coastalmanagement

Porirua Harbour

Broad Scale Habitat Mapping 2007/08

Prepared for Greater Wellington Regional Council and Porirua City Council

June 2008

Cover Photo: Pauatahanui Arm of Porirua Harbour

Porirua Harbour

Broad Scale Habitat Mapping 2007/08

Prepared for

Greater Wellington Regional Council and
Porirua City Council

By

Leigh Stevens and Barry Robertson

Wriggle Limited, PO Box 1622, Nelson 7040, NZ. Ph 021 417 936, 0275 417 935, www.wriggle.co.nz

All photos by Wriggle except where noted otherwise.

Contents

List of Figures

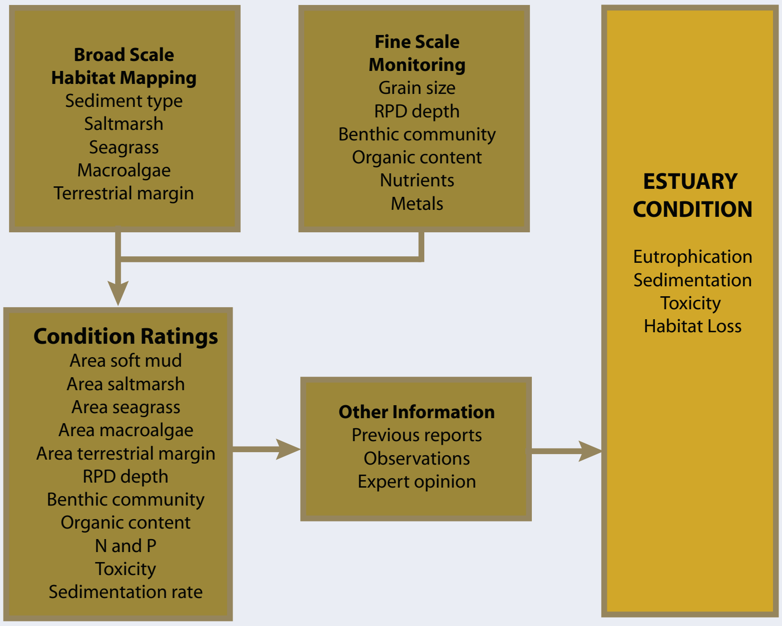
List of Tables

EXECUTIVE SUMMARY

Greater Wellington Regional Council (GWRC) has a proposed long-term monitoring programme to assess the condition of key estuaries, beaches and coastlines in its region. In 2007, GWRC added Porirua Harbour, an 800ha tidal lagoon estuary to the proposed monitoring programme. Intertidal monitoring to date consists of three components which are each reported separately: an ecological vulnerability assessment (Robertson and Stevens 2007b), broad scale habitat mapping (current report) and fine scale physical, chemical and biological monitoring (Robertson and Stevens 2008).

The current report describes the broad scale habitat mapping undertaken in December 2007. Broad scale intertidal habitat mapping is a tool used to assess the condition of estuaries. It includes mapping and condition ratings for the following key habitat elements; estuary sediment types, macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria, Enteromorpha*), seagrass (*Zostera*) beds, saltmarsh vegetation, and the 200m terrestrial margin surrounding the estuary. The methods used were based on the tools included in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002), and a number of extensions (Table 1).

The outcome is a series of GIS-based habitat maps (often complex), that provide measures of the extent of different types of habitat cover. Taken in combination with the fine scale monitoring results, these measures are then applied into different rating scales which are used alongside other relevant expert information to assess the condition of the estuary in relation to the key issues of sedimentation, eutrophication and habitat loss. Toxicity is addressed as part of fine scale monitoring, while disease risk is monitored and reported separately by GWRC, principally through its recreational water quality monitoring programme. A summary of the approach is outlined in the figure below.

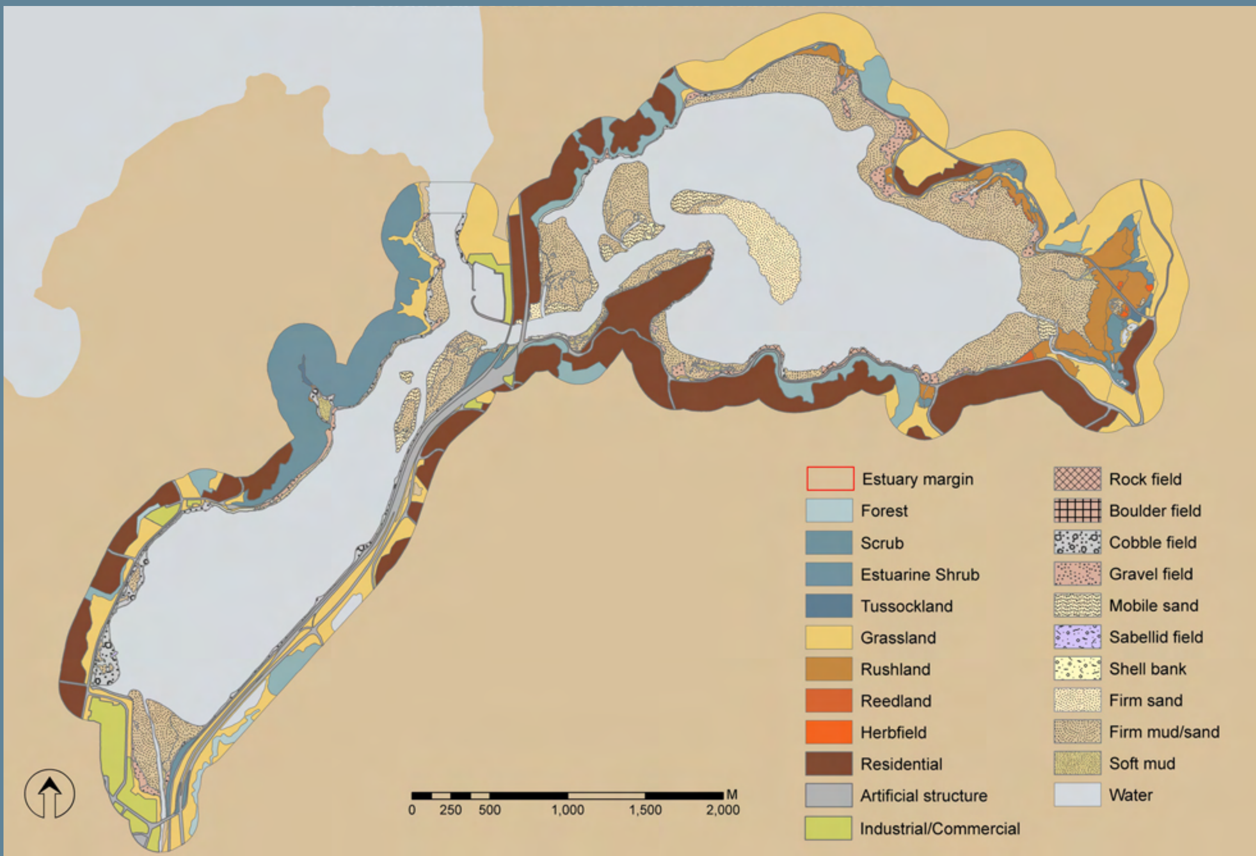


A broad scale summary map is presented on the next page (much reduced but included as a reminder of the more user-friendly GIS-based maps that accompany this report).

Using this approach, the key findings of the broad scale mapping in relation to the condition of Porirua Harbour and the key estuary issues were as follows:

EXECUTIVE SUMMARY

Summary of the broad scale features of Porirua Harbour, December 2007.



BROAD SCALE RESULTS

Porirua Harbour at 807ha (524ha in the Pauatahanui Arm and 283ha in the Porirua Arm) is moderate in size compared with other New Zealand estuaries. However, unlike the majority of New Zealand's tidal lagoon estuaries (which tend to empty almost completely at low tide), Porirua Harbour was found to be mainly subtidal (65% of the estuary was underwater at low tide), particularly the Porirua Arm. Such a characteristic is important, particularly in relation to the key estuary issues of sedimentation and eutrophication.

In relation to the major habitat types, the majority of the intertidal area in both arms was dominated by unvegetated, poorly sorted firm muddy sands (122ha in Pauatahanui Arm and 33ha in Porirua Arm). Firm sands and mobile sands occupied 28ha and 4.4ha respectively, whereas soft muds occupied only 1.9ha and 1.5ha respectively.

Saltmarsh was virtually non-existent in the Porirua Arm but occupied 51ha in the Pauatahanui Arm where it was dominated by wide beds of rushland (mostly searush and jointed wire rush) which, as the terrestrial influence increased, transitioned through areas dominated by saltmarsh ribbonwood (*Plagianthus divaricatus*) and grassland (mostly tall fescue - *Festuca arundinacea*). Areas of seagrass were relatively extensive, 41.2ha in the Pauatahanui Arm and 17.3ha in the Porirua Arm.

In relation to the terrestrial margin bordering the estuary (a 200m wide margin was mapped), the dominant habitat types were residential (118ha in the Pauatahanui Arm and 41ha in the Porirua Arm), grassland (108ha and 56ha respectively), artificial structures, primarily road and rail (43ha and 50ha respectively) and scrub and forest (33ha and 71ha respectively).

EXECUTIVE SUMMARY

BROAD SCALE CONDITION RATINGS

This intertidal broad scale mapping data were then used to determine the broad scale condition ratings for key broad scale indicators. The results were as follows.

BROAD SCALE RATING 2007	% COVER SOFT MUD	% COVER MACROALGAE	% COVER SEAGRASS	% COVER SALTMARSH	TERRESTRIAL VEGETATED BUFFER
PAUATAHANUI ARM	VERY LOW	MODERATE	LOW-MODERATE	MODERATE	POOR
PORIRUA ARM	VERY LOW	MODERATE	MODERATE	VERY LOW	POOR

ESTUARY ISSUES

The final step was to use the broad scale results, as well as other information, to provide an understanding of the estuary condition in relation to the key estuary issues of sedimentation, eutrophication and habitat loss. As mentioned previously, toxicity is addressed as part of fine scale monitoring and disease risk is monitored and reported separately by GWRC.

ISSUE RATING SEDIMENTATION
MODERATE SEDIMENTATION for whole Harbour

Sedimentation. If sediment inputs to an estuary are excessive, they infill quickly with muds, reducing biodiversity and human values and uses. In subtidally-dominated estuaries like the Porirua Harbour, fine muds tend to settle in three main areas; the subtidal central basin, and to a lesser extent the unvegetated intertidal area around the central basins; saltmarsh areas; and sheltered estuary arms. It is therefore not unexpected that the 2007 mapping showed that the intertidal area in both arms was dominated by sandy sediments, and previous studies (e.g. Healy 1980) showed that the subtidal basins were dominated by soft muds. Overall, the combined results indicate that sedimentation is an issue in Porirua Harbour and that ongoing monitoring and management is required. Because of the high cost of subtidal monitoring and the fact that soft mud already dominates the subtidal basins, broad scale mapping of the less impacted and more vulnerable intertidal area has been chosen as the preferred approach. In addition, measurement of the sedimentation rate in both intertidal and subtidal areas has been initiated with deployment of sediment plates at 4 intertidal sites and 1 subtidal site. In the future, it is recommended that additional subtidal plates be deployed and subtidal sediment type assessed at a few key sites.

ISSUE RATING EUTROPHICATION
MODERATELY EUTROPHIC for whole Harbour

Eutrophication. Typical New Zealand estuaries are shallow, well-flushed and have a large intertidal area. In such estuaries, nuisance intertidal macroalgal growth is a key broad scale indicator of eutrophication. In estuaries like Porirua Harbour, where the intertidal area is much smaller, macroalgal growth occurs both inter-tidally and to a certain extent (depending on water clarity and currents), sub-tidally. It is therefore important in such estuaries to consider both locations when drawing conclusions related to eutrophication status. Bearing this in mind, the 2007 macroalgal mapping results showed that approximately 70% of the intertidal area of each arm had a significant macroalgal cover (i.e. greater than 5% cover). Subtidal mapping has not been undertaken because of its expense, but observations of growth in a number of spot locations suggest that it is significant. Combining these findings with the "moderately enriched" classification for the 4 fine scale monitoring sites (Robertson and Stevens 2008), indicates an overall moderately enriched or moderately eutrophic classification for the estuary. Eutrophication must therefore be classed as an issue in Porirua Harbour with ongoing monitoring and management required. Like sedimentation, the intertidal area has been chosen as the most cost-effective and practical indicator for ongoing monitoring.

EXECUTIVE SUMMARY

ISSUE RATING HABITAT LOSS
MODERATE for Pauatahanui Arm
VERY HIGH for Porirua Arm

Habitat Loss. Estuaries function best with a large area of rooted vegetation, i.e. saltmarsh and seagrass (attributes are described in Appendix 2), as well as a healthy vegetated terrestrial margin. Loss of this habitat reduces wildlife, recreational and aesthetic values, while also adversely impacting on an estuary's role in flood and erosion protection, contaminant mitigation, sediment stabilisation, and nutrient cycling.

Past habitat losses from forest clearance, reclamations, roading and causeways, rubbish dumping, stock grazing, drainage, and erosion protection have reduced the extent of saltmarsh and the vegetated terrestrial buffer around Porirua Harbour. This was reflected in the 2007 broad scale mapping results which showed most of the estuary was immediately bounded by artificial structures (e.g. riprap seawalls, road and rail networks), with the terrestrial land cover dominated by residential and commercial/industrial developments, and grassland. Such modification of the estuary margin has contributed to "coastal squeeze" where the capacity for estuarine vegetation to respond to changes in sediment and water levels has been greatly reduced. This has significant implications for the ability of the estuary to respond to predicted sea level rise, one of the major stressors identified in the recent vulnerability assessment of the estuary (see Robertson and Stevens 2007b).

Further, the terrestrial buffer was not extensively vegetated and in many instances was physically separated from the estuary. Within the estuary itself, virtually no saltmarsh remains in the Porirua Arm, while the moderate cover of healthy saltmarsh in the Pauatahanui Arm is restricted primarily to the east. Overall, the combined results indicate that saltmarsh and margin habitat loss is a very high issue in the Porirua Arm and a moderate issue in the Pauatahanui Arm. Consequently, ongoing monitoring of the area of saltmarsh, and terrestrial vegetation is recommended (at 5 yearly intervals), with management encouraged to address habitat loss.

For saltmarsh, the scope for restoration is large, and there is evidence of strong community and regulatory support for restoration initiatives. Significant effort has been put into replanting saltmarsh and margin vegetation in the Pauatahanui Arm, and similar initiatives in the Porirua Arm are likely to greatly enhance the value of the estuary. Similarly, the scope for restoration of the terrestrial margin is large, but more challenging given the dominance of roads along the estuary margin.

