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NIWA
Taihoro Nukurangi

NZ Estuary Trophic Index

SCREENING TOOL 2. DETERMINING MONITORING INDICATORS AND ASSESSING ESTUARY TROPHIC STATE

Prepared for

Envirolink Tools Project: Estuarine Trophic Index

MBIE/NIWA Contract No: C01X1420

December 2015

STATEMENT OF AUTHORSHIP CONTRIBUTIONS

The ETI Screening Tool 1 and 2 technical report writing was done almost exclusively by Barry Robertson and Leigh Stevens (Wriggle Coastal Management) and Ben Robertson (Wriggle/University of Otago), including literature review, typology design, susceptibility assessment, NZ specific assessment approaches, indicator selection, initial thresholds and bandings, index scoring, data compilation, and development of underpinning supporting relationships. John Zeldis (NIWA) started the ETI project, led proposal writing, ran project management, contributed technical and editorial reviews of both reports with substantive additions, and managed the external reviews. Mal Green (NIWA) and Anna Madarasz-Smith (Hawkes Bay Regional Council) were key facilitators of project development and proposal writing and provided comments on the reports. Dave Plew (NIWA) provided written comments on Tool 1 and Terry Hume (Hume Consulting Ltd) reviewed the Tool 1 typology. The following contributed to a review of the technical reports at a workshop in December 2015 - Barry Robertson, Leigh Stevens, John Zeldis, Mal Green, Dave Plew, Anna Madarasz-Smith, Richard Storey (NIWA), and Megan Oliver (Wellington Regional Council).

ACKNOWLEDGEMENTS

We are grateful for the external reviews of the ETI Screening Tool 1 and 2 technical reports by Dr Drew Lohrer and Dr Mike Townsend of NIWA. We would like to also acknowledge the following for their invaluable assistance in providing data, support and advice:

The Regional Council coastal Special Interest Group (cSIG)
Nick Ward, Environment Southland
Juliet Milne, Greater Wellington Regional Council
Rachel Ozanne, Otago Regional Council
Trevor James, Tasman District Council
Dr Hilke Giles, Waikato Regional Council
Dr Sandy Elliot, NIWA
Dr Udi Shankar, NIWA

RECOMMENDED CITATION

Robertson, B.M, Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Oliver, M. 2016. NZ Estuary Trophic Index Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420. 68p.

Cover photo: Ruataniwha Estuary, Tasman region

Freshwater Estuary, Stewart Island

NZ Estuary Trophic Index

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by

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ABBREVIATIONS			
AA (OMBT)	Affected Area	NA	Not Assessed
AF	Assimilation Factor	NEMP	National Estuary Monitoring Protocol
AIH (OMBT)	Available Intertidal Habitat	NH3	Ammonia
AMBI	AZTI Marine Biotic Index	NH4	Ammonium
aRPD	Apparent Redox Potential Discontunity	NIWA	National Institute of Water and Atmospheric Research
ASSETS	Assessment of Estuarine Trophic Status	NLI (ASSETS)	Nutrient Load Influemce
BQI	Biological Quality Index	NNE	Nutrient Numeric Endpoints
CAP	Canonical analysis of the principal coordinates	NO2	Nitrite
CCC	Criterion Continuous Concentration	NO3	Nitrate
CE	Coastal Explorer	NOF	National Objectives Framework
chl a	Chlorophyll a	NPSFM	National Policy Statement for Freshwater Management
CICEET	Cooperative Institute for Coastal & Estuarine Environmental Technology	NSL	Natural State Sediment Load
CL (ASSETS)	Catchment N Load	NSR	Natural Sedimentation Rate
CLUES	Catchment Land Use for Environmental Sustainability Model	NSW	New South Wales
CMC	Criteria Maximum Concentration	NZ	New Zealand
cSIG	Coastal Special Interest Group	NZCHT	NZ Coastal Hydrosystems Typology
CSL	Current Sediment Load	OL (ASSETS)	Ocean N Load
CSR	Current Sedimentation Rate	OMBT (WFD)	Opportunistic Macroalgal Blooming Tool
DETR	UK Department of the Environment, Transport and the Regions	P	Phosphorus
DIN	Dissolved Inorganic Nitrogen (sum of nitrite, nitrate, and ammonia)	PMAV	Provisional maximum allowable values
DO	Dissolved Oxygen	ppt	parts per thousand
DON	Dissolved Organic Nitrogen	RPD	Redox Potential Discontunity
DP	Dilution Potential	Rw	Water Residence time
DRP	Dissolved Reactive Phosphorus	S	Sulphur
DSDE	Deeper subtidal dominated, longer residence time estuaries	SAV	Submerged Aquatic Vegetation
ECG	Ecological Condition Gradient	SF	Shape Function
ECI	Entrance Closure Index	SIDE	Shallow intertidal dominated estuaries
EF	Evacuation Factor	SR	Sedimentation Rate
ENSC	Estimated Natural Seagrass Cover	SSRTRE	Shallow, short residence time tidal river estuaries
EP	Export Potential	TBI	Traits Based Index
EQR (OMBT)	Ecological Quality Rating	TL	Tidal Lagoon
ETI	Estuary Trophic Index	TN	Total Nitrogen
EV	Estuary Volume	TOC	Total Organic Carbon
FP	Flushing Potential	TP	Total Phosphorus
FPIR	Final Primary Indicator Rating	TPR	Tidal Prism Ratio
FSIR	Final Secondary (or Supporting) Indicator Rating	TR	Tidal River
FTCR	Final Trophic Condition Rating	TRD	Tidal River + Delta
FW	Freshwater	TS	Total Sulphur
GNA	Gross Nuisance Area	TSD	Technical Supporting Document
HAB	Harmful Algal Blooms	US	United States
ICOLL	Intermittently closed/open lakes and lagoons estuaries	USA	United States of America
ITI	Infaunal Trophic Index	USEPA	United States Environmental Protection Agency
MfE	Ministry for the Environment	WDF	Water Directive Framework
N	Nitrogen	WHO	World Health Organization
N2	Nitrogen gas	WLTG	Waituna Lagoon Technical Group
N20	Nitrous oxide	ww	Wet Weight

Screening Tool 2 Contents

List of Tables

Tables in Technical Appendices of Supporting Information

List of Figures

Screening Tool 1 Contents

List of Tables

Tables in Technical Appendices of Supporting Information

List of Figures

Figures in Technical Appendices of Supporting Information

1. OVERVIEW

Managing nutrients and sediment that discharge to freshwater and estuarine environments in New Zealand (NZ), where they can cause eutrophication and sedimentation problems, has become an important national issue over the last 20 years due to ongoing intensification of agriculture, in particular dairy farming (Bidwell et al. 2009; Davies-Colley et al. 2013, Snelder et al. 2014). More than half of lowland rivers fail to meet national guidelines for total nitrogen nutrient levels and clarity, and these rivers feed directly to our estuaries. Consequently, eutrophication symptoms in estuaries, including excessive algal growth, sediment anoxia, and compromised biodiversity are becoming commonplace. Unfortunately, although nutrient enrichment threatens many NZ estuaries, guidance on how to assess the extent of eutrophication (including indexes and indicators that are useful for management) is limited. As a result, it is difficult to:

- Determine the current state of estuaries with regard to eutrophication;
- Assess the effects of the recent landuse intensification and change on estuaries;
- Gauge the consequences for estuaries of nutrient limits for freshwater (e.g. the National Policy Statement for Freshwater Management, NPSFM, 2014); and
- Set nutrient load limits to achieve estuarine objectives.

In response, Regional Council coastal scientists sought advice via the coastal Special Interest Group (cSIG), with funding through Envirolink Tools Grant (Contract No. C01X1420), on the development of a nationally consistent approach to the assessment of estuary eutrophication, including nutrient load thresholds. The purpose of this project, called the NZ Estuary Trophic Index (ETI) toolbox, is to assist Regional Councils in determining the susceptibility of an estuary to eutrophication, assess its current trophic state, and assess how changes to nutrient load limits may alter its current state. It does this by providing tools for determining estuary eco-morphological type, where an estuary sits along the ecological gradient from minimal to high eutrophication, and providing stressor-response tools (e.g. empirical relationships, nutrient models) that link the ecological expressions of eutrophication (measured using appropriate indicators) with nutrient loads (e.g. macroalgal biomass/nutrient load relationships). In terms of the Regional Council planning framework, the ETI provides vital supporting guidance for underpinning the ecological health component of Regional Plans by identifying relevant estuary attributes and outcomes for inclusion in plans, defining methods and indicators to measure ecosystem health attributes, and providing guidelines to assess whether or not the outcomes are being met.

1.1 SCOPE

ETI Output 1 is a stand-alone, hard-copy methodology that includes two sets of tools that provide screening guidance for assessing where an estuary sits in the eutrophication gradient, and what is required to shift it to a different location in the gradient. Each tool is presented in a separate report with supporting appendices (this report presents Screening Tool 2):

- **Screening Tool 1. Physical and Nutrient Susceptibility Tool (summarised in Figure 1).**
  This method is designed to provide a relatively robust and cost effective approach to enable the prioritisation of estuaries for more rigorous monitoring and management. It applies a desktop susceptibility approach that is based on estuary physical characteristics, and nutrient input load/estuary response relationships for key NZ estuary types. The tool produces a single physical susceptibility score that can be used to classify either the ***physical susceptibility*** (i.e. very high, high, moderate, low susceptibility), and/or be combined with nutrient load data to produce a ***combined physical and nutrient load susceptibility*** rating. Nutrient areal load/trophic state bands for each estuary eutrophication type will be developed as a long term goal, with data currently available for some estuary types, but not all as yet. This section also provides guidance on the use of a simple load/response model tool provided in the ETI toolbox, and recommendations for the use of more robust approaches for setting load limits.
- **Screening Tool 2. Trophic Condition Assessment Tool (summarised in Figure 2).**
  This tool is a monitoring approach that characterises the ecological gradient of estuary trophic condition for relevant ecological response indicators (e.g. macroalgal biomass, dissolved oxygen), and provides a means of translating these ratings into an overall estuary trophic condition rating (the ETI). It provides guidance on which condition indicators to use for monitoring the various estuary types (and why they have been chosen), and on assessing the trophic state based on the indicator monitoring results and their comparison to numeric impairment bands (e.g. very high, high, moderate, low). The latter involves measurement of the expression of both primary (direct) eutrophication symptoms (e.g. macroalgae phytoplankton) and supporting indicators for secondary (indirect) symptoms of trophic state.

Both tools are outlined in the first section of each report and in overview flow diagrams presented in Figures 1, 2 and 3. Technical information used to support the development of the ETI, has been provided as supporting appendices referenced to each report. The appendices have been developed as a skeleton of information (including available NZ estuary data) that support the recommended ETI components for determining estuary eutrophication susceptibility and trophic condition. It is anticipated that they will be expanded upon as new information becomes available.

Screening Tool 1

For determining eutrophication susceptibility using physical and nutrient load data

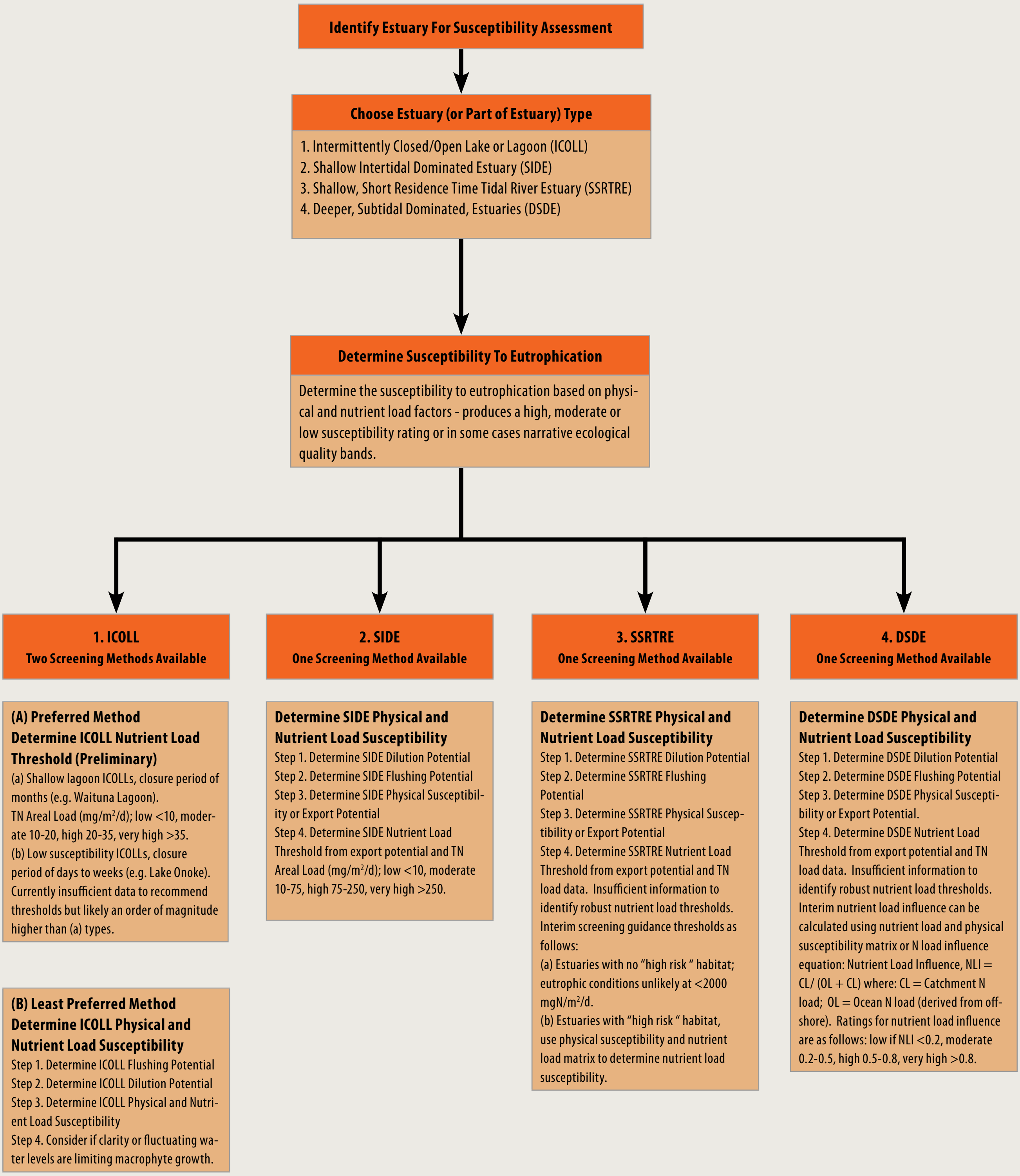


Figure 1. Screening Tool 1 - outline flow diagram.

Screening Tool 2

For determining trophic state using estuary monitoring data

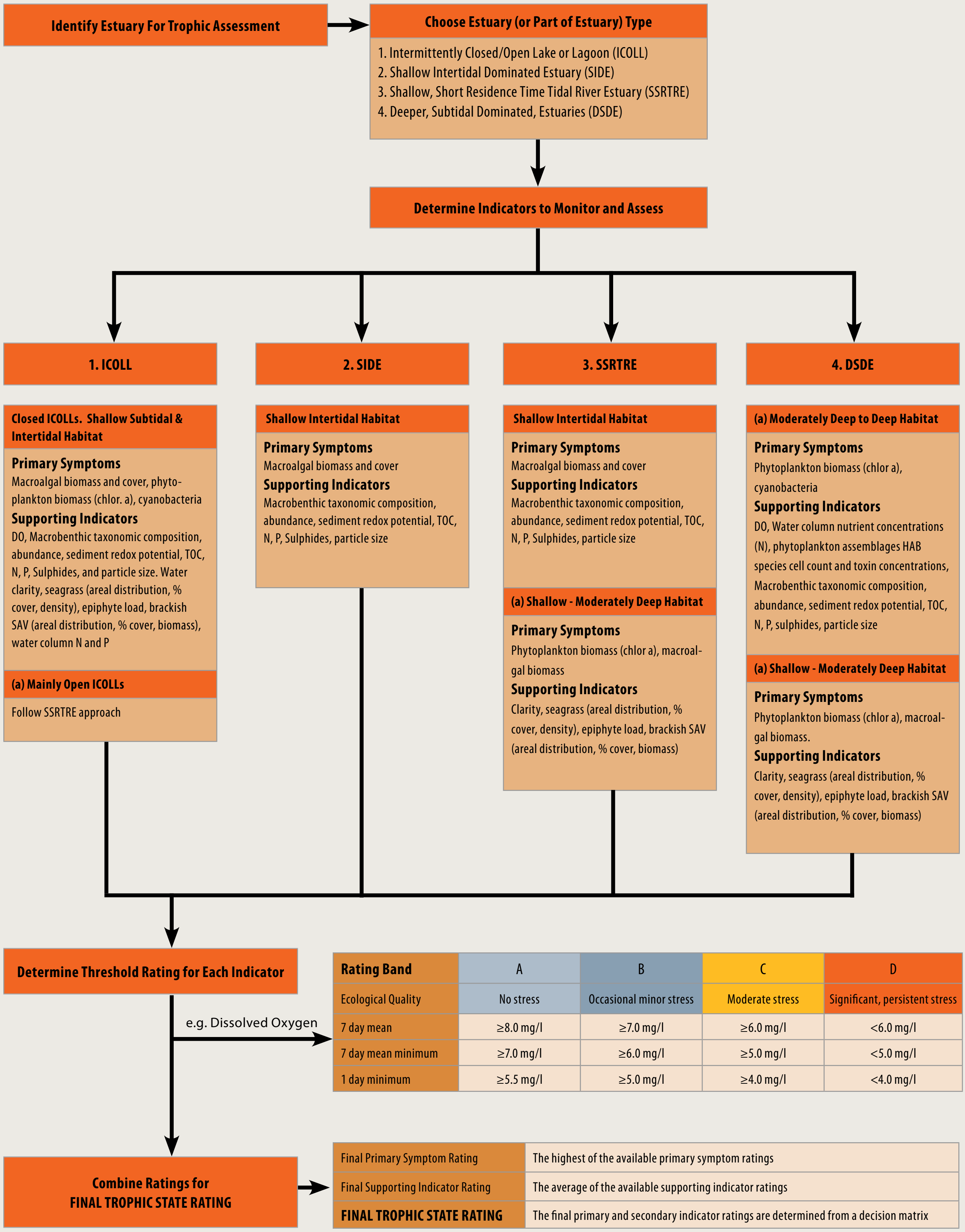


Figure 2. Screening Tool 2 - outline flow diagram.

SCOPE (CONTINUED)

Output 2 of the ETI will package the whole approach within a simple calculator framework to streamline the screening process, improve user-accessibility, and to provide preliminary guidance on load limits. Like the ASSETS approach, the calculator is primarily intended as a tool to estimate trophic state consistently across estuaries to set monitoring priorities. In addition, the calculator will enable the prediction of ETI bands (see Table 1) for each estuary typology under specified catchment nutrient loads, and from this, the ETI bands that supporting indicators are likely to be within. Subsequent monitoring of primary symptoms and supporting indicators is then recommended to determine actual trophic condition and to derive an ETI score. It is emphasised that the estuary response to changes in catchment nutrient loads may be strongly influenced by internal loading from sediment bound nutrients, and this may continue to drive eutrophic expressions for a considerable period after any catchment load changes (particularly reductions) are made.

This ETI combination package of ecological response indicators, thresholds, and nutrient loads, tailored for estuary type, provides a more direct risk-based linkage to estuary ecological values than nutrient concentrations or loads alone. Its weight of evidence approach, with multiple ecological response indicators and indicator thresholds and load/response relationships developed from relevant estuary ecological gradients, is expected to produce a robust assessment of eutrophication for most NZ estuary types, and to provide preliminary, screening-level, load limit guidance. For setting final load limits, the ETI recommends the use of more robust approaches; preferably relevant measured nutrient load/ecological response gradients, but if unavailable, using the modelling approaches it describes.

The approach adopted in the ETI has been to use, where appropriate, overseas estuary eutrophication assessment approaches where they meet the NZ situation {e.g. the US ASSETS framework (Bricker et al. 1999, 2003, 2007), the NSW ICOLLs approach (Haines et al. 2006) and ASSETS/DIPSIR Approach used on Basque Estuaries (Borja et al. 2006)}. Background information on these approaches is presented in Tool 1 Appendix 1. However, because the majority of NZ estuaries fall outside of the types used to develop the overseas assessment procedures, the overseas approaches have in many cases been modified to better suit the physical characteristics of NZ estuaries.

Table 1. A generalised summary of narrative ecological thresholds that exist along the eutrophication gradient.

Nutrient Load →

A Minimal Eutrophication	B Moderate Eutrophication	C High Eutrophication	D Very High Eutrophication
Ecological communities are healthy and resilient. *Primary Producers: dominated by seagrasses and microalgae. **Primary Producers: dominated by phytoplankton (diverse, low biomass). Water Column: high clarity, well-oxygenated. Sediment: well oxygenated, low organic matter, low sulphides and ammonia, diverse macrofaunal community with low abundance of enrichment tolerant species.	Ecological communities are slightly impacted by additional algal growth arising from nutrient levels that are elevated. *Primary Producers: seagrass/ microalgae still present but increasing biomass opportunistic macroalgae. **Primary Producers: dominated by phytoplankton (moderate diversity and biomass). Water Column: moderate clarity, mod-poor DO esp at depth. Sediment: moderate oxygenation, organic matter, and sulphides, diverse macrofaunal community with increasing abundance of enrichment tolerant species.	*Ecological communities are highly impacted by macroalgal or phytoplankton biomass elevated well above natural conditions. Reduced water clarity likely to affect habitat available for native macrophytes. **Ecological communities are highly impacted by phytoplankton biomass elevated well above natural conditions. Reduced water clarity may affect deep seagrass beds. *Primary Producers: opportunistic macroalgal biomass high, seagrass cover low. Increasing phytoplankton where residence time long e.g. ICOLLs. **Primary Producers: dominated by phytoplankton (low diversity and high biomass). Water Column: low-moderate clarity, low DO, esp at depth. Sediment: poor oxygenation, high organic matter, and sulphides, macrofauna dominated by high abundance of enrichment tolerant species.	*Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a persistent, degraded state without macrophyte/seagrass cover. **Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a nuisance algal bloom situation (often toxic). *Primary Producers: opportunistic macroalgal biomass very high or high/low cycles in response to toxicity, no seagrass. At very high nutrient loads, cyanobacterial mats may be present. Phytoplankton only high where residence time is long. **Primary Producers: dominated by nuisance phytoplankton (e.g cyanobacteria, picoplankton). Water Column: low clarity, deoxygenated at depth. Sediment: anoxic, very high organic matter, and sulphides, subsurface macrofauna very limited or absent. Eventually the sediments are devoid of macrofauna and are covered in mats of sulfur-oxidizing bacteria (i.e. *Beggiatoa*).

* shallow estuaries, often intertidal dominated, including shallow ICOLLs
** Open, moderate to deep subtidal dominated estuaries

Screening Tool 2.

FOR PROVIDING GUIDANCE ON:

1. **CONDITION INDICATORS TO USE FOR MONITORING THE VARIOUS ESTUARY TYPES**
2. **ASSESSING TROPHIC STATE (BASED ON INDICATOR MONITORING) IN COMPARISON TO NUMERIC BANDS**

Motupipi Estuary 2007: dense phytoplankton bloom (*Cryptomonas* sp.) in bottom waters of upper estuary

Cryptomonas sp. - a both heterotrophic and autotrophic unicellular, mobile and small flagellated alga (non-toxic)

Waimea Inlet 2015: sieving macroinvertebrate samples

Jacobs River Estuary: nuisance macroalgal growth

2. SCREENING TOOL 2.

FOR DETERMINING MONITORING INDICATORS AND ASSESSING ESTUARY TROPHIC STATE

2.1 OUTLINE

This section of the ETI framework is aimed at providing tools to assess the trophic condition of NZ estuaries based on their estuary (and habitat) susceptibility type. Screening Tool 1 should first be used to select the category of estuary (or part of an estuary) e.g. ICOLL, SIDE, SSRTRE, DSDE, and assess likely susceptibility to eutrophication for the relevant estuary category. Then Screening Tool 2 should be applied. The key outputs of Screening Tool 2 are summarised in Table 2 below.

Table 2. Summary of key outputs for Screening Tool 2.

• Determination of appropriate monitoring indicators to assess estuary trophic state, based on estuary habitat type.
• Determination of where an estuary sits along an ecological gradient of estuary trophic condition (i.e. from non-eutrophic to eutrophic) using data for relevant ecological response indicators (e.g. macroalgal biomass, dissolved oxygen).
• A means of translating these indicator ratings into an overall estuary trophic state rating.

The use of the tools comes with the proviso that the recommended ETI approach is a multi-criteria (physical, chemical and biotic indicator) approach to trophic state assessment (as it is in other international approaches), where individual indicators e.g. TOC measurements, are supported by related indicators, e.g. mud content, RPD, macroinvertebrates, macroalgal cover, and TN.

2.2 CHOOSING ECOLOGICAL RESPONSE INDICATORS

Internationally, simple indicator thresholds for assessing the eutrophic status of estuaries and coastal waters similar to freshwater guidelines have been developed in many countries (e.g. OSPAR 2008, Bricker et al. 1999). In the US based ASSETS toolbox, a simple screening-level assessment process has been developed which includes both primary and secondary symptoms of eutrophication (Bricker et al. 1999, 2003, 2008). The primary symptoms are high levels of phytoplankton (as measured by chlorophyll a), epiphytes, and/or macroalgae. Within ASSETS, the presence of primary symptoms at high levels indicates that an estuary is in the first stages of displaying undesirable eutrophic conditions. The second, much more degraded state, occurs when secondary symptoms of depleted dissolved oxygen, sulphide-rich sediments, seagrass loss, and nuisance/toxic algal blooms begin to appear.

However, in terms of the direct application of these indicators and their associated condition thresholds to NZ estuaries, there are potential problems, particularly for shallow, intertidal dominated estuaries and ICOLLs (which were not included in the ASSETS data set). In order to address these issues, the ETI approach taken for NZ estuaries has been to modify the assessment process to account for differences in the eutrophication response of these latter estuary types. The key modification has been to assign different monitoring indicators and different equations for calculating the Final ETI Condition Rating for each of the four estuary categories included. This is to ensure both the primary symptoms and secondary indicators are adequately represented in the final trophic assessment calculation (i.e. no artificial down playing of severity through inaccurate representation of irrelevant indicators, or ignoring of relevant indicators, in the final trophic assessment). Detailed background supporting information in relation to choosing appropriate monitoring indicators is provided in Tool 2 Appendix 7.

In overview, many methods have been developed in the world to assess estuary eutrophication and allow regulatory authorities to meet statutory requirements (e.g. to monitor and protect estuaries from degradation). These methods demonstrate that the eutrophication gradient is well understood and that the immediate biological response is increased primary production reflected as increased chlorophyll a and/or macroalgal abundance, which is often accompanied by secondary symptoms within both the water column and sediments. As a result, most methods include both primary symptoms and supporting indicators to provide the best possible evaluation of the nutrient related quality of the water body (Borja et al. 2012, Devlin et al. 2011, Sutula 2011).

