperature), consent data (e.g., point sources, physical modification), local knowledge and/or obvious changes on the imagery (e.g., physical damage from vehicle tracks, reclamation). Where there is no obvious cause of change, or the change is deemed significant, more detailed monitoring and assessment is likely required.

Localised increase in sediment-entrained nuisance macroalgae (*Gracilaria* spp.) from 2014 (top) to 2022 (bottom) in Nelson Haven.

ESTUARY WALKOVER

> **Note!** Qualitative estuary walkovers and targeted observations can be integrated into other field activities, such as fine-scale or sediment plate monitoring, or adjacent wetland and dune monitoring, and can be undertaken by council scientists, mana whenua or other stakeholders.

1. Review desktop data and imagery to identify areas of interest.
2. Plan a route or identify target areas that cover key intertidal habitats and potential problem areas. It can be helpful to print an overview map of the whole estuary to annotate in the field.
3. Walk the planned route or target area, visually assessing intertidal habitat features for obvious stressors, e.g., areas of nuisance macroalgae, particularly species known to persist (e.g., *Gracilaria* spp.), seagrass (if present), physical damage to habitats, potential barriers to habitat migration in response to sea level rise, areas of mud deposition, nutrient enrichment, and/or obvious discharges.
4. Mark locations of interest with a GPS point and collect photos to facilitate temporal comparisons. Photos should ideally include identifiable landmarks (e.g., jetties, trees, rock features) that can be used as reference points in any subsequent qualitative temporal comparisons.
5. Document qualitative observations along with metadata, e.g., date, time, tide height, any offsets in tide timings with known tide stations.
6. Assess whether further monitoring or management is required.

A wide-spread bloom of a brown filamentous algae in Catlins River Estuary, Otago was detected in a broad-scale survey, and qualitatively assessed the following year to determine its persistence.

Estuary walkover to assess sediment impacts following a flood impacting Delaware Inlet, Nelson 2022.

Photos from New River Estuary in 2019 (top) and 2020 (bottom) showing the impacts of flood scouring on opportunistic macroalgal beds.

APPENDIX 2. ECOLOGICAL VULNERABILITY ASSESSMENT (EVA)

The EVA approach [see 8, 43] is based on the key characteristics (and their interactions) that affect the ecological vulnerability of an estuary, which can be partitioned into four categories as follows:

- Ecological Values: Habitat types, species of ecological or conservation significance, and habitat intactness.
- Pressures: Current/existing natural and anthropogenic pressures on the ecological values.
- Susceptibility: Eutrophication susceptibility based on physical characteristics, and vulnerability to future changes in state due to changes in pressures.
- Condition: Estuary condition with respect to qualitative or quantitative indicators of health.

The EVA is intended to enable different estuaries and estuary types to be compared in a consistent manner. Similar to the original NEMP decision matrix, within each of the four categories, specific attributes are recognised (Fig. A2.1). Many of the attributes apply broadly across estuary types, even though they may differ naturally. For example, tidal rivers generally have less areas of salt marsh than estuaries with larger intertidal areas; however, these are rated against the same thresholds to highlight where relatively rare values may be present within a region. While there are still some limitations to the approach (e.g., data availability, data quality, thresholds under development, requirement for a formal peer review), the EVA provides a coarse, but transparent, screening tool to set priorities for future monitoring and management.

A2.1. Data sources used in the EVA

The EVA can be carried out via a desktop assessment or combined with field-based data collection. A site visit is preferred for attributes requiring field assessment (e.g., phytoplankton, macroalgae, mud extent).

Common data sources include, but are not limited to, monitoring data, land use maps (e.g., LCDB5), iNaturalist, current aerial imagery (e.g., LINZ), historic imagery (e.g., Retrolens or Google Earth History), consent data (e.g., discharges), council plans (e.g., protected sites), national models (e.g., sediment or nutrient loads), and council and/or government reports.

Attributes for which data are unavailable should be highlighted as a knowledge gap. For these gaps, ratings can be estimated (applying a conservative rating score) based on expert opinion, or the attribute may be excluded for all estuaries, or only included for a subset of estuaries. Note that water quality attributes most relevant to sub-tidally dominated tidal river estuaries (i.e., phytoplankton, dissolved oxygen, water clarity) can, but do not need to be, included if assessing intertidally dominated estuaries.

