Approaches for integrated freshwater - estuarine monitoring

Options for estuarine monitoring at the catchment level

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Cover Notes

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CONTENTS

1. INTRODUCTION

1.1 Purpose

The purpose of this document is to provide information for regional councils and unitary authorities about options for the integrated monitoring of estuaries at the catchment level.

1.2 Background

Estuaries and coastal ecosystems are recognised for their ecological importance and the provision of critical ecosystem services (Barbier et al., 2011). At the same time, coastal freshwater and estuarine ecosystems are under increasing pressure from human activities, including land based impacts such as increased nutrient and sediment loads, and large-scale implications such as climate change (Kennish, 2021; Malone et al., 2021). Estuarine ecosystems are closely connected to their associated rivers and streams, so that upstream impacts frequently affect the condition and functioning ("health") of the receiving estuary. For this reason, effective coastal management requires an integrated approach across both types of environment to assess and mitigate impacts from human activities.

To assess potential impacts on coastal environments, regional councils and unitary authorities (hereafter collectively referred to as "councils") conduct extensive State of the Environment (SOE) monitoring to assess the state and condition of freshwaters and estuaries in New Zealand (e.g., Fraser, 2023; Haidekker et al., 2016; Roberts et al., 2022a). Regular environmental monitoring of freshwater systems includes measurements of river flow and water quality, such as nutrient and sediment concentrations and other variables (e.g., Greater Wellington, 2023a; Greer, 2020; Ingley, 2023). SOE monitoring of estuaries is generally based on the National Estuary Monitoring Protocol (NEMP) and similar methods (Roberts & Stevens, 2023). This monitoring is focused on broad-scale habitat mapping, water quality, sediment characteristics, and benthic community assemblages; some monitoring programmes also include regular assessments of sedimentation rates and opportunistic nuisance macroalgae (e.g., Forrest & Stevens, 2021; Griffiths, 2016; Robertson & Robertson, 2018; Stevens, 2021; Stevens & Forrest, 2019b).

For the management of freshwaters, the National Policy Statement of Freshwater Management 2020 (NPS-FM 2020) explicitly includes estuaries as receiving environments, encompassing the concept of "ki uta ki tai" (from mountains to sea) (Ministry for the Environment, 2023). This inclusion of estuaries in freshwater management requires an integrated approach that incorporates both types of ecosystem in the monitoring (e.g., see Greater Wellington, 2023c).

1.3 Monitoring options

To provide information for this integrated approach under the NPS-FM 2020, the present document provides options for the monitoring of freshwater-estuarine linkages in New Zealand. The options are based on criteria initially developed for estuarine monitoring in Australia, following international best practice and supporting adaptive management (Hallett et al., 2016). The criteria for best practice approaches include requirements relating to legislative and conceptual frameworks, elements of monitoring protocols and assessments, and the reporting and communication of monitoring outcomes.

Requirements for meeting best practice criteria were applied to a New Zealand context to provide options for the monitoring of freshwater-estuarine linkages. Also considered were scientific approaches and tools that integrate monitoring data from freshwaters and estuaries to provide ecological assessments of estuarine health at the catchment level.

The monitoring options are presented here in a two-tiered approach (summarised in Table 1). Tier 1 options are predominantly based on existing data and SOE monitoring networks, specifically the NEMP (and similar methods) for estuaries. The Tier 1 options consider potential resource and funding limitations that prevent more extensive efforts to manage and monitor estuaries at the catchment level. Nevertheless, their implementation will support progress towards the integrated monitoring of estuaries based on SOE monitoring data. In comparison, Tier 2 options require dedicated resources and funding in addition to SOE monitoring to conduct catchment-wide assessments. Tier 2 options include a range of different approaches, from additional data collections to ecosystem modelling and assessments; the most suitable approach is dependent on regional settings, catchment characteristics, and management objectives. Depending on resourcing, different Tier-1 and Tier-2 options may be limited to individual estuaries or may be applied region wide. It is acknowledged that a number of councils have already conducted, or are in the process of conducting, monitoring and assessment activities specifically aimed at freshwater-estuarine linkages.

Although the options here are primarily focused on the monitoring of nutrients (nitrogen and phosphorus) and sediments in freshwater-estuarine environments, the overall approaches apply to the monitoring of other variables in the context of managing estuarine health in a holistic way.

1.4 Involvement of tangata whenua

The NPS-FM 2020 explicitly includes the role of tangata whenua and the application of diverse knowledge systems and approaches, such as mātauranga Māori (Ministry for the Environment, 2023). In the context of the present recommendations, a recent summary of tools and frameworks used by iwi and hapū provided an overview of "kaupapa Māori" tools for assessing freshwater environments (Rainforth & Harmsworth, 2019). Although the review focused on freshwater monitoring, several tools and frameworks applied a wider ecosystem approach or are applicable to estuaries and freshwater-estuarine linkages. An example of the incorporation of a kaupapa Māori approach within an existing monitoring programme is the whakapapa framework that forms the basis of the Natural Environment Regional Monitoring Network in Bay of Plenty (Bay of Plenty Regional Council, 2019). This framework encompasses an integrated monitoring approach across different environmental domains, including freshwaters and estuaries.

