coastalmanagement

Hutt Estuary

Fine Scale Monitoring 2009/10

Prepared for Greater Wellington Regional Council
May 2010

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By

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HUTT ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the first year of fine scale monitoring of two subtidal sites within Hutt Estuary, a 3km long, tidal river estuary that discharges to Wellington Harbour. It is one of the key estuaries in Greater Wellington Regional Council's (GWRC's) long-term coastal monitoring programme. An outline of the process used for estuary monitoring and management in GWRC is presented in the margin flow diagram, and the following table summarises fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

FINE SCALE MONITORING RESULTS

- Sediment Oxygen: Redox Potential Discontinuity (RPD) was 3-5cm deep indicating moderate oxygenation.
- The benthic invertebrate community condition rating indicated a slightly polluted or "good" condition.
- The indicator of organic enrichment (Total Organic Carbon) was at low concentrations.
- Nutrient enrichment indicators (total nitrogen and phosphorus) were at low-moderate concentrations.
- Sediment plates were deployed to provide a measure of sedimentation rate.
- The sediment had relatively high mud concentrations (approximately 31-56% mud).
- Heavy metals, DDT and PAH's were well below the ANZECC (2000) ISQG-Low trigger values.
- Intertidal macroalgal cover was high.

CONDITION RATINGS	Site A 2010	Site B 2010
Invertebrates (Mud tolerance)	HIGH - mud tolerant invert's dominant	HIGH - mud tolerant invert's dominant
Sedimentation Rate	Plates Deployed	
RPD Profile (Sediment oxygenation)	Fair-Good	Fair-Good
TOC (Total Organic Carbon)	Very Good	Very Good
Total Nitrogen (TN)	Good	Good
Total Phosphorus (TP)	Good	Good
Metals (Sb, Cd, Cu, Cr)	Very Good	Very Good
Metals (Ni, Pb, Zn)	Good	Good
DDT and PAH's	Very Good	Very Good
Invertebrates (Organic enrichment)	Good - Moderate	Good

ESTUARY CONDITION AND ISSUES

The first year of baseline monitoring shows that the dominant habitat (i.e. unvegetated subtidal mud/sand) in the Hutt Estuary was generally in a fair condition. The presence of elevated mud contents, moderately oxygenated sediments, moderate nutrient concentrations, an invertebrate community dominated by mud and organic enrichment tolerant species, coupled with intertidal nuisance macroalgal growths, suggests that the estuary is moderately enriched, and has excessive fine sediment inputs. Such issues are exacerbated by the damage from the historical loss of high value habitat caused by reclamations and channelisation.

RECOMMENDED MONITORING AND MANAGEMENT

In order to establish baseline conditions in this priority estuary, it is recommended that fine scale monitoring (including sedimentation rate and macroalgal mapping) be undertaken annually for the next 2-3 years (next monitoring January 2011). Broad scale habitat mapping should be undertaken every 10 years (next scheduled in 2014).

The 2010 fine scale monitoring results reinforce the need for management of nutrient and fine sediment sources entering the estuary. It is recommended that sources of elevated loads in the catchment be identified and management undertaken to minimise their adverse effects on estuary uses and values.

In order to improve estuary function, it is also recommended that steps be taken to increase the extent of high value estuary habitat (saltmarsh, seagrass, intertidal flats and natural vegetated margin) wherever possible.

Hutt Estuary

↓

Vulnerability Assessment
Identifies issues and recommends monitoring and management. Completed in 2007 (Robertson and Stevens 2007b)

↓

Hutt Estuary Issues
Moderate eutrophication
Excessive sedimentation
Habitat Loss (tidal flats, saltmarsh, seagrass and terrestrial margin)

↓

Monitoring

Broad Scale Mapping
Sediment type
Saltmarsh
Seagrass
Macroalgae
Land margin

5 -10 yearly
First undertaken in 2004.
Macroalgae undertaken 2010.

Fine Scale Monitoring
Grain size, RPD, Organic Content Nutrients, Metals, Invertebrates, Macroalgae, Sedimentation,

3-4yr Baseline then 5 yearly
Baseline yet to be completed.
Next survey 2011.

↓

Condition Ratings
Area soft mud, Area saltmarsh, Area seagrass, Area terrestrial margin, RPD depth, Benthic Community, Organic content, N and P, Toxicity, Sedimentation rate.

Other Information
Previous reports, Observations, Expert opinion

↓

ESTUARY CONDITION
Moderate Eutrophication
Excessive Sedimentation
Low Toxicity
Habitat Degraded (saltmarsh, terrestrial margin)

↓

Recommended Management
- Limit intensive landuse.
- Set nutrient, sediment guidelines.
- Margin vegetation enhancement.
- Manage for sea level rise.
- Enhance saltmarsh/seagrass.
- Manage weeds and pests.

1. INTRODUCTION

OVERVIEW

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

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 to establish priorities for a long-term monitoring programme for the region (Robertson and Stevens 2007a, 2007b and 2007c). These assessments identified the following estuaries as immediate priorities for monitoring: Porirua Harbour, Whareama Estuary, Lake Onoke, Hutt Estuary and Waikanae Estuary.

GWRC began monitoring Hutt Estuary in January 2010, with the work being undertaken by Wriggle Coastal Management using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions.

The Hutt Estuary monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** of the estuary to major issues (Table 1) and appropriate monitoring design. This component has been completed for Hutt Estuary and is reported on in Robertson and Stevens (2007b).
2. **Broad Scale Habitat Mapping** (EMP approach). This component, which documents the key habitats within each estuary and changes to these habitats over time, has been completed for the Hutt Estuary (Stevens and Robertson 2004).
3. **Fine Scale Monitoring** (EMP approach). Monitoring of physical, chemical and biological indicators (Table 2) including sedimentation plate monitoring. This component, which provides detailed information on the condition of the Hutt Estuary, began in January 2010 and is the subject of the current report.

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

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

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

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

1. Introduction (Continued)

Table 1. Summary of the major issues affecting most NZ estuaries.

Major Estuary Issues	
Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there.
Disease Risk	Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time. Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds. Diseases linked to pathogens include gastroenteritis, salmonellosis, hepatitis A, and noroviruses.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to estuaries through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Loss	Estuaries have many different types of habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes cited as sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff and wastewater discharges.

Table 2. 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 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.

2. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the EMP (Robertson et al. 2002) and provides detailed information on the condition of the estuary. Using the outputs of the broad scale habitat mapping, representative sampling sites (usually two per estuary) are selected and samples collected and analysed for physical, chemical and biological variables.

For the Hutt Estuary, two fine scale sampling sites (Figure 2, Appendix 1) were selected in the dominant estuary habitat (i.e. shallow subtidal margins). At each site, a 20m long transect, aligned parallel to the shore, was marked out. At 2m intervals along each transect, ten sampling locations were selected and the following sampling undertaken:

Physical and chemical analyses

- Within each sampling location, one core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average redox potential discontinuity (RPD) depth recorded.
- At each site, three samples (each a composite from four plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core. All samples were kept in a chillybin in the field.
- Chilled samples were sent to R.J. Hill Laboratories for analysis of the following (details in Appendix 1):
    - Grain size/Particle size distribution (% mud, sand, gravel).
    - Nutrients - total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC).
    - Organic toxicants {dichlorodiphenyltrichloroethane (DDT) isomers and polycyclic aromatic hydrocarbons - (PAH's)}.
    - Trace metal contaminants {total recoverable antimony (Sb), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn)}. Analyses were based on whole (sub 2mm) sample fractions which are not normalised to allow direct comparison with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000).
- Samples were tracked using standard Chain of Custody forms and results are checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Infauna (animals within sediments)

- One sediment core was taken from each of ten sampling locations using a 130mm diameter (area = $0.0133m^2$) PVC tube.
- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled plastic bag.
- Once all replicates had been collected at a site, the plastic bags were transported to a commercial laboratory (Gary Stephenson, Coastal Marine Ecology Consultants, see Appendix 1) for sieving, counting and identification. Each core was washed through a 0.5mm nylon mesh bag or sieve with the infauna retained and preserved in 70% isopropyl alcohol.

Figure 2. Hutt River Estuary Site Locations and Salinities, 21 January 2010. MHWS 10.45am. Salinity measured between 10.30-10.50am. Water temperature: 18.5°C above rail bridge, 19.4°C at lower site.

2. Methods (Continued)

Sedimentation Plate Deployment

Determining the sedimentation rate from the present and into the future involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried, levelled, and the elevation measured, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. In the future, these depths will be measured every 1-5 years and, over the long term, will provide a measure of the rate of sedimentation in representative parts of the estuary.

