Managing Upstream: Estuaries State and Values

Stage 1A report

Prepared for The Ministry for the Environment

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The *Managing upstream: Estuaries State and Values* project will provide the science to understand the impacts that limit-setting in freshwater management may have on estuarine values. This information will in turn enable future management decisions made regarding freshwater inputs into estuaries to be consistent with or support estuary values. The technical work is being delivered for the Ministry for the Environment (MfE) by an interdisciplinary team of researchers and scientists from Crown Research Institutes, several universities, several regional councils and private consultancies.

This report captures the outcomes for the first phase of work in stage one of this three stage project. It focuses on identifying candidate *attributes* with the strongest potential to be used to manage upstream (fresh water) pressures affecting national-level estuary values, specifically ecosystem health, human health for recreation, and mahinga kai. Upstream *aspects to be managed* in freshwater inflows to estuaries include the loading of sediments, nutrients, faecal contaminants, toxicants and emerging contaminants. The report also develops a short list of *state variables* that are likely to provide information about the condition, or state, of New Zealand's estuaries and values.

Several steps were completed to generate a short list of candidate attributes and state variables for further review and development. These included an on-line survey, expert workshop, and quantitative evaluation of variables by a small subgroup of subject experts using defined criteria and independent scoring. Compiled scores were then ranked by the report authors to prioritise candidate attributes. Consultation with Māori researchers ensured that kaupapa Māori perspectives were incorporated, and allowed variables linked to mahinga kai to be identified.

Following further review and assessment during a meeting involving core team members, external reviewers and experts, and MfE representatives, a 'short-list' of candidate attributes and state variables was developed.

- Twelve variables linked to ecosystem health (and mahinga kai), including those for both the water column and sediments, were identified as candidate attributes for further development in the next phase. Examples include measures of water clarity, macroalgae, mud content, and sediment accumulation rates in estuaries.
- Four variables linked to human health for recreation (and mahinga kai) were identified for review in the next phase of the project. These include faecal indicator bacteria (FIB) in water and in shellfish, as well as further investigation into the use of molecular markers (including bacteriophages) as candidate attributes.
- Approximately 20 variables across four categories (water quality, sediment quality, habitat diversity and quality, and species diversity) were identified for further consideration for monitoring in estuaries and as state variables for ecosystem health.
- Faecal indicator bacteria (FIB) in water and shellfish, along with the frequency of bathing beach and shellfish harvest closures were identified as potential variables for monitoring the state of Human Health for Recreation in estuaries.
- Potential state variables for mahinga kai include shellfish diversity and abundance in harvest areas, frequency of customary harvest closures, measures of harvest area accessibility, and finfish diversity and abundance.

- Further work related to selection of these variables needs to be validated by the Iwi Science Panel (ISP)/Iwi Advisory Group (IAG) - their selection is intended to begin dialogue with mana whenua over their preferences for state variables for mahinga kai.

This list of prioritised variables will be used to focus the next phase of the work, which will include identifying existing methods that may be used to obtain information on the candidate attributes and state variables, identifying and collating accessible datasets for these same variables that are identified as being useful for the later stages of the project, and exploring the datasets for gaps and methodological limitations.

1 Introduction and project overview

Estuaries are designated under the Coastal Marine Area (CMA) and their management is therefore subject to the New Zealand Coastal Policy Statement (NZCPS), which is led and administered by the Department of Conservation (DOC). However, they are the receiving waters for freshwater systems that are managed in accordance with the National Policy Statement for Freshwater Management (NPS-FM), led and administered by the Ministry for the Environment (MfE) (New Zealand Government 2014). The Ministry for the Environment (MfE) and regional councils have recognised that when setting management objectives and freshwater limits, there is also a requirement to protect estuary values. Policy A1(iii) of the NPS-FM requires that regional councils consider "the connections between freshwater bodies and coastal water". In addition, Policy C2(b) requires regional councils to "provide for the integrated management of the effects of the use and development of land and fresh water on coastal water".

This report is the first in a series that will be prepared for the "Managing upstream: Estuaries State and Values" project, which was commissioned by the Ministry for the Environment (MfE). The project aims to provide the scientific information required to:

- help inform management decisions made when establishing freshwater objectives under the NPS-FM, and
- increase knowledge on the state of different estuary types in NZ.

The project comprises three stages:

- Stage 1 (currently underway) includes the following activities:
  - identification of attributes and important indicators of estuarine state (the focus of this report)
  - review of available data and monitoring methods
  - identification of gaps in data and monitoring methods that limit full development of estuarine attributes required to manage freshwater limit-setting, and
  - provide advice on further development of attributes and monitoring protocols.
- Stage 2 (year 2, likely to be 2018 calendar year if approved) will include the following activities:
  - identification of critical thresholds for estuarine attributes that will be required to establish freshwater limits
  - provision of baseline and reference information to aid in the monitoring and assessment of estuarine state, and
  - establishment of standardised monitoring protocols that enable adaptive management approaches for addressing upstream pressures on estuaries.
- Stage 3 (year 3, likely to be in 2019 calendar year if approved) is likely to include the following activities:
  - development of tools to assist with making management decisions, such as frameworks for limit setting.

The project focuses on three national level values identified by MfE that are common to all estuaries:

- ecosystem health
- human health for recreation, and
- mahinga kai.

Under the NPS-FM, each of several mandatory values has attributes for which regional councils are required to set numeric objectives, and achieve these objectives within freshwater management units through management (limit setting or other means). These attributes are quantitative variables with defined bands (A through D) that represent different levels of water quality, from excellent to poor.

This project aims to develop attributes for estuaries that inform FW objective setting and also identify variables most useful for determining the state of estuaries with respect to the three values identified above (called state variables, defined in the next section). The attributes and state variables ultimately selected need to be robust, technically defensible, fit for purpose, and have broad acceptance by the estuarine scientific community. The attributes and state variables also need to meet council requirements or criteria, such as being practical to implement and use. To help ensure that the requirements of regional councils are met, the project is being undertaken as a partnership involving researchers and scientists from NIWA, Cawthron, Universities (Auckland, Canterbury, Otago and Waikato), independent consultancies (Wriggle Coastal Management, Streamlined Environmental Ltd), Landcare Research Limited and several regional councils (Auckland, Bay of Plenty, Hawke's Bay, Waikato, and Southland)[1]. Regional council representatives are included in the project team as part of an estuaries partners group that contributes to relevant aspects of the project and provides feedback on report outputs. The project team composition and roles and relationships are indicated in Figure A-1, Appendix A.

[1] Two regional council representatives have specific mandate to inform other regional councils collectively, and to provide feedback on project delivery from the regional council perspective.

1.1 Terminology

Key terms used in this project include **value**, **attribute**, **state variable**, and **aspects to be managed** (Table 1-1). Where possible, terminology is aligned with that used in the NPS-FM and the National Objectives Framework (NOF). A comprehensive glossary of terms and definitions related to the project is provided in Section 7.

Table 1-1 Definitions of terms.

Term	Definition	Example(s)
Value	Intrinsic qualities, uses or potential uses associated with estuaries. They may be qualities or uses that people and communities appreciate about estuaries and wish to see recognised (maintained or enhanced).	Shellfish gathering, bird watching, and swimming. Intrinsic values include ecosystem health, which encompasses the maintenance of ecosystem functions, natural form and character, and the provision of ecosystem goods and services.
Attribute	Measurable variables, including physical, chemical and/or biological, properties that are directly affected by upstream aspects to be managed, such as sediments and nutrients. Attributes must be manageable, and directly support values.	A measure of mud content in the estuary, which is closely linked to sediment loading in the catchment.
State variable	Measurable variables (or composite metric of multiple variables) that provide information about the condition, or state, of an estuary value. State variables are useful for reporting and communicating the change in estuary condition over time in relation to the value.	The areal extent of seagrass, the diversity of macrofauna, or the frequency of shellfish harvest closures in an estuary.
Aspect to be managed	Aspects of catchments that need to be managed in order to maintain and enhance estuary values.	Loading of nutrients, sediments, faecal bacteria, as well as other contaminants and toxicants (such as metals and emerging contaminants).

For this project, we focus on three values of national relevance identified by MfE that apply across all estuaries, namely: **ecosystem health**, **human health for recreation**, and **mahinga kai** (Table 1-2). Ecosystem health and human health for recreation are also 'compulsory national values' for fresh water, and these are considered compulsory for councils to include in objective setting when implementing the NPS-FM.

For "human health for recreation", the value is further defined as water-based recreation, including activities such as swimming, diving, waka ama, paddle boarding and boating. In this project, we are seeking to identify an attribute to assess the suitability of an estuary for water-based recreation in terms of whether water and sediment quality will adversely affect human health (rather than personal aesthetic experience, such as visual water clarity). To maintain consistency with existing terminology in the NOF and the terms of reference for this project, we will continue to refer to the value as "human health for recreation".

Many other values for estuaries exist, including those of tangata whenua, and other locally relevant values not covered by the national level values identified for this project. The NPS-FM indicates that the three national values do not take priority over other values considered important at regional or local level. Once a set of values is agreed (including additional national or locally identified values), regional councils are required to determine the level to which each value will be provided through objective setting (MfE 2015).

Table 1-2: National values for estuaries. Text modified from that used for the NPS-FM.

Value	Definition	Aspects to manage
Ecosystem health	The ability of an estuary to support an ecosystem appropriate to its type. In a healthy estuary ecosystem, ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to negative change.	Loading of nutrients, sediments, toxicants such as heavy metals from stormwater runoff, and habitat loss.
Human health for recreation	Recreation in estuaries ranges from activities involving full immersion, such as swimming and diving, to those with less contact with the water, such as boating. The suitability of an estuary for water-based recreation depends, among other things, on whether water quality will adversely affect human health.	Loading of faecal contaminants including pathogens (viruses and parasites) as well as loading of toxicants such as heavy metals and emerging contaminants (e.g., those associated with pharmaceuticals, petroleum products).
Mahinga kai	Māori traditional food species gathered from the environment. The definition also includes the places these species are gathered and the practices involved in their collection. Indigenous estuarine species have traditionally been used as food, tools, or other resources. The inter-generational transfer of knowledge and practices related to mahinga kai is an important means of maintaining iwi traditions.	Aspects to be managed for mahinga kai overlap with those for ecosystem health and human health for recreation. Mahinga kai requires sustainable populations of kai species, which depend on a healthy ecosystem, and the ability to harvest and consume kai requires the loading of contaminants that affect human health to be managed.

Attributes provide the link for transforming values and high level narrative objectives into numeric objectives which in turn provide for defining limits and management actions. Key criteria for identifying attributes include their ability to:

- link to the values
- be manageable through freshwater inputs
- be measurable and predictable, and
- set management objectives.

The development of attributes is an iterative process, and for this project can be guided by the following five categories of principles proposed for the development of freshwater attributes (NPS-FW; New Zealand Government 2014):

1. Link to the national value:
   - Is the attribute required to support the value?
   - Does the attribute represent the value?
2. Measurement and band thresholds:
   - Are there established protocols for measurement of the attribute?
   - Do experts agree on the summary statistic and associated time period?

- Do experts agree on thresholds for the numerical bands and associated band descriptors?

3. Relationship to limits and management:
   - Do we know what to do to manage this attribute?
   - Do we understand the drivers associated with the attribute?
   - Do quantitative relationships link the attribute state to resource use limits and/or management interventions?
4. Evaluation of current state of the attribute on a national scale:
   - Can we adequately assess the current state of the attribute at a national scale, including the extent, magnitude and location of failures to meet the proposed bottom line for the attribute?
   - Are data of sufficient quality, quantity and representativeness to assess the current state of the attribute on a national scale?
5. Implications of including the attribute in the NOF:
   - At a national level, can we quantify and assess the socio-economic impacts of managing the attribute to achieve a national bottom line relative to the status quo?

In some cases, variables that serve as attributes may also serve as state variables. An example is the concentration of faecal indicator bacteria (FIB) in water or shellfish, which can serve as an attribute linking land-derived faecal pollution for both human health for recreation and mahinga kai values. In turn, FIB concentrations, which also determine the frequency of bathing beach or shellfish harvest closures, could serve as a state variable for these values. Ideally, SVs are easily understood by communities and stakeholder groups, and enable comparison between estuaries. These characteristics imply that measurement and reporting methods may be standardised.

This project focuses on 'upstream' aspects to be managed; estuaries are also affected by human pressures in the estuaries themselves (e.g., disposal of treated wastewater, fishing, dredging, aquaculture, shoreline armouring, flapgates, and wildlife disturbance) as well as the surrounding ocean (e.g., fishing and climate related changes including sea level rise, temperature, and ocean acidification).

1.2 Report scope and structure

This first project report centres on the identification and prioritisation of attributes and state variables that will be developed further in the next phase of the project. Background information is provided to frame the work within the context of efforts already underway in New Zealand; this includes identifying how the project relates to the NPS-FM and the NOF.

Brief descriptions of related estuary projects recently completed or underway, including those involving development of kaupapa Māori monitoring frameworks are provided. As the project progresses, it will keep abreast of other projects and align efforts wherever possible.

We then describe the approach to producing a prioritised list of variables for use as attributes and/or state variables; efforts included an on-line survey, a workshop with experts, follow up evaluations, peer review, and finally, confirmation of a ‘short-list’ of variables to carry forward into the next phase of Stage 1 work.

No two estuaries are the same, and attributes and state variables may vary according to individual estuary characteristics, and even across different areas of one estuary. Although estuaries are unique, several broad types have been identified. The latest estuary typology work, along with the estuary classification developed as part of the Estuary Trophic Index (ETI) toolbox, is summarised within the context of this project. This project recognises this variability by considering the relevance of candidate attributes for different types of estuaries.

Results from these efforts are then summarised according to the three national values (ecosystem health, human health for recreation, and mahinga kai). We provide a series of tables that describe prioritised variables, highlighting their strengths and weaknesses. The final short list of recommended candidate attributes and state variables for further consideration in the next phase of the work, along with recommended next steps are summarised in the final section.

2 Background

2.1 Upstream pressures on estuaries

Estuaries are typically high-use environments, subject to multiple activities or uses. These include recreation, commercial extractions, disposal of treated wastes, providing for economic, cultural and spiritual values, as well as intrinsic ecological values. Estuaries are situated at the receiving end of rivers and streams – accordingly, the organisms, communities and habitats they support are exposed to stressors associated with land-based activities. Key aspects to be managed upstream include sediments, nutrients, faecal contaminants, toxicants, and emerging contaminants (such as by-products of pharmaceuticals, industrial chemicals and household cleaners). All estuaries in New Zealand are impacted in some way by human activity. The most pristine estuaries lie in areas with undeveloped catchments (e.g., in Fiordland and Stewart Island), and even though they may be free of human-induced runoff or heavy recreational use, they remain subject to large-scale atmospheric and ocean processes and pressures (e.g., climate-associated changes and commercial fishing), as well as impacts associated with invasive species.

According to the Department of Conservation on-line ”Our Estuaries” hub[2], more than 150 of New Zealand's estuaries are monitored in some way. Much of this monitoring is led by regional councils using the Estuary Monitoring Protocol (Robertson et al. 2002; Figure 2-1), and similar methods. Standardised monitoring approaches have enabled regional-scale assessments, such as comparisons of estuaries across the Tasman region (Robertson and Stevens 2009). These types of monitoring programmes have assisted in identifying the key pressures impacting estuaries (see definitions in Section 7).

In Southland, the New River estuary at Invercargill and the Jacobs River estuary at Riverton provide examples where both sediment and nutrient inputs from catchments are putting pressure on estuaries, with both estuaries showing symptoms of advanced eutrophication (e.g., Stevens and Robertson 2012; Robertson and Stevens 2013). Estuaries at this end of the loading spectrum highlight future challenges that will need to be met when managing upstream pressures for ecosystem health - particularly where thresholds for maintaining healthy estuary functioning have already been exceeded. Monitoring and related research has demonstrated that exposure to stressors (and thus degradation), can vary within an estuary. For example, the amount of fine material and nutrients in sediments are frequently highest close to stream and river mouths. This is evident in Southland estuaries, as well as in larger systems such as Tauranga Harbour (Ellis et al. 2015; Figure 2-2).

A full review of the state of NZ's estuaries is beyond the scope of this report. More complete reviews and regional- to national-scale assessments will be included in Stages 2 and 3 of this project. In addition, some of the projects described in Section 2.3 will provide this type of information through aligned research.

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2 www.doc.govt.nz/estuaries

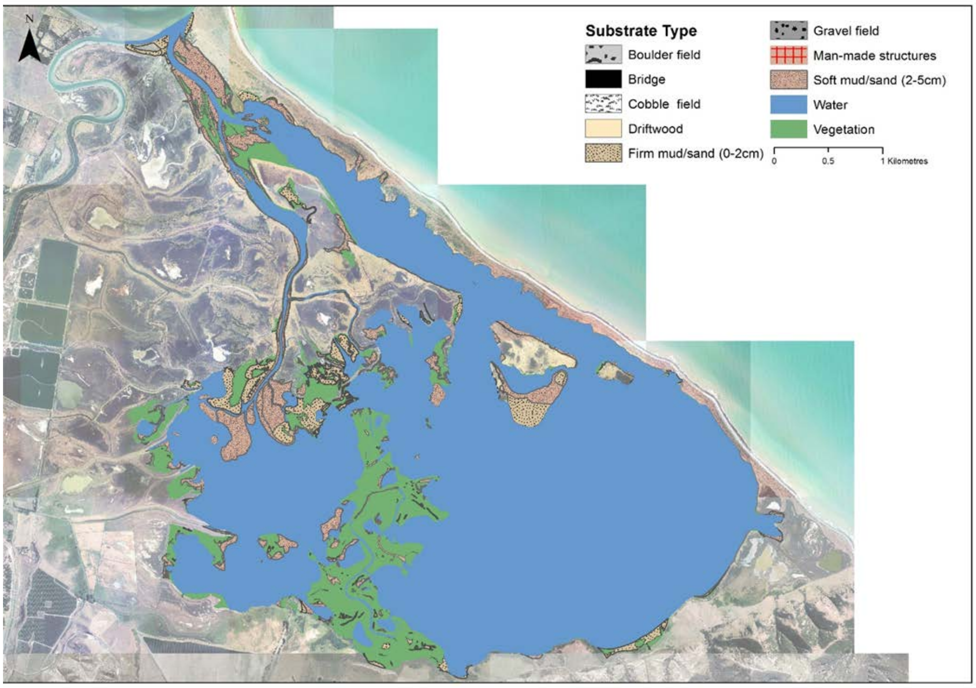

Figure 2-1: Council-led estuary monitoring in New Zealand. This monitoring typically involves a combination of broad-scale habitat mapping (top) and fine-scale monitoring of intertidal sediment communities (bottom). Examples are from Wairau Estuary in Marlborough (Photo and map from Berthelsen et al. 2016).

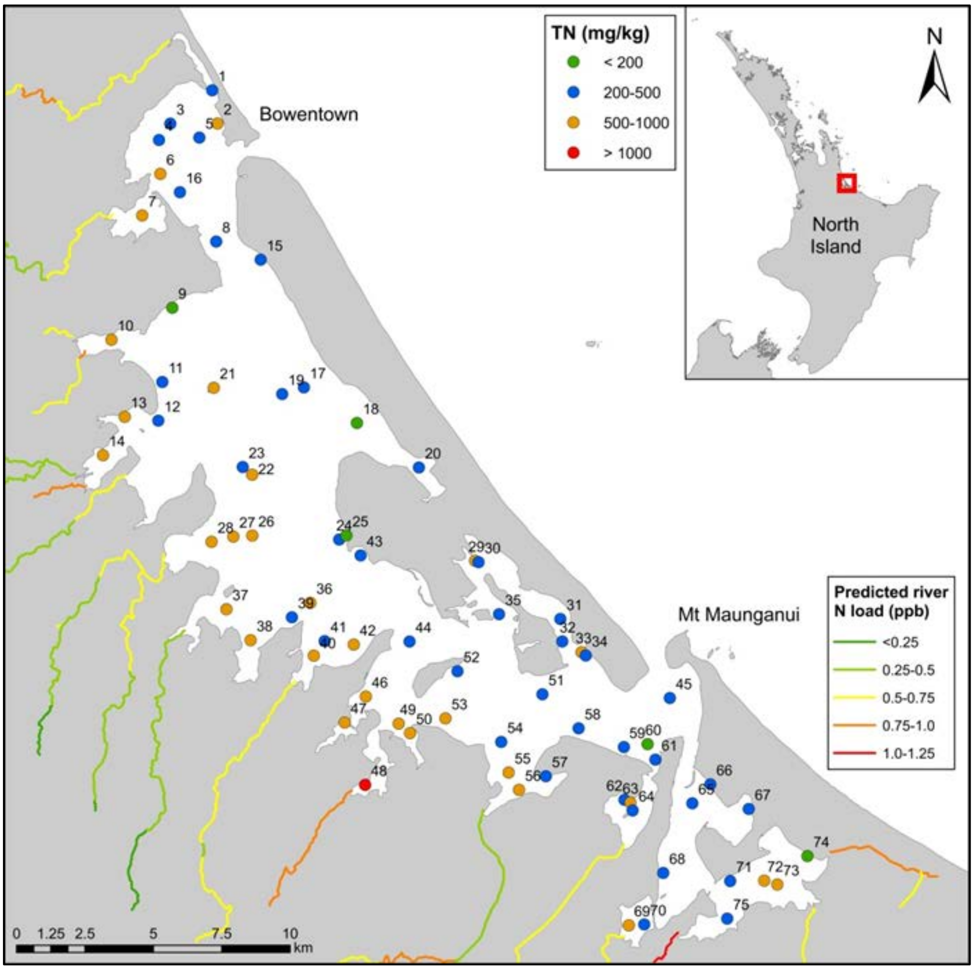

Figure 2-2: Patterns in total nitrogen (TN) concentrations in sediments from fine-scale sampling of sediments across the intertidal zone of Tauranga Harbour. Also shown are predicted nitrogen loads from rivers derived from the NIWA CLUES tool (https://www.niwa.co.nz/freshwater-and-estuaries/our-services/catchment-modelling/clues-%E2%80%93-catchment-land-use-for-environmental-sustainability-model) . Figure adapted from Ellis et al. 2015.

Although we are able to manage pressures associated with human activities, this requires knowledge regarding the linkages between stressors and effects on estuaries, and in particular, the ability to set appropriate limits to sustain the values estuaries provide to society. Non-linear responses and interactive effects of stressors have been identified in estuaries (Hewitt et al. 2016, Hewitt and Thrush 2010, Österblom 2010). The numbers of uses, users and variable responses to pressures within estuaries creates a highly complex management arena. As a result perhaps, several different methods, tools and frameworks have been proposed and used for managing estuaries (see following sections). These range from single-stressor, single-species fisheries models, to fully integrated catchment-to-sea ecosystem-based management approaches.

Knowledge regarding assessment of estuary health and management of upstream pressures within an international and New Zealand context is summarised in the next section. This includes a description of strategies for managing upstream pressures to achieve estuarine objectives through alignment with the NPS-FM and associated National Objectives Framework (NOF). The latter are specifically used for managing impacts on values. We also provide an overview of estuary typology.

2.2 National Policy Statement for Freshwater Management and National Objectives Framework approach

One of the primary aims of the current project is to inform management decisions regarding establishment of freshwater objectives under the NPS-FM, so that any objectives set for FW contaminants protect against deleterious effects in sensitive downstream receiving environments (i.e., estuaries). The management of fresh water is being reformed through implementation of the NPS-FM, which established a limits-based scheme for fresh water management (MfE 2015). The NPS-FM has driven “limits- based management” (LBM), which allows for a choice of development or restoration options, determined by the carrying capacity of the system. Councils set limits to maintain or enhance certain community values, and then establish policies to control land and water usage so that the limits are not exceeded. To some extent this is similar to the “total maximum daily loads” approach followed in the USA to achieve the goals of the Clean Water Act (CWA), 1972.

Against the background of declining water quality in New Zealand, expansion of the dairy industry, a government goal of doubling the value of exports from primary production by 2025, population increase and a growing public interest in water issues, the NZ government established the Land and Water Forum (LAWF) in 2009 to develop a stakeholder-led vision and plan for fresh water management reform. The LAWF comprises a wide range of stakeholders on all sides of water issues (water quality and, equally, water quantity), who followed a collaborative process to develop a wide range of recommendations, many of which were subsequently adopted by the Government. Early on, LAWF decided to focus on limit setting, stating “without limits it is hard to manage diffuse discharges… and impossible to deal with the cumulative effects on water bodies of water takes on the one hand and diffuse and direct discharges to water on the other” (Land and Water Forum 2010). This echoed previous commentary by Justice Salmon (2007), who argued that the best possible framework for managing cumulative effects under the Resource Management Act 1991 (RMA) would be based on identifying the resource and determining its capacity, and then limiting resource use accordingly.

