Estuarine Environmental Assessment and Monitoring:

A National Protocol

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PART C:
Application of the Estuarine Monitoring Protocol

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1. INTRODUCTION

Development of a standardised protocol for assessment and monitoring of New Zealand estuaries has, until now, been relegated to the too-hard basket by most estuarine managers and scientists. There are good reasons for this. Most importantly, estuaries are complex, dynamic and extremely heterogeneous environments. Consequently, with few exceptions, it has not been possible to identify general "indicators" of health or condition that are applicable to the full range of estuary types and habitats that occur in New Zealand. However, because estuaries play such a pivotal role in coastal ecosystems, and are often subjected to a wide variety of potentially conflicting uses and related impacts, a standardised monitoring protocol is of obvious high priority.

The Ministry for the Environment (MfE) have started the process by identifying a number of Environmental Performance Indicators (EPIs) for a variety of coastal environments (MfE 2001). A few of these are suitable for implementation now, while most require further development. After preliminary discussions with Andrew Fenemor (Tasman District Council) and Murray Bell (Ministry for the Environment), and later discussions with coastal managers throughout New Zealand, we decided that the time was right to further develop promising indicators and begin the implementation procedure. Thus the development of the Estuarine Monitoring Protocol (EMP) was initiated through the support of the MfE's Sustainable Management Fund and 11 New Zealand regional and local councils.

The present document (Part C) is the condensed form of the EMP. It gives a step-by-step description (or recipe) of how to select an estuary for monitoring, establish a baseline of estuary conditions and monitor change over time. The accompanying Parts A and B provide a more detailed description of how it was developed, the rationale/justification and methodology and complete datasets for the nine reference estuaries.

1.1 What is the EMP?

The estuary monitoring protocol is simply a standard method or approach to assess the current state or condition of a particular estuary in order to establish a benchmark for comparison with subsequent surveys. A major advantage of using a standard approach is that it generates an integrated database that not only facilitates comparisons with successive monitoring surveys, but also allows interpretation with respect to other estuaries/regions.

The EMP was intended to provide environmental resource managers with a set of tools to assess and monitor the status of estuaries in their region. To achieve this, the protocol was required to be scientifically defensible, cost-effective, practical/easy to use, and applicable to estuaries throughout New Zealand.

1.2 How was the EMP developed?

In summary, three estuarine assessment techniques were applied to a series of reference estuaries along the geographical/latitudinal range Northland to Southland (Figure 1). These techniques were:

1) A preliminary assessment of estuary condition for prioritising estuaries for monitoring,

2) Broad-scale mapping of intertidal habitat characteristics, and

3) Fine-scale assessment of one key representative habitat (the sand/mud, mid-low intertidal habitat) using analyses of a suite of characteristics relevant to estuarine condition.

Following these assessments, the data were analysed, and the results used as a guide to structuring a protocol that would adequately describe the current 'health' of the intertidal seabed (benthic) environment. This included selecting appropriate characteristics to use as 'indicators', and determining the number of replicate samples/analyses required for particular fine-scale analyses to enable managers to detect change over time with statistical reliability.

Undetaking habitat mapping at the Otamatea Arm of the Kaipara Estuary during this project

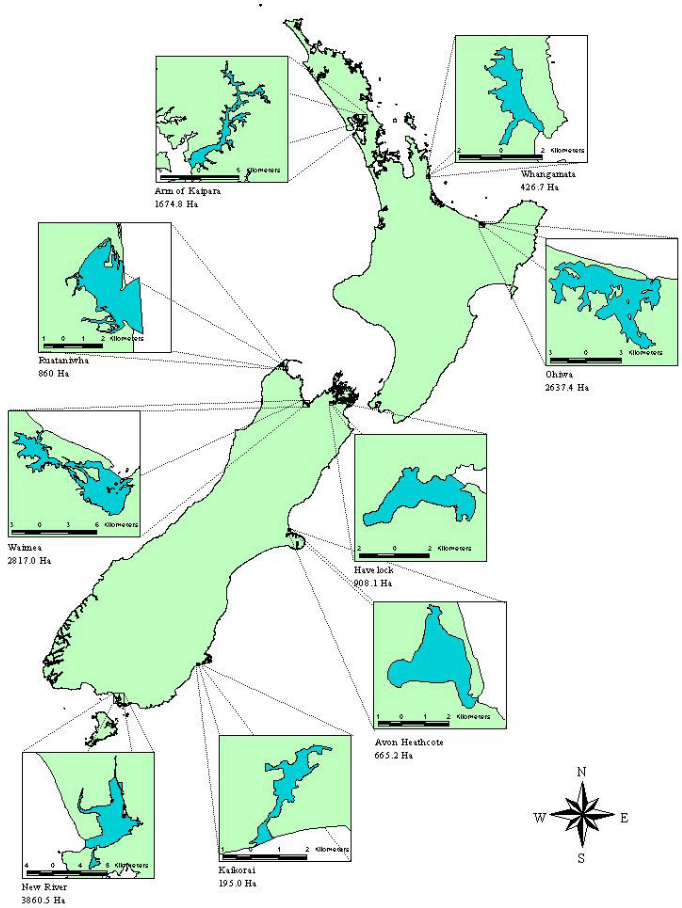


Figure 1: Locations of the nine reference estuaries with expanded inserts showing a magnified view of each estuary.

1.3 Using the EMP

The EMP provides a stepwise approach to applying the three techniques (tools) for the assessment of estuarine health.

For each of the three assessment methods, the following information is given:

- the equipment required (software, field equipment, chemicals *etc*),
- the methodology,
- estimated time/costs,
- a guide to interpreting the data,
- a guide for making management decisions based on the outputs of the assessment.

2. PRELIMINARY ASSESSMENT OF ESTUARY HEALTH

2.1 Overview

A preliminary characterisation and assessment of estuary health is a means of indexing estuarine health within a region. This approach utilises a combination of information that can be acquired easily from general literature and/or a brief site assessment, and information that is obtained from more involved studies. The aim is NOT to derive a 'magic' number that will represent the state of health of an estuary but rather to provide a flexible tool, the 'Decision Matrix' (DM) to give a rapid, broad overview of the condition/status of an estuary (Table 1). The DM uses four categories of factors to undertake the preliminary assessment; geomorphological classification, catchment use, water and sediment quality, and resource values/uses. Each of the various factors are assigned a score (or rating), tabulated, and an overall assessment score is assigned. By ranking estuaries based on the combination of these factors, estuaries in the region can be evaluated, and a risk-based approach can be made on deciding which estuaries require monitoring.

In completing the table for each of their estuaries, it is envisaged that managers will:

- become more familiar with their estuaries,
- identify knowledge gaps about their estuaries,
- identify the significant values within their estuaries,
- identify potential threats to estuarine values,
- prioritise estuary monitoring based on the current condition, potential threats, or values of significance (*e.g.* ecological, cultural, recreational, and economic).

It is accepted that the DM does have limitations:

- There will be some loss of individual detail as it condenses and simplifies a large amount of information about each estuary,
- It can not be applied to a broad comparison of estuaries outside a particular region. The ranking factors allocated in the examples are subjective and discretionary. They can be modified or replaced to emphasise particular features that are considered more relevant to estuaries in a region. Although this allows the ranking process to be tailored to the concerns and issues of the region, community or manager, it precludes its use for ranking estuaries against those in other regions,

- The ranking result is only as good as the information used in its application. This could also be seen as a strength as it will allow improvement of the result with the application of more or higher quality information about the estuary and,
- In the case of relatively undisturbed estuaries, particularly, further consideration will be required of the potential for future degradation of existing values; *e.g.* high natural freshwater (nutrient or sediment) inflows, low flushing rate, *etc*.

Requirements

- Decision matrix for prioritising estuaries for monitoring.
- Uses and values of each estuary.
- Relevant background information on the physical, chemical and biological characteristics of estuaries in the region including local experience.
- A background on the geology and land use characteristics of the surrounding catchments.

2.2 Methods

The process of undertaking the preliminary estuary assessment involves the following steps:

Step 1: Matrix Familiarisation

Read through and become familiar with the estuary assessment factors and scoring schedule in the DM (Table 1).

Step 2: Choose Estuaries to Prioritise

Decide on estuaries to be included in the prioritisation process. For example, this may be a cut-down list of 6 estuaries in the region that the manager has already targeted for prioritisation or it may be all encompassing and include all the estuaries in a region.

Step 3: Score Estuary Factors

For each estuary allocate an appropriate score for each factor or item on the Decision Matrix. To achieve this you will need to review available background information on the estuaries and their catchments and, depending on the amount of information available and familiarity with the estuaries, one or more site visits to each may be required.

