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Hutt Estuary 2016

Broad Scale Habitat Mapping

Prepared for
Greater Wellington Regional Council
June 2016

Cover Photo: Looking downstream towards the lower Hutt Estuary, January 2016.

Small intertidal flats at the Moera Stream mouth, January 2016

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Prepared for
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by

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Contents

List of Figures

List of Tables

All photos by Wriggle except where noted otherwise.

HUTT ESTUARY - EXECUTIVE SUMMARY

Hutt Estuary is a moderate sized (47ha), subtidally dominated, tidal river mouth estuary near Petone at the head of Wellington harbour. It is part of Greater Wellington Regional Council's (GWRC) coastal State of the Environment (SOE) monitoring programme. This report summarises the results of the 2016 broad scale habitat mapping of the estuary, and a synoptic assessment of subtidal sediment and water quality in the lower estuary. The following sections summarise broad scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations.

BROAD SCALE RESULTS

- Intertidal flats (21% of the estuary area) were dominated by cobble (3.7ha, 38%) located primarily in the upper estuary, and firm sandy mud (2.8ha, 31% - 58-87% sand) on intertidal flats. While relatively small, these are the largest remaining estuarine intertidal sandflats in Wellington Harbour.
- Seawalls, river protection works and reclaimed margins (2.3ha, 24%) extended throughout the upper tidal zone of the entire estuary.
- Soft mud (0.2ha, 2%) was not a prominent feature, and sediment rate monitoring showed no net annual accumulation on the Te Mome intertidal flats since 2010, and no increase in sediment muddiness since measures were established at this site in 2014.
- Opportunistic macroalgal growth (primarily *Ulva intestinalis)* was extensive (98% of the available habitat), but biomass was generally low with only very localised intertidal nuisance conditions (rotting algae, poorly oxygenated and sulphide-rich sediments) - most likely due to strong flushing and flood scouring of the estuary. Macroalgal cover has not changed appreciably since 2010.
- No significant gross eutrophic zones were present in 2016 (e.g. combined dense macroalgae, soft muds, and poor sediment oxygenation).
- Saltmarsh covered <1% of the estuary (0.5ha) and was limited by the hardened rockwalls that surround much of the upper tidal margin.
- The densely vegetated 200m margin cover (i.e. forest, scrub, tussock, and duneland) of the estuary was very low (<1%).
- A synoptic assessment of deeper subtidal habitat in the lower estuary found sediments to be relatively muddy with high organic, nutrient and total sulphur contents, low levels of sediment oxygenation, and high levels of the heavy metal nickel.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Major Issue	Indicator	2016 risk rating	Change since baseline
Sediment	Intertidal soft mud (% cover, vertical buildup, grain size)	VERY LOW	No significant change since 2004
Eutrophication	Macroalgal Growth (EQC)	HIGH	No significant change since 2010
	Gross Eutrophic Conditions (ha)	VERY LOW	No significant change since 2004
Habitat Modification	Saltmarsh (% of intertidal area)	HIGH	No significant change since 2004
	200m Vegetated Terrestrial Margin	HIGH	No significant change since 2004

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sediment, eutrophication, and habitat modification), the 2016 broad scale mapping results show that overall there is currently a "HIGH" risk of adverse impacts to the estuary ecology occurring because of extensive modification of estuary margins which has displaced saltmarsh and vegetated terrestrial margin buffers, excessive macroalgal growth throughout the estuary, and degraded subtidal habitat quality which indicates a high risk of stress to benthic communities in the area. No significant changes were recorded from baseline measures. Strong flushing and flood scouring of the estuary appears to currently restrict the extent of nuisance conditions (rotting macroalgae and poorly oxygenated and sulphide rich sediments) to localised areas on intertidal flats, and in subtidal areas near the Hutt River mouth.

The key consequence is a reduction in the ecological value of important habitat features, particularly a reduced capacity to assimilate sediment and nutrient inputs, and reduced supporting habitat to birds, fish (whitebait) and shellfish.

RECOMMENDED MONITORING AND MANAGEMENT

The following monitoring recommendations are proposed by Wriggle for consideration by GWRC:

Repeat broad scale habitat mapping 10 yearly (next due in 2026), unless obvious changes are observed in the interim.

Repeat fine scale monitoring of sediment quality at 5 yearly intervals (next due in 2017).

Measure sediment plates established in 2010 annually for sediment deposition rate and grain size to track changes in fine sediment when other monitoring work is being undertaken in the vicinity of the estuary.

Intensive investigations recommended to defensibly address issues of widespread macroalgal growth and subtidal habitat degradation are:

- Identify catchment sediment and nutrient sources (e.g. catchment wide inputs or localised sources), and derive a guideline limit for nutrient (likely to be nitrogen) inputs as the first step, followed by identification of major sources and their subsequent reduction to meet the guideline.
- Design and implement a subtidal mapping and monitoring programme to define the spatial extent of degraded subtidal habitat, and the extent of any biological impacts that may be occurring. Particular focus should be given to the impact of dredging in the lower estuary on the accumulation and settlement of organic material and fine muds.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. In 2007, Greater Wellington Regional Council (GWRC) identified a number of estuaries in its region as immediate priorities for long term monitoring and initiated monitoring of key estuaries in a staged manner. The estuaries currently monitored include; Porirua Harbour, Lake Onoke, and Whareama, Hutt and Waikanae estuaries. Risk assessments have also been undertaken to establish management priorities for a number of other estuaries (Robertson and Stevens 2007a,b,c).

The estuary monitoring process consists of three components developed from the NEMP (see Robertson et al. 2002 for original programme design), and subsequent extensions for fine scale monitoring (see Robertson and Stevens 2015) and broad scale habitat mapping (see Stevens and Robertson (2015a) as follows:

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (see Table 1) and appropriate monitoring design. This component has been completed for Hutt Estuary and is reported on in Robertson and Stevens (2007b).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. Broad scale intertidal mapping of a small part of Hutt Estuary was undertaken in 2004 (Stevens and Robertson 2004), and in Waiwhetu Stream in 2009 and 2012 (Stevens and Robertson 2009, 2012). In addition, mapping of macroalgal cover has been undertaken annually since 2010 (e.g. Stevens and Robertson 2015b). The current report focuses on detailed broad scale habitat mapping undertaken in the summer of 2015/16 to assess the current state of the estuary, and changes from baseline measures. It also includes synoptic assessment of subtidal habitat in the lower estuary.
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of an estuary across a three year baseline, commenced in 2010 and is reported on in Robertson and Stevens 2010, 2011, 2012. Sedimentation rates in the estuary have been monitored annually since 2010 (see Stevens and Robertson 2015c).

Report Structure: The current report presents an overview of key estuary issues in NZ and recommended monitoring indicators (Section 1). This is followed by risk indicator ratings (Section 2), sampling methods (Section 3), a summary and discussion of results (Section 4) including the results of:

- Broad scale mapping of estuary sediment types.
- Broad scale mapping of macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*).
- Broad scale mapping of gross eutrophic areas.
- Broad scale mapping of saltmarsh vegetation.
- Broad scale mapping of the 200m terrestrial margin surrounding the estuary.
- A synoptic fine scale assessment of subtidal habitat in the lower estuary.

To help the reader interpret the findings, results are related to relevant risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 5), and to guide monitoring and management recommendations (Sections 6 and 7 respectively).

The Hutt Estuary is a moderate-sized (3km long) "tidal river mouth" type estuary which drains into Wellington Harbour at Petone. Saltwater extends up to 3km inland (230m downstream of the Ewens Bridge) and the water column is often stratified (freshwater overlying denser saline bottom water).

The estuary has been highly modified from its original state. In 1909 it was much larger and included several large lagoon arms and extensive intertidal flats and saltmarsh vegetation (Figure 1) (Bell 1910). Over the next 50 years, most of the intertidal flats and lagoon areas were reclaimed and the estuary was trained to flow in one channel between artificial rip-rap (quarried boulder) banks. The terrestrial margin, which was originally vegetated with natural coastal shrub and forest species, was replaced for urban and industrial land uses.

As a result, the estuary now has extremely low habitat diversity. High value habitats such as tidal flats, saltmarsh and seagrass beds are virtually absent. Instead the estuary is dominated by lower value - subtidal sands and mud, and artificial seawalls. Several small streams which discharge into the estuary have also been highly modified, however, recent steps have been undertaken to improve conditions in the lower Waiwhetu Stream (Stevens and Robertson 2009, 2012).

The estuary currently receives high inputs of nutrients and sediment from the large catchment and consequently growths of green nuisance macroalgae are common along its banks, and the bed near the mouth is muddy and enriched.

Figure 1. Hutt Estuary - historical extent 1909 (from Bell 1910) and present day.

Table 1. Summary of the major environmental issues affecting most New Zealand estuaries.

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007, 2010, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension of fine sediments is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sediment Changes	Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
	Seagrass Area/Biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Mud Content	Grain size - estimates the % mud content of sediment.
	Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
	Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
	Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

2. Eutrophication

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll a concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox Potential Discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
	Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
	Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and supporting indicators, primary indicators being given more weight in assessing the significance of results. It is noted that many supporting estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data and presented in the NZ estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative) trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

The indicators and interim risk ratings used for the Hutt Estuary broad scale monitoring programme are summarised in Table 2, along with supporting notes explaining the use and justifications for each indicator (following page). Further detailed background notes presented in the NZ ETI (Robertson et al. 2016a and 2016b).

The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing.

Table 2. Summary of estuary condition risk indicator ratings used in the present report.

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts				
a. BROAD SCALE INDICATORS	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
Soft mud (% of unvegetated intertidal substrate)*	<1%	1-5%	>5-15%	>15%
Gross Eutrophic Conditions (ha or % of intertidal)	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Macroalgal Ecological Quality Rating (OMBT)*	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	0.0 - <0.4
Saltmarsh Extent (% of intertidal area)	>20%	>10-20%	>5-10%	0-5%
Supporting saltmarsh indicators: **Extent** (% remaining from estimated natural state)	>80-100%	>60-80%	>40-60%	<40%
Supporting saltmarsh indicators: **Extent** (% of available intertidal area)	>80-100%	>60-80%	>40-60%	<40%
Densely Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	0-25%
Percent Change from Monitored Baseline	<5%	5-10%	>10-20%	>20%
b. FINE SCALE INDICATORS				
Apparent Redox Potential Discontinuity (aRPD)**	Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (mV) (representative sites at 1cm depth)***	>+100	-50 to +100	-50 to -150	>-150
Sediment Mud Content (% mud)*	<5%	5-10%	>10-25%	>25%
Total Organic Carbon (TOC)*	<0.5%	0.5-<1%	1-<2%	>2%
Total Nitrogen (TN)*	<250mg/kg	250-1000mg/kg	>1000-2000mg/kg	>2000mg/kg
Metals	<0.2 x ISQG Low	0.2 - 0.5 x ISQG Low	0.5 x to ISQG Low	>ISQG Low

* NZ ETI (Robertson et al. 2016b) ** Hargrave et al. (2008) ***Robertson (in prep.), Keeley et al. (2012). See NOTES on following page, and App. 2 for further info.

2. Estuary Risk Indicator Ratings (continued)

NOTES to Table 2: See Appendix 2, and Robertson et al. (2016) for further information supporting these ratings.

Soft Mud Percent Cover. Soft mud (>25% mud content) has been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are a sink for sediments, the presence of large areas of soft mud are likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, its presence indicates where changes in land management may be needed. If an estuary is suspected of being an outlier (e.g. has >25% mud content but substrate remains firm to walk on), it is recommended that the initial broad scale assessment be followed by particle grain size analyses of relevant areas to determine the extent of the estuary with sediment mud contents >25%.

Sedimentation Rate. Elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse, and indicate where changes in land use management may be needed. Note the very low risk category is based on a typical NZ pre-European average rate of <1mm/year, which may underestimate sedimentation rates in soft rock catchments.

Sedimentation Mud Content. Below mud contents of 20-30% sediments are relatively incohesive and firm to walk on. Above this, they become sticky and cohesive and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon concentrations, which typically increase with mud content, as do the concentrations of sediment bound nutrients and heavy metals. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, and on intertidal flats of estuaries can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready resuspension of fine muds, impacting on seagrass, birds, fish and aesthetic values.

Redox Potential Discontinuity (RPD). RPD depth, the transition between oxygenated sediments near the surface and deeper anoxic sediments, is a primary estuary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Knowing if the RPD close to the surface is important for two main reasons:

1. As the RPD layer gets close to the surface, a “tipping point” is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and to worsen sediment conditions.
2. Anoxic sediments contain toxic sulphides and support very little aquatic life.