The ETI has selected indicators that show a direct or indirect gradient of water and/or sediment quality impairment in response to a matching gradient of nutrient loads or concentrations. Wherever possible, data from NZ estuary examples have been used to support the choice of indicators and their target thresholds. For example, extensive data are available for NZ's dominant estuary type i.e. shallow intertidal dominated estuaries, which demonstrate a strong stressor/primary response relationship (i.e. N load/macroalgal response, see Tool 1 Appendix 4), that is indirectly linked to supporting indicator responses (e.g. sediment RPD, TOC, TN, macroinvertebrates).

The remainder of this section provides details on the primary eutrophication symptoms and supporting indicators chosen for NZ estuaries. Primary symptoms (e.g. macroalgae outbreaks) are considered to exhibit unambiguous responses to eutrophication. Supporting indicators can have variable and/or ambiguous relationships with eutrophication but are useful in its measurement. The remainder of this section includes background information, existing thresholds (international and NZ), recommended NZ thresholds, and research and information gaps. In general, the eutrophication indicators have been developed from the lists of indicators and thresholds derived from previous studies, with others that are more relevant being added to the list. Figure 3 provides a summary of the chosen indicators and the habitats in which they should be used, as well as monitoring considerations.

Identify Estuary For Trophic Assessment

↓

Choose Estuary (or part of estuary) Type →

1. Intermittently Closed/Open Lake or Lagoon (ICOLL)
2. Shallow Intertidal Dominated Estuary (SIDE)
3. Shallow, Short Residence Time Tidal River Estuary (SSRTRE)
4. Deeper, Subtidal Dominated, Estuaries (DSDE)

→ **Determine Indicators to Monitor and Assess**

1. ICOLL

Closed ICOLLs. Shallow subtidal & intertidal habitat

Primary symptoms: Macroalgae, phytoplankton biomass (chlor a), cyanobacteria
Supporting Indicators: Dissolved oxygen, macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size, water clarity, seagrass, epiphyte load, brackish submerged aquatic vegetation (SAV), water column N and P.

Mainly Open ICOLLs

Follow SSRTRE approach

2. SIDE

Shallow intertidal habitat

Primary symptoms: Macroalgae
Supporting Indicators: Macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size, seagrass.

3. SSRTRE

Shallow intertidal Habitat

Primary symptoms: Macroalgae
Supporting Indicators: Macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size, seagrass.

Shallow - Moderately Deep Habitat

Primary Indicators: Macroalgae, phytoplankton biomass (chlor a), cyanobacteria
Supporting Indicators: Dissolved oxygen, water clarity, seagrass, epiphyte load.

4. DSDE

Moderately Deep to Deep Habitat

Primary symptoms: Phytoplankton biomass (chlor a), cyanobacteria
Supporting Indicators: Dissolved oxygen, water column nutrient concentrations (TN), phytoplankton assemblages especially Harmful Algal Bloom (HAB) species cell count and toxin concentrations.

Shallow - Moderately Deep Habitat

Primary symptoms: Macroalgae, phytoplankton biomass (chlor a), cyanobacteria
Supporting Indicators: Dissolved oxygen, water clarity, seagrass, epiphyte load, macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size.

Methods for monitoring eutrophication primary symptoms and supporting indicators

Macroalgae	% cover, biomass, entrainment (annual between Oct and early March). Follow broad scale mapping methods and EQR approach outlined in this report.	Macroinvertebrates	Macrobenthic taxonomic composition, abundance & biomass. Annual Oct-March at representative sites (both high and low susceptibility habitats).
Phytoplankton	Chlorophyll a. Mean monthly from representative areas of estuary water column.	Water Clarity	Light attenuation, suspended sediment conc. or turbidity; monthly measures or sufficient frequency to assess variability.
Cyanobacteria	Cell counts and toxin concentrations. Mean monthly from representative areas of estuary water column.	Seagrass	Seagrass areal distribution, % cover, density, epiphyte load. Annual Oct-March, follow broad scale habitat mapping approach.
Dissolved Oxygen (DO)	DO concentration using field meter. Daily for 7 days in worst case conditions (e.g. loggers), otherwise monthly (may need to include bottom water in stratified situations).	Brackish SAV	Brackish SAV areal distribution, % cover, biomass, epiphyte load. Annual broad scale mapping (including transects), Oct-March.
Sediment TOC	Monitor Total Organic Carbon concentration in upper 2cm of sediment. Annually Oct-March.	Epiphyte load	Areal distribution, % cover, biomass. Annual broad scale mapping (including transects), Oct-March. Often incorporated within assessments of macroalgae, seagrass or brackish SAV.
Sediment TN and TP	Monitor total nitrogen and total phosphorus concentration in upper 2cm of sediment. Annually Oct-March.	Water Column TN and TP	Monitor total nitrogen and phosphorus in water column at representative sites (may need to include bottom water in stratified situations and dissolved inorganic and organic nutrients).
Sediment Grain Size	Monitor grain size (especially mud) concentration in upper 2cm of sediment. Annually Oct-March.	HAB	Harmful Algal Bloom cell counts and toxins. Mean monthly from representative areas of estuary water column.
Sediment Sulphides	Sediment TS and S_{Cr} in upper 2 cm of sediment. Annually Oct-March.	Sediment Redox Potential Discontinuity depth (RPD)	Monitor RPD with ORP meter and visually. Use ORP meter to calibrate visual method. Annually Oct-March.

Figure 3. Screening Tool 2 - outline flow diagram and monitoring methods. Primary symptoms shaded dark, supporting indicators, light.

2.2.1. PHYTOPLANKTON (PRIMARY SYMPTOM)

Measuring the extent to which the phytoplankton community is balanced (as measured by chlorophyll a) is a well-proven approach to assessing overall estuarine ecosystem condition for the following reasons: it is sensitive to nutrient and sediment inputs, at the base of the food web, and it is indicative of enrichment effects on estuarine biota (e.g. Bricker et al. 1999, 2003, 2007, 2008; Devlin et al. 2011). Its use is particularly important for estuaries, or parts of estuaries, with residence times greater than the phytoplankton turnover time (>3-5 days) (Ferriera et al. 2005). Because most NZ estuaries do not retain phytoplankton for a sufficient length of time to reach high concentrations (i.e. flushing times <3 days), this indicator will likely be of lesser importance in these latter estuary types. Phytoplankton productivity and community structure are two additional indicators that could be measured and used to support the biomass estimates, but are not considered as stand-alone primary indicators for the following reasons:

- Phytoplankton productivity is highly variable within an estuary, and relatively difficult and time consuming to measure.
- Phytoplankton community structure varies depending on a wide range of factors and, to date with a few exceptions, little information exists regarding phytoplankton community structure in NZ enclosed bays and estuaries. As such, NZ specific thresholds based on community structure cannot yet be developed for NZ estuaries. However, where specific algal species cause toxicity (e.g. cyanobacteria), various toxicity guidelines are available that can be sought to establish health risks e.g. NZ Cyanobacteria Guidelines, Ministry for the Environment; Ministry of Health (2009).

Microphytobenthos (benthic microalgae) are included in the US ASSETS approach (Bricker et al. 1999) but is not considered a stand-alone primary indicator, and no condition rating thresholds are included. Because of this, and because there is little evidence of microphytobenthos problems in NZ estuaries, it is not recommended for inclusion in the ETI. However, if issues are identified in NZ, a site specific vulnerability assessment is recommended. For more details on the suitability of phytoplankton as indicators of estuarine eutrophication, a particularly useful evaluation is provided in Sutula (2011).

RECOMMENDED RATING THRESHOLDS FOR PHYTOPLANKTON

Based on the wealth of experience and studies that exist globally supporting phytoplankton chlorophyll a as a reliable response indicator (e.g. Sutula 2011), and taking residence time into account, it is recommended that phytoplankton biomass (chlorophyll a) be used as a primary symptom indicator for subtidal dominated estuaries (residence time weeks rather than days), and ICOLLs during their closed phase. For other estuary types, chlorophyll a can be measured, but the results only used to support the primary symptom indicator (e.g. macroalgae) rather than being included with it.

Currently, the data supporting a relationship between chlorophyll a and estuary trophic status in NZ subtidal dominated estuaries (residence time weeks rather than days), and ICOLLs during their closed phase, is limited. Consequently response thresholds developed from overseas estuary data have been used to produce interim NZ estuary thresholds (Table 3). In terms of ecological response ratings, the Basque estuary thresholds have received extensive recent review and consideration and include many estuaries similar to that which dominate the NZ coastline. For these reasons, these thresholds have been used to produce the interim NZ chlorophyll a threshold ratings for NZ estuaries.

Table 3. Recommended interim rating thresholds for phytoplankton chlorophyll a concentrations in NZ estuaries (as 90th percentile based on monthly measurements).

Band	**A**	**B**	**C**	**D**
Ecological Quality	Ecological communities are healthy and resilient.	Ecological communities are slightly impacted by additional phytoplankton growth arising from nutrients levels that are elevated.	Ecological communities are moderately impacted by phytoplankton biomass elevated well above natural conditions. Reduced water clarity likely to affect habitat available for native macrophytes.	Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a persistent, degraded state without macrophyte/seagrass cover.
Euhaline Estuaries[1]	<3 ug/l	3-8 ug/l	>8-12 ug/l	>12 ug/l
Oligo/Meso/Polyhaline Estuaries[1]	<5 ug/l	5-10 ug/l	>10-16 ug/l	>16 ug/l

[1]**90th percentile based on monthly measures.** Oligohaline 0.5-5ppt salinity, Mesohaline >5-18ppt, Polyhaline >18-30ppt, Euhaline>30ppt

In order to determine overall trophic status of an estuary, the chlorophyll a rating should be accompanied by ratings for other primary and secondary indicators as follows:

- **Additional Primary Symptom Indicators**: Cyanobacteria cell counts and toxin concentrations, and dissolved oxygen.
- **Supporting Response Indicators:** see Figure 3.

Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

2.2.2. OPPORTUNISTIC MACROALGAE (PRIMARY SYMPTOM)

Opportunistic macroalgae are species that survive well in conditions in which other species often struggle to survive or compete (Borum and Sand-Jensen 1996). Blooms in NZ estuaries principally contain species of green algae *Ulva* (this includes taxa formerly known as *Enteromorpha*) and *Cladophora*, red algae *Gracilaria*, and brown algae (e.g. *Ectocarpus, Pilayella, Bachelotia*). These bloom-forming species are a natural component of intertidal ecosystems (Adams 1994), but they only grow to bloom proportions when nutrient levels are elevated (Sutula et al. 2011) and sufficient light reaches the bed of the estuary (or the water column where macroalgae are suspended). As a consequence, they generally only reach nuisance conditions in shallow estuaries, or the margins of deeper estuaries. The macroalgal response to nutrient loads generally increases with water residence times (Painting et al. 2007), either of the whole estuary (as is often the case for many NZ short residence time estuaries), or part of the estuary (e.g. a poorly flushed upper estuary arm where nutrient-rich muds accumulate), or in 'backwaters' where drifting suspended macroalgae can accumulate (e.g. Avon-Heathcote Estuary: Bolton-Ritchie and Main 2005). There is some evidence this response may also be significantly attenuated by the presence of fringing saltmarsh, due to reductions in nutrient loading through processes such as denitrification (Valiela et al. 1997). Other factors that can influence the expression of macroalgal growth are the presence of suitable attachment strata, and physical and hydrodynamic conditions e.g. temperature (dessication), fetch (wind driven waves), currents (scouring) e.g. Hawes and Smith (1995).

RECOMMENDED RATING THRESHOLDS FOR OPPORTUNISTIC MACROALGAE

The Opportunistic Macroalgal Blooming Tool (OMBT - WFD 2014) thresholds have received extensive recent review and are considered highly appropriate for use in NZ's dominant estuary types (i.e. shallow, intertidal dominated estuaries, as well as in shallow intertidal areas in other "open" estuaries where macroalgae could reach nuisance levels), because they include both biomass and spatial measures.

"Open" Estuaries Rating; use OMBT approach with the following metrics (Table 4). Supporting response indicators include: sediment redox potential, total organic carbon (TOC), total S, total N, total P, grain size and macroinvertebrates.

Table 4. OMBT final face value thresholds and metrics for levels of the ecological quality status of "Open" estuaries.

OMBT Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass ($g.m^2$ wet weight) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass ($g.m^2$ wet weight) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae >3cm deep in sediment (entrained)	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

ICOLLs. In addition, based on the limited information from ICOLLs, it is envisaged that suitably modified OMBT thresholds could also be used as an interim measure (until more robust data are available) for rating ICOLLs. The recommended modifications are to reduce the average biomass ratings as depicted in Table 4 to those shown in Table 5.

"ICOLL" Estuaries Rating; use OMBT approach (Table 4) but modify the biomass ratings as depicted in Table 5. Supporting response indicators include: phytoplankton, aquatic macrophytes (areal distribution, % cover, biomass), water clarity (or light attenuation), and sediment redox potential, total organic carbon (TOC), total S, total N, total P, grain size and macroinvertebrates.

Table 5. Modified OMBT final face value thresholds and metrics for levels of the ecological quality status of ICOLLs.

OMBT Quality Status	High	Good	Moderate	Poor	Bad
Average biomass ($g.m^2$ wet weight)	≥0 - 100	≥100 - 200	≥200-500	≥500-2000	≥2000

In order to provide ratings that fit within a four band ecological gradient (similar to that used in the National Objectives Framework for freshwaters), the OMBT EQR ratings established in Table 4 have been slightly modified (i.e. 'Poor' and 'Bad' OMBT bands have been merged) to meet the four band ecological gradient approach (Table 6) for open estuaries. Further work is required to develop and validate ICOLL EQR bands.

Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

2.2.2. OPPORTUNISTIC MACROALGAE (PRIMARY SYMPTOM - CONTINUED)

Table 6. Recommended interim ratings for macroalgae threshold ratings in NZ estuaries (modified OMBT ratings)

Band	A	B	C	D
Ecological Quality	Ecological communities (e.g. bird, fish, seagrass, and macroinvertebrates) are healthy and resilient. Algal cover <5% and low biomass (<50gm-^{2} wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality high (e.g. RPD in Band A).	Ecological communities (e.g. bird, fish, seagrass, and macroinvertebrates) are slightly impacted by additional macroalgal growth arising from nutrients levels that are elevated. Limited macroalgal cover (5-20%) and low biomass (50-200gm-^{2} wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality transitional (e.g. RPD in Band B).	Ecological communities (e.g. bird, fish, seagrass, and macroinvertebrates) are moderately to strongly impacted by macroalgae. Persistent, high % macroalgal cover (25-50%) and/or biomass (>200-1000g/m^{2} wet weight), often with entrainment in sediment. Sediment quality degraded (e.g. RPD in Band C).	Ecological communities (e.g. bird, fish, seagrass, and macroinvertebrates) are strongly impacted by macroalgae. Persistent very high % macroalgal cover (>75%) and/or biomass (>1000g/m^{2} wet weight), with entrainment in sediment. Sediment quality degraded with sulphidic conditions near the sediment surface(e.g. RPD in Band D).
Open Estuaries: EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	0.0 - <0.4
ICOLLs: EQR (Ecological Quality Rating)	development of EQR for ICOLLs recommended, but use above as interim with ICOLL biomass			

2.2.3. CYANOBACTERIA (PRIMARY SYMPTOM)

Although most of the documented toxic cyanobacteria species are freshwater species, they are all halotolerant and can bloom in estuaries and saltwater (Vasconcelos 1995) where they can cause an environmental hazard (Miguel et al. 2001). Most marine forms (Humm and Wicks 1980) grow along the shore as intertidal benthic vegetation [mats along reef margins, epiphytically on other algae, in open space opportunistically after disturbances, or bloom in response to nutrient enrichment (McGlathery et al. 2013)]. Typical benthic genera are the filament-forming *Oscillatoria* and *Microcoleus* and the colony-forming *Merismopedia*. Many filamentous benthic cyanobacteria fix nitrogen gas (N_2) (Paerl and Pinckney 1996). Decreases in the nutrient N:P ratio and hydrological conditions favouring low-turbulence, often drive cyanobacterial blooms in freshwater and upper estuary areas (e.g. Peel-Harvey Inlet, Hilman et al. 1990).

RECOMMENDED RATING THRESHOLDS FOR CYANOBACTERIA

Based on the limited data for cyanobacteria response thresholds in estuaries (particularly the aquatic ecological response), it is recommended that cyanobacteria response thresholds for NZ estuaries be developed. In the interim, if toxic cyanobacteria are present, additional monitoring and issue evaluation of potential impacts should be undertaken.
Interim guidance on cyanobacteria response thresholds for estuaries should be sought from available freshwater guidelines. Guidance for monitoring and recognising freshwater cyanobacteria is provided in the New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters (Ministry for the Environment and Ministry of Health, 2009).
Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

Cyanobacterial algal mat

2.2.4. WATER COLUMN DISSOLVED OXYGEN (SUPPORTING INDICATOR)

Dissolved Oxygen (DO) concentrations are a well-known indicator of the health of estuarine biological communities (Sutula 2011). Aquatic animals including fish, benthic macroinvertebrates, and zooplankton depend on adequate levels of DO to survive and grow. These levels may differ depending on the species and life stage of the organism (e.g. larval, juvenile, and adult). For sediment dwelling animals and plants, sediment oxygenation (as measured by RPD or surrogates - see later section on RPD indicators) is generally measured, particularly for those estuary types with strong sediment/water coupling (i.e. shallow estuaries and lagoons).

The USEPA selected maintenance of aquatic life, as measured by the sufficiency of dissolved oxygen (DO) to maintain aquatic life in the water column, as one of three biological endpoints to derive numeric nutrient criteria for estuaries.

The dominant approach for NZ estuaries, has been to measure DO in the water column for deeper, mainly subtidal estuaries, and to measure aRPD depth (or preferably redox potential) and grain size in the sediments for NZs dominant shallow, short residence time estuaries. Because the majority of NZ estuaries are well flushed and unstratified or, if they have longer residence times, have low-moderate nutrient loads, the appearance of depleted bottom water DO concentrations is relatively rare (restricted to upper estuary deep holes (e.g. Robertson 1978). An important exception has been identified in the euryhaline, stratified section of the outer Firth of Thames, where significant oxygen depression occurs in late summer and autumn (Zeldis et al. 2015). However, extensive monitoring data from a wide range of sites in NZ's dominant estuary types show that where benthic macroalgal growth is excessive, oxygen penetration is commonly limited to the upper few millimetres of sediments, resulting in muddy, sulphide rich sediments and a degraded benthic infaunal community (Wriggle NZ estuary data 2000-2013).

RECOMMENDED RATING THRESHOLDS FOR DISSOLVED OXYGEN

There are insufficient data to derive DO criteria for native NZ estuarine species, therefore the recommended NZ approach is to modify the NZ freshwater approach for thresholds for dissolved oxygen (Davies-Colley et al. 2013) to include the information on estuary thresholds encompassed in the US ASSETS (Bricker et al. 1999), and US California (Sutula et al. 2012) approaches (Table 7).

Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

Table 7. Recommended dissolved oxygen thresholds for screening estuaries.

Band	A	B	C	D
Ecological Quality	No stress caused by low dissolved oxygen on any aquatic organisms that are present at near-pristine sites.	Occasional minor stress on sensitive organisms caused by short periods (a few hours each day) of lower dissolved oxygen. Risk of reduced abundance, performance and welfare of sensitive fish and macroinvertebrate species.	Moderate stress on a number of aquatic organisms caused by dissolved oxygen levels exceeding preference levels for periods of several hours each day. Risk of sensitive fish and macroinvertebrate species being lost.	Significant, persistent stress on a range of aquatic organisms caused by dissolved oxygen exceeding tolerance levels. Likelihood of local extinctions of keystone species and loss of ecological integrity.
7 day mean*	≥8.0 mg/l	≥7.0 mg/l	≥6.0 mg/l	<6.0 mg/l
7 day mean minimum*	≥7.0 mg/l	≥6.0 mg/l	≥5.0 mg/l	<5.0 mg/l
1 day minimum*	≥5.5 mg/l	≥5.0 mg/l	≥4.0 mg/l	<4.0 mg/l

*Use worst case water quality

Measuring dissolved oxygen with field meter

2.2.5. SEDIMENT ORGANIC MATTER (TOC) AND NUTRIENTS (TN AND TP) (SUPPORTING INDICATOR)

Organic matter in sediment consists of carbon and nutrients (derived from plant and animal matter) and is typically measured as total organic carbon (TOC). The rate of TOC production and decomposition, and the resulting microbial biomass, are at the heart of the eutrophication problem. The larger the TOC content, the greater the growth of microorganisms that can contribute to the depletion of oxygen supplies. Sediment nutrients are assessed as Total Nitrogen (TN) and Total Phosphorus (TP) concentrations, and have inorganic as well as organic sources. TOC/nutrient ratios are often used to predict certain estuarine ecological processes (see following).

- Low TOC:TN ratios indicate 'labile' organic matter (e.g. phytoplankton and macroalgae) that breaks down easily.
- Very high TOC:TN ratios indicate 'refractory' organic compounds (woody debris made of lignin and cellulose) and are highly resistant to degradation. Organic matter with very high TOC:TN ratios consumes more dissolved oxygen, supports less denitrification, and releases fewer nutrients to the water column when it breaks down than organic matter with low TOC:TN ratios (Twilley et al. 1999, Rivera-Monroy and Twilley 1996). Sediments with high TOC:TN ratios (and lower N contents) tend to support a lower biomass of benthic invertebrates (Heap et al. 2001).

Because organic matter has a strong affinity for muds, there is generally a positive correlation between TN or TOC and %mud in NZ estuaries (Robertson 2013, Robertson et al. 2015). Sites of organic matter accumulation in estuaries are therefore controlled to a large extent by processes that govern the transport and deposition of muds. In shallow, intertidal dominated estuaries, flanking upper estuary environments are the main traps for fine sediments (including mangroves, saltmarsh and unvegetated flats), and in subtidal dominated estuaries the central basin is usually the main sink. Once trapped, sediment organic matter can be a source of 'recycled nutrients' (both N and P) for water column and benthic productivity (including macroalgal blooms) when it degrades. Dissolved oxygen concentrations are usually lowered in the sediment when organic matter is degraded by bacteria, and anoxic and hypoxic conditions may develop and cause the sediment RPD layer to shift closer to the sediment surface.

RECOMMENDED RATING THRESHOLDS FOR ORGANIC MATTER AND NUTRIENTS

Robertson (2013) and Robertson et al. (2015) demonstrate consistent relationships between TN and TOC and biota for a wide range of NZ estuaries. However, information on the relationship between the spatial distribution of these supporting indicators, and overall biological impacts, is very limited. Notwithstanding, conditions that cause persistent ecological degradation (e.g. to macrofauna) indicate significant adverse impacts are occurring, and like the primary indicator macroalgae, a measure of the spatial distribution is also required in addition to the concentrations in order to determine an overall estuary rating for that indicator. Consequently, the ETI has, based on expert opinion in this regard, applied thresholds where significant stress causing high impacts should not be exceeded over >10% (or >30ha) of an estuary, and that areas of moderate stress should not exceed 50% (or 100ha) of an estuary. The validity of these TOC and TN thresholds for NZ estuaries are currently being assessed at Otago University (Ben Robertson PhD research). In the meantime, interim thresholds (Bands A to D) are provided for supporting guidance (Table 8), but only to be used in association with other related indicators (e.g. TS, RPD, macroalgal biomass, % mud, macroinvertebrate indices). In order to provide guidance on the extent to which TOC and TN is likely to affect the macroinvertebrate community at a particular site within an estuary, a "TN and TOC for Individual Sites" rating is also included.

Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

Table 8. Recommended TOC and TN thresholds for screening estuaries.

Band	A	B	C	D
Ecological Quality	No stress caused by the indicator on any aquatic organisms.	A minor stress on sensitive organisms caused by the indicator.	Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost.	Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity.
Total Organic Carbon (top 2cm)	<0.5% over 50% of estuary	0.5-1% over 50% of estuary	>1-2 % over 50% of estuary or >100ha	>2% over 10% of estuary or >30ha
Total Nitrogen (top 2cm)	<250 mg/kg over 50% of estuary	250-1000 mg/kg over 50% of estuary	>1000-2000 mg/kg over 50% of estuary or >100ha	>2000 mg/kg over 10% of estuary or >30ha
For Individual Sites (measured in upper 2cm of sediment)				
Total Organic Carbon	<0.5%	0.5-1%	>1-2%	>2%
Total Nitrogen	<250 mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg

2.2.6. SEDIMENT REDOX POTENTIAL AND RPD (SUPPORTING INDICATOR UNDER DEVELOPMENT)

Reduced sediment oxygenation has been related to reduced sediment quality and volume available for benthic infauna, and alterations in community structure. These effects have been linked to reduced availability of forage for fish, birds and other invertebrates, as well as to undesirable changes in biogeochemical cycling (Sutula et al. (2014).

The depth of sediment oxygenation (the zone where conditions change from oxidizing to reducing) is termed the Redox Potential Discontinuity (RPD). It can be assessed visually as the depth where sediment changes colour, termed the apparent RPD (aRPD), or can be measured directly (RPD). Visual aRPD depth measures (often done in situ when sediments are intertidal and with digital imaging if subtidal) rely on the assumption that in the absence of oxygen, microbial sulphate reduction results in the precipitation of Fe-sulphides, producing a grey/green or black sediment coloration. aRPD has been the primary method used to measure RPD depth in NZ estuaries to date. It is a recommended indicator in the NEMP (Robertson et al. 2002), but with the proviso that it only be used by experts trained using both visual and meter approaches. For meter approaches, redox potential (Eh) measurements represent a composite of multiple redox equilibria measured at the surface of a redox potential electrode coupled to a millivolt meter (Rosenberg et al. 2001) (often called an ORP meter) and reflects a system's tendency to receive or donate electrons. The electrode is inserted to different depths into the sediment and the extent of reducing conditions at each depth recorded (RPD is the depth at which the redox potential is ~0 mV, Fenchel and Riedl 1970, Revsbech et al. 1980, Birchenough et al. 2012, Hunting et al. 2012).

Chemically, anoxic sediments accumulate sulphides (which give sediments a black colour) and ammonium, which are highly pervasive causes of sediment toxicity to aquatic life (Losso et al. 2007, Machado et al. 2004). A shallow RPD layer forces most macrofauna towards the sediment surface to where oxygen is available. In sandy, porous, non-eutrophic sediments, the RPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy and interstitial spaces small. Pearson and Rosenberg (1978) developed a useful organic enrichment tool that indicates the likely macrofauna community that is supported at a particular site based on the measured RPD depth. This tool has been used extensively to date, in a multi-indicator approach, to help interpret intertidal monitoring data and its relationship to organic enrichment in NZ estuaries (Wriggle Coastal Management estuary reports 2002-2015).