Seagrass was present in relatively extensive intertidal beds in both arms, and beds appeared healthy, stable, and relatively free of fine sediment. It was rated a moderate issue overall with a baseline record established to measure future change, and development of a strategy to ensure the protection of remaining seagrass recommended. Subtidal mapping has not been undertaken because of its expense, but seagrass was also observed in shallow subtidal areas in a number of locations.

MONITORING

Porirua Harbour has been identified by GWRC as a priority for monitoring as part of GWRC's proposed coastal monitoring programme being undertaken in a staged manner throughout the region. Under this proposed long term programme, GWRC will undertake broad scale monitoring on a 5 yearly cycle (next scheduled for December 2012) to monitor and assess ongoing changes in broad scale substrate and vegetation in the Porirua Harbour.

RECOMMENDED MANAGEMENT

Because of the high use of Porirua Harbour and the presence of extensive past modifications that have degraded the estuary condition (e.g. saltmarsh reclamation, loss of vegetated terrestrial margin, increased muddiness, litter and disease risk), there is a high potential for estuary restoration to be undertaken, particularly given high local and regional motivation. In particular, the following management actions are encouraged:

Identify and Implement Catchment BMPs

- Catchment runoff is one of the major stressors in estuaries with the likely ecological response one of lowered biodiversity and lowered aesthetic and human use values. To prevent avoidable inputs, best management practices (BMPs) should be identified and implemented to reduce sediment, nutrient, and pathogen runoff from catchment "hotspots". Long term solutions such as this, along with a range of other planning mechanisms to address inputs, are being established and implemented by GWRC.

Restore Saltmarsh Habitat

- The almost complete loss of saltmarsh from the Porirua Arm has certainly contributed to reduced biodiversity and increased sedimentation reaching subtidal areas of the estuary, while also lowering aesthetic and human use values. It has also allowed rubbish and weeds to enter the estuary. Because of the importance of saltmarsh, it is recommended that a plan be developed to encourage its re-establishment, particularly along the Porirua foreshore, and to remove rubbish from the estuary. Development of the estuary margin (e.g. decreasing seawall gradients and recreating upper intertidal saltmarsh areas through reclamation) is likely to be both appropriate and necessary in many instances.

Reinstate Margin Buffer

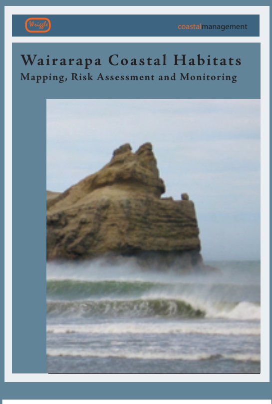
- Human development of the estuary margin has resulted in clearance of surrounding bush, and construction of artificial structures around much of the estuary. Additionally, there have been significant areas of saltmarsh drained and reclaimed for roading, rail and residential and commercial purposes. This has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary. Many areas are also adversely affected by nuisance weeds and rubbish. Because of the importance of a natural vegetated margin around the estuary, it is recommended that a strategy be developed to encourage re-establishment of a natural vegetated margin around the estuary where possible.

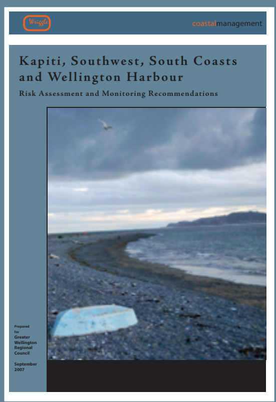
Coastal Squeeze

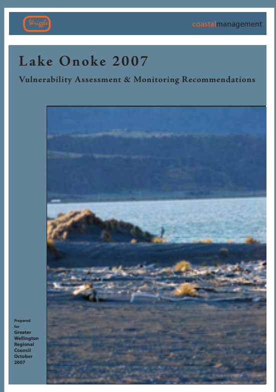
- Sea level rise is a key estuary stressor. The ability of estuary vegetation to respond to sea level rise relies to a large extent on saltmarsh and terrestrial margin vegetation being able to migrate landward to maintain suitable growing conditions. In the Porirua Harbour, migration is limited by reclamations, seawalls, roads and causeways, flood controls, and by drainage of low-lying land resulting in coastal squeeze. Areas where coastal squeeze is likely to occur should be identified and used to guide existing revegetation efforts, and to identify where conflict may occur between existing uses and estuary expansion as a consequence of sea level rise.

1. INTRODUCTION

OVERVIEW







Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. Recently, Greater Wellington Regional Council (GWRC) undertook vulnerability assessments of its region's coastlines and estuaries to establish priorities for a long-term coastal monitoring programme for the region (Robertson & Stevens 2007a,b,c). These assessments identified the following estuaries as immediate priorities for monitoring: Porirua Harbour, Whareama Estuary, Lake Onoke, Hutt Estuary and Waikanae Estuary. In late 2007, GWRC began estuary monitoring in a staged manner, with the Porirua Harbour (Porirua and Pauatahanui Arms) and Whareama Estuary (Wairarapa Coast) as the first estuaries. Wriggle Coastal Management were contracted to undertake the work using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions (Table 1).

The Porirua Harbour monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** of the estuaries to major issues and appropriate monitoring design. This component has been completed and is reported on in Robertson and Stevens (2007b).
2. **Broad scale habitat mapping,** (EMP approach). This component, which documents the key habitats within the estuary and changes to these habitats over time, is the subject of the current report.
3. **Fine scale physical, chemical and biological monitoring**, (EMP approach) including sedimentation plate deployment. This component, which provides detailed information on estuary condition, is reported separately in Robertson and Stevens (2008).

Porirua Harbour is a large, shallow, well flushed "tidal lagoon" type estuary consisting of two arms, Porirua Inlet and Pauatahanui Inlet. It has high uses and ecological values and provides a natural focal point for the thousands of people that live near or visit its shores. The harbour has been extensively modified over the years, particularly the Porirua Inlet where the once vegetated arms have been reclaimed, and now most of the inlet is lined with rockwalls. The Pauatahanui Inlet is less modified and has extensive areas of saltmarsh, a large percentage of which have been improved through local community efforts. Catchment landuse is dominated by urban use in the Porirua Inlet and by grazing in the steeper Pauatahanui Inlet catchment, although urban (residential) development is significant in some areas particularly along the southern shoreline.

Because of long term, low-moderate risks to Porirua Harbour from a number of sources (i.e. catchment landuse practices, invasive weeds and pests, margin development, sea level rise, sewer overflows, urban stormwater), as well as possible improvements that may change harbour condition (i.e. increased saltmarsh area, improved water quality), there is a need to collect further information, the bulk of which fits the description of a long term monitoring programme. This information will help guide any management actions, allow effectiveness to be monitored, and identify any need for revised actions.

This report documents the results of the broad scale monitoring undertaken in December 2007 of Porirua Harbour (both Porirua and Pauatahanui Arms). It includes:

- Broad scale mapping of estuary sediment types.
- Broad scale mapping of macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria, Enteromorpha*).
- Broad scale mapping of seagrass (*Zostera*) beds.
- Broad scale mapping of saltmarsh vegetation.
- Broad scale mapping of the 200m terrestrial margin surrounding the estuary.
- Condition ratings for the Porirua Harbour (based on Robertson & Stevens, 2006, 2007). A suggested monitoring or management response is linked to each condition rating.

Table 1. Coastal Monitoring Tools (Wriggle Coastal Management)

Resource	Tools for Monitoring and Management
Estuaries	Estuary vulnerability matrix. Broad scale estuary and 200m terrestrial margin habitat mapping. Fine scale estuary monitoring. Sedimentation rate measures (using plates buried in sediment). Historical sedimentation rates (using radio-isotope ageing of sediment cores). Macroalgae and seagrass mapping (reported as separate GIS layers). Condition ratings for key indicators. Georeferenced digital photos (as a GIS layer). Upper estuary monitoring and assessment.
Beaches, Dunes	Beach and dune vulnerability matrix. Broad scale beach, dune and terrestrial margin mapping. Fine scale beach monitoring.
Rocky Shores	Rocky shore vulnerability matrix. Broad scale rocky shore and terrestrial margin mapping. Fine scale rocky shore monitoring.

Table 2. Summary of the major issues affecting most NZ estuaries.

Issue	Impact
Sedimentation	If sediment inputs are excessive, an estuary infills quickly with muds, reducing biodiversity and human values and uses.
Eutrophication	Eutrophication is an increase in the rate of supply of organic matter to an ecosystem. If nutrient inputs are excessive, the estuary experiences macroalgal and/or phytoplankton blooms, anoxic sediments, lowered biodiversity and nuisance effects for local residents.
Disease Risk	If pathogen inputs are excessive, the disease risk from bathing, wading or eating shellfish increases to unacceptable levels.
Toxins	If potentially toxic contaminant inputs (e.g. heavy metals, pesticides) are excessive, estuary biodiversity is threatened and shellfish and fish may be unsuitable for eating.
Habitat Loss	If habitats (such as saltmarsh) are lost or damaged through drainage, reclamation, building of structures, stock grazing or vehicle access, biodiversity and estuary productivity declines.
	If the natural terrestrial margin around the estuary is modified by forest clearance or degraded through such actions as roading, stormwater outfalls, property development and weed growth, the natural character is diminished and biodiversity reduced.

Table 3. Summary of the broad and fine scale EMP indicators.

Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Eutrophication	Nuisance Macroalgal Cover	Broad scale mapping - estimates the change in the area of nuisance macroalgal growth (e.g. sea lettuce (*Ulva*), *Gracilaria* and *Enteromorpha*) over time.
Eutrophication	Organic and Nutrient Enrichment	Chemical analysis of total nitrogen, total phosphorus, and total organic carbon (calculated from ash free dry weight) in replicate samples from the upper 2cm of sediment.
Eutrophication	Redox Profile	Measurement of depth of redox potential discontinuity profile (RPD) in sediment estimates likely presence of deoxygenated, reducing conditions.
Toxins	Contamination in Bottom Sediments	Chemical analysis of indicator metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) in replicate samples from the upper 2cm of sediment.
Toxins, Eutrophication, Sedimentation	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).
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Habitat Loss	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
Habitat Loss	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.

1. INTRODUCTION (CONTINUED)

REPORT STRUCTURE

The report is structured as follows:

Section 1 Introduction to the scope and structure of the study.
Section 2 Methods - broad scale mapping (substrate, macroalgae, seagrass, saltmarsh, terrestrial margin), and estuary condition ratings.
Section 3 Results and Discussion.
Section 4 Conclusions.
Section 5 Monitoring.
Section 6 Recommended Management.
Section 7 Acknowledgements.
Section 8 References.

Appendix 1 Substrate and vegetation classification.
Appendix 2 Description of key estuary habitat features.

This report is the first of a proposed series of reports which will characterise the baseline broad scale conditions in the estuary on a 5 yearly cycle. The survey focuses on providing detailed information on key broad scale indicators of sedimentation, eutrophication and habitat loss (Table 3). The results will help determine the extent to which the estuary is affected by major estuary issues (Table 2), both in the short and long term.

Figure 1. Porirua Harbour showing the Pauatahanui and Porirua Arms.

2. METHODS

BROAD SCALE HABITAT MAPPING

Categories of percentage cover used to classify macroalgae and seagrass.

>1 %
1-5%
5-10 %
10-20 %
20-50 %
50-80 %
80-100 %

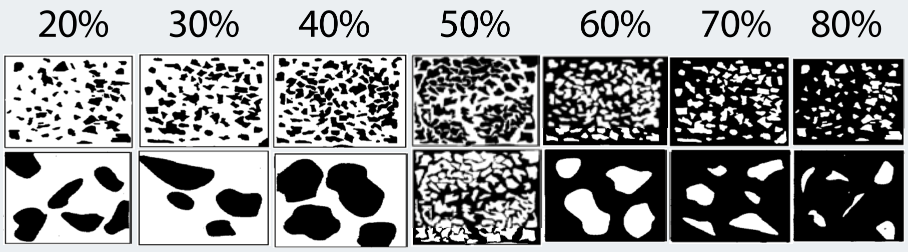
Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: seagrass, macroalgae, rushland, etc). It follows the EMP approach originally described for use in NZ estuaries by Robertson et al. (2002)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

- Obtaining laminated aerial photos for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing).
- Digitising the field data into GIS layers (ArcMap 9.2).

For the 2007 study, GWRC supplied rectified 0.5m/pixel resolution colour aerial photos flown in 2005. Photos covering the estuary at a scale of 1:5,000 were laminated, and two scientists ground-truthed the spatial extent of dominant habitat and substrate types by walking the extent of the estuary recording features directly on the laminated aerial photos over two days (Dec. 12-13, 2007).

The percentage cover of intertidal macroalgae and seagrass within the estuary was visually classified into seven categories using a visual rating scale (see examples below and left) to describe macroalgae and seagrass density and distribution within the estuary.

Visual rating scale for percentage cover estimates



Sampling positions and photographs were georeferenced and the information collected was used to produce GIS-based habitat maps showing the following:

- Dominant substrate.
- Percent cover of dominant macroalgae (e.g. *Gracilaria, Enteromorpha*).
- Percent cover of seagrass (*Zostera*).
- Dominant estuary vegetation.
- 200m wide terrestrial margin vegetation/landuse.

Appendix 1 lists the class definitions used to classify substrate and vegetation. Vegetation was further classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the two first 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).

2. METHODS (CONTINUED)

BROAD SCALE HABITAT MAPPING (CONTINUED)

Digital mapping

Results were entered by digitising features directly off aerial photos in the GIS using a Wacom Intuos3 electronic drawing tablet within ArcMap 9.2.

The spatial location, size, and type of broad scale habitat features in the estuary are provided as ArcMap 9.2 GIS shapefiles on a separate CD. Georeferenced digital field photos (GPS-Photolink) are also supplied as a GIS layer.

The broad scale results are summarised in the current report in Section 3, with the supporting GIS files providing much more detail in a data set designed for easy interrogation to address specific monitoring and management questions.

CONDITION RATINGS

RATING
Very Good
Good
Fair
Poor
Early Warning Trigger

At present, there are no formal criteria for rating the overall condition of estuaries in NZ, and development of scientifically robust and nationally applicable condition ratings requires a significant investment in research and is unlikely to produce immediate answers.

Therefore, to help GWRC interpret monitoring data, a series of interim broad scale estuary condition ratings have been proposed for Porirua Harbour (based on the ratings developed for Southland's estuaries - Robertson & Stevens 2006, 2007). The condition ratings are based on a review of monitoring data elsewhere in NZ, and expert opinion. They indicate whether monitoring results reflect healthy or degraded conditions, and also include an "early warning trigger" as an alert to any rapid or unexpected change. The condition ratings are designed to be used collectively rather than individually to evaluate estuary condition, with expert judgement used to determine overall estuary condition.