Freshwater management reform is thus centred on establishing limits to resource use. The NPS-FM requires maintaining or improving overall water quality within a freshwater management unit, and safeguarding of the life-supporting capacity, ecosystem processes, and indigenous species (including their associated ecosystems) of fresh water. Regional councils are required to:

- set freshwater objectives within “freshwater management units” by 2030 that reflect national and local values
- set flow, allocation and water quality limits to ensure that freshwater objectives are achieved
- address over-allocation, and manage land use and water in an integrated way, and
- involve iwi and hapū (Māori tribe or confederation of tribes, and sub-tribe, respectively) in freshwater decision-making.

Councils and communities can choose the timeframes to achieve the freshwater objectives and limits that they set.

In general terms, the following steps are involved:

1. Agree on desired values, which are the intrinsic qualities that people appreciate or benefit from, or the uses to which people put fresh water. Examples often given are swimming and mahinga kai.

2. Identify "attributes" associated with each value. These attributes must have characteristics that can be measured and managed to support the associated value(s).

3. Agree on the desired level for each value, and the "state" of each corresponding attribute that will provide for this (noting the state of an attribute as referred to here is different than a state variable for reporting on state of estuary values).

4. Convert attribute states into "SMART" objectives, which are specific, measurable, achievable, realistic and time-bound, e.g., "90% of streams will have less than 50% average periphyton cover by 2025".

5. Formulate limits to resource use that will result in the achievement of the objectives.

6. Develop a suite of management actions that, when implemented, will regulate resource use. These could include rules in regional plans and/or the development of environmental plans in conjunction with industry.

7. Adopt a monitoring programme to evaluate achievement of time-bound milestones and enable periodic review of objectives and policies to improve their effectiveness.

The NPS provides national direction to be applied by Councils through use of Freshwater Management Units (FMUs) [3], which allow flexibility around determining the spatial scale best suited to managing fresh water in the specific circumstances of a region. FMUs can range from individual water bodies (e.g., a special river reach) to entire catchments. In relation to Step 1, the NPS-FM identifies 13 national values and uses for fresh water. Two of these are compulsory values that apply to all water bodies: ecosystem health, and human health for recreation. Councils can also manage for any of the additional national values and other local or regional values, if they decide that these are appropriate to the water body. For Step 2, Appendix 2 of the NPS-FM provides some attributes for aspects to be managed to sustain compulsory values in rivers and lakes. Councils can also develop their own attributes to help further provide for any of the suggested national values or any other local values they have identified for their FMU's. Steps 4 through 7 are carried out for each FMU accordingly.

Although estuaries are not explicitly required to be managed under the NPS-FM, the adverse effects of rural and urban land-use intensification on New Zealand's estuaries are well documented. It can therefore be argued that values-driven management of fresh water requires consideration of impacts on estuarine health, including the extension of the NPS-FM limits-based management approach to contaminants that affect estuaries. As stated in the Introduction, the NPS-FM objectives are fairly explicit about the importance of managing in an integrated way, including the linkages between fresh and coastal waters, which the current project aims to support.

[3] A FMU is a water body, multiple water bodies or any part of a water body determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management.

2.3 Previous and current efforts aligned with "Managing Upstream"

Current and previous research efforts within New Zealand that align with the MfE Managing Upstream: Estuaries state and values project are listed in Table 2-1 and visualised in Figure 2-3. In the sections that follow, we briefly describe initiatives aligned to this project that can contribute toward strengthening management and protection of New Zealand's 300+ estuaries. These include efforts being undertaken by councils, as well as kaupapa Māori frameworks that are being developed.

Table 2-1: Current and previous research programmes that align with the MfE Managing Upstream: Estuaries state and values project. The numbers in the left-hand column refer to items in Figure 2-3, and the right-hand column indicates in which Section of this report the projects are briefly discussed.

No.	Project/Item	Author/Organisation	Section in this report
1	Nga Tohu O te Taiao: Enhancing wai Maori and mahinga kai	(Awatere and Harmsworth 2014)	2.3.6
2	Oranga Taiao Oranga Tangata	(Manaaki Taha Moana 2017b)	2.3.3
3	Matauranga Maori	(Manaaki Taha Moana 2017a)	2.3.6
4	ETI Tool 1	(Robertson et al. 2016a)	2.3.2
5	ETI Tool 2	(Robertson et al. 2016b)	2.3.2
6	Sustainable Seas projects	(National Science Challenge 2016a)	2.3.7
7	Dynamic Seas – "Tipping Points"	(National Science Challenge 2016b)	2.3.7
8	NIWA SSIF project: Managing Mud - fine sediment in our waterways	(Swales 2017)	2.3.8
9	NIWA SSIF project: Eutrophication risk assessment	(Elliott 2017)	2.3.9
10	CLUES Estuaries	(Zeldis 2011)	2.3.10

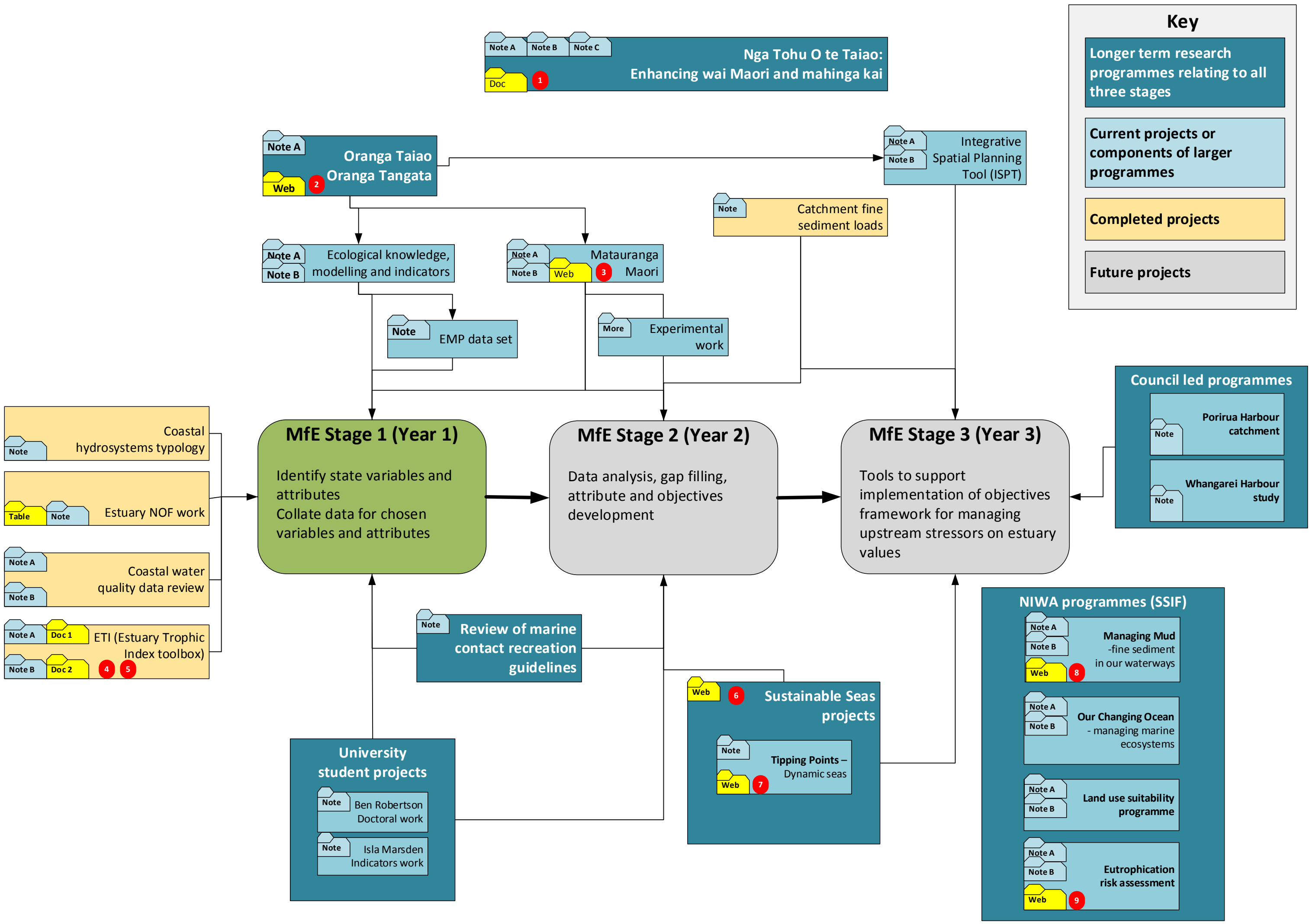

Figure 2-3: Schematic of projects aligned to the MfE Managing Upstream: Estuaries state and values project. In the version of this diagram available to the project team, links to embedded files and further information for related projects are included. Numbers in red circles are referenced in Table 2-1.

2.3.1 Estuary National Objectives Framework

In 2012, The Department of Conservation initiated a project to integrate estuaries objectives into the NPS-FM, this was led by DOC in partnership with MfE. A proposal was written and an expert panel convened that began deriving attributes for estuaries and identify key drivers of change in estuaries. The panel was asked to identify any existing state variables that were sufficiently developed to reflect values and attributes that could realistically be managed within an objectives framework, based on limit setting around key stressors (e.g., nutrients, sediments, toxicants, faecal contaminants). The panel first identified (within individuals' areas of expertise) the main drivers of ecosystem health, and then focused on a small number of attributes strongly affected by catchment inputs, and for which some supporting data for limit setting were immediately available.

Candidate attributes, including possible numeric bands, were suggested based on current data or expert opinion, with the caveat that they required further development and would be refined as knowledge was gained and feedback from the science community received. The work did not focus on the amenity and use values of estuaries, although there was some examination of the relationship between ecosystem integrity and those values. In 2013 the project was transitioned to a MfE led project as part of the freshwater policy and guidance development. The outcome of this work (a draft table of attributes and bands) was used to guide the review of variables in this report; alignment with these earlier efforts is highlighted in Section 4.2.

2.3.2 Estuary Trophic Index toolbox

The New Zealand Estuary Trophic Index (ETI) toolbox, funded by the Regional Council Coastal Special Interest Group (C-SIG) through an Envirolink Tools grant, provides regional councils with a methodology to determine the physical and nutrient susceptibility of an estuary to eutrophication, assess its current trophic state and estimate how changes to nutrient load may alter trophic state (Robertson et al. 2016 a, b). It provides tools for determining:

- estuary typology
- establishing where an estuary sits along the ecological eutrophication gradient, and
- stressor-response tools that link the ecological effects of eutrophication to nutrient loads.

The ETI also aims to support regional council planning by identifying relevant estuary attributes and outcomes for inclusion in regional plans, defining methods and indicators to measure ecosystem health, and providing guidelines to assess whether outcomes are being met.

2.3.3 Oranga Taiao, Oranga Tangāta

The Ministry for Business, Employment and Innovation (MBIE), funded the Oranga Taiao, Oranga Tangāta (OTOT) research programme, led by Massey University. This programme has the over-arching objective of "……producing knowledge and decision support tools to assist in the co-management of estuaries throughout New Zealand". The four year OTOT programme builds on a previous programme, Manaaki Taha Moana.[4] Research initiatives within OTOT that align with the current work include:

- research on indicators of estuarine ecosystem health, and

[4] see www.mtm.ac.nz

- the development of an integrated catchment-to-sea model that links changes in land use to responses of estuary indicators.

Although the focus for this research is Tauranga Harbour, estuarine ecological health indicators will be tested throughout New Zealand using data collected under the Estuarine Monitoring Protocol (Robertson et al. 2002). Another OTOT initiative is aimed at framing mātauranga Māori for management of estuaries and exploring the significance of environmental and whanau, hapū and iwi wellbeing. The OTOT programme is enabling hapū to identify frameworks for documenting and archiving hapū mātauranga, and to identify and fill hapū knowledge gaps. Ultimately, the project aims to discover ways in which this knowledge can be used to assist co-management and co-governance of estuaries.

2.3.4 Porirua Harbour

Significant efforts aligned to Managing Upstream are underway in Porirua Harbour. In 2015, Greater Wellington Regional Council (GWRC) established the Te Awarua-o-Porirua Whaitua Committee to make recommendations on freshwater management in the Porirua Harbour catchment, including managing for estuarine values in the harbour itself. The committee is supported by GWRC's Te Awarua-o-Porirua Collaborative Modelling Project, designed to provide science and other information regarding fresh water, estuarine and coastal values and the factors that affect them. Several projects have been commissioned; these include:

- specifications for models to be used to estimate contaminant loads in stormwater
- analysis of the cost and effectiveness of measures to mitigate runoff
- development of a hydrodynamic model to estimate the distribution of contaminants in the harbour
- development of Bayesian models to predict effects on particular species, and
- conduct of social and cultural impact assessments to consider the implications of different management scenarios.

Initial results are expected in late 2017.

In addition, Porirua City Council and Te Rūnanga O Toa Rangatira, along with GWRC, Wellington City Council, and the Pauatahanui Inlet Community Trust, are supporting research into the biophysical condition of the harbour and surrounding catchment. Several annual and long-term projects are underway that align to managing upstream stressors on estuaries, particularly management of sediment yields. While many of these efforts are related to on-going monitoring in relation to ecosystem health, projects aimed at reducing contaminant inputs to the harbour have been implemented. These include studies aimed at documenting patterns and rates of sedimentation within the harbour dating back to 1849.

More recent studies related to sedimentation are focusing on verifying sedimentation rates and identifying actions by the three councils to reduce sediment entering the harbour, which falls within an overarching Porirua Harbour and Catchment Strategy, developed by Porirua City Council.[5] Some of the methods used in the Porirua Harbour study are likely to inform Stage 3 of this project, and guide the development of tools for managing upstream stressors. For example, Green (2013) showed how a catchment–estuary sediment budget derived from a source-to-sea model can be used to

[5] http://www.pcc.govt.nz/DownloadFile/Publications/Harbour-Management/Porirua-Harbour-and-Catchment-Strategy-and-Action-Plan-March-2012

identify catchment sediment load limits likely to achieve a target estuary sedimentation rate. The method was applied in Pauatahanui Inlet (part of Porirua Harbour), where a target annual-average sedimentation rate of 1 mm/y was identified as likely to deliver a range of environmental outcomes in the harbour.

2.3.5 Whangarei Harbour

To assist with policy development focusing on the implementation of the NPS-FM, the Ministry for Primary Industries (MPI) and MfE worked with the Northland Regional Council (NRC) to undertake an environmental economic study within Whangarei Harbour (Daigneault and Samarasinghe 2015)[6]. The study developed a model integrating science and economics to assess the potential economic costs and environmental outcomes of meeting sediment and *E. coli* objectives and limits in fresh water and estuarine environments. It also intended to be a useful case study to inform further work on sediment attributes for the freshwater NOF. In addition, it had a broader goal of helping further develop a national understanding of cost-effective management of sediment and *E. coli*.

The study had two primary objectives; the first was undertaken by NIWA and the second by Landcare Research:

1. Develop models to assess catchment sediment and *E. coli* loads and determine how to express these loads as freshwater attributes.

2. Incorporate the sediment and *E. coli* models developed in Objective 1 into a catchment economic model to identify cost-effective ways of managing sediment and *E. coli* loads in rivers and streams, and in Whangarei Harbour.

Approaches used in the Whangarei Harbour study were similar to the modelling work in Porirua Harbour, and are likely to apply to Stage 3 of this project. These will be used to guide the development of tools for managing upstream stressors. Furthermore, these projects provide examples where attributes within estuaries are being developed to guide limit setting in the catchment. For Whangarei Harbour, this included an annual accumulation sediment rate (AASR) that was modelled for the harbour and which could be used as an attribute to manage sediment loading.

2.3.6 Kaupapa Māori monitoring frameworks

Managing to achieve mahinga kai values addresses some Māori concerns about the management of upstream stressors on estuaries. However, other benefits can be gained from the integration of kaupapa Māori monitoring frameworks and approaches to managing estuaries. In this section we summarise previous and current efforts to incorporate knowledge, skills, attitudes and values of Māori society in estuary monitoring and management.

Several shared governance and management models have emerged in New Zealand over the past 20 years (Durette and Barcham 2009, Muru-Lanning 2012, Waikato River Authority 2011, Robb et al. 2015, Harmsworth et al. 2015). These provide the context and justification for implementing kaupapa Māori monitoring tools. Harmsworth et al. (2016) demonstrated how terms such as governance (Ruru 2009, Te Aho 2010, Fenemor et al. 2011), co-governance (O'Brien 2012, Muru-Lanning 2012), co-management (Carlsson and Berkes 2005, Berkes 2009, Memon and Kirk 2012), and co-planning (Duff et al. 2010; Awatere et al. 2012) are often used interchangeably, whereas they have different meanings. Furthermore, Harmsworth et al. (2016) also identified that the success of collaborative planning processes relies on:

[6] https://www.mpi.govt.nz/document-vault/16540

- enduring relationships between local government (including regional councils) and Māori, and
- adequate resourcing for all partners contributing to the collaborative process.

Several sophisticated cultural monitoring and assessment methods based on a blend of mātauranga Māori, traditional concepts, and western science have been developed in New Zealand, and continue to be adapted for local use (e.g., Robb et al. 2015 (Fig 4); Awatere & Harmsworth 2014; Harmsworth et al. 2013). Some of the more commonly used tools are listed below. These are being used to varying degrees to inform and improve local and regional collaborative processes and enhance understanding of mātauranga Māori. They include:

- Taonga species monitoring and harvesting e.g., tau kōura (e.g., *pers comm.* Ian Kusabs), tuna (e.g., *pers comm*. Caleb Royal, Erina Watene, Erica Williams, Ian Ruru, Mahuru Robb), Kanakana (e.g., *pers comm.* Jane Kitson), native fish species such as Kōkopu, Koaro (regional councils/universities iwi/hapū), Kuta (*pers comm.* Mieke Kapa), Harakeke (iwi/hapū, Māori national weavers' collective Te Roopu Raranga Whatu o Aotearoa, Landcare Research) etc.
- Cultural Health Index (CHI) for Rivers and Streams (Tipa 1999, Tipa & Teirney 2003; Townsend et al. 2004; Nelson and Tipa 2012; Harmsworth et al. 2011) and many adaptations, including a CHI for estuarine environments – Tiakina Te Taiao (Walker 2009).
- Cultural indicators of wetlands (Harmsworth 2002); wetland habitats along the Waikato west coast e.g., Toreparu wetland assessment approach (Robb 2014).
- Linking cultural and science indicators (Harmsworth et al. 2011).
- State of Takiwā "toolbox" - iwi environmental monitoring and reporting tool Te Waipounamu/South Island – Ngāi Tahu (Mattingley & Pauling 2005; Pauling et al. 2007; Te Rūnanga ō Ngāi Tahu 2007).
- The Mauri compass (Ian Ruru 2015).
- The Mauri Assessment model (Morgan 2015).
- Mauri of Waterways Kete and Framework (Jefferies & Kennedy 2009).
- Significance assessment method for tangata whenua river values – Te Waipounamu/South Island (Tipa 2010).
- Kaitiaki tools: an internet-based Iwi Resource Management Planning Tool[7].
- Ngā Waihotanga Iho: Iwi Estuarine Monitoring Toolkit (Rickard & Swales 2009).

Underpinning Māori planning frameworks are the measures and indicators used to assess progress towards or progress away from shared outcomes. Iwi/hapū are continuing to develop, or have developed, specific indicators. A Māori Environmental Performance Indicator (MEPI) analogous to the CHI is a tohu created and configured by Māori to gauge, measure or indicate change in an ecosystem (Tipa 1999; Harmsworth 2002). The CHI index comprises three components:

[7] https://www.niwa.co.nz/freshwater/management-tools/water-quality-tools/kaitiaki-tools

- a **dichotomous variable** (yes/no) - whether the site has significance to Māori
- a mahinga kai index of **qualitative ordinal** rankings (1–5, where 1 is "low"), and
- a stream health index of **qualitative ordinal** rankings (1–5, where 1 is "low").

The qualitative nature of these data raises the issue of external validity – whether the results from the study can be generalised beyond the specific research context, i.e., can the results from one iwi/hapū rohe apply or relate to another. The context or location specificity of indigenous knowledge suggests otherwise – this is an outcome contrary to expectations from those concerned with universalism and generality. While the outputs from a CHI assessment may be incomparable from iwi/hapū to iwi/hapū, the method and process of the CHI assessment is transferable between rohe, albeit subject to some adaption (see for example the numerous derivatives of the CHI in Table 2-2). Chetham et al. (2010), Harmsworth et al. (2013), Environs Holdings Ltd (2011), Nelson and Tipa (2012) provide in-depth reviews of these kaupapa Māori monitoring tools/frameworks.

Table 2-2: List of CHI-related indicators.

CHI for streams and rivers
CHI adapted by Tiakina te Taiao
A Coastal Cultural Health Index for Te Taitokerau
CHI for kauri
CHI for estuaries
CHI for wetlands
CHI for marine ecosystems
State of the Takiwā

Successful implementation of kaupapa Māori monitoring tools such as the CHI for estuarine ecosystems is critically dependent on recognition of the governance and policy implementation role of iwi/hapū. MfE has recognised this key role of iwi/hapū, and is currently seeking advice from the Iwi Science Panel for freshwater management. To improve efficiencies and minimise participatory fatigue:

- alignment between the work currently underway with the Iwi Advisory Group (IAG) and Iwi Science Panel (ISP) in the freshwater space is required, as well as
- provision of additional advice from the same group on estuarine management and kaupapa Māori monitoring tools for estuaries.

Both of these actions have the potential to provide vital additional information to underpin development of the Managing Upstream project or inform future work. Specific recommendations to improving alignment with this current MfE project and the ISP/IAG include:

- An information sharing exercise, such as a workshop with MfE and the ISP/IAG to validate the framework and approach developed by the "Managing Upstream" project.
- Resources are provided to the ISP/IAG for an additional workstream, running in parallel with freshwater policy advice to develop a kaupapa Māori component for the Managing Upstream project or inform future work.
- Identify with the ISP/IAG through a workshop/wānanga, iwi/hapū perspectives, as well as the processes and frameworks necessary for evaluating progress towards achieving shared outcomes for estuaries.

- The current MfE project should workshop/wānanga with the ISP/IAG to consider how the values, attributes and western science monitoring tools may be used to inform iwi/hapū estuarine outcomes such as the restoration of the mauri for a harbour.

2.3.7 "Sustainable Seas" National Science Challenge

The Sustainable Seas National Science Challenge aims to enhance the value of New Zealand's marine resources, while providing a healthy marine environment for future generations.

New Zealand's marine estate is 20 times larger than our land mass, and includes fisheries, aquaculture, tourism, oil and gas, minerals, renewable energy and shipping. The sea is also an important part of the New Zealand lifestyle and culture – for food, recreation and spiritual well-being, with particularly strong Māori connections with the sea.

There is a growing conflict between New Zealand's many uses of the marine environment, including its important marine economy and protection of the marine environment, requiring new way(s) of managing marine resources that considers multiple and potentially conflicting uses, values and sources of knowledge.

Ecosystem-based management (EBM) can be a tool that enhances use of marine resources, by recognising interactions within ecosystems and with humans, and balances the use and conservation of resources. The challenge is to:

- engage with New Zealanders to understand the cultural, spiritual, economic and environmental values of our marine environment
- investigate and describe the impacts of natural and human stresses on marine ecosystems
- overcome impediments to enhanced resource use
- uphold commitment towards Te Tiriti o Waitangi and the sharing of information, resources and opportunities, as well as learning, action and shared decision-making.

One of the projects in the National Science Challenge is *"Tipping points in ecosystem structure, function and services"*. [8]

This research will:

- investigate how multiple uses of marine ecosystems affect the risk of abrupt change in ecosystem function
- provide clear evidence of the biological constraints on ecosystems and real examples of links between stressors and ecosystem responses so that we can gauge the implications of human activities in different circumstances
- foster wiser and more secure investment in marine ecosystems
- contribute new techniques to identify tipping points and potential indicators
- provide knowledge to underpin cumulative risk assessments for selected ecosystem functions and provision of services, and

[8] http://sustainableseaschallenge.co.nz/sites/default/files/2016-05/SS%204.2.1%20Tipping%20points%20in%20ecosystem%20structure%2C%20function%20and%20services.pdf

- analyse the implications of our findings for management techniques and setting of environmental thresholds and targets.