In sandy porous 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.

Gross Eutrophic Conditions. Gross eutrophic conditions occur when sediments exhibit combined symptoms of: a high mud content, a shallow Redox Potential Discontinuity (RPD) depth, elevated nutrient and total organic carbon concentrations, displacement of invertebrates sensitive to organic enrichment, and high macroalgal growth (>50% cover). Persistent and extensive areas of gross nuisance conditions should not be present in short residence time estuaries, and their presence provides a clear signal that the assimilative capacity of the estuary is being exceeded. Consequently, the actual area exhibiting nuisance conditions, rather than the % of an estuary affected, is the primary condition indicator. Natural deposition and settlement areas, often in the upper estuary where flocculation at the freshwater/saltwater interface occurs, are commonly first affected. The gross eutrophic condition rating is based on the area affected by the combined presence of poorly oxygenated and muddy sediments, and a dense (>50%) macroalgal cover:

Opportunistic Macroalgae. Opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 3 and Appendix 2), with results combined with those of other indicators to determine overall condition.

Seagrass. Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent is likely to indicate an increase in these types of pressures.

As a baseline measure of seagrass presence, a continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: ***SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100.*** Because estuaries are likely to support variable natural seagrass extents, the SC rating is intended to highlight estuaries with low seagrass cover for further evaluation (i.e. estimate natural seagrass cover to determine current state), and to provide an estuary specific metric against which future change can be assessed. It is not intended that the SC be used to directly compare different estuaries. The “early warning trigger” for initiating management action is a trend of a decreasing SC.

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. Two supporting metrics are also proposed: i. % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. ii. % of available habitat supporting saltmarsh. This assumes that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. The interim risk ratings proposed for these ratings are Very Low=>80-100%, Low=>60-80%, Moderate=>40-60%, and High=<40%. The “early warning trigger” for initiating management action/further investigation is a trend of a decreasing saltmarsh area or saltmarsh growing over <80% of the available habitat.

Vegetated Margin. The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the saltmarsh and estuary. This buffer is sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. It protects the estuary against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat. Reduction in the vegetated terrestrial buffer around the estuary is likely to result in a decline in estuary quality. The “early warning trigger” for initiating management action is <50% of the estuary with a densely vegetated margin.

Change from Baseline Condition. Where natural state conditions for high value habitat of seagrass, saltmarsh, and densely vegetated terrestrial margin are unknown it is proposed that % change from the first measured baseline condition be used to determine trends in estuary condition. It is assumed that increases in such habitat are desirable (i.e. represent a Very Low risk rating), and decreases are undesirable. For decreases, the interim risk ratings proposed are: Very Low=<5%, Low=>5-10%, Moderate=>10-20%, and High=>20%. For indicators of degraded habitat e.g. extent of soft mud or gross eutrophic conditions, the same interim risk rating bands are proposed, but are applied to increases in extent.

3. METHODS

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland, etc). It follows the NEMP approach originally described for use in NZ estuaries by Robertson et al. (2002) with a combination of aerial photography, detailed ground-truthing, and GIS-based digital mapping used to record the primary habitat features present. Appendix 1 lists the definitions used to classify substrate and saltmarsh vegetation. Very simply, the method involves three key steps:

- Obtaining aerial photos of the estuary for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing) using laminated aerial photos.
- Digitising ground-truthed features evident on aerial photographs into GIS layers (e.g. ArcMap).

The results are then used with risk indicators to assess estuary condition in response to common stressors.

For the current study, rectified ~0.4m/pixel resolution colour aerial photos flown in 2012/13 were sourced from LINZ, laminated (scale of 1:3,000) and used by experienced scientists who walked the area in January 2016 to ground-truth the spatial extent of dominant vegetation and substrate types (Figure 3). Sediment samples were collected from representative substrates and analysed for grain size to support the NEMP classifications applied (Figure 4). The "iGIS HD" Ipad app was used to show live position tracking on aerial photos (via an inbuilt GPS accurate to ~5m), and to log field notes. When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2 below).

Broad scale habitat features were digitised into ArcMap 10.2 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs to produce habitat maps showing the dominant cover i.e. substrate, macroalgae (e.g. *Ulva, Gracilaria*), seagrass, saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse. These broad scale results are summarised in Section 4, with the supporting GIS files (supplied as a separate electronic file) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions. An example of the detail available on the GIS files is presented in Figure 3.

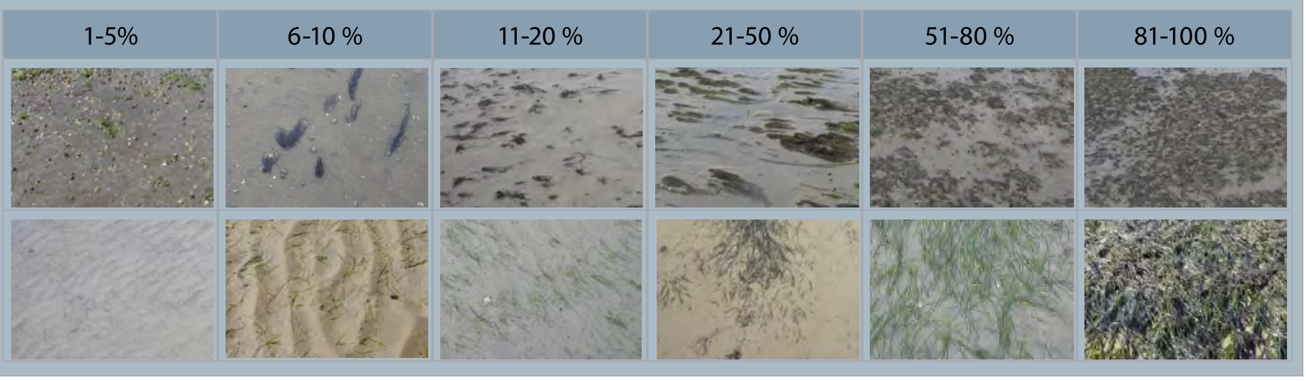
Intertidal macroalgae growth was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring biomass and the degree of macroalgal entrainment within sediment. When macroalgae was present, the presence of soft muds and surface sediment anoxia were also noted to assess whether gross nuisance conditions had established. Results were interpreted using a multi-index approach that included:

- percent cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of potential eutrophication issues).
- macroalgal biomass (providing a direct measure of areas of excessive growth).
- extent of algal entrainment in sediment (highlighting where nuisance condition have a high potential for establishing and persisting).
- gross eutrophic zones (highlighting significant sediment degradation by measuring where there is a combined presence of high algal cover or biomass, low sediment oxygenation, and soft muds).

The key component of the interpretative assessment of macroalgae is the use of a modified Opportunistic Macroalgal Blooming Tool (OMBT), (WFD-UKTAG 2014). The OMBT, described in detail in Appendix 2, is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands to rate macroalgal condition. This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution in the estuary.

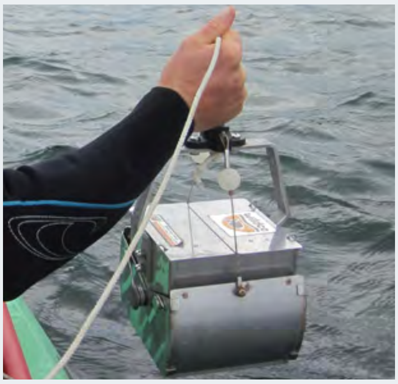
The georeferenced spatial habitat maps provide a robust baseline of key indicators against which future change can be assessed.

Figure 2. Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom).



3. Methods (continued)

YSI data sonde recording water quality parameters of DO, salinity, chl-a, depth and temperature.



Box core being prepared for deployment (photo above), and retrieved after sample collection (photo below).

Purpose built shallow water sediment sampler for collecting coarse sediments. Note the ability of the corer to retain unconsolidated organically enriched surface deposits overlying clean bottom sediments.

SYNOPTIC SUBTIDAL ASSESSMENT

As a consequence of extensive historical modification of the estuary margin (primarily drainage of saltmarsh, reclamation of intertidal habitat, and channelisation of river banks), the subtidal area of Hutt Estuary is now its most extensive remaining habitat. Fine scale synoptic sampling was undertaken in representative areas of this subtidal habitat to assess sediment quality as part of the broad scale assessment. Lower estuary areas with deep holes were the primary target of the investigation as these are a trap for fine sediment, nutrients and organic matter, and nuisance phytoplankton blooms can establish where flushing is poor or salinity or temperature stratification is present.

For the Hutt Estuary, 12 sampling sites (Figure 4), were selected in mid-channel subtidal habitat. Three samples were collected upstream of the Waione Street bridge from substrate within relatively shallow river dominated habitat, and nine samples from below the bridge in deeper habitat which is subject to regular dredging.

At each station, an open decked double kayak was anchored to hold a stable position in the channel. Once in position, the following water column measurements were taken from surface and bottom waters using a YSI data sonde (see upper sidebar photo).

- salinity,
- chlorophyll-a,
- dissolved oxygen,
- temperature, and
- depth.

Sediment samples were collected from the estuary bed using either a remotely triggered Ekman spring-jawed box corer (for soft sediment sites - see middle side bar photos) or a purpose built sediment sampler (for coarse sediments - see lower sidebar photo). The coarse sediment sampler is mounted on the end of a telescopic pole with a 4-5m reach, has a 20cm square flat bottom, two 20cm high enclosed sides and a supported open back, with a pointed front section which digs into the sediments.

Each sample collected was photographed, sediment texture described, and average apparent redox potential discontinuity (aRPD) depth recorded. From each core, approximately 250gms of surface (top 20mm) sediment was collected directly into pre-labelled sample containers supplied by R.J. Hill Laboratories, placed in a chilly bin and kept chilled until subsequent dispatch to the lab for analysis for the following variables.

- Grain size (% mud, sand, gravel).
- Organic Matter and Nutrients:
  - Total Organic Carbon (TOC)
  - Total Nitrogen (TN)
  - Total Phosphorus (TP)
  - Total Sulphur (TS)
- Heavy metals and metalloids:
  - Cadmium (Cd)
  - Chromium (Cr)
  - Copper (Cu)
  - Lead (Pb)
  - Mercury (Hg)
  - Nickel (Ni)
  - Zinc (Zn), and
  - Arsenic (As).

Details of lab methods and detection limits are presented in Appendix 2. All samples were sent to the lab on ice by overnight courier and were tracked using standard Chain of Custody forms. Results were checked and transferred electronically to avoid transcription errors.