A2.2. EVA scoring – raw values

Each of the four EVA categories are partitioned into the detailed attributes shown in Table A2.1, with a five-point rating scale for each attribute based on qualitative, semi-quantitative or fully quantitative descriptors. Thresholds for nutrients, macroalgae, phytoplankton and dissolved oxygen have been based on recent advancements for estuaries in New Zealand [11]. For ecological values and condition, a score of 5 indicates high values and good condition, whereas for pressures and susceptibility, 5 indicates high pressure and susceptibility.

A2.3. EVA scoring – weighting raw values

To emphasise attributes deemed to have a greater relative importance, a five-point weighting (e.g., in even increments from 0.2 to 1.0) may be applied to the raw values, with 1.0 being the highest weight and 0.2 being the lowest (Fig. A2.1). For example, a localised issue (e.g., marine contaminants) may receive a low weighting (0.2) while catchment land uses such as intensive agriculture and exotic forestry that can cause widespread long-term problems may receive a high weighting (1.0).

The same weighting for a given attribute should be applied consistently across estuaries to allow their direct comparison. This may be done at a regional scale or weighted in the broader context of New Zealand estuaries, or using risk assessment principles.

A2.4. EVA scoring – final category scores

To calculate a score for each of the four categories (i.e., ecological values, pressures, condition, and susceptibility) the final attribute scores for each category are averaged and standardised to 1.0 as shown in Fig. A2.1. The category scores enable closer interrogation of the EVA data. For example, the category scores can highlight estuaries that have both high ecological values and are at high-risk of future degradation (e.g., significant pressures and high susceptibility). As final category scores will be affected by the specific attributes included for each estuary (e.g., some attributes may be excluded from some estuaries due to a lack of data or relevance), it is better to compare relative differences across estuaries rather than absolute category scores.

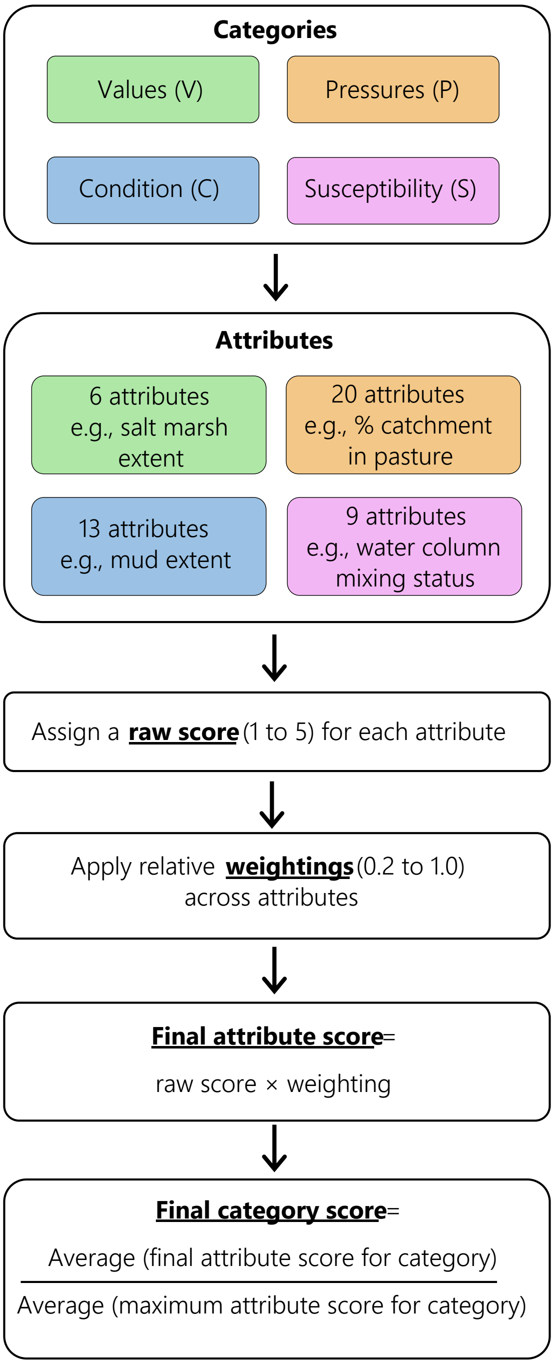

Fig. A2.1. Conceptual diagram of the EVA method.