For each of the condition ratings, a recommended monitoring frequency is proposed and a recommended management response is suggested. This usually corresponds to 5 yearly monitoring using the EMP where estuary conditions are good, and initiation of an evaluation and response plan (ERP) to further evaluate an issue and consider what response actions may be appropriate if conditions are degraded.

At this stage, the interim condition ratings reflect the best guidance able to be provided with the available information and budget. It is expected that the proposed ratings will continue to be revised and updated as better information becomes available. The interim broad scale condition ratings for Porirua Harbour are presented below along with a brief rationale for their use.

Soft Mud Percent Cover

Estuaries are a sink for sediments. Where large areas of soft mud are present, they are likely to lead to major and detrimental ecological changes that could be very difficult to reverse, and indicate where changes in land use management may be needed.

SOFT MUD PERCENT COVER CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Low	<2% of estuary substrate is soft mud	Monitor at 5 year intervals after baseline established
Low	2%-5% of estuary substrate is soft mud	Monitor at 5 year intervals after baseline established
Moderate	5%-15% of estuary substrate is soft mud	Post baseline, monitor 5 yearly. Initiate ERP
High	>15% of estuary substrate is soft mud	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	>5% of estuary substrate is soft mud	Initiate ERP (Evaluation and Response Plan)

2. METHODS (CONTINUED)

Soft Mud Area

Soft mud in estuaries decreases water clarity, lowers biodiversity and affects aesthetics and access. Increases in the area of soft mud indicate where changes in catchment land use management may be needed.

SOFT MUD AREA CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Area of cover (ha) not increasing	Monitor at 5 year intervals after baseline established
Good	Increase in area of cover (ha) <5% from baseline	Monitor at 5 year intervals after baseline established
Fair	Increase in area of cover (ha) 5-15% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Poor	Increase in area of cover (ha) >15% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	Trend of increase in area of cover (ha)	Initiate ERP (Evaluation and Response Plan)

Macroalgae Index

Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota.
A continuous index (the macroalgae coefficient - MC) has been developed to rate macroalgal condition based on the percentage cover of macroalgae in defined categories using the following equation: ***MC=((0 x %macroalgal cover <1%)+(0.5 x %cover 1-5%)+(1 x %cover 5-10%)+(3 x %cover 10-20%)+(4.5 x %cover 20-50%)+(6 x %cover 50-80%)+(7.5 x %cover >80%))/100.*** This index will continue to be refined as it is applied to estuary data from throughout NZ.

MACROALGAE CONDITION RATING

RATING	MACROALGAE COEFFICIENT (MC)	RECOMMENDED RESPONSE
Very low	0.0 - 0.2	Monitor at 5 year intervals after baseline established
Low	0.2 - 0.8	Monitor at 5 year intervals after baseline established
Low Low-Moderate	0.8 - 1.5	Monitor at 5 year intervals after baseline established
Low-Moderate	1.5 - 2.2	Post baseline, monitor yearly. Initiate ERP
Moderate	2.2 - 4.5	Post baseline, monitor yearly. Initiate ERP
High	4.5 - 7.0	Post baseline, monitor yearly. Initiate ERP
Very High	>7.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend of increasing MC or nuisance conditions	Initiate ERP (Evaluation and Response Plan)

Seagrass Index

Seagrass (*Zostera muelleri*) grows in soft sediments in NZ estuaries where its presence enhances estuary biodiversity. Though tolerant of a wide range of conditions, it is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide).
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 5-10%)+(3.5 x %cover 10-20%)+(6 x %cover 20-50%)+(9 x %cover 50-80%)+(12 x %cover >80%))/100.*** This index will continue to be refined as it is applied to estuary data from throughout NZ.

SEAGRASS CONDITION RATING

RATING	SEAGRASS COEFFICIENT (SC)	RECOMMENDED RESPONSE
Very low	0.0 - 0.2	Post baseline, monitor 5 yearly. Initiate ERP
Low	0.2 - 0.8	Post baseline, monitor 5 yearly. Initiate ERP
Low Low-Moderate	0.8 - 1.5	Post baseline, monitor 5 yearly. Initiate ERP
Low-Moderate	1.5 - 2.2	Post baseline, monitor 5 yearly. Initiate ERP
Moderate	2.2 - 4.5	Monitor at 5 year intervals after baseline established
High	4.5 - 7.0	Monitor at 5 year intervals after baseline established
Very High	>7.0	Monitor at 5 year intervals after baseline established
Early Warning Trigger	Trend of decreasing Seagrass Coefficient	Initiate ERP (Evaluation and Response Plan)

2. METHODS (CONTINUED)

Saltmarsh Percent Cover

A variety of saltmarsh species (commonly dominated by rushland but including scrub, sedge, tussock, grass, reed, and herb fields) grow in the upper margins of most NZ estuaries where vegetation stabilises fine sediment transported by tidal flows. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth and have strong aesthetic appeal. Where saltmarsh cover is limited, these values are decreased.

SALTMARSH PERCENT COVER CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very High	>20% of estuary area is saltmarsh	Monitor at 5 year intervals after baseline established
High	10%-20% of estuary area is saltmarsh	Monitor at 5 year intervals after baseline established
Moderate	5%-10% of estuary area is saltmarsh	Monitor at 5 year intervals after baseline established
Low	2%-5% of estuary area is saltmarsh	Post baseline, monitor 5 yearly. Initiate ERP
Very Low	<2% of estuary area is saltmarsh	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	<5% of estuary area is saltmarsh	Initiate ERP (Evaluation and Response Plan)

Saltmarsh Area

Saltmarshes are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Decreases in saltmarsh extent is likely to indicate an increase in these types of pressures.

SALTMARSH AREA CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Area of cover (ha) not decreasing	Monitor at 5 year intervals after baseline established
Good	Decline in area of cover (ha) <5% from baseline	Monitor at 5 year intervals after baseline established
Fair	Decline in area of cover (ha) 5-20% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Poor	Decline in area of cover (ha) >20% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	Trend of decrease in area of cover (ha)	Initiate ERP (Evaluation and Response Plan)

Terrestrial Vegetated Buffer Percent Cover

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 protects against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat.

TERRESTRIAL VEGETATED BUFFER PERCENT COVER CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very High	80%-100% cover of terrestrial vegetated buffer	Monitor at 5 year intervals after baseline established
High	50%-80% cover of terrestrial vegetated buffer	Monitor at 5 year intervals after baseline established
Fair	25%-50% cover of terrestrial vegetated buffer	Post baseline, monitor 5 yearly. Initiate ERP
Poor	5%-25% cover of terrestrial vegetated buffer	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	<50% cover of terrestrial vegetated buffer	Initiate ERP (Evaluation and Response Plan)

Terrestrial Vegetated Buffer Area

Estuaries are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Reduction in the vegetated buffer around the estuary is likely to result in a decline in estuary quality.

TERRESTRIAL VEGETATED BUFFER AREA CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Terrestrial buffer is 100% dense vegetation	Monitor at 5 year intervals after baseline established
Good	Decline in vegetated buffer (ha) <5% from baseline	Monitor at 5 year intervals after baseline established
Fair	Decline in vegetated buffer (ha) 5-10% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Poor	Decline in vegetated buffer (ha) >10% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	Trend of decrease in area of vegetated buffer (ha)	Initiate ERP (Evaluation and Response Plan)

3. RESULTS AND DISCUSSION

OVERVIEW

This section provides a summary of the dominant features of the estuary (Tables 4 and 5), followed by the results and a discussion of each broad scale GIS layer that has been mapped. For each layer (substrate, macroalgae, seagrass, saltmarsh, and the 200m terrestrial margin), condition ratings are used to assess each indicator, which are then evaluated along with other relevant expert information and fine scale results to assess the condition of the estuary in relation to the key issues of sedimentation, eutrophication and habitat loss.

A key feature in the overall summary in Table 4 is that unlike the majority of New Zealand's tidal lagoon estuaries (which tend to empty almost completely at low tide - see Figure 7), Porirua Harbour was found to be mainly subtidal (65% of the estuary was underwater at low tide). This has important implications in relation to the assessment of key estuary issues of sedimentation and eutrophication which need to include subtidal influences along with the broad scale intertidal mapping results.

The subtidal dominance of the estuary is in part due to its physical structure, but also reflects the extensive historical loss of upper intertidal estuary flats and saltmarsh through reclamation, such that the subtidal area is now comparatively large in comparison to the remaining intertidal area. This is highlighted by the very low amount of saltmarsh remaining in the Porirua Arm (0.3%), and emphasises the importance of the remaining saltmarsh, as well as the need to encourage its re-establishment.

Table 4. Summary of dominant broad scale features, December 2007.

Estuary Location	Pauatahanui Arm		Porirua Arm		Entire Estuary	
Area	Ha	%	Ha	%	Ha	%
Saltmarsh	50.5	9.6	0.8	0.3	51.3	6.4
Unvegetated	173.0	33.0	61.5	21.7	234.4	29.1
Water	300.2	57.3	220.7	78.0	520.9	64.6
TOTAL	523.7	100	283.0	100	806.6	100

Table 5 summarises significant vegetation cover other than saltmarsh in the intertidal area of the estuary. It shows that a significant cover of macroalgae was present across 68% of the estuary, while seagrass was also relatively abundant (21%). Subtidal seagrass and macroalgae are also present and need to be considered when assessing the overall condition of the estuary.

Table 5. Summary of dominant intertidal vegetation, December 2007.

Estuary Location	Pauatahanui Arm		Porirua Arm		Entire Estuary	
Area	Ha	%	Ha	%	Ha	%
Macroalgal Cover >5%	154.0	68.9	40.0	65.0	194.0	68.0
Seagrass Cover >5%	41.2	18.4	17.3	28.1	58.5	20.5

SUBSTRATE

Table 6 and Figure 2 summarise the unvegetated intertidal substrate of Porirua Harbour. Overall the estuary was dominated by firm mud/sand (66.1%) located mostly in the lower intertidal flats of both arms, and cobble, gravel and rock (16%) located primarily around the upper shores. Firm sand (8.2%) and mobile sand (5.4%) were also prominent around intertidal sand bars and in areas with high current flows near the entrance to each arm.

Compared to estuaries elsewhere in NZ, intertidal areas had relatively little soft mud (1.5%) as a dominant substrate. Substrates within the two arms of the estuary were very similar. The main difference was the Pauatahanui Arm had less cobble (1.6% vs 24%) and more firm sand (10.8% vs 1%) than the Porirua Arm.

Table 6. Summary of dominant surface substrate, December 2007.

Estuary Location	Pauatahanui Arm		Porirua Arm		Entire Estuary	
Area	Ha	%	Ha	%	Ha	%
Artificial structure	2.0	1.1	2.0	3.3	4.0	1.7
Boulder field man-made	0.1	0.1	1.5	2.5	1.6	0.7
Cobble field man-made	-	-	0.4	0.6	0.4	0.2
Railway	-	-	0.1	0.2	0.1	0.0
Road	1.1	0.6	-	-	1.1	0.5
Rock field man-made	0.7	0.4	0.0	0.0	0.7	0.3
Seawall man-made	0.0	0.0	0.0	0.0	0.1	0.0
Residential	0.8	0.5	0.6	1.0	1.4	0.6
Rock field	3.4	2.0	0.7	1.2	4.1	1.8
Boulder field	-	0.0	0.1	0.1	0.1	0.0
Cobble field	2.7	1.6	14.8	24.0	17.4	7.4
Gravel field	11.1	6.4	4.1	6.7	15.2	6.5
Sabellid (tube worm) field	0.1	0.1	0.2	0.3	0.3	0.1
Shell bank	1.1	0.6	0.2	0.3	1.3	0.6
Mobile sand	8.9	5.2	3.8	6.2	12.8	5.4
Firm sand	18.7	10.8	0.6	1.0	19.3	8.2
Firm mud/sand	122.3	70.7	32.8	53.3	155.0	66.1
Soft mud	1.9	1.1	1.5	2.5	3.4	1.5
Grand Total	173.0	100	61.5	100	234.4	100


Firm mud/sand flats in the Pauatahanui Arm (left) and Porirua Arm (right).

3. RESULTS AND DISCUSSION (CONTINUED)

SUBSTRATE

Artificial structures (1.7%) and residential boathouses (0.6%) were small in area, but notable features of the estuary. In particular, the presence of extensive areas protected by seawalls reflect where past reclamation has changed the character of the upper shore from predominantly gently sloping saltmarsh, to steep rocky edges that rise abruptly from the intertidal zone.

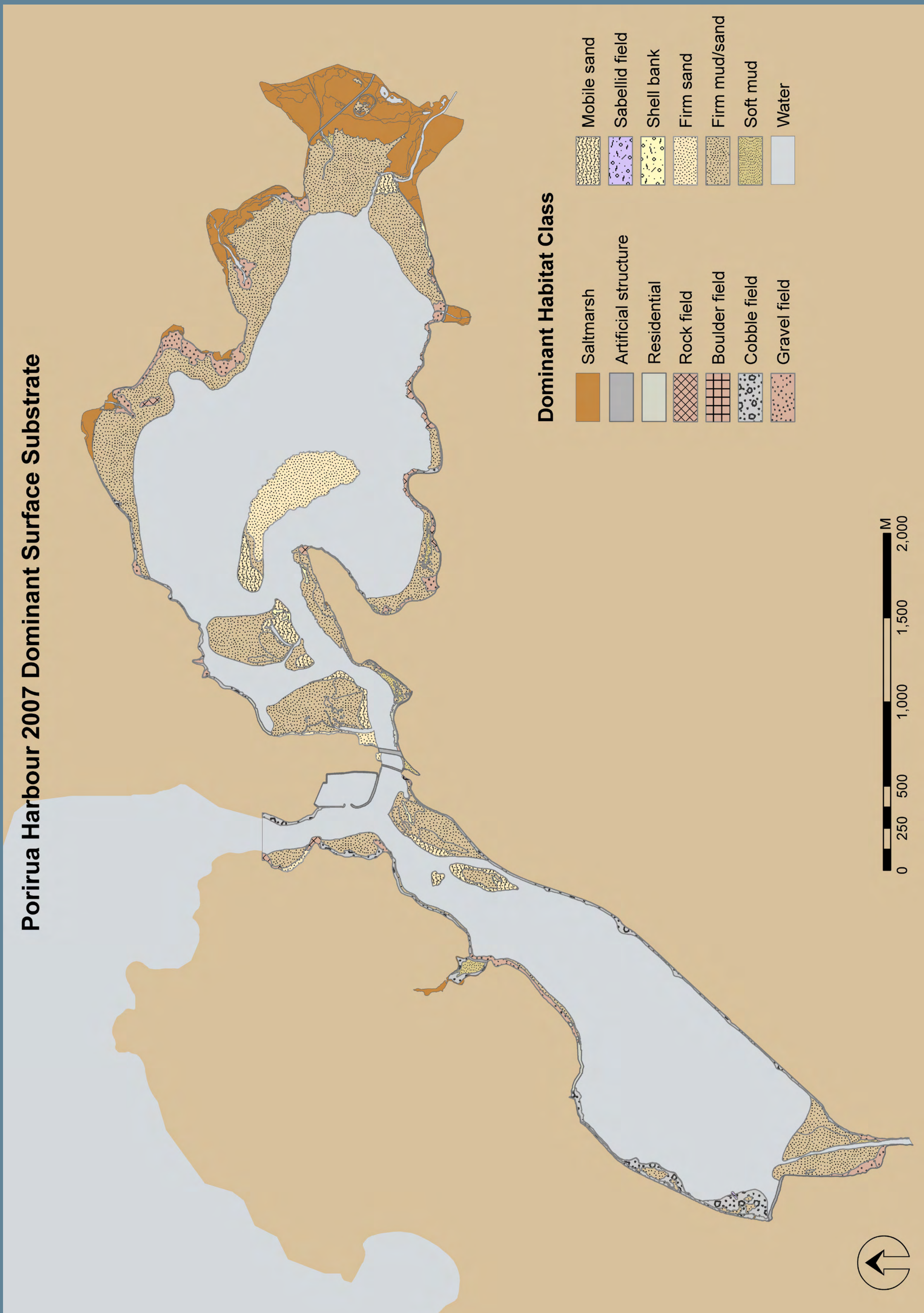
The steep slopes, along with associated increases in wave energy and tidal inundation, combine to create conditions generally unfavourable for the natural re-establishment of saltmarsh. Further, the seawalls greatly reduce the capacity for the estuary to respond to changes in sediment and water levels likely to result from predicted sea level rise, one of the major stressors identified in the recent vulnerability assessment of the estuary (see Robertson and Stevens 2007b).