RECOMMENDED RATING THRESHOLDS FOR REDOX POTENTIAL

The NZ relationship between redox potential, aRPD and macroinvertebrates is currently being investigated as part of PhD research on a wide range of NZ SIDE estuaries (Ben Robertson PhD research, Uni of Otago). Preliminary results indicate multi-depth redox potential measures provide a strong indication of the macrobenthic response to stress from reducing conditions, whereas visual (aRPD) measures provide a relatively weak indication, unless the aRPD is at 0cm. As such, it is recommended that redox potential measurements be used as the main indicator of sediment oxygenation effects on macrobenthic communities in NZ estuaries. Preliminary thresholds are proposed in Table 9 and follow Hargrave et al. (2008) (to be confirmed in the next 6 months). Like TOC and TN, a measure of spatial distribution is required in order to determine an overall estuary rating for this indicator. The ETI has, based on expert opinion in this regard, considered that if an estuary has severe reducing conditions near the surface (top 1cm) over >10% (or >30ha) of its area, a threshold for high impact (e.g. to macrofauna) has been exceeded. Areas of moderate stress should not exceed 50% (or 100ha) of an estuary. These interim screening thresholds should only be used in association with other related indicators (e.g. TS, TOC, macroalgal biomass, % mud, macroinvertebrate indices). In order to provide guidance on the extent to which redox potential is likely to affect the macroinvertebrate community at a particular site within an estuary, a "Redox Potential for Individual Sites" rating is also included.

Technical information supporting the thresholds is presented in Tool 2 Appendix 8.

Table 9. Recommended Redox Potential thresholds for screening estuaries. PRELIMINARY VALUES PENDING REVIEW

Band	A	B	C	D
Ecological Quality	No stress caused by the indicator on any aquatic organisms.	A minor stress on sensitive organisms caused by the indicator.	Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost.	Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity.
Redox potential (mV)	>0 mV at >5 cm over 50% of estuary	0 to -50 mV at 3-5 cm over 50% of estuary	-50 to -150 mV at 1-3 cm over 50% of estuary or >100ha	< -150 mV at <1 cm over 10% of estuary or >30ha
aRPD depth (cm)	Unreliable	Unreliable	Unreliable	At surface (0cm) over 10% of estuary or >30ha
Redox Potential for Individual Sites (measured at 1cm) - based on Hargrave et al. (2008)				
Redox potential (mV)	>100 mV	100 to -50 mV	-50 to -150 mV	< -150 mV

2.2.7. SULPHUR (SUPPORTING INDICATOR UNDER DEVELOPMENT)

Certain sulphur containing fractions in estuary sediments (particularly sulphides and total sulphur) provide an integrated measure of sediment oxygenation, and hence eutrophication, that are potentially better able to balance out short term and small scale spatial variance in redox potential measures. These fractions arise through the microbial decomposition, or oxidation, of organic matter. In coastal marine sediments, sulphate reduction accounts for up to 50% of organic matter degradation (Jørgensen 2000) and its rate can be large, reaching hundreds of $mg.m^{-2}.h^{-1}$ (e.g. Waikouaiti Estuary, 0.55-212 $mg.m^{-2}.h^{-1}$ Robertson 1978). High sulphide production leads to: unfavourable conditions for aerobic macrofauna, stress to plant root systems, and production of nuisance odours. In addition, because sulphides are considered to be a key-binding phase involved in the biogeochemical cycling of heavy metals in anoxic sediments, their presence can often indicate elevated heavy metal concentrations.

Two forms of reduced sulphide are often used as indicators of eutrophication, i. Acid Volatile Sulphur (AVS), an estimate of the free sulphides, determines the sulphide concentration within the sediment that is soluble in acid, and ii. Chromium Reducible Sulphur (S_{Cr}), sometimes called total reduced sulphur (TRS), provides a measure of reduced sulphur, including pyrite (FeS_2(s), elemental sulphur, and the more stable monosulphide fractions. Total sulphur (TS) is also often measured in conjunction with S_{Cr} because spatial variability in the availability of sulphur may influence the formation of reduced inorganic sulphur. Further, there is also some evidence that because TS is mainly composed of reduced forms (Chandran et al. 2012), it is also a potential indicator of eutrophication (Heggie and Skyring 2005). TS and S_{Cr} are currently much cheaper to measure in NZ than AVS.

TS has been found to have a proven linear relationship with sediment carbon concentrations, and to be a better indicator of macroinvertebrate stress than TOC when sediment mud content is >30% (Ben Robertson, preliminary PhD findings). This is consistent with international literature which reports that low TS concentrations indicate limited reducing conditions and low carbon preservation capacity, and high TS indicates strong reducing conditions and high TOC preservation. A measurable TS gradient between reducing and oxic estuarine sediments is therefore a good "direct" indicator of biological stress (i.e. macroinvertabrates likely to be most affected by the sulphur chemistry), and will complement measures of sediment redox conditions (i.e. a proxy for sediment oxygenation), and heavy metal chemistry.

RECOMMENDED RATING THRESHOLDS FOR SULPHUR

The validity of the S thresholds for NZ estuaries is currently being assessed at Otago University (Ben Robertson PhD research). Interim thresholds (Bands A to D) will be provided for supporting guidance when available. Like TOC, TN, and redox potential, a measure of spatial distribution is required in order to determine an overall estuary rating for this indicator. It is proposed, based on expert opinion, that if >10% (or >30ha) of an estuary has high TS or sulphide conditions near the surface (top 2cm), then a very high impact threshold is breached, likely resulting in persistent ecological degradation (e.g. to macrofauna). These interim screening thresholds should only be used in association with other related supporting indicators (e.g. TN, TOC, RPD, macroalgal biomass, % mud, macroinvertebrate indices).

In order to provide screening guidance on the extent to which S is likely to affect the macroinvertebrate community over both the whole estuary and at a particular site within an estuary, the following ratings are recommended (Table 10). Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

Table 10. Recommended sulphur and sulphide thresholds for screening estuaries.

Band	A	B	C	D
Ecological Quality	No stress caused by the indicator on any aquatic organisms.	A minor stress on sensitive organisms caused by the indicator.	Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost.	Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity.
% of Estuary with TS >???ppm in top 2cm	<1%	1-5%	>5-10%	>10%
% of Estuary with S_{Cr} >???ppm in top 2cm	<1%	1-5%	>5-10%	>10%
For Individual Sites (measured in upper 2cm of sediment)				
Total Sulphur	Under development : Ben Robertson Uni. of Otago PhD. Output expected 2016			
Total Sulphides	Under development : Ben Robertson Uni. of Otago PhD. Output expected 2016			

2.2.8. MUD CONTENT, SEDIMENTATION RATE (SUPPORTING INDICATOR)

In some estuaries, particularly shallow ones, increased fine sediment loads are often accompanied by elevated nutrient loads, resulting in significant mud deposition zones in the upper estuary tidal flats that can become eutrophic (Robertson and Stevens 2012, 2013). The resulting "soft mud/macroalgae cocktail" exacerbates sediment deoxygenation, production of sulphides, and degraded macrobenthos. For these reasons, and because it is a strong predictor of estuarine macrobenthos, mud is considered a useful supporting indicator for the assessment of estuary trophic status (i.e. if soft muds are present then the estuary is more prone to eutrophic sediments).

Based on extensive NZ estuary data, it is therefore recommended that mud content, mud sedimentation rate, and the spatial distribution of these be used as supporting indicators when assessing the trophic state of shallow, lagoon type estuaries (<3m mean depth). Such indicators will monitor the infilling rate, whether there has been a shift to finer sediments, and the spatial extent of any changes. Further, consideration should also be given to monitoring plants and animals so that the effects of mud changes on key biota (e.g. macroinvertebrates, fish, seagrass) can be gauged, as well as ensuring water clarity is not adversely impacted by suspended fine sediments. For example, the SAV section in Tool 2 Appendix 8 recommends an average value of at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed (to the depth of seagrass colonisation) to ensure adequate water clarity for seagrass.

Such results will help assessment of the trophic status and susceptibility of an estuary where expression of the primary indicator (e.g. opportunistic macroalgae) may be exacerbated by the presence of significant areas of soft muds, or high value habitat may be adversely impacted by secondary influences such as reduced water clarity. In other words, an estuary rated D for macroalgae but A for soft muds is likely to have better sediment quality than if it rated D for both macroalgae and soft muds.

RECOMMENDED RATING THRESHOLDS FOR MUD CONTENT AND SEDIMENTATION RATE

Extensive NEMP monitoring data from typical NZ shallow tidal lagoon, tidal river and ICOLL estuaries show that extensive areas of soft mud, elevated sedimentation rates, and high sediment mud contents are commonly associated with low seagrass cover, a degraded macroinvertebrate community and degraded sediment conditions if nutrients are excessive and soft mud areas are overlain with dense nuisance beds of opportunistic macroalgae. Because mud is less of an issue in relation to eutrophication in moderately deep to deep estuaries, and information on its impacts is limited, thresholds have not been proposed in the ETI for these less susceptible estuary types. Where significant sediment inputs are present in such estuaries, they should be considered on a site specific basis.

The aim of the proposed thresholds for mud indicators is to provide a gradient of likely ecological effects from mud on shallow lagoon type estuaries, as well as identifying the potential risk of enhancing eutrophication effects if nutrient loads are excessive. The ratings are based on four key indicators, with thresholds presented in Table 11:

1. **The mean mud content of the whole estuary area**.

   This threshold urgently requires further development but is proposed as a key indicator as changes to sediment mud content, a known driver of ecological shifts, can occur without being detected by other indicators (2-4 below).

2. **The percentage of the intertidal estuary area dominated by soft mud (sediments with >25% mud content)**.

   Like other primary and secondary indicators, a measure of spatial distribution is required in order to determine an overall estuary rating for soft mud. Although there is a strong relationship between increasing sediment mud content and persistent ecological degradation (e.g. to macrofauna - Robertson et al. 2015), the relationship between the spatial extent of muddy sediment and overall biological impacts is still being established for NZ estuaries. However, because it is obvious that extensive areas of soft mud will cause ecological damage, the ETI has opted to use expert opinion to conclude that if >15% of an estuary's area is soft mud, then a high impact threshold has been breached.

3. **The mean annual sedimentation ratio.**

   This proposed threshold is based on the natural sedimentation rate (NSR). The NSR is the sedimentation rate for the estuary when it was in its natural state (i.e. pre-human vegetation cover and wetland presence). This rate can be estimated as the current sedimentation rate (CSR) multiplied by the natural state sediment load (NSL)/current sediment load (CSL) ratio. Catchment models (e.g. CLUES) can be used to estimate NSL and CSL. CSR can be measured using sediment plates and/or bathymetric methods. A more robust approach would be to use hydrodynamic modelling methods to predict estuary retention and to replace NSL and CSL with retained NSL and retained CSL. The proposed shallow lagoon type estuary POOR or D Band threshold is a mean sedimentation rate of greater than five times the natural sedimentation rate (i.e. >5 x NSR mm/yr).

4. **The proportion of the estuary area with sedimentation rates >5 x the NSR mm/yr**.

   This indicator has been proposed to highlight where there is the potential for the rapid accumulation of sediments above a rate that an estuary can readily assimilate. It is included because soft muds are generally associated with increased organic content, nutrients, and decreased sediment oxygenation when compared to sandier sediments.

2.2.8. MUD CONTENT, SEDIMENTATION RATE (SUPPORTING INDICATOR - CONTINUED)

The proposed mud thresholds for assessing trophic state of NZ shallow estuaries need further validation (this is currently being assessed at Otago University, Ben Robertson PhD research). Interim thresholds (Bands A to D) are provided for supporting guidance (Table 11), but should only be used in association with other related supporting indicators (e.g. TOC, RPD, TN, macroalgal biomass, macroinvertebrate indices).

Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

Table 11. Sedimentation thresholds for screening shallow lagoon type estuaries.

Band	A	B	C	D*
Ecological Quality	No stress caused by the indicator on any aquatic organisms.	A minor stress on sensitive organisms caused by the indicator, especially if nutrient loads elevated.	Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost, especially if nutrient loads elevated.	Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity, especially if nutrient loads excessive.
% Mud Content (mean over whole estuary)	Urgent work is needed to determine the relationship between mean sediment mud content and ecological condition in NZ's dominant estuary types.			
% Estuary Area with Soft Mud ** (>25% sediment mud content)	<1%	1-5%	>5-15%	>15%
Mean Sedimentation Ratio Current Sed Rate (CSR) : Natural Sed Rate (NSR)	CSR = 1 to 1.1 x NSR	CSR = 1.1 to 2 x NSR	CSR = 2 to 5 x NSR	CSR > 5 x NSR
% Estuary Area with Sedimentation Rate (mm/yr) exceeding 5 x NSR	<1%	1-5%	>5-15%	>15%
For Individual Sites				
% Mud Content for Individual Sites	<5% mud	5-15% mud	>15-25% mud	>25% mud

* Note that if an estuary is rated D, then because of the short term difficulty in removing sediments from an estuary, the likely management response will be sediment input reduction and leaving already deposited sediment to gradually flush out over the long-term. In order to provide guidance on the extent to which mud is likely to affect the macroinvertebrate community at a particular site within an estuary, a "Mud Content for Individual Sites" rating is also included (based on preliminary results of NZ estuary studies from Ben Robertson PhD).

** Macrofaunal communities (used as an indicator of wider impacts on other ecological groups) show ecological degradation in response to soft mud, and consequently the larger the extent of mud areas, the greater the ecological damage. While excessive nutrient inputs do not cause increased muddiness, soft mud exacerbates eutrophication effects because they are generally associated with increased organic content, nutrients, and decreased sediment oxygenation when compared to sandier sediments.

Waikawa Estuary, Southland

Waikanae Estuary, Kapiti Coast

2.2.9. SUBMERGED AQUATIC VEGETATION (SAV) (SUPPORTING INDICATOR)

Submerged macrophytes, such as seagrass (e.g. *Zostera muelleri* in shallow tidal lagoon, tidal river, and coastal embayment estuaries, and *Ruppia megacarpa* and *Ruppia polycarpa* in some ICOLLs), play an important role in NZ estuarine ecology and are well-documented as keystone species that can reliably be used as target biological endpoints (e.g. USEPA Nutrient Numeric Criteria, Schallenberg and Tyrrell 2006). They attenuate and assimilate nutrients and sediment, and provide high value habitat for a wide range of biota. The presence of extensive SAV beds in good condition generally indicates low/moderate nutrient and mud inputs, combined with good water clarity, whereas die-off and absence of SAV is generally indicative of excessive nutrient and mud inputs and eutrophic conditions or poor water clarity. In shallow NZ estuaries, seagrass loss is generally associated with smothering by excessive macroalgal cover (in association with increased organic enrichment of sediments, low water clarity, poor oxygenation and increased muddiness) (e.g. Stevens and Robertson 2012). However, because seagrass habitat is potentially affected by a variety of non-eutrophication related stressors (i.e. muddiness, temperature, desiccation, toxicity, grazing, etc.) as well as eutrophication related stressors, its use as a primary trophic state indicator is not recommended.

RECOMMENDED RATING THRESHOLDS FOR SUBMERGED AQUATIC VEGETATION

Because seagrass habitat is affected by a variety of both eutrophication and non-eutrophication related stressors, it is unrealistic to expect a reliable condition gradient of expected seagrass cover that matches nutrient and/or sediment loads in the various NZ estuary types. For example, some shallow, intertidal dominated NZ estuaries show high seagrass cover at low nutrient and sediment loads (e.g. Freshwater Estuary, Whanganui Inlet) whereas others show low cover (e.g. most Golden Bay estuaries). However, despite this variability in response to nutrient and sediment loads, it is appropriate to develop estuary-specific thresholds using data on the estuary's seagrass cover prior to catchment development as the reference (Band A) threshold, i.e., set thresholds based on the extent SAV occurs naturally in a particular estuary. If pre-development seagrass cover is unknown, then best estimates can be obtained from inferences based on known cover in similar estuaries with minimal catchment development, or early aerial photographs where available. Recommended thresholds based on deviations from a natural state reference condition, or from a measured baseline, are presented in Table 12 (the magnitude of the deviations based on expert opinion rather than strong evidence). The thresholds are clearly interim and fit the category of a supporting indicator, for use in association with other indicators (e.g. mud, water clarity, macroalgae, epiphytes, sediment conditions). Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

Table 12. Seagrass interim thresholds for screening shallow lagoon type estuaries.

Band	A	B	C	D
Ecological Quality	No stress caused by the indicator on any aquatic organisms.	A minor stress on sensitive organisms caused by the indicator.	Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost.	Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity.
SAV Extent % of Estimated Natural State Cover (ENSC)	100 % of ENSC	>95-99% of ENSC	85-95%of ENSC	<85% of ENSC

Another approach, rather than using the above interim thresholds, is to use other indicators to ensure seagrass is not detrimentally shaded by eutrophication related factors (i.e. macroalgae, epiphytes, phytoplankton, mud, clarity) and that the sediment conditions (mud, RPD, TOC, TS, TN) are amenable. Ideally, it is recommended that research be undertaken to develop a model that predicts the potential of any NZ estuary in its natural state for high density seagrass growth, by accounting for both eutrophication and non-eutrophication related variables. Such a model would be capable of predicting numeric nutrient load criteria to support healthy seagrass beds.

Seagrass bed, Whanganui Inlet, Tasman District

Seagrass, Freshwater Estuary, Stewart Island

2.2.10. MACROINVERTEBRATES (SUPPORTING INDICATOR)

Because of their proven ability to indicate and integrate complex environmental conditions, soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). Such a classification is particularly useful given the fact that most NZ estuaries are dominated by soft sediments. As an estuary progresses along the gradient of increasing eutrophication and muddiness, the benthic macroinvertebrate community responds to lowering oxygen and increasing toxicity by shifting towards smaller, more stress tolerant species. These are not as efficient at bioturbation, which limits oxygen penetration into the sediments and effectively minimises the zone of coupled nitrification/denitrification in the sediments (Pearson and Rosenberg 1978, Sutula 2011). However, assessing estuarine condition by macroinvertebrates is complicated by the high variability of natural conditions in estuaries and their often modified nature. In particular, it is important to target sites that are representative of both highly susceptible habitats as well as less susceptible zones, and to ensure that sampling is undertaken at the same time each year.

RECOMMENDATIONS FOR MACROINVERTEBRATE INDICATORS FOR NZ ESTUARIES

It is strongly recommended that NZ macroinvertebrate/physico-chemical variable relationships be used to assess estuary condition in NZ. This is because the physical conditions of most NZ estuaries (dominated by largely intertidal, well-flushed, shallow, short residence time estuary types and the absence of midwater saltmarsh), differ greatly from the majority of the overseas estuaries types and the associated data sets (dominated by marine/estuarine subtidal data) which have been used to derive international biotic indices.

Further, in order to assess the ecological condition of NZ estuaries using macroinvertebrates, particularly in relation to three of the major estuary stressors, i.e. muddiness, eutrophication and toxicity, a multi-criteria approach using physical, chemical and biotic indicators is recommended. This approach is recommended because the response of NZ estuary macroinvertebrate taxa to these issues has not yet been reflected in any one integrated biotic indice. The recommended approach includes the following:

1. Determine NZ Hybrid AMBI biotic index rating (Robertson et al. 2016, in prep.) for each site using quantitatively derived estuarine sensitivities for NZ taxa (e.g. Robertson et al. 2015), and relevant international sensitivity ratings where local data are absent. Support results by analysing changes in species richness, individual species abundances (particularly in relation to their mud/enrichment tolerance groupings), mud, TOC, metals concentrations, and redox potential. For example, it may be useful to compare them with the following physico-chemical/macroinvertebrate response relationships for representative NZ estuaries.
   - TOC concentration: versus NZ hybrid AMBI (see Robertson et al. 2016 in prep.); versus species richness (see Tool 2 Appendix 8 TOC section); versus macroinvertebrate community similarity (see Tool 2 Appendix 8 TOC section, i.e. CAP Plot)
   - Mud concentration: versus NZ hybrid AMBI (see Robertson et al. 2016 in prep.); versus species richness (see Tool 2 Appendix 8 Mud Content section); versus macroinvertebrate community similarity (see Tool 2 Appendix 8 Mud Content section, i.e. CAP Plot)
2. If metal (or some other toxin) concentrations from anthropogenic sources are elevated above biologically stressful levels, then include these data as a potential explanatory variable. Note: toxic contaminant/macrobenthic response relationships will be developed once sufficient monitoring data from a range of NZ estuaries has been collected - the current data set held by Wriggle does not include high toxicity sites. Other indices such as NIWAs Traits Based Index (TBI) may provide appropriate assessment of toxicity when applied as part of a multi index approach, where taxa sensitivities have been quantitatively derived, potential confounding of toxin results (e.g. by TOC or mud content) are accounted for, and a representative spread of NZ estuaries is included for validation.

Sampling muddy, eutrophic zone in Moutere Inlet, Tasman

2.2.10. MACROINVERTEBRATES (SUPPORTING INDICATOR CONTINUED)

RECOMMENDED RATING THRESHOLDS FOR MACROINVERTEBRATES

In order to assess the likely risk of estuary ecological condition being affected by excessive muddiness or organic enrichment, it is recommended that the following thresholds be used (Table 13) (note that these are for open estuaries only, ICOLL ratings have yet to be developed). The thresholds use AMBI scores (based on NZ Ecological sensitivity Groups - NZEGs) to both indicate the condition of the macroinvertebrate community from representative parts of the dominant habitat, as well as a spatial measure that assumes, based on expert opinion, that the percent of an estuary containing a degraded macroinvertebrate community (e.g. AMBI >4.3) should be small. Technical information supporting these thresholds is presented in Tool 2 Appendix 8.

Table 13. Macroinvertebrate Index (AMBI - NZEGs) thresholds for screening shallow lagoon type estuaries

Band	A	B	C	D
Ecological Quality	None to minor stress on benthic fauna. Community intolerant of organically enriched conditions and elevated muds.	Minor to moderate stress on benthic fauna. Community tolerant of slight organic enrichment and moderate muds.	Moderate to high stress on benthic fauna. Community tolerant of moderate organic enrichment and elevated muds.	Persistent, high stress on benthic fauna. Community tolerant of high and very enrichment and elevated muds or community is devoid of life.
AMBI Rating	0-1.2	>1.2-3.3	>3.3-4.3	>4.3-7.0
% Estuary Area with AMBI >4.3	<1% with AMBI >4.3	1-5% with AMBI >4.3	>5-10% with AMBI >4.3 or >100ha	>10% with AMBI >4.3 or >30ha

Note: If the toxicity levels (apart from toxicity related to eutrophic conditions, i.e. elevated sulphide or ammonia) exceed levels that cause biotic stress, it is recommended that the TBI be used and the scores be verified in relation to the measured results and thresholds for toxic contaminants and mud content.

Collecting invertebrate samples

Sieving invertebrate samples

Typical invertebrate sample prior to sorting

Sorting invertebrate samples

3. ASSESSING OVERALL EXPRESSION OF EUTROPHICATION SYMPTOMS

ETI Screening Tool 2 provides the methodology for estimating estuary ecological condition based on its expression of primary symptoms and secondary effects. The ETI rationale is that the primary response to increased nutrients is that the types and relative abundance of the primary producer communities change, and result in an increased rate of organic matter production and subsequent microbial decomposition. The negative ecological effects of eutrophication result from the combination of both the direct effects of nuisance algal growth (e.g. algal toxins, shading) and the often more "ecologically stressful" secondary or indirect effects, i.e. deoxygenation causing increased sulphide concentrations (which have an inhibitory effect on macrophytes, macrofauna, and on some biogeochemical processes such as coupled nitrification/denitrification), and a shift towards heterotrophy, with elevated sediment nutrient release to the water column, thereby accelerating eutrophication.

The methodology for estimating the overall eutrophic condition of the estuary uses the monitoring information (for the indicators described in the previous section) to define where an estuary, or part of an estuary, fits along an ecological condition gradient from "minimally eutrophic" (totally or nearly totally undisturbed conditions) to "very highly eutrophic".

To derive a final trophic condition rating (called ETI Score), the multiple ratings for both Primary Symptoms and Supporting Indicators are scored on a normalised scale from 0 (="minimally eutrophic") to 1 (="highly eutrophic"). These are then combined to determine overall condition rating bands (e.g Table 14 scoring matrix) and the ETI Score (see below).

Table 14. Scoring matrix for determination of ETI Condition Rating.

		Final Primary Symptom Rating			
		0-0.25	0.25-0.50	0.50-0.75	0.75-1.0
Final Supporting Indicator Rating	0-0.25	Minimal Eutrophic Symptoms	Minimal Eutrophic Symptoms	Moderate Eutrophic Symptoms	High Eutrophic Symptoms
	0.25-0.50	Minimal Eutrophic Symptoms	Moderate Eutrophic Symptoms	High Eutrophic Symptoms	High Eutrophic Symptoms
	0.50-0.75	Moderate Eutrophic Symptoms	High Eutrophic Symptoms	High Eutrophic Symptoms	Very High Eutrophic Symptoms
	0.75-1.0	High Eutrophic Symptoms	High Eutrophic Symptoms	Very High Eutrophic Symptoms	Very High Eutrophic Symptoms

The use of bands provides a rapid initial assessment of trophic state. Normalised scores provide greater resolution by defining values for each indicator within bands. A summary table for calculating ratings for each of the four estuary types is presented in Table 15 for ICOLLs, Table 16 for SIDEs, Table 17 for SSRTREs and Table 18 for DSDEs.

STEPS IN CALCULATING THE FINAL ETI SCORE (TROPHIC CONDITION RATING)

1. **Determine the Final Primary Symptom Rating (FPSR)**. The final primary symptom rating (FPSR) is based on a "One Out, All Out" approach, which simply means that the highest of the available normalised* indicator ratings is chosen as the final primary indicator rating. This approach of not combining the primary indicator ratings reflects the independence of these indicators (i.e. macroalgae and phytoplankton can both exert a gradient of eutrophic conditions depending on estuary type).
2. **Determine the Final Supporting Indicator Rating (FSIR)**. The final supporting indicator (FSIR) rating is based on a "combined" approach, which simply means that the average of the available normalised* indicator ratings is chosen as the final secondary indicator rating. This approach of combining the supporting indicator ratings reflects the dependence of these indicators (e.g. sediment TOC, RPD, and macroinvertebrate organic enrichment indices) on each other.
3. **Determine the ETI Score (Trophic Condition Rating)**. The Final ETI score is calculated using normalised* indicator ratings in the following equation: **ETI score = FPSR + FSIR / 2**. This process acknowledges that the expression of both primary symptoms, and supporting indicators showing eutrophication, have more weight than just primary symptoms alone.