2.3.8 NIWA SSIF project: "*Managing Mud - fine sediment in our waterways*"

This research concerns the sources, characteristics, dynamics, and fate of fine sediment in NZ's streams and estuaries, and will underpin implementation of two government policies (NZ Coastal Policy Statement, National Policy Statement for Freshwater Management). These policies aim to preserve environmental and cultural values in waterways impacted by elevated sediment exports (and other contaminants) associated with land use.

Component studies will:

- link sediment-related environmental variables such as water clarity, to physical characteristics of stream sediment load so that environmental targets can be translated to limits on sediment loads
- use contemporary sediment source-tracing technologies to locate where catchment sediments originate so that load limits can be met by effective land use control
- build and test physically-based catchment-to-sea models that will link sediment sources in catchments to impact sites in stream channels and estuaries at time-scales ranging from runoff events to centuries.

Outputs will assist the Our Land and Water and Sustainable Seas National Science Challenges. The research will help implement Vision Mātauranga by partnering with iwi, making use of Māori history, building Māori capacity to monitor aquatic environments, and developing a transferable framework to enhance kaitiakitanga across NZ.

2.3.9 NIWA SSIF project: "*Eutrophication risk assessment*"

Nutrients originating from land activities can cause excessive growth of plants and algae in freshwater and estuaries, affecting the health of aquatic biota as well as social, economic and cultural values such as recreation and food gathering. Recent government policies seek to control the problem by applying nutrient load limits to waterways – these limits need to be based on accurate and precise relationships between nutrient loads and eutrophication responses. This project seeks to improve our knowledge of such relationships by:

- improving our ability to predict where eutrophication will occur
- what forms it will take, and
- the extent to which nutrient loads need to be altered to prevent excessive eutrophication.

These objectives will be achieved by

- conducting laboratory and field experiments on the interactions between nutrients and light affect the growth of aquatic plants and algae in streams and downstream estuaries
- building statistical models to predict where eutrophication occurs and how this is related to nutrients and other environmental factors

- build new types of models that represent how eutrophication responses develop over time and space, and
- bringing these tools together for the first time in a national-scale, structured Decision Support Framework that will assist New Zealand's water quality management.

2.3.10 CLUES Estuary Tool

Many of New Zealand's rivers fail to meet the national guidelines for nutrient levels, impacting on water quality in the receiving estuaries and coastal waters. In 2009 NIWA started developing a tool that predicts the effects of land use changes on the concentration of nutrients in estuaries, through a combination of GIS and hydrodynamic models. This was completed in 2011 as the "CLUES Estuary Tool", that combines three pre-existing tools:

1. CLUES (Catchment Land Use Environmental System). This tool allows the prediction of water quality (i.e., nitrogen and phosphorus levels), based upon land use, in river systems draining to estuaries.
2. Coastal Explorer. This is a database of the physical properties of estuaries across New Zealand, developed over the last few years by NIWA.
3. ACER is an estuarine hydraulics modelling system. It takes nutrients, salt and water input from rivers and the ocean, and uses physical parameters from Coastal Explorer to predict concentrations of salt and nutrients in estuaries.

The model can:

- forecast the effects of catchment development on potential nutrient levels
- identify threatened, but unmonitored estuaries
- identify likely 'pristine' estuaries which are useful as reference conditions for setting levels of water quality indicators
- enable hindcasting which can be used to assist with planning restoration objectives
- assist in the design of water quality monitoring programmes to ensure wise allocation of scarce resources
- enhance understanding of the drivers of trophic status in coastal systems.

The CLUES Estuary Tool addresses the NZ Coastal Policy Statement goals: Enhancement of water quality (Policy 21: identify deteriorating habitats), and Monitoring and reviewing effectiveness of NZCPS (Policy 28: Nationally consistent monitoring, reporting, perspectives).

3 Estuary typology

New Zealand has more than 300 estuaries that exhibit considerable variation in their coastal morphology, depths, tidal ranges and flushing, as well as the spatial extent and degree of freshwater influence. The linkages between these characteristics and the relative importance of stressors derived from both upstream and marine-sources, and their effects on estuarine values, are well documented. For instance, nutrient enrichment and the eutrophication process in estuaries is described and captured in the Estuary Trophic Index toolbox. Estuary types and their characteristics can influence the extent to which upstream activities impact values. An estuary classification system for the project is therefore required to guide the selection and development of attributes according to estuary type.

Estuaries are defined by Hume et al. (2016) as being partly enclosed by land and open to the sea for extended periods, within which seawater is measurably diluted by land drainage. An estuary's extent includes tidal habitats and adjacent wetlands. The spatial boundary of an estuary as defined by the ETI (Robertson et al. 2016a) is between the landward boundary where ocean derived salts measure less than 0.5 ppt during the period of average annual low flow and seaward to an imaginary line closing the mouth.

Morphological classifications developed for New Zealand (e.g., Kirk & Lauder 2000, Johnson & Gerbeaux 2004; Hume et al. 2007) were recently refined by Hume et al. 2016 (Table 3-1). Hume et al. (2016) classify coastal hydrosystems (including estuaries) according to geomorphic classes, which discriminate according to landscape and waterscape characteristics, e.g., geology and basin morphology, and by hydrodynamic features arising from river and oceanic forcing. Eleven geomorphic classes (along with subclasses in some categories) are recognized, although not all are estuarine (Table 3-1). The recognition of composite systems, which contain subsystems representing different geomorphic classes, acknowledges the importance of scale when classifying estuaries. Management questions would presumably determine whether a composite system should be classified as a single class or a collection of several classes.

Table 3-1: Geomorphic classes and subclasses in the classification system for coastal hydrosystems (Hume et al. 2016). For comparison, classes identified according to the ETI classification (Table 3-2) are also listed. As discussed below, ICOLLs fall within a subclass of SIDEs and SSTREs.

	Geomorphic class		Subclass	ETI typology classes
1	Damp sand plain lake (Lacustrine)			
2	Waituna-type lagoon (Lacustrine)	A	Coastal plain depression	Intermittently closed/open lakes and lagoons (ICOLL) estuaries*
		B	Valley basin	
3	Hāpua-type lagoon (Riverine)	A	Large	Some subclasses may be ICOLLs
		B	Medium	
		C	Small	
		D	Intermittent	
4	Beach stream (Riverine)	A	Hillside stream	Some subclasses may be ICOLLs
		B	Damp sand plain stream	
		C	Stream with pond	
		D	Stream with ribbon lagoon	
		E	Intermittent stream with ribbon lagoon	
5	Freshwater river mouth (Riverine)	A	Unrestricted	
		B	Deltaic	
		C	Barrier beach enclosed	
6	Tidal river mouth (Estuarine)	A	Unrestricted	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs). Some subclasses may be ICOLLS
		B	Spit enclosed	
		C	Barrier beach enclosed	
		D	Intermittent with ribbon lagoon	
		E	Deltaic	
7	Tidal lagoon (Estuarine)	A	Permanently open	Shallow intertidal dominated estuaries (SIDEs) Some subclasses may be ICOLLS
		B	Intermittently closed	
8	Shallow drowned valley (Estuarine)			Shallow intertidal dominated estuaries (SIDEs)
9	Deep drowned valley (Marine/Estuarine)			Deeper subtidal dominated, longer residence time estuaries (DSDEs)
10	Fjord (Marine/Estuarine)			Deeper subtidal dominated, longer residence time estuaries (DSDEs)
11	Coastal embayment (Marine)			

The management of coastal and fresh water requires an integrated and consistent approach, including consistent terminology. The NPS-FM 2014 specifically mentions intermittently closed and open lakes and lagoons (ICOLLs) (MfE 2015).[9] Hume et al. (2016) argue that the term ICOLL should not be used due to the differing conditions in New Zealand to those in Australia, for which conditions the term was originally developed. It is used in the NPS-FM and the ETI to describe estuaries that intermittently open or close. The ETI estuary typology classification has been modified to include ICOLLs as sub types of SIDEs and SSRTREs (see Table 3-2 for definitions).

[9] In the NPS-FM (New Zealand Government 2014) these are described as 'intermittently closing and opening lagoons' (ICOLs). However, the 2017 amendments to the NPS-FM has replaced this term with 'lakes and lagoons that are intermittently open to the sea'.

Robertson et al. (2016) defined four estuary types within the framework of the Estuary Trophic Index (ETI) (Table 3-2). The ETI framework categorises estuaries in relation to factors that influence their susceptibility to eutrophication, which is more directly influenced by specific physical modifying characteristics such as dilution, flushing, residence time, depth and intertidal extent. This approach to classification and the level of detail is consistent with what is required for the current project and managing estuaries in relation to upstream activities and freshwater inputs. The issue of scale is also recognized by acknowledging that many estuaries contain habitats that fit within other estuary types. Waterbody boundaries in the ETI classification system are generally consistent with those in Hume et al. (2016), but were based on the US typology of Madden et al. (2009).

Table 3-2: Estuary typology classification categories developed by Robertson et al. (2016a, b).

Abbreviation	Estuary category
ICOLL[10]	Intermittently closed/open lakes and lagoons estuaries
SIDE	Shallow intertidal dominated estuaries
SSRTRE	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries
DSDE	Deeper subtidal dominated, longer residence time estuaries

It is recommended that the project apply the simpler classification framework developed for the ETI toolbox, and integrate ICOLLs as a subcategory of SIDEs and SSTREs. This framework is consistent with the project aims, whereas the higher resolution of the detailed coastal hydrosystems classification based on morphology is unnecessarily complex for managing upstream impacts on estuaries - morphologically different estuaries do not necessarily require separate consideration for management with regard to freshwater inputs. Analyses of datasets and targeted fieldwork planned for Stage 2 of the project will help confirm whether the ETI Toolbox classification meets the needs for developing attributes and state variables for estuaries. In addition, this work will identify whether other forms of spatial delineation within larger and more complex estuarine systems may be needed (e.g., similar to the application of FMUs in the NOF).

[10] ICOLLs are now considered a subcategory of both SIDE and SSRTREs (to better reflect their modifying nature on those estuary types).

4 Approach to attribute and state variable development

In this section, we describe the steps that were followed to generate a prioritised list of candidate attributes. These will be reviewed and developed in the next phase of the project. The selection of attributes requires involvement and preferably consensus among the estuary science and management community. To do this effectively, we built on completed knowledge and made use of other projects in progress (see Figure 2-3). This was done by utilising the extensive knowledge base across organisations involved with research and management of estuaries. Although the evaluation process was geared primarily toward identifying variables most suitable for consideration as attributes, the information obtained through the steps described below, combined with existing knowledge around estuary monitoring, was also used to generate a prioritised list of variables for consideration as state variables.

A sequence of activities was undertaken to generate a comprehensive list of variables with potential for use as attributes and/or state variables. An important early task involved clarifying understanding of commonly-used terms and definitions. Agreement was ultimately achieved regarding definitions and selections of attributes and state variables (see Section 1.1) Key steps outlined in Figure 4-1 and further described in the following sections included:

- an on-line survey to help inform an estuary workshop
- a workshop with estuary experts from a range of research and management organisations, and
- an evaluation of variables using criteria for attributes and independent scoring, which was then compiled to rank the variables.

Consultation with Māori researchers on the team ensured that kaupapa Māori perspectives were included and identified variables linked to mahinga kai. Following these activities, a meeting between core team representatives, external reviewers and Ministry for the Environment was convened to confirm the final list of variables to carry forward into the next phase of the work.

4.1 Survey

To collect expert views on candidate attributes and state variables, an on-line survey was distributed to scientists and practitioners involved in estuary-related work (Appendix B). Many of these represent leaders in their specialist field. In total, 30 survey responses were received for consideration at the workshop. These results provided one source of information used to prioritise candidate attributes and state variables, and served to provide 'bottom-up' information, identifying linkages between upstream pressures and their effects on estuary ecology and values. The survey results were processed and summarised to produce the figures shown in Appendix C.

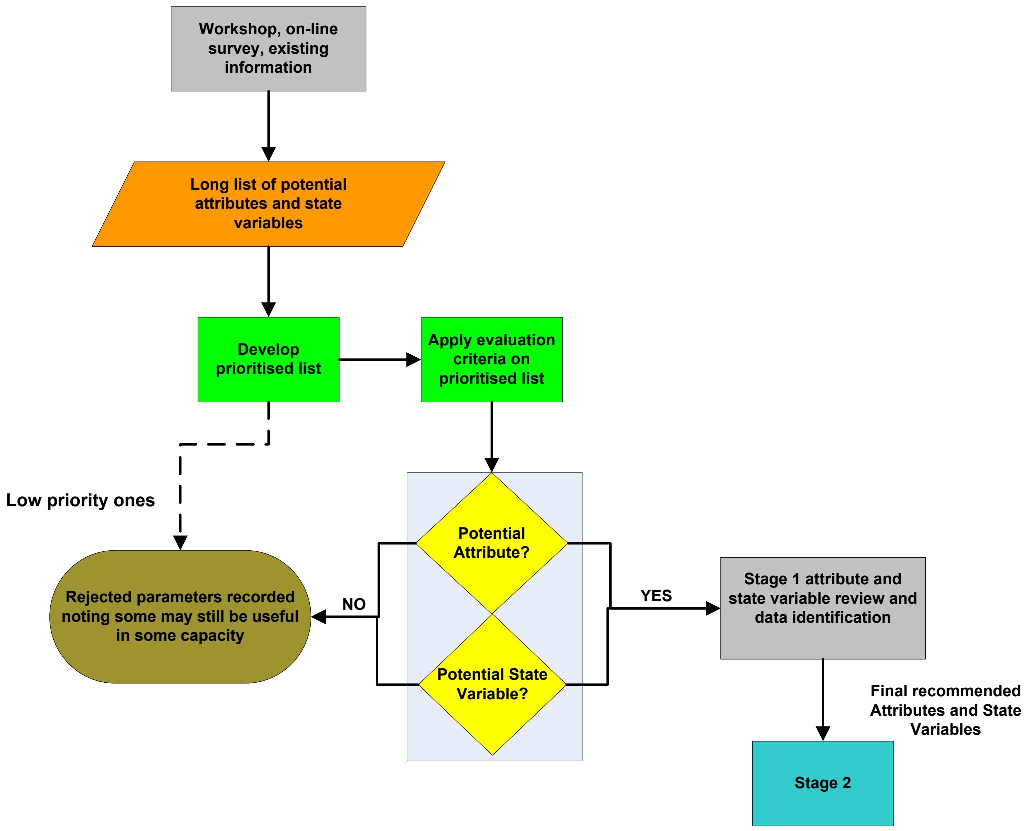

Figure 4-1: Schematic of steps followed to identify potential attributes and state variables.

4.2 Workshop

A workshop held on 8 February 2017 included a range of freshwater and estuary experts and practitioners, including 17 of the experts who had completed the online survey (Appendix B). This workshop and subsequent consultation provided most of the information required to identify attributes and important indicators of estuarine state for different estuary types. The entire workshop proceedings were made available to the wider project team using a shared website hosted by NIWA. Key workshop discussion points were recorded in minutes and subsequently reviewed by other experts who were unable to attend. The workshop summary included a broad list of candidate attributes and state variables that had been proposed by workshop attendees.

4.3 Matrix of variables

The results from the survey and workshop were collated into an Excel™ worksheet. Additional candidate attributes/state variables that had been identified in other, closely related efforts (e.g., 2014 Estuary NOF workshop), were also included. Once the worksheet was compiled, columns representing the common upstream stressors affecting estuaries were added. These components were then scored using a combination of survey results and expert opinion (Drs Anastasija Zaiko and Chris Cornelisen). A matrix, which provided a comprehensive list of physical, chemical and/or biological variables, arranged according to aspects to be managed, was then distributed to the wider group for review.

The strength of linkages between aspects to be managed and variables was ranked using the following criteria:

- 0 = no link.

- 1 = likely link (attribute likely affected through a sequence of ecological processes).
- 2 = demonstrated evidence of link.
- ? = not known / we are not sure.

Following this ranking exercise, the matrix was transformed into a flowchart scheme, visualizing linkages between values, aspects to be managed and groups of variables into a priority list, a possible (or second priority) list and a list of those unlikely to be recommended. The prioritisation was performed using a decision flowchart (Figure 4-2), which was based on the matrix information.

Groups of variables drawn from the priority list were revised by core team experts (Anastasija Zaiko, Chris Cornelisen, Judi Hewitt, and Leigh Stevens) and arranged according to the values ecosystem health, mahinga kai and human health for recreation. A more detailed matrix of variables was then developed (Appendix D). This list was used in the follow-up evaluation step by relevant experts (see Appendix B).

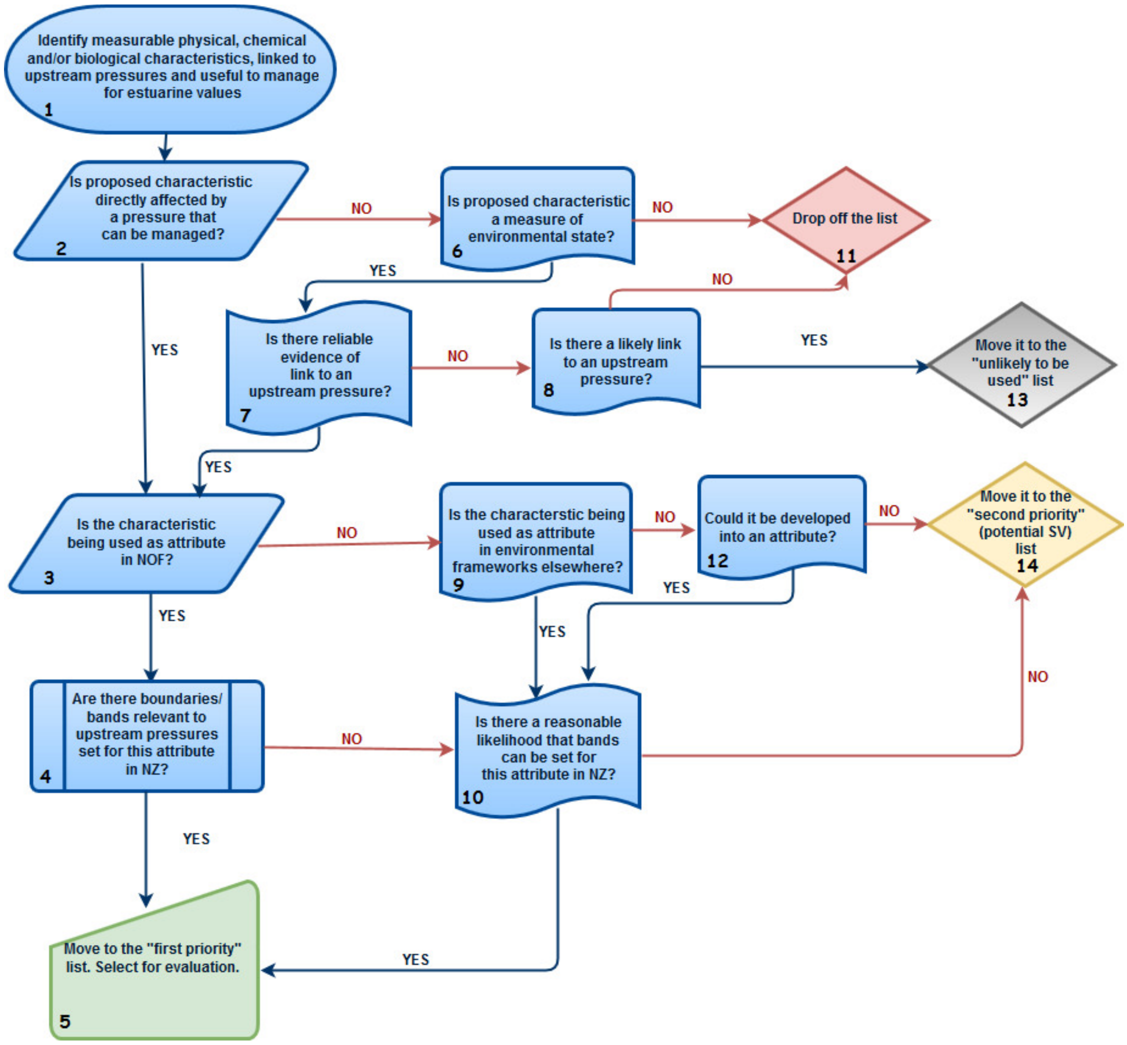

Figure 4-2: Decision-support flowchart for prioritising candidate attributes for the evaluation.

4.4 Evaluation

The evaluation was designed primarily to assess variables in terms of their potential as candidate attributes, although the results in combination with outputs from the survey and workshop are also useful in identifying variables that can be used as state variables. The set of criteria was based largely on the ICES (2013) and DEVOTES (Krause-Jensen et al. 2015) reports, and was refined following review and engagement with a subgroup of core team members. A set of five essential criteria for assessing the usefulness of each variable as an attribute to manage impacts of upstream pressures on estuarine values was compiled (Appendix E, see summary Table 4-1 below).

These essential criteria were prioritised for assessment in subsequent evaluations, because they relate to the most important characteristics required of attributes. Additional “Desirable” and “Informative” criteria were developed as well; however, evaluation results for these criteria were limited and not consistent across the criteria or the variables (Table 4-1). In this report, we therefore used only the “Essential” criteria for ranking and selecting the variables considered most promising for use in the next phase of the project.

Table 4-1. Table of criteria used to assess and score variables.

Essential Criteria	Desirable Criteria	Informative Criteria
Responsiveness to upstream aspects to be managed	Possibility to set bands	Easy to assess
Relevance to upstream management measures	Specificity	Precautionary capacity, early warning, anticipatory
Temporal-spatial stability	Scientific basis	Complexity
Cost-effective	Sensitivity	
Measurable, precise and repeatable	Non-destructive	

The spreadsheet with listed variables and criteria, along with guidelines for evaluation, were distributed to experts to score the variables. To ensure robustness and consistency of evaluation, experts were asked to assess variables and criteria relevant to their expertise. Contributing experts are listed in Appendix B.

Each criterion was assigned a score as follows:

- “fully met” = 1
- “partially met” = 0.5
- “not met” = 0

For each variable, evaluation scores were averaged per criterion and summed across criteria to generate an overall value. The evaluation step, due in part to its scoring design, resulted in a narrow range of scores across variables and results not entirely consistent with those expected. Individual criteria results were reviewed to assess whether some that may have scored highest for the two most important essential criteria relevant to the development of attributes (*Responsiveness to upstream aspects to be managed* and *Relevance to upstream management measures*) dropped out due to lower scores in the three other criteria. This tiered approach was adopted to ensure that potentially important variables for the project were not inadvertently missed in the final selection.

Eleven experts reviewed the variables for ecosystem health, and four experts evaluated those for human health for recreation (see Appendix B). Due to significant overlap in the set of variables selected for these two values with variables for mahinga kai, evaluations were first completed for the two former values. A hui was subsequently held with Māori researchers to assess those most relevant to mahinga kai.[11] The lists of variables along with scores submitted for the two other values (ecosystem health and human health for recreation) were reviewed by the researchers; those most relevant for mahinga kai were indicated alongside the overall scores from the evaluations for the other two values.

4.5 Generation of short list

The 'bottom up' selection process described above was useful in capturing a comprehensive 'long list' of priority attributes and state variables. It was evident however that the evaluation did not prioritise attributes and state variables according to expert knowledge or what is required to meet the aims of the project. For example, variables linked to upstream sediment loading that are currently being developed in aligned programmes seeking to manage upstream impacts on estuaries (see Section 2.3.5 for example) were low on the list based on the scoring alone. We therefore took a pragmatic 'top down' approach: the information generated was combined with expert knowledge to further scrutinise the candidate variables and produce a 'short list' of variables to help focus the next phase of the project.

A meeting was held on 9 August 2017 that involved core team members (Chris Cornelisen, Judi Hewitt, Anastasija Zaiko, Rebecca Stott, Shaun Awatere, Megan Carbines, Leigh Stevens, Neale Hudson) along with Mal Green, an external reviewer (Ton Snelder) and MfE representatives (Helli Ward, Pierre Tellier). The day prior, Anna Madarasz-Smith also provided valuable review and input in a meeting with Chris Cornelisen. Using the rankings from the evaluation within the context of the required principles of attributes, a short list of candidate attributes (including variables measured in the water and sediments) were listed according to the main aspects to be managed in upstream catchments (nutrients, sediments, flow alteration, toxicants (e.g., metals) and faecal contaminants). We then identified priority state variables to be used for monitoring and assessing changes in estuary condition in relation to the three values. The prioritisation of state variables was also informed by the response to the original on-line survey, which for example identified variables that reflect 'healthy' and 'unhealthy' estuaries.