Seawalls also reduce the diversity of available habitat for key ecological uses such as bird feeding and roosting and whitebait spawning, and create a physical barrier discouraging human access to the estuary.

Examples of artificial seawalls along the estuary margin.

Paremata boathouses

Figure 2. Map of Dominant Surface Sediments - Porirua Harbour, December 2007.



MACROALGAE

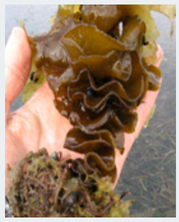
Low-Moderate cover of *Gracilaria* and *Enteromorpha* in the lower Pauatahanui Arm.

High cover of *Ulva* in the upper Porirua Arm.

Estuary eutrophication can result in regular macroalgal blooms. These can deprive seagrass areas of light causing their eventual decline, while decaying macroalgae can accumulate on shorelines causing depletion of sediment dissolved oxygen and nuisance odours. Table 7 and Figure 3 summarise the results of macroalgal mapping within Porirua Harbour and provide a baseline for comparing future changes using the condition rating proposed in Section 2.

Overall, 194ha (68% of the intertidal area) had a macroalgae cover >5%; 154ha (69%) in the Pauatahanui Arm and 40ha (65%) in the Porirua Arm. The Pauatahanui Arm was dominated by *Gracilaria* at densities <20% (see upper left photo), with only a small area (0.5ha, <1%) of sea lettuce (*Ulva*) with a percent cover >50%. In contrast, 24.9ha (41%) of the macroalgae in the Porirua Arm had a percent cover >50%. Sea lettuce dominated smaller amounts of *Gracilaria* and *Enteromorpha*, with the highest cover present where Porirua Stream enters the upper estuary, along the southwestern shore, and in the small northwestern arm/embayment (Figure 3). In areas of high cover, particularly in the Porirua Arm, macroalgae was generally present in a thick cover on the sediment surface (see lower left photo), and conditions were largely unsuitable for estuarine animals due to low levels of sediment dissolved oxygen.

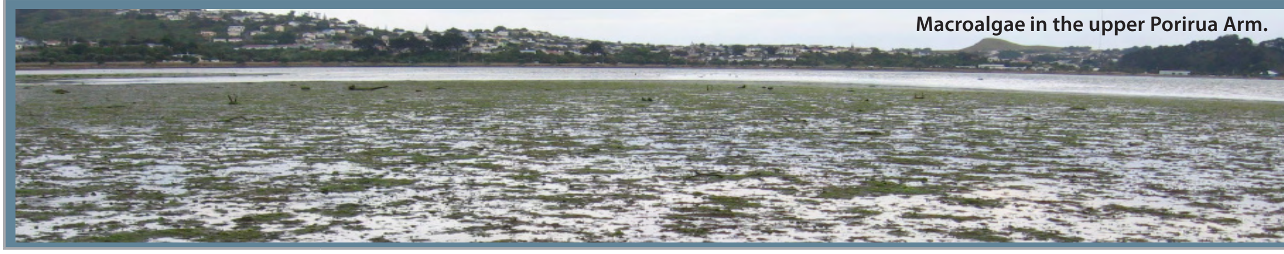
The condition rating (the Macroalgae Coefficient - MC) placed the Pauatahanui Arm in the "Low-Moderate" category (MC=1.9), the Porirua Arm in the "Moderate" category (MC=3.2), and the estuary overall in the "Moderate" category (MC=2.2).



While a very minor feature overall, a few individual plants of the invasive kelp *Undaria pinnatifida* (see inset photo) were also observed in both arms of the estuary.

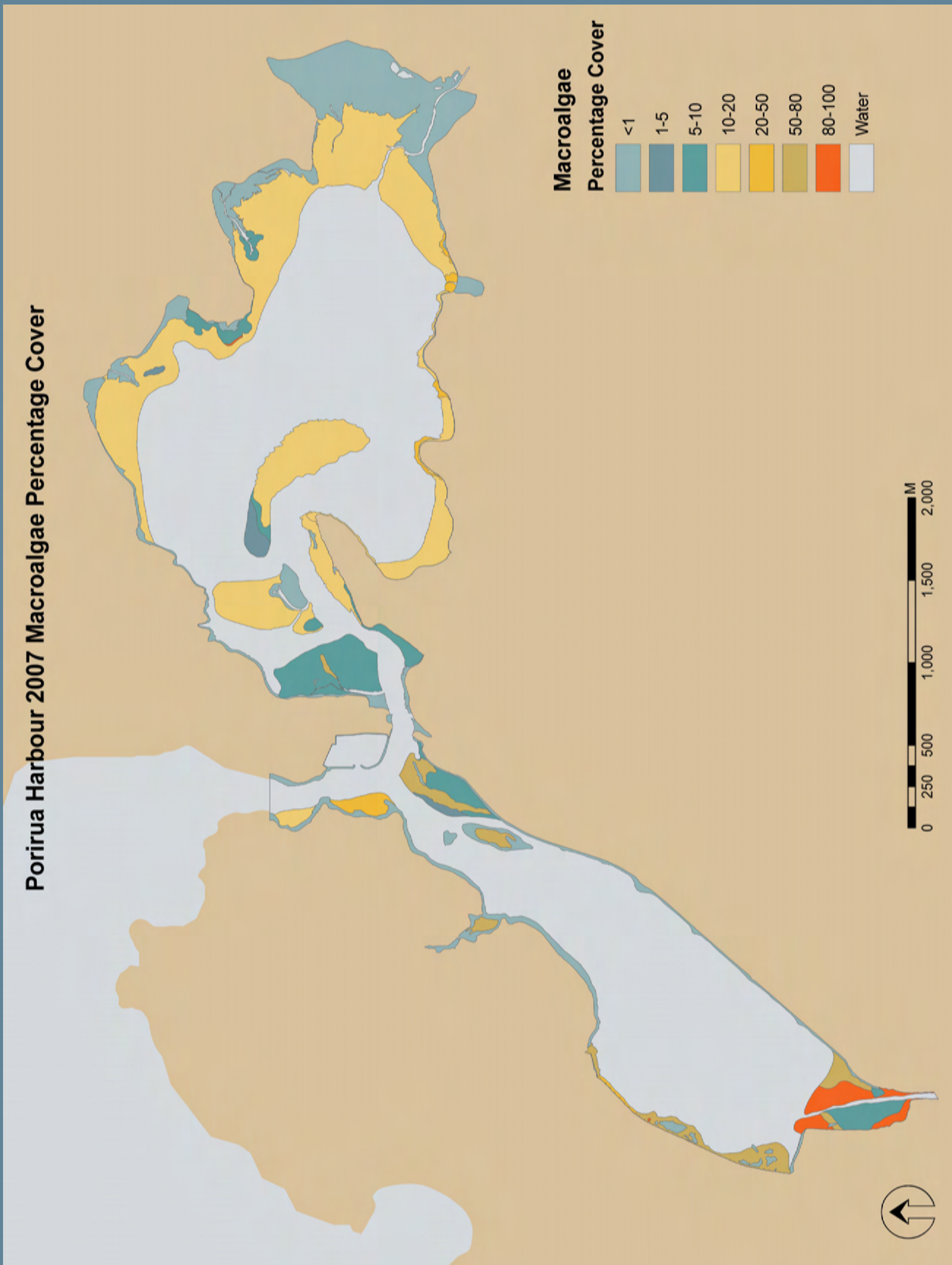
Table 7. Summary of intertidal macroalgal cover results, December 2007.

MACROALGAE	Pauatahanui Arm			Porirua Arm			Entire Estuary	
Percentage Cover	Ha	%	Dominant species	Ha	%	Dominant species	Ha	%
<1%	66.4	30	-	20.3	33	-	86.7	30
1-5%	3.2	1	*Ulva*	1.2	2	*Gracilaria, Ulva*	4.4	2
5-10%	23.9	11	*Gracilaria, Ulva*	9.9	16	*Gracilaria, Ulva*	33.8	12
10-20%	127.6	57	*Gracilaria, Ulva, Enteromorpha*	1.7	3	*Gracilaria,Ulva*	129.3	45
20-50%	2.0	1	*Enteromorpha, Gracilaria, Ulva*	3.5	6	*Gracilaria, Ulva*	5.5	2
50-80%	0.4	0	*Ulva*	17.1	28	*Ulva, Gracilaria*	17.5	6
>80%	0.1	0	*Ulva*	7.8	13	*Ulva, Enteromorpha*	7.9	3
TOTAL	**223**	**100**		**62**	**100**		**285**	**100**



Macroalgae in the upper Porirua Arm.

Figure 3. Map of Macroalgal Cover - Porirua Harbour, December 2007.



SEAGRASS

Seagrass (*Zostera muelleri*) is highly valued ecologically for its multiple roles in primary production, nutrient cycling, sediment stabilisation, and as a feeding and nursery area for fish and invertebrates. Seagrass meadows are also a major source of detrital material, and the bacteria and fungi that decompose this material provide a food source for zooplankton, worms, etc. which are the base of the predatory food web. Seagrass is also an important forerunner to the establishment of saltmarsh on tidal flats, and grows subtidally where water clarity allows light to penetrate to it. Table 8 and Figure 4 summarise the results of seagrass mapping within Porirua Harbour and provide a baseline for comparing future changes using the condition rating proposed in Section 2.

Table 8. Summary of intertidal seagrass cover results, December 2007.

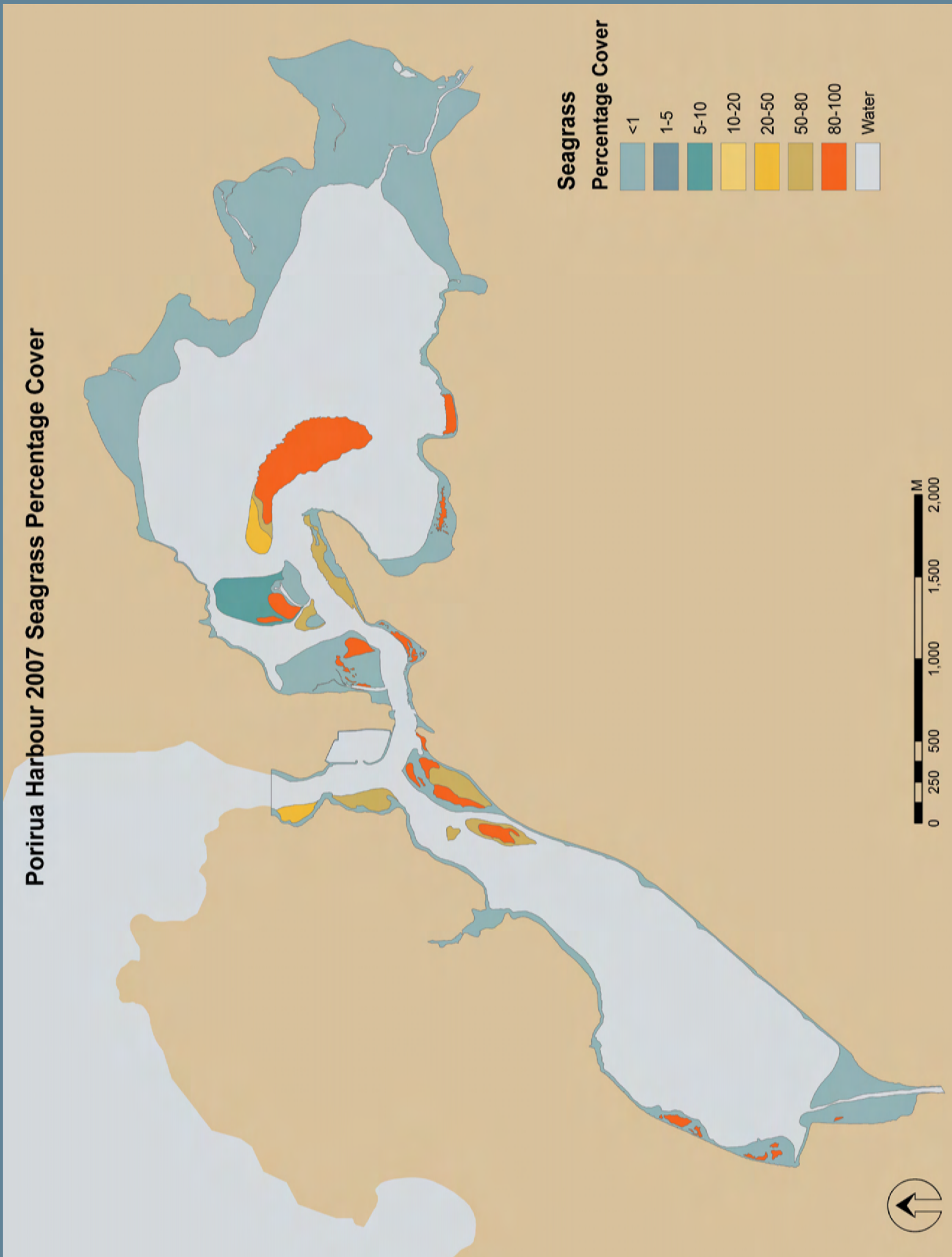
SEAGRASS	Pauatahanui Arm		Porirua Arm		Entire Estuary	
Percentage Cover	Ha	%	Ha	%	Ha	%
<1%	182.2	82	44.3	72	226.5	79
1-5%	0.0	0	0.0	0	0.0	0
5-10%	8.8	4	0.0	0	8.8	3
10-20%	0.0	0	0.0	0	0.0	0
20-50%	2.7	1	1.8	3	4.5	2
50-80%	5.7	3	9.4	15	15.1	5
>80%	24.0	11	6.1	10	30.1	11
TOTAL	**223**	**100**	**62**	**100**	**285**	**100**

Overall, 58.5ha of seagrass were present with a >1% cover in Porirua Harbour, 41.2 in the Pauatahanui Arm and 17.3ha in the Porirua Arm. Where present in densities >1%, percent cover was mostly >50% (45.2ha). The condition rating (the Seagrass Coefficient - SC) placed the Pauatahanui Arm in the "Low-Moderate" category (SC=1.7), the Porirua Arm in the "Moderate" category (SC=2.7), and the Porirua Harbour overall in the "Low-Moderate" category (SC=2.0).