3. Methods (continued)

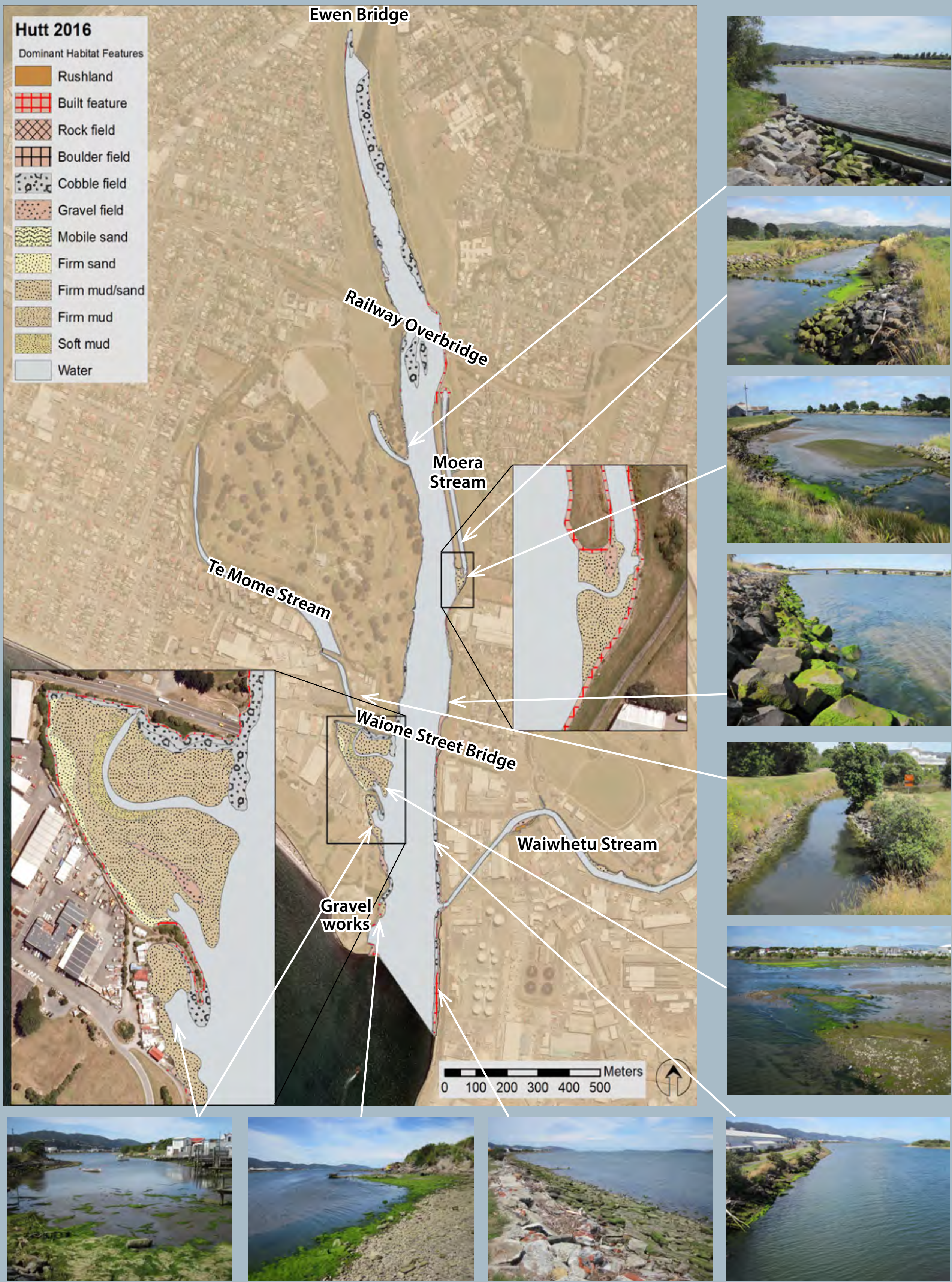
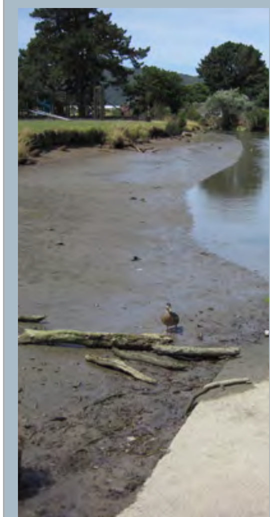


Figure 3. Hutt Estuary - mapped estuary extent and examples of selected habitats.

Figure 4. Hutt Estuary, showing intertidal and subtidal sample locations.

4. RESULTS AND DISCUSSION

BROAD SCALE MAPPING



Top to bottom - macroalgal covered sand flats, cobble field, and narrow mud banks, Hutt Estuary 2016.

The 2016 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation (including Waiwhetu Stream) as well as the dominant land cover of the 200m terrestrial margin, with the six dominant estuary features summarised in Table 3. The estuary has been highly modified through historical channelisation and reclamation with remaining habitat now subtidally dominated (79% of the estuary). Intertidal habitat (21%) is limited to narrow borders along river channels, and two small intertidal flats in the lower estuary. The estuary supports <1% saltmarsh. Seagrass was not found in the estuary (so is not discussed further). Opportunistic macroalgae was present throughout the estuary with a dense cover (>50%), although biomass in most intertidal areas was relatively low. The extent of the 200m wide terrestrial margin with a densely vegetated buffer was very low (<1%), the dominant cover being grassland (45% - park and amenity areas), commercial and industrial developments (27%), residential housing (24%) and roading (5%).

- In the following sections, various factors related to each of these habitats (e.g. area of soft mud) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification. Estimates of natural state cover have been used to indicate likely changes in broad scale features over time.
- In addition, the supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuary. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

Table 3. Summary of dominant broad scale features in Hutt Estuary, 2016.

	Dominant Estuary Feature	Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	9.7	21%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	7.8	17%
3.	Seagrass (>50% cover) [included in 1. above]	0.0	0%
4.	Saltmarsh	0.5	<1%
5.	Subtidal waters	37.4	79%
Total Estuary		**47.6**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer densely vegetated (e.g. scrub, shrub, forest)		<1%

4.1. INTERTIDAL FLATS (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 5) show the most common intertidal substrate was cobble (38%). This was primarily located in the upper estuary between the railway overbridge and Ewen bridge. Sands (31%) dominated on the intertidal flats that remain in the estuary, which also contained small areas of mud (2%). Seawalls and river protection works were also a very prominent feature (23%) and encompass the entire upper estuary margin, with cobble and gravel fields often located in mid-tide zones adjacent to these areas. Intertidal substrates were all relatively well oxygenated with the aRPD >2cm, a likely consequence of the well flushed nature of the estuary, a risk indicator rating of "LOW to VERY LOW".

Table 4. Summary of dominant intertidal substrate, Hutt Estuary, 2016.

Dominant Substrate	Ha	%	Comments
Built feature (seawalls)	2.3	23.6	Seawall and river bank protection works (concrete, rock/boulder)
Cobble field	3.7	38.1	River margins in front of armoured margins, and near estuary mouth
Gravel field	0.5	5.0	On intertidal flats by Te Mome and Moera streams mouths
Firm sand	0.2	1.8	High tide beaches on the Te Mome Stream intertidal flats
Firm mud/sand	2.8	29.1	Mid tide areas on the Te Mome and Moera stream intertidal flats
Soft mud	0.2	2.4	Mid tide areas on the Te Mome and Moera stream intertidal flats
Grand Total	**9.7**	**100**	

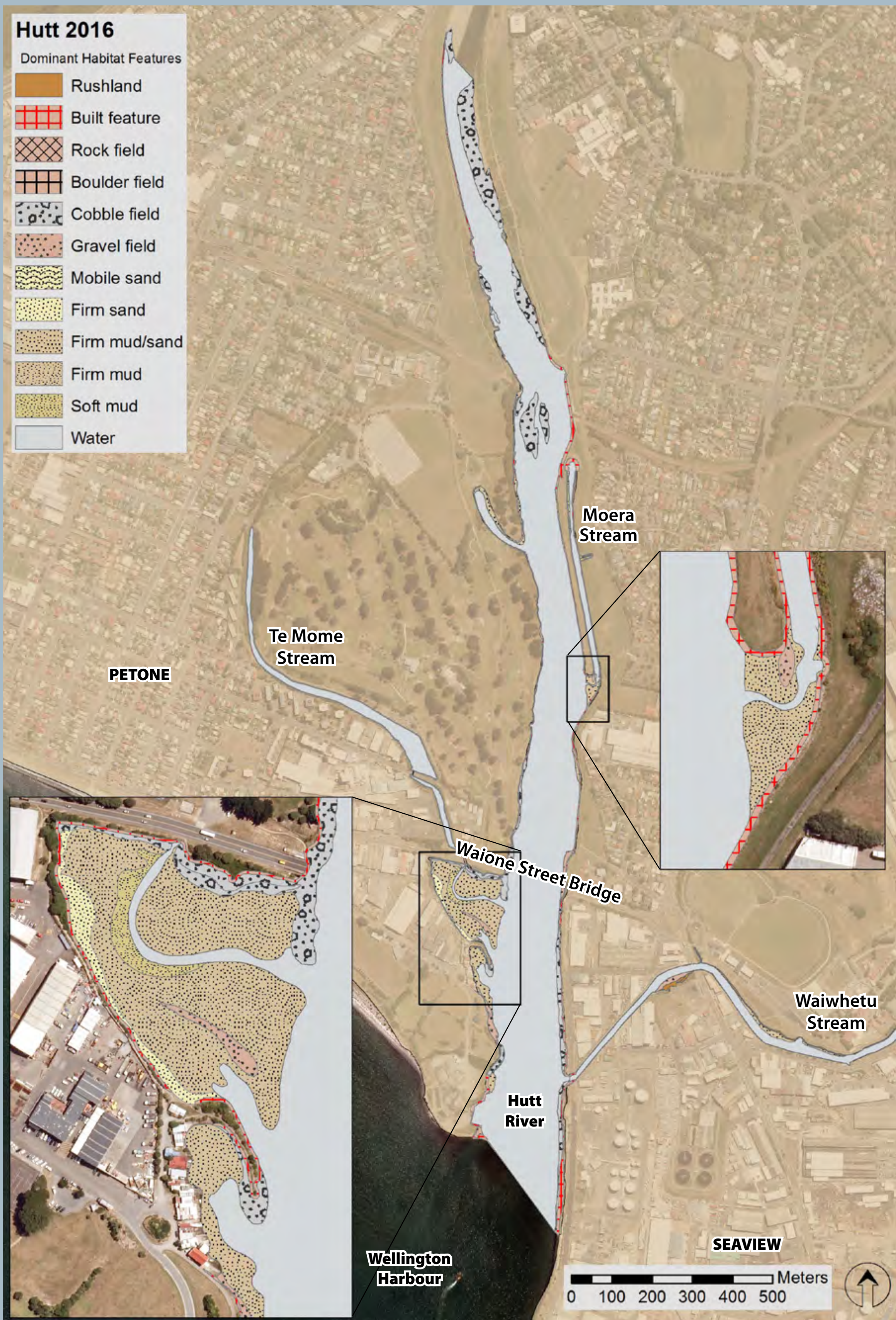
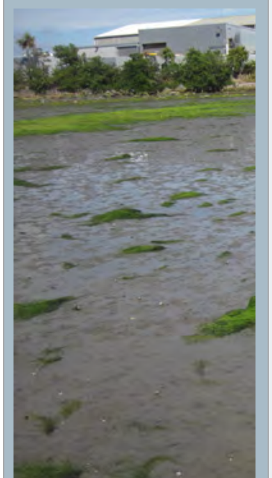


Figure 5. Map of dominant intertidal habitat types - Hutt Estuary, 2016.

4. Results and Discussion (continued)



Unvegetated sand flats near Moera Stream (top), and Te Mome Stream mouth (lower).

Soft Mud Habitat.

Where soil erosion from catchment disturbance exceeds the assimilative capacity of an estuary, adverse estuary impacts are expected from increased muddiness and turbidity, shallowing, increased nutrients, increased organic matter degradation by anoxic processes (e.g. sulphide production), increased contaminant concentrations (where fine muds provide a sink for catchment contaminants like heavy metals), and alterations to saltmarsh, seagrass, fish and invertebrate communities. In particular, multiple studies have shown estuarine macroinvertebrate communities to be adversely affected by mud accumulation, both through direct and indirect mechanisms including: declining sediment oxygenation, smothering, and compromisation of feeding habits (e.g. see Mannino and Montagna 1997; Rakocinski et al. 1997; Peeters et al. 2000; Norkko et al. 2002; Ellis et al. 2002; Thrush et al. 2003; Lohrer et al. 2004; Sakamaki and Nishimura 2009; Wehkamp and Fischer 2012; Robertson 2013).

Because of such consequences, three key measures are used to assess soft mud:

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 2)
ii. **Vertical buildup** (sedimentation rate) - fine scale assessment using sediment plates (or retrospectively through historical coring). Ratings are currently under development as part of National ANZECC guidelines.
iii. **Sediment mud content** - fine scale indicator - recommended guideline is no increase from established baseline.

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report. Figure 5 shows that soft mud habitat was not a significant intertidal feature in Hutt Estuary. Sedimentation rate monitoring further shows that there has been no net vertical buildup of sediment on the Te Mome intertidal flats since 2010, and no increase in sediment muddiness since measures were established in 2014 at this site (Stevens and Robertson 2016). Additional grain size analyses undertaken as validation of the broad scale substrate classifications used in the current report also show that the sediments on the intertidal flats (where sediment accumulation commonly occurs in estuaries) were sand-dominated with relatively low mud contents (9-21% mud).

These results are thought to reflect high flushing of the estuary from tidal and river flows, as well as the presence of deeper subtidal deposition zones in the lower estuary where fine sediments are known to accumulate (synoptic sampling of this habitat is presented in Section 5).

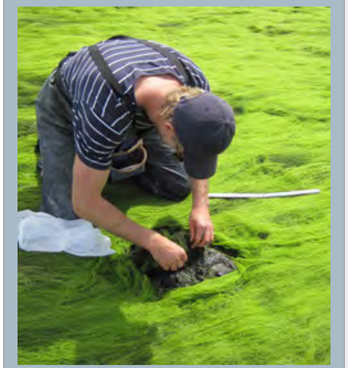
The overall risk of detrimental impacts to intertidal estuarine biota from muds was assessed as "VERY LOW" based on the small area of intertidal soft mud (2.4%), low rates of net annual sediment buildup, and relatively low mud contents within sediment on the largest intertidal flats (Table 5).