***Normalised indicator ratings:** For each indicator, the thresholds defining each band are normalised across a scoring range from 0-1 using a Normalisation Equation i.e. $z = [x - \min(x)] / [\max(x) - \min(x)]$; where z is the normalised value for x, and min(x) and max(x) are the upper and lower ranges expected (see following table). As most of the thresholds between bands are non-linear, equations will be used to match normalised values to the defined band thresholds. The equations can then be used to convert any indicator value to a normalised score relevant to the band thresholds. The ETI scoring component is scheduled for development during 2016 and will underpin the year 2 deliverable (i.e. ETI calculator.)

Indicator	Min (x)	Max (x)	Indicator	Min (x)	Max (x)	Indicator	Min (x)	Max (x)
Macroalgae EQR (already normalised)	1	0.2	Dissolved oxygen (mg/l)	10	2	Total sulphur	TBD	TBD
Phytoplankton (chlor a ug/l)	0.5	15	Total nitrogen (mg/kg)*	100	2500	SAV extent (% of ENSC)*	TBD	TBD
Total organic carbon (%)	0.1	3.5	% estuary area with soft mud (>25% sediment mud content)*	<1	100	Water column TN	TBD	TBD
Sediment Redox Potential (mV)	+50	-200	% estuary area with sediment rate (mm/yr) >5X NSR*	<1	100	Water column TP	TBD	TBD
Macroinvertebrate AMBI	1	5.5	Sedimentation Ratio (current annual mean relative to NSR)	1	>10	Water Clarity	TBD	TBD

*For indicators where the rating is based on areal extent of indicator expression: For initial banding, take the midpoint of the normalised band score e.g. TN (spatial extent) would give a normalised score of 0.125 for Band A, 0.375 for Band B, 0.625 for Band C, and 0.875 for Band D. TBD=to be developed.

4. USING THE ETI OUTPUTS

It is expected that Regional Councils will want to include guidance on individual metrics in their planning frameworks to both guide management and measure whether targets are being met. An example of likely outputs that the ETI tool use will underpin is presented below.

It is also expected that most Councils will want to define nutrient load thresholds at which an estuary is predicted to shift to another section of the condition gradient bands, e.g. to shift from Band A (natural state/minimal eutrophic symptoms) to B and B (moderate), to Band C (high) or Band D (very high). Screening Tool 1 can be used in this manner, where relevant data are available, to help Councils determine the likely magnitude of changes to nutrient inputs that will result in significant shifts in trophic status, either positive or negative.

EXAMPLE OF USE OF ETI TOOL TO UNDERPIN THE ESTUARY ECOLOGICAL HEALTH COMPONENT OF REGIONAL PLANS

Biological Attribute	**Macroalgae and Phytoplankton** Algal community is balanced with a low frequency of nuisance blooms	**Seagrass, Saltmarsh and Brackish SAV** Seagrass, saltmarsh and brackish SAV are resilient and diverse and their cover is sufficient to support invertebrate and fish communities	**Invertebrates** Invertebrate communities are resilient and their structure, composition and diversity are balanced	**Fish** Fish communities are resilient and their structure, composition and diversity are balanced
Desired Outcome for Biological Attribute	**Macroalgae and Phytoplankton** Low frequency of phytoplankton and nuisance macroalgal blooms	**Seagrass, Saltmarsh and Brackish SAV** No significant decline in cover from established baseline	**Benthic Invertebrates** No significant decline in community condition from established baseline	**Fish** No significant decline in community condition from established baseline
Method and Condition Guidelines for Assessing Biological Attribute	**Macroalgae (shallow estuaries or parts of estuaries)** % cover, biomass, entrainment. Macroalgal EQR <0.4 **Phytoplankton (for deeper estuaries or closed ICOLLs)** Chlor a, cyanobacteria counts and toxins. Chlor a. <12 ug/l	**Seagrass and Brackish SAV** % cover, biomass No significant decline in high density cover (>50%) from established baseline **Saltmarsh** % cover, dominant species, presence of weeds. No significant decline in cover from established baseline	**Benthic Invertebrates** Abundance, species diversity No significant decline in community condition from established baseline. Macroinvertebrate biotic Index AMBI <4.3	**Fish** Generally not measured in NZ for cost reasons, instead it is assumed that if habitat condition is good then the fish community is good also.

Method and Condition Guidelines for Assessing Habitat Attributes to Support Biological Attributes

For NZ's Dominant Estuary Type, Shallow, Intertidal Dominated Estuaries (SIDEs).

- **Sediment Mud Content.** No significant decline in mud content from established baseline, measured at sites representative broad estuary habitats.
- **Sedimentation Rate (SR).** The SR is within an acceptable range of that expected under natural state conditions. NSR is the natural sedimentation rate (i.e. pre European vegetation cover and wetland presence). This rate can be estimated as the current sedimentation rate (CSR) multiplied by the natural state sediment load (NSL)/current sediment load (CSL) ratio. Catchment models (e.g. CLUES) can be used to estimate NSL and CSL. CSR can be measured using sediment plates and/or bathymetric methods. The proposed shallow lagoon type estuary POOR or D Band threshold is a mean sedimentation rate of greater than five times the natural sedimentation rate (i.e. >5 x NSR mm/yr).
- **Area of Soft Muds (>25% mud content).** No significant increase in soft mud area from established baseline.
- **Sediment Total Organic Carbon.** TOC condition rating should be <2%.
- **Sediment Redox Potential.** Eh meter should be checked to establish extent and magnitude of low Eh potentials. Redox potential at >1cm should be >-150mV.
- **Sediment Nutrients.** No significant increase in total nitrogen from established baseline and should not exceed 2000mg/kg.
- **Water Column Clarity.** No significant decrease in water clarity from established baseline. Noting that the preferred water clarity for seagrass is an average value of at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed (to the depth of seagrass colonisation), assuming that the Secchi depth can be approximated to 20% of the surface light.

4. USING THE ETI OUTPUTS (CONTINUED)

In terms of reporting and managing monitoring data, the ETI is designed to define estuary trophic condition for any chosen year of monitoring data. For SOE reporting of multiple years of data it is recommended that the standard suite of SOE tools e.g. simple and multivariate statistics, trend analyses, etc., be applied as relevant to individual indicators in a manner consistent with other Council reporting.

Table 15. ETI Summary Table: ICOLLs - Intermittently Closed/Open Lake and Lagoon Estuaries

SCREENING TOOL 1: PHYSICAL AND NUTRIENT LOAD SUSCEPTIBILITY								**Estuary:**	_______________	
Use the combined physical and nutrient load factors described in Screening Tool 1 to determine the Final Susceptibility Rating (FSR) to eutrophication for the selected estuary (or subcomponent of estuary) type being assessed.								**FSR =**	_______________	
This Tool 1 susceptibility rating is not used in determining the Final ETI Score (Trophic Condition Rating).										
SCREENING TOOL 2: MONITORING INDICATORS AND ASSESSMENT OF TROPHIC STATE								**Indicator Value**	**Nor-malised Score****	**Final score**
Condition Band and Normalised Score Range				**Band A (0-0.25)**	**Band B (0.25-0.50)**	**Band C (0.50-0.75)**	**Band D (0.75-1.0)**			
PRIMARY SYMPTOM INDICATORS (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)								**Primary Symptom Scores**		
Required	Opportunistic Macroalgae (Includes epiphytic cover on SAV)	EQR	benthic and water column	≥0.8 - 1.0	≥0.6 - < 0.8	≥0.4 - < 0.6	0.0 - < 0.4			**FPSR= Highest Primary Symptom Score** _______
	Phytoplankton biomass - Chl- a (90 pctl) If issue identified, assess assemblage inc HAB's	Euhaline	water column	<3 ug/l	3-8 ug/l	8-12 ug/l	>12 ug/l			
		Oligo/Meso/Polyhaline		<5 ug/l	5-10 ug/l	>10-16 ug/l	>16 ug/l			
	Cyanobacteria (if issue identified)			Requires development						
SUPPORTING INDICATORS (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)								**Supporting Indicator Scores**		
Required Indicators	Sediment Redox Potential (mV) under development]*	Spatial Cover	Benthic	RP >0mV over 50% of estuary	RP 0-50 mV over 50% of estuary	RP 50 to -150 mV over 50% of estuary or >100ha	RPD>-150 mV/ aRPD 0 cm over 10% of estuary or >30ha			**FSIR = Aver-age of available indicator ratings** _______
		Representative sites (1cm)		>100 mV	100 to -50 mV	<-50 to -150 mV	< -150 mV			
	Sediment Total Organic Carbon*	Spatial Cover		<0.5% over 50% of estuary	0.5-1% over 50% of estuary	>1-2 % over 50% of estuary or >100ha	>2% over 10% of estuary or >30ha			
		Representative sites		<0.5%	0.5-1.0%	>1-2%	>2%			
	Sediment Total Nitrogen*	Spatial Cover		<250 mg/kg over 50% of estuary	250-1000 mg/kg over 50% of estuary	>1000-2000 mg/kg over 50% of estuary or >100ha	>2000 mg/kg over 10% of estuary or >30ha			
		Representative sites		<250mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg			
Optional Indicators	Water Column Dissolved Oxygen (mg/l)	7 day mean		≥8.0 mg/l	≥7.0 mg/l	≥6.0 mg/l	<6.0 mg/l			
		7 day mean minimum		≥7.0 mg/l	≥6.0 mg/l	≥5.0 mg/l	<5.0 mg/l			
		1 day minimum		≥5.5 mg/l	≥5.0 mg/l	≥4.0 mg/l	<4.0 mg/l			
	Macroinvertebrates	Biotic Index Rating		Requires development						
	Sediment Sulphur			Under development						
	% Mud Content (mean of whole estuary area)			Requires development						
	% Estuary Area with Soft Mud (>25% mud content)			<1%	1-5%	5-15%	>15%			
	Sedimentation Ratio (current annual mean relative to NSR)			CSR 1 to 1.1 x NSR	CSR 1.1 to 2 x NSR	CSR 2 to 5 x NSR	CSR > 5 x NSR			
	% Estuary Area with Sedimentation Rate >5xNSR			<1%	1-5%	5-15%	>15%			
	SAV (Seagrass) Extent (% of ENSC)			100% of ENSC	>95-99% of ENSC	85-95% of ENSC	<85% of ENSC			
	Water column nutrients (TN and TP)		water column	Requires development						
	Water Clarity			at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed						
*** denotes required supporting indicator (must include at least 1)** **** normalised scores derived from table on page 28.**				**Final ETI Score (Trophic Condition Rating)** **ETI score = normalised FPSR + FSIR / 2** **Use Table 14 Decision Matrix to determine band**						**ETI Score =** _______

Table 16. ETI Summary Table: SIDEs - Shallow, Intertidal Dominated Estuaries

SCREENING TOOL 1: PHYSICAL AND NUTRIENT LOAD SUSCEPTIBILITY									**Estuary:**	_______________
Use the combined physical and nutrient load factors described in Screening Tool 1 to determine the Final Susceptibility Rating (FSR) to eutrophication for the selected estuary (or subcomponent of estuary) type being assessed.									**FSR =**	_______________
This Tool 1 susceptibility rating is not used in determining the Final ETI Score (Trophic Condition Rating).										
SCREENING TOOL 2: MONITORING INDICATORS AND ASSESSMENT OF TROPHIC STATE								**Indicator Value**	**Nor-malised Score****	**Final score**
Condition Band and Normalised Score Range				**Band A (0-0.25)**	**Band B (0.25-0.50)**	**Band C (0.50-0.75)**	**Band D (0.75-1.0)**			
PRIMARY SYMPTOM INDICATORS (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)								**Primary Symptom Scores**		
Required	Opportunistic Macroalgae (Includes epiphytic cover on SAV)	EQR	shallow intertidal	≥0.8 - 1.0	≥0.6 - < 0.8	≥0.4 - < 0.6	0.0 - < 0.4			**FPSR= Highest Primary Symptom Score**
Optional	Phytoplankton biomass - Chl- a (90 pctl) If issue identified, assess assemblage inc HAB's	Euhaline	water column	<3 ug/l	3-8 ug/l	8-12 ug/l	>12 ug/l			
Optional		Oligo/Meso/Polyhaline	water column	<5 ug/l	5-10 ug/l	>10-16 ug/l	>16 ug/l			
Optional	Cyanobacteria (if issue identified)		water column	Requires development						_______
SUPPORTING INDICATORS (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)								**Supporting Indicator Scores**		
Required Indicators	Sediment Redox Potential (mV) under development]*	Spatial Cover	shallow intertidal habitat	RP >0mV over 50% of estuary	RP 0-50 mV over 50% of estuary	RP 50 to -150 mV over 50% of estuary or >100ha	RPD>-150 mV/ aRPD 0 cm over 10% of estuary or >30ha			**FSIR = Average of available indicator ratings**
Required Indicators		Representative sites (1cm)	shallow intertidal habitat	>100 mV	100 to -50 mV	<-50 to -150 mV	< -150 mV			
Required Indicators	Sediment Total Organic Carbon*	Spatial Cover	shallow intertidal habitat	<0.5% over 50% of estuary	0.5-1% over 50% of estuary	>1-2 % over 50% of estuary or >100ha	>2% over 10% of estuary or >30ha			
Required Indicators		Representative sites	shallow intertidal habitat	<0.5%	0.5-1.0%	>1-2%	>2%			
Required Indicators	Sediment Total Nitrogen*	Spatial Cover	shallow intertidal habitat	<250 mg/kg over 50% of estuary	250-1000 mg/kg over 50% of estuary	>1000-2000 mg/kg over 50% of estuary or >100ha	>2000 mg/kg over 10% of estuary or >30ha			
Required Indicators		Representative sites	shallow intertidal habitat	<250mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg			
Required Indicators	Macroinvertebrates*	AMBI rating	shallow intertidal habitat	0-1.2	>1.2-3.3	>3.3-4.3	>4.3			
Required Indicators		% area with AMBI >4.3	shallow intertidal habitat	<1% > AMBI 4.3	1-5% > AMBI 4.3	>5-10% > AMBI 4.3	>10% > AMBI 4.3			
Required Indicators		TBI (if toxicity an issue)	shallow intertidal habitat	not yet developed for NZ SIDEs						
Optional Indicators	Sediment Sulphur		shallow intertidal habitat	Under development : Ben Robertson Uni. of Otago PhD. Output expected 2016						
Optional Indicators	% Mud Content (mean of whole estuary area)		shallow intertidal habitat	requires development						_______
Optional Indicators	% Estuary Area with Soft Mud (>25% mud content)		shallow intertidal habitat	<1%	1-5%	5-15%	>15%			
Optional Indicators	Sedimentation Ratio (current annual mean relative to NSR)		shallow intertidal habitat	CSR 1 to 1.1 x NSR	CSR 1.1 to 2 x NSR	CSR 2 to 5 x NSR	CSR > 5 x NSR			
Optional Indicators	% Estuary Area with Sedimentation Rate >5xNSR		shallow intertidal habitat	<1%	1-5%	5-15%	>15%			
Optional Indicators	SAV (Seagrass) Extent (% of ENSC)		all habitat	100% of ENSC	>95-99% of ENSC	85-95% of ENSC	<85% of ENSC			
Optional Indicators	Water column nutrients (TN and TP)		shallow habitat	requires development						
Optional Indicators	Water Clarity		shallow habitat	at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed						
*** denotes required supporting indicator (must include at least 1)** **** normalised scores derived from table on page 28.**				**Final ETI Score (Trophic Condition Rating)** **ETI score = normalised FPSR + FSIR / 2** **Use Table 14 Decision Matrix to determine band**						**ETI Score =** _______

Table 17. ETI Summary Table: SSRTREs - Shallow Short Residence Time Tidal River and Tidal River-Lagoon Estuaries

SCREENING TOOL 1: PHYSICAL AND NUTRIENT LOAD SUSCEPTIBILITY — Estuary: _______________

Use the combined physical and nutrient load factors described in Screening Tool 1 to determine the Final Susceptibility Rating (FSR) to eutrophication for the selected estuary (or subcomponent of estuary) type being assessed. — FSR = _______________

This Tool 1 susceptibility rating is not used in determining the Final ETI Score (Trophic Condition Rating).

SCREENING TOOL 2: MONITORING INDICATORS AND ASSESSMENT OF TROPHIC STATE

	Condition Band and Normalised Score Range			Band A (0-0.25)	Band B (0.25-0.50)	Band C (0.50-0.75)	Band D (0.75-1.0)	Indicator Value	Normalised Score**	Final score
PRIMARY SYMPTOM INDICATORS (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)								**Primary Symptom Scores**		
Required	Opportunistic Macroalgae (Includes epiphytic cover on SAV)	EQR	shallow/ intertidal	≥0.8 - 1.0	≥0.6 - < 0.8	≥0.4 - < 0.6	0.0 - < 0.4			FPSR= Highest Primary Symptom Score
Optional	Phytoplankton biomass - Chl- a (90 pctl) If issue identified, assess assemblage inc HAB's	Euhaline	water column	<3 ug/l	3-8 ug/l	8-12 ug/l	>12 ug/l			
Optional		Oligo/Meso/Polyhaline	water column	<5 ug/l	5-10 ug/l	>10-16 ug/l	>16 ug/l			_______
Optional	Cyanobacteria (if issue identified)		water column	Requires development						
SUPPORTING INDICATORS (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)								**Supporting Indicator Scores**		
Required Indicators	Sediment Redox Potential (mV) under development]*	Spatial Cover	shallow/ intertidal habitat	RP >0mV over 50% of estuary	RP 0-50 mV over 50% of estuary	RP 50 to -150 mV over 50% of estuary or >100ha	RPD>-150 mV/ aRPD 0 cm over 10% of estuary or >30ha			FSIR = Average of available indicator ratings
Required Indicators		Representative sites (1cm)	shallow/ intertidal habitat	>100 mV	100 to -50 mV	<-50 to -150 mV	< -150 mV			
Required Indicators	Sediment Total Organic Carbon*	Spatial Cover	shallow/ intertidal habitat	<0.5% over 50% of estuary	0.5-1% over 50% of estuary	>1-2 % over 50% of estuary or >100ha	>2% over 10% of estuary or >30ha			
Required Indicators		Representative sites	shallow/ intertidal habitat	<0.5%	0.5-1.0%	>1-2%	>2%			
Required Indicators	Sediment Total Nitrogen*	Spatial Cover	shallow/ intertidal habitat	<250 mg/kg over 50% of estuary	250-1000 mg/kg over 50% of estuary	>1000-2000 mg/kg over 50% of estuary or >100ha	>2000 mg/kg over 10% of estuary or >30ha			
Required Indicators		Representative sites	shallow/ intertidal habitat	<250mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg			
Required Indicators	Macroinvertebrates*	AMBI rating	shallow/ intertidal habitat	0-1.2	>1.2-3.3	>3.3-4.3	>4.3			
Required Indicators		% area with AMBI >4.3	shallow/ intertidal habitat	<1% > AMBI 4.3	1-5% > AMBI 4.3	>5-10% > AMBI 4.3	>10% > AMBI 4.3			
Required Indicators		TBI (if toxicity an issue)	shallow/ intertidal habitat	not yet developed for NZ SIDEs						
Optional Indicators	Sediment Sulphur		shallow/ intertidal habitat	Under development : Ben Robertson Uni. of Otago PhD. Output expected 2016						
Optional Indicators	% Mud Content (mean of whole estuary area)		shallow/ intertidal habitat	requires development						_______
Optional Indicators	% Estuary Area with Soft Mud (>25% mud content)		shallow/ intertidal habitat	<1%	1-5%	5-15%	>15%			
Optional Indicators	Sedimentation Ratio (current annual mean relative to NSR)		shallow/ intertidal habitat	CSR 1 to 1.1 x NSR	CSR 1.1 to 2 x NSR	CSR 2 to 5 x NSR	CSR > 5 x NSR			
Optional Indicators	% Estuary Area with Sedimentation Rate >5xNSR		shallow/ intertidal habitat	<1%	1-5%	5-15%	>15%			
Optional Indicators	SAV (Seagrass) Extent (% of ENSC)		all habitat	100% of ENSC	>95-99% of ENSC	85-95% of ENSC	<85% of ENSC			
Optional Indicators	Water column nutrients (TN and TP)		water column	requires development						
Optional Indicators	Water Clarity		water column	at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed						
* denotes required supporting indicator (must include at least 1) ** normalised scores derived from table on page 28.				Final ETI Score (Trophic Condition Rating) ETI score = normalised FPSR + FSIR / 2 Use Table 14 Decision Matrix to determine band						ETI Score = _______

Table 18. ETI Summary Table: DSDEs - Deeper, Longer Residence Time, Subtidal Dominated Estuaries (Includes Coastal Embayments, Tidal Lagoons, Tidal Rivers and Fiords)

SCREENING TOOL 1: PHYSICAL AND NUTRIENT LOAD SUSCEPTIBILITY								**Estuary:**	_______________	
Use the combined physical and nutrient load factors described in Screening Tool 1 to determine the Final Susceptibility Rating (FSR) to eutrophication for the selected estuary (or subcomponent of estuary) type being assessed.								**FSR =**	_______________	
This Tool 1 susceptibility rating is not used in determining the Final ETI Score (Trophic Condition Rating).										
SCREENING TOOL 2: MONITORING INDICATORS AND ASSESSMENT OF TROPHIC STATE								**Indicator Value**	**Nor-malised Score****	**Final score**
Condition Band and Normalised Score Range				**Band A (0-0.25)**	**Band B (0.25-0.50)**	**Band C (0.50-0.75)**	**Band D (0.75-1.0)**			
PRIMARY SYMPTOM INDICATORS (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)								**Primary Symptom Scores**		
Required	Phytoplankton biomass - Chl- a (90 pctl) If issue identified, assess assemblage inc HAB's	Euhaline	water column	<3 ug/l	3-8 ug/l	8-12 ug/l	>12 ug/l			**FPSR= Highest Primary Symptom Score**
Required		Oligo/Meso/Polyhaline	water column	<5 ug/l	5-10 ug/l	>10-16 ug/l	>16 ug/l			
Required	Cyanobacteria (if issue identified)		water column	Requires development						
Optional	Opportunistic Macroalgae (Includes epiphytic cover on SAV)	EQR	shallow/ intertidal	≥0.8 - 1.0	≥0.6 - < 0.8	≥0.4 - < 0.6	0.0 - < 0.4			_______
SUPPORTING INDICATORS (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)								**Supporting Indicator Scores**		
Required Indicators	Sediment Redox Potential (mV) under development]*	Spatial Cover	benthic	RP >0mV over 50% of estuary	RP 0-50 mV over 50% of estuary	RP 50 to -150 mV over 50% of estuary or >100ha	RPD>-150 mV/ aRPD 0 cm over 10% of estuary or >30ha			**FSIR = Aver-age of available indicator ratings**
Required Indicators		Representative sites (1cm)	benthic	>100 mV	100 to -50 mV	<-50 to -150 mV	< -150 mV			
Required Indicators	Sediment Total Organic Carbon*	Spatial Cover	benthic	<0.5% over 50% of estuary	0.5-1% over 50% of estuary	>1-2 % over 50% of estuary or >100ha	>2% over 10% of estuary or >30ha			
Required Indicators		Representative sites	benthic	<0.5%	0.5-1.0%	>1-2%	>2%			
Required Indicators	Sediment Total Nitrogen*	Spatial Cover	benthic	<250 mg/kg over 50% of estuary	250-1000 mg/kg over 50% of estuary	>1000-2000 mg/kg over 50% of estuary or >100ha	>2000 mg/kg over 10% of estuary or >30ha			
Required Indicators		Representative sites	benthic	<250mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg			
Required Indicators	Water Column Dissolved Oxygen (mg/l)	7 day mean	water column	≥8.0 mg/l	≥7.0 mg/l	≥6.0 mg/l	<6.0 mg/l			
Required Indicators		7 day mean minimum	water column	≥7.0 mg/l	≥6.0 mg/l	≥5.0 mg/l	<5.0 mg/l			
Required Indicators		1 day minimum	water column	≥5.5 mg/l	≥5.0 mg/l	≥4.0 mg/l	<4.0 mg/l			
Optional Indicators	Macroinvertebrates	Biotic Index Rating	benthic	Requires development						
Optional Indicators	Sediment Sulphur		benthic	Under development						_______
Optional Indicators	% Mud Content (mean of whole estuary area)		benthic	Requires development						
Optional Indicators	% Estuary Area with Soft Mud (>25% mud content)		benthic	<1%	1-5%	5-15%	>15%			
Optional Indicators	Sedimentation Ratio (current annual mean relative to NSR)		benthic	CSR 1 to 1.1 x NSR	CSR 1.1 to 2 x NSR	CSR 2 to 5 x NSR	CSR > 5 x NSR			
Optional Indicators	% Estuary Area with Sedimentation Rate >5xNSR		benthic	<1%	1-5%	5-15%	>15%			
Optional Indicators	SAV (Seagrass) Extent (% of ENSC)		benthic	100% of ENSC	>95-99% of ENSC	85-95% of ENSC	<85% of ENSC			
Optional Indicators	Water column nutrients (TN and TP)		water column	Requires development						
Optional Indicators	Water Clarity		water column	at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed						
* denotes required supporting indicator (must include at least 1) ** normalised scores derived from table on page 28.				**Final ETI Score (Trophic Condition Rating)** **ETI score = normalised FPSR + FSIR / 2** **Use Table 14 Decision Matrix to determine band**						**ETI Score =** _______

5. INFORMATION GAPS

The ETI has highlighted a number of information gaps in relation to improving the precision of assessing eutrophication in NZ estuaries. These are raised here as issues that should ideally be addressed through targeted research as follows:

- Undertake more comprehensive studies to improve our understanding of the relationship between nutrient loads and ecological response in shallow, intertidal dominated estuaries and ICOLLS. In particular, it is recommended that monitoring of the following be undertaken and the data used to establish load response relationships: macroalgal biomass and sediment characteristics (nutrients, organic carbon, sulphur components, redox potential, bacterial composition) and the relationships of these variables with seagrass, mangroves, macroinvertebrates, and fish.
- Opportunistic macroalgae are the predominant source of elevated organic matter (and therefore eutrophication symptoms) in NZ's dominant estuary type (i.e. shallow, intertidally dominated estuaries). Currently, the data supporting a relationship between macroalgae and estuary trophic status in NZ estuaries is limited to a relatively small number of studies, but all confirm adverse impacts to sediment physico-chemistry and biota along similar lines to those found in overseas studies. In order to provide a more robust basis upon which to base the metrics used in the OMBT (WFD-UKTAG 2014) ecological quality rating for macroalgae, it is recommended that the ecological response thresholds for macroalgae be more thoroughly assessed, over all estuary types (but particularly those prone to macroalgal blooms i.e. shallow, intertidal dominated estuaries and ICOLLs). The studies should focus opportunistic macroalgal effects on biota (e.g. macroinvertebrates, fish, seagrass), and physico-chemical parameters (e.g. sediment redox potential, sulphur, organic carbon, nutrients and bacteria).
- Because NZ estuarine ecology is susceptible to the influence of fine sediments and nutrients, research is required to investigate the combined influence of fine sediment and nutrient loads on macroinvertebrates in NZ shallow estuaries. Such a study should aim to provide a predictive tool for macroinvertebrate response to nutrient and fine sediment input loads to key estuary types and estuary habitats (particularly shallow, intertidally dominated estuaries).
- Development of macrobenthic biotic indices for each of the major estuary issues of muddiness, organic enrichment and toxicity (especially sulphide toxicity). Research is required to tease apart the covariance between these issues so that macrobenthic response relationships can be derived for mud content alone, TOC/redox at varying mud contents, then TOC/redox, toxicants at varying mud contents. Careful site selection to minimise the influence of other variables (e.g. tide height, freshwater influence, resuspension, etc) is recommended in the design.
- Development of a model that predicts the potential of any NZ shallow estuary, along an ecological gradient from natural state to highly impacted by muds and eutrophication, to develop high density seagrass growth, by accounting for both eutrophication and non-eutrophication related variables. Such a model would be capable of predicting numeric nutrient load criteria to support healthy seagrass beds.
- Development of a model that predicts the potential of any NZ shallow estuary, along an ecological gradient from natural state to highly impacted by muds and eutrophication, to retain muds, by accounting for both eutrophication and non-eutrophication related variables. Such a model would be capable of predicting numeric sedimentation rate and hence sediment load criteria to support target ecological condition thresholds.
- Development of a model that predicts the potential of any NZ shallow estuary, along an ecological gradient from natural state to highly impacted by muds and eutrophication, to develop high density opportunistic macroalgal growth, by accounting for both eutrophication and non-eutrophication related variables. Such a model would be capable of predicting numeric nutrient load criteria to support minimal macroalgal growth.
- Collect and analyse data to support a robust relationship between sediment oxygenation (measured as redox potential, RPD, presence of sulphides, etc.) and effects on NZ estuarine biota (both plants and animals).
- Collect and analyse data to support a robust relationship between cyanobacteria and estuary trophic status (including nutrient levels and other factors leading to blooms).
- Although there are widespread studies supporting phytoplankton chlorophyll a and productivity as reliable response indicators, there is a lack of data for most NZ estuaries (with the exception of examples like the Firth of Thames) and a lack of specific studies to establish thresholds. Establishing the phytoplankton response (chlorophyll a and productivity) of subtidal dominated estuaries (residence time weeks rather than days), including ICOLLs during their closed phase, across a broad gradient of sediment and nutrient loads is important, if robust response thresholds are to be established for NZ. An important consideration for such studies is the strong possibility that precise thresholds may vary from estuary to estuary, depending on co-factors (e.g. opening and closing regimes of ICOLLs).