The largest beds were located on the well flushed tidal flats in the lower (seaward) part of each arm (Figure 4 and photos below), with plants appearing lush and healthy. Macroalgal growths were commonly present growing on and within the seagrass beds.

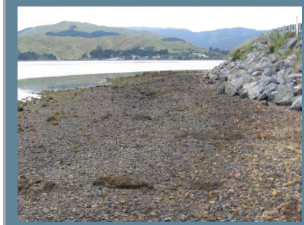
Examples of extensive *Zostera* beds in the Porirua Arm (left) and the Pauatahanui Arm (right).

Figure 4. Map of Seagrass Cover - Porirua Harbour, December 2007.



3. RESULTS AND DISCUSSION (CONTINUED)

VEGETATION



Typical unvegetated upper tidal zone of the estuary.

Herbfield restricted to a narrow habitat range on riprap wall.

Rushland in the eastern arm.

Herbfield (glasswort - *Sarcocornia quinqueflora*).

Saltmarsh vegetation (estuarine vegetation able to tolerate saline conditions and where terrestrial plants are unable to survive) is summarised in Table 9 with the broad vegetation class and species composition of the estuary shown in Figures 5 and 6, and Table 10. Overall, the most notable feature was the virtual absence of saltmarsh around the margins of the estuary that have been developed for residential, or commercial/industrial/transportation uses (Figure 5). The Porirua Arm in particular has only 0.3% of its area vegetated, which is very low compared to other estuaries around NZ (Figure 7). The urban areas in the west of the Pauatahanui Arm reflects a similar situation with almost no saltmarsh present, the 9.7% that is vegetated being located in the largely undeveloped eastern side of the estuary.

Within the Porirua Arm, the largest vegetated area was located in the small north-western arm/embayment which is dominated by rushland (searush *Juncus kraussii* and jointed wire rush *Apodasmia (Leptocarpus) similis*) and tussockland (*Carex* sp.) (Figure 6). Elsewhere the vegetation consisted mostly of small patches of *Sarcocornia* (glasswort) dominated herbfields at the edges of the main body of the estuary. The limited vegetation can be attributed predominantly to a lack of suitable intertidal habitat caused by past reclamation and margin development, with the plants restricted to a narrow range of suitable habitat mostly among the steep faced riprap seawalls bordering the upper tidal reaches.

In contrast to the Porirua Arm, the east of the Pauatahanui Arm (where more natural estuary profiles remain) had a much more diverse cover of vegetation (Figure 6). It was dominated by wide beds of rushland (mostly searush and jointed wire rush) which, as the terrestrial influence increased, transitioned through areas dominated by saltmarsh ribbonwood (*Plagianthus divaricatus*) and grassland (mostly tall fescue - *Festuca arundinacea*) (Figure 5). Within the dominant rushland and grassland vegetation classes a wide variety of common estuarine plants were present (Table 10), with introduced weeds a common subdominant cover, particularly among the grassland. *Sarcocornia* dominated herbfields were also common on raised shell banks at the upper tidal zone in the north and east.

Many of the terrestrial areas flanking the Pauatahanui Arm include plantings from restoration efforts from the local community, GWRC and Department of Conservation (DOC).

Table 9. Summary of saltmarsh vegetation mapping, December 2007.

Estuary Location	Pauatahanui Arm		Porirua Arm		Entire Estuary	
Area	Ha	%	Ha	%	Ha	%
Vegetated	50.6	9.7	0.8	0.3	51.4	6.4
Estuarine Shrub	11.3	2.1	-	0.0	11.3	1.4
Tussockland	0.7	0.1	0.5	0.2	1.2	0.1
Grassland	7.9	1.5	-	0.0	7.9	1.0
Rushland	29.2	5.6	0.2	0.1	29.4	3.6
Reedland	0.6	0.1	0.0	0.0	0.6	0.1
Herbfield	1.1	0.2	0.0	0.0	1.1	0.1
Unvegetated	473.2	90.3	282.2	99.7	755.3	93.6
Unvegetated substrate	173.0	33.0	61.5	21.7	234.4	29.1
Water	300.2	57.3	220.7	78.0	520.9	64.5
Total	523.8	100	282.9	100	806.7	100

Figure 5. Map of Saltmarsh Vegetation Class - Porirua Harbour, December 2007.

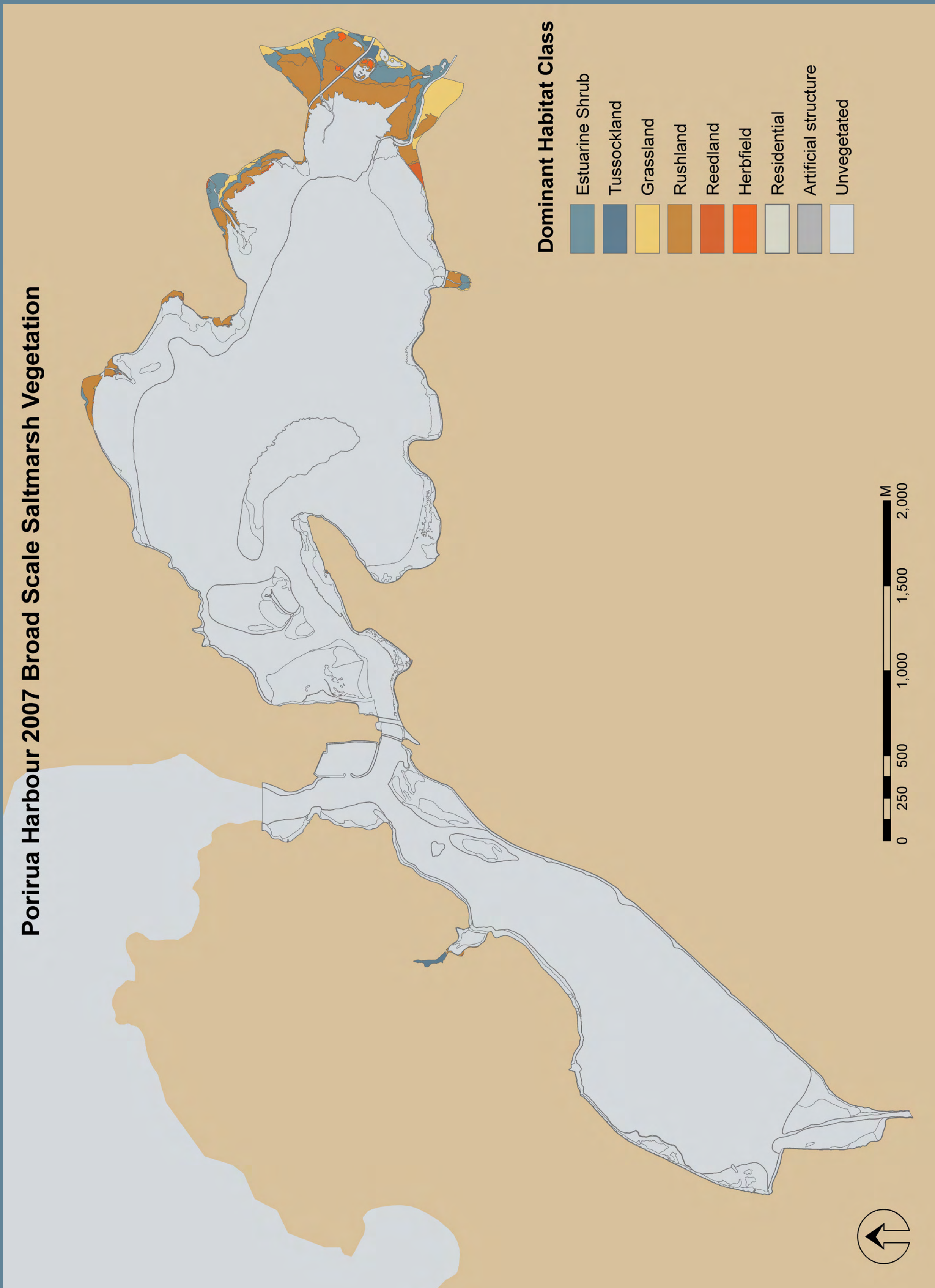


Table 10. Summary of broad scale vegetation of Porirua Harbour, December 2007.

Class	Dominant Species	Primary subdominant species	Pauatahanui		Porirua		Entire Estuary	
			Ha	%	Ha	%	Ha	%
Scrub			1.88	0.36			1.88	0.23
	Coprosma propinqua (Mingimingi)	*Plagianthus divaricatus (Saltmarsh ribbonwood)*	0.06	0.01			0.06	0.01
	Native scrub/forest		0.95	0.27			0.95	0.17
		Festuca arundinacea (Tall fescue)	0.99	0.19			0.99	0.12
Estuarine Shrub			9.25	1.77			9.25	1.15
	Plagianthus divaricatus (Saltmarsh ribbonwood)		0.12	0.02			0.12	0.02
	Plagianthus divaricatus (Saltmarsh ribbonwood)	*Festuca arundinacea (Tall fescue)*	3.65	0.70			3.65	0.45
		Juncus kraussii (Searush)	0.40	0.08			0.40	0.05
		Apodasmia similis (Jointed wirerush)	5.08	0.97			5.08	0.63
Tussockland			0.69	0.13	0.49	0.17	1.19	0.15
	Carex spp. (Sedge)				0.49	0.17	0.49	0.06
	Phormium tenax (New Zealand flax)	*Plagianthus divaricatus (Saltmarsh ribbonwood)*	0.69	0.13			0.69	0.09
Grassland			7.85	1.50			7.85	0.97
	Festuca arundinacea (Tall fescue)	*Ficinia (Isolepis) nodosa (Knobby clubrush)*	0.39	0.07			0.39	0.05
		Apodasmia similis (Jointed wirerush)	1.25	0.24			1.25	0.16
		Phormium tenax (New Zealand flax)	3.94	0.75			3.94	0.49
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.61	0.12			0.61	0.08
		Samolus repens (Primrose)	0.57	0.11			0.57	0.07
		Unidentified introduced weeds	0.03	0.01			0.03	0.00
	Unidentified grass		0.98	0.19			0.98	0.12
	Unidentified grass	*Unidentified introduced weeds*	0.09	0.02			0.09	0.01
Rushland			29.16	5.57	0.23	0.08	29.39	3.64
	Juncus kraussii (Searush)		11.31	2.16			11.31	1.40
		Festuca arundinacea (Tall fescue)	0.86	0.17			0.86	0.11
		Apodasmia similis (Jointed wirerush)	4.61	0.88	0.18	0.06	4.79	0.59
		Plagianthus divaricatus (Saltmarsh ribbonwood)	5.92	1.13			5.92	0.73
		Samolus repens (Primrose)	2.92	0.56			2.92	0.36
		Schoenoplectus pungens (Three-square)	0.01	0.00			0.01	0.00
	Apodasmia similis (Jointed wirerush)		1.14	0.22			1.14	0.14
		Juncus kraussii (Searush)	0.64	0.12	0.05	0.02	0.69	0.09
		Phormium tenax (New Zealand flax)	0.09	0.02			0.09	0.01
		Plagianthus divaricatus (Saltmarsh ribbonwood)	1.66	0.32			1.66	0.21
Reedland			0.58	0.11	0.01	0.00	0.59	0.07
	Typha orientalis		0.58	0.11	0.01	0.00	0.59	0.07
Herbfield			1.06	0.20	0.05	0.02	1.11	0.14
	Samolus repens (Primrose)		0.02	0.00			0.02	0.00
		Selliera radicans (Remuremu)	0.31	0.06			0.31	0.04
	Sarcocornia quinqueflora (Glasswort)		0.01	0.00	0.04	0.01	0.05	0.01
		Samolus repens (Primrose)	0.16	0.03			0.16	0.02
		Selliera radicans (Remuremu)	0.19	0.04			0.19	0.02
	Selliera radicans (Remuremu)		0.18	0.04			0.18	0.02
		Juncus kraussii (Searush)	0.02	0.00			0.02	0.00
		Samolus repens (Primrose)	0.17	0.03			0.17	0.02
		Sarcocornia quinqueflora (Glasswort)			0.01	0.00	0.01	0.00
Total saltmarsh vegetation			50.5	9.6	0.8	0.3	51.3	6.4
Unvegetated substrate			173.0	33.0	61.5	21.7	234.4	29.1
Water			300.2	57.3	220.7	78.0	520.9	64.6
Grand Total			**523.7**	**100**	**283.0**	**100**	**806.6**	**100**

Figure 6. Broad Scale Vegetation Classes of Porirua Harbour.