Step 4: Assign Weightings to Estuary Factors

For each factor on the list, decide on the appropriateness of the given weighting factor (the greater the weighting factor, the greater the priority for monitoring). Weighting factors range from a low weighting of 1 to a high weighting of 5. To achieve this, you will firstly need to decide if unmodified estuaries have a greater priority for monitoring in a particular region than highly modified estuaries. If so, you will need to downgrade the pre-set weightings for C and D as they are presently favouring factors that are characteristic of impacted or modified estuaries. For example, Factor 19 "Point Source Effluents" would be weighted with a 1 or 2 if unmodified estuaries were being given a high monitoring priority and a 4 or 5 if modified estuaries were being given the highest priority.

Step 5: Total Score for Each Factor

For each factor on the matrix, add the score to the weighting factor to give a total for each factor.

Step 6: Total Score for Each Estuary

Sum each of the factor totals in the whole matrix to give an Estuary Total Score.

Step 7: Interpreting the Data

Compare totals for each estuary in your prioritisation list. Estuaries with the highest scores have the highest priority for monitoring.

Step 8: **Stakeholder Input**

Ideally, the next step is to provide stakeholders with the completed decision matrices for each estuary under consideration and to seek their input.

Step 9: **Final Prioritisation**

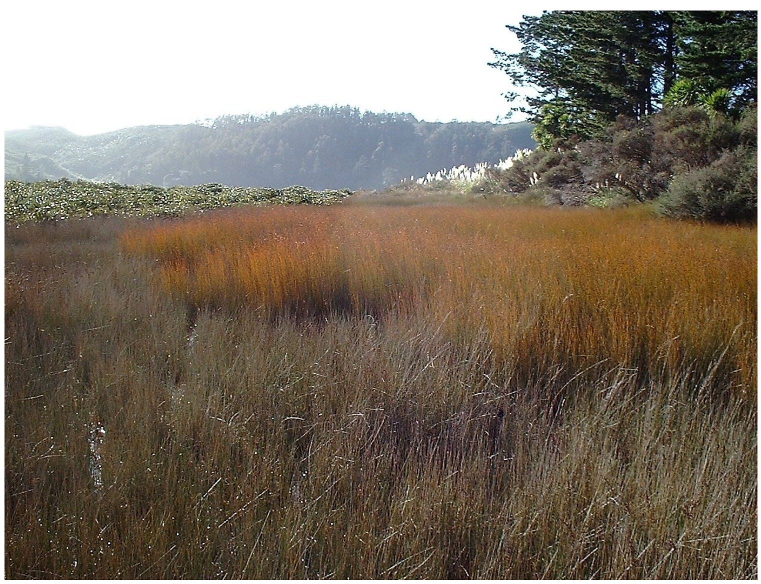
Following stakeholder input, undertake any necessary modifications to the matrix set-up and calculations and repeat Steps 6 and 7 to prioritise estuaries for monitoring.

2.3 How much will it cost?

The time to undertake the initial prioritisation of estuaries for monitoring will vary depending on the extent of existing information and the availability of local expert knowledge. If both are readily available, then this particular aspect could be undertaken by council staff for $5,000 or less.

2.4 Working With the Decision Matrix as a flexible management tool

It is envisaged that the primary use of the matrix will be for providing a defensible and transparent means of prioritising estuaries for long term monitoring. In particular, it will provide a tool for Regional Councils to use in the design of their State of Environment monitoring programmes. Once completed, the manager can prepare a summary of the matrix approach and estuary scores for a region which is then available as a tidy package for Council decision-makers. By periodically re-addressing the DM, the manager will be able to evaluate the effectiveness of management decisions and/or changing usage and values of estuarine resources.



A jointed wirerush (*Leptocarpus similis*) field in Whangamata Estuary

Table 1: The Decision Matrix- a preliminary assessment of estuary condition for prioritising estuaries for State of the Environment monitoring.