Table A2.1. Ecological Vulnerability Assessment – Attribute thresholds that correspond to raw score values (1 to 5) for ecological values.

Raw score values	**Very Good (5)**	**Good (4)**	**Fair (3)**	**Poor (2)**	**Very Poor (1)**
Ecological Values					
Area of estuary (ha) Value of the estuary increases with the area of the resource	>50	>20-5	>5-20	0.5-5	<0.5
Habitat Intactness (%) A subjective appraisal of the overall intactness and health of the site relative to estimated natural state.	>80 to 100% of the site is considered healthy and intact	>60 to 80% of the site is considered healthy and intact	>40 to 60% of the site is considered healthy and intact	>20 to 40% of the site is considered healthy and intact	>0 to 20% of the site is considered healthy and intact
Seagrass (extent; % of intertidal area) Provides erosion control, nutrient uptake, sediment deposition and wave dissipation, shelter and nursery for fish and other biota and carbon sequestration.	>20	>10 to ≤20	>5 to ≤10	>0 to ≤5	0
Salt marsh (extent; % of intertidal area) Provides erosion control, nutrient uptake, sediment deposition and wave dissipation, habitat, shelter and nursery for fish, roosting area for birds, and carbon sequestration.	>20	>10 to ≤20	>5 to ≤10	>0 to ≤5	0
Mangroves (extent; % of intertidal area) Provides erosion control, nutrient uptake, sediment deposition, wave dissipation, shelter and habitat and nursery for fish and other biota and carbon sequestration.	>20	>10 to ≤20	>5 to ≤10	>0 to ≤5	0
Intertidal shellfish beds (indigenous) Filter feeders improve water clarity, filter sediment and microphytobenthos	Common ≥10% across estuary including high density areas ≥10 individuals per $1m^2$	Frequent ≥5 to <10% across estuary or ≥10 - <100 individuals per $10m^2$	Occasional ≥1 to <5% across estuary or 1 - <10 individuals per $10m^2$	Rare <1% across estuary or <1 individual per $10m^2$	Absent No visible individuals
Biogenic reef (% across estuary) Increases habitat complexity, nursery for juvenile fish. e.g. tube worms, bryozoans, mussel beds, oyster reefs, sponges	Common ≥10%	Frequent ≥5 to <10%	Occasional ≥1 to <5%	Rare <1%	Absent 0%
Species of conservation significance Threatened or at-risk species e.g. birds: Caspian tern, banded rail e.g. diadromous fish: giant kokopu, lamprey, koaro, longfin eel	Supports nationally endangered or vulnerable species which are not commonly found in other countries.	Supports nationally endangered or vulnerable species or part of known range for nationally critical species.	Supports species in serious or gradual decline or known habitats for endangered or vulnerable species.	Supports endemic and non-threatened species or known habitats for at risk or endemic species.	Supports only non-threatened or migrant species
Protected status (within or adjacent to estuary i.e., terrestrial or marine) e.g. significant marine area, regionally significant wetland (inc. salt marsh), conservation areas, parks or reserves.	Designated Significant Marine Sites or regionally significant wetland within the estuary margin.		Designated Protected Area adjacent to the estuary margin.		None

Table A2.1. continued. Ecological Vulnerability Assessment – Attribute thresholds that correspond to raw score values (1 to 5) for pressures.