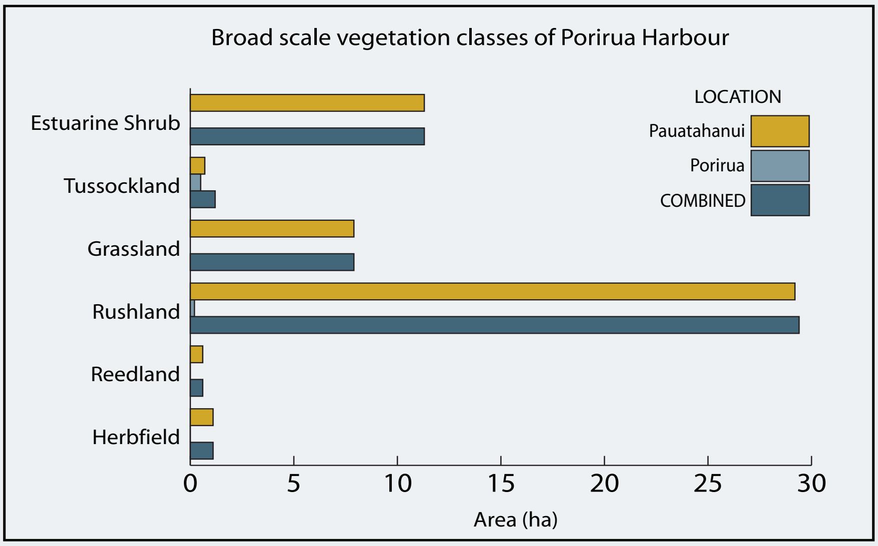
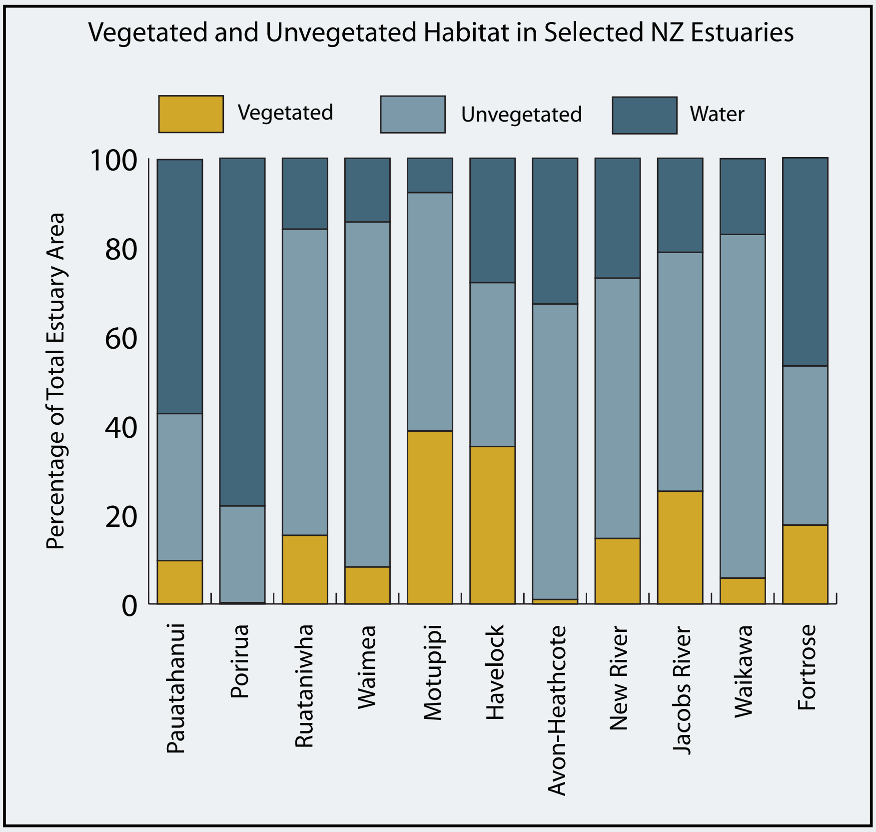


Figure 7. Percentage of Vegetated and Unvegetated Habitat in Selected NZ Estuaries.



TERRESTRIAL MARGIN MAPPING

The results of the 200m terrestrial margin mapping are summarised in Table 11 and Figure 8. Overall, half of the estuary margin was intensively developed (artificial structures, residential, and commercial/industrial) reflecting the predominantly urban nature of the estuary. Although not dominant in area, artificial structures (17%) were the key feature of the margin. Road and rail corridors directly bordered around 2/3rds of each arm of the estuary (see Figure 8) greatly impinging upon the aesthetic and natural values of the estuary, and ensuring an almost complete break in any natural sequence of estuarine to terrestrial vegetation.

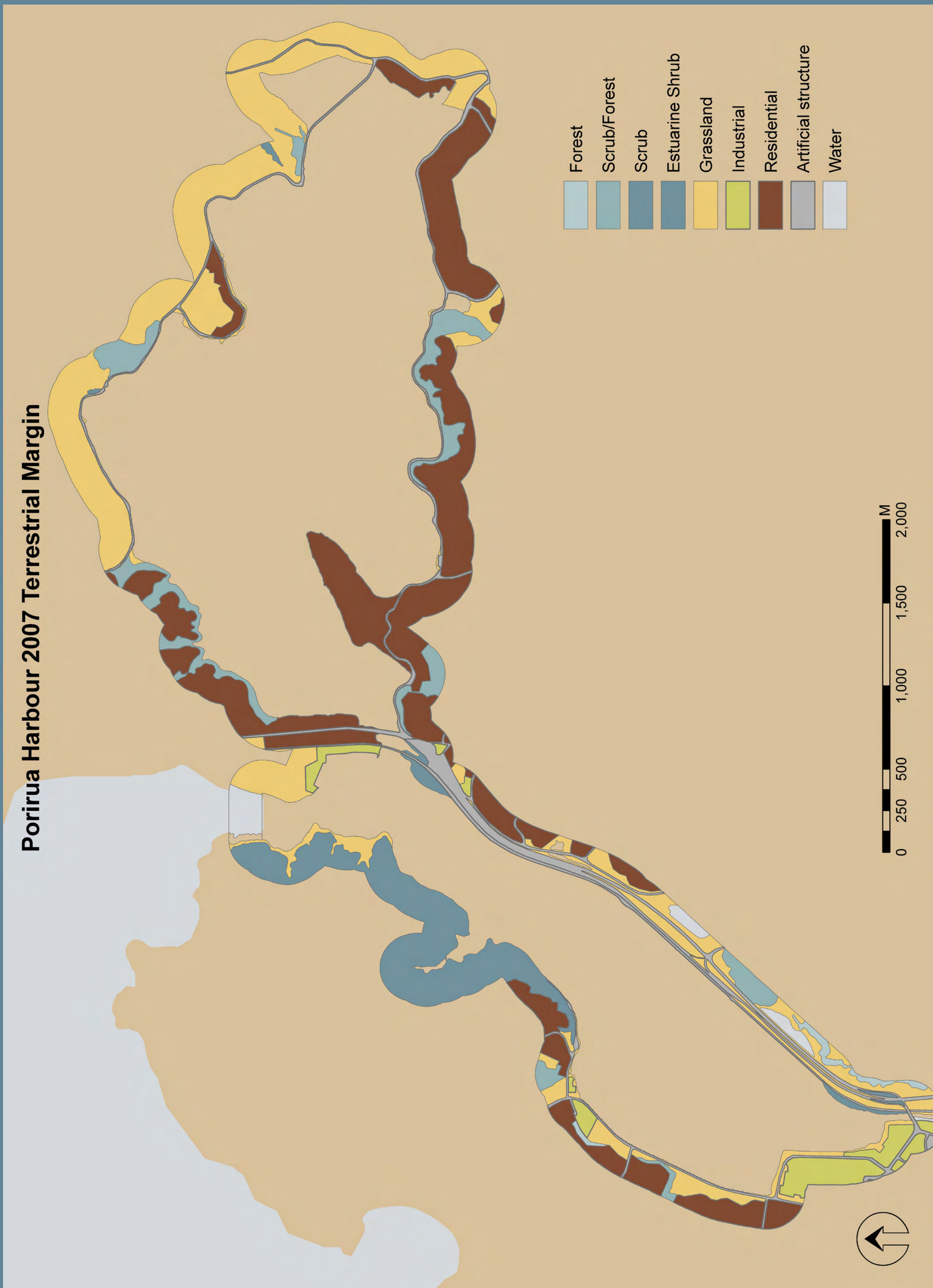
Outside of roading (14%), the Pauatahanui Arm was predominantly a mix of residential housing (39%), grassland (36%) and scrub/forest (11%). Residential areas are primarily in the north west and south, and are notable for the scrub/forest corridors remaining among the housing, and bordering the estuary. Public access tracks are well utilised in these areas, and the improvements from ongoing planting initiatives are obvious. The relatively undeveloped northern and eastern estuary margin was dominated by grassland (grazed pasture) with a few pockets of scrub/forest and residential development. Grassland adjacent to the estuary generally contained a range of introduced weeds.

The Porirua Arm comprised a mix of residential and commercial/industrial (25%), native and exotic scrub (25%), grassland (22%), and road and rail (20%). The entire eastern side of the Porirua Arm was dominated by the railway and motorway which prevent direct access to the estuary. A wide range of introduced weeds were present among grassland in this area. Almost all of the scrub in the margin was located in the relatively undeveloped northwest which also contained areas of grassland (grazed pasture). Around Porirua itself, the inland margin was dominated by residential and commercial/industrial developments, although grassed public amenity areas are present along much of the estuary edge. These amenity areas invite public use and appreciation of the estuary, and provide a great opportunity for enhancing the ecological, recreational and aesthetic value of the estuary through ongoing planting and rubbish removal.

Table 11. Summary of 200m terrestrial margin mapping, December 2007.

Class	Dominant Vegetation	Pauatahanui Arm		Porirua Arm		Entire Estuary	
		Ha	%	Ha	%	Ha	%
Forest		-	-	3.9	1.5	3.9	0.7
	Exotic forest	-	-	3.2	1.3	3.2	0.6
	Mixed native and exotic forest	-	-	0.6	0.3	0.6	0.1
Scrub/Forest	Mixed native and exotic scrub/forest	32.1	10.6	7.5	2.9	39.6	7.1
Scrub	Mixed native and exotic scrub	1.2	0.4	63.2	24.7	64.4	11.5
Estuarine shrub	*Plagianthus divaricatus* (Saltmarsh ribbonwood)	0.2	0.1	-	-	0.2	0.0
Grassland	Grassland (unidentified mixed grasses)	108.1	35.7	55.9	21.9	164.1	29.4
Unvegetated		-	-	1.9	0.7	1.9	0.3
Water		-	-	9.7	3.8	9.7	1.7
Artificial structure		43.2	14.3	49.9	19.5	93.1	16.7
	Railway	-	-	6.2	2.4	6.2	1.1
	Road	43.2	14.3	43.7	17.1	86.9	15.6
Residential		118.0	39.0	41.3	16.1	159.3	28.5
Industrial		-	0.0	22.5	8.8	22.5	4.0
TOTAL		**302.8**	**100**	**255.7**	**100**	**558.5**	**100**

Figure 8. Map of 200m Terrestrial Margin Mapping - Porirua Harbour, December 2007.



3. RESULTS AND DISCUSSION (CONTINUED)

CONDITION RATINGS

The 2007 broad scale mapping has enabled condition ratings to be applied for the key issues of sedimentation (extent of soft mud), eutrophication (macroalgal cover), and habitat loss (extent of saltmarsh, seagrass and terrestrial vegetated buffer). In addition a baseline has been established against which future changes in the estuary can be assessed. A summary of condition ratings is presented in Table 12, and results discussed for each issue in the following sections.

Table 12. Summary of Condition Ratings for indicators of estuary issues.

BROAD SCALE RATING 2007	% COVER SOFT MUD	% COVER MACROALGAE	% COVER SEAGRASS	% COVER SALTMARSH	TERRESTRIAL VEGETATED BUFFER
PAUATAHANUI ARM	VERY LOW	MODERATE	LOW-MODERATE	MODERATE	POOR
PORIRUA ARM	VERY LOW	MODERATE	MODERATE	VERY LOW	POOR

4. CONCLUSIONS

In conclusion, the broad scale monitoring of Porirua Harbour showed the estuary to be 65% subtidal, with the majority of the intertidal area in both arms dominated by unvegetated, poorly sorted firm muddy sands and very little soft mud. Much of the estuary margin was developed, with saltmarsh virtually non-existent in the Porirua Arm but present in the Pauatahanui Arm. Areas of seagrass and macroalgae were both relatively extensive. In order to provide a more comprehensive assessment of overall estuary condition, these results, in combination with other relevant information, are used in the following subsections to provide an understanding of the estuary condition in relation to the key issues examined in this broad scale assessment, namely sedimentation, eutrophication and habitat loss.

SEDIMENTATION: If sediment inputs to an estuary are excessive, they infill quickly with muds, reducing biodiversity and human values and uses. In subtidally-dominated estuaries like the Porirua Harbour, fine muds tend to settle in three main areas; the subtidal central basin, and to a lesser extent the unvegetated intertidal area around the central basins; saltmarsh areas; and sheltered estuary arms. It is therefore not unexpected that the 2007 mapping showed that the intertidal area in both arms was dominated by sandy sediments, and previous studies (e.g. Healy 1980) showed that the subtidal basins were dominated by soft muds. Overall, the combined results indicate that sedimentation is an issue in Porirua Harbour and that ongoing monitoring and management is required. Because of the high cost of subtidal monitoring and the fact that soft mud already dominates the subtidal basins, broad scale mapping of the less impacted intertidal area has been chosen as the preferred approach. In addition, measurement of the sedimentation rate in both intertidal and subtidal areas has been initiated with deployment of sediment plates at 4 intertidal sites and 1 subtidal site. In the future, it is recommended that additional subtidal plates be deployed and subtidal sediment type assessed at a few key sites.

EUTROPHICATION: Typical New Zealand estuaries are shallow, well-flushed and have a large intertidal area. In such estuaries, nuisance intertidal macroalgal growth is a key broad scale indicator of eutrophication. In estuaries like Porirua Harbour, where the intertidal area is much smaller, macroalgal growth occurs both inter-tidally and to a certain extent (depending on water clarity and currents), sub-tidally. It is therefore important in such estuaries to consider both locations when drawing conclusions related to eutrophication status. Bearing this in mind, the 2007 macroalgal mapping results showed that approximately 70% of the intertidal area of each arm had a significant macroalgal cover (i.e. greater than 5% cover). Subtidal mapping has not been undertaken because of its expense, but

observations of growth in a number of spot locations suggest that it is significant. Combining these findings with the "moderately enriched" classification for the four fine scale monitoring sites (Robertson and Stevens 2008), indicates an overall moderately enriched or moderately eutrophic classification for the estuary. Eutrophication must therefore be classed as an issue in Porirua Harbour with ongoing monitoring and management required. Like sedimentation, the intertidal area has been chosen as the most cost-effective and practical indicator for ongoing monitoring.

HABITAT LOSS: Estuaries function best with a large area of rooted vegetation, i.e. saltmarsh and seagrass (attributes are described in Appendix 2), as well as a healthy vegetated terrestrial margin. Loss of this habitat reduces wildlife, recreational and aesthetic values, while also adversely impacting on an estuary's role in flood and erosion protection, contaminant mitigation, sediment stabilisation, and nutrient cycling.

Past habitat losses from forest clearance, reclamations, roading and causeways, rubbish dumping, stock grazing, drainage, and erosion protection have reduced the extent of saltmarsh and the vegetated terrestrial buffer around Porirua Harbour. This was reflected in the 2007 broad scale mapping results which showed most of the estuary was immediately bounded by artificial structures (e.g. riprap seawalls, road and rail networks), with the terrestrial land cover dominated by residential and commercial/industrial developments, and grassland. Such modification of the estuary margin has contributed to "coastal squeeze" where the capacity for estuarine vegetation to respond to changes in sediment and water levels has been greatly reduced. This has significant implications for the ability of the estuary to respond to predicted sea level rise, one of the major stressors identified in the recent vulnerability assessment of the estuary (see Robertson and Stevens 2007b).