It is acknowledged here that best practice criteria are not befitting for kaupapa Māori monitoring approaches, because the selection, development, and application of the latter need to be led by iwi and hapū, in collaboration with council partners. "Best practice" in this context is defined by iwi and hapū, incorporating the local setting and culture. This requirement is clearly outlined by Rainforth and Harmsworth (2019), who highlight that the monitoring needs to meet Māori aspirations and requirements, "by Māori, for Māori, based on kaupapa Māori".

Other key considerations identified in the review by Rainforth and Harmsworth (2019) are the need to protect intellectual property in the collection and use of sensitive data as part of kaupapa Māori monitoring; and the lack of resourcing that frequently hinders

Māori monitoring efforts and also their incorporation in "western science" monitoring programmes.

2. MONITORING OPTIONS

2.1 Conceptual and legislative frameworks

Underlying principles for best practice monitoring encompass conceptual and legislative frameworks that form the basis of an effective and adaptive management approach. Applying a conceptual framework allows the identification of individual components and their connections that need to be formally considered in the monitoring, such as the state of estuaries, the stressors or pressures on them, and the effects of management actions. In addition, overarching legislation and the implementation of policies focused on aspects relating to assessment and reporting ensure ongoing and regular best practice monitoring of estuarine condition.

One concept widely used to support marine ecosystem management on a global scale is the driver-pressure-state-impact-response (DPSIR) framework, or variants of it, such as the DAPSI(W)R(M) framework (Atkins et al., 2011; Wolanski & Elliott, 2015). In these frameworks, drivers (D) relate to human needs, such as social and economic factors that cause activities (A) which generate pressures (P), leading to state changes (S) and social impacts (I) on human welfare (W) that require management responses (R) as measures (M) (Figure 1).

The DPSIR framework and similar environmental management concepts provide a structured approach for designing monitoring programmes and for identifying clear objectives (Jones, 2018). The concepts emphasise the need for measurable indicators for each component within the monitoring programme, including pressures. In addition to providing information, the indicators are used to determine causal relationships and evaluation of the effectiveness of management measures within an adaptive management strategy, including trade-offs (Borja & Dauer, 2008).

The conceptual framework also highlights the need for the monitoring to be able to distinguish impacts from natural variability, which can be particularly difficult for assessing estuaries, which are highly variable ecosystems by their nature. Nevertheless, this aspect is also relevant for consenting and establishing reference conditions.