Raw score values	Very low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Pressures					
Catchment					
Exotic Forest (% catchment) During establishment and harvest this land use can lead to excess sediment run-off compared to natural land cover.	<10	≥10 to <25	≥25 to <50	≥50 to <80	≥80 to 100
High producing grassland (% catchment) Land use results in higher levels of sediment and nutrient run-off compared to natural land cover.	<10	≥10 to <25	≥25 to <50	≥50 to <80	≥80 to 100
Urban & industrial development (% catchment) Results in more impervious surfaces that promote run-off of stormwater. Increased probability of wastewater and industrial discharges (i.e., increased nutrients, heavy metals, bacteria, viruses).	0 No industrial or urban development.	>0 to <5 Low urban or industrial development	≥5 to <10 Moderate urban or industrial development.	≥10 to <15 High urban or industrial development.	≥15 Extensive urban or industrial development.
Horticulture (% catchment) Land use generally leads to higher use of pesticides and trace elements to promote crop growth.	0 No horticulture present.	>0 to <5 Low horticultural development.	≥5 to <10 Moderate horticultural development.	≥10 to <15 High horticultural development.	≥15 Extensive horticultural development.
Nutrient Load Thresholds for symptoms of eutrophication* (e.g. macroalgae growth)	Very low (<5 $mg/m^2/d$ or <175 mg/m^3)	Low (>5 to ≤10 $mg/m^2/d$ or 175 to ≤335 mg/m^3)	Moderate (>10 to ≤50 $mg/m^2/d$ or >335 to ≤495 mg/m^3)	High (>50 to ≤250 $mg/m^2/d$ or >495 to ≤1000mg/m^3)	Very High (>250$mg/m^2/d$ or >1000$g/m^2/d$)
Sedimentation rate (CSR:NSR ratio^) ^CSR = Current sedimentation rate, NSR = natural sedimentation rate	CSR 1 to 1.1 x NSR	CSR 1.1 to 2 x NSR	CSR >2 to 5 x NSR	CSR >5 to 10 x NSR	CSR >10 x NSR
Grazing animals in estuary and on margin Grazing animals can lead to direct destruction of high value habitat and increase bank erosion.	Very Low No access to estuary by farmed animals. No known signs of wild animal activity.	Low No access to estuary by farmed animals. Signs (e.g. browsing, pugging, rooting) of wild animal activity (e.g. deer, pigs)	Moderate Potential access for farmed animals i.e., farming on margin and possibility animals could break through fence on occasion.	High Unrestricted access for farmed animals i.e., no fencing and open access to the estuary.	Very High Unrestricted access for farmed animals (i.e., no fencing and open access to the estuary) and evidence of damage to the margin.
Altered Hydrology Modification of freshwater input or tidal flow (e.g. flap gates, culvert, channelised watercourse, high water abstraction etc).	Very low No modification, natural hydrology.	Low Minor localised modification, natural flows largely intact.	Moderate Moderate localised modification of hydrology, natural flows altered.	High Moderate modification of hydrology across a large area, natural flows altered.	Very high Extensively modified hydrology, natural flows highly disrupted (e.g., hydropower).

Table A2.1. continued. Ecological Vulnerability Assessment – Attribute thresholds that correspond to raw score values (1 to 5) for pressures.

Raw score values	**Very low (1)**	**Low (2)**	**Moderate (3)**	**High (4)**	**Very High (5)**
Pressures					
Contaminants (chemical & biological)					
Chemical contaminants - marine e.g. Trace metals, SVOCs, emerging contaminants	Little or no connectivity Remote location with little or no vessel activity. No marine structures or known anchorages within 500m.	Low connectivity Anchorage or 1 to 5 private berths/ moorings but no other marine structures within 500m.	Moderate connectivity Moderate density (>5-20) private berths/ moorings or other marine structures within 500m.	High connectivity High density (>20-50) private berths/ moorings or other marine structures within 500m, or commercial vessel route within 500m.	Very high connectivity Very high density (>50) private berths/ moorings or other marine structures within 500m, or commercial vessel route or port/ marina within 500m.
Chemical contaminants - terrestrial e.g. Trace metals, SVOCs, emerging contaminants	Very Low Unmodified catchment. No contaminant inputs.	Low	Moderate Moderate contaminant inputs (e.g. moderate urban, industrial or horticultural development in catchment)	High	Very High Likely significant contaminant inputs (e.g. stormwater, wastewater, horticulture etc)
Marine oil spill risk Proximity of shipping/vessel activity or port to intertidal estuary	Little or no connectivity Remote location with little or no vessel activity. No marine structures or known anchorages within 5km.	Low connectivity Anchorage or 1 to 5 private berths/moorings but no other marine structures within 5km.	Moderate connectivity Moderate density (>5-20) private berths/moorings or other marine structures within 5km.	High connectivity High density (>20-50) private berths/ moorings or other marine structures within 5km, or commercial vessel route within 5km.	Very high connectivity Very high density (>50) private berths/ moorings or other marine structures within 5km, or commercial vessel route or port/ marina within 5km.
Introduced marine species Connectedness to main source populations of estuarine non-indigenous species. Pathways include vessels, structures or proximity to known populations.	Little or no connectivity Remote location with little or no vessel activity. No marine structures or known anchorages within 5km.	Low connectivity Anchorage or 1 to 5 private berths/moorings but no other marine structures within 5km.	Moderate connectivity Moderate density (>5-20) private berths/moorings or other marine structures within 5km.	High connectivity High density (>20-50) private berths/ moorings or other marine structures within 5km, or commercial vessel route within 5km.	Very high connectivity Very high density (>50) private berths/ moorings or other marine structures within 5km, or commercial shipping route or port/ marina within 5km.