These appendices have been developed as a skeleton of information (including available NZ estuary data) that support the recommended ETI approaches for determining estuary eutrophication susceptibility and trophic condition. It is anticipated that they will be expanded upon as new information becomes available.

Supporting Technical Information for Screening Tool 2.

FOR DETERMINING ESTUARY TROPHIC STATE FROM MONITORING DATA

TOOL 2: APPENDIX 7. BACKGROUND TO CHOOSING ECOLOGICAL RESPONSE INDICATORS

7.1 THE RELEVANCE OF INTERNATIONAL APPROACHES TO NZ ESTUARIES

As discussed previously in Section 2.2, many methods have been developed in the world to assess estuary eutrophication and allow regulatory authorities to meet statutory requirements (e.g. to monitor and protect estuaries from degradation). These methods demonstrate that the eutrophication gradient is well understood and that the immediate biological response is increased primary production reflected as increased chlorophyll a and/or macroalgal abundance, which is often accompanied by secondary symptoms within both the water column and sediments. As a result, most methods include both primary and supporting indicators to provide the best possible evaluation of the nutrient related quality of the water body (Borja et al. 2012, Devlin et al. 2011, Sutula 2011).

Internationally, simple indicator thresholds for assessing the eutrophic status of estuaries and coastal waters similar to freshwater guidelines, have been developed in many countries (e.g. OSPAR 2008, Bricker et al. 1999). However, in terms of the direct application of these indicators and their associated condition thresholds to NZ estuaries, there are potential problems, particularly for shallow, intertidal dominated estuaries and ICOLLs (which are not well represented in international data sets).

For example, the US based ASSETS toolbox (Bricker et al. 1999, 2003, 2008) uses a simple screening-level assessment incorporating both primary and secondary symptoms of eutrophication. Primary symptoms are high levels of phytoplankton (chlorophyll a), epiphytes, and/or macroalgae and, at high levels, indicate an estuary is in the first stages of displaying undesirable eutrophic conditions. The second, much more degraded state, occurs when secondary symptoms of depleted dissolved oxygen, sulphide-rich sediments, seagrass loss, and nuisance/toxic algal blooms begin to appear.

"Water column" indicators, e.g. chlorophyll a, are best suited to the larger volume, higher residence time estuaries (or parts of estuaries) which dominate the US data set, whereas "benthic or seabed" indicators (e.g. macroalgal biomass, sediment TOC, redox potential and macroinvertebrates) are indicators best suited to shallow, short residence time estuaries but are generally not as strongly expressed because they are less dominant features. Consequently, the ASSETS indicators, but more especially the thresholds used in the trophic state assessment protocols, can severely underestimate eutrophication in typical NZ shallow estuaries. This primarily arises because ASSETS calculates the overall expression of primary trophic symptoms in any estuary by averaging scores for phytoplankton, macroalgae and epiphytes. To be valid for all estuaries, all three condition indicators need to have equal opportunity for expression in all estuary types. This is often not the case. In addition, the calculation of the secondary trophic symptoms rating ignores vital sediment indicator data relevant to NZ.
Therefore, in relation to the expression of eutrophic symptoms in NZ estuaries, there are two major examples where use of the ASSETS approach results in erroneous conclusions, as follows.

- **Shallow, Intertidal Dominated Estuaries.** Shallow, intertidal dominated, estuaries with very short residence times (<1 day), that typify many NZ tidal lagoon and river estuaries, have such short residence times that phytoplankton are generally flushed from the system as fast as they can grow, reducing the estuary's susceptibility to phytoplankton induced eutrophication, whatever the nutrient load. Instead, such estuaries respond to increasing nutrient loads by expressing sediment (rather than water column) related impacts, i.e. opportunistic macroalgal and epiphyte growths become the primary symptoms of eutrophication, along with sediment oxygenation, organic content and nutrients as secondary expressions. Applying an unmodified ASSETS approach to NZ estuaries that are expressing eutrophication symptoms (high macroalgal growth, surface RPD, muddy sulphide rich sediments, elevated nutrients, loss of seagrass, and a poor macroinvertebrate condition index), yet have low water column chlorophyll and elevated oxygen levels, results in a low or low/moderate rating of eutrophication symptoms, and a consequent underestimation of the actual trophic state.
- **Intermittently Closed/Open Lake and Lagoon Estuaries (ICOLLs).** Shallow estuaries with intermittently open/closed mouths, i.e. ICOLLs, follow a primary indicator sequence that includes rooted macrophytes (e.g. *Ruppia* spp.) that can extend throughout the water column and are very susceptible to increasing nutrient loads. According to the macrophyte-macroalgae and/or phytoplankton succession concept of Duarte (1995) in relation to increasing eutrophication:
    - **Oligotrophic** coastal lagoons correspond to transparent waters with a dominance of macrophytes with limited associated macroalgae.
    - **Mesotrophic** lagoons include macrophyte species (often climax species), but also proliferating macroalgae.
    - **Eutrophic** lagoons show a disappearance of macrophytes, but proliferating macroalgae can still be present.
    - **Hypertrophic** lagoons exhibit exclusive dominance by phytoplankton.

Applying an unmodified ASSETS approach to these latter estuary types ignores the condition of the keystone macrophyte beds, and hence the overall primary trophic condition rating is an average of phytoplankton, macroalgae and epiphyte ratings. A more realistic approach would be to include a rating for macrophyte presence.

In order to address these issues, it is therefore important that the approach taken for NZ estuaries adequately represents both the primary and secondary symptoms, by strongly weighting indicators chosen to represent estuary type, and does not artificially downplay severity through an inaccurate representation of irrelevant indicators or by ignoring relevant indicators.

In relation to the initial step of identifying indicators, a very relevant and comprehensive evaluation of various primary and secondary indicators for assessment of trophic state in California's small estuaries (which includes most NZ estuary types) has recently been undertaken (Sutula 2011). The evaluation was instigated because Californian estuaries, like NZ estuaries, are highly variable (e.g. physiographic setting, salinity regime, freshwater flows, tidal range, sediment load, stratification, depth, residence time) and therefore experience relative differences in the dominant primary producer communities (i.e. phytoplankton, macroalgae, benthic algae, macrophytes) and pathways for nutrient cycling within estuaries. This high variability makes the California estuary evaluation a useful foundation for development of a defensible list of condition indicators for the NZ ETI approach. The approach taken by Sutula (2011) was to identify the at-risk habitat throughout all the estuary types, and then to identify the trophic state indicators (both primary and supporting) for each of the habitat types.

Sutula (2011) identified four key habitat types across the basic elevation gradient of all California estuary types: emergent saltmarsh, unvegetated intertidal flats and unvegetated shallow subtidal areas, intertidal and subtidal aquatic macrophyte beds, and deepwater subtidal habitat. Of these four habitat types, emergent saltmarsh was generally considered to be the least sensitive to eutrophication, due to high rates of denitrification, increased oxygenation of sediments within the rooted zone of marsh plants, and daily exposure to air and sunlight in the high intertidal zone increasing the decomposition of organic matter. For these reasons, the California review focused on indicators in the unvegetated intertidal and subtidal habitats. Given the similarity to NZ estuary types, the ETI has adopted a similar approach.

Two types of indicators were designated in the California estuaries evaluation (Sutula 2011). **Primary indicators** for which regulatory endpoints should be developed are those which met all of four defined evaluation criteria: 1) strong linkages to beneficial uses; 2) well-vetted means of measurement; 3) ability to model the relationship between the indicator, nutrient loads and other management controls; and 4) acceptable signal to noise ratio for eutrophication assessment. **Supporting indicators** fell short of meeting evaluation criteria, but may be used as supporting lines of evidence, though establishment of Nutrient Numeric Endpoints (NNE) for these indicators is not envisioned in the near term. Appropriate indicators were also selected independently for estuarine class as well as habitat type. The chosen habitats and the relevant primary and secondary indicators for each are identified in Table A11.

Table A11. Summary of recommended primary and supporting indicators by ocean inlet status and habitat type for Californian estuaries (adapted from Sutula 2011).

Type	Habitat	Primary Symptom Indicators	Supporting Indicators
Open Estuaries	All Subtidal Habitat	Phytoplankton biomass and productivity Cyanobacteria cell counts and toxin conc.[1] Dissolved oxygen	Water column nutrient concentrations and forms[2] (C, N, P, Si) Phytoplankton assemblages; HAB species cell count and toxin concs; Macrobenthic taxonomic composition, abundance & biomass; Sediment C, N, P, S, particle size (and ratios therein) and degree of pyritization
	Seagrass and Brackish SAV Habitat	Phytoplankton biomass and productivity Macroalgal biomass & cover	Light attenuation; suspended sediment concs. or turbidity; Seagrass areal distribution, % cover, density; Epiphyte load; Brackish SAV areal distribution, % cover, biomass
	Intertidal Flats	Macroalgal biomass and cover[3]	Sediment % OC, N, P, S, particle size, degree of pyritization; Microphytobenthic taxonomic composition, benthic chl a
Closed ICOLLs	All Subtidal Habitat	Phytoplankton biomass and productivity Cyanobacteria cell counts and toxin conc. Dissolved oxygen Rafting or floating macroalgae biomass and % cover	Sediment % OC, N, P, S, particle size, degree of pyritization; Microphytobenthic taxonomic composition, benthic chl a; Phytoplankton assemblages, including HAB species cell count and toxin concs; Sediment C, N, P, S, particle size (and ratios therein) and degree of pyritization; Microphytobenthos taxonomic composition and benthic chl a biomass; Water column nutrient concentrations and forms[2] (C, N, P, Si)
	Brackish SAV	Phytoplankton biomass and productivity Macroalgal biomass & cover Dissolved oxygen	Light attenuation, suspended sediment conc. Epiphyte load Brackish SAV areal distribution, % cover, biomass

[1] *Note that cyanobacteria cell counts and toxin concentrations are included for polyhaline and euhaline habitats in an attempt to capture effects of cyanobacteria blooms transported from freshwater and oligohaline environments.*
[2] *Forms referred to relative distribution of dissolved inorganic, dissolved organic, and particulate forms of nutrients, including urea and ammonium.*
[3] *Not an ideal indicator for sandy intertidal flats. Recommend the inclusion of microphytobenthos, though factors controlling biomass not understood and little known about taxonomy as an indicator of disturbance gradient.*

TOOL 2: APPENDIX 7. BACKGROUND TO CHOOSING ECOLOGICAL RESPONSE INDICATORS (CONTINUED)

7.2 RECOMMENDED PRIMARY AND SECONDARY (SUPPORTING) INDICATORS FOR NZ ESTUARIES

The recommended approach for trophic assessment of NZ estuaries is to focus on indicators in the unvegetated intertidal and subtidal habitats (Figure A9) (as was followed in the California estuaries approach, Table A11), and to include only those indicators that are proven relevant to the eutrophication process, i.e. indicators of nutrient enrichment, algal growth, balanced ecology, and water and sediment quality degradation.

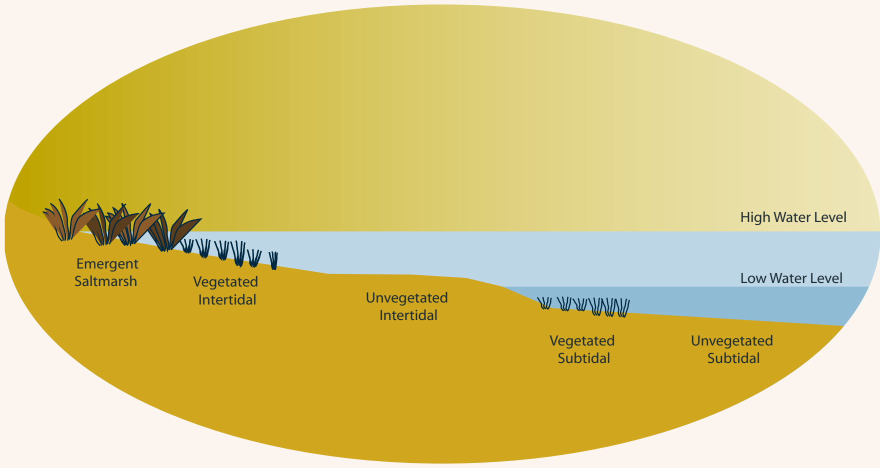


Figure A9. Typical estuarine habitats in NZ.

In addition, because the relative dominance of each of the primary producer groups (phytoplankton, macroalgae, microphytobenthos, and aquatic macrophytes) are controlled by a suite of factors (e.g. light, depth, temperature, desiccation, currents, grazing, nutrients, and organic matter) that affect each group differently, the ETI has adopted a “horses for courses” or type characterisation approach rather than the less robust “one size fits all” approach. The approach is summarised as follows:

Moderately Deep to Deep, Subtidal Dominated Estuaries or Parts of Estuaries

Includes fiords, sounds and some coastal embayments.

- Phytoplankton tend to dominate and become excessive at elevated nutrient concentrations in these deeper and/or turbid estuaries with longer residence times (weeks or months rather than days), or co-dominate with microphytobenthos in deepwater habitats with high water clarity (Day et al. 1989, Wetzel 2001).
- Bottom water oxygen depletion may be occurring (e.g. Milford Sound, Firth of Thames).
- Chlorophyll a, cyanobacteria counts, and dissolved oxygen are the major primary indicators.
- Sediment supporting indicators (e.g. TOC, TN, TP, TS, and grain size) are optional in such estuaries, given the vulnerability to bottom water oxygen depletion. Instead, the supporting indicators could include information on the phytoplankton assemblage (including cell counts of harmful species and toxin concentrations if appropriate).

Shallow to Moderately Deep, Subtidal Dominated Estuaries or Parts of Estuaries

Includes some tidal lagoons, some tidal rivers, some coastal embayments, and ICOLLs when closed.

- Phytoplankton and macroalgae (if water clarity is sufficient) tend to dominate and become excessive at elevated nutrient concentrations in these shallow to moderately deep, subtidal dominated estuaries (or parts of estuaries).
- Bottom water oxygen depletion is rare (e.g. Otago Harbour, or Waituna Lagoon when closed).
- Chlorophyll a, cyanobacteria counts, and macroalgal indices are the major primary indicators.
- Because the organic load (i.e. decaying algae) can cause sediment impacts, the supporting indicators are sediment related and include macroinvertebrate indices, TOC, TN, TP, TS, and grain size. Where macrophytes (e.g. seagrass) are naturally present in an estuary, macrophyte indices (e.g. biomass, density, % cover) are included as supporting indicators.

Shallow, Intertidal Dominated Estuaries

Includes some tidal lagoons, ICOLLs when open, some parts of tidal rivers (e.g. tidal river plus lagoon)

- Macroalgae tend to dominate and become excessive at elevated nutrient concentrations in these shallow, intertidal dominated estuaries (or parts of estuaries).
- Bottom water oxygen depletion is rare (e.g. Avon-Heathcote and New River estuaries).
- Macroalgal indices (biomass, cover, entrainment) are the major primary indicators.
- Because the organic load can cause sediment impacts, the supporting indicators are sediment related and include macroinvertebrate indices, TOC, TN, TP, TS, and grain size. Where macrophytes (e.g. seagrass) are naturally present in an estuary, macrophyte indices (e.g. biomass, density, % cover) are included as supporting indicators.

In summary, many methods have been developed in the world to assess estuary eutrophication and allow regulatory authorities to meet statutory requirements (e.g. to monitor and protect estuaries from degradation). These methods demonstrate that the eutrophication gradient is well understood and that the immediate biological response is increased primary production reflected as increased chlorophyll a and/or macroalgal abundance, which is often accompanied by secondary symptoms within both the water column and sediments. As a result, most methods include both primary and supporting indicators to provide the best possible evaluation of the nutrient related quality of the water body (Borja et al. 2012; Devlin et al. 2011, Sutula 2011).

The ETI has selected indicators that show a direct or indirect gradient of water and/or sediment quality impairment in response to a matching gradient of nutrient loads or concentrations. Wherever possible, data from NZ estuary examples have been used to support the choice of indicators and their target thresholds. For example, data are available for NZ's dominant estuary type i.e. shallow intertidal dominated estuaries, which demonstrate a strong stressor/primary response relationship (i.e. N load/macroalgal response, see Tool 1 Appendix 4), that is indirectly linked to secondary indicator responses (e.g. sediment RPD, TOC, TN, macroinvertebrates).

In general, the eutrophication indicators have been developed from the lists of indicators and thresholds derived from previous studies, with others that are more relevant being added to the list. Table A12 below provides a summary of the chosen indicators and the habitats in which they should be used in NZ.

Table A12. Summary of primary and supporting indicators for screening estuary eutrophication and habitat types in NZ.

Type	Habitat	Indicators
Intermittently closed/ open lakes and lagoons (ICOLL) estuaries	Closed ICOLLs. Shallow Subtidal and Intertidal habitat	**Primary Symptoms**; Macroalgae, phytoplankton biomass (chl. a), cyanobacteria **Supporting Indicators**; Dissolved oxygen, macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size, pH, water clarity, seagrass, epiphyte load, brackish submerged aquatic vegetation (SAV), water column N and P.
	Mainly Open ICOLLs	Follow SSRTRE approach.
Shallow intertidal dominated (SIDE) estuaries	Shallow intertidal habitat	**Primary Symptoms**; Macroalgae **Supporting Indicators**; Macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size, seagrass.
Shallow, short residence time tidal river and tidal river with adjoining lagoon (SSRTRE) estuaries.	Shallow intertidal habitat	**Primary Symptoms**; Macroalgae **Supporting Indicators**; Macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size, seagrass.
	Shallow - Moderately Deep habitat	**Primary Symptoms**; Macroalgae, phytoplankton biomass (chl. a), cyanobacteria, **Supporting Indicators**; Dissolved oxygen, water clarity, seagrass, epiphyte load.
Deeper subtidal dominated, longer residence time (DSDE) estuaries	Moderately Deep to Deep habitat	**Primary Symptoms**; Phytoplankton biomass (chl. a), cyanobacteria **Supporting Indicators**; Dissolved oxygen, water column nutrient concentrations (TN), phytoplankton assemblages especially HAB species cell count and toxin concentrations. Sediment phys. chem indicators optional.
	Shallow - Moderately Deep habitat	**Primary Symptoms**; Macroalgae, phytoplankton biomass (chl. a), cyanobacteria **Supporting Indicators**; Dissolved oxygen, water clarity, seagrass, epiphyte load, macroinvertebrates, sediment redox potential, total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), sulphides, particle size.

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS

8.1 PHYTOPLANKTON (PRIMARY SYMPTOM)

ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE RATINGS

- **Europe - WFD approach for Basque estuaries -** (Revilla et al. 2010). 90th percentile of chl. a (ug/l):

  Euhaline: Poor >12, Moderate 8-12, Good 4-8, High 2.67-4, Reference <2.67.

  Oligo/Meso/Polyhaline: Poor >16, Moderate 12-16, Good 8-12, High 5.33-8, Reference <5.33.
- **Europe - WFD approach for Basque estuaries -** (Borja et al. 2004). Chlorophyll a (quarterly sampling data) (ug/l): ratings are for number of events in 5 years that exceed 16ug/l; very low <4, low, 4-10, moderate 11-20, high 20-30, very high >30.
- **Europe - WFD -** Cantabrian coast, Basque Country (Ferriera et al. 2011): Summer chlorophyll a concentration mean. Bad >14, Poor 10.5-14, Moderate 7- 10.5, Good 3.5-7, High 0-3.5.
- **US EPA NCA** (USEPA 2005, 2008). Poor >20; Fair 5-20, Good 0-5; lower for sensitive systems.
- **IFREMER (lagoons) France** (Ferriera et al. 2011): Mean annual chl. a concentrations: >30 Red; 10-30 Orange; 7-10 Yellow; 5-7 Green; 0-5 Blue.
- **US - ASSETS Approach,** (Bricker et al. 1999). Maximum values observed over a typical annual cycle.

  Hypereutrophic (>60µg chl. a/l), High (>20, ≤60), Medium (>5, ≤20), Low (>0, ≤5).

  Ratings: Hyperteutrophic = 4, High = 3, Medium = 2, Low = 1.
- USEPA propose a chlorophyll a concentration of 20µg/L as the water quality target to define a nuisance algal bloom. Thus, estuarine waters with chlorophyll a concentrations that exceed this water quality target threshold are indicative of imbalanced populations of aquatic flora and fauna (more detail regarding EPA's analysis can be found in the TSD, Volume 1: Estuaries, Section 1.2.2). EPA also considered the available scientific research described in this section to establish an allowable frequency of occurrence of phytoplankton blooms, represented by chlorophyll a levels greater than 20µg/L, to further define this endpoint measure. EPA propose a value of 10% as an allowable frequency of occurrence of phytoplankton blooms, that is, chlorophyll a measurements may not exceed 20µg/L more than 10% of the time.
- Guidelines for Chesapeake Bay were derived for sensitive deep water/long residence time systems subject to anoxia and pH depression based on the evidence that severe degradation in Chesapeake Bay is accompanied by mean chlorophyll a levels in its mesohaline reaches of about 8mg chlorophyll a m^{-3} (Kemp et al. 2005).
- As a consequence, restoration targets ranging from 2.2 to 8.7mg chlorophyll a m-3 (depending on season and river flow) have been recommended (Harding et al. 2014)
- It is likely that the physiography of Chesapeake Bay renders it susceptible to blooms, and its similarity in that regard with the Firth of Thames (subject to stratification) implies that the Firth of Thames may be susceptible as well (J. Zeldis, pers. comm. 2015).

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS (CONTINUED)

8.2 OPPORTUNISTIC MACROALGAE (PRIMARY SYMPTOM)

ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE RATINGS

1. US - ASSETS Approach - (Bricker et al. 2007).
The ASSETS approach is relatively simple, but lacks standard methods and fails to differentiate between abundance and magnitude of bloom patches, species composition (including sediment-entrained algae) and ecological response.
ASSETS Rating:

- High = periodic or persistent macroalgal bloom problems have been observed,
- Moderate = episodic macroalgal bloom problems have been observed,
- Low = no macroalgal problems observed.
- Definitions; Frequency of problem: Episodic (occasional/random); Periodic (seasonal, annual, predictable); Persistent (always/continuous).

2. UK - Water Framework Directive (WFD) Approach (2014).
The WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group, 2014) approach for opportunistic macroalgal condition is a relatively comprehensive rating tool that is currently used on NZ estuaries and is recommended for use in the ETI. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries. It considers composition, macroalgal cover, biomass, and entrainment and disturbance-sensitive taxa. The OMBT is a comprehensive 5 part multimetric index described below. It allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. Details of the approach are well-described in WFD-UKTAG (2014) but, in order to enable user understanding and uptake, are included in this section as well.
A key component of the OMBT approach is the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of mud, muddy sand, sandy mud, sand, stony mud and mussel beds. Areas which are judged unsuitable for algal blooms, e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH.
The 5 components of the index are as follows:

1. **Percentage cover of the available intertidal habitat (AIH).** The percent cover of opportunistic macroalgal within the AIH is assessed, generally through visual rating by experienced ecologists, with independent validation of results. All areas within the AIH where macroalgal cover >5% are mapped spatially. In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric was established. This is the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worst case scenario.
2. **Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH, %).**
3. **Biomass of AIH ($g.m^{-2}$).** Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the affected areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within +/- 5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.
4. **Biomass of AA ($g.m^{-2}$).** Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.
5. **Presence of Entrained Algae (percentage of quadrats).** Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for overwintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool.

All the metrics are equally weighted and combined within the multimetric, in order to best describe the changes in the nature and degree of opportunist macroalgae growth on sedimentary shores due to nutrient pressure.

8.2 OPPORTUNISTIC MACROALGAE (PRIMARY SYMPTOM - CONTINUED)

Suitable Locations

- **Estuaries (Intertidal).** The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). It can also be used in shallow subtidal waters using appropriate sampling methodologies and by including this area as available habitat.
- **ICOLLs**. The tool methods can be used for assessing ICOLLs, however due to a lack of data for setting suitable reference (natural) conditions, and macroalgae/ecological impacts relationships (e.g. loss of macrophytes) the rating component of the tool is currently inappropriate for ICOLLs. Instead, an alternative rating approach is provided for screening NZ ICOLLs in the ETI.

Timing. The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in spring-summer (Oct-March), although peak timing may vary among water bodies, therefore local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the spring-summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification; e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling is best carried out during spring low tides in order to access the maximum area of the AIH.

Derivation of Threshold Values.
Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A13).