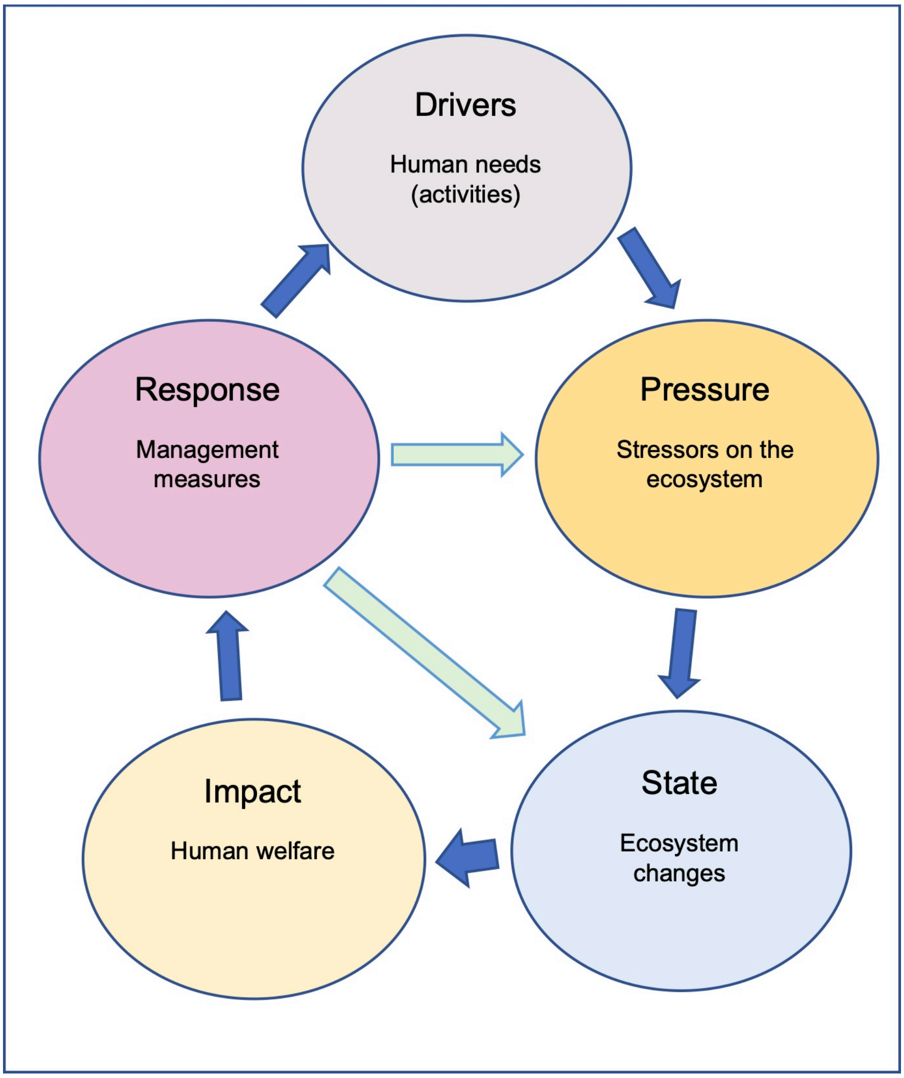

Figure 1: Diagram of the conceptual Drivers - Pressure - State - Impact - Response (DPSIR) framework (modified from Atkins et al., 2011). The concept has been widely used to synthesise ecological and socio - economic science for integrated coastal management.

2.1.1 Identification of key pressures

An underlying requirement for effective monitoring programmes is the formal identification, ranking and mapping of different pressures on regional estuaries. The formal assessment of pressures on estuaries can be based on a combination of existing data and updated ecological surveys (compared with previous survey data) (e.g., see Stevens & Forrest, 2019a). Examples include condition ratings for a range of ecosystem variables, such as intertidal mud content, opportunistic macroalgae, enrichment conditions, and eutrophication susceptibility. Other ratings are focused on social, cultural, and ecosystem values, and also the restoration potential of each estuary.

The advantages of regional assessments and the application of a ranking system include the ability to develop or amend monitoring programmes based on the ratings, and the identification of management and assessment priorities at a regional level. These aspects mean that SOE monitoring efforts can focus on particular estuaries that have been highlighted as having high value rankings and high overall pressure. In comparison, estuaries with low value rankings and low overall pressure may receive less monitoring effort, such as at a reduced frequency or focused on specific variables such as nuisance macroalgae.

Challenges for applying this approach include resource and financial limitations that may prevent a multi-estuary or regional-level approach. These limitations may in part be addressed by focusing on particular pressures (e.g., eutrophication or sedimentation), or on individual estuaries that may be particularly susceptible to environmental degradation, as identified from existing information, such as SOE monitoring.

Tier 1
The identification of key pressures on estuaries may be based on existing council-held data, such as SOE time series, consenting data (e.g., wastewater treatment plants) and spatial land use data (e.g., agricultural land use versus native forest). For councils holding multi-survey SOE monitoring data for their regional estuaries, analysis of these time-series data can provide condition ratings and information of pressures over time. The outcomes of this type of analysis can then be used to inform SOE monitoring at the catchment level, before conducting further field surveys and data collections.

Similarly, an alternative approach to a generally extensive community-led process of assigning values (and pressures) may be consideration of human uses and activities and ecosystem values based on existing information and expert knowledge. Examples include the known use of estuaries for recreational and customary fisheries, tourism activities, and provision of habitat for migrating birds, fish, and other significant wildlife.

Tier 2
Targeted research to identify key pressures includes additional data collection, analysis and modelling, such as updated monitoring surveys, apportionment of nutrient sources, and eutrophication assessments (Crawshaw et al., 2022; Morrisey & Stevens, 2023; Plew, 2017). Where possible, this process also considers socio-economic aspects, such as human uses and activities, which are then compared to ecosystem services and values.

The latter is frequently a community-led process, involving a wide range of stakeholders and public engagement, and may also include community surveys.

2.1.2 Defining management objectives

Within an adaptive management framework, another important requirement is the identification of specific and well-defined management objectives, which inform the design of the monitoring programmes (Hallett et al., 2016). This aspect includes the ability to assess and refine management actions based on the monitoring outcomes. It means that the monitoring is not limited to inventory-style data collections, and that monitoring information is analysed and reported within relevant timeframes to allow adjustments to the sampling programme as needed, based on the objectives. Ideally, management objectives relate to targets that support limit-setting and the identification of limit exceedance to prompt management action in relation to catchment impacts.

In New Zealand, guidance for the development and setting of management objectives for freshwaters is provided by the National Objectives Framework (Ministry for the Environment, 2023). Monitoring and management at the catchment level requires similar guidance for defining clear management objectives that incorporate the connection of estuaries to rivers and streams.

A significant difficulty for setting relevant (freshwater) limits for estuaries is the potential lack of information to determine suitable estuarine standards and limits, including the consideration of cumulative effects (Carter et al., 2017). This aspect is also relevant in the context of national standards and condition rankings.

Tier 1
A suggested approach for clear management objectives at the catchment level is the inclusion of estuaries within regional Freshwater Management Units (FMUs) (Parliamentary Commissioner for the Environment, 2020). Some councils already (formally) include estuaries in their FMUs (e.g., Environment Southland; Ward & Roberts, 2018), or conduct catchment-wide assessments to determine ecosystem health across freshwater-estuarine domains (e.g., Greater Wellington, 2023b).