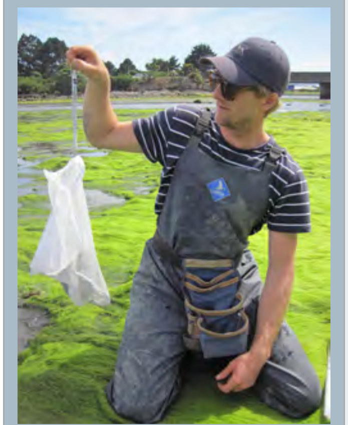
Table 5. Grain size results from representative intertidal sediments, Hutt Estuary, 2016 (refer to Figure 4 for locations).

Site	Broad Scale Classification	% mud	% sand	% gravel
S1	**Firm sandy mud:** A sand/mud mixture dominated by sand with an elevated mud fraction (e.g. 10-25%), the mud fraction visually conspicuous when walking on it. The surface appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm or soft mud, and very soft mud. When walking an adult will sink 0-2 cm. Granular when rubbed between the fingers, but with a smoother consistency than firm muddy sand.	16.4	74.8	8.8
S2		20.0	79.5	0.5
S3		14.2	58.0	27.9
S4		16.2	79.4	4.4
S5		13.0	83.8	3.2
S6		9.7	86.7	3.6
S7		21.2	75.8	3.0

4. Results and Discussion (continued)

4.2. OPPORTUNISTIC MACROALGAE





Opportunistic macroalgae are a primary symptom of estuary eutrophication. They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Decaying macroalgae can also accumulate subtidally and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the subsequent impacts.

Opportunistic macroalgal growth was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 6), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT) described in Appendix 2.

The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and relates to a quality status threshold band (i.e. bad, poor, good, moderate, high - Appendix 2). The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change (Table 2).

The results of intertidal mapping of opportunistic macroalgal in Hutt Estuary in January 2016 are summarised in Table 6 and Figures 6 and 7 with full data in Appendix 2. The 2016 results were very similar to those present in 2015:

- As the highly modified estuary is confined within extensive floodbanks, the available intertidal habitat is restricted to narrow bands along steep rip-rap rock walls and small areas of sandflat habitat present at the mouths of the Te Mome and Moera Streams and within Waiwhetu Stream.
- Of the Available Intertidal Habitat (7.9ha), 99% had opportunistic macroalgal growth present (Affected Area = 7.8ha).

Table 6. Summary of intertidal opportunistic macroalgal cover, Hutt Estuary, January 2016.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	7.9		
Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	63.2	0.25	Poor
Biomass of AIH ($g.m^{-2}$) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	753.1	0.37	Poor
Biomass of Affected Area ($g.m^{-2}$) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	764.6	0.36	Poor
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	0.0	1.00	High
Affected Area (use the lowest of the following two metrics)		0.01	Bad
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	7.8	0.84	High
Size of AA in relation to AIH (%) = (AA / AIH) x 100	98.5	0.01	Bad
OVERALL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.40**	**POOR (High Risk)**
OVERALL GROSS EUTROPHIC ZONE RISK RATING *GEZ (ha) = combined area with soft mud, RPD =0cm, and macroalgal biomass>500$g.m^{-2}$ or % cover>50%*	0	n/a	**VERY LOW**
TOTAL MACROALGAL BIOMASS (kg wet weight)			**59,552kg**
Biomass (kg) of macroalgal cover <5% = AIH - AA (ha) * mean biomass *(nominally 50$g.m^{-2}$ unless stated otherwise)*			59kg
Biomass (kg) of macroalgal cover >5% = sum of patch biomass measures			59,493kg

4. Results and Discussion (continued)

Figure 6. Map of intertidal opportunistic macroalgal biomass (g.m^{-2}) - Hutt Estuary, Jan. 2016.

- The green alga *Ulva intestinalis* was the dominant opportunistic macroalgal species present, growing on almost every area of available habitat. *Ulva lactuca* (sea lettuce) and the red alga *Gracilaria* were also observed as subdominant growths near the estuary mouth.
- In general, macroalgae growing along the predominantly hard substrates of the extensively modified estuary margins had a low biomass (e.g. <50g.m-^{2}) and was not entrained in underlying sediment.
- Macroalgal biomass on the Te Mome intertidal flats ranged from high (>500g.m-^{2}) to very high (>2000g.m-^{2}).
- There were no significant intertidal gross eutrophic zones identified (e.g. when there is a combined presence of high macroalgal biomass and cover, soft muds, and poor sediment oxygenation (RPD depth <0.5cm)).
- In shallow subtidal areas, very dense growths of *Ulva intestinalis* (biomass 5000-8000g.m-^{2}) were present in 5-10m wide bands along the lower channel margins below Moera Stream mouth and below the Waione Street bridge.

The overall opportunistic macroalgal Ecological Quality Rating (EQR) for Hutt Estuary was 0.40, a quality status of "POOR" and a risk rating of "HIGH". This rating was driven primarily by the widespread presence of macroalgae throughout most of the available habitat in the estuary - an affected area quality status of "BAD", and "POOR" ratings for percent cover and biomass. The EQR score was moderated only by the absence of algal entrainment in underlying sediments, a quality status of "HIGH". The gross eutrophic zone risk rating was "VERY LOW", reflecting that underlying intertidal sediments had not been significantly adversely impacted by the macroalgal growth present.

A comparison with previous years results show that gross eutrophic zones have not changed (no significant areas present). Because biomass data are not available prior to 2015, EQR values have been estimated for 2010-2014 using maps of percentage cover and photos of biomass. These show that macroalgal cover in 2010-2014 was consistent and very similar to the conditions present in both 2015 and 2016 and thus have been rated with a similar EQR (Figure 7).

The consistent and very widespread presence of opportunistic macroalgae throughout the estuary since 2010, combined with high macroalgal biomass on the only remaining intertidal flats in the estuary, and the presence of luxuriant, very high biomass growths in shallow subtidal habitat, show nutrient inputs to the estuary are sufficient to support extensive growths of macroalgae.

Despite such growths, nuisance conditions (e.g. rotting macroalgae and poorly oxygenated and sulphide rich sediments) were not a significant intertidal feature, but were much more readily apparent in subtidal areas below the Waione Street Bridge which is currently muddy, poorly oxygenated, and sulphide rich (see Section 4.4).

The primary factor preventing widespread nuisance conditions appears to be the regular flushing of macroalgae from the estuary. This flushing, and particularly flood scouring of the river following rain, is likely to be limiting the length that nuisance macroalgae can grow to along the intertidal main channel margins, while also dislodging and washing macroalgae growing or deposited on the intertidal flats into subtidal zones or out to sea.

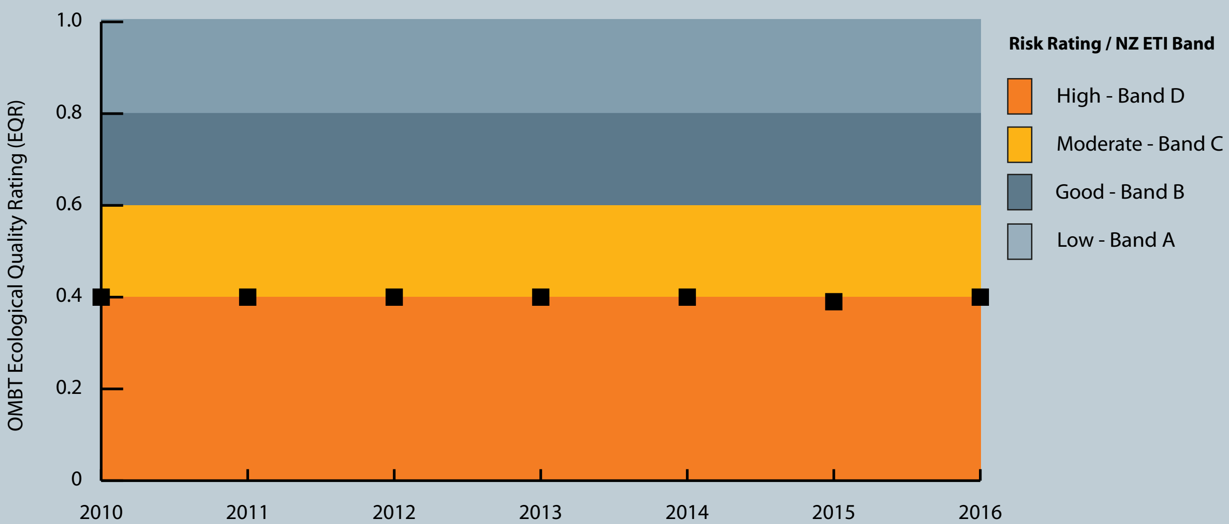
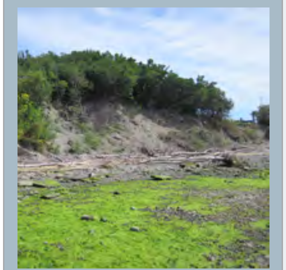
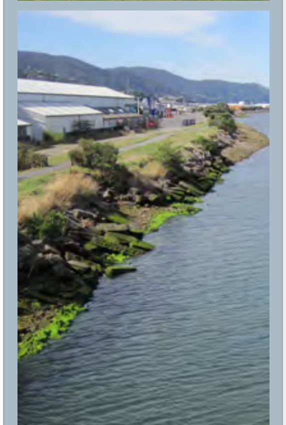


Figure 7. Macroalgal Ecological Quality Rating (EQR), Hutt Estuary, 2010-2016.
EQR values for 2010-2014 estimated based on previously mapped percentage cover and field photos showing very similar conditions to those quantified in 2015 and 2016.

4. Results and Discussion (continued)

4.3. SALTMARSH AND THE 200m TERRESTRIAL MARGIN





Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, and provides an important habitat for a variety of species including fish and birds. Saltmarsh generally has the most dense cover in the sheltered and more strongly freshwater influenced upper estuary, and relatively sparse cover in the lower (more exposed and saltwater dominated) parts of the estuary, with the lower boundary of saltmarsh growth limited for most species to above the height of mean high water neap (MHWN).

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Two supporting measures are used: i. loss compared to estimated natural state cover, and ii. percent cover within the estimated available saltmarsh habitat - defined as the area between MHWN and the upper tidal extent in the upper estuary, and getting progressively narrower as marine salinities limit growth in the lower estuary.

In Hutt estuary, there is no significant saltmarsh present due to the high level of historical estuary margin modification and reclamation, particularly bank steepening, armouring with rockwalls, and channelisation for flood control purposes. A total of 0.5ha of saltmarsh was mapped, mostly located in Waiwhetu Stream where saltmarsh has been replanted following stream restoration work in 2012 (Stevens and Robertson 2012). Elsewhere, there are occasional rushland plants confined within a very narrow band near the upper tide range, but no beds >2m in diameter.

Saltmarsh cover was <1% of the intertidal area, a risk rating of "HIGH". The supporting ratings similarly indicate a "HIGH" potential risk of adverse ecological effects with the likely natural state cover (e.g. Figure 1), and the percent cover within the estimated available saltmarsh habitat, both estimated as <40%.

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity. The results of the 2016 200m terrestrial margin mapping are summarised in Table 7 and Figure 8, and illustrated in the sidebar photos. Results show that there is no dense buffering vegetation surrounding Hutt Estuary. Land cover is dominated by public grassland and the golf course (45%), residential housing (24%), and commercial and industrial developments (26%). The open grassland areas provide a high level of amenity value and very good public access to most of the estuary margins, however, its ecological value to the estuary is negligible. The extent of the 200m terrestrial margin that was densely vegetated was <1%, a risk rating of "HIGH".

Table 7. Summary of 200m terrestrial margin land cover, Hutt Estuary, 2016.

Class	Dominant features	Percentage
Built feature	Road and rail corridors	4.8
Industrial	Lower estuary edges and Waiwhetu Stream margins	22.8
Commercial	Lower estuary edges and Waiwhetu Stream margins	3.6
Residential	Housing areas - often separated from the estuary by stopbanks	23.9
Scrub/Forest	Isolated restoration planting on the Waiwhetu Stream margins	0.1
Grassland	Public parkland and golf course inside stopbanks flanking the estuary margins	44.5
Unvegetated	Carparks	0.3
Total		**100**

Figure 8. Map of 200m Terrestrial Margin - Dominant Land Cover, Hutt Estuary, 2016.