Table A2.1. continued. Ecological Vulnerability Assessment – Attribute thresholds that correspond to raw score values (1 to 5) for pressures.

Raw score values	Very low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Pressures					
Contaminants (chemical & biological)					
Phytoplankton algal blooms Phytoplankton blooms reduce water clarity, can lead to low oxygen conditions upon breakdown and can be harmful to shellfish/ fish.	No previous blooms		Occasional blooms		Re-occurring blooms (e.g. annual)
Pathogens Risk to ecology if exotic or indigenous pathogens are introduced (e.g. shellfish/fish) or emerge due to environmental pressures.	Very low pressures or little or no connectivity to likely terrestrial or marine (see biosecurity) sources.	Low pressures or low connectivity to likely terrestrial or marine (see biosecurity) sources.	Moderate pressures or moderate connectivity to likely terrestrial or marine (see biosecurity) sources.	High pressures or high connectivity to likely terrestrial or marine (see biosecurity) sources.	Very high pressures or very high connectivity to likely terrestrial or marine (see biosecurity) sources.
Human use					
Direct Human use Non-commercial use (e.g. recreation)	Very low Little or no use	Low Occasional use	Moderate Seasonal use	High High year-round use	Very High Very High year-round use
Direct Human use Commercial marine species harvest or aquaculture within estuary (e.g. shellfish harvest or marine farms). Presence of wharf, port or marina.	Very low None	Low Occasional harvest, no permanent aquaculture structures	Moderate Seasonal harvest, no permanent aquaculture structures	High Year-round harvest, no permanent aquaculture structures	Very High Year-round harvest and/or permanent aquaculture structures
Disturbance of wildlife Direct human access - level of protection.	Restricted e.g. fence around important habitat or breeding area.		Limited e.g. signage to prevent dog access		Unrestricted
Habitats					
Salt Marsh pressures (number of recorded pressures) Pressures include grazing/ vehicle damage, reclamation, drainage, erosion, weeds and other	≤1	2	3	4	≥5
Seagrass pressures (number of recorded pressures) Pressures include macroalgal smothering, epiphytic growth on leaves, sediment smothering, leaf die-off, physical erosion and grazing or other	≤1	2	3	4	≥5
Fish passage Many of New Zealand's fish species migrate between freshwater and marine environments as part of their lifecycles. Infrastructure can inhibit the natural connectivity reducing the abundance of these species.	Very Low No barriers to fish passage		Moderate Partial barrier to fish passage (i.e., not all access is restricted)		Very High Complete barrier to fish passage (i.e., all access is restricted)

Table A2.1 continued. Ecological Vulnerability Assessment – Attribute thresholds that correspond to raw score values (1 to 5) for susceptibility.

Raw score values	Very low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Susceptibility					
Current physical susceptibility to eutrophication					
Estimated Physical Susceptibility Overall susceptibility of an estuary is, in part, dependent on dilution and flushing (see Robertson et al. 2016a)	High export Low susceptibility		Moderate export Moderate susceptibility		Low export High Susceptibility
Mixing status (i.e., well mixed, partially mixed, stratified) i.e. Stratification can influence dissolved oxygen concentration and phytoplankton growth.	Unlikely to stratify		Potential to stratify for short periods (<1 week)		Likely to stratify (>1week)
Extent of increase in pressures in <10 years					
Catchment pressures (e.g. forestry harvest, farming intensification, land disturbance)	Low		Moderate		High
Contaminants (chemical & biological) (e.g. increase in vessel numbers, marine structures, development)	Low		Moderate		High
Human Use (e.g. aquaculture expansion or intensification, population increase, increased accessibility to estuary)	Low		Moderate		High
Extent of increase in pressures in >10 y					
Catchment pressures (e.g. forestry harvest, farming intensification, land disturbance)	Low		Moderate		High
Contaminants (chemical & biological) (e.g. increase in vessel numbers, marine structures, development)	Low		Moderate		High
Human Use (e.g. aquaculture expansion or intensification, population increase, increased accessibility to estuary)	Low		Moderate		High
Adaptive capacity of estuary to sea level rise Ability of estuary to migrate landward with sea level rise (e.g. physical barriers to migration artificial or natural)	Very high No barriers to landward migration.	High Few barriers to landward migration, e.g. low intensity land use and/or low gradient coastal plain (slow inundation).	Moderate Some barriers to landward migration, e.g. high intensity land use and/or moderate gradient coastal plain.	Low Many barriers to landward migration, e.g. armouring, infrastructure, steep gradient coastal plain (rapid inundation).	Very low No meaningful capacity for landward migration (e.g. steep margin, rock, cliff)
Climate change adaptation and resilience (e.g. to rising sea temperatures, marine heat waves, ocean acidification, increased storm frequency etc)	Needs further development The criteria should consider exposure, sensitivity, and adaptive capacity. However, high resolution data at a regional scale is required to make a meaningful assessment.				