Further, the terrestrial buffer is not extensively vegetated and in many instances is physically separated from the estuary. Within the estuary itself, virtually no saltmarsh remains in the Porirua Arm, while the moderate cover of healthy saltmarsh in the Pauatahanui Arm is restricted primarily to the east. Overall, the combined results indicate that saltmarsh and margin habitat loss is a very high issue in the Porirua Arm and a moderate issue in the Pauatahanui Arm. Consequently, ongoing monitoring of the area of saltmarsh, and terrestrial vegetation is recommended (at 5 yearly intervals), with management encouraged to address habitat loss.

For saltmarsh, the scope for restoration is large, and there is evidence of strong community and regulatory support for restoration initiatives. Significant effort has been put into replanting saltmarsh and margin vegetation in the Pauatahanui Arm, and similar initiatives in the Porirua Arm are likely to greatly enhance the value of the estuary. Similarly, the scope for restoration of the terrestrial margin is large, but more challenging given the dominance of roads along the estuary margin.

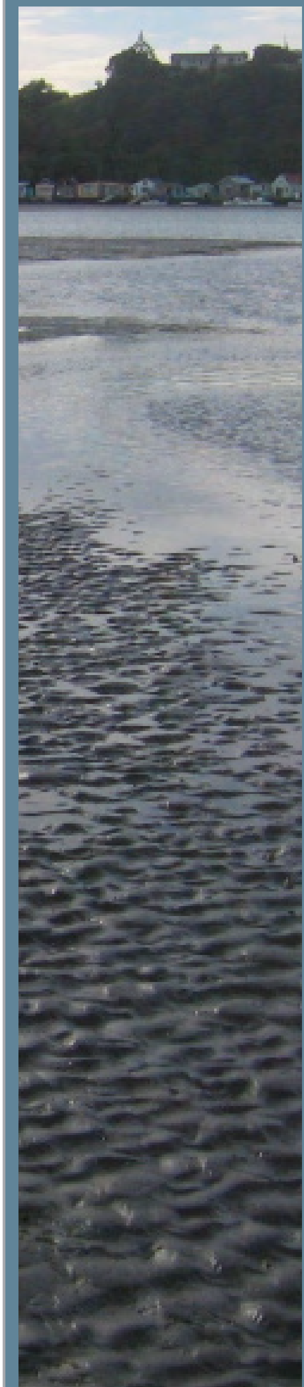
Seagrass was present in relatively extensive intertidal beds in both arms (18% of the Pauatahanui Arm and 28% of the Porirua Arm had a >5% cover). Beds appeared healthy, stable, and relatively free of fine sediment and were rated a moderate issue overall. A baseline record of intertidal seagrass has been established to measure future change, and development of a strategy to ensure the protection of remaining seagrass is recommended. Subtidal mapping has not been undertaken because of its expense, but seagrass was also observed in shallow subtidal areas in a number of locations and should be considered when making management decisions.

Another feature noted was the large amount of litter in the upper Porirua Arm of the estuary. Much of the litter (see photos left) consisted of relatively small items including plastic bottles and bags, tyres and road marking cones that are relatively easy to remove.

5. MONITORING

Porirua Harbour has been identified by GWRC as a priority for monitoring as part of GWRC's proposed coastal monitoring programme being undertaken in a staged manner throughout the region. Under this proposed long term programme, GWRC will undertake broad scale monitoring on a 5 yearly cycle (next scheduled for December 2012) to monitor and assess ongoing changes in broad scale substrate and vegetation in the Porirua Harbour.

6. RECOMMENDED MANAGEMENT



Because of the high use of Porirua Harbour and the presence of extensive past modifications that have degraded the estuary condition (e.g. saltmarsh reclamation, loss of vegetated terrestrial margin, increased muddiness, litter and disease risk), there is a high potential for estuary restoration to be undertaken, particularly given high local and regional motivation. The following management actions are encouraged:

Identify and Implement Catchment BMPs

- Catchment runoff is one of the major stressors in estuaries with the likely ecological response one of lowered biodiversity and lowered aesthetic and human use values. To prevent avoidable inputs, best management practices (BMPs) should be identified and implemented to reduce sediment, nutrient, and pathogen runoff from catchment "hotspots". Long term solutions such as this, along with a range of other planning mechanisms to address inputs, are being established and implemented by GWRC.

Restore Saltmarsh Habitat

- The almost complete loss of saltmarsh from the Porirua Arm has certainly contributed to reduced biodiversity and increased sedimentation reaching subtidal areas of the estuary, while also lowering aesthetic and human use values. It has also allowed rubbish and weeds to enter the estuary. Because of the importance of saltmarsh, it is recommended that a plan be developed to encourage its re-establishment, particularly along the Porirua foreshore, and to remove rubbish from the estuary. Development of the estuary margin (e.g. decreasing seawall gradients and recreating upper intertidal saltmarsh areas through reclamation) is likely to be both appropriate and necessary in many instances.

Reinstate Margin Buffer

- Human development of the estuary margin has resulted in clearance of surrounding bush, and construction of artificial structures around much of the estuary. Additionally, there have been significant areas of saltmarsh drained and reclaimed for roading, rail and residential and commercial purposes. This has almost certainly contributed to reduced biodiversity and increased sedimentation in the estuary. Many areas are also adversely affected by nuisance weeds and rubbish. Because of the importance of a natural vegetated margin around the estuary, it is recommended that a strategy be developed to encourage re-establishment of a natural vegetated margin around the estuary where possible.

Coastal Squeeze

- Sea level rise is a key estuary stressor. The ability of estuary vegetation to respond to sea level rise relies to a large extent on saltmarsh and terrestrial margin vegetation being able to migrate landward to maintain suitable growing conditions. In the Porirua Harbour, migration is limited by reclamations, seawalls, roads and causeways, flood controls, and by drainage of low-lying land resulting in coastal squeeze. Areas where coastal squeeze is likely to occur should be identified and used to guide existing revegetation efforts, and to identify where conflict may occur between existing uses and estuary expansion as a consequence of sea level rise.

7. ACKNOWLEDGEMENTS

This work has been funded jointly by Greater Wellington Regional Council and Porirua City Council and has been undertaken with help from various people. Particular thanks are due to the locals who freely discussed changes and issues associated with the area, and to Juliet Milne, Paul Denton, Summer Warr and Piotr Swierczynski (Greater Wellington Regional Council) and Maz Robertson (Wriggle Coastal Management) for field assistance and feedback on the report.

8. REFERENCES

REPORT REFERENCES

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.

Healy, W.B. 1980. Pauatahanui Inlet - An Environmental Study. New Zealand DSIR, DSIR Information Series No. 141, Wellington, 198p.

Robertson, B.M. Gillespie, P.A. Asher, R.A. Frisk, S. Keeley, N.B. Hopkins, G.A. Thompson, 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. 2006. Southland Estuaries State of Environment Report 2001-2006. Prepared for Environment Southland.

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

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. 22p.

Robertson, B.M. and Stevens, L. 2008. Porirua Harbour Fine scale monitoring 2007/08. Prepared for Greater Wellington Regional Council.

Stevens, L. and Robertson, B.M. 2007. Waituna Lagoon 2007. Broad Scale Habitat Mapping and Historical Sediment Coring. Report prepared by Wriggle Coastal Management for Environment Southland. 36p.

Stevens, L. and Robertson, B.M. 2007a. Waituna Lagoon 2007. Ecological Vulnerability Assessment and Monitoring Recommendations. Report prepared by Wriggle Coastal Management for Environment Southland. 40p.

Stevens, L. and Robertson, B.M. 2006. Broad scale habitat mapping of Sandy Beaches and River Estuaries on the Western Wellington Coast. Prepared for Greater Wellington Regional Council.

Stevens, L. and Robertson, B.M. 2004. Broad scale mapping of intertidal habitat and ecology of 16 sandy beaches and 4 river estuaries in Wellington Harbour, 2004. Prepared for Greater Wellington Regional Council. Cawthron Report No. 913.

APPENDIX REFERENCES

Bartholdy, J. 2000. Process controlling import of fine-grained sediment to tidal areas: a simulation model. Coastal and Estuarine Environments: sedimentology, geomorphology and geoarchaeology, Geological Society Special Publication, 175, 13-30.

Boorman, L.A., Garbutt, A. & Barratt, D. (1998). The role of vegetation in determining patterns of the accretion of salt marsh sediment. In Black, K.S., Paterson, D.M. & Cramp, A. (eds) Sedimentary Processes in the Intertidal Zone . Geological Society, London, Special Publications 139: 389-399.

Burns, N. M.; Hume, T. M.; Roper, D. S.; Smith, R. K. 1990: Estuaries. In: Climate change: impacts on New Zealand – implications for the environment, economy and society. Wellington, Ministry for the Environment. pp. 81–84

Deegan, L.A. 2002. Lessons Learned: The Effects of Nutrient Enrichment on the Support of Nekton by Seagrass and Salt Marsh Ecosystems. Estuaries, Volume 25, Issue 4, p.727-742.

Eisma, D. and Dijkema, K.S. 1997. The influence of salt marsh vegetation on sedimentation. In: Eisma, D (ed.), Intertidal Deposits. Boca Raton: CRC Press, 403-414.

Friedrichs, C. T. & Perry, J. E. 2001. Tidal Salt Marsh Morphodynamics: A Synthesis. Journal of Coastal Research, 27, 7-37.

Mills, C.E. 2001. Jellyfish blooms: are populations increasing globally in response to changing ocean conditions?. Hydrobiologia 451: 55-68.

Pethick, J., An Introduction to Coastal Geomorphology, London, 1984.

Pennings, S.C., Stanton, L.E. and Brewer, J.S. 2002. Nutrient Effects on the Composition of Salt Marsh Plant Communities Along the Southern Atlantic and Gulf Coasts of the United States. Estuaries Vol. 25, No. 6A, p. 1164–1173.

Thayer, G.W., W.J. Kenworthy, and M.S. Fonseca. 1984. The ecology of eelgrass meadows of the Atlantic coast: A community profile. US Fish Wildl. Serv. FWS/OBS-84/02. 147 pp.

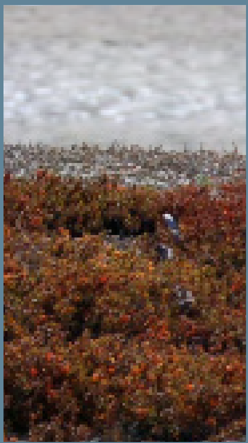
Wells, J.T. and Coleman, J.M. 1987. Wetland loss and the subdelta life cycle. Estuarine Coastal and Shelf Science, 25(1), 111-125.

APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

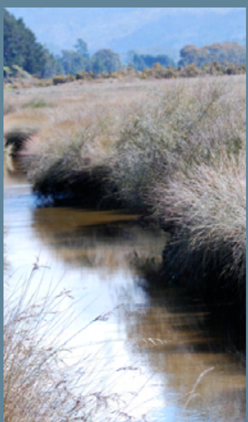
Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.
Treeland: 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.
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.
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: The substrate is clearly recognised by the granular beach sand appearance and the often rippled surface layer. Mobile sand is continually being moved by strong tidal or wind-generated currents and often forms bars and beaches. When walking on the substrate you'll sink <1 cm.
Firm sand: Firm sand flats may be mud-like in appearance but are granular when rubbed between the fingers, and solid enough to support an adult's weight without sinking more than 1-2 cm. Firm sand may have a thin layer of silt on the surface making identification from a distance difficult.
Soft sand: Substrate containing greater than 99% sand. When walking on the substrate you'll sink >2 cm.
Firm mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink 0-2 cm.
Soft mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When you'll sink 2-5 cm.
Very soft mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When walking you'll sink >5 cm.
Cockle bed: Area that is dominated by both live and dead cockle shells.
Mussel reef: Area that is dominated by one or more mussel species.
Oyster reef: Area that is dominated by one or more oysters species.
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. DESCRIPTION OF KEY ESTUARY HABITAT FEATURES

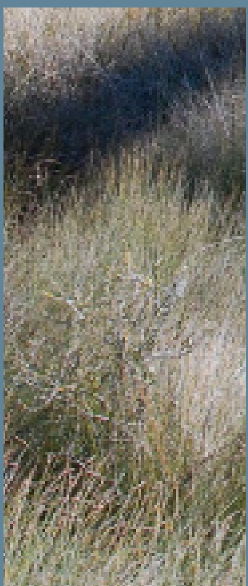
SALTMARSH HABITAT



Glasswort.



Searush.



Jointed wire rush.

Description: A salt marsh is classified as being the intertidal area of fine sediment that has been transported by water and is stabilised by vegetation (Boorman et al., 1998). Extensive saltmarshes tend to be present if the coastal plain is gently sloping and wide (Freidrichs and Perry 2001). In general, marsh grasses cannot survive below mean tide level (the midway point between MLW and MHW) and are outcompeted by terrestrial plants above spring high tide (Pethick 1984). Saltmarshes often have distinct communities. For example:

- a “rushland/sedge” community consisting of primarily searush (*Juncus kraussii*), oioi (*Apodasmia similis*) and three square (*Schoenoplectus pungens*);
- a “saltmarsh ribbonwood/rush” community consisting of a mix of saltmarsh ribbonwood (*Plagianthus divaricans*) and rushes;
- a “salt meadow” community consisting of small herb-like plants including, sea primrose (*Samolus repens*), remuremu (*Selliera radicans*), glasswort (*Sarcocornia quinqueflora*) and in more brackish areas batchelor’s button (*Cotula coronapifolia*), leptinella (*Leptinella doica*), slender clubrush (*Isolepis cernua*) and arrow grass (*Triglochin striata*), and
- a “weed” community consisting of various introduced grasses, blackberry, gorse and iceplant (*Carpobrotus edulis*).

Importance: Saltmarsh is one of the most productive environments on earth, and serve as important nursery grounds and wildlife habitat. They provide nutrients to surrounding areas, fuelling other marine food webs. These dynamic ecosystems provide tremendous additional benefits for humans including flood and erosion control, water quality improvements, opportunities for recreation and for atmospheric gas regulation - estuaries tend to be “carbon sinks,” since carbon dioxide is absorbed in the photosynthesis carried out by the prolific plant growth.

Threats: Tidal salt marshes have the ability to respond rapidly to physical stressors, and their condition is often a dynamic balance between relative sea level rise, sediment supply and the frequency/duration of inundation (Freidrichs and Perry 2001). However, if sea level rises too much, or the sediment supply or inundation through flooding is excessive, then the balance can be upset and the saltmarsh is lost or its condition deteriorates. This balance varies between different types of estuaries but their response centres around how each reacts to sediment inputs and inundation (the latter is particularly important in face of predicted accelerated sea level rise through global warming).