DECISION MATRIX FOR PRIORITISING ESTUARIES FOR STATE OF ENVIRONMENT MONITORING

	Estuary Assessment Factor	Explanation	Scoring Schedule	Estuary 1			Estuary 2		
				Score	Weighting factor	Total	Score	Weighting factor	Total
A.	**Existing Estuary Physical and Biological Characteristics**								
1	Area of Estuary (ha)	Value of an estuary increases with the area of the resource.	1 = <500 ha, 2 = 500-2500 ha, 3 =>2500 ha.						
2	Diversity of intertidal habitat	Estuaries with the broadest array of intertidal habitats have the greatest potential for high intertidal biodiversity and therefore have greatest ecological value to a region. Habitats include: rushes, reeds, seagrasses, tussocks, herbfields, scrub, rock, cobble, gravel, mobile sand, sand, shell, muddy sand, soft muds, shellfish beds, sabellid beds.	1 = limited array of habitats, 2 = moderate array of habitats, 3 = most common habitats present and in good condition						
3	Diversity of subtidal habitat	Estuaries with the broadest array of subtidal habitats over a wide depth range have the greatest potential for high subtidal biodiversity and therefore have greatest ecological value to a region. Habitats include: macroalgal beds, seagrass beds, rock, cobble, gravel, mobile sand, sand, shell, muddy sand, soft muds, shellfish beds.	1 = limited array of habitats, 2 = moderate array of habitats, 3 = most common habitats present and in good condition						
4	Flushing time (days)	Flushing time is the average period during which a quantity of freshwater derived from a stream or seepage remains in the estuary. The very well-flushed estuaries will be least at risk from build-up of contaminants.	1 = >10 days, 2 = 3-10 days, 3 = < 3 days						
5	Freshwater input (m^3/s)/Area of estuary (ha) ratio	Estuaries with a high FW/A ratio have a large freshwater influence and often result in a relatively harsh environment for aquatic life (*i.e.* biodiversity tends to be less).	1 = >100, 2 = 10-100, 3 = <10.						
6	Extent of mangrove and saltmarsh habitat	Estuaries where mangrove and/or saltmarsh habitats have been reduced or reclaimed have lower ecological value, fewer feeding and nursery habitat for other species, and a decreased ability to assimilate contaminant and sediment entry. These habitats act as coastal buffers.	1 = low or severely reduced, 2 = moderately reduced, 3 = habitat present in unaltered extent and in good condition (For regions outside the range of mangroves, use saltmarsh habitat as the single assessment factor)						
7	Extent of fish/shellfish resources	Occurrence of fish and shellfish resources in an estuary enhances the value. A drop in abundance and diversity could result from an increase in nutrients and pollutants to an estuary.	1 = low or no fish and shellfish resources, 2 = medium abundance/diversity, 3 = High abundance and/or diversity						
B.	**Natural Character and Values**								
8	Wetland and wildlife status	Estuaries are often important habitat for coastal fisheries and international migratory birds, and may be recognised as having significant conservation value. Estuaries with high wetland and wildlife status have a high perceived value.	1 = low, 2 = medium, 3 = high wetland and wildlife status						
9	Recreational use	An estuary can be a significant social resource, used for water sports, food gathering, sightseeing, exercising *etc.*	1 = low utilisation for recreation, 2 = moderate, 3 = high utilisation for recreation						
10	Cultural significance	The values of tangata whenua, including the issue of mana whenua (customary authority) may be significant to an estuary. Estuaries may have a high cultural value if they are or were a traditional food-gathering site, papa taakoro or of other cultural importance.	1 = low perceived cultural significance, 2 = medium, 3 = high perceived cultural significance						
11	Commercial use	An estuary can be a commercial resource with economic importance, for example through shellfish/fish harvesting, aquaculture, ecotourism *etc.*	1 = low commerical use, 2 = moderate, 3 = high commercial use						
12	Perceived value by the communities in the region	Estuaries may have high aesthetic and amenity value to surrounding residential communities. They may also be important for education, tourism, or significant to the communities' natural character or identity.	1 = low perceived value by communities, 2 = medium, 3 = high perceived value by communities						
13	Potential for rehabilitation	Historically impacted estuaries may have a greater potential for rehabilitation of estuary condition than currently impacted estuaries.	1 = low potential for rehabilitation, 2 = medium, 3 = high potential for rehabilitation						
C.	**Characteristics that Indicate a Potential for an Adverse Impact**								
14	Proportion of urban/industrial landuse in the estuary catchment	Modified catchments are likely to pose greatest risk to each estuary from contaminant entry. Urban and industrial contaminants include heavy metals, nutrients, organochloride pesticides *etc.*	1 = high extent of urban/industrial landuse, 2 = medium, 3 = low extent of urban/industrial landuse						
15	Proportion of agricultrual landuse in the estuary catchment	Modified catchments are likely to pose greatest risk to each estuary from contaminant entry. Agricultural run-off has been attributed to increased sedimentation, nutrients and contaminants in estuaries.	1 = high extent of agricultural landuse, 2 = medium, 3 = low extent of agricultural landuse						
16	Proportion of exotic forest landuse in the estuary catchment	Modified catchments are likely to pose greatest risk to each estuary from contaminant entry. Exotic forestry can impact on estuaries by causing increased erosion of the catchment, increased sedimentation and nutrients in the estuaries.	1 = high extent of exotic forest landuse, 2 = medium, 3 = low extent of exotic forest landuse						
17	Proportion of unmodified estuary catchment	The least modified catchments are likely to pose least risk to each estuary from contaminant entry. Unmodified land may also include parks, reserves and other protected areas on the estuary margin.	1 = low extent of unmodified catchment, 2 = medium, 3 = high extent of unmodified catchment						
18	Estuary margin alteration (*e.g.* reclamation)	Estuaries where margins have been altered and/or reclamation has been undertaken have less value and a decreased ability to assimilate contaminant entry and increased erosion and sedimentation processes.	1 = high extent, 2 = medium extent, 3 = low extent of margin alteration						
19	Point Source effluents	Presence of point source discharges of wastewater (municipal, industrial and/or agricultural) into an estuary poses a high risk of contaminant entry.	1 = extensive discharges, 2 = moderate discharges, 3 = very low or no discharges.						
20	Aquaculture licences	Presence of aquaculture activities in an estuary provides a greater risk of contaminant entry and other impacts (*e.g.* biosecurity risk and impingement on the natural and aesthetic values of an estuary).	1 = aquaculture licences exist in estuary, 2 = estuary is at risk from aquaculture developments, 3 = estuary has no current or likely future aquaculture activities.						
21	Extent of biosecurity risk	Infiltration of an estuary by foreign plants and/or animals poses risks to the existing habitat and community structure. Risk assessment should include such factors as: likelihood of entry (*e.g.* high risk for ports, areas with extensive aquaculture or areas which attract boats), likelihood of invaders surviving, and risk of impacts on perceived estuary values.	1 = high risk, 2 = medium risk, 3 = low biosecurity risk						
22	Extent of risk of accidental spills	Accidental spillage of hazardous wastes (*e.g* . oil) lowers values in an estuary.	1 = high risk, 2 = medium risk, 3 = low risk of accidental spills						
D.	**Characteristics that Indicate an Existing Impact**								
23	Extent of nuisance macro and micro-algal blooms	Algal blooms (*e.g. Ulva* sp.) indicate nutrient enrichment. Estuaries with algal bloom problems often have widespread adverse ecological and aesthetic effects. Additionally, there may be health risks associated with eating contaminated shellfish during bloom events.	1 = frequent algal bloom problems and/or large areas of nuisance macroalgae, 2 = occasional algal bloom problems 3 = rare algal bloom problems						
24	Extent of invasive species	Occurrence of exotic invasive species can threaten the natural character and biodiversity of an estuary (*e.g.* Pacific oyster, *Spartina* sp.)	1 = large colonisation of invasive species, 2 = low extent of invasive species, 3 = no known invasive species						
25	Extent of modification of estuary hydrodynamic characteristics	The hydrodynamic processes of an estuary can be altered by gravel or sand extraction, roading, reclamation and structures, creating modified water circulation patterns, increased sedimentation, less flushing and an increase in contaminant loading.	1 = large extent, 2 = moderate extent, 3 = low extent of modification of hydrodynamic characteristics						
26	Extent of water clarity problems	Widespread water clarity problems (*e.g.* after heavy rain and/or wind events) lower the perceived value of an estuary, have an adverse social effect and adversely effect aquatic ecosystems.	1 = frequent, 2 = occasional, 3 = rare water clarity problems						
27	Suitability for human contact	Water that people would not swim in or wade in has low value. Waters that are appealing to swim or wade in have highest value. Water quality problems include water-borne disease risks.	1 = water frequently not suitable for human contact, 2 = water on occasions not suitable for human contact, 3 = water always suitable for human contact						
28	Extent of faecal contamination problems	Widespread faecal contamination problems lower estuary values. Problems are indicated by high faecal coliforms and enterococci in the water column and shellfish, illness or perceived health risk.	1 = High extent, 2 = moderate extent, 3 = low or no extent of faecal contamination problems						
29	Extent of nuisance odour problems	Widespread nuisance odour problems lower estuary values, *e.g.* from effluent, decomposing macroalgae, anaerobic sediments.	1 = frequent problems, 2 = occasional problems, 3 = rare or no nuisance odour problems						
30	Extent of toxicity problems	Widespread toxicity problems or perceived problems (*e.g.* metals, organics, sulphide, ammonia) lower estuary values. Toxicity problems can be both in the water column and sediment, and may have extensive adverse effects for the biological communities within the estuary.	1 = High extent, 2 = moderate extent, 3 = low or no extent of toxicity problems						
31	Solid waste	The presence of solid waste (*e.g.* refuse) lowers estuary values.	1 = High occurrence, 2 = medium occurrence, 3 = low occurrence of solid waste						
	Total Score	**If estuaries with existing and potential adverse effects and currently degraded estuary condition are prioritised for monitoring, then the lower the final score the higher the priority for state of environment monitoring. If the estuaries with near to pristine condition, high natural values and low potential for adverse effects are prioritised for monitoring, then the higher the final score the higher the priority for state of the environment monitoring.**							

3. BROAD-SCALE MAPPING OF INTERTIDAL HABITATS

3.1 Overview

The aim of broad-scale habitat mapping is to describe an estuary according to different dominant habitat types based on surface features of substrate characteristics (mud, sand, cobble, *etc*) and vegetation type (mangrove, eelgrass, salt marsh species, *etc*), and develop a baseline habitat map. Once a baseline map has been constructed, the distribution of the various habitats can be compared amongst different estuaries/regions to provide a better understanding of how estuarine ecosystems in New Zealand are structured. Changes in the position and/or size of habitats (MfE Confirmed Indicators for the Marine Environment, ME6 2001) can then be monitored by repeating the mapping exercise. This procedure involves the use of aerial photography together with detailed ground-truthing and digital mapping using Geographical Information System (GIS) technology.

Equipment Required

General

- GIS software (*e.g.* Arcview™)
- Image analysis software (*e.g.* ERDAS)
- Colour aerial photographs of the selected estuary (taken at low tide at a maximum scale of 1:10,000)
- Scanner (capable of creating resolution of 508 dpi yielding an image resolution of 0.5 m per pixel)

Field

- 4WD vehicle
- Small boat and outboard (if necessary)
- GPS unit with data logger (*e.g.* Trimble Pathfinder Pro, with TD1 data logger)
- Chest-high waders
- Waterproof notebook and pencils
- Camera
- Checklist of likely dominant plant and substrate types (preferably include taxonomic keys/photographs to enable easy identification)
- Plastic bags for any samples that may later require identification
- 6 fine tipped felt pens (3 different colours)
- Laminated colour aerial photographs of whole estuary and margins (scale 1:5000 to 1:10,000)
- Watch and tide chart

3.2 Methods

Step 1: Colour aerial photography

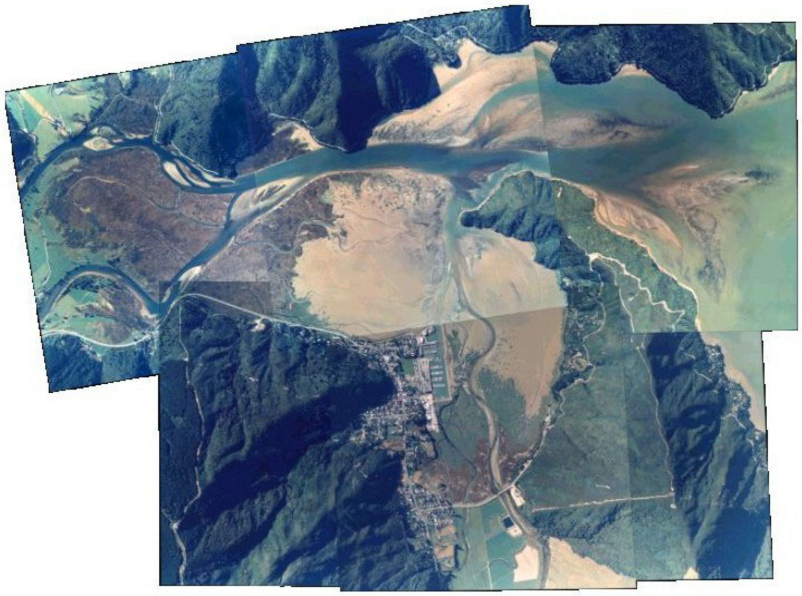
The first step is to obtain aerial photographs of your estuary **at low tide on a clear day**. The maximum scale should be **1:10000**, based on the fact that with a broader scale you will lose some of the detail of the estuary and it will become difficult to accurately determine changes in habitats over time. Working with a finer scale will require more photographs, increasing the cost of the exercise. Using the recommended scale you can achieve a resolution of 508 dots per inch (dpi), equating to 0.5 m per pixel. You may already have existing aerial photographs of your estuary. Although historical photographs may be black and white, it may still be possible to distinguish and identify major habitats. Aerial photographs, suitable for the mapping purposes can be obtained from various New Zealand companies (*e.g.* New Zealand Aerial Mapping Ltd. (Auckland/Hastings), Air Logistics (Auckland/Nelson).