Table A2.1. continued. Ecological Vulnerability Assessment – Attribute thresholds that correspond to raw score values (1 to 5) for condition.

Raw score values	**Very Good (5)**	**Good (4)**	**Moderate (3)**	**Poor (2)**	**Very Poor (1)**
Condition					
Habitat					
Estimated historical salt marsh extent (% of historic salt marsh remaining) **estimated from known data sources or historic imagery*	≥80 to 100	≥60 to <80	≥40 to <60	≥20 to <40	<20
Proportion (%) of current salt marsh degraded *Pressures include grazing/ vehicle damage, reclamation, drainage, erosion, weeds and other	<20	≥20 to <40	≥40 to <60	≥60 to <80	≥80 to 100
% Seagrass decline from estimated baseline **estimated from known data sources or historic imagery*	<5	≥5 to <10	≥10 to <15	≥15 to <20	≥20
Proportion (%) of current seagrass degraded *Pressures include macroalgal smothering, epiphytic growth on leaves, sediment smothering, leaf die-off, physical erosion, grazing etc.	<20	≥20 to <40	≥40 to <60	≥60 to <80	≥80 to 100
Substrate					
Diversity of substrate types * Based on REA criteria.	≥5	4	3	2	1
Predicted sedimentation rate (mm/y)	0	>0 to <0.5	≥0.5 to <1	≥1 to <2	≥2
Mud extent (% intertidal)	<1	≥1 to <5	≥5 to <15	>15 to <50	≥50
Eutrophication					
Opportunistic macroalgae extent (% available intertidal habitat OR OMBT-EQR)	≤5 OR (OMBT ≥0.8 to 1.0)	>5 to ≤15 OR (OMBT ≥0.6 to <0.8)	>15 to ≤25 OR (OMBT ≥0.4 to <0.6)	>25 to ≤75 OR (OMBT ≥0.2 to <0.4)	>75 (OMBT 0.0 to ≥0.2)
Phytoplankton (µg/L) Categories dependent on salinity (ppt)	<3µg/L (>30ppt) <5µg/L (≤30ppt)	>3 to 8µg/L (>30ppt) <5 to 12µg/L (≤30ppt)	>8 to 12µg/L (>30ppt) >12 to 16µg/L (≤30ppt)	>12 to 16µg/L (>30ppt) >16 to 32 µg/L (≤30ppt)	>16µg/L (>30ppt) >32µg/L (≤30ppt)
Dissolved oxygen (mg/L) 1-day minimum	≥7mg/L	≥6.0 to <7.0mg/L	≥5.0 to <6.0mg/L	≥4.0 to <5.0mg/L	<4.0mg/L
Water clarity i.e., light penetration through water controls plant growth. Light penetration can be limited by the amount of suspended sediments in the water column, chlorophyll-*a* or tannins.	Water clarity to 100% of bottom depth	≥75 to <100% of bottom depth	≥ 50 to <75% of bottom depth	≥ 25 to <50% of bottom depth	<25% of bottom depth
High Enrichment Conditions (Ha or % intertidal area)	0ha OR 0%	>0 to <0.5ha OR >0 to <1%	≥0.5to <5ha OR ≥1 to <5%	≥5 to <20ha OR ≥5 to <10%	≥20ha OR ≥10%

Table A2.1. continued. Ecological Vulnerability Assessment – Attribute thresholds that correspond to raw score values (1 to 5) for condition.