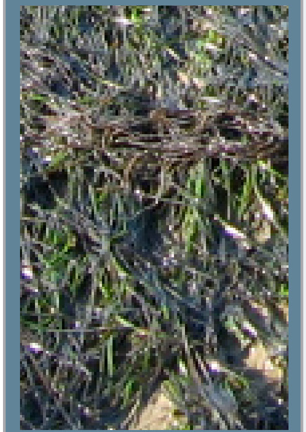
- **Sedimentation**: Sedimentation within saltmarshes is relatively high [approximately 5 times that of adjacent unvegetated flats (Eisma and Dijkema 1997)] with most of the sediment depositing close to the sediment source (e.g. tidal creek) or spread evenly if sourced from the main body of the estuary. Sedimentation rates increase with grass stem density and because most New Zealand saltmarsh plants tend to grow in dense stands [e.g. searush (*Juncus kraussii*) and oioi (*Apodasmia similis*)], sedimentation rates in NZ saltmarsh are expected to be relatively high. The increase in sedimentation and subsurface plant growth results in an elevation of bed level for most NZ estuaries.
- **Inundation**: The vulnerability to inundation of saltmarsh habitat in tidal lagoon estuaries of New Zealand is mainly from sea level rise. There are two processes by which sea level can increase relative to the marsh surface: (1) sea level rises because of increases in the volume of the oceans, and (2) the marsh surface sinks (subsides) because of soil compaction and other geologic processes [coastal fringe marshes with a thin layer of sediment deposits have low rates of sinking, whereas areas underlain with thick, unconsolidated sediments have higher subsidence rates (e.g. Mississippi delta)]. Under current conditions, we know that the majority of marsh environments tend to keep pace with sea level changes due to sedimentation and subsurface plant growth (Bartholdy, 2000). These environments are capable of responding very rapidly to changing conditions, be it sea level rise or alteration of current patterns. However, under an accelerated rate of sea-level rise it is expected that bed elevation through sedimentation will lag further behind relative sea-level rise and plant stress will increase until the plants die, the soil volume collapses, and the marsh becomes submerged. The vulnerability to saltmarsh decline is expected to vary between estuaries with different tidal ranges. The most vulnerable are the microtidal estuaries (those with a tidal range of less than 2m) because a relatively small increase in sea level or decrease in sedimentation rate can submerge the marsh vegetation to a level that is too stressful for survival. Conversely, when sedimentation is high, microtidal marshes will expand seaward more quickly than systems in higher tidal ranges. This is because it takes relatively little upward growth to significantly reduce submersion, causing available suspended sediment to be deposited further seaward. The potential for massive marsh expansion in such systems in the presence of plentiful sediment is highlighted by historical mapping studies (Wells and Coleman 1987) which document horizontal marsh expansion rates of hundreds of meters per year on the Mississippi Delta, soon followed by equally remarkable marsh loss rates once the sediment supply decreased.

Saltmarsh is also vulnerable to increased nutrient inputs, particularly nitrogen. Added nutrients stimulate saltmarsh growth but, if excessive, may lower dissolved oxygen levels, change food web dynamics, alter community composition and stimulate the growth of algae and weeds (Deegan 2002, Pennings et al. 2002).

In addition, although the Water and Soil Conservation Act (1967) and the Resource Management Act (1991) introduced wide-ranging controls over the destruction of saltmarshes and other wetlands, since 1967 the legacy of detrimental saltmarsh impacts remains visible in the undersized culverts below roads, railways and stopbanks that prevent adequate salt-water flow into these environments, and drainage and reclamation. The reduced salinity alters the plant community and facilitates the spread of the invasive species (e.g. reed *Phragmites australis*), which out-competes other salt marsh vegetation. Because of its lower habitat value for many species, biodiversity is reduced in areas where *Phragmites* becomes dominant. Docks and piers that span the width of the saltmarsh shade the vegetation and can cause reduced growth rates or death of the plants.

APPENDIX 2: HABITAT DETAILS (CONTINUED)

SEAGRASS BEDS

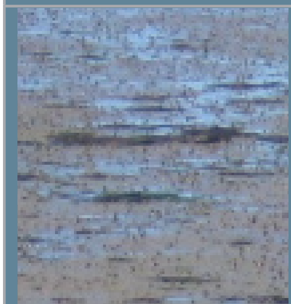

Eelgrass.

Description: New Zealand has primarily one species of seagrass, *(Zostera muelleri),* called eelgrass. Apart from its common intertidal habitat, eelgrass can also grow as subtidal fringes in New Zealand estuaries if water clarity is high enough (i.e. there is sufficient light penetration). Eelgrass can grow in bottom sediments ranging from coarse sand to mud.

Importance: New Zealand eelgrass beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. They are one of the most productive marine habitat types and rival the productivity of intensively managed farmland (Thayer et al. 1984). They are also important for their role as a forerunner for the establishment of a saltmarsh on tidal mudflats. They promote sedimentation of muds and increasingly fertile underlying soils. When the soil becomes too fertile, the eelgrass can no longer grow, but salt marsh plants can (often beginning with salt meadow communities like glasswort, remuremu and sea primrose and/or searush communities).

Threats: These submerged plants need sunlight to survive. Decreased water clarity due to elevated sediment inputs and re-suspension are a direct threat as is direct smothering through excess sediment. Another widespread current threat comes from the excess input of nitrogen to estuaries which stimulate the growth of macroalgae and phytoplankton that shade out the seagrass. In terms of global warming impacts, it is predicted that eelgrass may be detrimentally affected by a rise in sea temperature (its tolerance to low salinities decreases as temperature increases - Burns et al. 1990). Sea level rise may also be detrimental in that plants become light limited as water depth increases. Seagrass beds are difficult to restore once they have become degraded.

MUD HABITAT

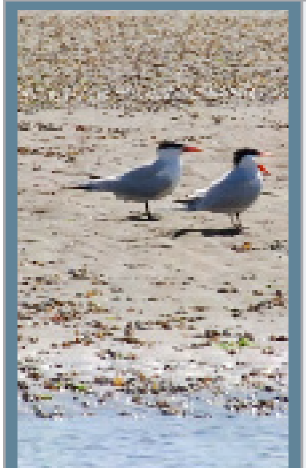

Intertidal mud flats.

Description: Mud flats are areas of unconsolidated fine-grained sediments that are either unvegetated or sparsely to densely vegetated by algae and/or diatoms. They are found in sheltered environments and support high biodiversity (snails, crabs, burrowing polychaete worms, shellfish and other macroinvertebrates). Most of the organisms inhabit the upper 10cm, because below that level, mud often becomes anoxic (low in oxygen or oxygen depleted). To adjust to these harsh physical conditions, many organisms build and maintain burrows or tubes to access oxygen in the air or water, or have adaptations such as siphons.

Importance: They provide a number of important ecosystem services including; primary and secondary production; habitat for polychaetes, crustaceans, flatfish and shellfish; refuge and nursery habitat for juvenile fish; and interception, uptake and processing of nutrients and contaminants from watershed drainage. Bacteria living in the sediments of estuaries can also help to break down certain pollutants.

Threats: The major threats are from agricultural and urban development and include: excessive sedimentation leading to infilling, contamination with toxicants and disease causing microbes, reclamation and drainage, building of structures, and spread of introduced species, e.g. Pacific oyster.

SAND HABITAT


Sandflats and Caspian Terns.

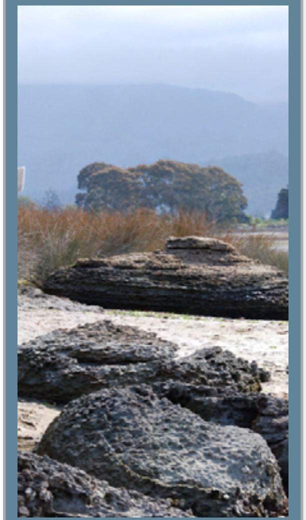
Description: This habitat includes both dune areas near the mouth and along the sand barrier spits, as well as extensive areas of sand flats in the main basin (which often include a mud or silt component and shell fragments) and sandy channel areas. In these highly dynamic environments, sand is moved by tides, winds, and storm surges, and this movement is responsible for shaping these habitats. Sand flats typically occur in higher energy areas than mud flats where the substrate is predominantly sand and is exposed to sorting from wave and current action.

Importance: Sand habitat tends to be the area most intensively used by humans for recreation. Shellfish, polychaetes, crustaceans and young fish are typical animals that inhabit sand flats. Sand channels generally occur in open, deeper areas where channels form. These open areas are typically inhabited by bivalve shellfish, polychaetes, young flat fish, and sand loving algae. They are also important for provision of refugia and food for anadromous, resident, and marine fishes, and transport of sediments.

Threats: Major threats are excessive sedimentation leading to muddy sediments and/or infilling, contamination with toxicants and disease causing microbes, reclamation and drainage, building of structures, and spread of introduced species. In addition, commercial and residential development on sand dunes, as well as by developing just landward of dunes, humans have prevented the natural movement of these landforms away from the sea. Trampling and grazing of dune vegetation can also lead to dune demise. Erosion can threaten sand beaches, especially when natural migration of sand is disrupted by jetties, groins, and seawalls. Off-road vehicles threaten sandy beach and sand flat inhabitants by compacting the sand, making burying and burrowing more difficult. These vehicles can also crush organisms that live just below the surface, and disturb crabs and nesting birds. Sand mining for beach nourishment poses a threat to communities inhabiting sandy bottoms, especially if large quantities of sand are continually removed from one area.

APPENDIX 2: HABITAT DETAILS (CONTINUED)

ROCK HABITAT



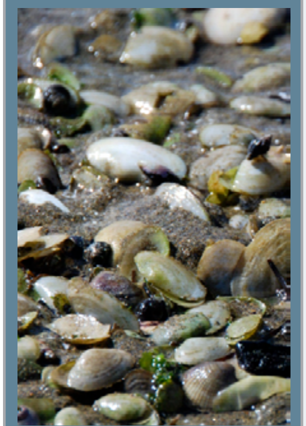
Rock habitat.

Description: Includes a range of larger material from solid rock ledges and boulders to cobble and gravel. This size regime strongly influences the composition of the biological community in the rocky habitat. A typical intertidal rock ledge community, for example, includes attached organisms with relatively long life spans (such as brown algae, anemones, barnacles, and mussels), while cobble beaches that are frequently disturbed by wave action tend to host small and ephemeral creatures, such as amphipods and isopods (e.g., beach hoppers and scuds). Rocky subtidal habitats commonly harbour seaweeds, crabs, sea urchins, and a variety of fish species. Some of the organisms found attached to rock ledges and boulders include mussels, oysters, limpets, chitons, and anemones. Finally, the biota of subtidal rocky habitats is distinct—many of the species found in these habitat types can only be found attached to rocky substrates.

Importance: The physical structure provided by both the rocks, and the plants and animals that adhere to them, provide valuable habitat for many other organisms, especially small invertebrates and juvenile fish. This structure is important for spawning and for providing protection from predation by larger organisms that cannot access the small spaces between rocks. Seaweed in the subtidal zone and the other algae in the intertidal zone are vitally important because they provide shelter and structure. Intertidal algae protect snails, mussels, barnacles, and crabs from exposure to sun, wind, rain, and predators when the tide is low. Because of their high productivity, algae in these rocky habitats also serve as important food source. The high abundance of animals that occur in subtidal rocky habitats also support larger species such as diving birds and large fish and humans that target these habitat types while fishing.

Threats: Coastal and catchment development can degrade rocky intertidal habitats, so that sediments accumulate on rocky shores. Human presence can damage habitat through trampling or excessive harvest. Rocky intertidal shores have been the subject of scientific scrutiny for decades and recent shifts in species distributions (i.e., declines in cold-tolerant species and increases in the relative abundance of warmer water species), which are potentially linked to climate change, have been documented.

SHELLFISH BEDS



Pipi bed.

Description: In dense groupings, bivalve molluscs (e.g. mussels, cockles, oysters and pipi), form a habitat type known as shellfish beds. Small organisms, such as polychaete worms, juvenile crabs and snails find refuge in the spaces between the shells, while other organisms attach to the shells' hard surfaces, which provide an anchor unavailable in the surrounding soft sediments. Each species of bed-forming shellfish has different habitat requirements, which means that shellfish beds can be found in a range of depths, salinities, or substrates (surfaces, such as sand, rock, or mud).

Importance: Humans, crabs, fish, and seabirds all consume large quantities of shellfish. For coastal residents and tourists, collecting shellfish is an important pastime, while in some estuaries, shellfish beds support a significant commercial fishery. Through filter-feeding, shellfish improve water quality by removing suspended material and particulate pollutants from the water column. Shellfish beds also provide an important link between benthic (bottom) and pelagic (open water) habitats by capturing small food particles from the water column and transferring them to the benthos.

Threats: Intensification of landuse and excessive runoff of nutrients, sediment, pathogens and toxicants represent the largest threat to nearshore shellfish beds, through diminished water quality. Increased temperature through global warming is another significant threat. Overfishing of shellfish can also diminish their filtering function, potentially leading to increased turbidity (cloudiness due to sediments or other substances in the water) and diminished light penetration to the seafloor. Shellfish beds can be destroyed if they are dredged or if dredged material is deposited nearby or in upstream locations. Some introduced shellfish e.g. Pacific oyster can become nuisance organisms.

WATER COLUMN

Mullet in lower estuary.

Description: The water column is a dynamic environment subject to waves, currents, tides, and riverine influences. In New Zealand estuaries it is generally well supplied with sunlight and consequently phytoplankton (tiny plants suspended in the water column) are major primary producers. Phytoplankton include a wide range of species, but are generally dominated by diatoms in healthy waters. The water column also includes a variety of animal life including; zooplankton (tiny animals suspended in the water column), fish and jellyfish.

Importance: Human use of the water column is high with swimming, boating and fishing all popular activities. The water column has an important role in nutrient, dissolved oxygen, salinity, and contaminant concentrations and distribution, as well as fish and shellfish habitat.

Threats: Non-point source pollution is currently the greatest threat to estuary water quality. Harmful algal blooms (HABs) (which are caused by a superabundance of toxin-producing planktonic plants known as dinoflagellates) are also becoming increasingly prominent along the New Zealand coast. HABs can lead to shellfish closures through risk of shellfish poisoning in humans. Overfishing may also strongly influence the species found in the water column. For example, the dramatic increases in the abundance of jellyfish in coastal waters has been linked to the depletion of fish stocks. Many jellies eat similar food items as fish, and food that was formerly consumed by fish is now available for jellyfish (Mills 2001). Global climate change, and the associated change in weather and current patterns, pose another threat to water column habitats.