One site (with 4 plates) was established in Hutt Estuary in April 2010 on a small intertidal flat near the mouth of estuary downstream of fine scale Site A (Figure 2). It was located in muddy habitat where sedimentation rates are likely to be elevated. At the site, four plates (20cm wide square concrete blocks) were buried 2m apart in a straight line at right angles to the stream channel. The site was marked with 5 pegs inserted to 100mm above the ground at 0m, 4m, 8m 12m, and 16m. The distance of each plate from the peg closest to the Hutt River channel (0m) was as follows: Plate 1 @ 2m, Plate 2 @ 4m, Plate 3 @ 6m and Plate 4 @8m.

The GPS position of each plate was logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded (Appendix 2).

CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented below) have been proposed for Hutt Estuary (based on the ratings developed for Southland's estuaries - e.g. Robertson & Stevens 2006). The ratings are based on a review of estuary monitoring data, guideline criteria, and expert opinion. They are designed to be used in combination with each other (usually involving expert input) when evaluating overall estuary condition and deciding on appropriate management. The condition ratings include an "early warning trigger" to highlight rapid or unexpected change, and each rating has a recommended monitoring and management response. In most cases initial management is to further assess an issue and consider what response actions may be appropriate (e.g. develop an Evaluation and Response Plan - ERP).

Total Nitrogen

In shallow estuaries like the Hutt, the sediment compartment is often the largest nutrient pool in the system, and nitrogen exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL NITROGEN CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<500mg/kg	Monitor at 5 year intervals after baseline established
Good	500-2000mg/kg	Monitor at 5 year intervals after baseline established
Fair	2000-4000mg/kg	Monitor at 2 year intervals and manage source
Poor	>4000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Total Phosphorus

In shallow estuaries like the Hutt, the sediment compartment is often the largest nutrient pool in the system, and phosphorus exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL PHOSPHORUS CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<200mg/kg	Monitor at 5 year intervals after baseline established
Good	200-500mg/kg	Monitor at 5 year intervals after baseline established
Fair	500-1000mg/kg	Monitor at 2 year intervals and manage source
Poor	>1000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

2. Methods (Continued)

Total Organic Carbon

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, release of excessive nutrients, and adverse impacts to biota - all symptoms of eutrophication.

TOTAL ORGANIC CARBON CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<1%	Monitor at 5 year intervals after baseline established
Good	1-2%	Monitor at 5 year intervals after baseline established
Fair	2-5%	Monitor at 2 year intervals and manage source
Poor	>5%	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Benthic Community Index (Organic Enrichment)

Soft sediment macrofauna can be used to represent benthic community health and provide an estuary condition classification (if representative sites are surveyed). The AZTI (AZTI-Tecnalia Marine Research Division, Spain) Marine Benthic Index (AMBI) (Borja et al. 2000) has been verified successfully in relation to a large set of environmental impact sources (Borja, 2005) and geographical areas (in both northern and southern hemispheres) and so is used here. However, although the AMBI is particularly useful in detecting temporal and spatial impact gradients care must be taken in its interpretation in some situations. In particular, its robustness can be reduced when only a very low number of taxa (1–3) and/or individuals (<3 per replicate) are found in a sample. The same can occur when studying low-salinity locations (e.g. the inner parts of estuaries), some naturally-stressed locations (e.g. naturally organic matter enriched bottoms; *Zostera* beds producing dead leaves; etc.), or some particular impacts (e.g. sand extraction, for some locations under dredged sediment dumping, or some physical impacts, such as fish trawling).

The equation to calculate the AMBI Biotic Coefficient (BC) is as follows;

$$BC = \{(0 \times \%GI) + (1.5 \times \%GII) + (3 \times \%GIII) + (4.5 \times \%GIV) + (6 \times \%GV)\}/100.$$

The characteristics of the above-mentioned ecological groups (GI, GII, GIII, GIV and GV) are summarised in Appendix 3.

BENTHIC COMMUNITY ORGANIC ENRICHMENT RATING			
ECOLOGICAL RATING	DEFINITION	BC	RECOMMENDED RESPONSE
High	Unpolluted	0-1.2	Monitor at 5 year intervals after baseline established
Good	Slightly polluted	1.2-3.3	Monitor 5 yearly after baseline established
Moderate	Moderately polluted	3.3-5.0	Monitor 5 yearly after baseline est. Initiate ERP
Poor	Heavily polluted	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Bad	Azoic (devoid of life)	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Trend to slightly polluted	>1.2	Initiate Evaluation and Response Plan

Benthic Community Index (Mud Tolerance)

Soft sediment macrofauna can also be used to represent benthic community health in relation to the extent of mud tolerant organisms compared with those that prefer sands. Using the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) a “mud tolerance” rating has been developed similar to the “organic enrichment” rating identified above.

The equation to calculate the Mud Tolerance Biotic Coefficient (MTBC) is as follows;

$$MTBC = \{(0 \times \%SS) + (1.5 \times \%S) + (3 \times \%I) + (4.5 \times \%M) + (6 \times \%MM\}/100.$$

The characteristics of the above-mentioned mud tolerance groups (SS, S, I, M and MM) are summarised in Appendix 3.

BENTHIC COMMUNITY MUD TOLERANCE RATING			
MUD TOLERANCE RATING	DEFINITION	MTBC	RECOMMENDED RESPONSE
Very Low	Strong sand preference dominant	0-1.2	Monitor at 5 year intervals after baseline established
Low	Sand preference dominant	1.2-3.3	Monitor 5 yearly after baseline established
Moderate	Some mud preference	3.3-5.0	Monitor 5 yearly after baseline established. Initiate ERP
High	Mud preferred	5.0-6.0	Post baseline, monitor yearly. Initiate ERP
Very High	Strong mud preference	>6.0	Post baseline, monitor yearly. Initiate ERP
Early Warning Trigger	Some mud preference	>1.2	Initiate Evaluation and Response Plan

2. Methods (Continued)

Metals

Heavy metals provide a low-cost preliminary assessment of toxic contamination in sediments, and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for the presence of other major contaminant classes: pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

METALS CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<0.2 x ISQG-Low	Monitor at 5 year intervals after baseline established
Good	<ISQG-Low	Monitor at 5 year intervals after baseline established
Fair	<ISQG-High but >ISQG-Low	Monitor at 2 year intervals and manage source
Poor	>ISQG-High	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Sedimentation Rate

Elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse, and indicate where changes in land use management may be needed.

SEDIMENTATION RATE CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Low	0-1mm/yr (typical pre-European rate)	Monitor at 5 year intervals after baseline established
Low	1-2mm/yr	Monitor at 5 year intervals after baseline established
Moderate	2-5mm/yr	Monitor at 5 year intervals after baseline established
High	5-10mm/yr	Monitor yearly. Initiate ERP
Very High	>10mm/yr	Monitor yearly. Manage source
Early Warning Trigger	Rate increasing	Initiate Evaluation and Response Plan

Redox Potential Discontinuity

The RPD is the grey layer between the oxygenated yellow-brown sediments near the surface and the deeper anoxic black sediments. It is an effective ecological barrier for most but not all sediment-dwelling species. A rising RPD will force most macrofauna towards the sediment surface to where oxygen is available. The depth of the RPD layer is a critical estuary condition indicator in that it provides a measure of whether nutrient enrichment in the estuary exceeds levels causing nuisance anoxic conditions in the surface sediments. The majority of the other indicators (e.g. macroalgal blooms, soft muds, sediment organic carbon, TP, and TN) are less critical, in that they can be elevated, but not necessarily causing sediment anoxia and adverse impacts on aquatic life. Knowing if the surface sediments are moving towards anoxia (i.e. RPD close to the surface) is important for two main reasons:

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

The tendency for sediments to become anoxic is much greater if the sediments are muddy. In sandy porous sediments, the RPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1 cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

RPD CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	>10cm depth below surface	Monitor at 5 year intervals after baseline established
Good	3-10cm depth below sediment surface	Monitor at 5 year intervals after baseline established
Fair	1-3cm depth below sediment surface	Monitor at 5 year intervals. Initiate ERP
Poor	<1cm depth below sediment surface	Monitor at 2 year intervals. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

3. RESULTS AND DISCUSSION

OUTLINE

A summary of the results of the 21 January 2010 fine scale monitoring of Hutt Estuary is presented in Table 3, with detailed results presented in Appendices 2 and 3. The results and discussion section is divided into three subsections based on the key estuary problems that the fine scale monitoring is addressing: sedimentation, eutrophication, and toxicity. Within each subsection, the results for each of the relevant fine scale indicators are presented. A summary of the condition ratings for each of the two sites is presented in the accompanying figures.

Table 3. Physical, chemical and macrofauna results (means) for Hutt Estuary (21 January 2010).