[11] The hui was held on 26/05/17 in NIWA Hamilton with Māori researchers Shaun Awatere (Landcare Research), Caine Taiapa (Manaaki Te Awanui Charitable Trust), and Kura Paul-Burke (NIWA) to discuss the lists of variables, and identify those linked with mahinga kai.

5 Results

5.1 Linkages between variables, values and aspects to be managed

Analysis of the on-line survey results (see Appendix C), outcomes from the workshop, and matrix analysis (i.e., the 'bottom up' stages of the work) identified linkages between five aspects to be managed, groups of variables, and estuarine values (Figure 5-1). There was considerable overlap, indicating that variables can be affected by multiple stressors (aspects to be managed) and are relevant to more than one value. For instance, macrofauna (organisms living within estuary sediments) are affected by contaminants, sediments and nutrient enrichment, and relate to all three values. Most of the variables were linked to at least two values, often ecosystem health and mahinga kai. Other attributes were linked to human health for recreation and mahinga kai.

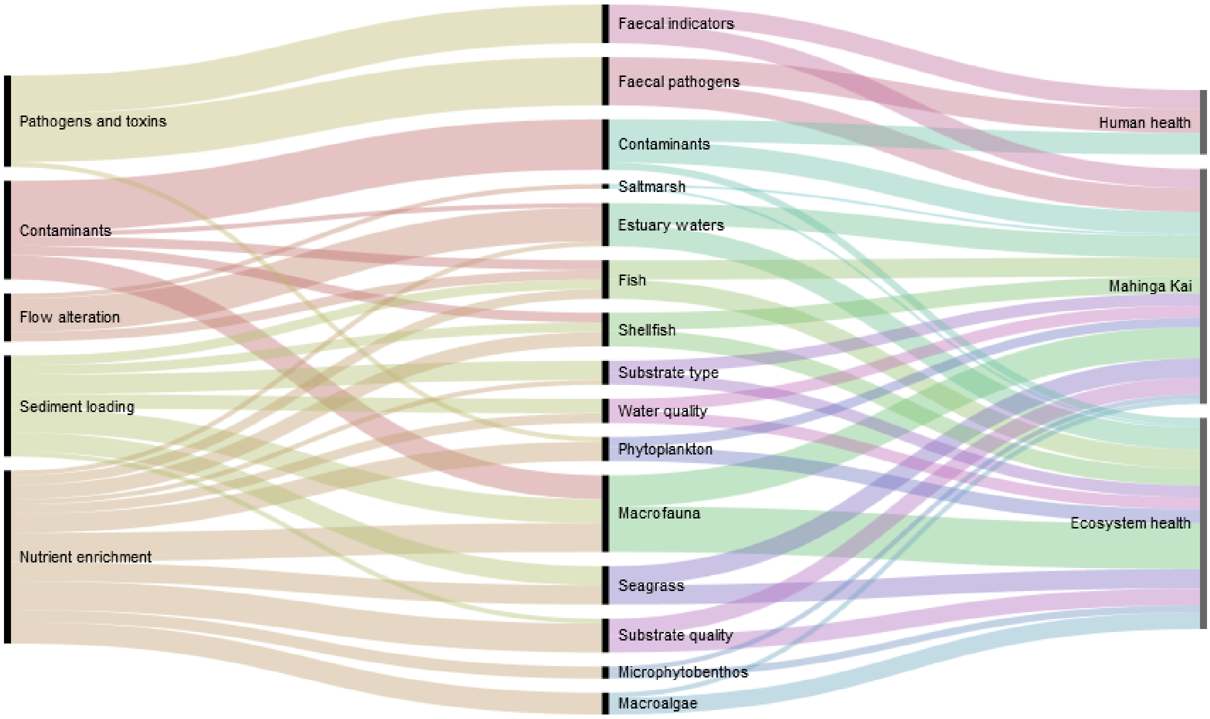

Figure 5-1: Alluvial diagram showing linkages between aspects to be managed (left), variables (middle) and values (right). See comprehensive matrix in Appendix D.

Following application of an evaluation/ decision process (see Figure 4-2), a matrix was produced, where groups of variables were linked to ecosystem values and prioritised according to their relevance to the aspects to be managed (see Appendix D). In this matrix, the "unpacked" list of the priority group (89 variables) were further considered to assess their potential for use as attributes and/or state variables. These results provided a good spread of a range of variables across the three values that can be measured in estuaries; these also had potential to be developed into attributes and/or contribute to estuary monitoring as state variables.

5.2 Evaluation results

5.2.1 Ecosystem health

Overall scores for the five essential criteria for ecosystem health variables ranged between three and 11 (Figure 5-2). To assist in prioritising variables for consideration in the next phase of the project, we applied an arbitrary threshold of ≥ 8 for the overall scores from the evaluation. The top 26 of 56 total variables for ecosystem health were selected, including several variables with the same rank/score. Ecosystem health variables included those that can be categorised according to sediment quality, water quality, habitat quality, and biotic components such as macrofauna. Descriptions of these variables, including whether they were previously considered as part of the earlier Estuary NOF work, and their strengths and weaknesses, are provided in a series of tables in Appendix F. As noted in the tables, some of these variables will be suitable for further consideration as candidate attributes, whereas others are more likely to be useful in estuary monitoring, perhaps serving as state variables.

The evaluation step can be considered a 'bottom up' approach to prioritising variables for further consideration as attributes. This, combined with a limited scoring range resulted in some variables falling lower on the list than would have been expected based on the knowledge of upstream impacts on estuaries. For instance, sediments are a major stressor in NZ estuaries, yet measures of sediment accumulation/deposition were ranked low on the list based on overall scores. However, they did score highly for the first two essential criteria that relate to their relevance and responsiveness to upstream management of fresh water (see Figure G-1 and Figure G-2I n Appendix G). These included variables such as frequency of major deposition events, modelled sediment accumulation and measured sediment deposition. These three variables also appeared in the earlier Estuary NOF work and were therefore prioritised for further consideration.

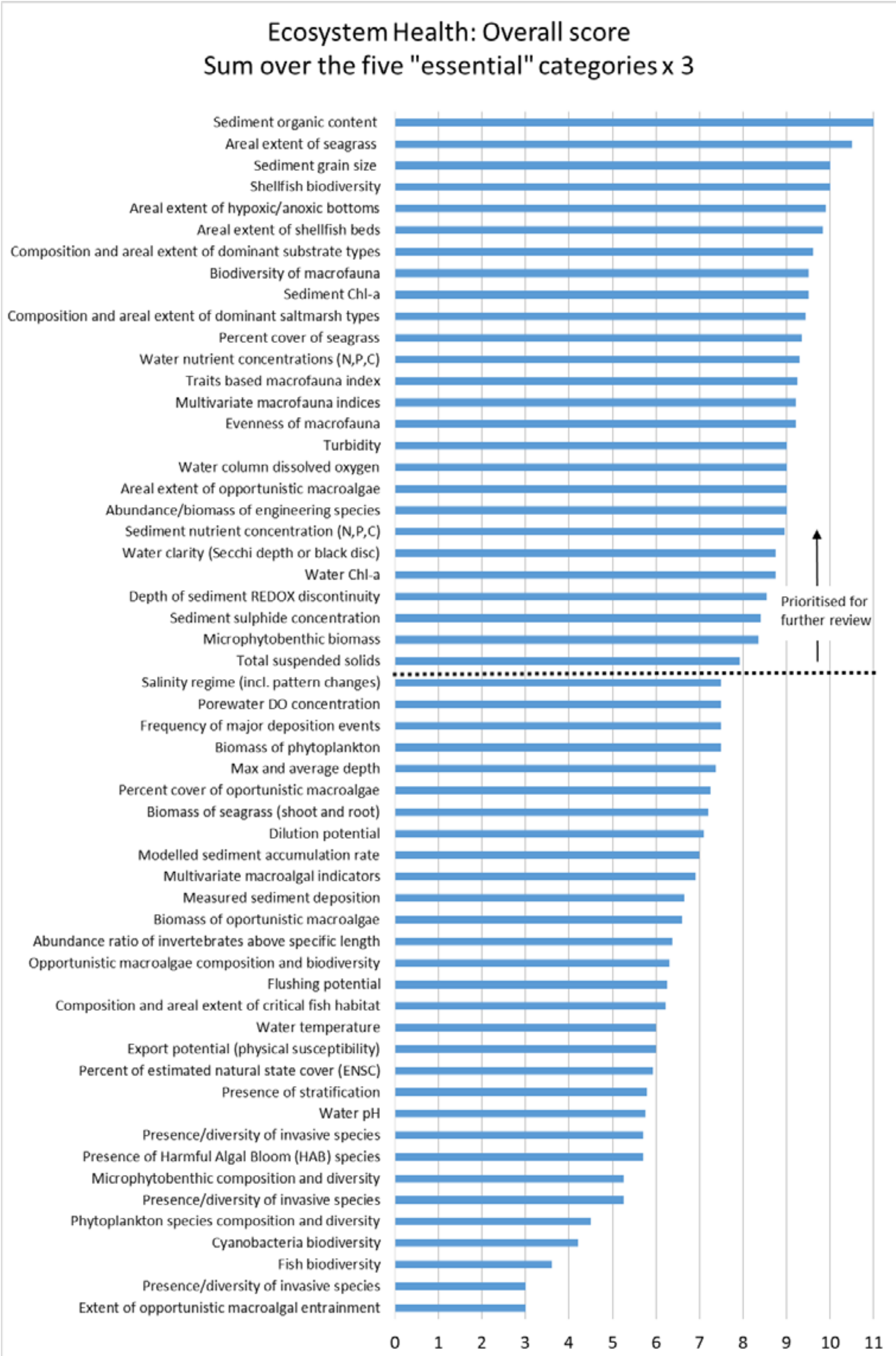

Figure 5-2: Overall scores for the combined five critical evaluation criteria. Scores are based on average per evaluation category, multiplied by 3 (Appendix G). Those with scores ≥ 8 were identified as candidates for further review and are described in Appendix F. Those below this threshold may still be important in monitoring and supporting management of estuaries (e.g., as state variables or to augment monitoring is some other capacity).

In some cases, the evaluation assessed standalone variables for a given estuary variable versus an integrated or composite measure based on multiple variables. For example, the Opportunistic Macroalgal Blooming Tool (OMBT) includes measures of several variables related to macroalgal growth (% cover, biomass, etc.,) to determine an Ecological Quality Rating (EQR) for opportunistic macroalgae in estuaries (a primary symptom of eutrophication). The OMBT and composite EQR, which was not captured in the list of individual macroalgae variables assessed, was recently developed into an attribute linking management of upstream nutrients and ecosystem health in estuaries as part of the ETI (Robertson et al. 2016b).

In general, the evaluation demonstrated variability in experts' judgements. There was unanimity for a few attributes that received mid-range scores (around 0.5), but more disagreement around higher or lower scores, which potentially represents differing levels of uncertainty or specificity of expert knowledge related to a particular variable.

5.2.2 Human health for recreation

A group of 27 variables linked to human health for recreation was evaluated independently from those associated with ecosystem health. These included bacteria, viruses and pathogens (including parasites) associated with faecal contamination of human or animal origin (including farmed animals and wildlife), and inorganic and organic compounds (includes toxicants and emerging contaminants). Inorganic and organic compounds (see Section 7 for definitions) can affect the health of plants and animals in the estuary, including taonga species; their management is therefore also relevant to the value ecosystem health. Variables important for the value human health for recreation were found to have relevance to mahinga kai as well, since the quality of both water and harvestable shellfish are degraded by contaminants.

Fifteen of the 27 evaluated variables were prioritised for further review (Figure 5-3). The highest-ranking variables associated with faecal pollution were the traditional Faecal Indicator Bacteria (FIB), including *Escherichia coli* and *Enterococci* spp. Descriptions of these and the other higher ranked variables (scores ≥ 8) are provided in Table F-6 in Appendix F. Faecal Indicator Bacteria such as *E. coli* have been used for more than a century to indicate the likely presence of pathogens such as enteric viruses, *Campylobacter* and protozoans such as *Cryptosporidium* spp. and *Giardia* spp. Recent efforts associated with revisions of the Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (Ministry for the Environment, 2003) may assist in implementing attribute(s) based on FIB for estuaries. It should be noted that assessment of risks to human health involve a specific risk-assessment component, as opposed to using measures of FIB or other indicators only.

As in the case of bathing waters, variables based on shellfish should follow programmes linked to food safety advice, which falls under the jurisdiction of public health and commercial shellfish sanitation programmes. These will sometimes vary in terms of the FIB used; for instance, *Enterococci* concentrations in water are used for bathing, whereas faecal coliforms in water and *E. coli* in shellfish flesh are used to assess suitability of shellfish for harvesting (see Table F-6).

The lowest ranked variables linked to faecal pollution included viruses. These are almost exclusively associated with upstream sources, but scored low due to the expense involved in their measurement and the difficulty in detecting and measuring viruses using current technologies. Looking for viruses in dilute environmental samples is like trying to find a needle in a haystack, and correlates such as traditional FIB or emerging PCR markers are likely to be more useful within a framework for managing upstream pressures on estuaries.

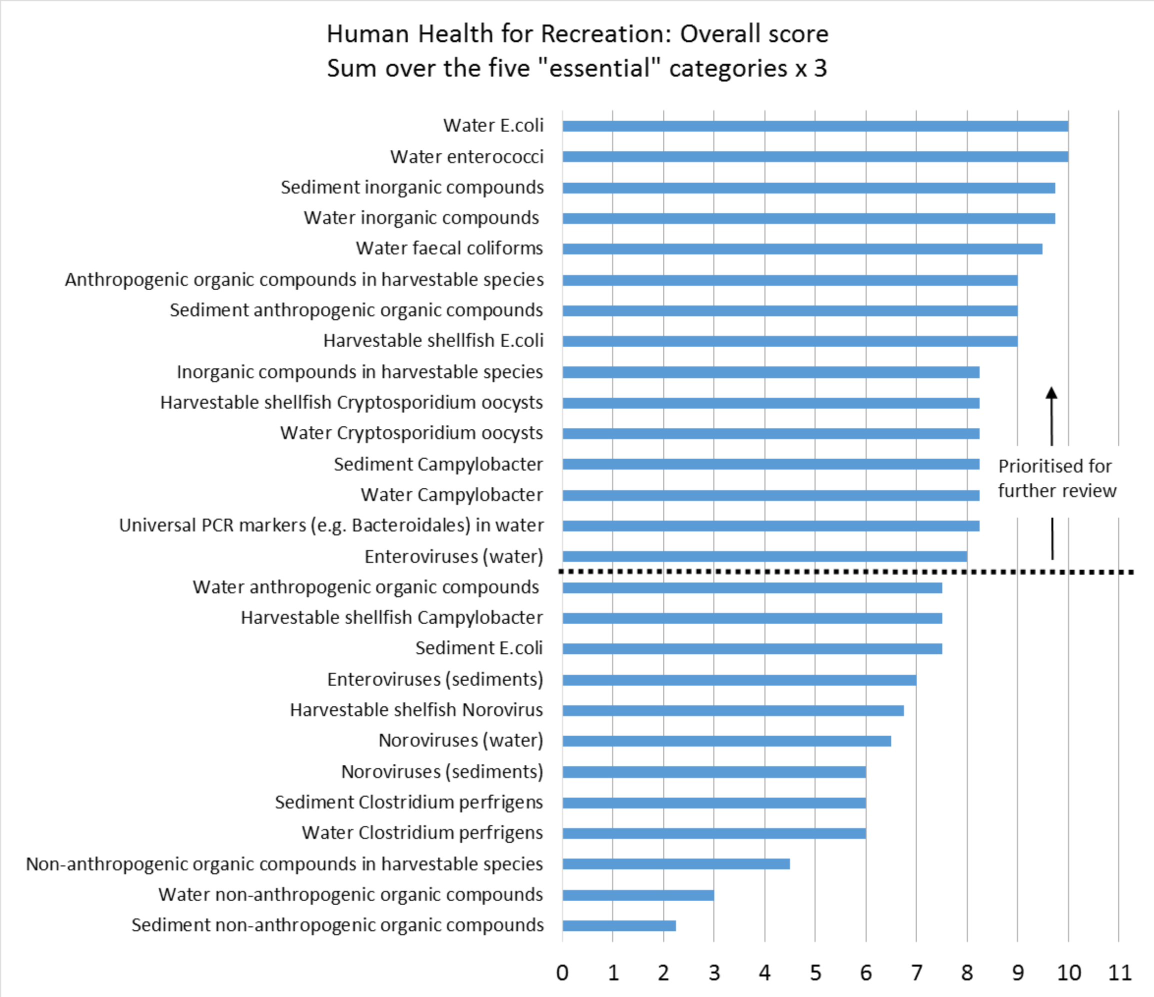

Figure 5-3: Overall scores for the combined five critical evaluation criteria. Scores are based on average per evaluation category, multiplied by 3 (see Appendix G). Those with scores ≥ 8 are identified for review and development in the next phase of the project and are described in Appendix F. Those below this threshold may still be important in monitoring and supporting management of estuaries.

Although not ranked highly, new molecular techniques are proving useful for water management because they assist in identifying the source of the contamination, and in turn prioritising steps to solve water quality problems. These include PCR-based tools for source-specific makers for bacteria and viruses. Several studies aimed at developing these types of tools for councils and the aquaculture industry have been carried out with mixed results (Cornelisen et al. 2012; Kirs and Cornelisen 2011). The universal PCR-based markers that are not source specific may also provide useful as faecal indicators in future because they can target strains (e.g., Bacteroidales) that are unlikely to persist in the environment, so may be better indicators of recent contamination (see Cornelisen et al. 2012).

Molecular markers for bacteriophages may also be useful in managing upstream impacts on bathing water quality and shellfish quality. These include:

- **Somatic coliphages.** More numerous in sewage and most prevalent at freshwater recreation sites relative to FRNA phage (McBride et al. 2002) – but some may replicate in water. Epidemiological evidence suggests a relationship with gastro-intestinal (GI) illness (US EPA, 2015).

- **f-RNA coliphage** Generally a good model of human virus behaviour in aquatic environments – can be further serogrouped to identify faecal pollution of animal or human origin. Epidemiological evidence suggests a relationship with GI illness (US EPA, 2015).
- **Bacteroides phage** (e.g., *B. fragilis* phages) Very persistent in the environment and some strains are specific indicators of human derived faecal contamination.

While it may not be possible to implement some of the above emerging molecular-based indicators as attributes, they may assist in informing management for the attribute (and in turn upstream sources of contamination) through aligned monitoring and research programmes.

Human health is also put at risk by the presence and accumulation of various inorganic and organic compounds; these include what are commonly referred to as toxicants and emerging contaminants. These compounds can also affect the health of plants and animals in the estuary, so are relevant to ecosystem health and mahinga kai values as well. The concentration of inorganic and organic compounds in sediments and shellfish were ranked higher than equivalent measures in the water column (Figure 5-3). This is likely because sediments and filter-feeding organisms such as mussels integrate pollutants that can be highly variable spatially and over time in the water column. Inorganic compounds are also ranked higher than organic compounds - inorganic compounds, such as metals, do not degrade once in the estuary, and their concentrations can be tracked over time. Organic compounds degrade due to biological processes; so while their loading rates may be monitored, their accumulation in estuaries is difficult to measure due to decreasing concentrations.

5.2.3 Mahinga kai

As described in Section 4.1, the majority of variables link with more than one of the three values (see also Appendix D). The value mahinga kai includes the ability to access, harvest and consume traditional food species; all aspects rely on good water quality to minimise risks to human health. The condition, abundance, and diversity of mahinga kai species in estuaries are in turn affected by the overall health of the estuary. For example, access to abundant, safe-to-eat populations of shellfish such as cockles and pipi relies on the presence of suitable habitat conditions, which can be compromised by sedimentation and inflow of contaminants. For these reasons, the variables identified for management of ecosystem health and human recreation health are similar to those that could be used to manage for mahinga kai.

Due to the overlap in variables among the three values, a separate evaluation of variables under mahinga kai was not carried out. Instead, the results of the evaluations were discussed at a hui as described in Section 4.4 to confirm and ensure that variables evaluated under ecosystem health and human health for recreation sufficiently covered off mahinga kai adequately.

The same prioritised (scores ≥8) variables for ecosystem health and for human health for recreation were identified at the hui as being relevant to mahinga kai, with two exceptions: measures of evenness in macrofauna communities (i.e., how evenly abundances of organisms are spread across the different species present), and Universal PCR markers (e.g., Bacteroidales) in water.

5.2.4 Taonga species variables

Taonga species are native plants and animals of special cultural significance and importance to Māori. During the evaluation process, six variables involving taonga species were identified and evaluated. The variables relate to faecal contaminants and toxicants and therefore were originally grouped and evaluated with the variables for human health for recreation. Variables receiving the highest scores included organic and inorganic compounds (contaminants) in taonga species, and concentrations of *E. coli* in taonga species (see summary of scores in Appendix G). Along with the variables for mahinga kai, the topic of taonga species was discussed at a hui (see Section 4.4). It was decided that these could be grouped with ecosystem health, since taonga species include those beyond mahinga kai, and in many cases, they would not be consumed (i.e., were not relevant to human health for recreation). Taonga species, including mahinga kai, are also important components of the ecosystem. The variables identified may contribute to monitoring the state of ecosystem health in estuaries, but require further clarification around what species other than shellfish would be the best to consider.

5.3 Recommended short list

As described in Section 4.5, a meeting was convened in Wellington on 9 August 2017 to discuss the results and further reduce the list of variables to better focus the next phase of the project. The meeting resulted in development of a refined list of variables, indicated those which have the most potential to be developed into attributes, and those likely to be useful in monitoring the state of estuary values (as state variables, or for use in some other capacity in estuary monitoring).

5.3.1 Attributes

Variables with the greatest potential for development into attributes can: link to the values; be manageable through freshwater inputs; be measurable and predictable; and set management objectives. Variables identified as having these characteristics and recommended for further consideration as attributes are summarised in Figure 5-4 and Table 5-1. The variables are arranged according to the three values, linkages to upstream aspects to be managed, and three main "compartments" where they would be measured or estimated: the water column, sediments, and shellfish.

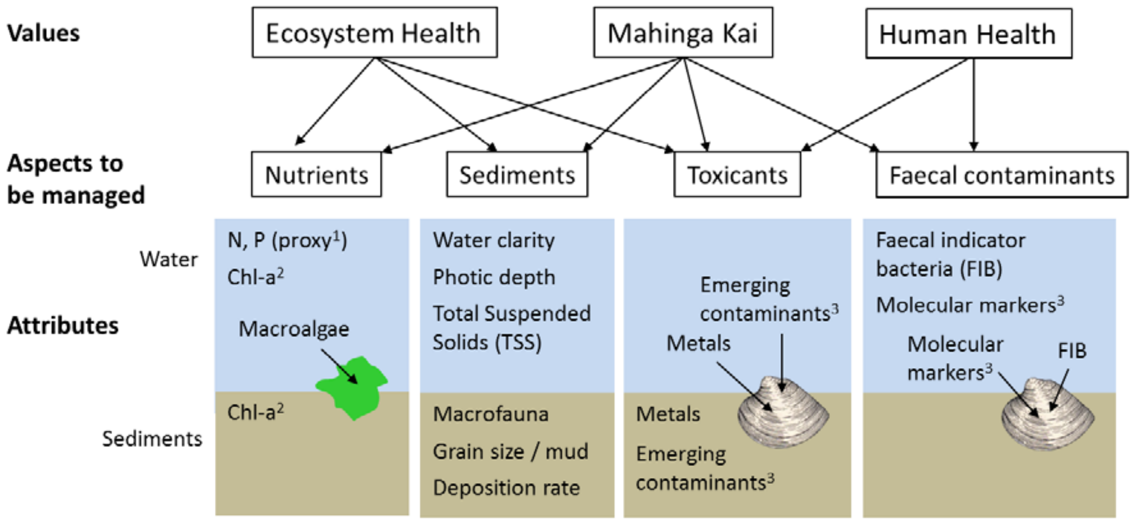

Figure 5-4. Variables recommended for further consideration as attributes. [1]For nutrients such as nitrogen (N) and phosphorus (P), a proxy, such as modelled potential nutrient concentrations may be used. [2]Chl-a is a proxy for phytoplankton in the water and microphytobenthos (small algae) in the sediments. [3]The inclusion of emerging contaminants and molecular markers for faecal bacteria and pathogens is intended to mark their potential future role in managing and monitoring estuaries following further research and development. It is unlikely these would be developed into attributes within this project.