4. Results and Discussion (continued)

4.4 SYNOPTIC FINE SCALE SEDIMENT AND WATER QUALITY SURVEY

As a consequence of extensive historical modification of the estuary margin (primarily drainage of saltmarsh, reclamation of intertidal habitat, and channelisation of river banks), the most extensive remaining habitat within Hutt Estuary is now its subtidal component. Widespread intertidal macroalgal growth, and the presence of very dense macroalgal growths in shallow subtidal areas along the channel margins in the lower estuary, highlight that subtidal habitat may be at risk from adverse eutrophication symptoms. In order to assess this, a synoptic abiotic fine scale sediment (and associated water) quality survey was undertaken in the mid-lower Hutt Estuary (Figure 9) in conjunction with the broad scale habitat mapping. Sites A-C were located in the deeper basin areas, and Site D was in shallow well flushed river gravels. The results of this survey are presented in Table 8, alongside their ecological risk ratings, with photos of each sample in Figure 13. Sites A-C were characterised by a thick anaerobic, organically enriched and muddy layer overlying relatively clean sediments.

A discussion of water and sediment quality results follows.

WATER QUALITY
The mid-lower section of the Hutt Estuary forms a shallow basin approximately 1.2-3.0m deep. Water quality in this section, assessed on 24 January 2016 (details see Appendix 3) indicated a salinity stratified water column with lighter, low salinity water on the surface (<0.5m) and denser, high salinity water below (>0.5m) (Figure 10). The data also showed some elevated chlorophyll a concentrations in the bottom water at the deeper lower sites (Figure 11), but water column Dissolved Oxygen (DO) concentrations all well above saturation (Figure 12).

Figure 9. Hutt Estuary sediment and water quality sampling locations, Jan. 2016.

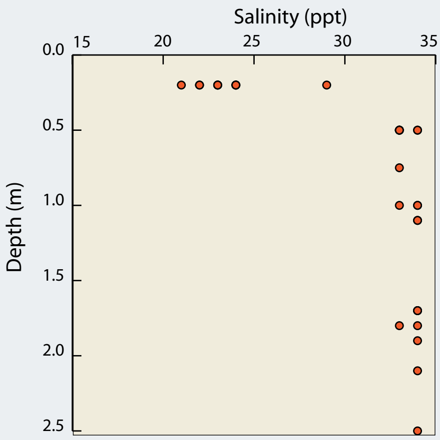


Figure 10. Salinity, Hutt Estuary, Jan. 2016.

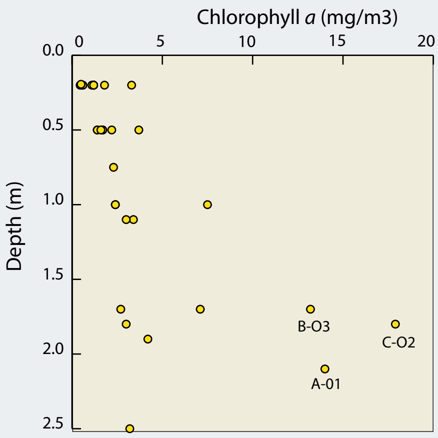


Figure 11. Chlorophyll *a*, Hutt Estuary, Jan. 2016.

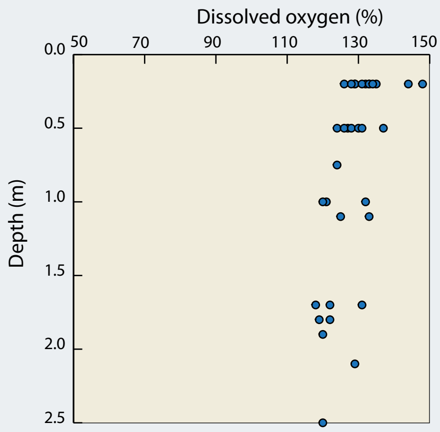


Figure 12. Dissolved oxygen, Hutt Estuary, Jan. 2016.

4. Results and Discussion (continued)

Site A1 sediment sample showing organic slime on mud/sand surface.

Site A2 sediment sample with sticks and leaves in anoxic mud/sands.

Site A3 sediment sample with thick bark layer over mud/sands.

Site B1 sediment sample showing anoxic mud/sands.

Site B2 sediment sample with shellfish in anoxic mud/sands.

Site B3 sediment sample with anoxic mud/sands.

Site C1 sediment sample with macroalgae and leaves in anoxic mud/sands.

Site C2 sediment sample with organic/mud slime over anoxic mud/sands.

Site C3 sediment sample with anoxic mud/sands.

Site D1 well oxygenated sediment sample dominated by gravels.

Site D2 well oxygenated sediment sample dominated by gravels.

Site D3 sediment sample dominated by gravels and macroalgae on large cobble.

Figure 13. Hutt Estuary, photographs of subtidal sediment samples, 24 January 2016.

Table 8. Sediment quality: physical and chemical results for Hutt Estuary, 24 January 2016.

Site/Rep/Date	Mud	aRPD	TOC	TN	TP	Salinity	Sand	Gravel	TS
	%	cm	%	mg/kg		ppt	%	%	mg/kg
Hutt A1 2016	48.9	0	2.9	1900	730	34	37.4	13.7	2600
Hutt A2 2016	25.3	0	4.7	2600	680	34	66.9	7.8	2500
Hutt A3 2016	13.3	>5	1.14	600	500	34	82.7	4	1100
Hutt B1 2016	43.1	0	3.1	2300	720	34	49.3	7.6	2400
Hutt B2 2016	29.2	0	1.08	1000	610	34	69.7	1.1	1100
Hutt B3 2016	33.9	0	2.7	2100	660	34	65.5	0.6	2900
Hutt C1 2016	31.6	0	6.7	6100	970	34	14.4	54	7600
Hutt C2 2016	49.9	0	6.2	5500	930	33	33.4	16.7	6000
Hutt C3 2016	45.5	0	3.4	3300	720	34	53.5	1.1	2900
Hutt D1 2016	3	>5	0.19	500	1,090	34	18.6	78.4	400
Hutt D2 2016	1.3	>5	0.16	500	540	34	41.8	56.8	400
Hutt D3 2016	1.7	>5	0.16	500	430	34	38.3	60.1	300
Condition Thresholds (from NZ ETI (Robertson et al. 2016a and 2016b)									
Band A - Very Low Risk	<5	NA	<0.5	<250	NA	NA	NA	NA	NA
Band B - Low Risk	5-15	NA	0.5-1.0	250-1000	NA	NA	NA	NA	NA
Band C - Moderate Risk	15-25	0.5-2cm	1-2	1000-2000	NA	NA	NA	NA	NA
Band D - High Risk	>25	<0.5cm	>2	>2000	NA	NA	NA	NA	NA

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
Hutt A1 2016	0.095	17.3	14.1	22	14.6	73	6.3	0.1
Hutt A2 2016	0.103	15.5	15.1	19	13.9	76	7	0.118
Hutt A3 2016	0.05	14.4	9.7	12.5	13.5	56	4.1	0.07
Hutt B1 2016	0.102	16.7	14.5	22	13.7	74	7.3	0.101
Hutt B2 2016	0.061	15.1	11.6	16.2	13.8	65	5.8	0.079
Hutt B3 2016	0.085	16.2	14.4	21	14.2	76	6.8	0.095
Hutt C1 2016	0.135	15.4	18.7	25	12.6	100	8	0.099
Hutt C2 2016	0.126	16.2	21	28	14.4	128	8.5	0.096
Hutt C3 2016	0.083	16.1	17.8	23	15.2	101	7.6	0.103
Hutt D1 2016	0.018	10.9	6.5	9.2	10.4	43	3.1	0.063
Hutt D2 2016	0.032	12	7.6	9.7	12.2	46	3.7	0.06
Hutt D3 2016	0.027	12.3	7.6	9.8	12.1	47	3.2	0.061
Condition Thresholds (ANZECC 2000 criteria, Very Low, <0.2 x ISQG Low; Low, 0.2 - 0.5 x ISQG Low; Moderate, 0.5 x to ISQG Low; High, >ISQG Low)								
Band A - Very Low Risk	<0.3	<16	<13	<4.2	<10	<40	<4	<0.03
Band B - Low Risk	0.3 - 0.75	16 - 40	13 - 32.5	4.2 - 10.5	10 - 25	40 - 100	4 - 10	0.03 - 0.075
Band C - Moderate Risk	0.75 - 1.5	40 - 80	32.5 - 65	10.5 - 21	25 - 50	100 - 200	10 - 20	0.075 - 0.15
Band D - High Risk	>1.5	>80	>65	>21	>50	>200	>20	>0.15
ISQG-Low	1.5	80	65	21	50	200	20	0.15
ISQG-High	10	370	270	52	220	410	70	1

EUTROPHICATION INDICATORS

The primary variables indicating eutrophication impacts in deeper subtidal habitat are sediment mud content, RPD depth, sediment organic matter (TOC), and nitrogen and phosphorus concentrations (TN and TP).

Sediment Mud Content

Sediment mud content (i.e. % grain size <63µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments, unless naturally erosion-prone with few wetland filters (e.g. Whareama Estuary), are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island).

In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >25% mud) in the primary sediment settlement areas e.g. where salinity driven flocculation occurs, or in areas that experience low energy tidal currents and waves (i.e. upper estuary intertidal margins and deeper subtidal basins). Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

The 2016 monitoring results showed that the subtidal Hutt Estuary sites A-C (in the deeper lower estuary) had relatively high (25-50%) sediment mud contents (Table 10, Figure 14), while Site D (shallow upstream river gravels) had low mud content (<5% mud). The elevated mud contents at the majority of the sites is likely indicative of relatively poor sediment oxygenation, and a high stress risk to mud and organic enrichment sensitive benthic biota as shown by the orange Band D rating (Robertson et al. 2015).

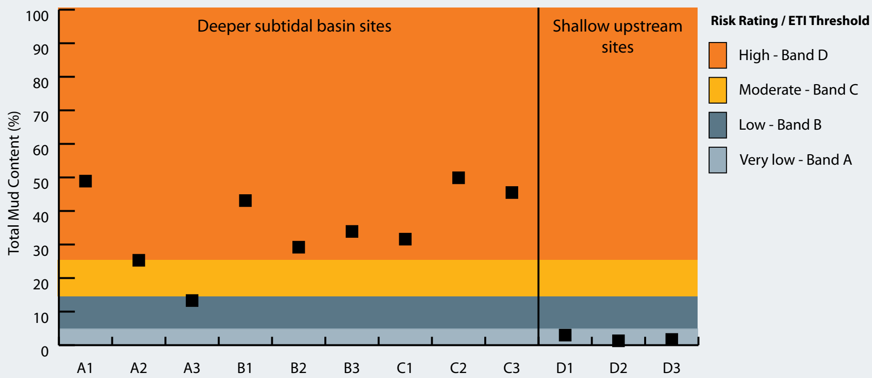


Figure 14. Sediment mud content at 12 sites in Hutt Estuary, Jan. 2016.

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the extent of oxygenation within sediments. Currently, the condition rating for redox potential is under development (Robertson et al. 2016b) pending the results of a PhD study in which redox potential (measured with an ORP electrode and meter) and visually assessed aRPD depth, and are being assessed across a gradient of eutrophication symptoms. Initial findings indicate that the recommended NZ estuary aRPD and redox potential thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Table 2 and Figure 15).

For this synoptic assessment, aRPD of sediments was assessed. Results show that the aRPD depth was at the surface of sediments (0cm) at most subtidal sites in the lower estuary (below the bridge) indicating a high risk of ecological impacts and poor conditions for sediment macrofauna in that area. Within the gravel and cobble dominated substrate at upstream Site D, sediment oxygenation was good.

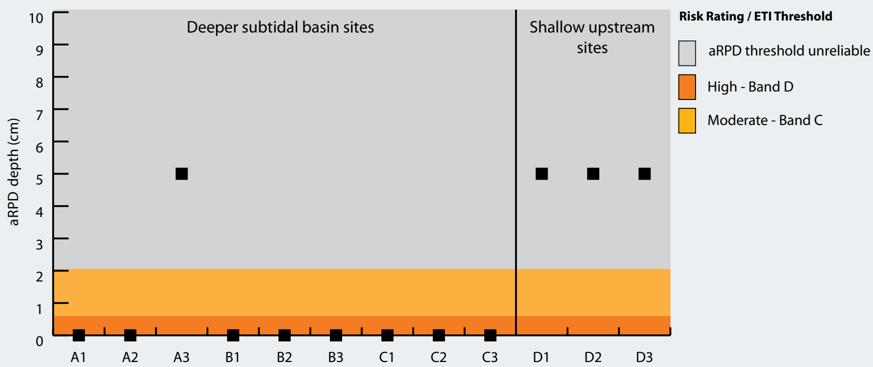


Figure 15. Mean apparent Redox Potential Discontinuity (aRPD) depth at 12 sites in Hutt Estuary, Jan. 2016.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow aRPD, excessive algal growth, high NZ AMBI biotic coefficient, then elevated TN, TP and TOC concentrations provide supporting information to indicate that loadings are exceeding the assimilative capacity of the estuary.