Step 2: Rectification

The second step is to rectify the images. When you join together all the aerial photographs into a mosaic of the estuary, the photos are overlapped on a flat 2-D plane. Unavoidably, you can get some shifting of the image, and a consequent reduction in positional accuracy. The actual shape/area of a habitat won't change much, but its position might.

Rectification is ideally undertaken using a minimum of six prominent landmarks per photo (*e.g.* road intersections, islands, buildings, polythene markers, *etc*.), each of which has been visited and its differential GPS position recorded (we use a Trimble Pathfinder Pro GPS unit). Occasionally large homogeneous areas of the estuary are lacking in suitable landmarks for rectification. Where this is likely to be a problem, white polythene sheets (2 m x 2 m) with overlaid black crosses should be pegged out on the seabed immediately before the survey and removed afterward.

The individual photos should then be scanned at a resolution of 508 dpi yielding an image resolution of 0.5 m per pixel. This is achieved by converting the landmarks to Arcview shapefiles. ERDAS image analysis software, running under Arcview (v 3.1), can be used to register, rectify, and mosaic the scanned photos. Positional accuracy can be calculated by documenting the root mean square (RMS) error for each landmark. In general, RMS error should be within ± 5 m using this procedure, however much greater accuracy can be achieved for many of the photos. With this approach, the maximum summed error depends on the number of photos required (*i.e.* the size of the estuary) and can range from approximately 2-15 m at any point. The actual error is often much lower, however.



A mosaic of aerial photographs of the Havelock Estuary, Marlborough following rectification

Step 3: Classification of habitat features

The classification of the features follows the proposed national classification system (with adaptations), which is currently being developed under another SMF funded programme (Monitoring Changes in Wetland Extent: An Environmental Performance Indicator For Wetlands) by Lincoln Environmental, Lincoln. The classification system for wetland types is based on the Atkinson System (Atkinson 1985) and covers 4 levels, ranging from broad to fine-scale;

- Level I: Hydrosystem (*e.g.* intertidal estuary)
- Level II: Wetland Class (*e.g.* saltmarsh)
- Level III: Structural Class (*e.g.* marshland)
- Level IV: Dominant Cover (*e.g. Leptocarpus similis*)

For this project, you will only need to use Level III (Structural Class) and Level IV (Dominant Cover).

- The individual vegetation species are named by using the two first letters of their Latin genus and species names, *e.g.* Pldi = ribbonwood, *Plagianthus divaricatus*.
- / separates canopy vegetation, *e.g.* Pldi/Lesi (ribbonwood is taller than jointed wire rush).
- \- separates vegetation with approximately the same height, *e.g.* Lesi-Jukr (jointed wire rush is the same height as searush).
- ( ) are used for subdominant species, *e.g.* (Pldi)/Lesi = dominant cover is jointed wire rush and subdominant cover is ribbonwood. The use of ( ) is not based on percentage cover but from the subjective observation of which vegetation is the dominant or subdominant species within the patch.
- The classification always starts with the tallest vegetation type and works down, *e.g.* (Pldi/Baju)/Lesi-Jukr = a patch with a dominant cover of jointed wire rush and searush (which are of the same height) with a subdominant cover of ribbonwood and *Baumea juncea* (which are taller than the dominant cover).

A list of all the classification types used in the study and their codes are given in Table 2.

Leptocarpus similis (Jointed wirerush)

Table 2: Adapted Estuarine components of UNEP-GRID classification

Level I Hydrosystem	Level IA Sub-System	Level II Wetland Class	Level III Structural Class	Level IV Dominant Cover	Habitat Code
Estaurine	Intertidal/supratidal	Saltmarsh	Grassland	*Ammophila arenaria*, "Marram grass'	Amar
(alternating				*Agrostis stolonifera* "Creeping bent"	Agst
saline and				*Elytrigia pycnanph*,, "Sea couch"	Elpy
freshwater)				*Festuca arundinacea*, "Tall fescue"	Fear
				Paspalum distichum, "Mercer grass"	Padi
			Herbfield	*Apium prostratum*, "Native celery"	Appr
				Cotula coronopifolia , "Bachelor's button"	Coco
				Leptinella dioica	Ledi
				Plantago coronopus, "Buck's-horn plantain"	Plco
				Samolus repens, "Primrose"	Sare
				Sarcocornia quinqueflora, "Glasswort"	Saqu
				Selliera radicans, "Remuremu"	Sera
				Suaeda novae – zelandiae, "Sea blite"	Suno
				Triglochin striata, "Arrow-grass"	Trst
			Reedland	*Glyceria maxima*, "Reed sweetgrass"	Glma
				Spartina anglica, "Cord grass"	Span
				Spartina alterniflora, "Smooth cord grass"	Spal
				Typha orientalis, "Raupo"	Tyor
			Rushland	*Baumea juncea*, " Bare twig rush"	Baju
				Isolepis nodosa, "Knobby clubrush"	Isno
				Juncus artoiculatus, "Jointed rush"	Juar
				Juncus effuses, "Softrush"	Juef
				Juncus kraussii, "Searush"	Jukr
				Juncus pallidus, " Pale rush"	Jupa
				Leptocarpus similis, "Jointed wirerush"	Lesi
				Wilsonia backhousei	Wiba
			Sedgeland	*Cyperus eragrostis*, "Umbrella sedge"	Cyer
				Cyperus ustulatus, "Giant umbrella sedge	Cyus
				Eleocharis sphacelata, "Bamboo spike-sedge"	Elsp
				Isolepis cernua, "Slender clubrush"	Isce
				Schoenoplectus pungens, "Three-square"	Scpu

Table 2 continued.

Level I Hydrosystem	Level IA Sub-System	Level II Wetland Class	Level III Structural Class	Level IV Dominant Cover	Habitat Code
			Scrub	*Avicennia marina var. resinfera*, “Mangrove”	Avre
				Cordyline australis, “Cabbage tree”	Coau
				Cytisus scoparius, “Broom”	Cysc
				Leptospermum scoparium, “Manuka”	Lesc
				Plagianthus divaricatus, “Saltmarsh ribbonwood”	Pldi
				Ulex europaeus, “Gorse”	Uleu
			Tussockland	*Cortaderia* sp., “Toetoe”	Co sp
				Phormium tenax, “New Zealand flax”	Phte
				Poa, “Silver tussock”	Poa
				Puccinella stricta, ”Salt grass”	Pust
				Stipa stipoides, “Needle tussock”	Stst
		Seagrass meadows	Seagrass meadow	*Zostera novazelandica*, “Eelgrass”	Zo sp
		Macroalgal bed	Macroalgal bed	*Enteromorpha* sp.	En sp
				Gracilaria chilensis	Grch
				Ulva rigida, “Sea lettuce”	Ulri
		Mud/sandflat	Firm shell/sand (<1cm)		FSS
			Firm sand (<1cm)		FS
			Soft sand		SS
			Mobile sand (<1cm)		MS
			Firm mud/sand (0-2cm)		FMS
			Soft mud/sand (2-5cm)		SM
			Very soft mud/sand (>5cm)		VSM
		Stonefield	Gravel field		GF
			Cobble field		CF
		Boulderfield	Boulder field		BF
		Rockland	Rockland		RF
		Shell bank	Shell bank		Shell
		Shellfish field	Cocklebed		Cockle
			Musselreef		Mussel
			Oysterreef		Oyster
		Worm field	Sabellid field		Sabellid
	Subtidal	Water	Water		Water

Level III Structural classes are defined as follows:

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 in which the 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 in which the lichen cover exceeds that of any other growth form or bare ground.

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. If the reed is broken the stem is both round and hollow – somewhat like a soda straw. The flowers will each bear six tiny petal-like structures – neither grasses nor sedges will bear flowers, which look like that. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either hollow or have a very spongy pith. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata.* Some species covered by the Rushland or Sedgeland classes (below) are excluded.