	Site	Reps	RPD	Salinity	TOC	Mud	Sand	Gravel	Sb	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP	Abundance	No. Species
			cm	ppt	%				mg/kg									No./m²	No./core
2010	Hutt A	3	4-5	30	0.9	51.0	48.5	0.6	0.15	0.040	13.0	8.7	11.0	15.3	61.3	1467	420	25,680	9.5
2010	Hutt B	3	3-5	30	0.7	35.3	62.6	2.1	0.09	0.038	13.7	9.3	12.0	17.0	69.3	1157	427	21,937	10.3

PAH's (mg/kg)	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]anthracene	Benzo[a]pyrene (BAP)	Benzo[b]fluoranthene + Benzo[j]fluoranthene	Benzo[g,h,i]perylene	Benzo[k]fluoranthene	Chrysene	Dibenzo[a,h]anthracene	Fluoranthene	Fluorene	Indeno(1,2,3-c,d)pyrene	Naphthalene	Phenanthrene	Pyrene	Low Molecular Wgt PAH	Hi Molecular Wgt PAH
ANZECC ISQG Low Trigger	0.016	0.044	0.085	0.261	0.430	-	-	-	0.384	0.063	0.600	0.019	-	0.160	0.240	0.665	0.552	1.700
Hutt A	< 0.002	0.007	0.006	0.052	0.061	0.110	0.051	0.036	0.043	0.009	0.072	0.0021	0.036	< 0.011	0.023	0.082	0.038	0.319
Hutt B	< 0.002	< 0.002	0.003	0.012	0.013	0.029	0.017	0.009	0.010	< 0.002	0.024	< 0.002	0.009	< 0.010	0.016	0.026	0.019	0.085

DDT (mg/kg)	2,4'-DDD	4,4'-DDD	2,4'-DDE	4,4'-DDE	2,4'-DDT	4,4'-DDT	Total DDT Isomers
ANZECC ISQG Low Trigger	-	-	-	-	-	-	0.0016
Hutt A*	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.030
Hutt B*	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.030

* Although organic toxicants should be normalised to 100% mud before comparison with ANZECC trigger values, the fact that they were below detection limits made this step unnecessary.

SEDIMENTATION

Soil erosion is a major issue in New Zealand and the resulting suspended sediment impacts are of particular concern in estuaries because they act as a sink for fine sediments or muds. Sediments containing high mud content (i.e. around 30% with a grain size <63μm) are now typical in NZ estuaries that drain developed catchments. In such mud-impacted estuaries, the muds generally occur in the areas that experience low energy tidal currents and waves [i.e. the intertidal margins of the upper reaches of estuaries (e.g. Waikanae Estuary), and in the deeper subtidal areas at the mouth of estuaries (e.g. Hutt Estuary)] (Figure 3). In contrast, the main intertidal flats of developed estuaries (e.g. Porirua Harbour) are usually characterised by sandy sediments reflecting their exposure to wind-wave disturbance and are hence low in mud content (2-10% mud). In estuaries where there are no large intertidal flats, the presence of mud along the narrow channel banks in the lower estuary can also be elevated (e.g. Hutt Estuary and Whareama Estuary, Wairarapa Coast). In estuaries with undeveloped catchments the mud content is extremely low (e.g. Freshwater Estuary, Stewart Island where the mud content is <1%).

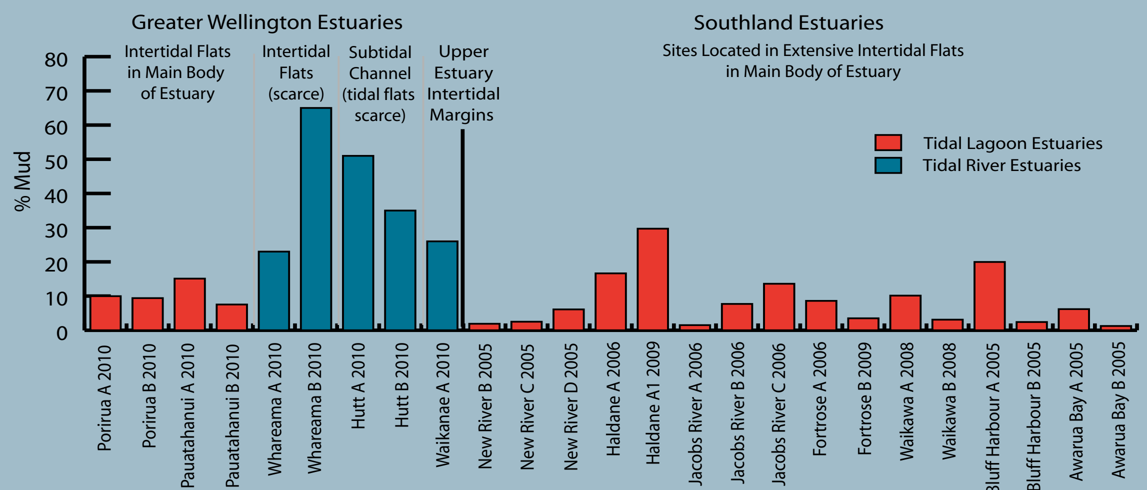


Figure 3. Percentage of mud at fine scale sites in NZ estuaries. Location of fine scale sites within each estuary type are also shown.

3. Results and Discussion (Continued)

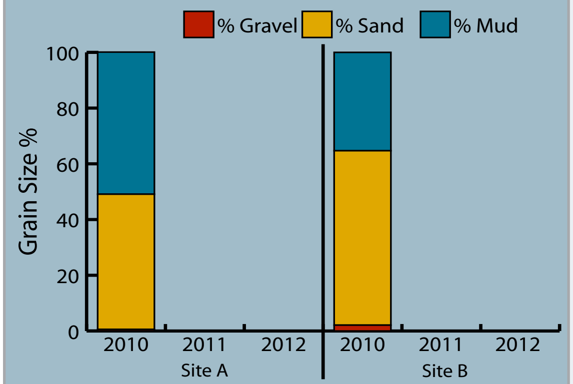


Figure 4. Grain size, Hutt Estuary, January 2010.

In order to assess sedimentation in the Hutt Estuary, a number of indicators have been used: grain size, the presence of mud tolerant macro-invertebrates and sedimentation rate.

Grain Size

Grain size (% mud, sand, gravel) measurements provide a good indication of the muddiness of a particular site. The first year monitoring results show that both Sites A and B, which were typical of the whole estuary, had relatively high mud concentrations (approximately 51% mud for Site A and 35% for Site B). The source of the muds to the Hutt Estuary is almost certainly from the surrounding developed catchment. To address the potential for ongoing sedimentation within the estuary and to measure its magnitude, sediment plates were deployed at the lower estuary fine scale monitoring site (Site A) in April 2010.

Macro-invertebrate Tolerance to Muds

The macro-invertebrate community in the Hutt Estuary was found to have low-moderate number of species compared with other NZ estuaries (mean 9-10 species per core - Figure 5) and a high mean abundance at 22,000-26,000/m^2 (Figure 6).

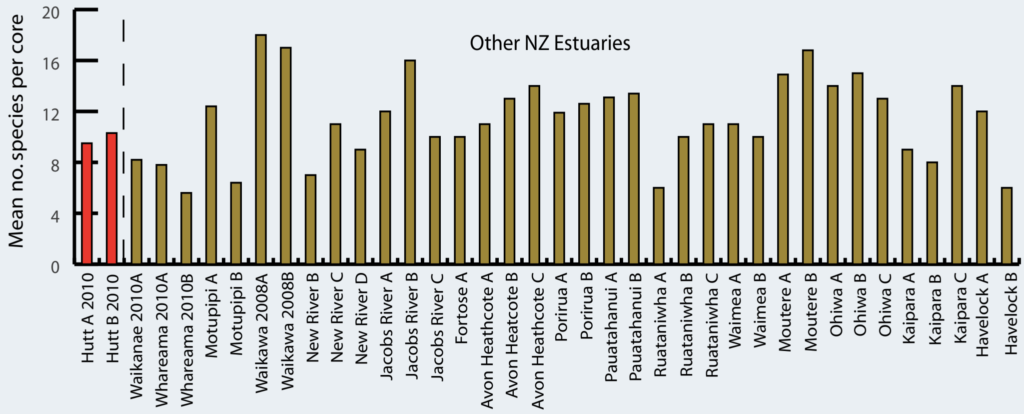


Figure 5. Mean number of infauna species, Hutt Estuary compared with other Wellington and NZ estuaries (source Robertson et al. 2002, Robertson and Stevens 2006, Robertson and Stevens 2010a and b).