Table 5-1. Description of variables prioritised as candidate attributes. Further information on these and other variables is provided in Appendix F.

Medium	Variable	Relevance to upstream management	Strengths and weaknesses, considerations
Water	Nutrient concentrations (N, P).	Responds upstream loading of nutrients, although importance will depend on benthic fauna and flora cycling of nutrients and inputs from other sources (e.g., ocean).	Measured concentrations likely too difficult to develop into attribute due to variability, although could serve role as state variable. Modelled nutrient loads and/or potential concentrations identified as alternative to measured, with loads being the aspect to be managed upstream.
Water	Chlorophyll-a (Chl-a).	Chl-a (proxy for phytoplankton) can increase with nutrient loading from upstream sources; it is one of the symptoms of eutrophication. Chl-a can respond negatively to increased sediment loading due to lower light levels.	Under the NPS-FM, Chl-a is proxy for periphyton (rivers) and phytoplankton (lakes) attributes. Difficult to separate out response to different stressors. Spatially and temporally variable within estuary.
Water	Water clarity (Secchi depth or black disc) Total suspended solids (TSS).	Increases with incoming sediments during flood events, and also resuspension of mud and sediments within the estuary, which can occur during wind/wave events.	Water clarity (which is affected by the levels of TSS) and TSS are being investigated as attribute under NPS-FM. Highly variable and can respond to factors other than upstream pressures (e.g., resuspension).
Water	Faecal Indicator Bacteria (FIB).	Elevation of FIB in estuary waters is primarily attributable to upstream sources in catchments and/or point source discharges (outfalls).	*E. coli* indicator of choice for health risk to recreational users of fresh waters (an attribute under NPS-FM), and in some estuary waters. Variability in time and space (patchiness) can impede ability to identify trends in response to changes in pressures. Standard methods and easy to measure. Can persist and grow in the environment (e.g., in sediments) and often correlated with other water quality parameters (e.g., suspended solids). *Enterococci* the indicator of choice for health risk to recreational users of coastal waters and some estuary waters. Emerging molecular technologies, such as PCR markers and bacteriophages, are becoming more commonplace for assessing faecal contamination, and can also be linked to source.
Macroalgae	Variables include EQR calculated from the Opportunistic Macroalgal Blooming Tool.	Can be directly a function of nutrient loading from catchments, particularly in cases where the downstream estuary is poorly flushed, and increased nutrients can result in blooms of nuisance macroalgae (e.g., *Ulva* spp).	Developed as part of ETI toolbox. Not all macroalgal growths are solely anthropogenically driven – can be facilitated by naturally high nutrient levels entering from the catchment or ocean. Present information suggests a strongly non-linear response once the system is degraded.

Medium	Variable	Relevance to upstream management	Strengths and weaknesses, considerations
Macrofauna	Variables incl. biodiversity, multivariate indices, trait based index.	Measures of macrofauna community structure are highly sensitive to changes in pressures (good for early warning), and can integrate over time. Respond in different ways to contaminants, nutrients, organic enrichment, deposition rates, turbidity, and changes in muddiness.	Sensitivity of macrofaunal communities and power of multivariate community analyses make macrofauna-based indicators particularly good. Levels indicative of health are available using published indices. Spatial and temporal variation reasonably well understood. Will be important in monitoring and use as state variable(s) for Ecosystem Health.
Sediments	Sediment Chl-a.	Increase due to increased benthic productivity in response to nutrient loading from catchments, Decrease due to reduced light availability / sediment resuspension with sediment loading.	Easy to measure. Seasonally and spatially variable. Multiple factors can influence; difficult to distinguish between upstream pressures. Links to ecosystem health status have not been demonstrated.
Sediments	Sediment grain size (includes mud content).	Increased loading of fine sediments from catchments can result in an increased proportion of mud in estuary sediments.	Two different methods typically used (sieving and laser). Has well documented correlations with macrofaunal measures/indicators. Spatially variable as a function of hydrodynamics and resuspension. Links to ecosystem health status have been demonstrated.
Sediments	Sediment deposition rate (modelled or measured).	Sediment deposition can be significantly increased by land use changes in the catchment and decreased by mitigation. Also affected by within estuary activities such as building structures, dredging and alteration of hydrological regimes.	Deposition rates can be predicted using existing tools (e.g., CLUES) and depositional modelling (e.g., S2S), including spatial variability. Can be calculated as Average Annual Sedimentation Rate (AASR). Rates are spatially variable within estuaries (depositional versus erosional zones, influenced by waves, currents and residual circulation). Important to consider frequency and size of major depositional events. Sedimentation rate measurements can be made using settlement plates at locations within estuaries but so far results are highly temporally variable.
Sediments	Metals, and emerging contaminants.	The majority of anthropogenic inorganic and organic compounds will enter estuaries from upstream sources, including sewerage discharges, landfill leachate, and stormwater runoff.	Sediments are a good integrator over time compared to water samples. Can be expensive to analyse. ANZECC guidelines provide limits, but these are based largely on Australian conditions. Emerging contaminants.
Shellfish	Metals, and emerging contaminants.	As for metals and emerging contaminants in sediments.	Metals concentrations in shellfish link to all three values. Shellfish good integrators over time for contaminants, since they are too low/variable in water to reliably measure.
Shellfish	Faecal Indicator Bacteria (FIB).	As for water FIB. Contamination of shellfish will primarily be linked to upstream sources.	*E. coli* in flesh used by regulatory agencies and shellfish sanitation programmes. Emerging molecular technologies, such as PCR markers and bacteriophages, are becoming more commonplace for assessing faecal contamination, and can be linked to source.

In the case of macroalgae and macrofauna, variables may be combined to form a composite index that may serve as the attribute for this project (see Section 5.2.1). An important consideration is that models can be employed for attributes where measurements prove difficult. For example, in cases where there is significant spatial and temporal variability of the variable to be measured, such as nutrient concentrations or rates of sediment accumulation, appropriately calibrated modelled estimates used as proxies may be more conducive to developing management objectives for estuaries. This does not preclude measured forms of the variables to be implemented as part of estuary monitoring or as state variables. Similarly, some variables may not be directly linked to the aspect to be managed, but rather signify the integrated response of the stressor. Examples include the use of chlorophyll a (Chl-a) or macroalgae in water or sediments as proxies for nutrient enrichment, versus measuring nutrient concentrations directly, which are known to be highly variable spatially and temporally. Lastly, some of the variables suggested for further consideration include those related to emerging issues and aspects to be managed (such as emerging contaminants), or involve developing new technologies that may open up the ability to implement variables not previously able to be considered (such as molecular markers for faecal contaminants).

5.3.2 State variables

The evaluation component of this report was focussed on assessing variables according to their potential as attributes. Many of the variables evaluated in this report, including those both above and below the threshold for further prioritisation (see Figure 5-3), will be important in monitoring the state of New Zealand's estuaries. These may include variables used to for assess (and report on) the state of a particular value (state variables), as well as variables that may assist in interpreting changes in attributes or state variables over time. For example, water temperature and salinity may not serve as attributes or state variables, but these variables may be useful in interpreting results and understanding drivers of change. It should be noted that climate change will also impact both temperature and salinity, with some catchments generating more (or less) freshwater volume.

It is important that attributes have documented relationships with both upstream aspects to be managed and the value for which it is being managed. The linkages between attributes and values may be strengthened through use of state variables that are affected by changes in the attribute, and can be routinely monitored to assess the state of estuary values in response to management actions. For example, the Macroinvertebrate Community Index (MCI) is being investigated as a performance measure for ecosystem health in freshwater management, versus its use as an attribute to drive freshwater limit setting (MfE 2014). Variables for macrofauna have strong potential to serve a similar role in describing the state of estuaries where they can be related to specific upstream aspects to be managed.

Responses to the on-line survey (Appendix C) and workshop outcomes provided useful information for prioritising what is important to be monitored in estuaries, and for categorising variables that have the greatest potential to be used as state variables. Key characteristics of healthy estuaries include: high quality of water and sediments, high diversity and functioning of estuary habitats, and the presence of highly diverse native fauna. During the meeting on 9 August 2017, we identified priority variables representative of these categories that can contribute to estuary monitoring, and have potential to be developed into state variables (Table 5-2). Most variables listed fell within the top tier in the evaluation (see Appendix F), and with the exception of water quality variables, are those often included in estuary monitoring programmes. There may be other variables that will be important to some estuaries that aren't captured here, such as the presence or abundance of non-native species. There will also be variables which are informative and contribute to monitoring programmes, but will not act as attributes or SVs; for example: water temperature, pH levels, and salinity. Finally, although there is overlap in variables that have potential to serve as both attributes and state variables, how (and where) they are measured in an estuary may vary depending on their intended use.

Table 5-2. Variables recommended for further consideration as state variables. Those which are **bold** are also candidate attributes.

Value	Category	Recommended priority variables
Ecosystem Health	Water quality	**Nutrient concentrations (N, P)**) **Chl-a** Dissolved oxygen **Water clarity (e.g., Secchi disk)** **Total Suspended Sediments (or consideration of proxy such as turbidity)**
	Sediment quality	Broadscale extent of dominant substrate types, including: ▪ areal extent of mud ▪ areal extent of anoxic bottoms **Rate of sediment deposition** Fine-scale sediment variables at select sites, including: ▪ **grain size / mud content** ▪ sediment nutrients ▪ Total Organic Carbon (TOC) ▪ sulphides ▪ redox potential discontinuity (RPD) ▪ **sediment metals** ▪ **chl-a**
	Habitat diversity and quality	**Macroalgae: OMBT EQR from ETI toolbox (Section 5.2.1)** Broadscale extent of habitats, including for example: ▪ areal extent of seagrass ▪ areal extent of opportunistic macrolgae ▪ areal extent of salt marsh ▪ areal extent of shellfish beds ▪ areal extent of dominant substrate types
	Species diversity	**Macrofauna variables** (includes shellfish)
Human Health for Recreation	Bathing water quality	**Faecal indicator bacteria (FIB)** Frequency of bathing beach closures
	Shellfish quality	**Faecal indicator bacteria (FIB) in shellfish** Frequency of harvest closures (recreational & commercial) **Metals in shellfish**
Mahinga Kai	Shellfish	Shellfish distribution and abundance
		Frequency of customary harvest closures
		Harvest area accessibility
	Finfish	Finfish diversity and abundance

6 Conclusions

Concluding remarks and recommendations according to the key components of the first phase of the project include the following:

- The simpler classification framework for estuaries developed for the ETI toolbox should be applied, integrating ICOLLs as a subcategory of SIDEs and SSTREs (see Table 3-2). This simple framework is conductive to the project aims.
- Twelve variables linked to ecosystem health (and mahinga kai), including those for both the water column and sediments, were identified as candidate attributes for further development in the next phase. These are summarised in Figure 5-4.
- Four variables linked to human health for recreation (and mahinga kai) were identified as candidate attributes for further development in the next phase. These include faecal indicator bacteria in water and in shellfish, as well as further investigation of molecular markers (including bacteriophages) as candidate attributes.
- Approximately 20 variables across four categories (water quality, sediment quality, habitat diversity and quality, and species diversity) were identified for further consideration for monitoring in estuaries and as state variables for ecosystem health. These are summarised in Table 5-2.
- Faecal indicator bacteria (FIB) in water and shellfish, along with the frequency of bathing beach and shellfish harvest closures were identified as potential variables for monitoring the state of Human Health for Recreation in estuaries.
- Potential state variables for mahinga kai include shellfish diversity and abundance in harvest areas, frequency of customary harvest closures, measures of harvest area accessibility, and finfish diversity and abundance. Further work regarding these variables need to be validated by the Iwi Science Panel (ISP)/Iwi Advisory Group (IAG); their consideration is also intended to begin dialogue with mana whenua over their preferences for state variables for mahinga kai.
- The project will benefit from closer alignment with kaupapa Māori monitoring frameworks. Specific recommendations to improving alignment, including information sharing exercises and workshop(s) with this project and the ISP/IAG, are provided in Section 2.3.6.
- Several estuary projects are underway that align closely with the MfE project. The next phase of the project will involve identification and compilation of useful estuary datasets from various sources.
  - It is likely this phase will strengthen linkages between projects, and improve alignment, minimise duplication and maximise outcomes.
  - Team members for this project are also involved in related projects (e.g., OTOT, Porirua Harbour), and will help to ensure that alignment occurs and that overlap is minimised.

The prioritised lists of variables provided in this report will assist in focusing the next phase of Stage 1 for the project.

7 Glossary of abbreviations and terms

The following table provides definitions and narratives for a range of terms used in this project. For consistency, we have incorporated wording and definitions from the NPS-FM.

Areal extent	The extent of a 2-dimensional surface enclosed within a specified boundary. Measures of areal extent of habitats are typically determined with the aid of aerial imagery and walking the estuary to delineate areas with images, maps and a GPS.
Attribute	Measurable characteristics of estuaries, including physical, chemical and/or biological, properties that are directly affected by upstream aspects to be managed, such as sediments and nutrients.
Biogenic habitat	Biogenic habitats are created by plants and animals and may be the organism itself, such as a seagrass meadow or a bed of horse mussels, or arise from an organism's activities, such as the burrows created by crabs. Examples in New Zealand estuaries include mangrove forests, seagrass meadows, green-lipped mussel and oyster reefs. Less widely recognised examples are horse mussel beds, bryozoan fields, tubeworm mounds, dog cockle beds, and beds of *Caulerpa*, a green alga.
Coastal hydrosystem	A coastal system comprising hydrological, geomorphic and ecological components, including significant surface water and/or groundwater components, that spans within a gradient through fresh water to brackish to saline (Hume et al. 2016).
Coastal marine area	The foreshore, seabed, and coastal water, and the air space above the water: a) of which the seaward boundary is the outer limits of the territorial sea: b) of which the landward boundary is the line of mean high water springs, except that where that line crosses a river, the landward boundary at that point shall be whichever is the lesser of— (i) 1 kilometre upstream from the mouth of the river; or (ii) the point upstream that is calculated by multiplying the width of the river mouth by 5. (RMA definition).
Coastal water	Means seawater within the outer limits of the territorial sea and includes: a) seawater with a substantial freshwater component; and b) seawater in estuaries, fiords, inlets, harbours, or embayments. (RMA definition).
Community	An assemblage of two or more species of organisms and/or populations interacting in a specific area (habitat) or time.
Estuary	Estuaries are spatially bounded as seaward from an imaginary line closing the mouth (opening to the ocean), to landward where ocean derived salts measure less than 0.5ppt during the period of average annual low flow (Robertson et al. 2016a). The recent coastal hydrosystems typology defines an estuary as partly enclosed by land, open to the sea for extended periods, within which seawater is measurably diluted by land drainage, and which typically experiences daily tidal ingress (i.e., has a tidal prism; Hume et al. 2016).
Eutrophication	Process whereby excessive nutrient inputs to a water body result in accelerated primary production (phytoplankton and macroalgae growth), and flow-on effects to the wider ecosystem, such as reduced water clarity, physical smothering of biota, or extreme reductions in dissolved oxygen because of microbial decay.

Flushing	Using measures of tidal range, and the ratio of river runoff to estuarine volume, flushing is the time for freshwater inflows and the tidal prism volume to replace the estuary volume. An estuary with large volumes and short flushing times are less susceptible to eutrophication from upstream nutrient loading than estuaries with smaller volumes and long flushing times.
Habitat	An ecological area made up of physical and biological factors that provides an organism(s) with food, shelter, ability to reproduce, etc.
Inorganic compounds	Any compound that lacks a carbon atom and is not of biological origin. For example, trace metals, minerals and inorganic forms of nutrients.
Limit	Based on the NPS-FM definition, a limit is the maximum amount of resource that is available for use while still enabling an objective to be met. It is a specific quantifiable amount that links the objective (the desired state) to use of the resource. A limit puts constraints on how much of that resource is available for use. As an example, for estuary *water quality*, the assimilative capacity of the water (its ability to absorb contaminants) is the resource being limited. A quality limit would describe how much of a contaminant (e.g., a nutrient) could be discharged into the water by users without exceeding an objective.
Macrofauna	Macrofauna are invertebrates that live on or in sediment, or attached to hard substrates. They include infauna (those in the sediments) and epifauna (those colonising the surface of sediments). They are generally classified according to size, with invertebrates greater than 0.5 mm or 1 mm in size regarded as macrofaunal.
National bottom line	Based on the NPS-FM definition, the national bottom line is the boundary between the C and D states for the attributes associated with the compulsory national values ('ecosystem health' and 'human health for recreation'). According to this definition, all estuaries (or manageable units within estuaries) would have objectives set above nationally-defined bottom lines.
National Objectives Framework (NOF)	The National Objective Framework (NOF) directs regional decision-making in the setting of objectives. It consists of a process, a set of national values, and a set of attributes for setting freshwater objectives to achieve those values.
National value	Originating from the NPS-FM, national values are those intrinsic qualities, uses or potential uses that were determined by Government both to be appropriate based on a set of criteria, and to be of national significance. Some are compulsory and must have objectives set for them, while others may be considered compulsory at a regional level by regional councils.
Naturally occurring processes	Processes that could have occurred in New Zealand prior to the arrival of humans. In the case of the NPS-FM, where existing conditions are below a national bottom line due to naturally occurring processes, a regional council may set an objective below a national bottom line. By definition, any deterioration in water quality that is caused by human interventions, and would not have occurred without that intervention, does not qualify a water body to have an objective set for it below a bottom line.
Organic compounds	Organic compounds contain carbon atoms and can be of synthetic or natural origin. Those that can be toxic to organisms include compounds derived from petroleum and gas (polycyclic aromatic hydrocarbons, or PAHs), organic herbicides, and organochlorine insecticides.

Pressure	Pressures are the human activities (e.g., urbanisation, farming, climate change) and natural processes (e.g., floods) that generate stressors that in turn lead to environmental changes.
REDOX	Reduction-oxidation potential, a measure of the reducing conditions in a medium, e.g., sediment.
RPD - REDOX Potential Discontinuity	The zone within estuarine sediments where it changes from aerobic to anaerobic conditions. It can be visually assessed by observing the colouration gradient of well oxygenated sediments near the surface (lightly coloured) to anaerobic sediments (black) that are deeper within a collected core sample.
Secondary contact	People's contact with water that involves only occasional immersion and includes wading or boating (except boating where there is high likelihood of immersion; NPS-FM definition). The term is used in relation to objectives that require the health of people and communities, at least as affected by secondary contact with water, to be safeguarded. This objective is supported by the compulsory national value 'human health for recreation'.
State Variable	Measurable variables or metrics derived from multiple variables that provide information about and/or describe the state of estuary values.
Stressor	Stressors are the physical, chemical, or biological 'agents of change' on ecosystem health, functioning and productivity. Sediment loading is an example of an upstream stressor that affects estuaries.
Substrate	The sediment or material on or from which an organism grow and live.
Taonga species	Species of native birds, plants and animals of special cultural significance and importance to Māori.
Turbidity	Is a measure of the cloudiness or haziness in a liquid caused by light scattering by suspended particulate matter. An increase in turbidity results in a corresponding decrease in water clarity. High turbidity may be from an increase in phytoplankton (algae) or an increase in suspended sediments.
Value	Means: a) any national value; and b) includes any value in relation to estuaries, that is not a national value, which a regional council identifies as appropriate for regional or local circumstances (including any use value). Values are intrinsic qualities, uses or potential uses associated with estuaries. They are qualities or uses that people and communities appreciate about estuaries and wish to see recognised in their on-going management. Intrinsic qualities include ecosystem health, and natural form and character.
Visual clarity	Visual clarity is the maximum distance at which an object (typically a black disk) can be seen horizontally through the water column.

8 Acknowledgements

We thank the many people from the wider project team and beyond that participated in the on-line survey, workshop, follow up consultation and the evaluation of variables (see Appendix B). We also thank Shaun Awatere, Caine Taiapa, and Kura Paul-Burke for their time reviewing and discussing results in relation to mahinga kai. We also acknowledge helpful feedback and input from Helli Ward (MfE), Mal Green (Streamlined), Leigh Stevens (Wriggle) and Council scientists, including Anna Madarasz-Smith (Hawke's Bay Regional Council) and Megan Carbines (Auckland Council).

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Appendix A Project team

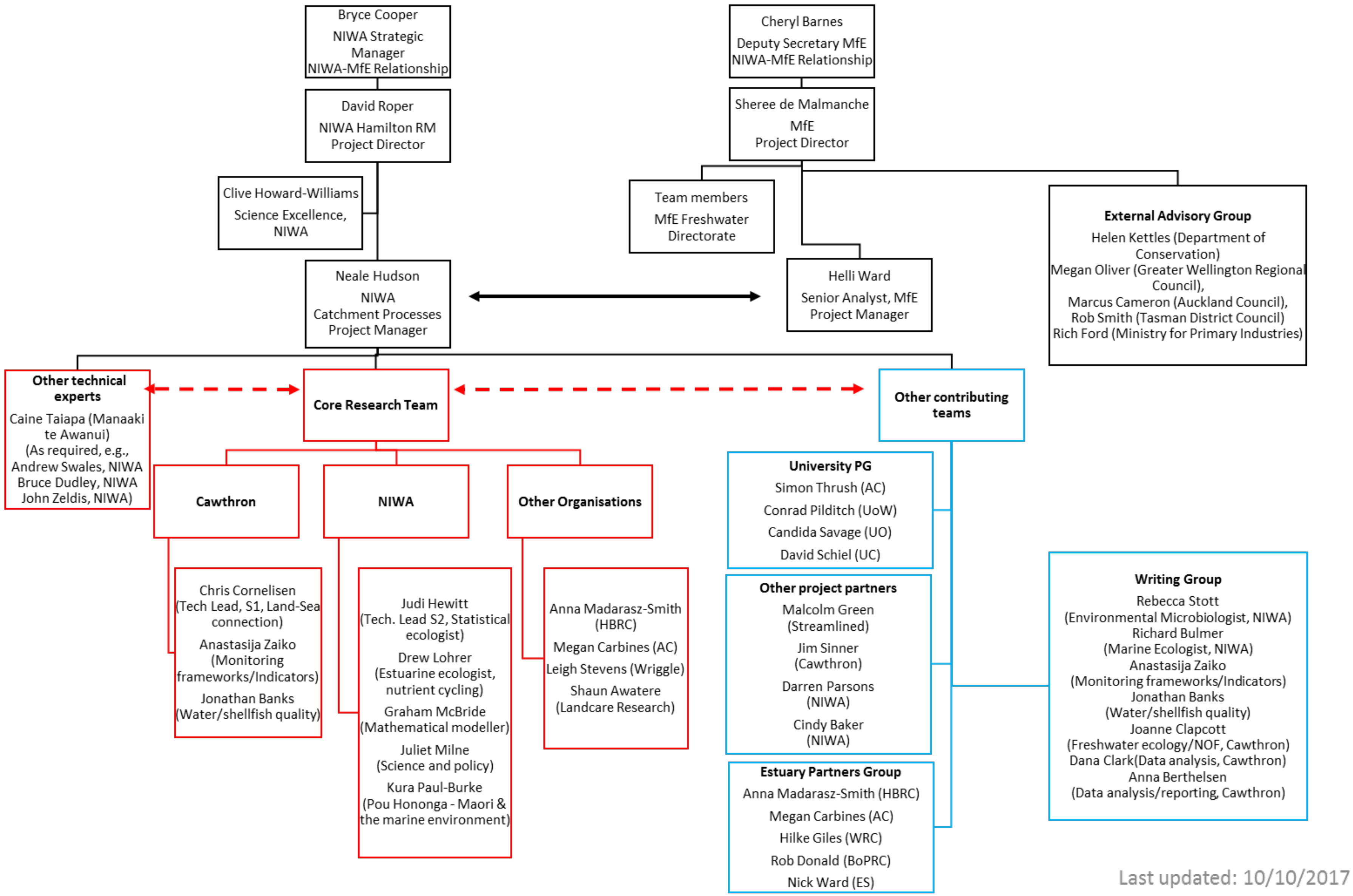

Figure A-1: Project team members, broad roles and team relationships.