Raw score values	Very Good (5)	Good (4)	Moderate (3)	Poor (2)	Very Poor (1)
Current State					
Invasive Species					
Existing presence of invasive species in the estuary (e.g. *Spartina*, pacific oysters, *Undaria* sp.)	Absent No visible individuals	Rare <1 individual per 10m² or <1% across estuary	Occasional 1 - <10 indiv. per 10m² or ≥1 to <5% across estuary	Frequent ≥10 - <100 indiv. per 10m² or ≥5 to <10% across estuary	Common ≥10% across estuary with high density areas ≥10 individuals per 1m²
Modification					
Reclamation and/or drainage of habitat (% area affected)	<1%	1-5%	5-10%	>10 to 25%	>25%
Shoreline length modified/ disturbed (% shoreline modified) (e.g. grassland, infrastructure, exotic bush etc)	<20	≥20 to <40	≥40 to <60	≥60 to <80	≥80
Hardening of estuary margin (% hardened) (e.g. artificial rock wall, earth bund, reinforcement armouring)	<20	≥20 to <40	≥40 to <60	≥60 to <80	≥80
200m terrestrial margin (% densely vegetated) (LCDB classes 45-71)	≥80	≥50 to <80	≥25 to <50	≥10 to >25	<10


Tautāne Estuary entrance.

APPENDIX 3. DIFFERENCES BETWEEN THE ORIGINAL NEMP AND CURRENT UPDATE

Roberts and Stevens (2023) [3] discuss the limitations of existing indicators and provide specific recommendations for updating the NEMP. While some of these recommendations have been incorporated into this NEMP update, the scope remains confined to the indicators listed in Tables 3 and 4 of the current document, with limited scope for literature review or development of new indicators or methods. As such this update aims to address the main limitations of the original NEMP (e.g., lack of practical detail) and formalise ad-hoc modifications that have become standard practice (e.g., percent cover of macroalgae and seagrass, improved laboratory methods). Tables A3-1 and A3-2 summarise the original NEMP approach and highlight the key method revisions that have been made for estuary-wide and site-specific indicators, respectively.

These changes are described in more detail in the broad-scale and fine-scale documents respectively (Forrest et al. 2025 [5]; Roberts et al. 2025 [4]).

Collection of infauna core and measurement of aRPD.

Table A3-1. Estuary-wide (broad-scale) indicators methods in the original and updated NEMP. The updated NEMP methods represent the intermediate and comprehensive levels of monitoring.

Indicator	Original NEMP	Updated NEMP
Estuary-wide (broad-scale) mapping		
Substrate type	Substrate not recorded beneath vegetation. Basic descriptors that rely on sinking to differentiate different levels of mud/sand.	Substrate recorded beneath vegetation. Comprehensive substrate classification system based on standard geological terms and mud content, independent of 'sinking' (Intermediate). Methodology can be validated by collecting sediment grain size samples (Comprehensive).
Salt marsh	Mapped extent when it is a dominant feature (i.e., >20%-100% cover). Substrate beneath vegetation not recorded. Classified by structural class and dominant cover.	Mapped extent of salt marsh classified by structural classes (e.g., herbfield, rushland) based on dominant cover (>20%) with substrate recorded beneath vegetation (Intermediate). Species composition can also be recorded (Comprehensive).
Mangroves	Mapped extent when it is the dominant canopy feature (i.e., >80% cover) Substrate beneath vegetation not recorded.	Mapped extent of mangroves classified by structural classes (tree, sapling, seedling, pneumatophore) with substrate recorded beneath vegetation (Intermediate). Additionally, mangrove cover classes can be recorded (Comprehensive).
Seagrass	Mapped extent. Assumed to be when it is the dominant feature (i.e., >50% cover). No substrate beneath vegetation recorded.	Mapped extent of seagrass with a percent cover (>1-100%) assigned to each patch (Intermediate). Where more detail on seagrass health is required descriptors and percent cover of health indicator are assigned to each patch (Comprehensive).
Macroalgae	Mapped extent. Assumed to be when it is the dominant feature (i.e., >50% cover). No substrate beneath vegetation recorded.	Mapped extent of macroalgae with a percent cover (>1-100%) assigned to each patch (Intermediate). Where more detailed characterisation of the macroalgal issue, or the calculation of the opportunistic macroalgal blooming tool (OMBT) is required, biomass and entrainment can be measured (Comprehensive).