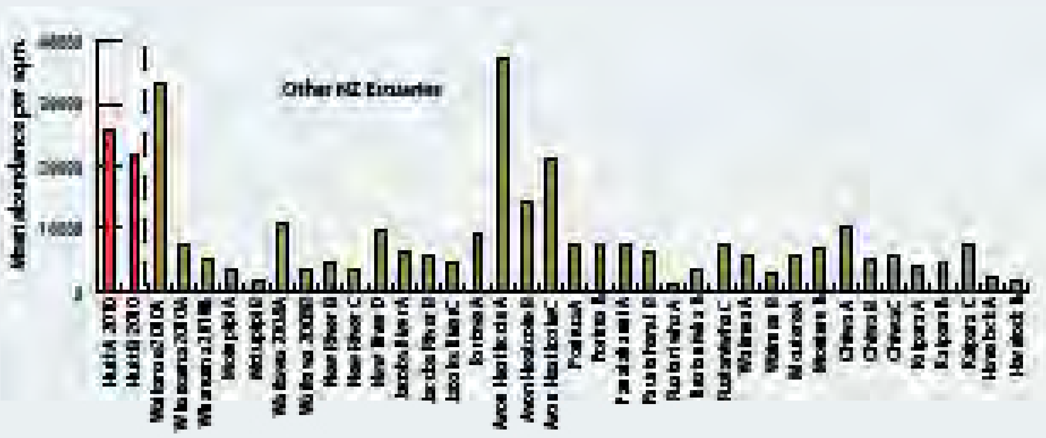


Figure 6. Mean total abundance of macrofauna, Hutt Estuary compared with other Wellington and NZ estuaries (source Robertson et al. 2002, Robertson and Stevens 2006, Robertson and Stevens 2010a and b).

3. Results and Discussion (Continued)

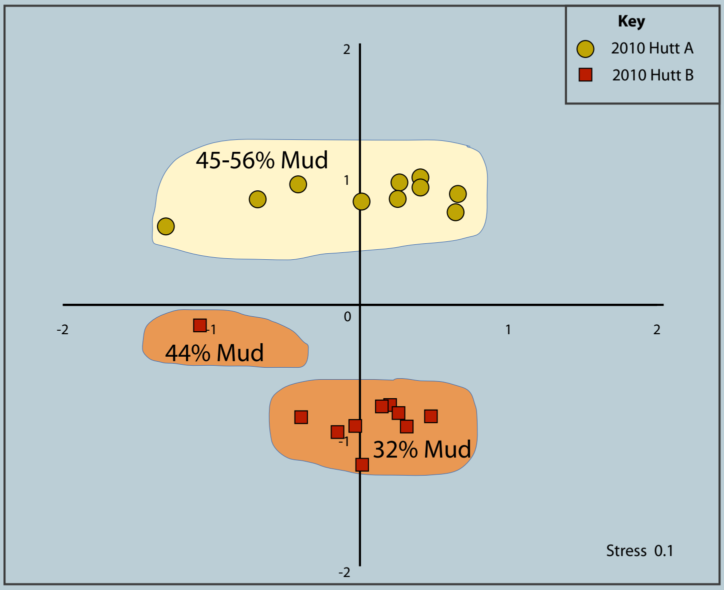


Figure 7. NMDS plot showing the relationship among samples in terms of similarity in macro-invertebrate community composition for Sites A and B, for the January 2010 sampling occasion. The plot shows each of the 10 replicate samples for each site and is based on Bray Curtis dissimilarity and square root transformed data.

The approach involves multivariate data analysis methods, in this case non-metric multidimensional scaling (NMDS) using PRIMER vers. 6.1.10. The analysis basically plots the site and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities i.e. how low the calculated stress value is. Stress values greater than 0.3 indicate that the configuration is no better than arbitrary and we should not try and interpret configurations unless stress values are less than 0.2.

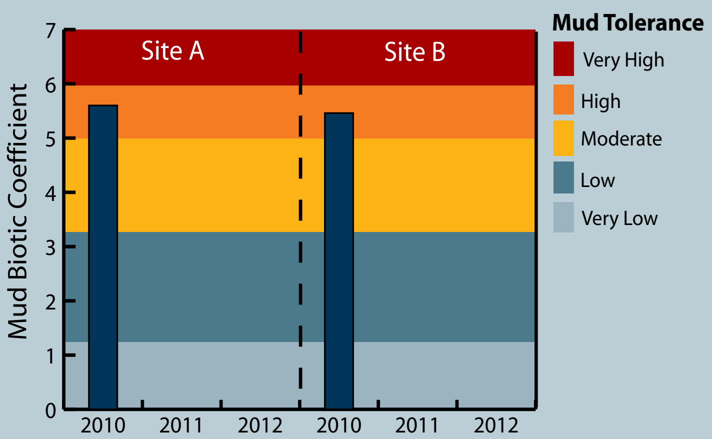


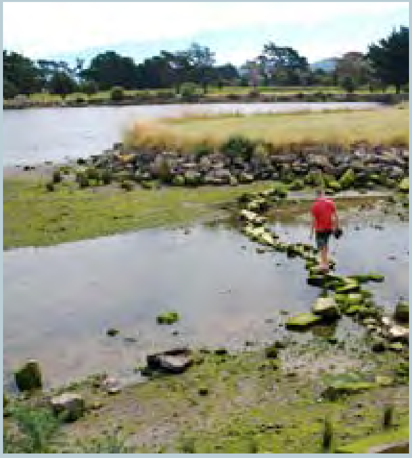
Figure 8. Mud tolerance macro-invertebrate rating, Sites A and B, 2010.

Multivariate techniques were firstly used to explore whether the macro-invertebrate communities at each of the two sites in the Hutt Estuary were different from each other. The results (Figure 7) show that they were, and that the difference in mud contents between each of the sites was the likely reason.

The next step was to use the response of typical NZ estuarine macro-invertebrates to increasing mud content (Gibbs and Hewitt 2004) to assess the mud tolerance of the Hutt Estuary macro-invertebrate community (Figures 8 and 9 and Appendices 2 and 3). The results show that the Hutt Estuary macro-invertebrate mud tolerance rating was in the "high" category which indicates that the community was dominated by species that prefer mud rather than those that prefer sand. The tube-dwelling amphipod *Paracorophium excavatum*, which has a strong mud preference and is also tolerant of low salinities and moderate organic enrichment, was the most abundant at both sites. Other mud-tolerant species that were present at elevated levels included:

- Juvenile pipis (*Paphies australis*) (1-10mm long) which are often found in sandy mud habitats like Hutt Estuary, but not as adults because the optimum and distribution range for adults is 0-5% mud (Norkko et al. 2001).
- The estuarine snails *Potamopyrgus antipodarum* and *P. estuarinus,*
- The ubiquitous spionid polychaetes *Scolecolepides benhami* and *Microspio maori*,
- The capitellid polychaetes (*Capitella* sp. and *Heteromastus filiformis*),
- The active surface deposit feeding nereid polychaetes (including *Perinereis vallata*).

Moderate numbers of cockles (*Austrovenus stutchburyi*), mainly juvenile (up to 10mm in length and one year old) and pre-adult (10-20mm) were also present but included a few 40mm adults. The highest cockle numbers were found at the less muddy Site B. Cockles prefer sand environments with an optimum range of 5-10% mud but can be also be found sub-optimally in 0-60% mud.



These findings indicate that the pipi and cockle communities in the Hutt Estuary (30-55% mud) are almost certainly growing in sub-optimal conditions. Pipis would need to move away from these muddy sites to become adults, and cockles, although they could become adults, would never reach prime condition.

Another strong sand preference organism (*Aonides oxycephala*) was present at the sites but in very low numbers. This organism was present well outside its optimum and distribution ranges of 0-5% mud. A possible explanation for this is that the mud content has increased relatively recently and that the *Aonides* population is declining from a previously higher level. If mud content stays the same or increases further, such organisms will disappear.

Overall this indicates that macro-invertebrate diversity and abundance in the Hutt Estuary are likely to be adversely affected by the sediment mud content, and that fine sediments have reached levels where all sites, and nearly all sensitive species, are affected.