Tier 2
Having clear management objectives for estuaries is not limited to their formal inclusion within FMUs, and regional resource management plans developed by councils include management objectives for estuarine environments. These objectives generally correspond with identified values relating to water quality, but are not necessarily linked to stressors derived from rivers and streams. To relate management objectives to targets that support limit-setting requires extensive efforts by councils. For example, Hawke's Bay Regional Council underwent a plan change to its Regional Resource Management Plan (Plan change 9; the "TANK catchment plan") to formally define trigger levels for two estuaries within the context of freshwater management at a catchment level (e.g., water column nutrient and chlorophyll concentrations, sediment mud content, Madarasz-Smith, 2019).

2.1.3 Legislation and policies for estuarine monitoring

In New Zealand, legislation and policies for freshwater and estuary management include the Resource Management Act 1991 and policies such as the NPS-FM 2020 and the New Zealand Coastal Policy Statement 2010 (Parliamentary Commissioner for the Environment, 2020). The relevant documents outline monitoring requirements for councils, and provide guidance on how freshwater and coastal environments need to be managed. Under the NPS-FM 2020, the National Objectives Framework includes guidelines for the identification of FMUs, and the development of objectives, attribute states, and limits for freshwaters (Ministry for the Environment, 2023). It provides monitoring guidance through the identification of compulsory values and attributes, with corresponding national bottomlines for some of them.

Similar guidance is not currently available for estuaries, although there has been progress towards the development of national estuarine attributes and limits (e.g., Cornelisen et al., 2017; Hewitt et al., 2022; Zaiko et al., 2018).

For monitoring at the catchment level, an investigation of suitable attributes (or indicators) for New Zealand was specifically focused on freshwater-estuarine linkages (Zaiko et al., 2018). The selection of candidate attributes in this investigation included the requirement that they are predictable from upstream measures. Relating to estuarine ecosystem health, attributes meeting this requirement were sediment deposition rate, water nutrient concentrations (nitrogen, phosphorus), total suspended solids, macroalgae, macrofauna, and mud content. To date, relevant limits or thresholds have not been set for these (or other) estuarine attributes.

Tier 1
Current estuarine SOE monitoring includes ratings for some indicators that are directly related to freshwater inputs (e.g., the New Zealand Estuary Trophic Index (NZ ETI) score, mud-dominated habitat, total nitrogen)(Roberts et al., 2022b). In the absence of national attributes and standards, these ratings from the SOE surveys may be used to guide management objectives, such as shifting low-quality ratings towards higher-quality ratings of estuarine ecosystem health.

Tier 2
Dedicated efforts may focus on developing regional attributes and limits to support monitoring activities (e.g., Griffiths, 2016; Madarasz-Smith, 2019). These efforts are guided by information from New Zealand and elsewhere to identify trigger levels and limits that may be suitable for the management of estuaries in different regions. Examples of this information include the NZ ETI Tool 2 (Robertson et al., 2016), and default trigger levels provided by the Australian and New Zealand Environment and Conservation Council (Australian and New Zealand Environment and Conservation Council, 2000) (although the latter values are default values for estuaries in south-eastern Australia and may not be applicable to some estuary types in New Zealand; see also guidance by Townsend & Lohrer, 2015).

2.2 Monitoring of freshwater - estuary linkages

Best practice monitoring requires the assessment of estuarine ecological conditions based on a holistic approach, incorporating multiple indicators for different ecosystem components and processes or functions. This approach allows interdisciplinary assessments that integrate indicators across biological, physical, chemical, and hydrological components for measuring and assessing aquatic ecosystem condition, including state changes (Borja & Dauer, 2008).

Recommendations focused on catchment-level monitoring encompass the use of multiple indicators that reflect different aspects of ecosystem health and allow the detection of changes in estuarine state and condition. Directly related to these requirements is benchmarking, i.e., determining baseline and reference conditions.

2.2.1 Interdisciplinary monitoring

Current SOE monitoring of estuaries in New Zealand is based on the National Estuary Monitoring Protocol (NEMP) and similar methods, providing a standardised approach across multiple indicators, with amendments and additions by some councils (Roberts & Stevens, 2023). Under the NEMP, broad-scale habitat mapping and fine-scale sampling provide information of estuarine condition and health, with relevant indicators providing (repeated) measurements of habitat types, sediment nutrient (nitrogen, phosphorus) concentrations, and sediment grain size and organic content. Other indicators include the monitoring of nutrients and phytoplankton in estuarine water, sedimentation rates, and opportunistic nuisance macroalgae. Monitoring of the latter is based on a multi-metric index that combines information of the growth, distribution, and establishment of these seaweeds (e.g., see Stevens, 2018a).

Both the broad- and fine-scale assessments under the NEMP include some condition ratings or ecosystem health metrics, reflecting categories of estuarine condition based on individual indicators. The individual ratings for different ecosystem aspects provide the basis for an overall condition ranking for the estuary. For estuaries with repeat surveys, earlier assessments provide a baseline to assess changes over time.

To directly link the freshwater and estuarine monitoring, the freshwater monitoring needs to include sampling sites in terminal river reaches, which may require some amendments or additions to existing monitoring networks. Data from these sampling sites are necessary to gain an understanding of the nutrient and sediment loads that directly enter the estuary via upstream sources.

In addition, current SOE estuarine monitoring predominantly focuses on intertidal areas. Dependent on the estuary type and catchment pressures, the monitoring may need to be extended to cover subtidal areas, based on multiple indicators (e.g., see Roberts et al., 2021).