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

Juncus krausii (searush)

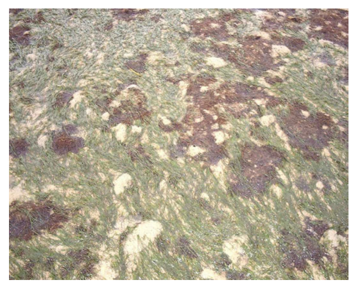
Sedgeland: Vegetation in which the cover of sedges in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. “Sedges have edges.” Sedges can be differentiated from grass by feeling the stem. If the stem is flat or rounded, it’s probably a grass or a reed, if the stem is clearly triangular, it’s a sedge. Included in the sedge growth form are many species of *Carex, Uncinia,* and *Scirpus.* Tussock-sedges and reed-forming sedges (c.f. REEDLAND) are excluded.

Scrub: Woody vegetation in which the 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 diameter at breast height (dbh).

Tussockland: Vegetation in which the cover of tussocks in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussocks include all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and > 10 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.*

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 dbh. Tree ferns ≥ 10cm dbh are treated as trees.

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 occassionally 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.



Zostera novazelandica
(eelgrass)

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 that can be seen without the use of a microscope.

Firm mud/sand: A mixture of mud and sand, the surface appears brown and may have a black anaerobic layer below. When walking on the substrate you'll sink 0-2 cm.

Soft mud/sand: A mixture of mud and sand, the surface appears brown and may have a black anaerobic layer below. When walking on the substrate you'll sink 2-5 cm.

The simple way to classify
mud/sand: how deep you sink

Very soft mud/sand: A mixture of mud and sand, the surface appears brown, often with a black anaerobic layer below. When walking on the substrate you'll sink greater than 5 cm.

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 currents and often forms bars and beaches. When walking on the substrate you'll sink less than 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 impossible.

Soft sand: Substrate containing greater than 99% sand. When walking on the substrate you'll sink greater than 2 cm.

Stonefield/gravelfield: Land in which the area of unconsolidated gravel (2-20 mm diameter) and/or bare stones (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. The appropriate name is given depending on whether stones or gravel form the greater area of ground surface. Stonefields and gravelfields are named from the leading plant species when plant cover of ≥ 1%.

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

Rockland: Land in which the area of residual bare rock exceeds the area covered by any one class of plant growth-form. Cliff vegetation often includes rocklands. They are named from the leading plant species when plant cover is ≥1%

Cocklebed: Area that is dominated by cockle shells.

Musselreef: Area that is dominated by one or more mussel species.

Oysterreef: Area that is dominated by one or more oyster species.

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

Step 4: Ground-truthing of habitat features

Field surveys are undertaken to verify photography, and identify dominant habitat and map boundaries. The approach involves at least one experienced estuarine scientist plus a technician walking over the whole estuary at low-mid tide, identifying dominant habitat and their boundaries and recording these as codes on aerial images at a scale of between 1:5,000 and 1:10,000. For example, approximately 25 images were used to ground-truth the New River estuary. The codes and list of dominant habitat types, including various categories of bare and vegetated substrate, are shown in Table 2.

Access

A four wheel drive vehicle is the preferred option for access to the estuary and its margins, although for some areas a small boat and outboard may be necessary (e.g. islands). Participants in the survey require a reasonable level of fitness particularly for those areas where deep mud conditions exist. Participants should be trained in negotiating mud conditions prior to the survey commencing. Flexible-leg chest waders have proven the most effective footwear for survey work within the estuary. Adequate drinking water supplies and some snack food are essential.

Weather Conditions and Timing

This survey must be undertaken during dry weather or it becomes impossible to record habitat types on the laminated photographs. Ideally the survey should be undertaken during the period September through till May when most plants are still visible and have not died back.

Extent of Survey

For the purposes of the intertidal survey the upper boundary of each estuary could be set at MHWS, however we have included supra-littoral categories in the classification system in case these are required. The lower boundary is set at MLWS.

Dr Barry Robertson undertaking ground-truthing by mapping dominant substrate/habitats onto laminated aerial photographs

Identification and Recording

The aim in this survey is to coarsely map the intertidal features of the estuary. This will require the guidance of a specialist scientist to make decisions on what features should be mapped and what they should be called. This survey is not designed to record detail. The substrate types and their extents are confirmed by field verification of the textural and tonal patterns identified on the aerial photographs.

Step 5: Digitisation of habitat boundaries

Vegetation and substrate features are then digitally mapped on-screen from the rectified photos using the Arcview 'image analysis' extension. This procedure requires using the mouse to draw boundaries on the computer screen, as precisely as possible, around the features identified from the field surveys. Each drawing is then saved to a shape file or GIS layer associated with each specific feature. To calculate the area cover for a chosen habitat type, the Arcview 'X-tools' extension is used. This gives the area of any selected features in hectares. These GIS layers, along with supplemental field information, can then be combined with the image mosaic and written to CD-ROM.

Limitations

Mapping and classification of substrates and vegetation using colour aerial photography is labour intensive. Degradation of images by scanning and digitising can result in a loss of information, and the scanning, digitising and rectification increases processing costs. Any imperfections in photographic images (*e.g*. uneven developing, or poor print quality) interfere with image analysis. Aerial photography is also subject to interference from cloud cover, reflection, *etc*.

3.3 Working with the GIS maps

The completed GIS maps of an estuary provide a foundation of defensible information for use in answering a variety of habitat-related questions. In particular:

- the use of habitat area ratios for comparison with other estuaries and assessing aspects of estuarine function.
- historical comparison of specific habitats using past aerial photographs (*e.g*. to show what is growing in area and what is shrinking). In this particular case, historical aerial photographs can not be ground-truthed but often dominant vegetation types can be estimated and their boundaries mapped.
- identification of sites for more detailed study. In particular, areas of dominant mid-low tide habitat can be identified for fine-scale monitoring at a later date.

- development of cause and effect hypotheses. The survey provides an overview framework which helps identify issues within and estuary and their likely causes. For example, locations of muddy habitat in relation to potential sources.
- decision-making – *e.g.* habitat restoration.

Monitoring Frequency

We suggest that a monitoring frequency of five years would be suitable to provide input for addressing most medium to long-term, management-related questions/strategies. Shorter term questions, such as the rate of invasion of an exotic species, or the effects of a major hydrological modification, may require more frequent (*e.g.* yearly) surveys.

A typical view of the upper Waimea Estuary, Nelson, showing a mixture of *Juncus krausii* (sea rush) and *Sarcocornia quinqueflora* (glasswort) and upper littoral scrub and grass.

3.4 How much will it cost?

As a rule of thumb, the cost to survey the broad-scale habitat of an estuary can range from $15,000 to $30,000, depending on its size and whether or not suitable aerial photographs are already available.

3.5 Changing technology

The technologies available for broad-scale habitat mapping are advancing rapidly (*e.g.* satellite imagery, GIS software, *etc*.). For this reason, it is essential that the resulting protocol be viewed as an evolving document that can be updated as new and better methods become available.

4. FINE-SCALE ENVIRONMENTAL MONITORING

4.1 Overview

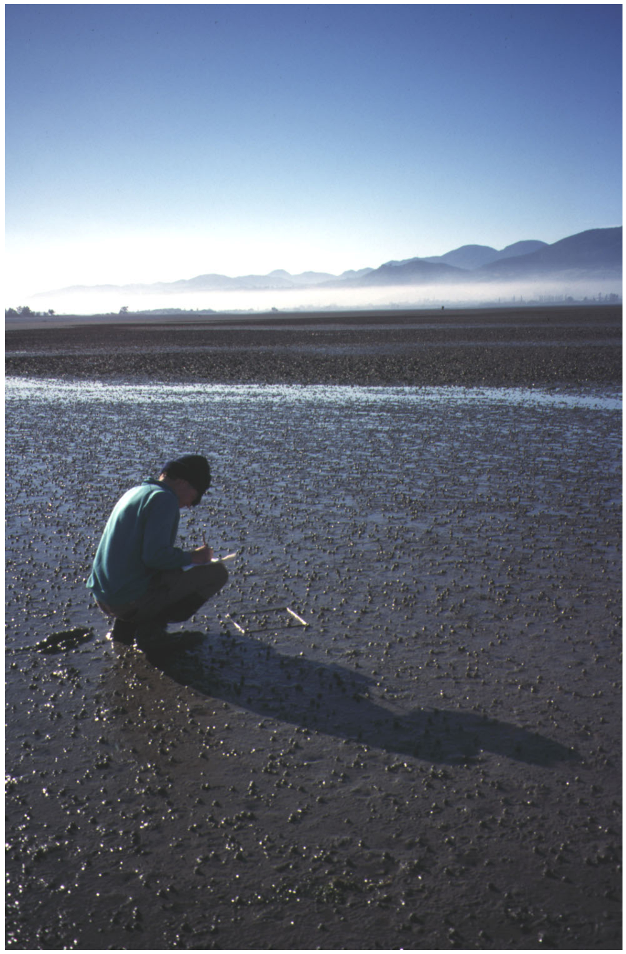
Once an estuary has been classified according to its main distinguishing features, and the dominant habitats have been described and mapped on a broad scale, suitable habitats may be selected and targeted for fine-scale monitoring. An appropriately designed monitoring protocol will enable many of the key issues (*e.g.* nutrient enrichment, extent of sediment contamination/toxicity) affecting estuary condition to be addressed at an appropriate level of investigation. The EMP targets one commonly impacted intertidal habitat, the soft sediment (sand/mud) habitat, in the mid to low tidal range.