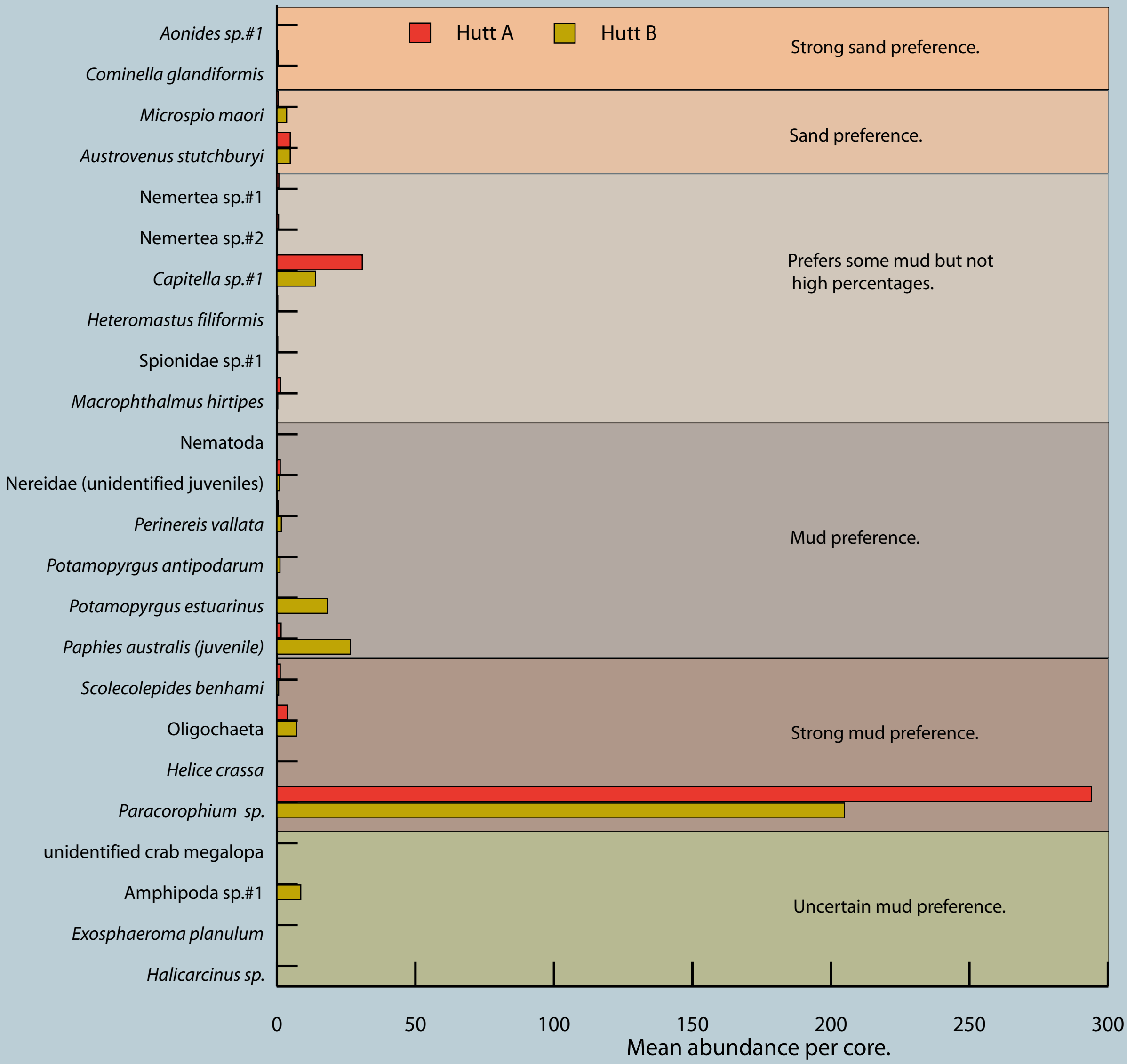
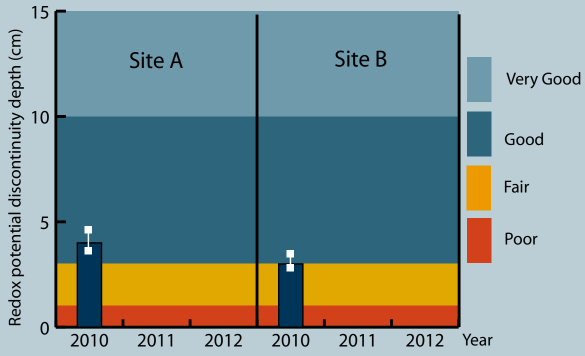


Figure 9. Hutt Estuary 2010 - mud sensitivity of macro-invertebrates at Sites A and B (see Appendix 3 for sensitivity details).

EUTROPHICATION



2010 RPD RATING	Fair - Good

Figure 10. RPD depth (mean and range), Hutt Estuary, January 2010.

The primary fine scale indicators of eutrophication are grain size, RPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and the community structure of benthic invertebrates. The broad scale indicators (reported in Stevens and Robertson 2008 and 2009) are the percentages of the estuary covered by macroalgae and soft muds.

Redox Potential Discontinuity (RPD)

Figures 10 and 11 (also Table 4) show the RPD depths and sediment profiles for each of the two Hutt sampling sites, and indicate the likely benthic community at each site based on the measured RPD depth (adapted from Pearson and Rosenberg 1978).

The RPD depth at both sites in Hutt Estuary was moderate (3-5cm) and therefore sediments are likely to be moderately oxygenated. Such RPD values fit the "fair-good" condition rating and indicate the benthic invertebrate community is likely to be in a transitional to stable state.

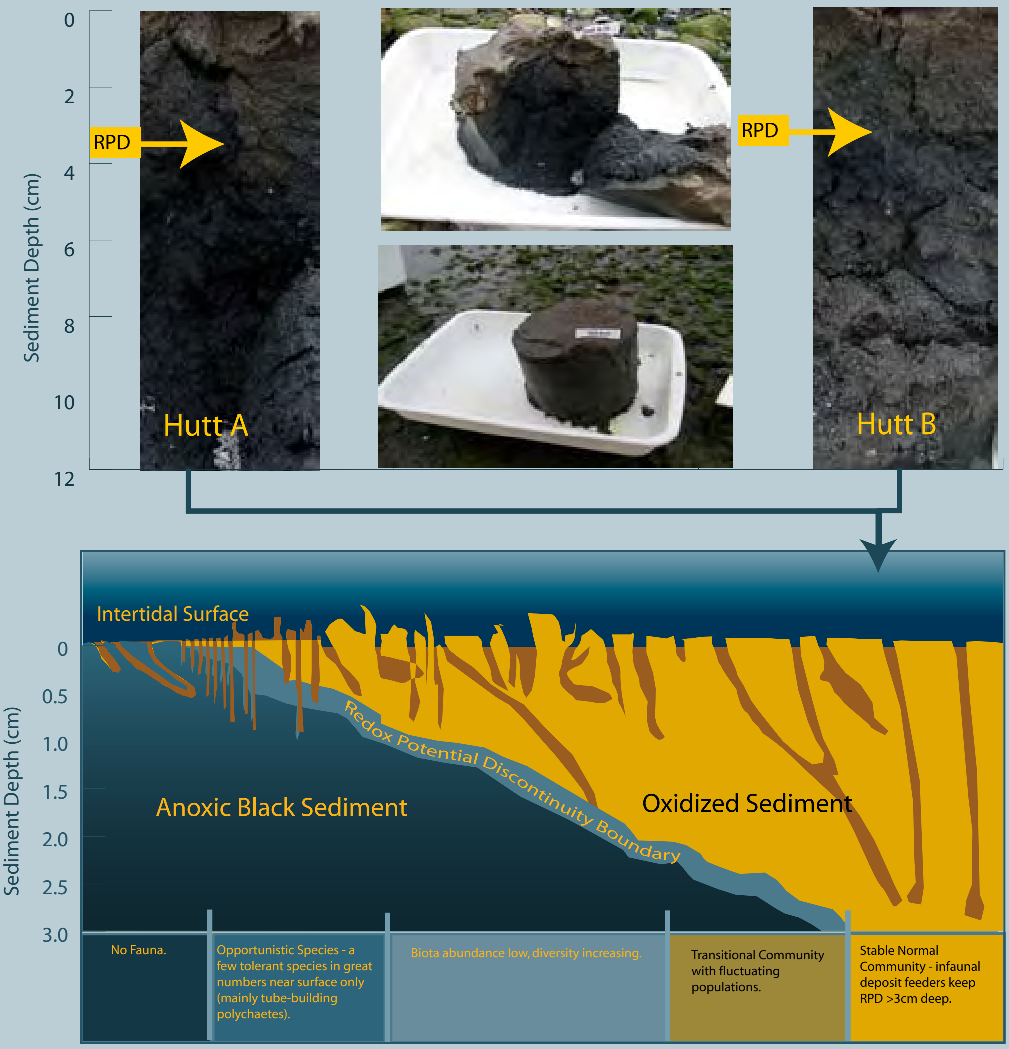


Figure 11. Sediment profiles, depths of RPD and predicted benthic community type, Hutt Estuary 21 January 2010. Arrow below core relates to the type of community likely to be found in the core.

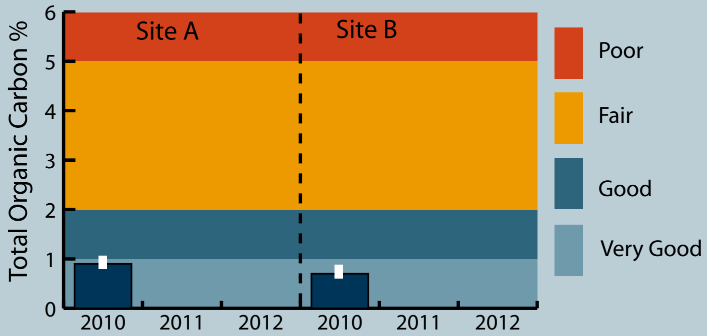


Figure 12. Total organic carbon (mean and range), Hutt Estuary, January 2010.