Tier 1
Based on resource limitations, estuarine assessments within catchments may be limited to SOE monitoring of proxy measures of riverine inputs under the NEMP and similar methods. For this approach, it is recommended that the SOE monitoring includes the following key indicators: estuarine sediment nutrient and organic matter content, sediment grain size (i.e., mud content), sedimentation rates, and opportunistic nuisance macroalgae.

Initial estuarine surveys guide the selection of other NEMP indicators that are relevant to freshwater estuarine linkages, such as estuarine water column nutrient and phytoplankton (chlorophyll *a*) concentrations. Repeat surveys are required to track changes over time, ideally based on a rating system applied to the monitoring data (i.e., bands for ranking ecosystem quality). Freshwater monitoring data provide additional information, allowing the detection of changes in rivers and streams.

By including sedimentation rates and opportunistic nuisance macroalgae, the estuarine monitoring provides an indication of catchment-level ecosystem impacts. Where funding limitations prevent the monitoring of sedimentation rates, broad-scale mapping of soft mud areas may be used as a proxy measure, as included under the NEMP. Similarly, surveys of opportunistic macroalgae can be used as an indication of eutrophication instead of targeted and detailed eutrophication assessments that require data analysis at the catchment level.

Repeat surveys of these indicators are required to provide data for spatial and temporal assessments. Time-series data are also required to establish a baseline and reference conditions, in lieu of more extensive approaches.

Because some estuarine nutrients and sediments may also be ocean-derived (although generally at relatively small quantities), analysis of data from the freshwater water quality monitoring (and consenting data) help elucidate the inputs from different sources as required. This aspect further highlights the need for freshwater monitoring sites in terminal river reaches.

Tier 2
Requiring dedicated resources and funding, more extensive catchment-level assessments include targeted studies and investigations of sediment and nutrient impacts. Integrative methods and tools available for assessing this freshwater-estuary

linkage include spatial data analysis, and spatial, catchment, and ecosystem modelling (e.g., hydrodynamic and biogeochemical processes)(Nobre & Ferreira, 2009). Different combinations of integrative analysis and modelling approaches are available for catchment-wide assessments across different regions, using existing data from freshwater and estuarine monitoring. The selection and application of assessment methods may be guided by a review of existing council monitoring data (e.g., Gadd et al., 2020), which may be augmented by consent data and information from dedicated surveys.

These more extensive and detailed assessments may be chosen to assess estuarine eutrophication susceptibility and impacts from sedimentation, such as on benthic macrofaunal assemblages. These targeted investigations may require additional data collections; e.g., bathymetry and benthic surveys, flow information, water nutrient concentrations in the estuary and in (terminal) river reaches. Possible integrated approaches include hydrodynamic and nutrient modelling, Bayesian Belief networks, scenario modelling, and detailed apportionment of nutrient or sediment sources.

New Zealand examples of catchment-level assessments include targeted investigations focused on estuarine nutrient load limits from riverine inputs (Plew, 2021), susceptibility to eutrophication (Crawshaw et al., 2022), and scenario modelling to explore the effects of nutrient reductions under different conditions (Snelder & Fraser, 2023). These assessments can be directly aimed at supporting management decisions and interventions, providing information to explore the potential success of different options (e.g., Plew, 2023).

Scientific tools available for these assessments include a range models and approaches, such as eutrophication models developed in the United States (ASSETS, Assessment of Estuarine Trophic Status; Bricker et al., 2003) and in New Zealand (CLUES, Catchment Land Use for Environmental Sustainability model; Elliott et al., 2016), and the Coastal Receiving Environment Scenario Tool (CREST[1], for predicting nutrient (and contaminant) loads). In addition, Bayesian Belief modelling (or Bayesian Belief Networks) has been increasingly used in ecosystem-based monitoring and management of coastal environments, including estuaries (Gilby et al., 2016; McDonald et al., 2015). Bayesian Belief Networks have been developed in New Zealand to assess the influence of multiple stressors and their cumulative effects on estuarine ecosystem functioning, and to calculate Estuary Trophic Index scores (Bulmer, 2022; Bulmer et al., 2018; Zeldis & Plew, 2022).

The selection of different tools is dependent on data availability and management objectives, including the requirement for in-depth assessments of estuarine condition. The latter aspect includes the potential need to conduct additional data collections to carry out catchment-level assessments.

2.2.2 Detection of state changes in estuarine condition

Another important requirement for the selection of indicators is the ability to detect changes in ecosystem condition, and to link these changes to human caused stressors (Hallett et al., 2016). This requirement means indicators need to be suitable for determining and quantifying cause-effect relationships for different stressors in relation to natural variability in freshwaters and estuaries. Considering freshwater estuary linkages in New Zealand, an investigation of suitable indicators for estuarine

[1] https://www.dhigroup.com/projects/healthy-harbours-in-auckland

ecosystem health suggested the monitoring of sediment deposition rate, water nutrient concentration (nitrogen, phosphorus), macroalgae, macrofauna, and mud content (Zaiko et al., 2018). State changes can be assessed through repeat surveys providing data for temporal comparisons.