Table A3-2. Site-specific (fine-scale) indicators methods in the original and updated NEMP. The updated NEMP methods represent the intermediate and comprehensive levels of monitoring.

Indicator	Original NEMP	Updated NEMP
Site-specific (fine-scale) monitoring		
Sedimentation	Not included.	Sedimentation is measured as accrual or erosion over buried concrete plates. Site configuration is dependent on the objective of monitoring.
Grain size classes	10 replicate samples collected adjacent to the infauna core. Top 20mm of sediment scraping from the sediment surface and laboratory analysis of particle grain size (% mud, sand, gravel) by: • Wet sieving and calculation of percent fractions according to dry weight.	3 composite sediment samples collected across the site (Intermediate & Comprehensive). The sediment sample is collected as a surface scoop using a trowel or shallow core to a sample depth of 20mm. Particle grain size laboratory analysis by: • Wet sieving with dispersant and calculation of percent fractions according to dry weight.
Sediment quality (TOC, TN, TP and Trace metals)	10 replicate samples collected adjacent to the infauna core. Top 20mm of sediment scraping from the sediment surface. Laboratory analyses: • TOC measured as Ash free dry weight (AFDW) after combustion at 550°C • TKN distillation, then analysed by colourimetry. • TP persulfate digestion, then analysed by colourimetry. • Trace metals (Cu, Cr, Cd, Ni, Pb, Zn) perchloric/nitric acid digestion, then analysed via flame Atomic Absorption Spectrometry (AAS).	3 composite sediment samples collected across the site (Intermediate & Comprehensive). The sediment sample is collected as a surface scoop using a trowel or shallow core to a sample depth of 20mm. Laboratory analyses: • TOC measured following acid pre-treatment and catalytic combustion (900°C and O_2) on Elemental Analyser. • TN measured by catalytic combustion (900°C and O_2) on Elemental Analyser, trace level. • TP measured following nitric/hydrochloric acid digestion, then analysed via ICP-MS (Inductively coupled plasma mass spectrometry). • Trace metals (As, Cd, Cr, Cu, Ni, Pb, Zn, Hg) measured on <2mm fraction after nitric /hydrochloric acid digestion, then analysed via ICP-MS at the trace level.
aRPD	Measured in a separate core profile (60mm diameter x 100mm depth perspex core)	Measured in a core profile, where cores are collected, or by trowel for aRPDs <50mm. Where infauna cores are collected aRPD is measured in the same core. aRPD is measured as visual transition between oxygenated (brown) surface sediments and deeper deoxygenated (black) sediments.
Colour, odour & microbial growths	Not included.	Field-based descriptive categories for enrichment indicators (colour, odour and microbial growths) that complement aRPD measurements.
Macro-invertebrates (infauna)	10 cores across site within each the sub-quadrants, core size 130mm diameter to 150mm depth. Sieved in 0.5mm mesh. Preserved in 95% ethanol.	10 cores across site within each of the sub quadrants, core size 130mm diameter to 150mm depth. Sieved in 0.5mm mesh. Preserved in ≥70% ethanol or isopropyl alcohol in water/seawater.
Epifauna and macroalgae	All animals observed on the sediment surface are identified and counted in 10 replicate 0.25m^2 quadrats within each site. Macroalgae were also assessed.	Semi-quantitatively assessed site-wide using the "SACFOR" abundance (animals), or percent cover method for macroalgae (and seagrass where relevant). Better captures patchy or clumpy distributions. Optional sampling: 10 replicate 0.25m^2 quadrats.
Benthic microalgae	10 composite samples collected by using a cut-off syringe slicing off the surface 5mm. Laboratory analysis by sediment extraction with 90% acetone, filtration and analysis via spectrophotometry.	Semi-quantitatively assessed site-wide using the "SACFOR" percent cover method. Optional sampling: 3 composite samples for analysis of chlorophyll-*a* and phaeopigments. Laboratory analysis by extraction with 90% buffered acetone and measured using a fluorometer before and after the addition of hydrochloric acid, which removes phaeopigments.

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