2010 TOC RATING	Very Good

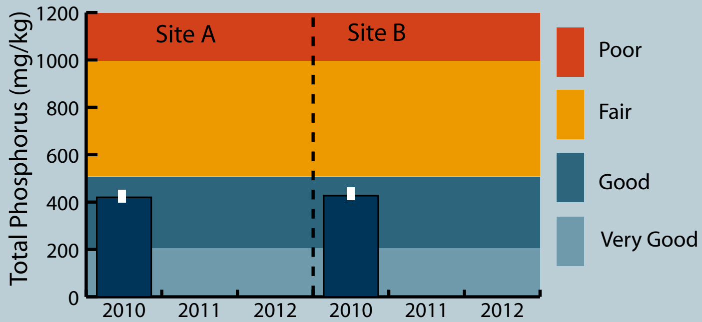


Figure 13. Total phosphorus (mean and range), Hutt Estuary, January 2010.

2010 TP RATING	Good

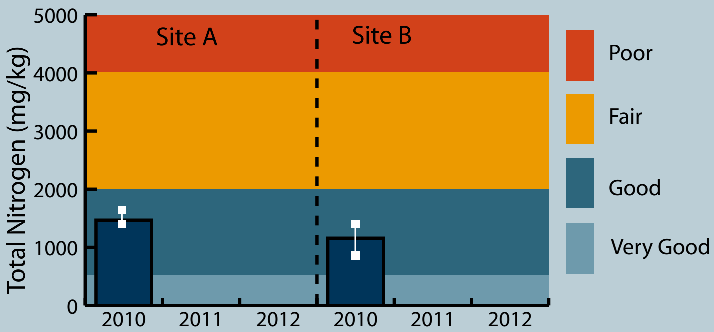


Figure 14. Total nitrogen (mean and range), Hutt Estuary, January 2010.

2010 TN RATING	Good

ORGANIC MATTER (TOC)

Fluctuations in organic input are considered to be one of the principal causes of faunal change in estuarine and near-shore benthic environments. Increased organic enrichment results in changes in physical and biological parameters, which in turn have effects on the sedimentary and biological structure of an area. The number of suspension-feeders (e.g. bivalves and certain polychaetes) declines and deposit-feeders (e.g. opportunistic polychaetes) increases as organic input to the sediment increases (Pearson and Rosenberg 1978).

The indicator of organic enrichment (TOC) at both sites in 2010 (Figure 12) was at low concentrations (<1%) at all sites and met the “very good” condition rating.

TOTAL PHOSPHORUS

Total phosphorus (a key nutrient in the eutrophication process) was present in 2010 at moderate concentrations and was rated in the “good” category (Figure 13).

This means that the Hutt Estuary sediments have a moderate store of P in the sediments (sourced from both recent and historical catchment inputs).

TOTAL NITROGEN

Like phosphorus, total nitrogen (the other key nutrient in the eutrophication process) was present in 2010 at moderate concentrations and was rated in the “good” category (Figure 14).

This means that the Hutt sediments have a moderate store of N in the sediments (sourced from both recent and historical catchment inputs).

Overall, the combined results for the indicators of eutrophication indicate a moderate presence of eutrophication symptoms in the Hutt Estuary in 2010 based on:

- low-moderate concentrations of N, P and TOC,
- moderate-high cover of macroalgae as measured in the 2010 survey of macroalgal cover in the Hutt Estuary (Stevens and Robertson 2010), and
- “fair-good” condition rating for RPD or sediment oxygenation.

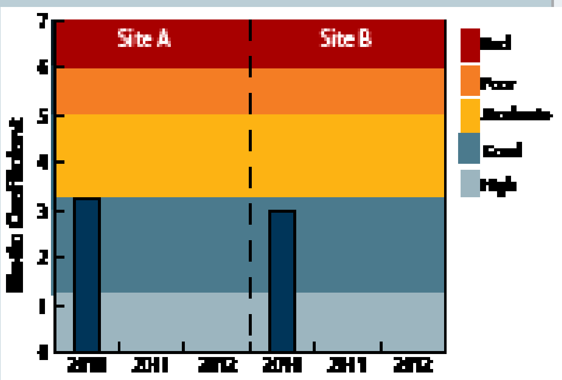


Figure 15. Organic enrichment macro-invertebrate rating, Hutt Estuary, January 2010.

2010 Benthic Community ORGANIC ENRICHMENT RATING	Good-Moderate

Macro-invertebrate Organic Enrichment Index

The macro-invertebrate response to increasing organic enrichment (Borja et al. 2000) was used to assess the tolerance of the Hutt Estuary macro-invertebrate community (Figure 15 and Appendices 2 and 3). The results show that the Hutt Estuary fitted the "good-moderate" or "slightly polluted - polluted" category in 2010 (Figure 15) based on the benthic community organic enrichment rating. The rating indicated that the community was dominated by enrichment-tolerant species, and that the sites were moderately enriched.

This dominance is demonstrated more clearly in Figure 16 which shows a complete absence of Type I or "very sensitive" organisms, a few Type II organisms (pipis and cockles) which are "indifferent to organic enrichment", and elevated numbers of Types III, IV and V tolerant organisms. The most abundant organism, the tube-dwelling amphipod *Paracorophium excavatum*, has a strong mud preference and is moderately tolerant of organic enrichment.

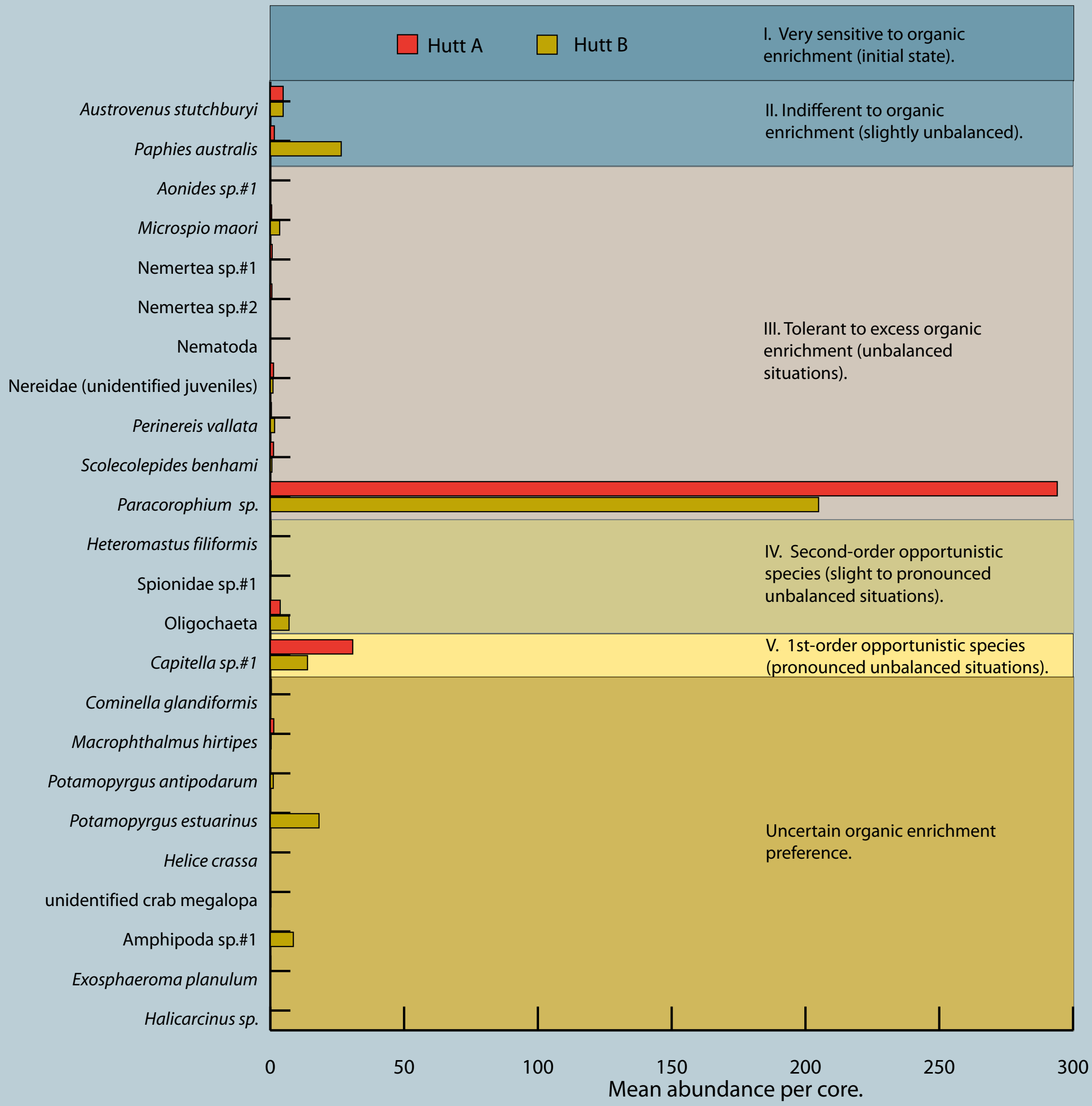


Figure 16. Hutt Estuary 2010 - organic enrichment sensitivity of macro-invertebrates at Sites A and B (see Appendix 3 for sensitivity details).