Tier 1
The inclusion of these indicators in the NEMP means that changes in the state and condition of estuaries in relation to catchment level impacts can be achieved under standard estuarine SOE monitoring programmes. Examples of relevant SOE indicators are the distribution and spatial extent of soft mud areas and opportunistic nuisance macroalgae, and measurements of sediment deposition over time. By including these indicators in estuarine SOE monitoring programmes, state changes can be determined over time, with data from early surveys allowing comparisons with subsequent assessments. The temporal comparison of data from repeat surveys omits the need for additional assessment efforts alongside the SOE monitoring.

Tier 2
Where resources and funding are available, dedicated efforts may be directed at particular estuaries or investigations to determine state changes, as outlined above for eutrophication and sedimentation assessments in general.

In this context, additional data collection may be required to address information needs of dedicated assessment approaches. For example, for nutrient loads in estuaries, particularly nitrogen, eutrophication assessments in different regions have highlighted that estuarine water quality data alone may not reflect ecosystem impacts (e.g., Plew, 2017). To address this limitation, water quality data were combined with hydrodynamic and flow information to assess different ecosystem components (e.g., phytoplankton versus macroalgae) in relation to nutrient inputs, and to predict the eutrophication susceptibility of estuaries. Where water quality data are not routinely collected in estuarine SOE monitoring, further data collection are required to carry out this type of assessment.

Additional data collections and assessments may also be needed to determine potential impacts from sedimentation, such as on the biodiversity and functioning of estuarine benthic assemblages. The application of available assessment tools such as Benthic Health Models (Clark et al., 2020), the traits based index (Rodil et al., 2013), and the AZTI marine biotic index (Borja et al., 2019) require benthic data, which may not be available through standard SOE monitoring.

2.2.3 Establishing baselines and reference conditions

To detect changes in ecosystem health and impacts from stressors, the monitoring data need to be compared to a "natural" state or reference conditions of undisturbed estuaries or sites within them (Hallett et al., 2016). This benchmarking also requires baselines for indicators to set thresholds, targets and limits for different aspects of ecosystem condition (see Zaiko et al., 2018). Although the identification of reference conditions and baselines is crucial for distinguishing effects from human activities from natural variability, this process can be challenging, particularly in regions where non-disturbed ecosystems are rare or few ecosystems share key similarities. Furthermore, a frequent lack of comprehensive data of ecosystem condition hampers efforts to determine baseline states and set thresholds and limits.

Extensive monitoring by councils throughout New Zealand provides information about the state and condition of estuaries. Where available, time-series data from SOE monitoring provide the ability to understand baseline conditions across regions through temporal assessment. This approach has been frequently used in lieu of targeted studies.

Tier 1
For estuaries, establishing relative baselines and reference conditions can be based on the SOE monitoring under the NEMP and similar methods, with early estuarine SOE assessments providing initial environmental data to support this process and allow comparisons with subsequent monitoring outcomes. Regional SOE data may also be compared with national datasets (e.g., for water quality) for this kind of benchmarking; however, these comparisons may need to account for natural differences in estuarine environments and catchments across regions, considering regional characteristics. This aspect is also relevant for setting estuarine thresholds and limits, particularly as the setting of freshwater limits for receiving estuaries can be challenging.

Tier 2
Alternative approaches for establishing reference conditions, but which require dedicated resources and funding, include predictive modelling, hindcasting (determining non-impacted estuarine condition based on historical data), and the use of expert knowledge and judgement (Borja et al., 2012). Scientific methods for this benchmarking include the use of Bayesian Belief Networks, which allow the combination of quantitative and qualitative data (e.g., expert and traditional knowledge, mātauranga Māori) in an analytical framework. Examples of dedicated efforts in New Zealand to determine estuarine baselines and limits in relation to sedimentation include different analysis and modelling approaches applied to existing datasets. For example, the combined analysis of historical and current sedimentation rates was used to determine a baseline for Waikato estuaries (Hunt, 2019); in Bay of Plenty, modelling based on best-available data was used to determine sediment load limits for Tauranga Harbour (Park et al., 2022). These examples illustrate different approaches for progress towards establishing regional guidelines and standards for estuarine monitoring at the catchment level (see also Griffiths, 2016; Madarasz-Smith, 2019).

2.2.4 Comparison of data across multiple scales

For the effective management of estuarine ecosystems at regional and national levels, monitoring outcomes from individual estuaries need to be shared across broader scales; e.g., between estuaries and between catchments. The ability to compare findings across multiple spatial scales is crucial for supporting management decisions, such as prioritising responses for a particular environmental impact or location. Comparability is also required for reporting purposes. To achieve comparability, the monitoring and assessment need to use indicators that allow the comparison of estuary condition at relevant spatial scales, based on a common ranking system. The latter may be based on shared reference conditions or by "intercalibrating" assessment tools against common standards or benchmarks (Birk et al., 2012).