The 2016 results showed that for most lower estuary sites, both TOC and TN were at high levels (TOC >2% and TN >2000mg/kg) indicating, like the aRPD results, a high risk of ecological impacts and poor conditions for sediment macrofauna in that area (Figures 16 and 17). Total phosphorus concentrations were also measured (Table 8) and, like TN, showed high concentrations at the lower estuary sites, but unlike TN showed high concentrations at Site D as well.

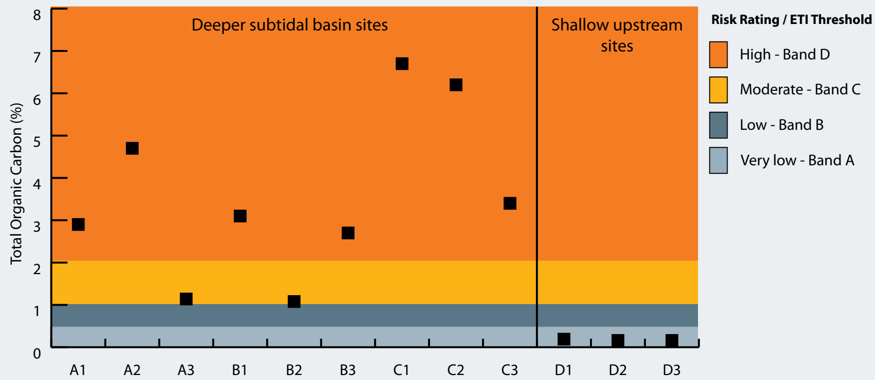


Figure 16. Sediment total organic carbon (TOC) at 12 sites in Hutt Estuary, Jan. 2016.

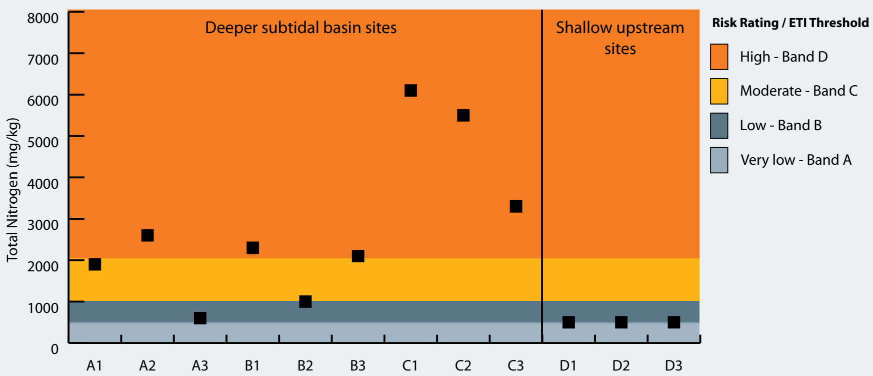


Figure 17. Mean Total Nitrogen (TN) at 12 sites in Hutt Estuary, Jan. 2016.

TOXICITY INDICATORS

At all sites, the heavy metals Cd, Cr, Cu, Hg, Pb, Zn, and arsenic used as an indicator of potential toxicants, were present at “VERY LOW” to “MODERATE” concentrations (Table 8) with all non-normalised values below the ANZECC (2000) ISQG-Low trigger values (and therefore unlikely to pose a toxicity threat to aquatic life). However, the heavy metal nickel exceeded the ISQG-Low trigger values at the majority of lower estuary sites, but not the ISQG-High values. In such cases as this, where the ISQG low limit is exceeded, the next step in the procedure according to ANZECC (2000) is to undertake toxicity testing of the contaminated sediment. This will determine whether the concentrations present are likely to cause harm to biota.

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping of Hutt Estuary in January 2016 showed it to be a moderate sized (47ha), highly modified, tidal river estuary. The key findings were:

- Intertidal flats (21% of the estuary area) were dominated by cobble (3.7ha, 38%) located primarily in the upper estuary, and firm sandy mud (2.8ha,31% - 58-87% sand) on intertidal flats. While relatively small, these sand flats are the largest remaining estuarine intertidal soft sediment flats in Wellington Harbour.
- Seawalls, river protection works and reclaimed margins (2.3ha, 24%) extended throughout the upper tidal zone of the entire estuary.
- Soft mud (0.2ha, 2%) was not a prominent feature, and sediment rate monitoring showed no net annual accumulation on the Te Mome intertidal flats since 2010, and no increase in sediment muddiness since measures were established at this site in 2014.
- Opportunistic macroalgal growth (primarily *Ulva intestinalis)* was extensive (98% of the available habitat), but biomass was generally low with only very localised intertidal nuisance conditions (rotting algae, poorly oxygenated and sulphide-rich sediments) areas - most likely due to strong flushing and flood scouring of the estuary. Macroalgal cover has not changed appreciably since 2010.
- No significant intertidal gross eutrophic zones have been recorded.
- Saltmarsh covered <1% of the estuary (0.5ha) and was limited by the hardened rockwalls that surround much of the estuary.
- The densely vegetated 200m margin cover (i.e. forest, scrub, tussock, and duneland) of the estuary was very low (<1%).

A synoptic assessment of deeper subtidal habitat in the lower estuary found sediments to be relatively muddy with high organic, nutrient and total sulphur contents, low levels of sediment oxygenation, and high levels of the heavy metal nickel. Such degraded conditions in the main lower estuary basin of Hutt Estuary indicate a high risk of stress to benthic communities in the area. In addition, very dense beds of nuisance macroalgae observed growing throughout shallow subtidal habitat strongly suggest elevated catchment nutrient inputs (from both water column and sediment sources) are driving observed growths.

Risk indicator ratings were used in relation to the key estuary stressors (i.e. sedimentation, eutrophication and habitat modification), and changes from baseline conditions, to assess overall condition (Table 9).

Table 9. Summary of intertidal broad scale risk indicator ratings for Hutt Estuary, 2016, and changes from baseline measures.

Major Issue	Indicator	2016 risk rating	Change since baseline
Sedimentation	Intertidal soft mud (% cover, vertical buildup, grain size)	VERY LOW	No significant change since 2004
Eutrophication	Macroalgal Growth (EQC)	HIGH	No significant change since 2010
	Gross Eutrophic Conditions (ha)	VERY LOW	No significant change since 2004
Habitat Modification	Saltmarsh (% of intertidal area)	HIGH	No significant change since 2004
	200m Vegetated Terrestrial Margin	HIGH	No significant change since 2004

The risk of adverse impacts occurring to estuary ecology was rated "HIGH" based on the extensive modification of the estuary margins which has displaced saltmarsh and vegetated terrestrial margin buffers, excessive macroalgal growth, and degraded subtidal habitat quality which indicates a high risk of stress to benthic communities in the area. No significant changes were recorded from baseline measures.

Strong flushing and flood scouring of the estuary appears to currently restrict the presence of nuisance conditions (rotting macroalgae and poorly oxygenated and sulphide rich sediments) to localised areas on intertidal flats, and in subtidal areas near the Hutt River mouth.

The key consequence is a reduction in the ecological value of important habitat features, particularly a reduced capacity to assimilate sediment and nutrient inputs, and reduced supporting habitat to birds, fish (whitebait) and shellfish.

6. MONITORING

Hutt River has been identified by GWRC as a priority for monitoring, and is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout the Wellington region. Based on the 2016 monitoring results and risk indicator ratings, the following monitoring recommendations are proposed by Wriggle for consideration by GWRC:

Broad Scale Habitat Mapping.
Continue broad scale habitat mapping at 10 yearly intervals, unless obvious changes are observed in the interim. Next monitoring recommended for Jan-Mar 2026.

Fine Scale Monitoring.
A three year annual fine scale monitoring baseline (2010 -2012) has been completed and repeat monitoring at five yearly intervals is recommended (next monitoring scheduled for January 2017.

Sedimentation Rate Monitoring.
Although fine sediment has not been identified as a priority issue in the estuary, it is recommended that sediment plates established in the estuary in 2010 be annually measured, and a single composite sediment sample be analysed for grain size, if other monitoring is being undertaken in the vicinity of the estuary.

Intensive Investigations.
In addition to the above routine SOE monitoring of long term fine scale and broad scale elements, to defensibly address the likely cause of macroalgal growths and subtidal habitat degradation, it is recommended that the following intensive investigations be considered:

1. Identify catchment sediment and nutrient sources (e.g. catchment wide nutrient inputs or localised sources), and derive a guideline limit for nutrient (likely to be nitrogen) inputs as the first step, followed by identification of major sources and their subsequent reduction to meet the guideline.

The key steps in such an approach are as follows:

- Assign catchment nutrient load guideline criteria to the estuary based on available catchment load/estuary response information from other relevant estuaries.
- Estimate catchment nutrient loads to the estuary using available catchment models and stream monitoring data.
- Determine the extent to which the estuary meets guideline catchment load criteria.
- Assess the potential for requiring more detailed assessments of priority catchments (e.g. estuary response modelling, stream and tributary monitoring, catchment load modelling).
- Develop plans for targeted management or restoration of priority catchments.

GWRC is currently investigating the sources of nutrients in the Hutt River catchment with a focus on nitrogen. Preliminary results from work by GWRC and GNS indicate that in addition to catchment sources, groundwater is a significant source of nitrogen to the river. Although these investigations are currently centred around the occurrence of cyanobacteria blooms in the Hutt River, the information will also be relevant to macroalgal blooms in the estuary.

2. Design and implement a subtidal mapping and monitoring programme to define the spatial extent of degraded subtidal habitat, and the extent of any biological impacts that may be occurring. Particular focus should be given to the impact of dredging in the lower estuary on the accumulation and settlement of organic material and fine muds.

7. MANAGEMENT

Using the results of the above investigations, it is recommended that the Council identify through stakeholder involvement an appropriate "target" estuary condition and determine any catchment management changes needed to achieve the target. For example, ensuring Good Management Practices (GMPs) are being implemented within the catchment. This step may require additional detailed investigation of fine sediment and nutrient sources, transport, deposition and export within the estuary, to provide underpinning information upon which to base management decisions.

Overall, the step-wise approach presented above is intended to cost effectively address the source of sediment, identify management targets, and guide management to help ensure that the assimilative capacity of the estuary is not exceeded so that the estuary can flourish and provide sustainable human use and ecological values in the long term.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

ANZECC. 2000. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

Atkinson, I.A.E. 1985. Derivation of vegetation mapping units for an ecological survey of Tongariro National Park Nth Island, NZ. NZ Journal of Botany, 23; 361-378.

Bell, J.M. 1910. The Physiography of Wellington Harbour, Trans. N.Z. Inst., 42 : 534–540.

Ellis, J., Cummings, V., Hewitt, J., Thrush, S. and Norkko, A. 2002. Determining effects of suspended sediment on condition of a suspension feeding bivalve (Atrina zelandica): results of a survey, a laboratory experiment and a field transplant experiment. Journal of Experimental Marine Biology and Ecology, 267, 147–174.

Hargrave, B.T., Holmer, M. and Newcombe, C.P. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Marine Pollution Bulletin, 56(5), pp.810–824.

Jørgensen, N. and Revsbech, N.P. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. Limnology and Oceanography 30:111-122.

Keeley, N.B., Forrest, B., Crawford, C. and Macleod, C. 2012. Exploiting salmon farm benthic enrichment gradients to evaluate the regional performance of biotic indices and environmental indicators. Ecological Indicators, 23, pp.453–466.

Lohrer, A., Thrush, S., Hewitt, J., Berkenbusch, K., Ahrens, M. and Cummings, V. 2004. Terrestrially derived sediment: response of marine macrobenthic communities to thin terrigenous deposits. Marine Ecology Progress Series, 273, 121–138.

Mannino, A. and Montagna, P. 1997. Small-Scale Spatial Variation of Macrobenthic Community. Estuaries, 20, 159–173.

Nelson, Walter G. (ed.) 2009. Seagrasses and Protective Criteria: A Review and Assessment of Research Status. Office of Research and Development, National Health and Environmental Effects Research Laboratory, EPA/600/R-09/050.