3. Results and Discussion (Continued)

TOXICITY

2010 TOXICITY RATING
Good
Very Good

METALS, DDT AND PAH'S

Heavy metals (Sb, Cd, Cr, Cu, Ni, Pb, Zn), used as an indicator of potential toxicants, were at low to very low concentrations in 2010, with all values well below the ANZECC (2000) ISQG-Low trigger values (Figure 17). In 2010 metals met the "good" condition rating for lead, nickel and zinc and the "very good" condition rating for antimony, cadmium, chromium and copper. DDT isomers and PAH's measured in 2010 were all below detection limits and ANZECC (2000) criteria (Table 3). These results indicate that there is no widespread toxicity in the dominant shallow subtidal mud/sand habitat of the Hutt Estuary.

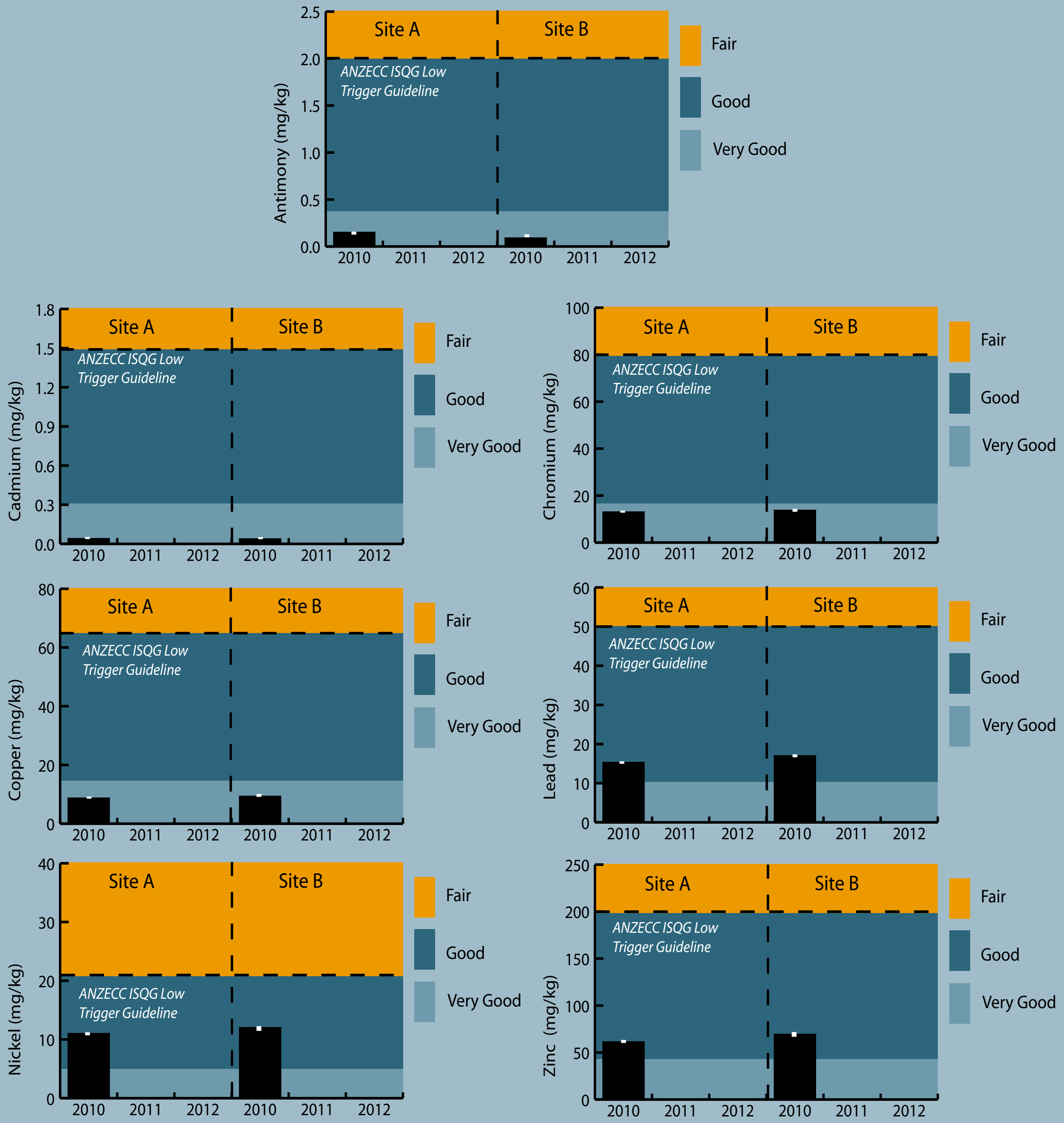


Figure 17. Total recoverable metals (mean and range), Hutt Estuary, January 2010.

4. SUMMARY AND CONCLUSIONS

The key initial finding was that, unlike most other NZ estuaries, the Hutt Estuary lacked significant areas of intertidal flats and, therefore, the monitoring sites needed to be located subtidally. This reflects the fact that the estuary has been highly modified in the past through extensive reclamations and channelisation, resulting in drastic reduction in size, and the loss of its high value habitats (saltmarsh, seagrass, intertidal flats and natural vegetated margin). As a consequence, the ability of the estuary to function effectively and to support diverse populations of fish, shellfish, birds, and a wide range of human uses, has been impaired.

The results of the monitoring showed that, as may be expected from such a heavily modified estuary, the subtidal sediments had a relatively high mud content, and moderate levels of sediment oxygenation, organic carbon, nitrogen and phosphorus. The benthic invertebrate community was dominated by species tolerant of mud and organic enrichment. Perhaps less expected, given the exposure to urban runoff, were the low concentrations of potential toxicants (heavy metals, DDT and PAH's).

Overall the findings indicate that the estuary:

- is moderately enriched with nutrients (mesotrophic),
- has excessive muds and is likely to have elevated sedimentation rates,
- has low levels of toxicity, and
- has been damaged by extensive historical loss of high value habitat.

5. FUTURE MONITORING

Hutt Estuary has been identified by GWRC as a priority for monitoring, and is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout the Greater Wellington region. Based on the first year of baseline monitoring results and condition ratings, it is recommended that monitoring continue as outlined below:

Fine Scale, Macroalgal and Sedimentation Rate Monitoring. Continue fine scale baseline monitoring for a further 2 to 3 years. Subsequently, monitor at five yearly intervals or as deemed necessary based on the condition ratings. Baseline monitoring should include measuring the depths of the existing four sediment plates, and broad scale intertidal macroalgal growth. The next monitoring is scheduled for January 2011.

6. MANAGEMENT

The fine scale monitoring results reinforce the need for management of nutrient and fine sediment sources entering the estuary. It is recommended that sources of elevated loads in the catchment be identified and management undertaken to minimise their adverse effects on estuary uses and values.
In order to improve estuary function, it is also recommended that steps be taken to increase the extent of high value estuary habitat (saltmarsh, seagrass, intertidal flats and natural vegetated margin) wherever possible.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from the staff of Greater Wellington Regional Council, in particular, the support and feedback of Juliet Milne is much appreciated. Many thanks also to Maz Robertson (Wriggle) for editing help.

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Air dry (35 degC, sieved to pass 2mm and 63um sieves, gravimetric - (% sand, gravel, silt)	N/A
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable antimony	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt
Organochlorine Pesticides and Polycyclic Aromatic Hydrocarbons (PAH's)			
Environmental Solids Prep.	R.J Hill	Air dried at 35°C and sieved, <2mm fraction	
Organochlorines Trace in Soil	R.J Hill	Sonication extraction, SPE cleanup, GPC cleanup (if req.), 4, 8 dual column GC-ECD analysis	0.001 mg/kg dry wgt
PAH's Trace in Soil	R.J Hill	Sonication extraction, SPE cleanup, GC-MS SIM analysis US EPA 8270C	0.001 mg/kg dry wgt

* Coastal Marine Ecology Consultants (established in 1990) specialises in coastal soft-shore and inner continental shelf soft-bottom benthic ecology. Principal, Gary Stephenson (BSc Zoology) has worked as a marine biologist for more than 25 years, including 13 years with the former New Zealand Oceanographic Institute, DSIR. Coastal Marine Ecology Consultants holds an extensive reference collection of macroinvertebrates from estuaries and soft-shores throughout New Zealand. New material is compared with these to maintain consistency in identifications, and where necessary specimens are referred to taxonomists in organisations such as NIWA and Te Papa Tongarewa Museum of New Zealand for identification or cross-checking.