- **Reference Thresholds.** A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this adverse effects were not seen, so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning.
  The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g.m^{-2} wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed.
  An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for unimpacted waters. After some empirical testing in a number of UK water bodies a High/Good boundary of 1% of quadrats was set.
- **Class Thresholds for Percent Cover**
  High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.
  Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).
  Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Wells et al. 2010).
- **Class Thresholds for Biomass.** Class boundaries for biomass values were derived from DETR (2001) recommendations that <500g.m^{-2} wet weight was an acceptable level above the reference level of <100g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500g.m^{-2} represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500g.m^{-2} but less than 1,000g.m^{-2} would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1000g.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).
- **Thresholds for Entrained Algae**: Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (macroalgae growing >3cm within sediments) (Poor/Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High/Good standard of 1% was selected (this allows for the odd change quadrat or error to be made). Consequently the Good/Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over-wintering had started.

8.2 OPPORTUNISTIC MACROALGAE (PRIMARY SYMPTOM - CONTINUED)

EQR Calculation. Each metric in the OMBT has equal weighting and is combined to produce the Ecological Quality Rating score (EQR) (Table A13).

Table A13. The final face value thresholds and metrics for levels of the ecological quality status.

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass ($g.m^2$ wet weight) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass ($g.m^2$ wet weight) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status as in Table A13. The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:
   - Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 - where Total % cover = Sum of {(patch size) / 100} x average % cover for patch
   - Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)
   - Biomass of AIH ($g.m^{-2}$) = Total biomass / AIH - where Total biomass = Sum of (patch size x average biomass for the patch)
   - Biomass of Affected Area ($g.m^{-2}$) = Total biomass / AA - where Total biomass = Sum of (patch size x average biomass for the patch)
   - Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
   - Size of AA in relation to AIH (%) = (AA/AIH) x 100
2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A14).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

*Final Equidistant Index score = Upper Equidistant range value – ({Face Value - Upper Face value range} * (Equidistant class range / Face Value Class Range)).*

Table A14 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range.
Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.
The final EQR score is calculated as the average of equidistant metric scores.
A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores, as is a methodology for calculating the statistical uncertainty of the ratings produced by the OMBT.

ADDITIONAL SUPPORTING INFORMATION FOR SETTING THRESHOLDS

In addition to the above international thresholds, numeric macroalgal thresholds for NZ estuaries, including ICOLLs, are based on the following assumptions.

- Blooms of rapidly growing macroalgae can have deleterious effects on intertidal and shallow subtidal communities, and cause an undesirable imbalance with effects such as: blanketing of the surface causing a hostile physico-chemical environment in the underlying sediment, sulphide poisoning of infaunal species, anoxic gradient at the water sediment interface, effects on birds including changes in the feeding behaviour of waders, smothering of seagrass beds - (Duarte 1995, Taylor et al. 1995, Valiella et al. 1997, Sutula et al 2012), excessive algal growths, or rafts of floating or detached weed causing interference with water users, aesthetic effects such as nuisance odours, or deposition in bathing waters. Where excessive macroalgae cause extreme sediment anoxia (measured by redox potential) there is an accompanying exclusion of normal communities of benthic macrofauna (e.g. Grizzle and Penniman 1991); increased production of sulphides which can be toxic to rooted macrophytes (Lamers et al. 2013, Holmer and Bondgaard 2001, Viaroli et al. 2008, Geurts et al. 2009, Green et al. 2014), and release of dissolved phosphorus and ammonium that exacerbate eutrophication (e.g. Søndergaard et al. 2003).

8.2 OPPORTUNISTIC MACROALGAE (PRIMARY SYMPTOM - CONTINUED)

Table A14. Values for the normalisation and re-scaling of face values to EQR metric.

METRIC	QUALITY STATUS	FACE VALUE RANGES			EQUIDISTANT CLASS RANGE VALUES		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH ($g.m^{-2}$ wet weight)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) ($g.m^{-2}$ wet weight)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

- Zones of extreme sediment degradation, called "Gross Nuisance Areas (GNAs)", are currently used as an indicator of excessive opportunistic macroalgae (including epiphytes) that are associated with anoxic sediment (Robertson and Stevens 2013). Such findings are supported by widespread monitoring of NZ shallow estuaries which indicate that excessive macroalgal cover in poorly flushed parts of these estuaries can result in GNAs (i.e. combined conditions of high mud content, surface sediment anoxia, elevated organic matter and nutrient concentrations, an imbalanced benthic invertebrate community and seagrass dieoff (Robertson and Stevens 2013, 2013a). Similar GNAs occur in shallow coastal lagoons or ICOLLs where conditions are not too turbid e.g. Waituna Lagoon. As a consequence, the use of macroalgal abundance as a trophic state indicator must be used alongside other supporting indicators, such as mud content and RPD (e.g. Sutula et al. 2012) in order to accurately predict the trophic status of such estuaries. The presence of persistent and extensive areas of GNAs in estuaries, however, provides a clear signal that the assimilative capacity of the estuary is being exceeded.
- For ICOLLs, an increase in the cover of macroalgae is often the first indication of macrophyte collapse in ICOLLs (Viaroli et al. 2008, WLTG 2012).
- In a survey of eight Californian tidal lagoon estuaries (including some ICOLLs) by Sutula et al. (2014) found that macroalgae of $175g.m^{-2}$dw ($1450g.m^{-2}$ ww), total organic carbon of 1.1% , and sediment TN of 0.1% were thresholds associated with anoxic conditions near the surface (RPD <1cm).
- In two Californian estuaries, macroalgal abundances as low as $110\text{-}120g.m^{-2}$ dw (or $840\text{-}930g.m^{-2}$ ww) had significant and rapid negative effects on benthic invertebrate abundance (declining by >67%) and species richness (declining by >19%) within two weeks at most sites (Green et al. 2014).

8.2 OPPORTUNISTIC MACROALGAE (PRIMARY SYMPTOM - CONTINUED)

- An effects threshold of 500-1000g.m^{-2} ww (wet weight per square metre) was proposed by Scanlan et al. (2007) to avoid effects on benthic macrofauna in estuaries, but the authors emphasised that the proposed thresholds required further validation. McLaughlin et al. (2013) reviewed and tested the biomass thresholds proposed by Scanlan et al. (2007) and considered them reasonable for application to Southern Californian ICOLLs. For example, the review found elimination of surface deposit feeders when macroalgal biomass was in the range of 700-800g.m^{-2} ww.
- In some situations it is possible for macroalgae to continue growth after being covered by sediment (i.e. entrainment) (WFD UK TAG 2014).
- A review of monitoring data from 25 typical NZ estuaries (shallow, short residence time estuaries) supports an opportunistic macroalgal biomass "exhaustion" threshold of approximately 1000-2000g.m^{-2} ww above which there was a major shift in the chemistry of the underlying sediment to surface anoxia (RPD at the surface), elevated TOC (>1.5%) and a degraded macrofaunal community (Wriggle Coastal Management database 2009-2014). Such conditions have been used to identify GNAs. Based on the measured detrimental impact on macrofauna in NZ tidal lagoons, it has been estimated that if GNAs cover >15% of the estuary area or >30ha, then estuary ecological condition is seriously impaired.
- Waituna Lagoon, a NZ ICOLL, was estimated to have a mean macroalgal biomass of 800-1000g.m^{-2} ww when the lagoon was showing signs of gross eutrophication (RPD at surface) and a degraded seagrass community. At 100-300g.m^{-2} ww the seagrass community was maintained with moderately low levels of stress (Hamilton et al. 2012).

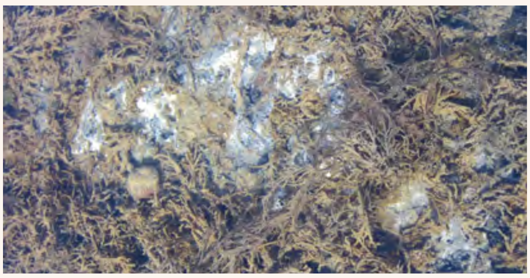
ICOLL THRESHOLDS

Literature indicates that where macroalgal growth is excessive in estuaries (mainly shallow tidal lagoon estuaries), sediment anoxia almost always occurs (e.g. Robertson and Stevens 2012, 2013, Sutula et al. 2014) and is accompanied by a degraded macrofaunal community. Due to the similarities between ICOLLs and permanently open tidal lagoon estuaries (e.g. keystone species are seagrass in both estuary types), it is expected that a similar, if not more extreme, response to excessive macroalgae occurs in shallow ICOLLs. ICOLLs are likely to be more sensitive to macroalgal cover than estuaries because the macroalgal cover tends to occur sub-tidally rather than in intertidal areas. Consequently, subtidal dissolved oxygen concentrations in decaying beds, and in underlying sediments, are likely to be reduced, giving rise to a more degraded macrofaunal community and higher levels of physiological stress to seagrass beds in the ICOLLs as compared to the intertidal habitat. Also such conditions in lagoons can reduce denitrification and enhance sediment P release, leading to build-up of P in the overlying water column. Consequently, the macroalgae ratings derived from effects on estuaries have been adjusted to account for the greater sensitivity of ICOLLs and brackish lakes.

Moutere Inlet 2015: dense macroalgae (>3000g.m^{-2}. ww) and anoxic muds in upper estuary

Jacobs River Estuary 2013: dense macroalgae (>5000g.m^{-2}. ww), and soft anoxic muds in upper estuary

Papanui Inlet: sea lettuce blooms in main estuary basin



New River Estuary 2013: dense macroalgae (>3000g.m^{-2}. ww) and surface anoxia plus *Beggiatoa* mats

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS (CONTINUED)

8.3 CYANOBACTERIA (PRIMARY SYMPTOM)

ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE RATINGS

For cyanobacteria cell counts and toxins concentrations, international and national guidelines exist to establish thresholds in fresh water habitats, based on human and faunal exposure to toxin concentrations. However, the applicability of these endpoints have yet to be examined for translation to estuarine habitats. In the interim, if toxic cyanobacteria are present, additional monitoring and issue evaluation of potential impacts should be undertaken, and guidance on cyanobacteria response thresholds for estuaries be sought from available national and international freshwater guidelines.

The World Health Organization (WHO) Guidelines for Drinking-water Quality (WHO 1993, 1996) features guidelines for cyanobacteria cell counts, toxin concentrations and chlorophyll-a representative of safe levels for primary contact (Table A15). These WHO guidelines represent a scientific consensus, based on very broad international participation, of the health risks to humans presented by cyanobacteria but does not necessarily reflect an adequate protection level for aquatic organisms.

Table A15. Thresholds associated with risks from human exposure to cyanobacterial blooms in recreational or drinking waters (from WHO 1996).

Probability of health effect	Cyanobacterial Cell Counts	Expected Toxin Concentration	Chlorophyll-a (µg L-1)
Low	20,000 cells per ml	2-4µg/l (concs up to 10 in highly toxic blooms)	<10
Moderate	100,000 cells per ml	50 ug/l	<50

In New Zealand, the Ministry of Health and the Ministry for the Environment have set standards and provide guidelines for monitoring cyanobacteria and their toxins in drinking water and recreational areas. Provisional maximum allowable values are provided for 7 cyanotoxins in Drinking Water Standards for New Zealand. When cyanotoxin concentrations in drinking water rise above 50% PMAV, monitoring twice a week is required to ensure these levels do not fluctuate above the PMAV (Ministry of Health, 2008).

The New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters (Ministry for the Environment and Ministry of Health, 2009) provides thresholds of potential toxicity (green, amber, and red modes) for both phytoplanktonic and benthic forms of cyanobacteria.

Cyanobacterial (or blue-green algal) bloom in Florida.

Cyanobacteria are a naturally occurring part of the food chain. Although they are most closely related to bacteria, they contain chlorophyll and depend on sunlight to grow, like plants. They can be found all over the world, and occur in New Zealand's freshwater and brackish habitats, such as lakes, rivers and estuaries. Some, but not all, blue-green algae can produce toxins that can contribute to environmental problems and affect public health. Scientists know little about what causes the algae to produce these toxins. Even those blue-green algae that are known to produce toxins do not always do so. Many countries monitor blue-green algae closely because excessive nutrients (such as nitrogen and phosphorus) appear to intensify blue-green algae outbreaks.

8.4 WATER COLUMN DISSOLVED OXYGEN (SUPPORTING INDICATOR)

ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE RATINGS

- **US - ASSETS Approach,** Bricker et al. (1999) mg/l: Very Poor (Anoxia) (0mg/l), Poor (Hypoxia) (>0 ≤2mg/l), Fair (Biological Stress) (>2 ≤5mg/l), Low (>5mg/l).
- **OSPAR (2009) Approach,** Decreased levels (<2mg/l: acute toxicity; 4-6mg/l: deficiency causing biological stress, >6mg/l: low stress and lowered % oxygen saturation.
- **US Estuary Standards,** (USEPA 2000). To support the maintenance of aquatic life in Florida's estuaries the requirements are an instantaneous DO concentration of 4.0mg/L, a daily average DO concentration of 5.0mg/L, and a bottom water average DO concentration of 1.5mg/L. Both the instantaneous minimum of 4.0mg/L and the daily average of 5.0mg/L are spatial averages over the water column for each estuarine segment.
- **ANZECC,** (2000). No DO criteria for NZ estuaries but recommends the use of interim trigger values for south-east Australian estuarine systems, i.e. risk of adverse ecological effects if <80% saturation and >110% saturation.
- **NZ- National Objectives Framework (NOF) for Rivers,** (Davies-Colley et al. 2013). Proposed NOF limits for dissolved oxygen regime in rivers and streams have been developed (Table A16) but are inappropriate for direct application to estuaries because the solubility of oxygen in water is reduced when salinity increases. This means that an oxygen saturated seawater sample will contain less oxygen than a saturated freshwater sample at the same temperature and barometric pressure. For example, at 25 degrees C, freshwater dissolves up to 8.3mg/L of oxygen, while seawater dissolves only 6.6mg/L of oxygen.

Table A16. Proposed National Objectives Framework thresholds for dissolved oxygen regime in rivers and streams.

Band	A	B	C	D
7 day mean	≥9.0 mg/l	≥8.0 mg/l	≥6.5 mg/l	<6.5 mg/l
7 day mean minimum	≥8.0 mg/l	≥7.0 mg/l	≥5.0 mg/l	<5.0 mg/l
1 day minimum	≥7.5 mg/l	≥5.0 mg/l	≥4.0 mg/l	<4.0 mg/l
Ecological Quality	No stress caused by low dissolved oxygen on any aquatic organisms that are present at near-pristine sites.	Occasional minor stress on sensitive organisms caused by short periods (a few hours each day) of lower dissolved oxygen. Risk of reduced abundance of sensitive fish and macroinvertebrate species.	Moderate stress on a number of aquatic organisms caused by dissolved oxygen levels exceeding preference levels for periods of several hours each day. Risk of sensitive fish and macroinvertebrate species being lost.	Significant, persistent stress on a range of aquatic organisms caused by dissolved oxygen exceeding tolerance levels. Likelihood of local extinctions of keystone species and loss of ecological integrity.

- **California EPA,** (Sutula et al. 2012). A recent review of the science supporting dissolved oxygen criteria for California estuaries recommended use of the criteria that represent broad estuary types presented in Table A17.

Table A17. Dissolved oxygen criteria for California estuaries.

Risk Level	CMC* (acute value)	CCC** (chronic value)
All Estuaries	4.0	5.8
All Estuaries (salmonids present)	4.0	6.3
ICOLLs	2.3	5.8

* The Criteria Maximum Concentration (CMC) is an estimate of the lowest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect.
** The Criterion Continuous Concentration (CCC) is an estimate of the concentration (in this case the lowest) of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

A meta-analysis undertaken by Vaquer-Sunyer and Duarte (2008) highlighted differences in oxygen thresholds for hypoxia across taxa, and questioned widespread use of the 2mg O_2 L^{-1} threshold in conventional applications, showing it to be below the empirical sublethal and lethal O_2 thresholds for half the species tested. They recommended its upward revision to 4.6 mg O_2 L^{-1} as 'a precautionary limit to avoid catastrophic mortality events, except for the most sensitive (e.g. crab) species, and to effectively preserve biodiversity'.

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS (CONTINUED)

8.5 SEDIMENT ORGANIC MATTER (TOC) AND NUTRIENTS (TN AND TP) (SUPPORTING INDICATORS)

ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE RATINGS

In relation to the ecological impacts associated with elevated TOC in estuaries, there have been several relevant studies.

- Hyland et al. (2005) expanded upon the Pearson and Rosenberg (1978) model (which describes benthic community response along an organic enrichment gradient) by using it for defining lower and upper thresholds in TOC concentrations corresponding to low versus high levels of benthic species richness in samples from seven coastal regions of the world. Specifically, it was shown that risks of reduced macrobenthic species richness from organic loading and other associated stressors in sediments should, in general, be relatively low where TOC values were <1%, and relatively high where values were >3.5%. However, because TOC is not a direct measure of the sediment factors that macrobenthos is likely being affected by, it was anticipated that these TOC thresholds should serve as a general screening-level indicator of ecological stress in the benthos from related factors (i.e. a supporting indicator). Such factors may include high levels of ammonium and sulphide, or low levels of dissolved oxygen associated with the decomposition of organic matter, or the presence of chemical contaminants co-varying with TOC in relation to a common controlling factor such as sediment particle size.
- A review of monitoring data from 25 typical NZ estuaries (shallow, intertidal dominated) (Wriggle database 2009-2014) confirmed a “high” risk of reduced macrobenthic species richness when TOC values were >2% and a “very high” risk at >3.5% (this last value is more tentative given the low number of data-points beyond this TOC concentration) (Figure A10). This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of TOC content, Figure A11) by the increasing dissimilarity in the macrobenthic community as TOC concentrations increase above 2%.

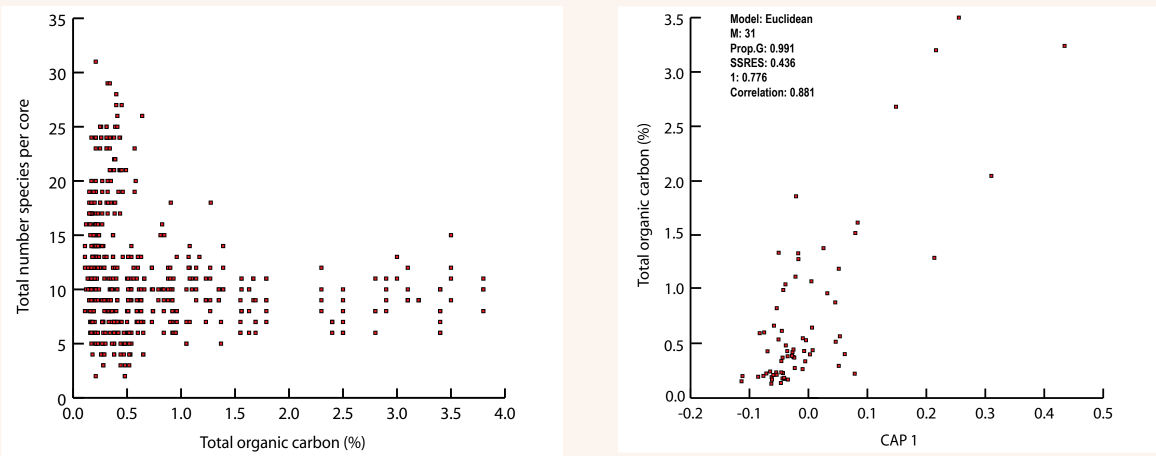


Figure A10. Left; Sediment TOC and macroinvertebrate species number from 12 NZ shallow, intertidal dominated estuaries (Wriggle database 2009-14). Right; Canonical analysis of the principal coordinates (CAP) for the effect of TOC on macroinvertebrate assemblages.

Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.

- Analysis of TOC sediment data collected in EMAP-Virginian Province Study indicated that TOC values in the 1 to 3% range were associated with impacted benthic communities, while values less than 1% were not (Paul et al. 1999).
- Recently, Sutula et al. (2014) established ecological response thresholds for TOC, TN, aRPD, %mud and macroalgal biomass using data from intertidal areas in 8 Southern California shallow, bar-built estuaries. Ranges of 25-125g.m^{-2} ww macroalgae, 0.4–0.7% TOC and 500-700mg.kg^{-1} TN were identified as transition zones from reference conditions across these estuaries. Ranges of 1450g.m^{-2} ww macroalgae, 1.1% TOC and 1000mg.kg^{-1} TN were identified as thresholds associated with a shallowing of aRPD to near zero depths. As an indicator of ecosystem condition, shallow aRPD has been related to reduced volume and quality for benthic infauna and alteration in community structure. These effects have been linked to reduced availability of forage for fish, birds and other invertebrates, as well as to undesirable changes in biogeochemical cycling.
- Magni et al. (2009) confirmed a high risk of reduced macrobenthic species richness for Mediterranean coastal lagoons when TOC values were >2.8%.

8.5 SEDIMENT ORGANIC MATTER (TOC) AND NUTRIENTS (TN AND TP) (SUPPORTING INDICATORS - CONTINUED)

- A review of monitoring data from 14 typical NZ SIDE estuaries (Wriggle database 2009-2014) confirmed a “high” risk of elevated TOC values (>2%) when macroalgal biomass (wet weight) was greater than 4000g.m^{-2} (Figure A11 left). Figure A11 (right) provides data for 5 NZ SSRTRE estuaries which supports the typical low macroalgal biomass and sediment TOC concentrations at representative sites in these estuaries (unless the estuary has extensive areas of hard substrate, like the Hutt Estuary).

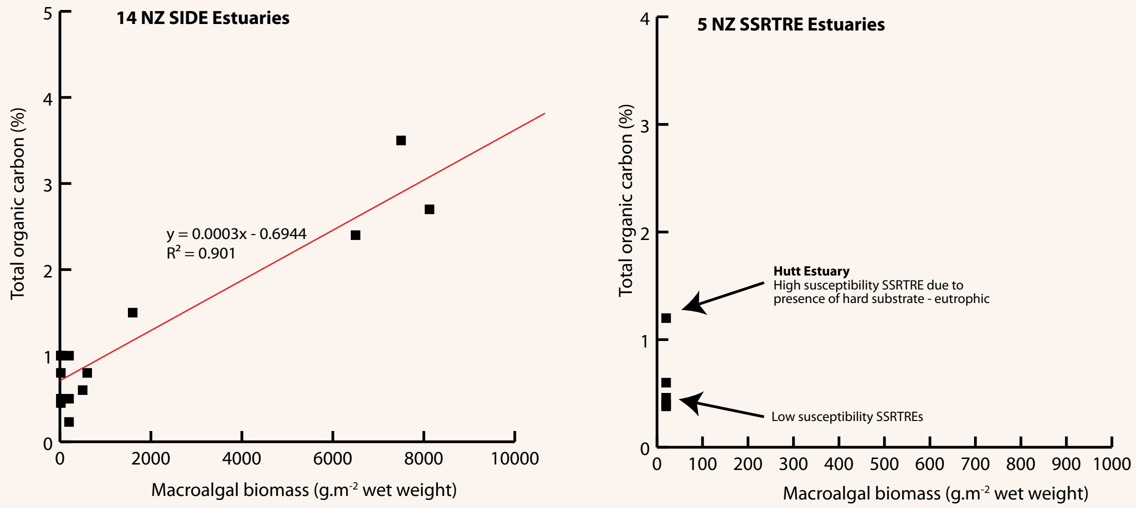


Figure A11. Left: Macroalgal biomass and sediment TOC concentrations from high susceptibility deposition zones of 14 typical NZ SIDEs estuaries (left graph) and 5 SSRTRE estuaries (right graph) **(Wriggle database 2009-2014).**

- Data from 12 estuaries scattered throughout NZ, and representing most NZ estuary types, were reviewed in relation to sediment TOC and nutrients (Figure A12). Total nitrogen (TN) was found to be very strongly correlated with TOC (r^2 =0.90). Total phosphorus (TP) was less strongly correlated (r^2 =0.68) (Figure A12).

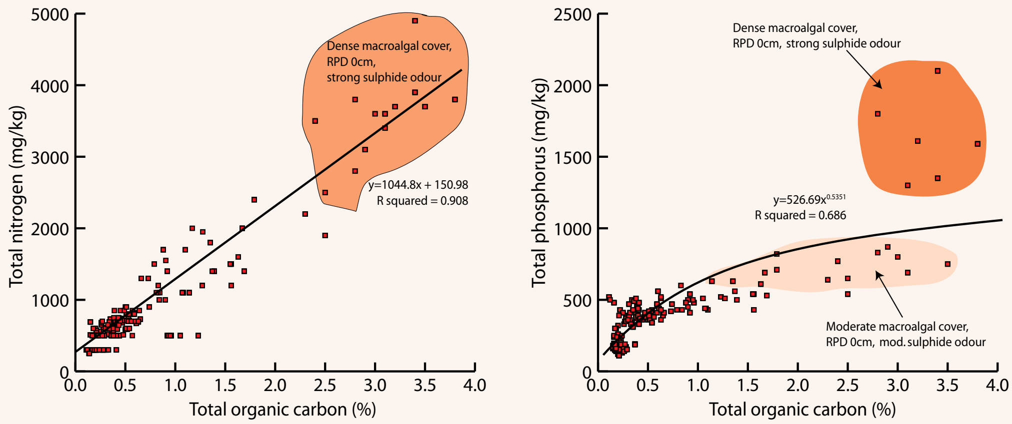


Figure A12. Sediment TOC and TN, and sediment TOC and TP concentrations from 12 estuaries scattered throughout NZ, and representing most NZ estuary types **(Wriggle Coastal Management database 2009-2013).**

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS (CONTINUED)

8.6 SEDIMENT REDOX POTENTIAL AND RPD (SUPPORTING INDICATORS)

ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE INFORMATION

- Pearson and Rosenberg (1978) developed a useful organic enrichment tool that indicates the likely benthic macrofauna community supported at a particular site based on the measured RPD depth (see Figure A13 for summary). This tool has been used extensively to date, in a multi-indicator approach, to help successfully interpret intertidal monitoring data and its relationship to organic enrichment in NZ estuaries (Wriggle Coastal Management estuary reports 2002-2015).

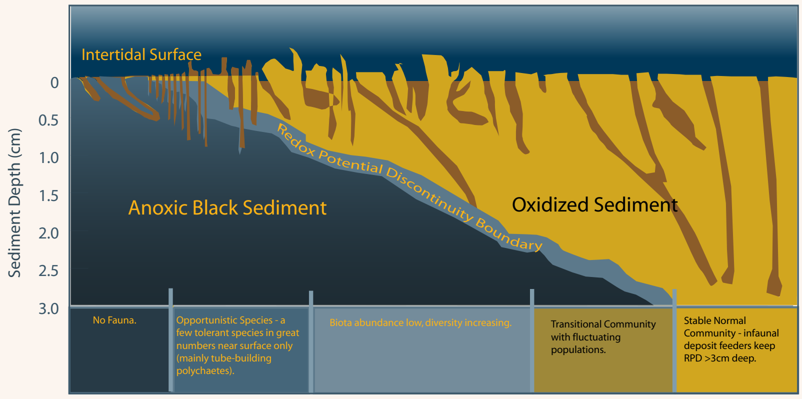


Figure A13. Indication of the likely benthic community at measured RPD depths (from Pearson and Rosenberg 1978).