Tier 1
Estuarine monitoring in New Zealand generally follows a standardised approach through the application of the NEMP and comparable methods (Roberts & Stevens, 2023). This standardisation means that monitoring data are comparable across estuaries within individual regions. Some noted shortcomings, for example in assessment outputs

(see Berthelsen et al., 2017), are addressed by using shared ranking systems that provide meaningful comparisons across multiple scales. Examples from the NEMP include rankings for different indicators under the fine-scale and broad-scale monitoring approaches.

Tier 2
For comparing outcomes from targeted investigations, comparability of data is achieved through the application of universal assessment tools that are based on SOE monitoring data. Examples include the New Zealand Estuary Trophic Index (ETI, for estuarine eutrophication; Robertson et al, 2016), and the AZTI marine biotic index (AMBI; Borja et al., 2019), Benthic Health Models (for sedimentation and heavy metal contamination; Clark et al., 2020), and the traits based index (TBI; Rodil et al., 2013.

2.3 Monitoring outputs and management responses

Requirements for best practice monitoring also place importance on the reporting and communication of monitoring outcomes. For the reporting, it recommended that complex findings are summarised and presented in a way that is accessible to a wide range of audiences, including community members, stakeholders, policy makers and managers.

In this context, monitoring findings need to be reported and communicated in a way that allows the eliciting of a management response, clearly indicating when it is required.

2.3.1 Reporting and communication

A widely used approach for reporting and communicating survey findings is the "translation" or integration of environmental data into summative indices for each indicator, which are combined into an overall ecosystem ranking. For example, an index for estuarine water quality may be based on the assessment of nutrients, dissolved oxygen, primary productivity, and turbidity; an index for freshwater communities and processes may incorporate measures of physical and chemical variables, fish and macroinvertebrate communities, and ecosystem processes. Based on the measurements, each index is ranked along a scoring scale (comparable to attribute bands). By providing a ranking for each index against a baseline or reference, and also an aggregated score for overall ecosystem health, monitoring findings can be easily reported on, including comparisons across sites and trends over time.

Examples for this reporting in New Zealand include the interactive LAWA (Land And Water Aotearoa[2]) web portal that presents SOE monitoring data from councils in a standardised format. Nevertheless, data summaries for estuary health and freshwater water quality are provided separately, based on individual health indicators and stressors. In addition, there is no overall ecosystem score that incorporates both types of ecosystem. Similarly, the reporting of assessment outcomes under the NEMP include condition ratings with measurements placed into the context of rating bands; however, there is generally no further aggregation of individual rankings into an overall score.

Making the reporting of assessment outcomes easily accessible is also important for the communication of monitoring results, which in turn supports public outreach efforts and community involvement. Best practice recommendations for this communication

[2]https://www.lawa.org.nz/

include dissemination of assessment outcomes in multiple formats, suitable for non technical audiences, and widely accessible and publicised (Hallett et al., 2016).

Formats used in New Zealand include technical survey reports (e.g., Forrest et al., 2022; Stevens, 2018b), high-level SOE monitoring reports (e.g., Gisborne District Council, 2020), short summaries in report cards (e.g., Waikato Regional Council[3]), and interactive websites that allow the exploration and downloading of environmental data (e.g., Auckland Council[4,5], Bay of Plenty Regional Council[6], and Greater Wellington[7]). Freshwater and marine environments are usually distinguished and reported separately in the communication of monitoring outputs.

Tier 1
Application of the NEMP (and similar methods) ensures comparability of data for the sharing, reporting, and communication of assessment outcomes. The application of a ranking or scoring system to environmental data supports the translation of monitoring outcomes into "plain" language, including spatial and temporal comparisons. This rating is currently provided for some of the indicators used in SOE monitoring, but the ratings are frequently for individual indicators only, and provided separately for freshwater and estuarine ecosystems. Similarly, freshwater and marine environments are usually distinguished and reported separately in the communication of monitoring outputs. Ideally, these individual ratings are combined into summative indices or bands that incorporate different environmental measures into an overall rating.

Tier 2
Combining individual ratings into overall rankings may require further analysis and modelling to derive a unifying condition score or ranking across different indicators, including freshwater variables, for each estuary. Other potential enhancements to current reporting and communication efforts include the provision of concise summaries of monitoring outcomes on interactive websites. For example, by using a combination of data visualisations and interpretative, plain language text, monitoring findings are made accessible to a range of audiences. Some of the current SOE reporting includes condition ratings, which are illustrated in rating matrices across indicators. This kind of information could be included with interpretative text on websites that link to relevant detailed reports and datasets. Where resources are available, interactive web portals that allow the exploration of monitoring data may also be augmented by providing these summaries via data visualisations.

2.3.2 Management response

Environmental monitoring programmes are intended to support the management of natural environments, ensuring their sustainability and preventing degradation. For this reason, monitoring outcomes need be reported in a timely manner, and indicate clearly when a management response is required (Hallett et al., 2016). The latter is usually based on the exceedance of set limits or thresholds. Within an adaptive management framework, the efficacy of management measures is also assessed and refined as necessary.

[3]https://www.waikatoregion.govt.nz/environment/coast/ecosystem-health/marine-report-cards/
[4]https://www.knowledgeauckland.org.nz/publications/state-of-the-environment-report/
[5]https://environmentauckland.org.nz/
[6]https://www.boprc.govt.nz/environment/maps-and-data/environmental-data/
[7]https://www.gw.govt.nz/environment/environmental-data-and-information/

The lack of national limits and standards for estuaries in New Zealand means that management responses are largely guided by regional information and targeted investigations.