A typical fine-scale monitoring programme involves measuring one or more environmental characteristics that are known to be indicative of estuary condition, and are likely to provide a means for detecting subsequent change. For the purpose of this study, the environmental characteristics assessed were restricted to a suite of commonly used benthic indicators (see Part A, Section 2.4 for justification). Decisions regarding which of these analyses are most appropriate and how many samples are needed in order to get reliable estimates, are critical, and will ultimately determine the usefulness of the data. The rationale for the overall study design is discussed in Part A, Section 2 and summarised in Table 7 of Part A. Case study results providing justification for the study design are provided in Part A, Section 6.4.

4.2 Application of reference estuary results to the EMP

The fine-scale sampling approach trialled for development of the EMP was successful in obtaining a baseline data set of benthic intertidal variables from the eight reference estuaries. Statistical analyses were then applied to investigate the variability of the data, both among estuaries and at sites within estuaries. Those variables that were closely correlated were also identified, enabling some to be considered as surrogates for others in a monitoring programme. The optimum number of samples was determined for each variable to accommodate the established spatial variability, as well as the expected level of change able to be detected with different levels of variability

(~sampling precision). Parts A and B of this document contain the baseline data and describe the development of the project and the methodologies employed.



Estuary sampling on the Waimea Inlet.

Equipment Required for Fieldwork

General

- Chest waders (lightweight PVC)
- Handheld GPS unit
- Clipboard, waterproof notebook and pencils, marker pen
- Field taxonomic guide
- Camera (digital optional)
- Sleds (3) with rope and storage bins (optional, for transporting equipment across mudflats)
- Spade (hand)
- Cell phone
- Wooden stakes and tape measure(to mark out site)

Epifauna

- Quadrat(s) (0.25 m^2)
- Waterproof field sheets (with expected species list)

Infauna

- PVC corer (130 mm, with 0.5 mm mesh bag)
- Wide-mouth funnel (bag → plastic container)
- 500 or 1000 ml plastic containers (10 per site)
- Waterproof labels to place inside containers
- Ethanol preservative (95%)

Macroalgae

- Gridded quadrat (0.25 m^2 with 36 equally spaced internal squares)

Microalgae

- Cut-off 10 ml (15 mm internal diam.) syringe barrels (4)
- 50 ml centrifuge tubes (10 per site)

Sediments

- Perspex corer (about 60 mm diameter) with plunger
- Labels
- Re-sealable polyethylene (plastic) bags
- Ruler (x 2)
- 250 ml plastic jars (acid rinsed) (10 per site)
- Plastic spatula
- Chilli bin (and ice)
- White, shallow plastic display tray

4.3 Methods

Step 1: Choose appropriate monitoring sites

The choice of sites (generally a total of 2 to 4 per estuary) is made using a combination of the knowledge collected through the broad-scale habitat mapping and on-site, specialist expertise as follows:

- Broad-scale habitat maps and local knowledge are used to locate broad areas of unvegetated, mid-low water, mud/sand habitat located away from river mouths (mean salinity of overlying water > 20 ppt).
- A representative position within each of the broad areas is then chosen to locate potential sampling sites. Areas of significant vegetation and channel areas are avoided.
- The number of sites selected for an estuary should be allocated proportionately, based on estuary size, extent of the mud/sandflat habitat, and the number of isolated arms. Large (*i.e.* >3000 ha) and/or highly branched estuaries should be allocated more sites (*e.g.* four), while those that are small or less complex in shape, can be allocated fewer.
- Additional sites may be added for areas that are of particular interest or concern (*i.e.* consent monitoring sites).

Step 2: Carry out the field work (between January-March)

See Figure 2 for a summary diagram of the sampling strategy. Ideally you will require three trained and reasonably fit staff to undertake the sampling.

1. A person capable of identifying estuarine epifauna.
2. A person able to operate the hand-held GPS and camera.
3. A person able to collect physical, chemical and infauna core samples.

Each of these people should be wearing lightweight, flexible leg, chest waders so they can easily sit and keep warm and dry in soft mud conditions.

Sampling in the mud, demonstrating how important chest waders are!

Sampling can be undertaken on wet days, but ideally it should be dry. The work will need to be carried out over the low tide period beginning approximately 1.5 hrs prior to low water. It will usually take around two hours per site. Don't leave the sampling till too late in the day because an hour or two is required to sieve infauna samples before preserving. All samples should be clearly labelled with estuary, site, station (plot), date/time and collectors (pre-labelling is a must given the generally muddy conditions at each site). Tide (spring or neap) and weather conditions and any site features of interest should be recorded in the field notebook.

Marking out the sites: The areal extent of the sand/mud habitat may differ considerably from one estuary to another. Thus there may be reason to consider the use of sites proportional to the size of the estuary or habitat. To simplify this decision, we suggest that sites of a standard size of 60 x 30 m would be suitable in most cases.

- Sites of 60 x 30 m are marked out with the aid of a tape measure for placement of wooden stakes at each corner.
- Corner positions are recorded using differential GPS to enable subsequent repeat surveys.
- The site is then subdivided into 12 equal-sized (*i.e.* 15 x 10 m) plots. Plot intersections can be marked with temporary stakes (*e.g.* bamboo) to provide reference points when sampling. It is recommended that 10 of these plots be sampled on each occasion.

Fine-scale sampling at the New River Estuary, showing the collection of sediment core samples.