- Depth of the RPD is commonly measured using one of 2 methods:
  - **Visually** (often in situ when sediments are intertidal and with digital imaging if subtidal). The visual method relies on the assumption that in the absence of oxygen, microbial sulphate reduction results in the precipitation of Fe-sulphides, producing a grey/green or black sediment coloration of the sediment. The RPD is located where the sediment changes colour, and when redox measurements (Eh) are not considered simultaneously, the RPD is termed the apparent RPD (aRPD). This has been the primary method used to measure RPD in NZ estuaries to date and is a recommended indicator in the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002), but is recommended with the proviso that it only be used in the hands of an expert trained using both visual and meter approaches.
  - **With redox potential electrodes** coupled to a millivolt meter (Rosenberg et al. 2001). Redox potential (Eh) measurements represent a composite of multiple redox equilibria at the surface of the electrode and reflects a system's tendency to receive or donate electrons. The electrode is inserted to different depths into the sediment and the RPD depth is identified as the zone where conditions change from oxidizing to reducing i.e. positive to negative mV readings (Fenchel & Riedl 1970, Revsbech et al. 1980, Birchenough et al. 2012, Hunting et al. 2012).

Recently, Gerwing et al. (2013) compared the methods and found similar results for stable subtidal (Rosenberg et al. 2001) and deep sea sediments (Diaz and Trefry 2006), but different results for relatively dynamic intertidal sediments.

Such findings, indicate two important points: firstly, the use of the Pearson-Rosenberg (1978) approach for assessing macrobenthic response to organic enrichment in dynamic, shallow intertidal sediments (i.e. the dominant habitats in most NZ estuaries and beaches) has yet to be proven, and secondly, the appropriate RPD method for use in such intertidal sediments and its relationship with biotic indicators needs to be identified. In order to potentially rectify this gap, PhD research is currently being undertaken at Otago University (Ben Robertson) to identify the relationship between RPD (measured both visually and by meter) and other physico-chemical factors, and the macroinvertebrate community, in order to define redox potential/ecological response thresholds for NZs dominant estuary type. Although estuarine studies relating sediment RPD to biotic effects is very limited, recent SOE monitoring of Southland estuaries (Robertson and Stevens 2012, 2012a, 2013, 2013a) have demonstrated that the macroinvertebrate community at gross eutrophic sites (high macroalgal biomass >3000g.m^{-2} w.w. and RPD at 0cm) were dominated by surface feeding species that are tolerant of poor conditions, whereas adjacent cleaner sites (low macroalgal biomass <200g.m^{-2} w.w., RPD 1-3cm) had a relatively diverse fauna with a wide range of feeding groups.

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS (CONTINUED)

8.7 SULPHUR (SUPPORTING INDICATOR)

THE FOLLOWING INFORMATION HAS BEEN PROVIDED BY BEN ROBERTSON AS PART OF PRELIMINARY OTAGO UNIVERSITY PHD RESEARCH OUTPUTS AND MAY NOT BE REPRODUCED WITHOUT PERMISSION.

Certain sulphur containing fractions in estuary sediments provide an integrated measure of sediment oxygenation, and hence eutrophication, that are potentially better able to balance out short term and small scale spatial variance in aRPD measures. These fractions arise through the microbial decomposition, or oxidation, of organic matter. Energetically, the most favourable electron acceptor is molecular oxygen, but bacteria (of which there are a multitude of types) use others when the supply of oxygen is depleted. In organic-rich estuarine and marine sediments (e.g. beneath decaying macroalgal beds in estuaries), sulphate (SO_4^{2-}) is the dominant terminal electron acceptor and hydrogen sulphide (H_2S) is the initial product. Although manganese dioxide ($Mn0_2$), nitrate ($N0^{3-}$), and iron oxide (Fe_2O_3) are more preferable energetically than SO_4^{2-} as electron acceptors, they are usually less important in estuaries because of their limited supply in marine sediments. In freshwater sediments sulphate is limiting, so carbon dioxide is used through the process of methanogenesis. In coastal marine sediments, sulphate reduction accounts for up to 50% of organic matter degradation (Jørgensen 2000) and it's rate can be large, reaching hundreds of $mg.m^{-2}.h^{-1}$ (e.g. Waikouaiti Estuary, 0.55-212$mg.m^{-2}.h^{-1}$ Robertson 1978). High sulphide production leads to unfavourable conditions for aerobic macrofauna, stress to plant root systems, and production of nuisance odours. In addition, because sulphides are considered to be a key-binding phase involved in the biogeochemical cycling of heavy metals in anoxic sediments, their presence can often include elevated heavy metal concentrations. Because sulphate reduction is temperature dependent, global warming may contribute to even higher sulphide concentrations and benthos mortality.

Bacterial sulphate-reduction in estuarine sediments produces 'free' sulphide (S^{2-}), which then forms an equilibrium in water with hydrogen sulphide ions (HS^-) and hydrogen sulphide (H_2S). Free sulphide is highly toxic to aerobic organisms even in very low concentrations. Because of its lipid solubility, H_2S freely penetrates biological membranes and, like cyanide, it blocks electron transport in aerobic respiration, and is also able to modify oxygen transport proteins and inhibit other enzymes (Bagarino 1992, Reiffenstein et al. 1992). However, the availability of the free sulphides in sediment is a function of the availability and redox state of sulphide-precipitable cations (such as ions of iron, manganese, copper and other transition metals) within the sediment (Billon et al. 2001). These two forms of reduced sulphide are often used as indicators of eutrophication and are estimated by the following methods:

- Acid volatile sulphur (AVS), which is an estimate of the free sulphides, determines the sulphide concentration within the sediment that is soluble in acid (cold 9 M HCl, 18 hr). These are typically considered to be metastable monosulphides, and are dominated by the dissolved sulphide species aqueous FeS clusters, but may include HS^-, H_2S, mackinawite, greigite and polysulphides (Rickard & Morse 2005).
- Chromium reducible sulphur (S_{Cr}), sometimes called total reduced sulphur (TRS), provides a measure of reduced sulphur that includes pyrite (FeS_2(s), elemental sulphur, and the more stable monosulphide fractions (some FeS and H_2S are likely to be lost on drying of sediment before analysis). Total sulphur (TS) is also often measured in conjunction with S_{Cr} because spatial variability in the availability of sulphur may influence the formation of reduced inorganic sulphur. There is also some evidence that because TS is mainly composed of reduced forms (Chandran et al. 2012), it is also a potential indicator of eutrophication (Heggie and Skyring 2005).

Sulphide-rich sediments - Waituna Lagoon

Sulphide rich sediments beneath oxic surface layer, New River Estuary

8.7 SULPHUR (SUPPORTING INDICATOR - CONTINUED)

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ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE INFORMATION

In relation to toxicity levels for biota, and concentrations in eutrophic sediments, the following have been cited:

- In Japan, sulphide compounds in marine sediments are regulated at less than 200mg.kg^{-1} under the aquaculture criteria so as to support sustainable aquaculture activities.
- Sulphide toxicity effects to seagrass, saltmarsh and mangrove species range from ~5 to >300mg.l^{-1} (Lamers et al. 2013).
- In the industrially polluted eutrophic Cochin Estuary, Chandran et al. (2012) found that the concentrations of extractable sulphate ranged from 610-1055ppm, acid volatile sulphur (AVS) 96-3336ppm, and chromium reducible sulphur (CRS) 632-5592ppm. The analytical results of geochemical parameters were pH 4.48-6.87, organic carbon 2.4-6%, and iron 2.8-4.0%.
- In the estuaries near New York, Schartup et al. (2014) found total sulphur (TS) to vary from <1000ppm in less organically enriched areas (TOC <0.5%) to >5,000ppm in more enriched and polluted situations (TOC>2%).
- In the eutrophic Peel-Harvey estuary (W. Aust.) Kilminster (2010) found moderate to high concentrations of organic matter (1.8-7.4% TOC), low redox potential (average -130 mV) and high concentrations of reduced sulfur (S_{Cr}) (4100-17,000ppm), acid volatile sulphides (500-5,500ppm) and total sulphur (7,000-26,000ppm) at most sites (Figure A14).
- In the only NZ estuary study to date (Stevens and Robertson 2013), the moderately enriched Porirua Harbour exhibited sediment TS concentrations of 400-1800mg/kg (TOC 0.5-2.5%) with TS increasing as TOC increases (Figure A15).

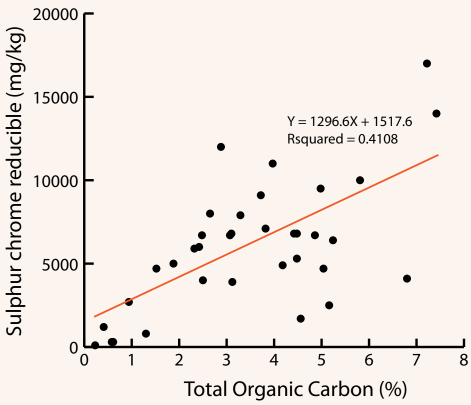

Figure A14. Subtidal sediment TOC and Sulphur (S_{Cr}) concentrations, eutrophic W. Australian estuaries (Kilminster 2010).

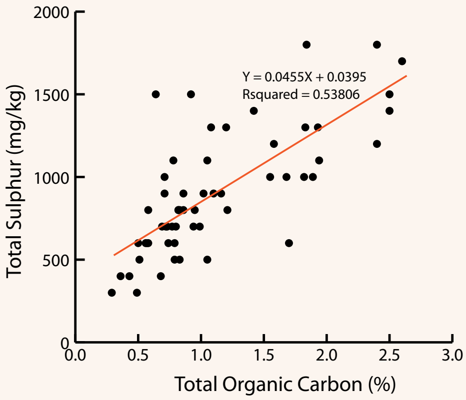

Figure A15. Subtidal sediment TOC and TS concentrations, Porirua Harbour (Stevens and Robertson 2013).

In a multiple Australian estuaries study, Heggie and Skyring (2005) used the differences in TOC:TS ratios across estuaries to reflect the relative magnitude of sulphate reduction in the decomposition of organic matter, and thus give a qualitative indication of the redox status of the environment of deposition as follows: TOC:TS >5 indicates mainly oxic sediment and oxic bottom water; 1.5-5 indicates periodic anoxia (transitional conditions) and <1.5 indicates anoxic sediments and water anoxic.

Unfortunately, such thresholds have not yet been tested for their applicability to NZ estuaries, but given these initial international findings, it is strongly recommended that monitoring of TOC, TS and reduced S, redox potential and macroinvertebrates be undertaken, and thresholds developed for a broad range of NZ estuary types and habitats.

PhD research is being undertaken at Otago University (Ben Robertson) in order to help rectify this gap and to identify the relationship between TS, RPD (measured both visually and by meter) and other physico-chemical factors, and the macroinvertebrate community, in order to define TS and other sulphur species/ecological response thresholds for NZs dominant estuary type.

8.8 MUD CONTENT, SEDIMENTATION RATE (SUPPORTING INDICATOR)

In their natural state, most NZ estuaries had undeveloped bush clad catchments and downstream wetlands that served to minimise fine sediment input loads. As a consequence, their waters were relatively clear, and their sediments dominated by sandy or shelly substrates. Such conditions favoured a rich and diverse ecosystem including the widespread presence of species sensitive to muds, e.g. seagrass, and certain shellfish, fish and invertebrate species. With catchment development and drainage, and associated increased fine sediment loads, the water column of the downstream estuaries have tended to become cloudier and the sediments muddier (particularly in the upper estuary tidal flats in shallow intertidal dominated estuaries, and the central basin in deeper, subtidal dominated estuaries). This shift towards a widespread increase in muds (grain size <63um) has resulted in detrimental and difficult to reverse changes in biotic community composition, and adverse impacts to human uses and values.

In some estuaries, particularly the shallow ones, increased fine sediment loads were accompanied by elevated nutrient loads, resulting in significant areas of eutrophic, mud deposition zones in the upper estuary tidal flats (Robertson and Stevens 2012, 2013) (see Figure A16 for example). The resulting "soft mud/macroalgae cocktail" exacerbates sediment deoxygenation, production of sulphides and degraded macrobenthos. For these reasons, mud is considered a useful supporting indicator for the assessment of estuary trophic status (i.e. if soft muds are present then the estuary is more prone to eutrophic sediments). It includes four key aspects; mud content, the rate of mud accumulation (sedimentation rate), the spatial distribution of these two factors throughout the estuary, and water clarity (that results from suspended fine sediments) and which is addressed as a separate indicator elsewhere in this report (see Submerged Aquatic Vegetation). The results allow managers to assess the infilling rate, whether there has been a shift to finer sediments, and any changes in the spatial extent. By including data on plants and animals, the effects of such changes on key biota (e.g. macroinvertebrates, fish, seagrass) can be gauged.

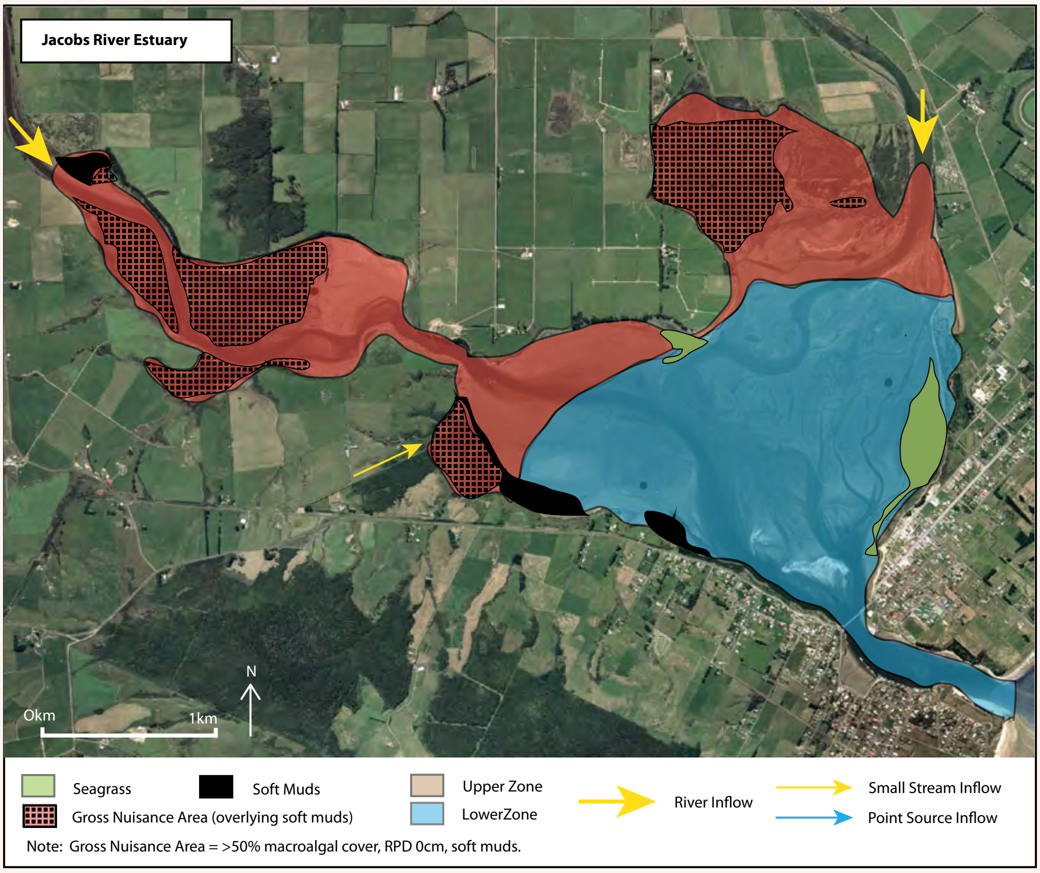

Figure A16. Map of soft mud, high density macroalgae and seagrass cover of Jacobs River Estuary (modified from Stevens and Robertson 2013).

8.8 MUD CONTENT, SEDIMENTATION RATE (SUPPORTING INDICATORS - CONTINUED)

Evidence that supports the mud/eutrophication relationship are as follows:

Mud Content - Relationship to Macroinvertebrate Community.

A review of monitoring data from 25 typical NZ estuaries (shallow, short residence time estuaries) (Wriggle database 2009-2014, Robertson 2013, Robertson et al. 2015) confirmed a "high" risk of reduced macrobenthic species richness for NZ estuaries when mud values were >25-30% mud, and a "very high" risk at >55% (this last value is more tentative given the low number of data-points beyond this mud content) (Figure A17). This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of mud content) by the increasing dissimilarity in the macrobenthic community as mud contents increase above 25-30% mud (Figure A18). Other studies show that sediments become "cohesive" or sticky once the % mud content increases above approximately 20-30% mud depending on such factors as the clay content (Houwing 2000).

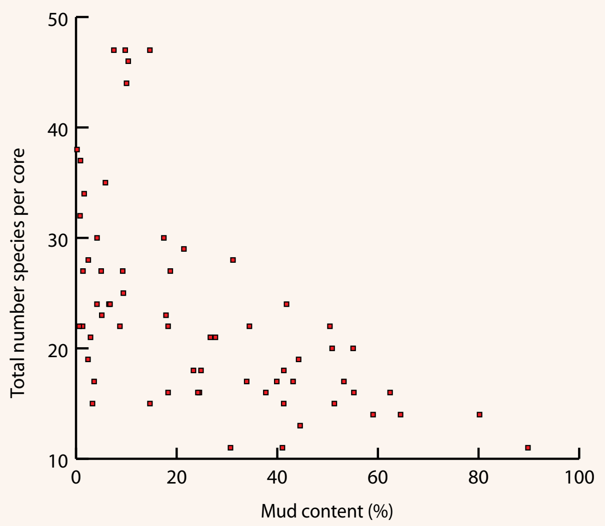

Figure A17. Sediment mud content and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types **(Wriggle Coastal Management database 2009-14).**

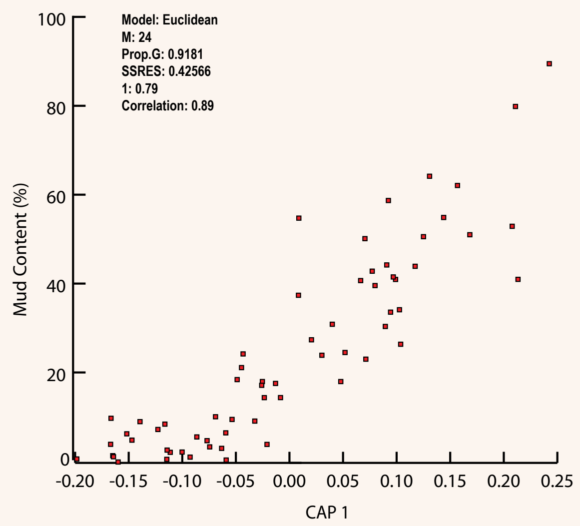

Figure A18. Canonical analysis of the principal coordinates (CAP) for the effect of sediment mud content (exclusively) on the macroinvertebrate assemblages from 25 typical NZ estuaries (i.e. CAP1) among sites.

Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.

Mud Content - Relationship to Gross Nuisance Conditions.

The trophic response to muddy sediments under elevated nitrogen loadings, in this case macroalgal cover, has been explored for 15 shallow tidal lagoon estuaries in NZ (tidal lagoon type with flushing potentials <0.1 days, mean depth 0.5-2m, intertidal flats >50% estuary area). The results (Figure A19) showed that where mud content was greater than 40% and the nitrogen load to the estuary was greater than 100mgN.m^{-2}.d^{-1}, macroalagal cover was greater than 80% and was accompanied by gross eutrophic conditions (mud content >30%, TOC >3%, RPD at surface). Similar gross eutrophic conditions have been found to occur in shallow coastal lagoons or ICOLLs where conditions are not too turbid (e.g. Hoopers Inlet, Waituna Lagoon), but the minimum mud content at which they occur is expected to be much less than for tidal lagoon estuaries. Further work is however required to confirm this. The macroalgal response to muddy sediments under elevated nitrogen loadings has also been explored for 5 shallow tidal river estuaries in NZ (tidal river type with flushing potentials <0.1 days, mean depth 0.5-2m, intertidal flats <5% estuary area). In these narrow, well flushed, tidal river estuaries, where intertidal area is small and therefore the opportunity for nuisance macroalgal growth limited, such gross eutrophic conditions were rare (Figure A20).

8.8 MUD CONTENT, SEDIMENTATION RATE (SUPPORTING INDICATORS - CONTINUED)

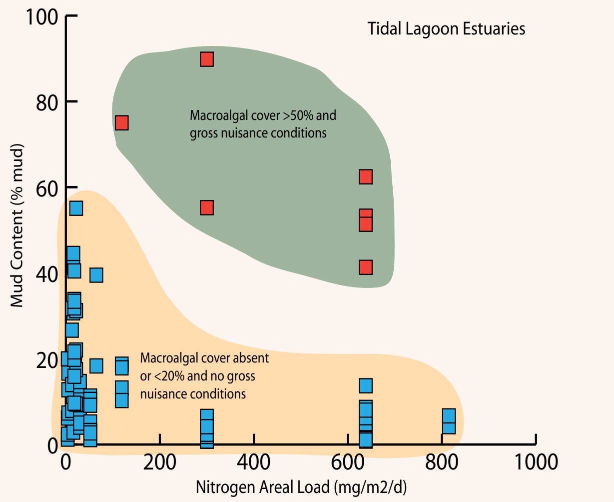

Figure A19. Sediment mud content and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 15 typical NZ tidal lagoon estuaries (shallow, residence time <3d, >50% of estuary intertidal) **(Wriggle Coastal Management monitoring reports 2006-2013, Robertson et al. 2002).**

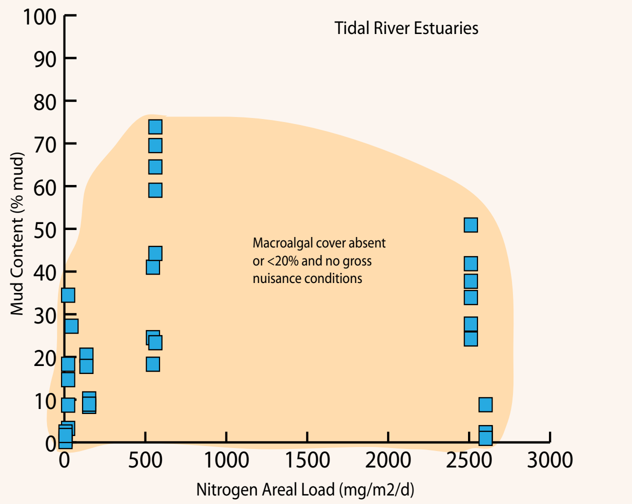

Figure A20. Sediment mud content and nitrogen load (per unit area of the estuary) for fine scale monitoring sites at 5 typical NZ tidal river estuaries **(data sourced from Wriggle Coastal Management monitoring reports 2006-2013).**

Spatial Extent of Soft Muds.
"Total Soft Mud" area is defined as the combination of the "soft mud" and "very soft mud" indicators used to assess broad scale estuary condition in the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002). These are defined as follows:

- Soft Mud. A mixture of mud and sand, the surface appears grey-brown (may have a black anaerobic layer below) and when a human walks on it they sink 2-5cm.
- Very Soft Mud. A mixture of mud and sand, the surface appears grey-brown and may have a black anaerobic layer below and when a human walks on it they sink >5cm.

Subsequent to the development of the NEMP, the characteristics of "total soft mud" (combined NEMP categories of soft mud and very soft mud) has been further defined. Based on the results from a selection of typical NZ tidal lagoon and tidal river estuaries (Table A18), the percent mud content of "total soft mud" generally equates to estuarine sediments with a % mud content in the 25-100% range (i.e. the range above which sediments become "cohesive" or sticky, and significant shifts in macroinvertebrate communities are observed). Variable relationships will obviously exist between %mud content and depth of sinking under certain conditions e.g. muds within a gravel matrix.

Because the available literature on NZ estuaries indicates that there is a marked shift in the macroinvertebrate assemblage when mud content exceeds 25-30%, to one dominated by mud tolerant and/or species of intermediate tolerance (Robertson 2013), and that this shift is most apparent when elevated mud content is contiguous with high total organic carbon (TOC) concentrations (Robertson 2013), mapping the extent of total soft muds in an estuary (i.e. using the NEMP broad scale mapping methodology) provides a strong indication of the spatial extent of mud related macrobenthic effects.

Total Soft Mud Area - Relationship to Seagrass Cover.
The preferred sediment mud content for seagrasses is 0.4%–30% mud content, based on a US review (Batiuk et al. 2001). Preliminary findings from NZ estuary monitoring data (Wriggle reports 2002-2013), tend to support this range, for example extensive broad scale mapping of seagrass cover for 45 typical NZ tidal lagoon and tidal river estuaries (shallow, residence time <3 days) indicate that seagrass cover is absent or less than 1% cover for estuaries with greater than 20-30% of the estuary area as soft mud (i.e. >25% mud content) (Figure A21). It is expected that this is primarily caused by reduced water clarity, and hence light availability, as a result of resuspension and elevated suspended sediment input loads, as well as degraded sediment conditions. In relation to individual examples, extensive high density seagrass (*Zostera*) beds are found at 0.3-0.6% mud content in Freshwater Estuary, Stewart Island and in Waikawa Estuary, seagrass beds are present at 10% mud content but often absent in the extensive 25-80% mud content zone. However, in situations like Westhaven Inlet where the water clarity is high, the mud input load low, and the upper estuary muddy (particularly in sheltered arms), then seagrass growth in the muds can be dense. Nevertheless, growth is not as luxuriant, particularly in relation to root growth, as it is in clean sandy sediments (e.g. Freshwater Estuary).

8.8 MUD CONTENT, SEDIMENTATION RATE (SUPPORTING INDICATORS - CONTINUED)

Table A18. Relationship between "soft mud" and % mud content of intertidal habitat of various NZ estuaries.

Estuary	Muddiness Category	Human Footprint Depth (cm)	% Mud Content	Source
Porirua Harbour	Firm Muddy Sand	0-2cm	1.7-11.1%	Wriggle Coastal Management database 2009-2014
	Soft Mud	2-5cm	37-49%	
	Very Soft Mud	>5cm		
Waikanae Estuary	Soft Mud	2-5cm	27-47%	
	Very Soft Mud	>5cm		
Hutt Estuary	Firm Muddy Sand	0-2cm	21%	
	Soft Mud	2-5cm	28-51%	
	Very Soft Mud	>5cm		
Whareama Estuary	Firm Muddy Sand	0-2cm	21%	
	Soft Mud	2-5cm	39-86%	
	Very Soft Mud	>5cm		
Waimea Estuary	Firm Muddy Sand	0-2cm		
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		
Havelock Estuary	Firm Muddy Sand	0-2cm	17%	
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		

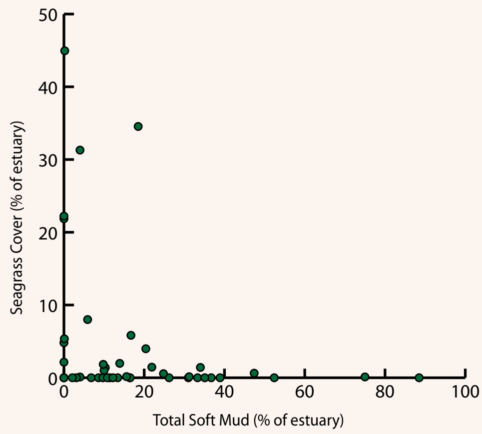

Figure A21. Percentage soft mud and seagrass cover of 45 typical NZ tidal lagoon and tidal river estuaries (shallow, residence time <3 days). (Wriggle Coastal Management monitoring reports 2006-2013 and Robertson et al. 2002).