Tier 1

In the absence of national guidelines, ranking systems under the SOE monitoring and regional limits and standards may be used to elicit a management response. For example, time-series data indicating estuary degradation in lower-quality rankings over time may lead to management actions targeted at particular indicators with low-quality rankings.

Tier 2

Management responses may be prompted by targeted investigations and assessments to support decisions about management interventions by councils (e.g., Plew, 2023).

Similarly, regional limits and standards, even restricted to estuaries only, support management decisions about interventions and mitigation efforts.

Table 1: Summary of options for different aspects of a best practice monitoring framework applied to freshwater-estuarine linkages. Options follow a two-tiered approach, with Tier 1 largely based on existing State of the Environment (SOE) monitoring, and Tier 2 requiring dedicated resources and funding. FMU, Freshwater Management Unit; NZ ETI, New Zealand Estuary Trophic Index; NEMP, National Estuary Monitoring Protocol.

Best practice framework	Monitoring aspect	Tier 1	Tier 2	Examples
Conceptual & legislative framework	Identification of key pressures	Use of existing data & expert knowledge.	Community-led process; targeted research; additional data collections, analysis and modelling.	T1: SOE data of ecosystem variables (e.g., sediment mud content, opportunistic macroalgae), consenting, spatial land use data, human uses & activities. T2: Updated monitoring surveys; apportionment of sediment & nutrient sources; eutrophication studies.
	Clear management objectives	Estuaries included in FMUs; catchment-wide assessments.	Setting of estuarine limits, trigger levels.	T1: Southland estuaries formally included in FMUs; Greater Wellington's Te Awarua-o-Porirua catchment sediment monitoring. T2: Estuarine limits in Regional Resource Management Plan, Hawke's Bay.
	Legislation & policies for estuarine monitoring	Existing ratings to guide management objectives, such as maintaining or shifting environmental outcomes towards high-quality rating.	Regional attributes and limits to support monitoring.	T1: Use of NEMP (& similar) indicators (e.g, mud-dominated habitat, sediment nutrients); NZ ETI. T2: Development of regional attribues, limits, guidelines for Hawke's Bay & Northland.
Monitoring of freshwater-estuarine linkages	Multiple interdisciplinary indicators	Monitoring of relevant NEMP (& similar) indicators; freshwater monitoring sites in terminal river reaches; subtidal monitoring sites in estuaries (as required).	Additional data collections; targeted investigations. Use of integrative tools (e.g., spatial data analysis, modelling).	T1: Repeat SOE surveys of riverine inputs via proxy measures; e.g., NEMP & similar indicators: estuarine nutrients, sediment organic matter & mud content, nuisance macroalgae. T2: Catchment-wide nutrient assessment, estuarine loading & eutrophication, scenario modelling.

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	Detection of state changes in estuarine condition	Repeat monitoring for temporal comparisons.	Additional data collections & targeted investigations into state changes (eutrophication & sedimentation).	T1: Repeat surveys of NEMP (& similar) indicators; e.g., spatial extent of soft mud areas, opportunistic macroalgae, sediment deposition rates. T2: Assessments of estuarine eutrophication susceptibility, sedimentation impacts; biodiversity & functioning of estuarine benthic assemblages.
	Establishing baseline & reference conditions	Repeat monitoring for temporal comparison; national datasets for benchmarking.	Dedicated benchmarking via predictive modelling, hindcasting (historical data use), expert knowledge & judgement.	T1: Repeat surveys of NEMP (& similar) indicators; comparison with national dataset (e.g., water quality). T2: Data analysis to determine sedimentation baselines for regional estuaries (Waikato); modelling of best-available data to determine sediment load limits (Tauranga Harbour, Bay of Plenty).
	Data comparison across multiple scales	Use of standard SOE assessment methods & outputs.	Targeted investigation applying universal assessment tools; additional data collection.	T1: NEMP (& similar) indicators; e.g., ETI score, nutrient concentration, sediment mud content. T2: Application of the NZ ETI, Benthic Health Models, AZTI marine biotic index, traits-based index, Bayesian Belief modelling.
Monitoring outputs & management responses	Reporting & communication	Summative indices & bands of ecosystem health based on individual indicator ratings (freshwater & estuarine).	Additional analysis & modelling to combine individual ratings across freshwater-estuarine domains.	T1: Existing rating system for different indicators under the NEMP (& similar methods) translating data into quality categories. Easily accessible communication of rating outcomes. T2: Website information of estuarine condition ratings across indicators, ecosystem quality categories; interpretative text; interactive data exploration.

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Management response	Existing rating system under SOE monitoring to elicit management response.	Setting of regional limits and standards to identify exceedance. Targeted investigations to support and assess management decisions and intervention.	T1: Identified changes in indicator ratings to guide management; e.g., prioritising specific aspects of estuarine health. T2: Formal catchment-level assessments; exceedance of trigger levels; assessment of management response.

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