Norkko, A., Talman, S., Ellis, J., Nicholls, P. and Thrush, S. 2002. Macrofaunal Sensitivity to Fine Sediments in the Whitford Embayment. Auckland Regional Council, Technical Publication, 158, 1–30.

Peeters, E., Gardeniers, J., Koelmans, A. 2000. Contribution of trace metals in structuring in situ macroinvertebrate community composition along a salinity gradient. Environmental Toxicology and Chemistry, 19, 1002–1010.

Rakocinski, C., Brown, S., Gaston, G., Heard, R., Walker, W. and Summers, J. 1997. Macrobenthic Responses to Natural and Contaminant-Related Gradients in Northern Gulf of Mexico Estuaries. Ecological Applications, 7, 1278–1298.

Robertson, B.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., Thompson and S.J., Tuckey, B.J. 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

Robertson, B.M. and Stevens, L. 2015. Porirua Harbour: Fine Scale Monitoring 20014/15. Prepared for Greater Wellington Regional Council. 39p.

Robertson, B.M. and Stevens, L. 2012. Hutt Estuary: Fine Scale Monitoring 2011/12. Prepared for Greater Wellington Regional Council. 26p.

Robertson, B.M. and Stevens, L. 2011. Hutt Estuary: Fine Scale Monitoring 2010/11. Prepared for Greater Wellington Regional Council. 25p.

Robertson, B.M. and Stevens, L. 2010. Hutt Estuary: Fine Scale Monitoring 2009/10. Prepared for Greater Wellington Regional Council. 24p.

Robertson, B.M. and Stevens, L. 2007a. Wairarapa Coastal Habitats: Mapping, Risk Assessment and Monitoring. Prepared for Greater Wellington Regional Council. 120p.

Robertson, B.M. and Stevens, L. 2007b. Wellington Harbour, Kapiti, Southwest and South Coasts - Risks and Monitoring. Prepared for Greater Wellington Regional Council. 57p.

Robertson, B.M. and Stevens, L. 2007c. Lake Onoke 2007 - Vulnerability Assessment & Monitoring Recommendations. Prepared for Greater Wellington Regional Council. 57p.

Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016a. NZ Estuary Trophic Index. Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 47p.

Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016b. NZ Estuary Trophic Index. Screening Tool 2. 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.

Robertson, B.P. 2013. Determining the sensitivity of macro-invertebrates to fine sediments in representative New Zealand estuaries. Honours thesis, University of Victoria, Wellington.

Robertson, B.P., Gardner, J.P.A. and Savage, C. 2015. Macrobenthic - mud relations strengthen the foundation for benthic index development : A case study from shallow, temperate New Zealand estuaries. Ecological Indicators, 58, pp.161–174. Available at: http://dx.doi.org/10.1016/j.ecolind.2015.05.039.

9. References (continued)

Sakamaki ,T., Nishimura, O. 2009. Is sediment mud content a significant predictor of macrobenthos abundance in low-mud-content tidal flats? Marine and Freshwater Research, 60, 160.

Stevens, L. and Robertson, B.M. 2015a. Havelock Estuary 2014 Broad Scale Habitat Mapping. Prepared for Marlborough District Council. 43p.

Stevens, L. and Robertson, B.M. 2015b. Hutt Estuary: Intertidal Macroalgal Monitoring 2014/15. Prepared for Greater Wellington Regional Council. 12p.

Stevens, L. and Robertson, B.M. 2015c. Hutt Estuary: Intertidal Sediment Monitoring 2014/15. Prepared for Greater Wellington Regional Council. 2p.

Stevens, L. and Robertson, B.M. 2014. Hutt Estuary: Intertidal Macroalgal Monitoring 2013/14. Prepared for Greater Wellington Regional Council. 6p.

Stevens, L., and Robertson, B. 2012. Waiwhetu Stream 2012. Broad and Fine Scale Monitoring in the Tidal Reaches. Prepared for Greater Wellington Regional Council. 35p.

Stevens, L. and Robertson, B.M. 2010. Hutt River Estuary: Intertidal Macroalgal Monitoring. Prepared for Greater Wellington Regional Council. 4p.

Stevens, L., and Robertson, B. 2009. Waiwhetu Stream 2009. Broad and Fine Scale Monitoring in the Tidal Reaches. Prepared for Greater Wellington Regional Council. 28p.

Stevens, L., Robertson, B.M., and Robertson, B. 2004. Broad scale mapping of sandy beaches and river estuaries - Wellington Harbour and South Coast, 2004. Prepared for Greater Wellington Regional Council. 69p.

Stevens, L. and Robertson, B.M. 2012. Hutt River Estuary: Intertidal Macroalgal Monitoring. Prepared for Greater Wellington Regional Council. 4p.

Stevens, L. and Robertson, B.M. 2011. Hutt River Estuary: Intertidal Macroalgal Monitoring. Prepared for Greater Wellington Regional Council. 4p.

Stevens, L. and Robertson, B.M. 2010. Hutt River Estuary: Intertidal Macroalgal Monitoring. Prepared for Greater Wellington Regional Council. 4p.

Thrush, S.F., Hewitt, J., Norkko, A., Nicholls, P., Funnell, G. and Ellis, J. 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progress Series 263, 101–112.

Wehkamp, S., Fischer, P. 2012. Impact of hard-bottom substrata on the small-scale distribution of fish and decapods in shallow subtidal temperate waters. Helgoland Marine Research, 67, 59–72.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group). 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Retrieved from http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

References for Table 1

Abrahim, G. 2005. Holocene sediments of Tamaki Estuary: characterisation and impact of recent human activity on an urban estuary in Auckland, NZ. PhD Thesis, University of Auckland, Auckland, NZ, p 361.

Anderson, D., Gilbert, P. and Burkholder, J. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25, 704–726.

Ferreira, J., Andersen, J. and Borja, A. 2011. Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science 93, 117–131.

Gibb, J.G. and Cox, G.J. 2009. Patterns & Rates of Sedimentation within Porirua Harbour. Consultancy Report (CR 2009/1) prepared for Porirua City Council. 38p plus appendices.

IPCC. 2007. Intergovernmental Panel on Climate Change web site. https://www.ipcc.ch/publications_and_data/ar4/wg1/ (accessed December 2009).

IPCC. 2013. Intergovernmental Panel on Climate Change web site. https://www.ipcc.ch/report/ar5/wg1/ (accessed March 2014).

Kennish, M.J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation 29, 78–107.

National Research Council. 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. Ocean Studies Board and Water Science and Technology Board, Commission on Geosciences, Environment, and Resources. Washington, DC: National Academy Press. 405p.

Painting, S.J., Devlin, M.J., Malcolm, S.J., Parker, E.R., Mills, D.K., Mills, C. and Winpenny, K. 2007. Assessing the impact of nutrient enrichment in estuaries: susceptibility to eutrophication. Marine pollution bulletin 55(1-6), 74–90.

Robertson, B.M. and Stevens, L.M. 2007. Waikawa Estuary 2007 Fine Scale Monitoring and Historical Sediment Coring. Prepared for Environment Southland. 29p.

Robertson, B.M. and Stevens, L.M. 2010. New River Estuary: Fine Scale Monitoring 2009/10. Report prepared by Wriggle Coastal Management for Environment Southland. 35p.

de Salas, M.F., Rhodes, L.L., Mackenzie, L.A. and Adamson, J.E. 2005. Gymnodinoid genera Karenia and Takayama (Dinophyceae) in New Zealand coastal waters. New Zealand Journal of Marine and Freshwater Research 39,135–139.

Stewart, J.R., Gast, R.J., Fujioka, R.S., Solo-Gabriele, H.M., Meschke, J.S., Amaral-Zettler, L.A., Castillo, E. Del., Polz, M.F., Collier, T.K., Strom, M.S., Sinigalliano, C.D., Moeller, P.D.R. and Holland, A.F. 2008. The coastal environment and human health: microbial indicators, pathogens, sentinels and reservoirs. Environmental Health 7 Suppl 2, S3.

Swales, A. and Hume, T. 1995. Sedimentation history and potential future impacts of production forestry on the Wharekawa Estuary, Coromandel Peninsula. Prepared for Carter Holt Harvey Forests Ltd. NIWA report no. CHH004.

Valiela, I., McClelland, J., Hauxwell, J., Behr, P., Hersh, D. and Foreman, K. 1997. Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. Limnology and Oceanography 42, 1105–1118.

Wade, T.J., Pai, N., Eisenberg, J.N.S. and Colford, J.M. 2003. Do U.S. Environmental Protection Agency Water Quality Guidelines for Recreational Waters Prevent Gastrointestinal Illness? A Systematic Review and Meta-analysis. Environmental Health Perspective 111, 1102–1109.

APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Vegetation was classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the first two letters of their Latin genus and species names e.g. marram grass, *Ammophila arenaria*, was coded as Amar. An indication of dominance is provided by the use of ( ) to distinguish subdominant species e.g. Amar(Caed) indicates that marram grass was dominant over ice plant (*Carpobrotus edulis*). The use of ( ) is not always based on percentage cover, but the subjective observation of which vegetation is the dominant or subdominant species within the patch. A measure of vegetation height can be derived from its structural class (e.g. rushland, scrub, forest).

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.

Treeland: Cover of trees in the canopy is 20-80%. Trees are woody plants >10cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.

Scrub: Cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.

Shrubland: Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.

Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of *Cortaderia, Gahnia,* and *Phormium*, and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla,* and *Celmisia*.

Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.

Grassland: Vegetation in which the cover of grass (excluding tussock-grasses) in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground.

Sedgeland: Vegetation in which the cover of sedges (excluding tussock-sedges and reed-forming sedges) in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. "Sedges have edges." Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it's probably a grass or a reed, if the stem is clearly triangular, it's a sedge. Sedges include many species of *Carex, Uncinia,* and *Scirpus*.

Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Leptocarpus*.

Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata*.

Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.

Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and where herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.

Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and where lichen cover exceeds that of any other growth form or bare ground.

Introduced weeds: Vegetation in which the cover of introduced weeds in the canopy is 20-100% and in which the weed cover exceeds that of any other growth form or bare ground.

Seagrass meadows: Seagrasses are the sole marine representatives of the Angiospermae. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and is mapped separately to the substrates they overlie.

Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain cholorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope. Macroalgal density, biomass and entrainment are classified and mapped separately to the substrates they overlie.

Cliff: A steep face of land which exceeds the area covered by any one class of plant growth-form. Cliffs are named from the dominant substrate type when unvegetated or the leading plant species when plant cover is ≥1%.

Rock field: Land in which the area of residual rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. Boulder fields are named from the leading plant species when plant cover is ≥1%.

Cobble field: Land in which the area of unconsolidated cobbles (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Cobble fields are named from the leading plant species when plant cover is ≥1%.

Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. Gravel fields are named from the leading plant species when plant cover is ≥1%.

Mobile sand: Granular beach sand characterised by a rippled surface layer from strong tidal or wind-generated currents. Often forms bars and beaches.

Firm or soft sand: Sand flats may be mud-like in appearance but are granular when rubbed between the fingers and no conspicuous fines are evident when sediment is disturbed e.g. a mud content <1%. Classified as firm sand if an adult sinks <2 cm or soft sand if an adult sinks >2 cm.

Firm muddy sand: A sand/mud mixture dominated by sand with a moderate mud fraction (e.g. 1-10%), the mud fraction conspicuous only when sediment is mixed in water. The sediment appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm sandy mud, firm or soft mud, and very soft mud. When walking an adult sinks 0-2 cm. Granular when rubbed between the fingers.

Firm sandy mud: A sand/mud mixture dominated by sand with an elevated mud fraction (e.g. 10-25%), the mud fraction visually conspicuous when walking on it. The surface appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm or soft mud, and very soft mud. When walking yan adult sinks 0-2 cm. Granular when rubbed between the fingers, but with a smoother consistency than firm muddy sand.

Firm or soft mud: A mixture of mud and sand where mud is a major component (e.g. >25% mud). Sediment rubbed between the fingers retains a granular component but is primarily smooth/silken. The surface appears grey or brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm sandy mud, and very soft mud. Classified as firm mud if an adult sinks <5 cm (usually if sediments are dried out or another component e.g. gravel prevents sinking) or soft mud if an adult sinks >5 cm.

Very soft mud: A mixture of mud and sand where mud is the major component (e.g. >50% mud), the surface appears brown, and may have a black anaerobic layer below. When walking an adult sinks >5 cm unless another component e.g. gravel prevents sinking. From a distance appears visually similar to firm muddy sand, firm sandy mud, and firm or soft mud. Sediment rubbed between the fingers may retain a slight granular component but is primarily smooth/silken.

Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.

Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.

Shell bank: Area that is dominated by dead shells.

Artificial structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS

2. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5 part multimetric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool 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. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5 part multimetric OMBT, modified for NZ estuary types, is fully described below. It is based on macroalgal growth within 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 following measures are then taken:

1. Percentage cover of the available intertidal habitat (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH with macroalgal cover >5% are mapped spatially.

2. Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH, %).

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 established 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 water body. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse case scenario.

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 over-wintering 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.

Timing: Because the OMBT has been developed to classify data over the maximum growing season, sampling should target the peak bloom in summer (Dec-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 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 should be carried out during spring low tides in order to access the maximum area of the AIH.

Suitable Locations: 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). The tool is not currently used for assessing ICOLLs due to the particular challenges in setting suitable reference conditions for these water bodies.

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 A2).

- **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 un-impacted 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 (Foden et al. 2010).
- **Class Thresholds for Biomass.** Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 $g.m^{-2}$ wet weight was an acceptable level above the reference level of <100 $g.m^{-2}$ wet weight. In Good status only slight deviation from High status is permitted so 500 $g.m^{-2}$ 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 >500 $g.m^{-2}$ but less than 1,000 $g.m^{-2}$ would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1kg.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 (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 in a quadrat or error to be taken into account). 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 of macroalgae had started.

Each metric in the OMBT has equal weighting and is combined to produce the ecological quality ratio score (EQR).

Table A2. The final face value thresholds and metrics for levels of ecological quality status in the UK-WFD 2014.

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 ($g.m^2$) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass ($g.m^2$) 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.

Appendix 2. Estuary Condition Risk Ratings (continued)

EQR calculation

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Ratio** score (EQR).

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 by using the following categories:

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

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 A3).

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 A3 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.

References

DETR, 2001. Development of ecological quality objectives with regard to eutrophication. Final report, unpublished.

Foden, J., Wells, E., Scanlan, C. and Best M.A. 2010. Water Framework Directive development of classification tools for ecological assessment: Opportunistic Macroalgae Blooming. UK TAG Report for Marine Plants Task Team, January 2010, Publ. UK TAG.

Hull, S.C. 1987. Macroalgal mats and species abundance: a field experiment. Estuar. Coast. Shelf Sci. 25, 519-532.

Lowthion, D., Soulsby, P.G. and Houston, M.C.M. 1985. Investigation of a eutrophic tidal basin: 1. Factors affecting the distribution and biomass of macroalgae. Marine Environmental Research 15: 263–284.

Raffaelli, D., Hull, S. and Milne, H. 1989. Long-term changes in nutrients, weedmats and shore birds in an estuarine system. Cah. Biol. Mar. 30, 259–270.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group) 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Retrieved from http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

Wither, A. 2003. Guidance for sites potentially impacted by algal mats (green seaweed). EC Habitats Directive Technical Advisory Group report WQTAG07c.

Appendix 2. Estuary Condition Risk Ratings (continued)

Table A3. 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)	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)	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.

Table A4. The final face value thresholds and metrics for levels of ecological quality status used to rate opportunistic macroalgae in the current in the study (modified from UK-WFD 2014).

MACROALGAL INDICATORS (OBMT approach - WFD_UKTAG 2014)					
QUALITY RATING	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) [>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.m² wet wgt) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 2000	≥2000
Average biomass (g.m² wet wgt) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 2000	≥2000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

APPENDIX 3. HUTT ESTUARY MACROALGAL DATA, JAN. 2016

Patch ID	Patch area (ha)	Percent cover	Mean Biomass (g.m-2 wet weight)	Presence (1) or absence (0) of entrained algae)	aRPD (cm)	Presence (1) or absence (0) of soft mud	Patch Biomass (kg)	Dominant species
1	0.16	70	80	0	>5	0	124	*Ulva intestinalis*
2	0.44	70	80	0	>5	0	352	*Ulva intestinalis*
3	0.05	70	80	0	>5	0	36	*Ulva intestinalis*
4	0.33	50	50	0	NA	0	163	*Ulva intestinalis*
5	0.96	80	80	0	NA	0	18	*Ulva intestinalis*
6	0.24	80	100	0	2	0	5	*Ulva intestinalis*
7	0.05	75	10	0	2	0	123	*Ulva intestinalis*
8	0.18	75	10	0	2	0	770	*Ulva intestinalis*
9	0.02	100	600	0	2	0	50	*Ulva intestinalis*
10	0.34	50	30	0	3	0	102	*Ulva intestinalis*
11	0.25	20	20	0	NA	0	91	*Ulva intestinalis*
12	0.23	100	40	0	NA	0	500	*Ulva intestinalis*
13	0.19	80	3500	0	3	0	6640	*Ulva intestinalis*
14	0.28	80	180	0	2	0	1539	*Ulva intestinalis*
15	0.49	20	315	0	3	0	7321	*Ulva intestinalis*
16	0.72	60	1020	0	2	0	244	*Ulva intestinalis*
17	0.29	30	250	0	2	0	57	*Ulva intestinalis*
18	0.58	100	4640	0	3	0	27135	*Ulva intestinalis*
19	0.11	100	50	0	>5	0	2360	*Ulva intestinalis*
20	0.06	100	4000	0	2	0	5748	*Ulva intestinalis*
21	0.10	100	6000	0	2	0	7	*Ulva intestinalis*
22	0.01	50	80	0	2	0	15	*Ulva intestinalis*
23	0.03	20	10	0	NA	0	13	*Ulva intestinalis*
24	0.01	80	75	0	2	0	14	*Ulva intestinalis*
25	0.20	40	160	0	1.5	0	211	*Ulva intestinalis*
26	0.05	70	30	0	2	0	2	*Ulva intestinalis*
27	0.04	70	30	0	2	0	7	*Ulva intestinalis*
28	0.03	90	40	0	2	0	3	*Ulva intestinalis*
29	0.10	30	220	0	3	0	315	*Ulva intestinalis*
30	0.02	20	10	0	NA	0	6	*Ulva intestinalis*
31	0.01	50	80	0	>5	0	725	*Ulva intestinalis*
32	0.10	30	450	0	2	0	434	*Ulva intestinalis*
33	0.01	80	120	0	2	0	34	*Ulva intestinalis*
34	0.04	40	80	0	3	0	13	*Ulva intestinalis*
35	0.26	50	50	0	1	0	132	*Ulva intestinalis*
36	0.33	80	40	0	NA	0	131	*Ulva intestinalis*
37	0.02	80	60	0	NA	0	10	*Ulva intestinalis*
38	0.01	40	30	0	2	0	3	*Ulva intestinalis*
39	0.01	30	50	0	NA	0	6	*Ulva intestinalis*
40	0.29	40	1200	0	2	0	3434	*Ulva intestinalis*
41	0.02	80	2500	0	2	0	557	*Ulva intestinalis*
42	0.14	70	30	0	>5	0	41	*Ulva intestinalis*

Appendix 3. Hutt Estuary Macroalgal Data, Jan. 2016 (continued)

Figure A1. Location of macroalgal patches (>5% cover) used in assessing Hutt Estuary, Jan. 2016.

APPENDIX 4. ANALYTICAL METHODS AND 2016 DETAILED RESULTS

Indicator	Laboratory	Method	Detection Limit
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g/100g dry wgt
Dry Matter (Env)	R.J. Hill	Dried at 103°C (removes 3-5% more water than air dry).	NA
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg/kg dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt
Total Sulphur	R.J. Hill	LECO SC32 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.005 g/100g dry wgt

Subtidal Station Locations

SUBTIDAL SITES	Hutt Sub A-01	Hutt Sub A-02	Hutt Sub A-03	Hutt Sub B-01	Hutt Sub B-02	Hutt Sub B-03	Hutt Sub C-01	Hutt Sub C-02	Hutt Sub C-03	Hutt Sub D-01	Hutt Sub D-02	Hutt Sub D-03
NZTM EAST	1759253	1759276	1759306	1759270	1759245	1759216	1759259	1759225	1759190	1759276	1759242	1759205
NZTM NORTH	5433739	5433734	5433730	5433516	5433531	5433545	5433403	5433410	5433409	5433242	5433247	5433245

Intertidal Station Locations

INTERTIDAL SITES	S1	S2	S3	S4	S5	S6	S7
NZTM EAST	1759095	1759386	1759124	1759100	1759078	1759018	1759033
NZTM NORTH	5433548	5434098	5433536	5433447	5433627	5433655	5433634

Appendix 4. Analytical Methods and 2016 Detailed Results (continued)

Field measures of water quality at Hutt Estuary synoptic subtidal sites, 24 January 2016.

Surface Water Quality	Depth	Salinity	DO	DO	Chl-a
Site	**(m)**	**(ppt)**	**(% saturation)**	**(mg/l)**	**(mg/m³)**
Hutt Sub A-01	0.2	21	134	11	3.3
Hutt Sub A-02	0.2	24	148	11.5	0.5
Hutt Sub A-03	0.2	23	144	11.5	0.4
Hutt Sub B-01	0.2	24	133	10.7	0.6
Hutt Sub B-02	0.2	23	131	10.7	1.2
Hutt Sub B-03	0.2	24	128	10	1.8
Hutt Sub C-01	0.2	24	126	10.2	1.1
Hutt Sub C-02	0.2	22	132	10.7	1.2
Hutt Sub C-03	0.2	23	129	10.4	1.2
Hutt Sub D-01	0.2	22	129	10.5	0.6
Hutt Sub D-02	0.2	23	135	11	0.5
Hutt Sub D-03	0.2	29	133	11	1.2
Mid -Depth Water Quality	**Depth**	**Salinity**	**DO**	**DO**	**Chl-a**
Site	**(m)**	**(ppt)**	**(% saturation)**	**(mg/l)**	**(mg/m³)**
Hutt Sub A-01	0.5	33	131	10.2	3.7
Hutt Sub A-02	0.5	33	137	10.7	1.6
Hutt Sub A-03	0.5	24	130	10.5	1.4
Hutt Sub B-01	0.5	34	128	10	2.2
Hutt Sub B-02	0.5	33	126	9.7	1.4
Hutt Sub B-03	0.5	33	127	9.3	1.7
Hutt Sub C-01	1	33	120	9.3	2.4
Hutt Sub C-02	0.5	33	124	9.6	1.7
Hutt Sub C-03	0.75	33	124	9.6	2.3
Near Bottom Water Quality*	**Depth**	**Salinity**	**DO**	**DO**	**Chl-a**
Site	**(m)**	**(ppt)**	**(% saturation)**	**(mg/l)**	**(mg/m³)**
Hutt Sub A-01	2.1	34	129	10	14
Hutt Sub A-02	1.7	34	131	10.2	2.7
Hutt Sub A-03	1.1	34	133	10.1	3
Hutt Sub B-01	1.8	34	122	9.5	3
Hutt Sub B-02	1.9	34	120	9.4	4.2
Hutt Sub B-03	1.7	34	122	9.5	13.2
Hutt Sub C-01	1.7	34	118	9.2	7.1
Hutt Sub C-02	1.8	33	119	9.2	17.9
Hutt Sub C-03	2.5	34	120	9.3	3.2
Hutt Sub D-01	1.1	34	125	9.8	3.4
Hutt Sub D-02	1	34	132	10.2	7.5
Hutt Sub D-03	1	34	121	9.4	2.4

*Near bottom water quality measured approximately 0.2m above the seabed.

Field description of sediments at Hutt Estuary synoptic subtidal sites, 24 January 2016.

Site	Dominant surface feature	Underlying substrate
Hutt Sub A-01	Anoxic mud and organic matter	Oxic Sand
Hutt Sub A-02	Anoxic mud and organic matter	Oxic Sand
Hutt Sub A-03	Oxic mud and organic matter	Oxic Sand
Hutt Sub B-01	Anoxic mud	Oxic Sand
Hutt Sub B-02	Anoxic mud	Oxic Sand
Hutt Sub B-03	Anoxic mud	Oxic Sand
Hutt Sub C-01	Anoxic mud and organic matter	Oxic Gravel
Hutt Sub C-02	Anoxic mud and organic matter	Oxic Gravel
Hutt Sub C-03	Anoxic mud and organic matter	Oxic Gravel
Hutt Sub D-01	Oxic Gravel	Oxic Sand
Hutt Sub D-02	Oxic Gravel	Oxic Sand
Hutt Sub D-03	Oxic Gravel	Oxic Sand