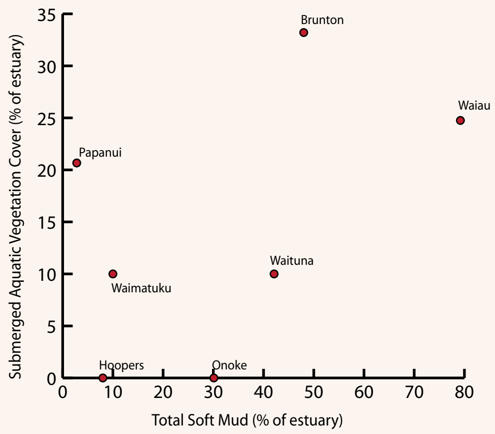

Figure A22. Percentage soft mud and submerged aquatic vegetation cover of 7 typical NZ ICOLL estuaries (shallow, residence time variable). (Wriggle Coastal Management monitoring reports 2006-2013).

In relation to ICOLLs, the available information indicates that submerged aquatic vegetation (SAV) can survive in some ICOLLs that are dominated by muddy sediments (Figure A22). This occurs primarily as a result of the ability of brackish tolerant aquatic macrophytes, e.g. *Ruppia*, to grow up to the surface and hence obtain sufficient light for growth. ICOLLs with low SAV are generally SAV limited by reasons other than soft muds, unless the SAV is *Zostera* (such as in Papanui Inlet). For example, in Lake Onoke, SAV is limited by the short period opening/closing regime: in Waimatuku, SAV is limited by the very long opening period and short closed period, in Waituna SAV is limited by a combination of macroalgal/epiphyte cover, muddiness, and the opening/closing regime.

Sedimentation Rate - Influence on Ecology

Another obvious mud related indicator that influences estuary ecology and its trophic state, is the rate of mud sedimentation or infilling of the estuary with soft muds. In coastal waterways, sedimentation rates refer to the amount of material (organic and mineral) deposited by the action of water over a given interval of time. In most NZ estuaries, increased inputs of fine sediments or muds from catchment sources has been the major driver of sedimentation in upper estuary areas. In the lower estuary, inputs of sands from the ocean are generally the main source.

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS (CONTINUED)

8.8 MUD CONTENT, SEDIMENTATION RATE (SUPPORTING INDICATORS - CONTINUED)

Sedimentation is measured in terms of vertical accumulation over time ($mm.yr^{-1}$) and in order to provide a realistic long term estimate, must include episodic sedimentation events that occur during floods. For example, a single flood in May 1985 delivered 75% of the 20-year annual average sediment load to the Mahurangi Estuary (Swales et al. 1997). A further consideration is that deposition rates for mud naturally vary throughout an estuary. For example, habitats that tend to favour sedimentation include flocculation zones and slower current speed and wind/wave turbulence areas. Accordingly, rates tend to be most pronounced in the following habitats:

- Poorly flushed, flanking tidal flats of the upper reaches of shallow intertidally-dominated estuaries (i.e. low current flocculation zones).
- ICOLLs (due to their high sediment trapping efficiency when closed).
- Subtidal basins (i.e. low current settling basins) of subtidal dominated estuaries with developed catchments and large river inputs.

Although it is natural for estuaries to infill over a period of thousands to a few tens of thousand years at a rate usually $<1mm.yr^{-1}$ (Vernberg and Vernberg 2001, Swales et al. 2005, Morrison et al. 2009, Robertson and Stevens 2007), it has become common in NZ and overseas estuaries with developed catchments to have rates significantly >2mm/yr. For example, in NZ shallow, intertidal dominated estuaries, sedimentation rates vary from $<0.5mm.yr^{-1}$ in estuaries with undeveloped catchments to 2-60mm.yr^{-1} in those with developed catchments (Morrison et al. 2009, Robertson and Stevens 2012, Zeldis et al. 2015). In East Coast USA estuaries rates varied from 1.5-51.8 $mm.yr^{-1}$ (Vernberg and Vernberg 2001).

This excessive sedimentation is exemplified by a recent study in Porirua Harbour where an estimated mean rate of 5-10$mm.yr^{-1}$ of muds were deposited from catchment sources in the 1974-2009 period, and indicated that both estuary arms were highly likely to rapidly infill and change from tidal estuaries to brackish swamps within 145-195 years, if rates of deposition over the last ~30 years continued (Gibb and Cox 2009). Currently, this estuary is being managed by reducing current catchment sediment loads to meet a long term target of 1$mm.yr^{-1}$ by 2031.

In terms of ecological impacts, the obvious effect of increased mud deposition is on habitat, with non-muddy habitat becoming muddy, and muddy habitat becoming muddier. The available habitat for biota within the estuary also declines at a much greater rate as the estuary infills. In addition to the impacts of mud on macroinvertebrates and seagrass habitat identified previously in this section, there are a number of others as identified in the NLWRA 2008: Estuarine, coastal and marine habitat condition, indicator guideline for Sedimentation Rates (see OZCoasts website, http://www.ozcoasts.gov.au/indicators/sediment_rates.jsp) as follows:

- *"Habitats may be smothered where sediment is deposited more rapidly than tolerated by benthic communities. For example, loss of seagrass areas and macroalgae can destabilise bottom sediments formerly protected from wind and tidal erosion by the sheltering and binding abilities of macrophyte colonies. Such changes also constitute pressures on fish assemblages and benthic invertebrate numbers.*
- *Turbidity levels and the amount of sediment-bound nutrients (e.g. TP, TN and TOC), trace elements (e.g. Fe, Zn, Pb) and other toxicants entering estuaries from their catchments also tend to increase in association with increased rates of sedimentation. Greater nutrient loads can lead to periods of eutrophication which can further enhance sedimentation rates because the amount of organic matter being deposited also increases.*
- *Increased sedimentation rates also allow more organic matter to be degraded by anoxic processes (e.g. sulphate reduction; see also TOC:TS ratios) because the exposure time of organic matter to dissolved oxygen in the water column is shortened. Denitrification efficiencies are lowered under anoxic conditions, and more dissolved nutrients are recycled to the water column. Loss of nitrification and denitrification (and increased ammonium efflux from sediment) in coastal and estuarine systems is also an important cause of hysteresis. [This is suggested as an enrichment mechanism in the Firth of Thames by Green and Zeldis 2015, and Zeldis et al. (2015).]*
- *The net result of enhanced sedimentation rates is an increase in the maturity of coastal waterways, and a decrease in their overall life spans. Reductions in the biodiversity, health and integrity of coastal ecosystems may also occur. In order to make better-informed management decisions there is clearly a need to accurately assess the rate and nature of sedimentation within coastal waterways and any changes in other sedimentological parameters over time."*

Another aspect to consider in relation to increased muddiness is its impact on water clarity. The preferred water clarity for seagrass, is an average value of at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed (to the depth of seagrass colonisation), assuming that the Secchi depth can be approximated to 20% of the surface light (Lorenzen 1972). This is similar to the USEPA approach as put forward in the following studies (Dennison et al. 1993, Duarte 1991, Gallegos 1996, Steward et al. 2005). While clarity can obviously be affected by factors other than mud, it needs to be considered in any overall assessment of the expression of eutrophic responses.

8.9 SUBMERGED AQUATIC VEGETATION (SUPPORTING INDICATOR)

A summary of the actions of the major stressors on seagrass are provided as follows.

- **Nutrients:** see Appendix 8.5.
- **Macroalgae:** see Appendix 8.2.
- **Mud Content:** The preferred sediment mud content for seagrasses is 0.4%–30% mud content, based on a US review (Batiuk et al. 2001). Preliminary findings from NZ estuary monitoring data (Wriggle reports 2002-2013), tend to support this range, for example extensive high density seagrass (*Zostera*) beds (Figure A23) are found at 0.3-0.6% mud content in Freshwater Estuary, Stewart Island and in Waikawa Estuary, seagrass beds are present at 10% mud content but absent in the extensive 25-80% mud content zone.
- **Water Clarity:** The preferred water clarity for seagrass, is an average value of at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed (to the depth of seagrass colonization), assuming that the Secchi depth can be approximated to 20% of the surface light (Lorenzen 1972). This is similar to the USEPA approach as put forward in the following studies (Dennison et al. 1993, Duarte 1991, Gallegos 1996, Steward et al. 2005).
- **Low Salinity:** Excessive low salinity detrimentally affects seagrass growth. Germination trials for *Zostera muelleri* have demonstrated that the species germinates over a restricted range of salinities, from 15ppt to 30ppt (Brenchley and Probert 1998). In general *Zostera* growth is absent or very stunted in the freshwater inflow channels to NZ estuaries, but is present on the intertidal flats above the channel influence (e.g. Waihopai Arm New River Estuary, and upper Waikawa Estuary). *Ruppia* species in general appear well adapted to salinity variations but are not present under freshwater conditions. Data from *Ruppia* beds in Waituna Lagoon supports this generalisation. For example, ES data from 2003-2011 show *Ruppia* present when the lagoon was open to the sea (salinity was 10-35ppt) and when closed (0.2-10ppt). Studies on Lake Ellesmere suggested that the optimum growth rates for *R. polycarpa* and *R. megacarpa* are achieved at 4-8ppt salinity (Gerbeaux 1989). However, Australian studies indicate both species can survive a greater range (Brock 1982).
- **Dessication/Temperature:** Intertidal habitats with long exposure times (particularly in the mid-high water range) have low SAV growth except where protected by a layer of water. This influence is exacerbated by higher temperature environments. In general, growth of *Zostera muelleri* is restricted to approximately 0.5m below MHW (mid-tide level) in the South Island, and lower North Island (Turner and Schwarz 2006).
- **Wave Exposure/Currents:** Excessive wave exposure and current speed causes physical disturbance (sand scour) and hence patchy seagrass beds (Turner and Schwarz 2006). Data from NZ seagrass monitoring studies (Stevens and Robertson Regional Council Monitoring 2000-2013) indicate that areas of high wind fetch do produce patchy, low density cover (e.g. eastern flats of New River and Jacobs River Estuaries, Southland, mid Waikawa Estuary). Fonseca et al. (1983) proposed that the maximum current velocity that *Z. marina* can tolerate is 120 to 150cm.s^{-1}.
- **Depth/Light Limitation, Tidal Range:** Generally, *Zostera* growth within NZ estuaries is limited by light to the first few metres of water and therefore is generally located in intertidal areas. They only reach greater depths (>3m) in open, clear water embayments such as Bluff Harbour (maximum depth recorded at 5m), or the Bay of Islands.
- **Fluctuating Water Levels:** Irregularly fluctuating water levels, as found in some ICOLLs, provide a stressful environment for seagrass/SAV species because of the alternating freshwater to saline conditions and dessication. ICOLLs with short open/closed periods (e.g. Lake Onoke), do not generally contain seagrass or SAV because of the regular "washout" when the lagoon is open, which tends to repress seagrass recruitment via seed (Haines et al. 2006).
- **Sulphide, Ammonia and Nitrate Toxicity:** Sulphide negatively affects seagrass photosynthesis, metabolism and growth (Goodman et al. 1995, Ralph et al. 2006). In *Z. marina*, moderate sulphide levels (>12,500mg/kg) caused various stress related responses (Goodman et al. 1995, Holmer and Bondgaard, 2001). Seagrass can also be lost through toxicity effects from high ammonium concentrations resulting from decaying macroalgae (van Katwijk et al. 1997). Ammonia toxicity has been reported in seagrasses (*Ruppia drepanensis* and *Zostera marina* at 1750ug/l water column NH_4^+ applied over 5 weeks (Touchette and Burkholder 2000). Water-column nitrate enrichment (in the order of nitrate-N 80-170ug.l^{-1}) has also been reported to cause death to *Zostera marina* as a direct physiological impact, unrelated to algal turbidity, and acted synergistically with increasing temperatures and decreasing light availability to promote this *Zostera* decline (Burkholder et al. 1994). However, the evidence to support direct toxic effects is still considered somewhat tenuous and is a topic of debate in the literature (Moore and Wetzel, 2000). For example, *Zostera marina* thrives in at least one Oregon estuary (Yaquina Bay) where both ambient water column and sediment nitrogen (nitrate and ammonium) concentrations are 3 to 10 times higher than the levels used in any of the experiments that exhibit toxic effects.
- **Grazing:** In New Zealand, the black swan (*Cygnus atratus*) is the only large grazer of intertidal seagrass. A recent study (Dos Santos et al. 2012) in Tauranga Harbour showed that black swans foraged primarily at high tide (both during the day and night) and were more numerous at sites with larger meadows, particularly during autumn. At sites where grazing was most intense (annual removal of 19–20% of the average seagrass biomass), a substantial decline (43–69%) in plant biomass in the subsequent growing season was observed. These results suggest that black swan grazing could constitute a threat to seagrass under high grazing pressure.

8.9 SUBMERGED AQUATIC VEGETATION (SUPPORTING INDICATOR - CONTINUED)

ECOLOGICAL RESPONSE THRESHOLDS - AVAILABLE INFORMATION

- The US based ASSETS thresholds for SAV loss (from a measured baseline) in large deeper estuaries are as follows (Bricker et al. 2003): High Loss: ≥50 but ≤100% of estuarine surface water area. Medium Loss: ≥25 but >50% of estuarine surface water area. Low: ≥10 but >25% of estuarine surface water area. Very Low: ≥0 but >10% of estuarine surface water area.

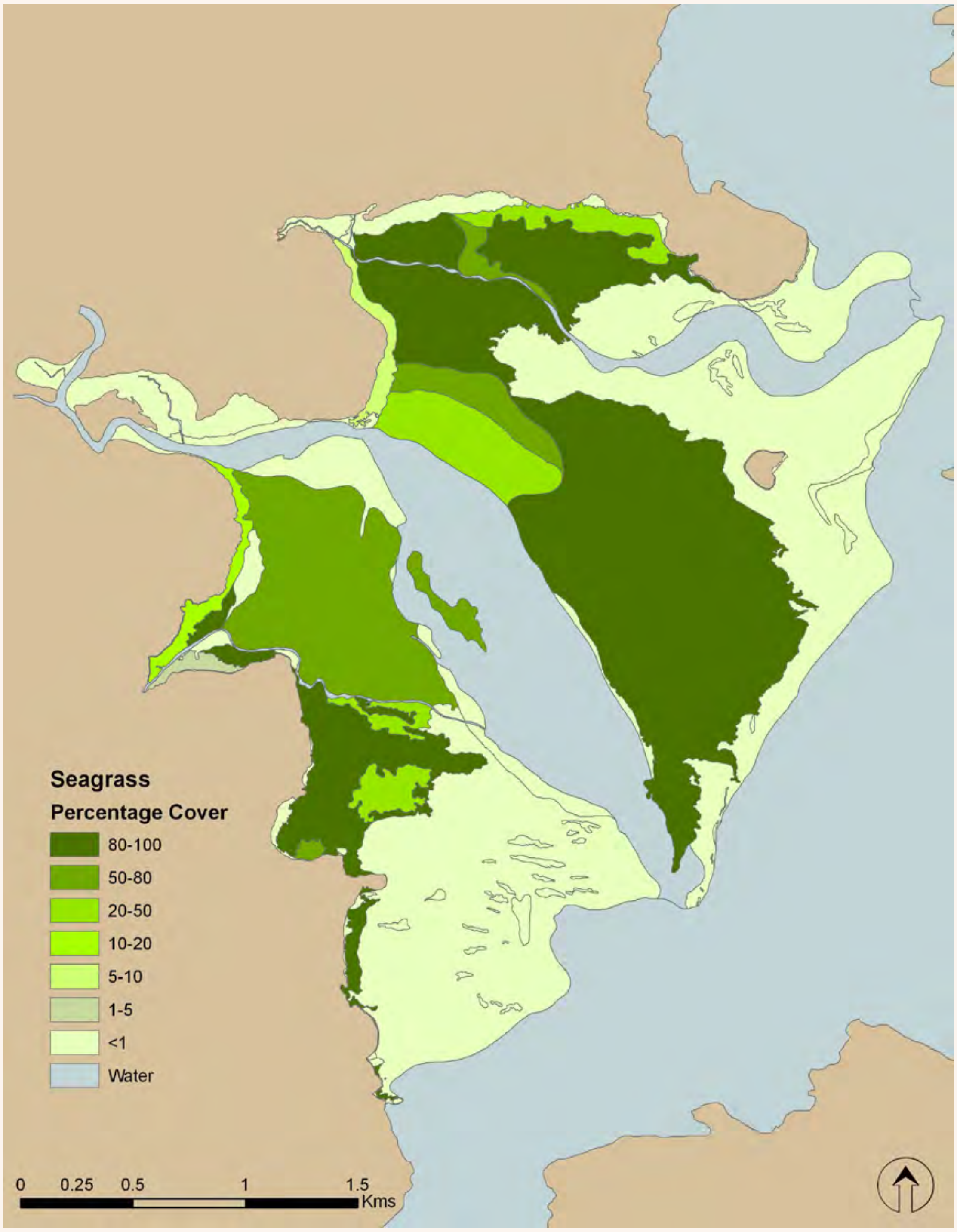

Figure A23. Broad scale habitat mapping for seagrass, Freshwater Estuary 2013 (Wriggle Coastal Management)

TOOL 2: APPENDIX 8. TECHNICAL SUPPORT FOR EUTROPHICATION INDICATORS (CONTINUED)

8.10 MACROINVERTEBRATES (SUPPORTING INDICATOR) - AUTHORED BY BEN ROBERTSON, UNIVERSITY OF OTAGO

As a by-product of the development of macroinvertebrate/estuary condition indicator relationships, a large number of macroinvertebrate biotic indices (sometimes associated with other environmental or biological variables) have been developed and used to assess estuary condition. These range from simple univariate indices, such as species richness (number of species), and diversity indices (e.g. Shannon diversity index, H'), to more complex functional indices, multimetric indices (e.g. BQI: Biological Quality Index) and multivariate approaches (e.g. Multivariate-AMBI [M-AMBI]) (see list in Borja et al. 2012).

These indices result in a single number which summarises the complex estuary condition and is statistically supported by a wide range of physical, chemical and biological measures. The development of these indices reflects the facts that biological communities are a product of their environment, and organisms can be grouped according to different habitat preferences and pollution tolerance. Most of the estuarine biotic indices are only used in a limited way at present, but AMBI and M-AMBI, BQI (and its various adaptations), B-IBI, and Infaunal Trophic Index (ITI) are currently widely used throughout the world (Borja et al. 2012). However, a recent review (Borja et al. 2012) concluded that no single biotic index can correctly assess the estuary macroinvertebrate condition, and that a multi-criteria approach is favoured.

Within NZ, there have been several approaches to the development of macroinvertebrate/estuary condition relationships based on the response of NZ species to estuarine variables. The most common environmental variables for which taxa responses have been identified are: mud content (Norkko et al. 2002, Robertson et al. 2015), heavy metals (Rodil et al. 2013), and organic enrichment (Robertson 2013, Robertson et al. 2015). A summary of the approaches and results, in order of their development, are presented below.

- **Mud Sensitivity Ratings** - based on the environmental condition indicator of % mud. From a limited data set of 14 upper North Island estuaries, as well as short-term laboratory experiments, a macroinvertebrate-mud sensitivity rating was estimated for 38 taxa, of which 13 were able to be statistically modelled, and 25 assessed through visual interpretation of the raw macroinvertebrate abundance data (Norkko et al. 2002, Thrush et al. 2003). These species ratings have been subsequently used to assess benthic macroinvertebrate community condition in relation to muddiness in estuaries throughout NZ (e.g. see Gibbs and Hewitt 2004, Hailes and Hewitt 2012). However, in a national context, such ratings potentially lack strong regional transferability and are limited in terms of the number of taxa with assigned ratings. As such, their use in assessing estuary condition at any particular site needs to be supported by information that indicates that: i. the estuary in question fits within the upper North Island estuary type classification used to produce the ratings, ii. that due regard is given to taxa that have not yet been rated for sensitivity and, iii. that the ratings are only used to assess sensitivity to sediment mud content. Use of a multi-metric approach is required to gain a true indication of the factors driving a particular macroinvertebrate assemblage, particularly the inclusion of indicators of eutrophication and toxicity.
- **Local Traits Based Index (TBI)**. This index is based on the environmental condition indicators of % mud and metal concentrations. Rodil et al. (2013) developed the local Traits Based Index (TBI) primarily to predict the response of the macrofauna community to metal gradients. They assigned macroinvertebrate species from 84 intertidal soft-sediment sites from three Auckland harbour estuaries (Mahurangi, Waitemata, and Manukau), into one of 29 functional groupings. Correlation strengths between the number of taxa and individuals in each of the 29 functional groups were evaluated and related to sediment mud content (using the Mahurangi data) and metal content (using the Waitemata/Manukau data). Based on these correlations, seven functional groups were retained for use in the TBI, due to their observed responsiveness to both mud and metals in two independent data sets. The utility of the TBI was then verified using independent data from >100 additional Auckland estuary sites and results from these upper North Island estuaries showed the TBI responded to changes in sediment mud percentage and heavy metal contaminant concentration gradients at levels below international toxicity thresholds, and therefore successfully tracked the most relevant local stressors.

Collecting macroinvertebrate samples, Moutere Inlet

Sieving macroinvertebrate cores, Moutere Inlet

8.10 MACROINVERTEBRATES (SUPPORTING INDICATOR - CONTINUED) - AUTHORED BY BEN ROBERTSON, UNIVERSITY OF OTAGO

The TBI rating results were also compared with results from two other indices; the AMBI, which is designed to respond to mud and organic enrichment, and the B-IBI which evaluates the ecological condition of a sample by comparing values of benthic community attributes to reference values expected under non-degraded conditions in similar habitat types (Weisberg et al. 1997). The AMBI coefficients were in the low range (1-4, indicating undegraded states), which was expected given that all the sites experienced low levels of organic enrichment (expert opinion rather than measured). They also predictably showed that the increased AMBI scores (indicative of degrading health) were associated with declines in the abundances of sensitive species and declines in species diversity. The results from the B-IBI, which was calculated using well known metrics of species abundance, diversity and the abundance of sensitive species, carnivores and deposit feeders, were correlated with gradients of increasing muddiness, although B-IBI was unsuccessful at distinguishing reference sites from known degraded sites. It calculated 58% of the sites correctly as uncontaminated, and it was not closely related to the mud gradient. Concordance between the two indices was also relatively poor.

In overview, the TBI is a promising tool, that needs to be tested for other estuaries outside of the upper Nth Island, and also for influencing factors, particularly organic enrichment indicators (e.g. TOC, TN, macroalgal cover, RPD). Therefore, although this rating is likely to be useful in the Auckland region, and potentially other regions where metal toxicity and muddiness are the key stressors, at this stage it is not recommended for wider use in other NZ estuaries where organic enrichment, muddiness and low metal concentrations are more evident.

- **Mud and Organic Carbon Sensitivity Ratings.** Robertson (2013, Robertson et al. 2015) used organic enrichment, grain size and macroinvertebrate data from 135 sites in 25 estuaries scattered throughout NZ, and representing most NZ estuary types, to produce mud and organic sensitivity ratings for NZ estuarine macroinvertebrates. The results confirmed sediment mud content and TOC as co-varying (R2 = 0.706; P = 0.001) key drivers of the macroinvertebrate community (noting that all sites had metals concentrations below ANZECC ISQG toxicity thresholds). Mud/organic enrichment sensitivity ratings (5 sensitivity groupings - called "Ecological Groups" by Robertson et al. 2015) were subsequently established through statistical modelling for a total of 42 species, with a further 56 species assessed through visual interpretation of the raw data. These results were then used as inputs to the AMBI biotic coefficient equation to produce an integrated mud and organic enrichment rating for available NZ data as follows.
- **NZ Hybrid AMBI Using NZ Mud and Organic Carbon Sensitivity Ratings.** Applied worldwide, the AMBI benthic index provides a cost-effective, defensible means of assessing the environmental integrity of coastal soft-bottom ecosystems in relation to anthropogenic disturbances. In assessing the condition of a particular benthic location, the two key drivers of the AMBI scoring approach are the correct assignment of macroinvertebrate taxa to specific ecological groups, which reflect their sensitivities to particular stressors, and the disturbance thresholds or bands used to categorise that site's condition. In a recent NZ wide estuary study, Robertson et al. (2016 in prep.) directly strengthened the AMBI for use in NZ and overseas estuaries through integration of previously established, quantitative ecological group classifications (Robertson et al. 2015), through the computationally simple addition of a meaningful macrofaunal component (taxa richness), and through the derivation of classification- and breakpoint-based thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents). The latter was used to evaluate the applicability of existing AMBI condition bands, which were shown to accurately reflect benthic condition for the >100 intertidal estuarine sites surveyed: 2% to ~30 % mud reflected a 'normal' to 'impoverished' macrofauna community, or 'high' to 'good' status; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an 'unbalanced' to 'transitional to pollution' macrofauna community, or 'good' to 'moderate' status; and >3% to 4% TOC reflected a 'transitional to pollution' to 'polluted' macrofauna community, or 'moderate' to 'poor' status. In addition, the AMBI was successfully validated (R^2 values >0.5 for mud, and >0.4 for total organic carbon) for use in shallow, intertidal dominated estuaries New Zealand-wide. The AMBI is therefore currently the only available index that has been validated on multiple estuaries and enrichment gradients from throughout NZ using quantitatively derived estuarine sensitivities for NZ taxa.
- **Recommended Approach.** As such, it is strongly recommended that the NZ Hybrid AMBI approach (Robertson et al. 2016 in prep.), supported by species richness, comparisons of individual species, mud, TOC, and metals concentrations and redox potential, be used to indicate macrobenthic response to key stressors in NZ estuarine habitat. Interim rating thresholds for 4 bands of ecological condition have been proposed (Table 13) based on estuary data from throughout NZ (Robertson et al. 2016 in prep). PhD research (Ben Robertson Uni of Otago) is currently addressing this aspect in further detail. At sites where toxicity is present, the use of a validated TBI mentioned above (or similar) is recommended, particularly as a screening tool. Any tool/index applied should establish clear relationships among key variables that may potentially co-vary e.g. TOC, mud, heavy metals so that appropriate management targets can be identified.

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