Appendix B Participant Lists

On-line survey participants

Attendee	Affiliation
Anna Berthelsen	Cawthron
Anastasija Zaiko	Cawthron
Chris Cornelisen	Cawthron
Jonathan Banks	Cawthron
Paul Gillespie	Cawthron
Cindy Baker	NIWA
Darren Parsons	NIWA
Graham McBride	NIWA
Judi Hewitt	NIWA
Juliet Milne	NIWA
Shaun Awatere	Landcare Research
Caine Taiapa	Manaaki Te Awanui
Leigh Stevens	Wriggle Coastal Management
Malcolm Green	Streamlined Environmental
Anna Madarasz-Smith	Hawke's Bay Regional Council
Oli Wade	HBRC
Sandy Gorringe	GDC
Claire Conwell	GWRC
Megan Oliver	GWRC
Ricky Eyre	NRC
Trevor James	TDC
Hilke Giles	WRC
Megan Carbines	Auckland Council
Nick Ward	Environment Southland
Rob Donald	Bay of Plenty Regional Council
Candida Savage	University of Otago
Conrad Pilditch	University of Waikato
David Schiel	University of Canterbury
Simon Thrush	University of Auckland

Workshop participants

Contributor	Affiliation
Helli Ward, Serina Callachan	MfE
Graham McBride, Juliet Milne, Drew Lohrer, Judi Hewitt, Neale Hudson, Rebecca Stott	NIWA
Anatasija Zaiko, Chris Cornelisen, Jim Sinner, Jonathan Banks, Anna Berthelsen	Cawthron
Anna Madarasz-Smith	Hawke's Bay Regional Council
Hilke Giles	Waikato Regional Council
Megan Carbines	Auckland Council
Leigh Stevens	Wriggle Coastal Management
Shaun Awatere	Landcare Research
Conrad Pilditch	University of Waikato
Rob Donald	Bay of Plenty Regional Council
Candida Savage	University of Otago
David Schiel	University of Canterbury
Caine Taiapa	Te Manaaki Te Awanui
Toni White	AgResearch – Meeting Facilitator

Evaluation participants

Estuarine value	Contributor	Affiliation
Ecosystem Health	Anna Berthelsen	Cawthron
Ecosystem Health	Anastasija Zaiko	Cawthron
Ecosystem Health	Leigh Stevens	Wriggle Coastal Management
Ecosystem Health	Malcolm Green	Streamlined Environmental
Ecosystem Health	Anna Madarasz-Smith	Hawke's Bay Regional Council
Ecosystem Health	Paul Gillespie	Cawthron
Ecosystem Health	Judi Hewitt	NIWA
Ecosystem Health	Cindy Baker	NIWA
Ecosystem Health	Darren Parsons	NIWA
Ecosystem Health	Megan Carbines	Auckland Council
Ecosystem Health	Candida Savage	University of Otago
Ecosystem Health	Conrad Pilditch	University of Waikato
Ecosystem Health	Simon Thrush	University of Auckland
Human Health for Recreation	Chris Cornelisen	Cawthron
Human Health for Recreation	Jonathan Banks	Cawthron
Human Health for Recreation (toxicants)	Olivier Champeau	Cawthron
Human Health for Recreation	Graham McBride	NIWA
Human Health for Recreation	Rebecca Stott	NIWA
*Ecosystem Health, Human health for recreation	Kura Paul-Burke	NIWA
*Ecosystem Health, Human health for recreation	Caine Taiapa	Manaaki Te Awanui
*Ecosystem Health, Human health for recreation	Shaun Awatere	Landcare Research

*Caine, Kura and Shaun reviewed variables within the context of mahinga kai, and identified those within ecosystem health and human health for recreation that were relevant.

Draft report review and terminology standardisation workshop participants

Contributor	Affiliation
Judi Hewitt, Rebecca Stott, Neale Hudson	NIWA
Helli Ward, Pierre Tellier	Ministry for the Environment
Ton Snelder	Land, Water, People (for MfE)
Chris Cornelisen, Anastasija Zaiko	Cawthron
Mal Green	Streamlined Environmental
Leigh Stevens	Wriggle
Megan Carbines	Auckland Council, Estuary Partners Group
Shaun Awatere	Landcare Research (part attendance)

Appendix C On-line survey results

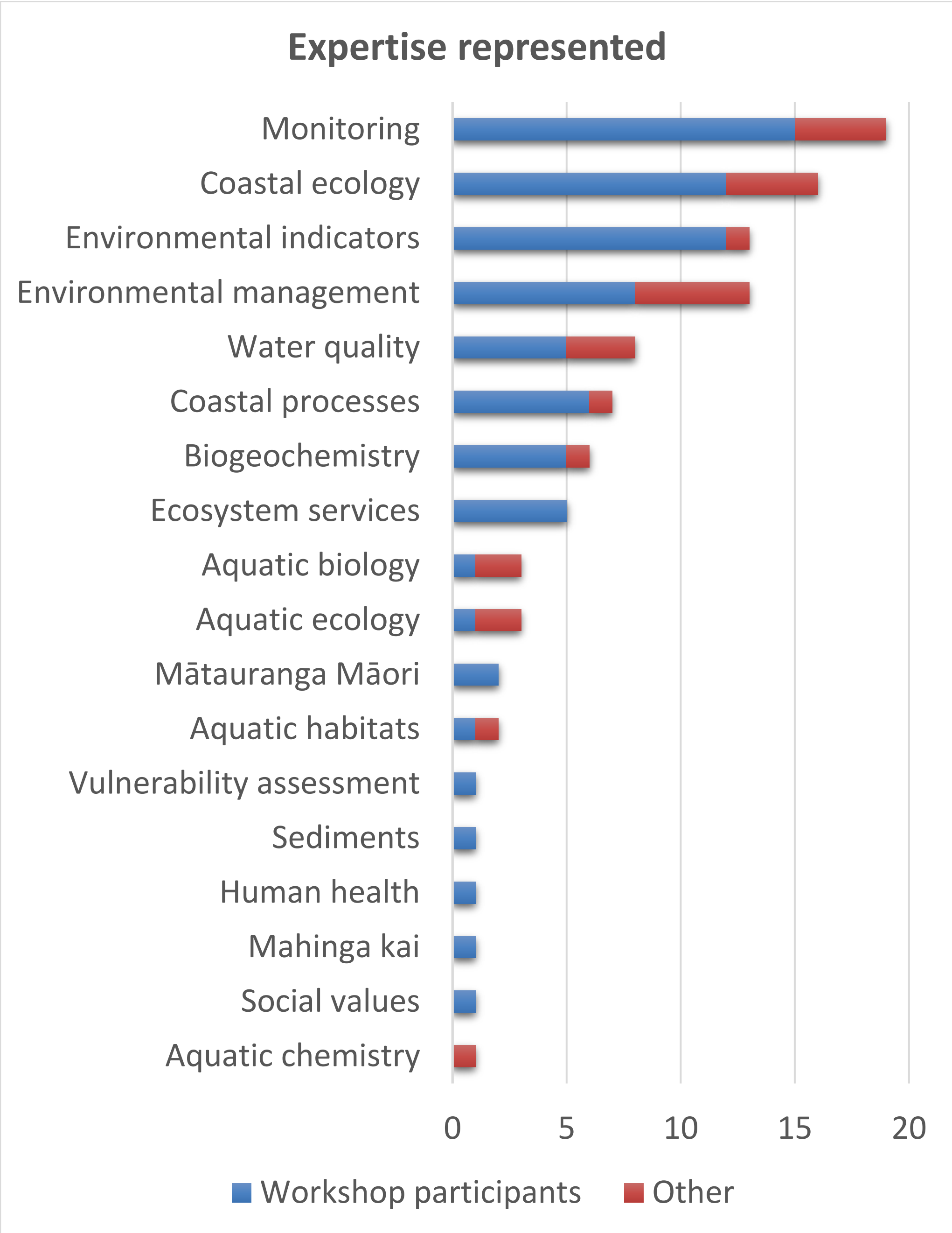

Figure C-1: Summary of on-line survey results according to expertise of the ~30 respondents.

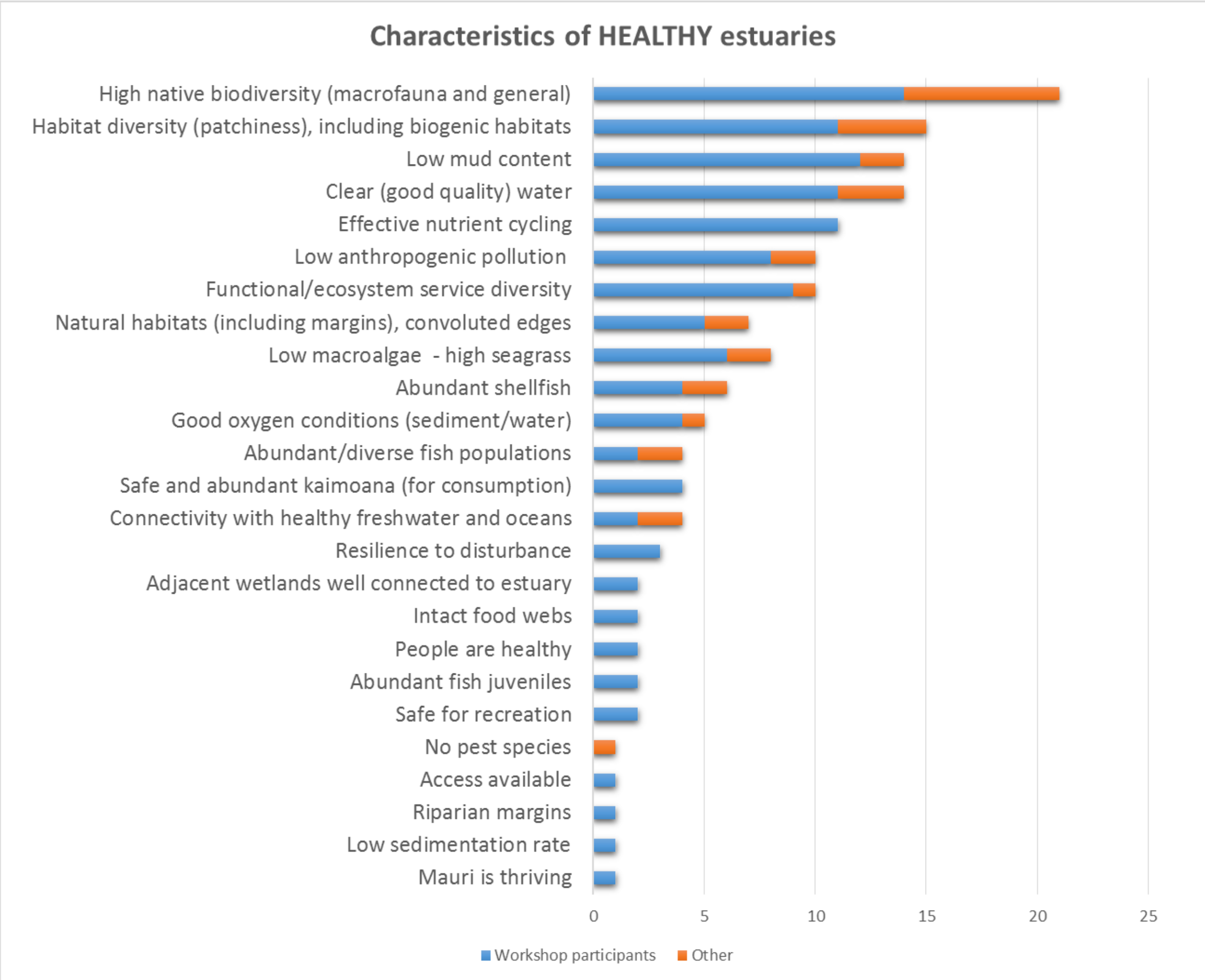

Figure C-2: Top 5 characteristics of healthy estuaries identified by respondents.

It is important to note that because respondent expertise is unevenly represented (e.g., significantly more ecologists responded than human health or matauranga Māori experts), the number of times a feature is nominated does not necessarily equate to its level of significance.

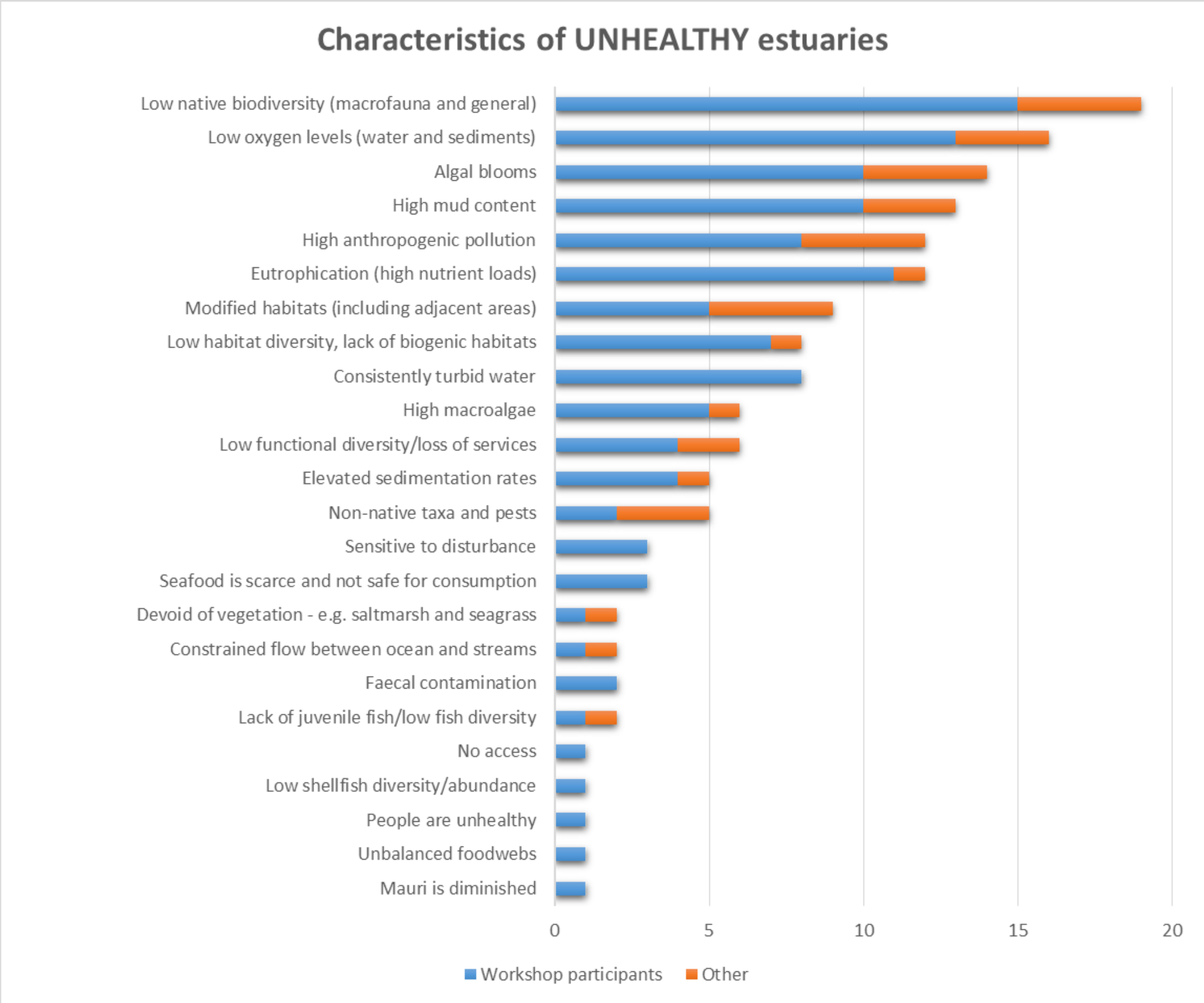

Figure C-3: Top 5 characteristics of unhealthy estuaries identified by respondents.

It is important to note that because respondent expertise is unevenly represented (e.g., significantly more ecologists responded than human health or matauranga Māori experts), the number of times a feature is nominated does not necessarily equate to its level of significance.

Variables (grouped)	Ecosystem health	Human health	Mahinga kai
Key macrofauna/ diversity	19	1	11
Macroalgal cover/diversity	11	8	5
Visual clarity/turbidity	10	5	6
Microbial faecal indicators		10	9
Nutrients (water, sediments)	10	4	5
Dissolved oxygen/sediment oxygen	11		5
Organic/metal contaminants	7	3	5
Shellfish densities/diversity/size	7	1	6
Fish diversity/ abundance	6	1	5
Sediment accumulation rate	6	2	3
Algae blooms/abundance	5	3	3
Natural/undisturbed habitats characteristics	6	1	4
Sediment characteristics	6	1	4
Mud/sand ratio	6	1	3
Microbial pathogens		5	4
Toxic algae	3	3	3
Chl-a (water)	4	1	2
Shellfish harvest	3	1	2
Suspended sediments	3	1	2
Mauri/Cultural indicators	1	1	3
Grain size	3		1
Benthic productivity	2	1	1
Seagrass cover	3		
Kai indicators			3
Indicator/valued species	1	1	1
Landuse	1	1	1
Functional diversity	2		
Plankton diversity/abundance	2		
Foodweb health	1		1
Invasive pests	1		1
Saltmarsh/seagrass	1		1
Water temperature	1	1	
pH	1		1
Microplastics	1		
Historic mangrove	1		
Biogenic habitats	1		
Microphytobenthos biomass	1		

Figure C-4: Linkages between variables and values. Numbers correspond to the number of respondents that indicated a linkage between a variable.

It is important to note that because respondent expertise is unevenly represented (e.g., significantly more ecologists responded than human health or matauranga Māori experts), the number of times a feature is nominated does not necessarily equate to its level of significance.

	Point(s) of origin		
Identified stressor	Upstream	Estuary	Ocean
Nutrient loads	17	5	1
Harvesting/fishing	2	10	6
Sediment loads	13	3	1
Organic/chemical/metal contamination	11	6	0
Physical disturbance/destruction	3	7	1
Biological invasions	1	3	3
Wastewater/faecal contamination	3	2	0
Climate change	1	2	2
Urban infrastructure	1	2	0
Property rights	1	1	1
Barriers	1	1	1
Microbial contamination	3	0	0
Land clearance	1	0	0
Forestry	1	0	0
Agriculture	1	0	0
Catchment sediment erosion	1	0	0

Figure C-5: Stressors listed by respondents and their point(s) of origin (sources). Numbers correspond to the number of respondents that indicated a linkage between a variable and a value.

It is important to note that because respondent expertise is unevenly represented (e.g., significantly more ecologists responded than human health or matauranga Māori experts), the number of times a feature is nominated does not necessarily equate to its level of significance.

Table C-1: Importance of stressors in driving variables (low/uncertain-1; medium-2; high-3), based on the highest indicated by respondents.

Variables (grouped)/Stressors	Wastewater/ faecal contamination	Land clearance	Climate change	Urban development	Sediment loads	Nutrient loads	Harvesting/ fishing	Organic/chemical/metal contamination	Physical disturbance/destruction	Biological invasions	Barriers	Forestry	Agriculture	Microbial contamination	Catchment sediment erosion
Key macrofauna/ diversity	3	3	2	3	3	3	3	3	3	3	3	2	3	1	3
Macroalgal cover/diversity	2		3	3	3	3	3	3	3		2	2	3		
Visual clarity/turbidity	1	3	1	2	3	3	3	3	2	2	3	3	3	3	3
Microbial faecal indicators	3	2	1	3	3	3	1	3	3	1	1	1	3	3	
Nutrients (water, sediments)	1			3	3	3	2	2	2		2	2	3	2	
Dissolved oxygen/sediment oxygen	1		1	2	3	3	1		3	1	3	3	3		2
Organic/chemical/metal contaminants	1				2	1	1	3	2	1				1	2
Shellfish densities/diversity/size	3	3	2	2	3	2	3	3	3	2				1	
Fish diversity/ abundance	2	3	2	3	3	3	3	3	3		3				
Sediment accumulation rate	1	3	2	3	3	1	1	1	1			3	3	1	3
Algae blooms/abundance	2				2	3	3	1	2		2				1
Natural/undisturbed habitats characteristics					3	3	3	2	3	3	2				
Sediment characteristics					3	3	3	3	3	3	3				
Mud/sand ratio			1	3	3	2	2	2	3	1	2	3	3		3
Microbial pathogens	3	2	1	1		1	1		2					3	
Toxic algae					3	3	3	3							
Chl-a (water)					2	3	1	1	1	1					
Shellfish harvest	3				3	1	3	3	3	3					
Suspended sediments	2				3	2	1								
Mauri/Cultural indicators	3				3	3	3	3		3					
Grain size					3	3	1	3						1	
Benthic productivity					3	3	1		3				2		3
Saltmarsh/Seagrass cover			2	2	3	2	2	1		2		2			
Kai indicators					3	3	3	3		3					
Indicator/valued species					3	3	3	2		3				1	
Landuse					3	2		2						2	
Functional diversity					3	2		3	1					1	
Plankton diversity/abundance					3	3		3	2						
Foodweb health					3	3	3	1		3					
Invasive pests					3	3	3	1		3					
Water temperature			3	2								1	1		
pH					2	3	1	2							
Microplastics					3	3	3		3						
Historic mangrove					3	1									
Biogenic habitats					3	3									
Microphytobenthos biomass					2	3	1	2							

Appendix D Matrix of variables compiled from an on-line survey and workshop with experts

Managing upstream: Estuaries State and Values

Values → Ecosystem health | Mahinga Kai** | Human health for recreation

Aspects to be managed →	Sediment loading	Nutrient enrichment	Flow alteration/ barriers	Others (marine, estuarine, global)***	Contaminants (synthetic, non-synthetic compounds)	Introduced microbial pathogens, other toxins
PRIORITY LIST of variables*	- Areal extent of substrates - Species composition (*e.g., diversity, abundance, distribution of sediment macrofauna or selected key taxa*) - Grain size/mud content - Particulate matter (e.g., TSS) - Water clarity - Sediment accumulation - Major deposition events	- Primary production (e.g., *chl-a, macroalgae, phytoplankton cyanobacteria*) - Sediment oxygenation - Species composition (*e.g., diversity, abundance, distribution of sediment macrofauna or selected key taxa*) - Sediment organic content - Sediment nutrients - Sediment sulphide concentration - Biogenic habitats (Macroalgae) - DO - Water nutrients - Grain size/ mud content	- Sequencing of habitats - Barriers to fish passage - Modified flow regime	- Critical habitats - Species composition (*e.g., diversity, abundance, distrib. of selected key taxa*) - Sediment contaminants - Sediment accumulation - Biogenic hab extent/dynamics - Pathogens and faecal in Taonga - Contaminants in Taonga - DO - Water nutrients - Particulate matter - Water clarity - Water contaminants - Water pathogens and faecal in. - pH - Water temperature	- Sediment contaminants - Species composition (*e.g., diversity, abundance, distribution of sediment macrofauna or selected key taxa*) - Contaminants in Taonga spp. - Contaminants in harvestable species - Water contaminants - Human health and wellbeing **NOTE:** includes metals, chemicals, SVOCs, estrogen-like compounds, pesticides, PCBs etc.	- Water microbial pathogens - Water faecal indicators - Sediment microbial pathogens - Sediment faecal indicators - Path. and faecal ind in Taonga - Natural toxins in Taonga sp. - Cyanobacteria & HAB
POSSIBLE (SECOND PRIORITY) LIST	- Habitat diversity/fragmentation - Biogenic hab extent/dynamics - Sediment oxygenation - Sediment org content - Functional diversity - Dissolved oxygen - Primary production - Condition of biogenic habitats - Human health/wellbeing - Modified flow regime	- pH - Particulate matter - Water clarity - Habitat diversity/fragmentation - Areal extent of substrates - Grain size/mud content - Sequencing of habitats - Biomass of habitat form spp - Condition of biogenic habitats - Functional diversity - Denitrification rate - N/P flux - Oxygen flux - Benthic metabolism - CDOM - Water natural toxins	- Critical habitats - Areal extent of substrates - Sediment oxygenation - Species composition (*e.g., diversity, abundance, distribution of sediment macrofauna*) - Grain size/mud content - Sediment organic content - Sediment nutrients - Sediment sulphides - Sediment contaminants - Sediment accumulation - Major deposition events - Biogenic hab extent/dynamics - Water temperature	- Habitat diversity/fragmentation - Sediment pathogens - Sediment faecal indicators - Biogenic hab patchiness - Biogenic habitat condition - Biomass of hab forming species - Functional diversity - Primary production - Natural toxins - Frequency of closures - Human health - Modified flow	- Sediment sulphide conc - Condition of selected spp - pH	- Frequency of closures - Human health and wellbeing - Catch of harvestable spp - Size/condition of selected spp - Recruitment of key taxa

UNLIKELY TO BE CONSIDERED FURTHER

- Patchiness of biogenic habitats
- Trophic transfer and skew
- Secondary production
- Resilience
- Facilitative relationships
- Regional hydrodynamics patterns
- Shell deposits abundance/ distribution

* **Attributes** are measurable characteristics of estuaries, including physical, chemical and/or biological, properties that are directly affected by upstream (freshwater) pressures.
**Pressures (aspects to be managed) affecting mahinga kai overlap with those identified for Ecosystem Health and Human Health; however, there may be specific attributes relevant to mahinga kai for a particular pressure.
***This includes pressures like physical habitat alterations, introduction of non-indigenous species, harvesting/extraction of living resources, alterations of catchment area, climate change. We are not going to develop attributes linked to these, but need to know whether selected attributes / state variables can be affected by them.