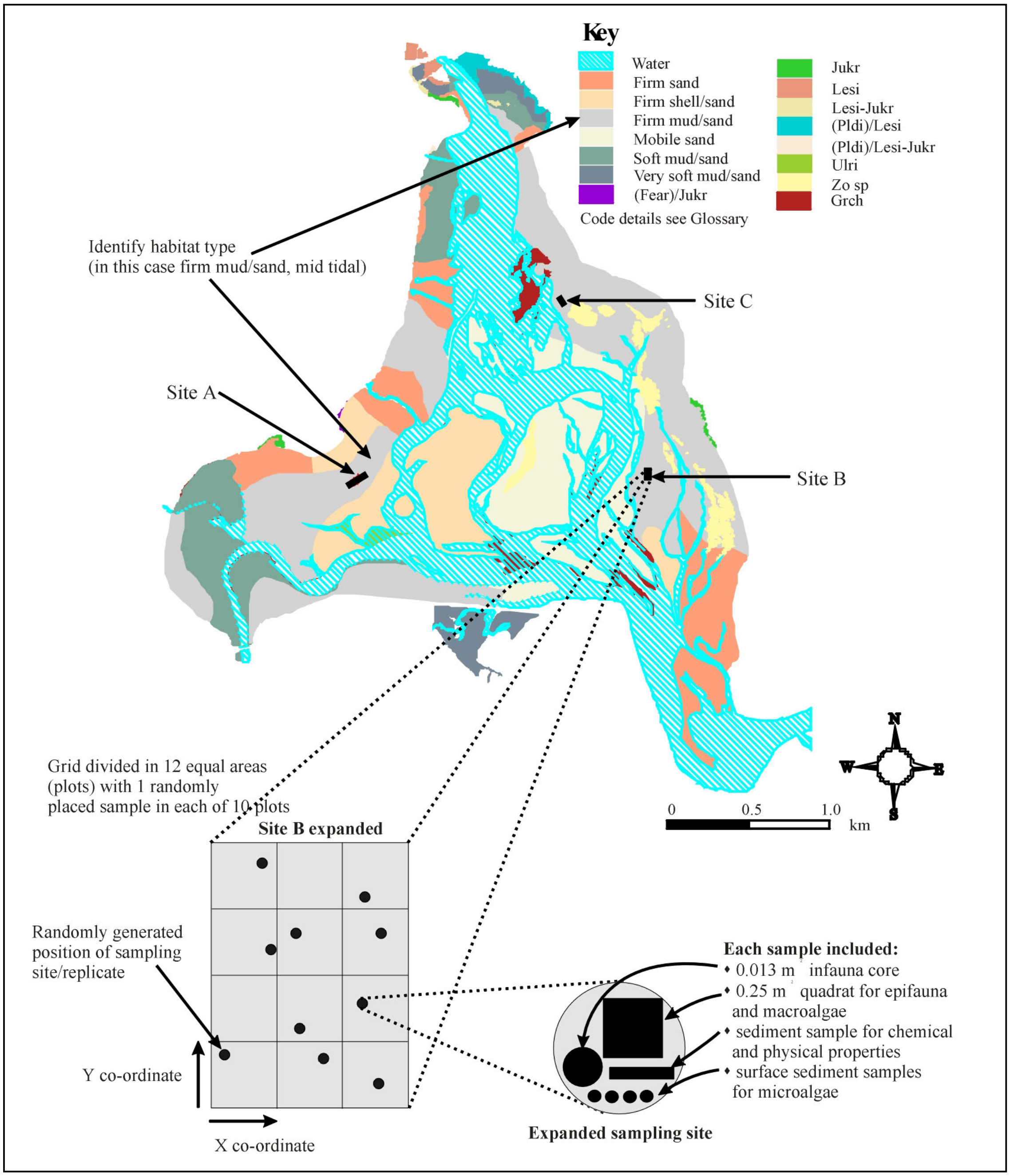


Figure 2: Summary of the sampling strategy applied to each estuary, with a sampling site and station expanded for clarity. The Avon-Heathcote Estuary is used as the example.

Photographs: Photographs are taken to provide a record of the general site appearance. If a digital camera is available, these can easily be archived for comparison with subsequent survey results.

Sediment core profiles (and the depth of the Redox Discontinuity Layer):

- One randomly positioned 60 mm perspex core is collected to a depth of at least 100 mm from each plot.
- The core is extruded onto a white plastic tray, split lengthwise (vertically) into two halves and photographed along side a ruler and a corresponding label.
- The stratification of colour and texture are described with particular attention to the occurrence of any black (anoxic) zones. Where these occur, the average depth of the lighter-coloured surface layer is recorded as the depth of the Redox Discontinuity Layer (RDL).

The perspex corer used to sample sediments.

Notes:

- Distinct RDLs were not observed at any of the REs. However in highly enriched situations, the black anoxic layer may be at, or very near, the sediment surface and a strong rotten egg odour of hydrogen sulphide gas will be evident. In extreme situations a patchy, white bacterial mat may be visible on the surface of the sediment. These are the white sulphur bacteria (*Beggiatoa* sp.) that help to detoxify the system by oxidising the H_2S.

Epifauna: (surface-dwelling animals):

- Epifauna are assessed from 10 replicate 0.25 m^2 quadrats within each site (one randomly placed within 1m of the Perspex core sample within each plot). All animals observed on the sediment surface are identified and counted, and any visible microalgal mat development is noted. Crab burrows may be counted as a relative indicator of mud crab populations, but the data can not be used as a direct measure of abundance without calibration. The species, abundance and related descriptive information are recorded on specifically designed, waterproof field data sheets containing a checklist of expected species (see the example provided in Table 3).

- Photographs of representative quadrats are taken and archived for future reference.

Macroalgae** (seaweeds) **% cover:

- Where a significant macroalgal cover exists, the percent coverage is estimated from the epifauna quadrats, but with gridlines dividing it into 36 equally-spaced squares. The number of grid intersections (49 in total, including the outer frame) that overlap vegetation are counted and the result converted to a percent (*i.e.* No. x 2 = %). The data can be recorded on the same field data sheets used for epifauna analyses.

Infauna (animals living buried in the sediments):

- Ten sediment cores (one randomly placed within 1 m of the Perspex core sample within each plot) are collected from each site using 130 mm diameter (area = 0.0133 m^2) PVC tubes with 0.5 mm nylon mesh bags affixed to the top to act as a sieve.

- The core tubes are manually driven 150 mm into the sediments, removed with core intact and inverted so that the core is retained in the mesh bag.

The PVC corer with 0.5 mm mesh bag attached for sampling infauna.

- The contents of the core are washed through the attached sieve using seawater from a nearby source. The remaining contents are carefully emptied into a plastic container with a waterproof label and preservative is added. Although 4% formalin (made up in seawater) is traditionally used as a preservative, **it is a potentially dangerous chemical**. We recommend using 95% ethanol instead (enough to roughly double the volume of the sample).

Table 3: Checklist of expected epibiota for New Zealand estuaries

Plot		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Species	**Common name**										
Cominella glandiformis	Mudflat whelk										
Cominella maculosa	Spotted Whelk										
Diloma surostrata	Mudflat topshell										
Diloma zelandica											
Micrelenchus huttoni	Topshell										
Zeacumantus subcarinata	Small spire shell										
Zeacumantus lutulentus	Spire shell										
Amphibola crenata											
Notoacmea helmsi	Estuarine limpet										
Austrovenus stutchburyi	cockle										
Paphies australis	pipi										
Mactra discors	large trough shell										
Macra ovata	oval trough shell										
Crassostrea gigas	Pacific oyster										
Crab holes											
Halicarcinus varius	Pilbox crab										
Enteromorpha											
Isopod											
Edwardsia tricolor	Burrowing anemone										
Anthopleura aureoradiata	Mudflat anemone										
Elminius modestus	Estuarine barnacle										
Gracilaria											
Ulva											

Equipment: 10 Quadrats, Cores, (grain size and AFDW) bags, Pottles (nutrients, org C, metals), syringe (microalgae), photos, benthic algae, GPS.

Notes:

- In firm substrates, it may be necessary to remove the core by digging.
- Avoid rigorous handling of samples (especially during rinsing through mesh) to avoid damaging organisms.
- If water for sieving the infauna samples is too far away, you may need to use larger plastic bags (well-labelled) to transport the cores to the water (after sampling is finished at that site). Do not pour water through the mesh bag. Just immerse the closed end of the bag into the water and gently agitate to wash the fine sediment through the sieve. Then transfer the remaining contents into plastic containers (labelling and adding preservative).
- When transporting preserved samples, care must be taken to avoid spillage. Place containers in a large, tied-off plastic bag to minimise leakage.

Benthic microalgae:

- Cut-off 10 cc syringe barrels (15 mm internal diameter) are used to collect sediment cores (four per plot from within 0.5m of the epifauna quadrat).
- The top 5 mm of the cores are sliced off and mixed in a 50 ml centrifuge tube to obtain one sediment composite per plot.
- Samples are stored on ice (in the dark) while in the field and frozen (-20^{o}C) upon return.

Notes:

- The primary objective of benthic microalgal analyses is to identify any major bloom occurrences that could be indicative of eutrophic (highly enriched) conditions. Sediment chl *a* and phaeopigment concentrations provide an indication of the degree of mat development
- Some species of benthic microalgae (*e.g.* euglenoids) and cyanobacteria (blue green algae) may be indicative of nutrient enrichment; particularly if they dominate the microalgal community. However, more data is required before this can be developed as a useful indicator. If you would like to contribute to this process, collect one additional composite sample using the same procedure as for chl a, but preserve it with Lugol's Iodine solution (do not freeze).

Physical and chemical analyses:

- Ten replicate samples (one from each plot) are collected from an area within 300 mm of the position of the infauna cores. The top 20 mm of sediment is scraped into a clean, acid-rinsed (see note) 250 ml plastic jar and stored on ice until processed (preferably within 12 hours).

Notes:

- The clean plastic container should be rinsed thoroughly with 10% HCl, followed by deionised water, prior to use.
- Avoid cross-contamination of samples and any contact with metal implements (use a plastic spatula).
- Do **not** place a label inside the plastic container. If necessary, cover the outer label with Cellotape to keep dry.

Step 3: Process the samples

Epifauna

- Field notes are transferred to a spreadsheet or database for statistical analyses.

Infauna

- Samples are washed through a series of sieves (from 4.0 mm to 0.5 mm) within a fume cabinet to roughly sort invertebrates into size classes.
- The contents of each sieve are systematically scanned, by eye or by microscope, and the invertebrate species identified (to at least the family level), counted and recorded.
- The data is transferred to a spreadsheet or database ready for statistical analyses.

Notes:

- Skill/experience is required for the identification of invertebrate species. There are a variety of suitable reference texts available (refer reference list, Part A).
- It is often helpful to keep a reference collection of invertebrate species obtained from the sediment samples.
- If formalin is used as a preservative, care should be taken to avoid inhalation of fumes which can be hazardous to health.