Appendix E Evaluation criteria for assessing variables for their use as attributes

Table E-1: Essential criteria used to score and rank variables in terms of their potential as candidate attributes.

Responsiveness to upstream aspects to be managed (pressures/stressors) (Essential)	Relevance to upstream management measures (Essential)	Temporal-spatial stability (Essential)	Cost-effective (Essential)	Measurable, precise and repeatable (Essential)
Changes in attribute are caused by variation in the specified upstream pressure.	Able to respond to appropriate management measures and response is detectable, the relationship between management activity, corresponding pressure and attribute is clearly understood so that limits can be derived.	Variability of an attribute allows reliable assessment of estuarine state/ pressure magnitude using reasonable temporal-spatial monitoring grid.	High quality data on attribute can be obtained at an affordable cost.	Easily and accurately determined using technically feasible and quality assured methods.
Fully met (1): the attribute is directly responsive to upstream pressure(s), all the pressure-state relationships are defined. **Partially met (0.5)**: indirectly responsive to upstream pressure(s), can be significantly influenced by estuarine or coastal pressures. **Not met (0)**: no clear pressure-state relationship in attribute's response to upstream pressures (responds to estuarine or coastal pressures only).	**Fully met (1)**: one can advise on the direction AND extent of required changes in ALL relevant pressures/stressors. **Partially met (0.5)**: one can only advise on the direction of required changes in ALL relevant pressures or direction AND extent of required changes in SOME of relevant pressures/stressors. **Not met (0):** no reasonable advice can be provided on direction or extent of required changes in relevant pressures/stressors.	**Fully met (1)**: very stable, signals cumulative changes over extended time span (season to year) and spatial range. **Partially met (0.5)**: moderately variable timewise (days-weeks), relatively stable across the estuary (zonation can be pre-defined). **Not met (0):** variable, high temporal-spatial patchiness, dense measurements needed to cover the range.	**Fully met (1)**: the attribute can be reliably measured at low cost independently on selected approach and estuary type. **Partially met (0.5)**: the attribute can be measured at relatively low cost depending on selected measurement approach/estuary type and scale. **Not met (0)**: the attribute assessment is expensive/time consuming.	**Fully met (1)**: the attribute can be reliably measured with well-established technically feasible methods in all types of estuaries. **Partially met (0.5)**: potential issues with measurement and/or quality in some/all types of estuaries. **Not met (0):** no tangible method exists, or methods are not fully developed/validated.

Table E-2: Evaluation criteria identified as 'desirable' for use as variables.

Possibility to set bands (Desirable)	Specificity (Desirable)	Scientific basis (Desirable)	Sensitivity (Desirable)	Non-destructive (Desirable)
Clear bands can be set that reliably relate to corresponding upstream targets and reflect management objectives.	Does not overlap/interfere with other attributes, unlikely to be significantly influenced by other factors and additional pressures.	Relevance to estuary state and pressure(s) is based on sound scientific concept as documented by peer reviewed publications and general acceptance within the scientific community.	Sensitive to the minor changes in pressure, before the critical shift in state, have a high signal to noise ratio.	No or minimal harm to ecosystem is done in the course of assessment (sampling, measurements).
Fully met (1): bands can be set for all types of estuaries, that reliably relates to the upstream targets. **Partially met (0.5)**: bands can be set for some estuaries, but a target trend direction related to upstream targets can be established for all estuaries. **Not met (0):** no bands or trends can be set for all estuaries in relation to upstream targets.	**Fully met (1)**: very specific, represents one or few closely related pressures, does not overlap with other attributes. **Partially met (0.5)**: specific, represents one or few related pressures, partially overlaps with other attributes. **Not met (0):** not specific, represents many pressures, fully overlaps with one/few other attributes.	**Fully met (1)**: relevance is well evidenced from observational/experimental studies in NZ, reported in peer-reviewed literature (REF to be provided). **Partially met (0.5)**: relevance is evidenced elsewhere, or evidenced in NZ but not peer-reviewed. **Not met (0):** no documented evidence, or documented in contradictory/unreliable sources.	**Fully met (1)**: sensitive - detectably signals minor changes in pressure(s), independently on measurement method and/or estuary type. **Partially met (0.5)**: detectably signals minor changes in pressure(s), depending on measurement approach and/or estuary type. **Not met (0):** not sensitive - detectably signals only major changes in pressure(s).	**Fully met (1)**: no or minimal harm to ecosystem. **Partially met (0.5):** some harm can be done to ecosystem depending on measurement approach or estuary type. **Not met (0):** sampling and measurement is destructive in all cases.

Table E-3: Evaluation criteria identified as 'informative'.

Easy to assess (Informative)	Precautionary capacity/early warning/anticipatory (Informative)	Complexity (Informative)
The assessment does not require specific expert knowledge (e.g., taxonomic expertise, operation of sophisticated instruments, etc.,) at a certain stage (data gathering, laboratory measurements, data analyses, etc.).	Signals potential future change in an ecosystem state, before actual harm.	Directly measured, or derived from other measurements/ relies on assessment of other attributes.
Fully met (1): no expert knowledge required, the assessment can be performed by non-experts after short training/induction. **Partially met (0.5):** assessment might require expert knowledge depending on the measurement approach. **Not met (0):** requires expert knowledge.	**Fully met (1)**: attribute is able to provide early warning with short response time to upstream pressure(s) (days-weeks). **Partially met (0.5)**: sensitive to upstream pressure(s), but signal in estuary can be detected with a time lag (months). **Not met (0):** response time to upstream pressure(s) is >1 year.	**Fully met (1)**: the information on attribute is obtained by direct measurements. **Partially met (0.5):** part of the information on attribute is obtained by direct measurements (depending on measurement method and/or type of estuary). **Not met (0):** the information is derived from other measurements/relies on assessment of other attributes.

Appendix F Variable descriptions

Table F-1: Sediment quality variables (with overall scores ≥ 8) linked to ecosystem health, and where indicated, mahinga kai. In some cases, the rank is the same for multiple variables when scores were equal. Also indicated is whether the variable was considered in the earlier Estuary NOF work, and whether the variable has potential to be an attribute and / or a state variable. In some cases the variable may end up contributing to an integrated metric.

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Sediment organic content	1	Yes (as Total Organic Carbon (TOC)).	High sediment organic content can result in anoxic sediments, release of excessive nutrients and adverse impacts to biota including Mahinga Kai.	Organic content increases with loading of terrestrial organic matter, and in response to nutrient driven algal growth within estuaries, and decomposition leads to more nutrient enriched sediments.	Organic enrichment will vary across different estuary types (poorly vs highly flushed, shallow vs deep).	AFDW (ash free dry weight) - a surrogate measure can be converted to TOC, but conversions give highly variable results. Can be cheaply and directly measured as TOC. Spatially variable within estuaries Likely to show non-linear response to nutrient loading. Links to ecosystem health status have been demonstrated.	State variable
Sediment grain size	3	Yes (mud content).	Sediment grain size, including the degree of 'muddiness' affects distribution, abundances and health of sediment dwelling organisms (incl. mahinga kai species).	Increased loading of fine sediments from catchments can result in an increased proportion of mud in estuary sediments.	Will likely vary among estuaries with differing water depths, flushing, and hydrodynamic characteristics.	Two different methods typically used (sieving and laser). Has well documented correlations with macrofaunal measures/indicators. Spatially variable as a function of hydrodynamics and resuspension. Links to ecosystem health status have been demonstrated.	Attribute
Composition and areal extent of dominant substrate types	6	Yes (focused on areal extent of soft mud.)	Diversity, abundance and distribution of Kai that inhabit sediments (e.g., cockles, pipi) is strongly linked to substrate type, such as soft mud vs firm sand dominated substrates.	As above for grain size. Terrigenous sediment input into estuaries from catchment activities can alter areal extent of substrate types (e.g., increase the area of the estuary with mud content >20%).	Yes. Will vary between different types of estuaries, and within a given estuary due to influence of hydrodynamics, estuary morphology, resuspension, transport, etc.	Can be easily measured. Support from literature for relationships with values. Data on mud content routinely collected by Councils and significant databases exist. Some links to ecosystem biodiversity status have been demonstrated.	Attribute and State variable

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Sediment Chl-a	7	No	Chl-a is a proxy for primary production and shellfish food sources (e.g., micro-phytobenthos).	Increase due to increased benthic productivity in response to nutrient loading from catchments, Decrease due to reduced light availability / sediment resuspension with sediment loading.	Not dependent on estuary type	Easy to measure. Seasonally and spatially variable. Multiple factors can influence; difficult to distinguish between upstream pressures. Links to ecosystem health status have not been demonstrated.	Attribute and state variable
Sediment nutrient concentrations (N, P, C)	14	Yes	Linked to organic enrichment, and primary production (shellfish food). The sediment compartment can be the largest nutrient pool in the system, and can play a large role in determining growth of algae.	Nutrients, and in particular N, P and C, can increase in response to upstream inputs of nutrients, although importance will depend on benthic fauna and flora cycling of nutrients and inputs from other sources (e.g., ocean).	May be more closely linked to upstream pressures in shallow, poorly flushed estuaries than highly flushed ones, or those that have a strong oceanic input of nutrients.	Spatially variable within estuary. Temporally variable with changes in freshwater inflows, nutrient cycling processes, resuspension, etc. Generally considered that historic levels may take a while to change. Links to ecosystem health status have been demonstrated for N.	State variable
Depth of RPD (REDOX Potential Discontinuity) in sediments	16	Yes	Can limit the depth to which biota (including shellfish) can inhabit the sediments (a shallowing RPD depth forces organisms to sediment surface). Amenity effects at high levels (black smelly sediment).	Linked to nutrient loading and high magnitude sedimentation events. Corresponds with grain size and organic accumulation in sediments, and with sediment hypoxia/anoxia (see table with habitat attributes).	May depend on estuary type in a similar manner as those parameters that relate to oxygenation of the sediments (e.g., grain size, organic content).	Can be cost effective if visual method used, although this method does not always correspond with laboratory measures for sediments with high Fe (e.g., many west coast estuaries). Can be easily measured using an ORP probe and meter in situ. Can be difficult to separate out effects of nutrients vs sedimentation event. Spatially variable Links to ecosystem health status demonstrated.	State variable

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Sediment sulphide concentration	17	No	High levels of sulphides can be toxic to shellfish and other organisms in the sediments.	Closely correlated with depth of RPD (see above).	Not dependent on estuary type.	Usually measured using calibrated probe, which can be difficult to use in the field. Must be analysed within hours of arrival at lab. Links to ecosystem health status have not been demonstrated, but likely to be directly linked at high concentrations.	State variable.
Micro-phytobenthos (MPB) biomass	18	Yes (under macro and micro algae growths).	Important component of estuary food webs and a food source for many shellfish species.	See sediment Chl-a, which is a proxy for MPB biomass.	Not dependent on estuary type.	MPB biomass requires conversion to Carbon units, which requires knowledge of C/Chl-a ratios that can vary depending on the types of diatoms, other algae, cyanobacteria making up the MPB. Links to ecosystem health status have not been demonstrated.	Attribute (assessed as Chl-a) and state variable.

Table F-2: Water quality variables (with overall scores ≥ 8) linked to ecosystem health, and where indicated, mahinga kai. In some cases, the rank is the same for multiple variables when scores were equal. Also indicated is whether the variable was considered in the earlier Estuary NOF work, and whether the variable has potential to be an attribute and / or a state variable. In some cases the variable may end up contributing to an integrated metric.

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Water nutrient concentrations (N, P, C)	10	Yes (including loadings).	Excessive nutrient loading (particularly N) can lead to concentrations that enhance growth of phytoplankton and nuisance macroalgae, which can lead to other symptoms of eutrophication that adversely affect Mahinga Kai (e.g., low oxygen, increased sulphides).	Can respond to upstream inputs of nutrients, although importance will depend on benthic fauna and flora cycling of nutrients and inputs from other sources (e.g., ocean).	Will be more closely linked to upstream pressures in shallow, poorly flushed estuaries than highly flushed ones, or those that have a strong oceanic or within estuary inputs.	Affected by nutrient cycling processes, and fluctuate hourly to seasonally in response to tides and primary production, respectively, therefore requires high-frequency sampling that can be expensive. Highly spatially variable, requiring high spatial resolution of sampling. Links to ecosystem health status have not been demonstrated In earlier Estuary NOF work, *nutrient loads* and/or *potential concentrations* identified as alternative measures	Attribute (modelled values) State variable (measured values)
Water column dissolved oxygen (DO)	13	Yes (under hypoxia-anoxia).	Hypoxia creates stress on organisms. With lower oxygen levels or longer duration events, mortality will occur.	Indirectly related to increased nutrient loadings via rates of primary production and decomposition of organic matter.	Less likely to be an issue in well flushed estuaries. The same bands and bottom lines would likely apply to all estuaries (i.e., anoxia is not a natural feature of NZ estuaries.	Easy to measure with instrumentation, but requires ongoing maintenance High frequency required as it can vary considerably over hours, days, seasons DO is attribute under NPS-FM for use below point sources Measurements are affected by salinity and temperature Links to ecosystem health status have not been demonstrated.	State variable
Turbidity	13	Yes	Turbidity (proxy for TSS) can have adverse effects on feeding and ecology of Mahinga Kai. Increased turbidity reduces light penetration, which can affect primary.	Increases with incoming sediments during flood events, and also resuspension of mud and sediments within the estuary, which can occur.	Shallow, exposed estuaries and deeper estuaries with strong currents will be more susceptible to within estuary generated turbidity (i.e., resuspension of seabed	Turbidity is highly variable even on shortest of time scales. A range of measures are available, each with advantages and disadvantages. A key gap that needs to be addressed is how turbidity/light/SSC can be meaningfully monitored.	Attribute (noting other measures likely preferred – see water clarity, TSS).

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
			production and in turn food availability for suspension feeders; increased turbidity can affect "sight" predators such as some birds and fish.	during wind/wave events.	sediments). Poorly flushed and smaller estuaries will have a reduced capacity to dilute and assimilate TSS inputs.	Directly links to ecosystem health status but complicated non-linear responses likely.	
Water Chlorophyll-a (Chl-a)	15	Yes	A proxy for phytoplankton biomass, which is a primary food source for many shellfish species.	Chl-a can increase with increased nutrient loading from upstream sources; it is one of the symptoms of eutrophication. Chl-a can respond negatively to increased sediment loading due to lower light levels.	Yes: estuaries with reduced tidal flushing will be more susceptible to measurable changes in Chl-a, whereas, more open, frequently flushed estuaries will not. However, primary production in the water column is important in deeper water estuaries.	Under the NPS-FM, Chl-a is proxy for periphyton (rivers) and phytoplankton (lakes) attributes. In oligotrophic systems, a non-linear response would be expected. Difficult to separate out response to different stressors. Spatially and temporally variable within estuary. Links to ecosystem health status have not been demonstrated.	Attribute and state variable.
Water clarity (Secchi depth or black disc)	15	Yes (under turbidity).	As for turbidity.	As for turbidity.	As for turbidity.	Water clarity is being investigated as attribute under NPS-FM. Can be easy and cost effective to measure. Same issues as turbidity relating to variability, and correlations with factors other than upstream pressures (e.g., resuspension).	Attribute and state variable.
Total suspended solids (TSS)	19	No	As for turbidity.	As for turbidity.	As for turbidity.	TSS is being investigated as an attribute under NPS-FM. Can be more expensive due to lab analysis of water samples. Same issues as turbidity relating to variability, and correlations with factors other than upstream pressures (e.g., resuspension).	Attribute and state variable.

Table F-3: Habitat variables (with overall scores ≥ 8) linked to ecosystem health, and where indicated mahinga kai. In some cases, the rank is the same for multiple variables when scores were equal. Also indicated is whether the variable was considered in the earlier Estuary NOF work, and whether the variable has potential to be an attribute and / or a state variable. In some cases the variable may end up contributing to an integrated metric.

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Areal extent of seagrass	2	Yes	Seagrass provides critical habitat for various life stages of Kai species, and is also often associated with some shellfish species.	Seagrass (*Zostera muelleri*) is vulnerable to excessive nutrients and increased turbidity in the water column that can lead to light limitation. Excessive macroalgal growths associated with nutrient loading can smother seagrass.	Yes. Generally, inhabits intertidal and shallow soft sediment areas, so is more likely to be dominant in shallow tidally flushed estuaries with tidal flats, and restricted to shallow margins.	Easy to measure with aerial photography and ground truthing (broadscale mapping). Long term cycles of expansion and contraction of sea grass bed area have been recorded in northern estuaries. This is not well understood but could affect the interpretation of changes in cover. Likely to be non-linear response. Difficult to separate response to different stressors. Links to ecosystem health status have not been demonstrated.	State variable
Areal extent of hypoxic/anoxic bottoms	4	Yes	Anoxia (low Oxygen) results in organism displacement, mortality and low abundance and diversity of Kai.	Excessive nutrient and sediment loading from upstream sources can both contribute to hypoxic/anoxic conditions within estuarine sediments.	yes	Direct link to ecosystem health status at high levels. Relates to several other variables, including depth of sediment RPD (Table 4-1), water column DO (Table 4-2), and also pore water DO.	State variable
Areal extent of shellfish beds	5	No	Directly linked.	Distribution of shellfish beds are influenced by sediment grain size characteristics, which is influenced by sediment loading and increased muddiness. Also affected by depositional events.	yes	Need to understand cultural and recreational pressures, conversely these aspects can be used to allow citizen monitoring. Direct link to ecosystem health.	State variable

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Composition and areal extent of dominant saltmarsh types.	8	Yes	Saltmarshes are highly productive; they serve as important nursery grounds, enhance water quality, and fuel estuary food webs important to Mahinga Kai.	Primary impact on saltmarshes is habitat alteration, engineering affecting flow rates and coastal development. Many estuaries have undergone extensive modification, particularly where land has been drained and developed, and/or hydrology compromised (e.g., by roads).	Yes	Easy to measure with aerial photography and ground truthing (broadscale mapping). Historical changes have been highly variable between estuaries; would likely need to set a rating based on change from present state. Likely to be affected by invasions.	State variable.
Percent cover of seagrass.	9	Yes (percent area).	See areal extent of seagrass above.	See areal extent of seagrass above.	See areal extent of seagrass above.	Seasonally and spatially variable. Requires *in situ* measurement alongside aerial extent measures. Can be affected by wasting disease and other natural cycles. Links to ecosystem health status have not been demonstrated.	State variable.
Areal extent of opportunistic macroalgae.	13	Yes (under macro and micro algae growths).	Macroalgal growth or deposits of macroalgae on sediments can cause anoxia (lack of oxygen) underneath them, killing benthic animals, and can displace normally occurring communities of plants and animals, and cause nuisance (smells).	Can be directly a function of nutrient loading from catchments, particularly in cases where the downstream estuary is poorly flushed, and increased nutrients can result in blooms of nuisance macroalgae (e.g., *Ulva* spp., *Graciliaria* spp.). Alterations in estuary bathymetry, sediments (increased muddiness) and hydrology may influence macroalgae growth. Macroalgal growth can in turn influence bathymetry by stabilising and trapping fine sediments.	Macroalgal blooms most likely to be associated with estuaries with high nutrient loading, non-limiting light conditions (shallow), low flushing. However, can be an issue in estuaries with short retention and high flushing.	This variable is addressed in the ETI in a more comprehensive manner – needs to be further reviewed in context of implementing ETI approach (Opportunistic Macroalgal Blooming Tool). Easy to measure with aerial photography and ground truthing (broad-scale mapping). not all macroalgal growths are solely anthropogenically driven – can be facilitated by naturally high nutrient levels entering from the catchment or ocean. Present information suggests a strongly non-linear response once the system is degraded.	Attribute (as part of integrated metric). State variable.

Table F-4: Macrofauna variables (with overall scores ≥ 8) linked to ecosystem health, and where indicated mahinga kai. In some cases, the rank is the same for multiple variables when scores were equal. Also indicated is whether the variable was considered in the earlier Estuary NOF work, and whether the variable has potential to be an attribute and / or a state variable. In some cases the variable may end up contributing to an integrated metric.

Variable	Rank	Estuary NOF?	Linkages to Mahinga Kai	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Shellfish biodiversity	3	Yes (grouped under macro-benthic community structure).	Directly linked.	Like other macrofauna, shellfish diversity will be strongly correlated to habitat conditions and affected by upstream pressures such as sedimentation.		Would be best measured at the estuary scale. Integrates over weeks to months. Not particularly temporally variable. Links to ecosystem health status have been demonstrated.	State variable.
Biodiversity of macrofauna	7		These indicators correlate with the health and functioning of soft sediment communities, which are relied on by key Mahinga Kai species.	Measures of macrofauna community structure are highly sensitive to changes in pressures (good for early warning), and can integrate over time. Respond in different ways to contaminants, nutrients, organic enrichment, deposition rates, turbidity, and changes in muddiness.		Sensitivity of macrofaunal communities and power of multivariate community analyses make macrofauna-based indicators particularly good. Levels indicative of health are available using published indices. Spatial and temporal variation reasonably well understood. Will be important in monitoring and for use as state variable(s) for gauging Ecosystem Health.	State variable.
Traits based macrofauna index	11						State variable.
Evenness of macrofauna	12						State variable.
Multivariate macrofauna indices	12						Attribute and / or state variable.
Abundance / biomass of engineering species	13		Engineering species include burrowing organisms that aerate sediments and distribute nutrients that support mahinga kai.				State variable.

Table F-5: Variables related to sedimentation and linked to ecosystem health and mahinga kai. These variables were not within the top tier (scores > 8), but were within the top tier for the first two essential criteria relevant to upstream pressures and management, and were included in the earlier Estuary NOF work.

<table>
<tr><th>Variable</th><th>Rank</th><th>Estuary NOF?</th><th>Linkages to Mahinga Kai</th><th>Relevance to upstream management</th><th>Dependent on estuary type?</th><th>Strengths and weaknesses, considerations</th><th>Attribute and/or state variable?</th></tr>
<tr><td>Frequency of major deposition events.</td><td>20</td><td>Yes</td><td>Deposition events can result in smothering/ mass mortality of entire soft sediment communities and sediment dwelling organisms such as mahinga kai.</td><td>There are factors beyond human control that influence major deposition events, but land use practices in catchments can make them prone to erosion and slips during events.</td><td>Importance likely dependent on flushing and resuspension characteristics of estuaries. Location of the deposition within an estuary also matters – mud deposited on a coarse substrate will have greater effects than mud deposited on mud.</td><td>Spatially and temporally variable.
Easy to measure in intertidal areas (if you can predict from weather models when they are likely to occur and can mobilise ground staff), but difficult in subtidal.
Lag times between the rate of sediment loading to rivers, and delivery of sediments to estuaries.
May be applicable for monitoring earthworks activities, rather than long-term monitoring tool.
Issues in defining and measuring an “event” both at a spatial and temporal scale have been raised.</td><td>State variable.</td></tr>
<tr><td>Modelled sediment accumulation rate.</td><td>25</td><td>Yes (under deposition rate).</td><td rowspan="2">High rates of sediment accumulation and rates at which fine silt/mud accumulates can stress organisms inhabiting soft sediment environments.</td><td rowspan="2">These both address the overall rate of sediment inputs from freshwater. This can be significantly increased by land use changes in the catchment and decreased by mitigation.
They are also affected by within estuary activities such as building structures and dredging and alteration of hydrological regimes.</td><td>Will likely require estuary specific limits derived by using catchment loading information and multipliers.</td><td>Deposition rates can be predicted using existing tools (e.g., CLUES) and depositional modelling (e.g., S2S), including spatial variability.
Ground truthing is required but this may need monitoring over a long duration before results are known (but see core profiling below).
Links to ecosystem health status not demonstrated.</td><td>Attribute.</td></tr>
<tr><td>Measured sediment deposition.</td><td>27</td><td>Yes (under deposition rate).</td><td>Yes, as above, and noting different estuary types have different susceptibility.</td><td>Rates are spatially variable within estuaries (depositional versus erosional zones, influenced by waves, currents and residual circulation).
Sedimentation rate measurements can be made using settlement plates at locations within estuaries but so far results are highly temporally variable.
Core profiling studies and bathymetric surveying are techniques often required for interpreting data.
Effects of within-estuary vs freshwater inputs should be able to be separated.
Some links to ecosystem health have been demonstrated.</td><td>Attribute and state variable.</td></tr>
</table>

Table F-6: Variables (with overall scores ≥ 8) linked to human health for recreation. In all cases, these variables are in some way linked to the mahinga kai value. Inorganic and organic compounds may also be linked to ecosystem health. Note that many tied for the same rank.

Variable		Rank	Estuary NOF?	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Water	*E. coli*	1	Yes	Elevation of *E. coli* in estuary waters is primarily attributable to upstream sources in catchments. Exceptions include birds, marine mammals, discharge from vessels, and faecal shedding from bathers.	No, but patterns in survivorship and prevalence will vary temporally and spatially within estuaries as a function of rainfall, salinity levels, water temperature, and water clarity, which affects rates of die off due to solar radiation. Concentrations will be influenced by rates of mixing and dilution, which is affected by tidal flushing and volume of receiving waters.	Indicator of choice for health risk to recreational users of fresh waters (an attribute under NPS-FM), and in some estuary waters. Variability in time and space (patchiness) can impede ability to identify trends in response to changes in pressures. Standard methods and easy to measure Can persist and grow in the environment (e.g., in sediments). Often correlated with other water quality parameters (e.g., suspended solids).	Attribute and state variable.
Water	Enterococci	1	Yes	As for *E. coli.*	As for *E. coli.*	As above for *E. coli.* *Enterococci* the indicator of choice for health risk to recreational users of coastal waters and some estuary waters. *E. coli* and *Enterococci* considered transitional in brackish waters – both likely important for estuaries.	Attribute and state variable.
Sediment	Inorganic compounds	2	Yes (trace metals)	With the exception of metals from catchment sediments, the majority of inorganic compounds will enter estuaries from anthropogenic upstream sources, including sewerage discharges, landfill leachate, and stormwater runoff. In some cases, aquaculture structures and ports can be sources of contaminants.	No, but likely to be concentrated in sediments closest to river mouths and discharges (outfalls).	Sediments are a good integrator over time compared to water samples. Can be expensive to analyse. ANZECC guidelines provide limits, but these are based largely on Australian conditions.	Attribute and state variable.

Variable		Rank	Estuary NOF?	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Water	Inorganic compounds.	2	No	As for sediment inorganic compounds.	As for sediment inorganic compounds.	High temporal and spatial variability in water. Expensive to analyse, and near detection limits.	Neither due to variability and difficulty in measuring (sediments and shellfish alternative).
Water	Faecal coliforms.	3	No	As for *E. coli.*	As for *E. coli.*	As above for *E. coli* and *Enterococci* Routinely used to assess the condition of shellfish growing waters.	Attribute and state variable.
Biota	Anthropogenic organic compounds in harvestable species.	4	No	As for inorganic compounds in sediments and water.	As for inorganic compounds in sediments and water.	Shellfish are good integrators of what is happening in the water column, and the concentration of toxicants within their tissues can provide an indication of levels within the water body.	May serve as attribute and/or state variable in future following further research/data.
Sediment	anthropogenic organic compounds.	4	No	As for inorganic compounds in sediments and water.	As for inorganic compounds in sediments and water.	The seabed is often a good integrator similar to shellfish.	May serve as attribute and/or state variable in future following further research/data.
Biota	Harvestable shellfish *E. coli.*	4	Yes	As for water *E. coli.* Contamination of shellfish primarily due to upstream sources.	As for water *E. coli*	Used by regulatory agencies as the faecal indicator for shellfish flesh.	Attribute and state variable.
Biota	Inorganic compounds in harvestable species.	5	No	As for inorganic compounds in sediments and water.	As for inorganic compounds in sediments and water.	Metals concentrations in shellfish link to all three values. Shellfish good integrators over time for metals, since they are too low/variable in water to reliably measure.	Attribute (metals in shellfish).
Biota	Harvestable shellfish *Cryptosporidium* oocysts.	5	No	The protozoan *Cryptosporidium* is associated with upstream sources of contamination. *Cryptosporidium* oocysts have been found to accumulate in shellfish (Graczyk et al. 2007).	No; however, characteristics of surrounding catchments (number of animals) combined with flushing characteristics of the estuary will likely influence concentrations.	Consider both parvum and hominis strains. The former is animal-related, the latter human-related and somewhat more infectious.	Possibly state variable over time following further research/data.

Variable		Rank	Estuary NOF?	Relevance to upstream management	Dependent on estuary type?	Strengths and weaknesses, considerations	Attribute and/or state variable?
Water	*Cryptosporidium* oocysts.	5	No	*Cryptosporidium* oocysts have been found to accumulate in shellfish (Graczyk et al. 2007).	As for *Cryptosporidium* in shellfish.	NZ Drinking-Water standards include requirement for its removal.	Neither.
Sediment	*Campylobacter.*	5	No	Animals in upstream catchments are the greatest reservoir of this potentially waterborne pathogen.	As for *Cryptosporidium* in shellfish.	Used as the basis of NPS-FM water quality standards. the greatest cause of bacterial dysentery worldwide; campylobacterisos is the most common reported notifiable disease in New Zealand. Prevalent in New Zealand freshwaters (McBride et al. 2002, Till et al. 2008). May be present in shellfish flesh. Sediment may be a good integrator .	Possibly state variable over time following further research/data.
Water	*Campylobacter.*	5	No	As for sediment *Campylobacter.*	As for sediment *Campylobacter.*	As for sediment *Campylobacter* May be difficult to measure reliably in estuary waters if too diluted.	Neither.
Water	Universal PCR markers (e.g., Bacteroidales).	5	No	As for other faecal indicators such as *E. coli.*	As for other faecal indicators such as *E. coli.*	As an anaerobe, *Bacteroidales* does not persist and grow in the marine environment, so may be a better indicator of ‘recent’ contamination.	Possibly future use as attribute and state variable following further research/data.
Water	Enteroviruses.	6	No	Directly a function of upstream human sources of contamination, although could enter estuaries through outfalls and activities on the water (vessels).	As for other faecal indicators such as *E. coli.*	Both a pathogen and an indicator (because they are a group with many members). Long-term health impairment may arise from exposure to these viruses whereas other viruses of concern for water contact tend to have shorter-term consequences. Human-specific strains found to be present on many occasions at freshwater recreation sites (McBride et al. 2002).	Neither, unless technology for detection changes/ improves.

Appendix G Variable scores (mean) for five essential criteria

Note: Eleven experts reviewed the variables for ecosystem health, and four experts evaluated those for human health for recreation. Due to significant overlap in these two values with variables for mahinga kai, evaluations were first completed for the two former values, and then a hui was held with Māori researchers to assess those most relevant to mahinga kai.

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Sediment organic content	Sediment quality	0.50	0.50	0.67	1.00	1.00	11.00
Sediment grain size	Sediment quality	0.50	0.44	0.56	0.89	0.94	10.00
Composition/areal extent of dominant substrate types	Sediment quality	0.56	0.63	0.69	0.69	0.64	9.62
Sediment Chl-a	Sediment quality	0.50	0.50	0.42	0.75	1.00	9.50
Sediment nutrient concentration (N, P, C)	Sediment quality	0.50	0.42	0.40	0.83	0.83	8.95
Depth of sediment REDOX discontinuity	Sediment quality	0.50	0.43	0.42	0.71	0.79	8.54
Sediment sulphide concentration	Sediment quality	0.50	0.40	0.40	0.80	0.70	8.40
Microphytobenthic biomass	Sediment quality	0.50	0.50	0.43	0.57	0.79	8.36
Water nutrient concentrations (N, P, C)	Water quality	0.60	0.40	0.30	0.90	0.90	9.30
Water column dissolved oxygen	Water quality	0.50	0.43	0.29	0.79	1.00	9.00
Turbidity	Water quality	0.57	0.43	0.21	0.86	0.93	9.00
Water Chl-a	Water quality	0.50	0.42	0.33	0.83	0.83	8.75

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Water clarity (Secchi depth or black disc)	Water quality	0.50	0.42	0.33	0.83	0.83	8.75
Total suspended solids	Water quality	0.50	0.36	0.29	0.64	0.86	7.93
Areal extent of seagrass	Habitat quality	0.50	0.56	0.81	0.75	0.88	10.50
Areal extent of hypoxic/anoxic bottoms	Habitat quality	0.80	0.70	0.60	0.60	0.60	9.90
Areal extent of shellfish beds	Habitat quality	0.50	0.56	0.71	0.69	0.81	9.83
Composition and areal extent of dominant saltmarsh types	Habitat quality	0.36	0.43	0.71	0.71	0.93	9.43
Percent cover of seagrass	Habitat quality	0.50	0.42	0.70	0.75	0.75	9.35
Areal extent of opportunistic macroalgae	Habitat quality	0.50	0.56	0.50	0.63	0.81	9.00
Shellfish biodiversity	Macrofauna	0.50	0.50	0.58	0.83	0.92	10.00
Biodiversity of macrofauna	Macrofauna	0.50	0.58	0.58	0.58	0.92	9.50

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Traits based macrofauna index	Macrofauna	0.50	0.50	0.67	0.58	0.83	9.25
Evenness of macrofauna	Macrofauna	0.50	0.43	0.57	0.57	1.00	9.21
Multivariate macrofauna indices, e.g., AMBI	Macrofauna	0.50	0.57	0.71	0.57	0.71	9.21
Abundance/biomass of engineering species	Macrofauna	0.42	0.33	0.67	0.67	0.92	9.00
Frequency of major deposition events	Sedimentation	0.64	0.57	0.50	0.36	0.43	7.50
Modelled sediment accumulation rate	Sedimentation	0.58	0.42	0.50	0.33	0.50	7.00
Measured sediment deposition	Sedimentation	0.50	0.50	0.43	0.36	0.43	6.64
Additional Ecosystem Health variables (scores <8.0)							
Biomass of phytoplankton	Water quality	0.42	0.33	0.33	0.67	0.75	7.50
Porewater DO concentration	Sediment quality	0.50	0.42	0.33	0.58	0.67	7.50
Salinity regime (incl. pattern changes)	Water quality	0.57	0.50	0.43	0.43	0.57	7.50

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Max and average depth	Habitat quality	0.14	0.31	0.57	0.71	0.71	7.37
Percent cover of opportunistic macroalgae	Habitat quality	0.50	0.42	0.33	0.58	0.58	7.25
Biomass of seagrass (shoot and root)	Habitat quality	0.40	0.50	0.70	0.20	0.60	7.20
Dilution potential	Water quality	0.29	0.44	0.57	0.64	0.43	7.10
Multivariate macroalgal indicators e.g., OMBT EQR	Macroalgae	0.40	0.40	0.50	0.50	0.50	6.90
Biomass of opportunistic macroalgae	Macroalgae	0.50	0.50	0.40	0.30	0.50	6.60
Abundance ratio of invertebrates above specific length	Sediment biota	0.38	0.38	0.38	0.30	0.70	6.38
Opportunistic macroalgae composition and biodiversity	Habitat quality	0.40	0.30	0.50	0.30	0.60	6.30
Flushing potential	Water quality	0.25	0.42	0.42	0.67	0.33	6.25
Composition and areal extent of critical fish habitat	Habitat quality	0.43	0.29	0.29	0.36	0.71	6.21

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Export potential (physical susceptibility)	Water quality	0.30	0.50	0.30	0.60	0.30	6.00
Water temperature	Water quality	0.08	0.08	0.08	0.83	0.92	6.00
Percent of estimated natural state cover (ENSC)	Habitat quality	0.40	0.30	0.38	0.30	0.60	5.93
Presence of stratification	Water quality	0.50	0.21	0.36	0.36	0.50	5.79
Water pH	Water quality	0.17	0.08	0.17	0.67	0.83	5.75
Presence of Harmful Algal Bloom (HAB) species	Phytoplankton	0.40	0.30	0.30	0.40	0.50	5.70
Presence/diversity of invasive species	Biogenic habitat	0.20	0.20	0.40	0.50	0.60	5.70
Microphytobenthic composition and diversity	Habitat quality	0.42	0.42	0.25	0.17	0.50	5.25
Presence/diversity of invasive species	Sediment biota	0.08	0.08	0.33	0.50	0.75	5.25
Phytoplankton species composition and diversity	Phytoplankton	0.40	0.20	0.20	0.10	0.60	4.50
Cyanobacteria biodiversity	Phytoplankton	0.40	0.20	0.20	0.10	0.50	4.20
Fish biodiversity	Fish	0.20	0.20	0.10	0.10	0.60	3.60

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Extent of opportunistic macroalgal entrainment	Macroalgae	0.25	0.13	0.25	0.25	0.13	3.00
Presence/diversity of invasive species	Macroalgae	0.08	0.08	0.08	0.17	0.58	3.00
Taonga species variables							
Anthropogenic organic compounds in Taonga species	Taonga species	0.50	0.75	0.50	0.50	0.75	9.00
Inorganic compounds in Taonga species	Taonga species	0.50	0.50	0.50	0.50	0.75	8.25
Non-anthropogenic organic compounds in Taonga species	Taonga species	0.25	0.25	0.25	0.00	0.25	3.00
Taonga species *E. coli*	Taonga species	0.50	0.50	0.50	0.75	1.00	9.75
Taonga species *Cryptosporidium* oocysts	Taonga species	0.75	0.50	0.50	0.25	0.50	7.50
Taonga species *Campylobacter*	Taonga species	0.75	0.50	0.25	0.25	0.50	6.75
Human Health variables							
Water *E. coli*	Faecal indicators	0.67	0.50	0.50	0.83	0.83	10.00

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Water enterococci	Faecal indicators	0.67	0.50	0.50	0.83	0.83	10.00
Sediment inorganic compounds	Contaminants	0.50	0.75	0.50	0.75	0.75	9.75
Water inorganic compounds (e.g., heavy metals, metals, metalloids)	Contaminants	0.75	0.50	0.50	0.75	0.75	9.75
Water faecal coliforms	Faecal indicators	0.67	0.33	0.50	0.83	0.83	9.50
Anthropogenic organic compounds in harvestable species	Contaminants	0.50	0.75	0.50	0.50	0.75	9.00
Sediment anthropogenic organic compounds	Contaminants	0.50	0.75	0.50	0.50	0.75	9.00
Harvestable shellfish *E. coli*	Faecal indicators	0.50	0.50	0.50	0.67	0.83	9.00
Inorganic compounds in harvestable species	Contaminants	0.50	0.50	0.50	0.50	0.75	8.25
Harvestable shellfish *Cryptosporidium* oocysts	Faecal pathogens	0.75	0.50	0.50	0.25	0.75	8.25
Water *Cryptosporidium* oocysts	Faecal pathogens	0.75	0.75	0.25	0.25	0.75	8.25

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Sediment *Campylobacter*	Faecal pathogens	0.75	0.50	0.50	0.25	0.75	8.25
Water *Campylobacter*	Faecal pathogens	0.75	0.75	0.25	0.25	0.75	8.25
Universal PCR markers (e.g., Bacteroidales) in water	Faecal indicators	1.00	0.50	0.50	0.25	0.50	8.25
Enteroviruses (water)	Faecal pathogens	0.83	0.67	0.33	0.17	0.67	8.00
Additional Human Health variables (scores <8.0)							
Harvestable shellfish *Campylobacter*	Faecal pathogens	0.75	0.50	0.25	0.25	0.75	7.50
Sediment *E. coli*	Faecal indicators	0.33	0.33	0.33	0.67	0.83	7.50
Water anthropogenic organic compounds (pesticides, polychlorinated and polyhalogenated compounds, emerging contaminants)	Contaminants	0.75	0.75	0.00	0.25	0.75	7.50
Enteroviruses (sediments)	Faecal pathogens	0.83	0.50	0.33	0.17	0.50	7.00

Variable	Category	Essential Criteria Scores					Overall score Sum x 3
		Responsiveness to upstream aspects to be managed	Relevance to upstream management measures	Temporal-spatial stability	Cost-effective	Measurable, precise and repeatable	
Harvestable shellfish Norovirus	Faecal pathogens	0.75	0.50	0.50	0.00	0.50	6.75
Noroviruses (water)	Faecal pathogens	0.83	0.67	0.17	0.00	0.50	6.50
Noroviruses (sediments)	Faecal pathogens	0.83	0.33	0.33	0.00	0.50	6.00
Sediment *Clostridium perfrigens*	Faecal indicators	0.25	0.25	0.50	0.25	0.75	6.00
Water *Clostridium perfrigens*	Faecal indicators	0.25	0.25	0.50	0.25	0.75	6.00
Non-anthropogenic organic compounds in harvestable species	Contaminants	0.25	0.25	0.25	0.25	0.50	4.50
Water non-anthropogenic organic compounds (natural toxins)	Contaminants	0.25	0.25	0.25	0.00	0.25	3.00
Sediment non-anthropogenic organic compounds	Contaminants	0.25	0.25	0.25	0.00	0.00	2.25

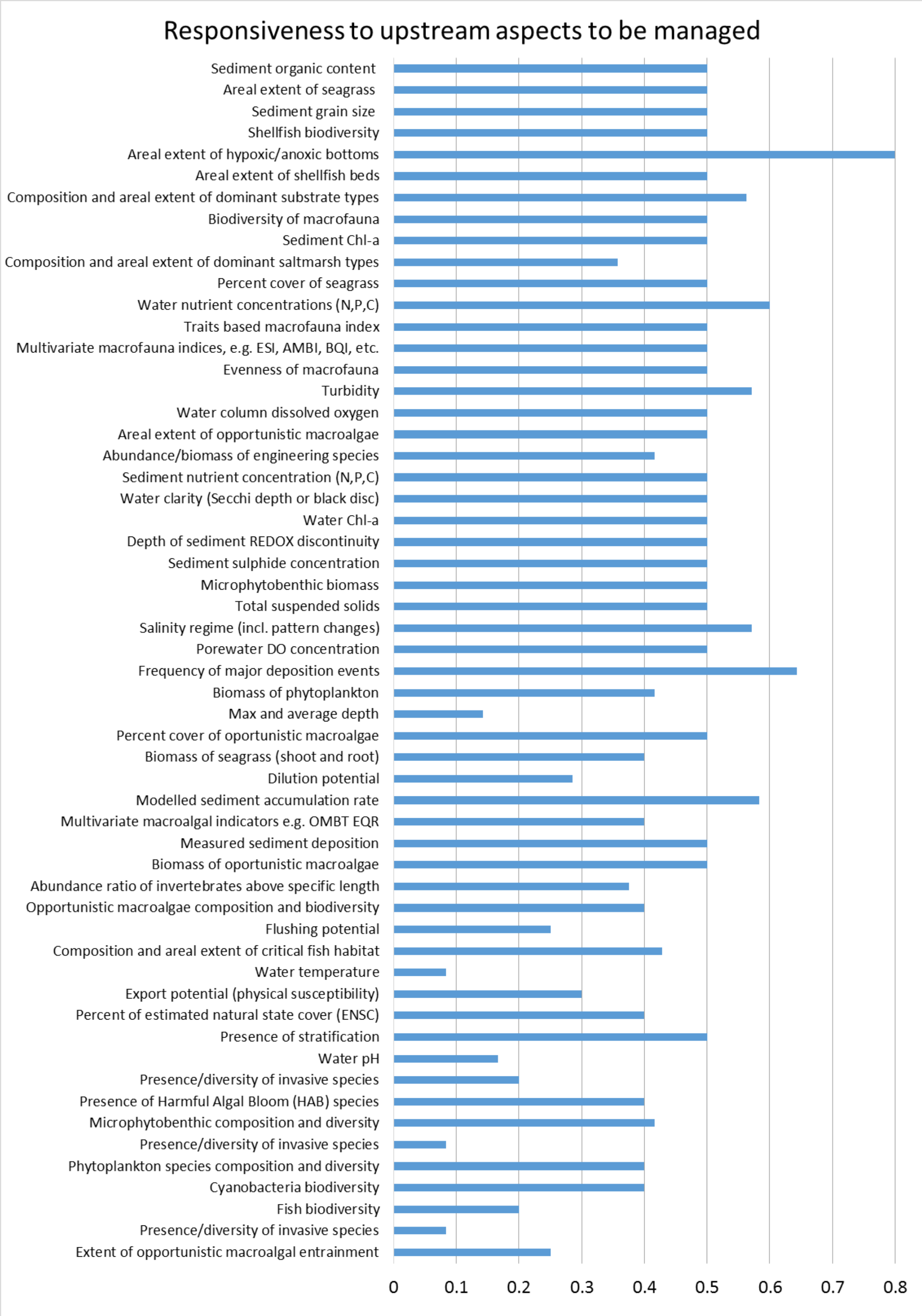

Figure G-1: Average scores (+1 SD) for the criteria evaluating responsiveness of ecosystem health variables to upstream aspects to be managed.

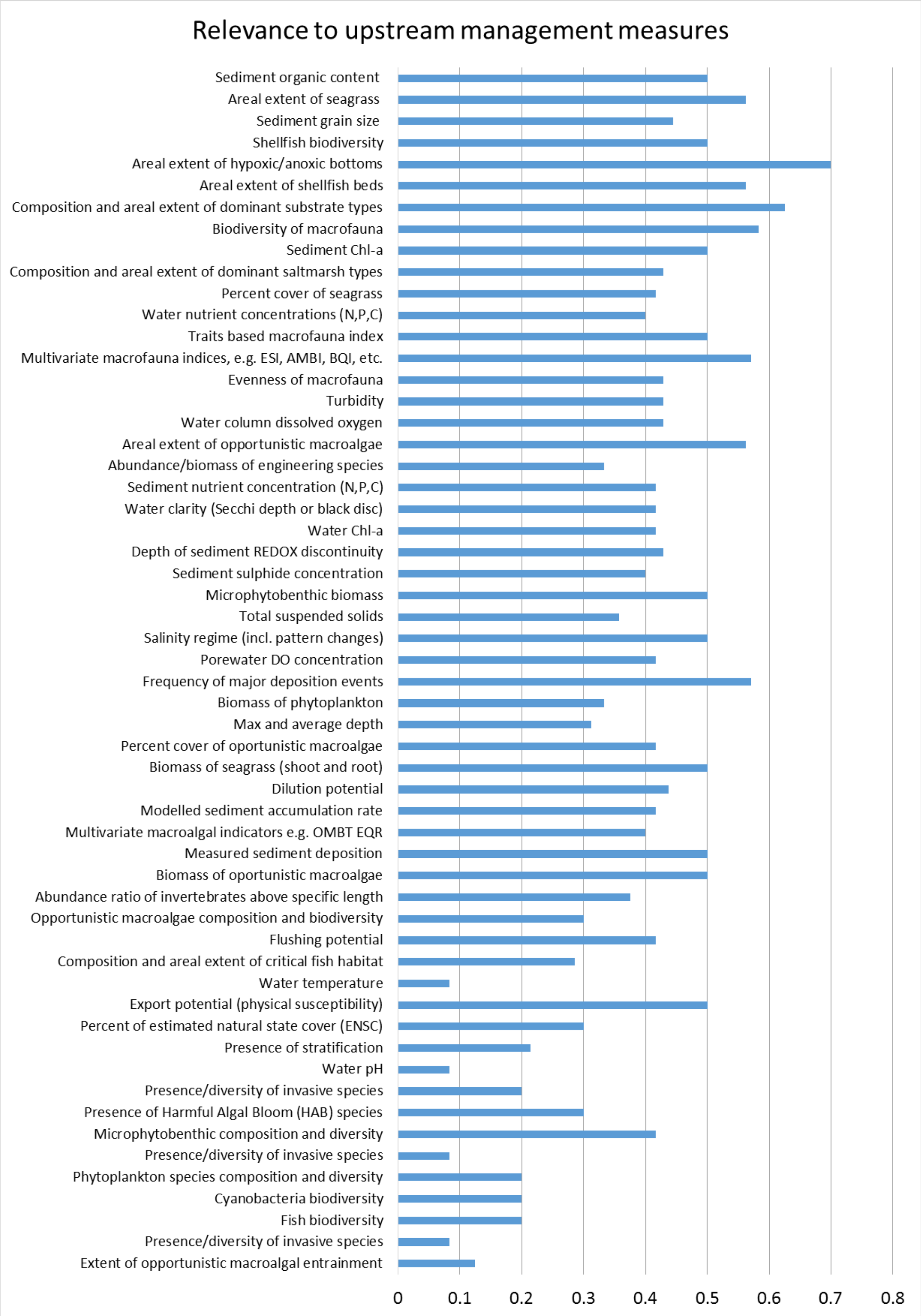

Figure G-2: Average scores (+1 SD) for the criteria evaluating relevance of ecosystem health variables to upstream management measures.