Microalgae

- Pigments are analysed as described in Part A, Table 19.
- Optional identification of dominant species may be carried out using an inverted microscopic. These analyses require technical expertise/training.

Physical and chemical analyses

- The chilled samples are sent to an appropriate analytical laboratory, where the they are analysed for the following characteristics (as described in Part A, Table 19):
  - Particle size distribution (% mud, sand, gravel)
  - Nutrients (total nitrogen and total phosphorus)
  - Ash free dry weight (AFDW) as a measure of total organic content
  - Common trace metal contaminants (copper, cadmium, nickel, lead, zinc and chromium).

- All data are transferred to a spreadsheet or database for statistical analyses.

> **Note:**
> - Analyses of other metals/contaminants may be included where they are of particular concern in an estuary.

Step 4. Carry out data analyses

Data Manipulation

a) Arrange data logically in a spreadsheet (replicates aligned in columns, variables in adjacent rows, anticipate incorporating consecutive years data).

b) Check data values:

- Check that the units are appropriate (*e.g.* infauna core area, concentrations), convert the data if necessary.
- Check the comparability of the sampling procedures and analytical methods,
- Check for values recorded as <detection limits. Less-than signs (<) preceding data values often inhibit computation and the associated detection limit represents the maximum likely value. Although not entirely accurate, assigning a value, *ca.* 0.5 × detection limit, allows the result to be included in further analyses. An indication that the result was very low (*i.e.* below detection limit) is important information, despite not knowing the exact magnitude.
- Check for anomalies or aberrant data points. Box plots may help with this. If the result is obviously erroneous or can be attributed to interference or contamination from an irrelevant source, it can be removed. Data should not be removed without justification.
- Check that missing data are represented by empty cells rather than zeros. Zeros in place of missing data will erroneously lower the mean value and effect sample variability.

c) Create a secondary table where the chemical values are normalised to the % mud fraction. This is achieved by dividing the result by the corresponding % mud value and then multiplying by 100.

d. Calculate statistics for each variable: Mean, SD, CV, SE, 95% CI. This can be carried out easily in electronic spreadsheets such as Microsoft Excel or equivalent.

e. Present the mean values in uncomplicated figures that have the facility to indicate variation (SE or 95% CI). Be sure to indicate somewhere which measure is used, preferably in the figure caption.

Assess appropriateness of sampling strategy

After the first round of sampling the degree of variability should be put into context by relating it to the size of change that is measurable given a specified probability of committing Type I (α) or Type II (β) errors (i.e. power analysis). The number of samples that are required will depend on a number of things, as discussed in Sections A and B, but briefly:

- Different analyses have inherently different variability associated with them (*i.e.* the aggregated nature of biotic assemblages (infauna) means they are typically more variable than sediment chemistry characteristics). The more variable the indicator, the more samples that are required to detect changes (Table 3).
- Different variables may warrant extra attention in order to identify smaller changes (*e.g.* contaminants of concern, or known to be approaching guideline levels). The smaller the change you wish to detect, the more samples that are required (Table 4).
- The importance of the specified change is reflected in the significance criterion (*i.e.* probability of committing a Type I or Type II error) that are used in the model. By convention, most models use an α of 0.05 and a β of 0.1-0.3 (power of 0.9-0.7). Adjustments to the power of the model can be made based on an assessment of the consequence of failing to find a difference between samplings when there, in fact, was one (failing to reject a false null hypothesis). A high level of confidence in the findings (power of 0.9) requires more samples.

A good rule of thumb is however, that a CV of <25% is necessary in order to detect changes smaller than 50%. If this is not achieved in the first round of sampling, a change to the sampling strategy may be required (*i.e.* more samples, larger samples or further investigation into the spatial variation that exists within the area and the sampling approach adjusted accordingly).

Table 4: Approximate number of replicates required to detect specified levels of change (10-50%) for four different levels of CV ranging from 8 to 58%. Upper range is number of samples given by G*Power model (α = 0.05, β = 0.2) and lower range is number given by Zar (1999: α = 0.05, β = 0.1).

	Measurable change			
***e.g.* CV**	**10%**	**20%**	**30%**	**50%**
8%	10-12	3-6	3-4	3+
25%	69-170	19-44	9-20	5-10
40%	170-430	46-106	21-48	9-18
58%	351-824	51-208	28-94	10-36

Step 5. Interpret the data

- If this is a baseline survey, assess current state of the estuary according to the selected habitat. To achieve this, the results are used to place the estuary into context nationally and internationally by comparing them to relevant guideline values and/or results from other estuaries.
- In situations where an indicator or indicators of estuary condition are found to be elevated, the reason may be evident. Consider local anomalies. For example, nickel and chromium concentrations were found to be unusually high in Waimea Inlet and to a lesser extent in Havelock Estuary. This can be explained by the fact that the catchments of both estuaries drain the mineral belt in the Dun mountain region.
- Explore 100% mud-normalised data to see if unusually elevated contaminant concentrations occur at any sites in comparison to other estuaries assessed. Since more research is required in order to determine the relevance of normalised data, these comparisons should be used as a rough guideline only.
- If this is a repeat monitoring survey, the results can be compared to the previous survey results. This can be accomplished by examining the plots and carrying out paired t-tests. Significant changes in various indicators may ring “alarm bells”, triggering further investigation of potential cause and effect relationships. However it is important to recognise that natural year to year or longer term variation could be a major contributing factor. Our ability to interpret the importance of change in terms of the health of the estuary, will improve over time as additional repeat surveys are completed, both in the estuary of concern and other New Zealand estuaries. Trend analyses of several consecutive years of data may require consultation with a specialist statistician. In this way it will be

possible to consider, not only short term impacts but also longer term trends in indicator levels.

4.4 How often to sample and report?

It is recommended that a suitable long-term monitoring programme will include an initial period of 3-5 years of annually monitoring of the same sites, at the same time of year, in each estuary. This will broaden the baseline by providing an indication of the inter-annual variability thus enhancing the ability to interpret change over time. State of Environment reporting with detailed interpretation would be undertaken say every 4 years. Reporting of results only would be undertaken in intervening years. Once the initial yearly monitoring period is finished, the data would be used to optimise the design to a lesser monitoring frequency (for example, every two to five years).

4.5 How much will it cost?

Estimated costs for fine scale monitoring are approximately $15,000 to $25,000 per estuary (2-4 sites).

Sleds can be handy when travelling between fine-scale sampling sites (New River Estuary shown).

5. THE FUTURE OF THE EMP

5.1 The "Living Document" concept

All three documents comprising the EMP should be updated periodically. The individual estuary results provide potentially valuable datasets for managers that can be further evaluated and/or expanded as additional data becomes available. As the protocol is applied to additional estuaries, the expanded database will most likely extend the range of conditions within the continuum from pristine to highly modified. It will also extend the range of estuary types and habitat types compared.

The expanding data base will also provide opportunities for future development of various indices of estuarine condition. For example, as the data base expands, the species and abundance of animal communities may be used to develop **biotic indices**, while physico-chemical characteristics could lead to development of **companion indices** (*e.g.* of nutrient enrichment). Ultimately, **guidelines** may be recommended in order to facilitate evaluation of the state of health of estuarine habitats in New Zealand.

Methodologies can also be improved over time (*e.g.* taxonomic precision), and new tools may become available (*e.g.* satellite imagery, GIS software capabilities). Thus the Protocol and supporting data should be viewed as a "living document" that will improve with use and technological advancement.

5.2 A National estuaries database

The EMP provides coastal managers with a standardised methodology to collect a variety of data types from various disciplines. The different data types include GIS mapping information and fine-scale physical, chemical and biological descriptions of estuary condition. The large volumes of data generated, particularly with regard to the fine-scale monitoring, can be difficult to manage effectively. In order to facilitate this, we envisage the development of a database for the entry, storage and retrieval of this information as a logical follow-on to the existing project. However, rather than trying to develop and maintain a centralised database for all the information collected by the various groups, we believe it would be more effective to develop a stand-alone version that can be distributed (via the web) and operated by the various end-users but would still guarantee that the data was collected and maintained in a similar format. Essentially, the National database would be housed individually but could be incorporated into a single entity in the future if need arose.

5.3 Continued technical support

Cawthron's Coastal and Estuarine Group are dedicated to continued support of the EMP initiative. In some instances, councils may wish to develop and carry out their own monitoring programmes with minimum consultation (*i.e.* advice only). In others, they may elect to contract some or all of the work to an independent science provider. Cawthron would be pleased to provide support in either capacity.

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