APPENDIX 2. 2010 DETAILED RESULTS

Station Locations (NZGD2000 NZTM)

HUTT A	HuttAPeg1	HuttA 1	HuttA 2	HuttA 3	HuttA 4	HuttA 5	HuttA 6	HuttA 7	HuttA 8	HuttA 9	HuttA 10	HuttAPeg2
NZTM East	1759174.1	1759175.8	1759175.8	1759175.8	1759175.7	1759175.7	1759175.7	1759175.7	1759175.6	1759175.5	1759175.5	1759174.4
NZTM North	5433638.0	5433637.0	5433635.3	5433633.3	5433631.3	5433629.3	5433627.3	5433625.3	5433623.2	5433621.2	5433619.2	5433618.1
HUTT B	**HuttBPeg1**	**HuttB 1**	**HuttB 2**	**HuttB 3**	**HuttB 4**	**HuttB 5**	**HuttB 6**	**HuttB 7**	**HuttB 8**	**HuttB 9**	**HuttB 10**	**HuttBPeg2**
NZTM East	1759369.4	1759367.2	1759367.2	1759367.2	1759367.3	1759367.3	1759367.3	1759367.3	1759367.4	1759367.5	1759367.5	1759369.0
NZTM North	5434135.8	5434117.5	5434119.5	5434121.4	5434123.6	5434125.5	5434127.5	5434129.6	5434131.5	5434133.5	5434135.3	5434116.9

Physical and chemical results for Hutt Estuary, 21 January 2010.

Site	Reps*	RPD	Salinity	TOC	Mud	Sands	Gravel	Antimony	Cd	Cr	Cu	Ni	Pb	Zn	TN	TP
		cm	ppt	%				mg/kg								
HuttA	1-4	1	30	0.92	56.0	43.4	0.6	0.11	0.041	13.0	8.7	11.0	15.0	60.0	1400	410
HuttA	5-8	1	30	0.73	45.6	53.8	0.6	0.22	0.036	13.0	8.7	11.0	15.0	62.0	1300	420
HuttA	9-10	1	30	1.10	51.3	48.2	0.5	0.11	0.043	13.0	8.8	11.0	16.0	62.0	1700	430
HuttB	1-4	3.5	30	0.66	32.5	66.4	1.0	0.08	0.033	13.0	9.0	12.0	16.0	68.0	1300	410
HuttB	5-8	3	30	0.61	31.2	67.4	1.4	0.09	0.041	14.0	9.4	12.0	18.0	71.0	670	440
HuttB	9-10	2	30	0.79	42.2	53.9	3.9	0.11	0.039	14.0	9.6	12.0	17.0	69.0	1500	430

* composite samples

PAH's mg/kg	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]anthracene	Benzo[a]pyrene (BAP)	Benzo[b]fluoranthene + Benzo[j]fluoranthene	Benzo[g,h,i]perylene	Benzo[k]fluoranthene	Chrysene	Dibenzo[a,h]anthracene	Fluoranthene	Fluorene	Indeno(1,2,3-c,d)pyrene	Naphthalene	Phenanthrene	Pyrene
Hutt A	< 0.0022	0.0068	0.006	0.052	0.061	0.11	0.051	0.036	0.043	0.0095	0.072	0.0021	0.036	< 0.011	0.023	0.082
Hutt B	< 0.0020	< 0.0020	0.0029	0.012	0.013	0.029	0.017	0.0087	0.01	< 0.0020	0.024	< 0.0020	0.0093	< 0.010	0.016	0.026

DDT mg/kg	2,4'-DDD	4,4'-DDD	2,4'-DDE	4,4'-DDE	2,4'-DDT	4,4'-DDT	Total DDT Isomers
	mg/kg						
Hutt A	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0060
Hutt B	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0060

APPENDIX 2. 2010 DETAILED RESULTS (CONTINUED)

Sediment Plate Locations and Depths (mm)

Location	Site	NZTM East	NZTM North
Hutt	Plate 1	1759100.6	5433548.2
	Plate 2	1759096.6	5433548.0
	Plate 3	1759092.5	5433547.9
	Plate 4	1759088.5	5433547.9
	SedPeg1	1759102.6	5433548.2
	SedPeg2	1759098.6	5433548.1
	SedPeg3	1759094.5	5433548.0
	SedPeg4	1759090.5	5433547.9
	SedPeg5	1759086.7	5433547.8

Depth	Site	Jan 2010	Jan 2011	Jan 2012
Hutt	Plate 1	Plates deployed. Surface sediments settling. Measure baseline in 2011.		
	Plate 2			
	Plate 3			
	Plate 4			

Infauna (numbers per 0.01327m² core) (Note NA = Not Assigned)

Hutt A													
Group	**Species**	AMBI Group	MUD Group	Hutt A-01	Hutt A-02	Hutt A-03	Hutt A-04	Hutt A-05	Hutt A-06	Hutt A-07	Hutt A-08	Hutt A-09	Hutt A-10
NEMERTEA	Nemertea sp.#1	III	3	2			1		1	1	1	1	
	Nemertea sp.#2	III	3	1			1		2				2
NEMATODA	Nematoda	III	4										1
POLYCHAETA	*Aonides* sp.#1	III	1						1				
	Capitella sp.#1	V	3	79	34	36	35	36	19	5	28	13	23
	Heteromastus filiformis	IV	3							3			
	Microspio maori	III	2		1		1			1	2		
	Nereidae (unidentified juveniles)	III	4	2		1		4		2	1	1	1
	Perinereis vallata	III	4	1	2								1
	Scolecolepides benhami	III	5	2	2	1			3	1		1	2
	Spionidae sp.#1	IV	3									3	
OLIGOCHAETA	Oligochaeta	IV	5	4	1	1	8	6	8	1	4	2	2
GASTROPODA	*Cominella glandiformis*	NA	1					1	2		1		
	Potamopyrgus antipodarum	NA	4										
	Potamopyrgus estuarinus	NA	4										
BIVALVIA	*Austrovenus stutchburyi*	II	2	6	6	4	2	2	3	6	6	9	4
	Paphies australis	II	4				1		10	1		2	1
CRUSTACEA	Amphipoda sp.#1	NA	?										
	Exosphaeroma planulum	NA	?				1		1				
	Halicarcinus sp.	NA	?								1		
	Helice crassa	NA	5										
	Macrophthalmus hirtipes	NA	3	1	1			1	1	2	2	2	3
	Paracorophium sp.	III	5	164	407	425	445	323	323	171	329	282	72
	unidentified crab megalopa	NA	5							1			
Total individuals in core sample				262	454	468	495	373	374	195	375	316	112
Total Species/Core				10	8	6	9	7	12	12	10	10	11

AMBI and MUD Group details see page 24

Infauna (numbers per 0.01327m² core) **(Note NA = Not Assigned)**

Hutt B

Group	Species	AMBI Group	MUD Group	Hutt B-01	Hutt B-02	Hutt B-03	Hutt B-04	Hutt B-05	Hutt B-06	Hutt B-07	Hutt B-08	Hutt B-09	Hutt B-10
NEMERTEA	Nemertea sp.#1	III	3								1		
	Nemertea sp.#2	III	3										
NEMATODA	Nematoda	III	4										
POLYCHAETA	*Aonides sp.#1*	III	1										
	Capitella sp.#1	V	3	18	12	22	9				2	38	38
	Heteromastus filiformis	IV	3										
	Microspio maori	III	2	3	3	8	5	2	2	6	2	4	
	Nereidae (unidentified juveniles)	III	4	1		2	1		1	3	2		
	Perinereis vallata	III	4	1	1		2	3	4	2		1	2
	Scolecolepides benhami	III	5	4		1					1		
	Spionidae sp.#1	IV	3										
OLIGOCHAETA	Oligochaeta	NA	5	8	5	11	7	12	5	10	5		7
GASTROPODA	*Cominella glandiformis*	NA	1										
	Potamopyrgus antipodarum	NA	4		1	1		2	2		3	2	
	Potamopyrgus estuarinus	NA	4	9	14	28	36	20	6	8	35	23	3
BIVALVIA	*Austrovenus stutchburyi*	II	2		1	5	8	13	6	4	6	1	4
	Paphies australis	II	4	35	34	29	27	32	17	19	37	27	8
CRUSTACEA	Amphipoda sp.#1	NA	?	3	8	14	16	9	3	19	3	9	2
	Exosphaeroma planulum	NA	?										
	Halicarcinus sp.	NA	?				1						
	Helice crassa	NA	5	1									
	Macrophthalmus hirtipes	NA	3										3
	Paracorophium sp.	III	5	136	171	239	280	135	181	294	262	253	98
	unidentified crab megalopa	NA	5								1	1	
Total individuals in core sample				219	250	360	392	228	227	365	360	359	165
Total Species/Core				11	10	11	11	9	10	9	13	10	9

AMBI and MUD Group details see page 24

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group ***	Tolerance to Mud****	Details
Nemertea	Nemertea sp.1, 2	III	I Optimum range 55-60% mud,* distribution range 0-95%*	Ribbon or Proboscis Worms, mostly solitary, predatory, free-living animals. Intolerant of anoxic conditions.
Nematoda	Nematoda sp.	III	M Mud tolerant.	Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5mm mesh sieve. Generally reside in the upper 2.5cm of sediment. Intolerant of anoxic conditions.
Polychaeta	*Aonides oxycephala*	III	SS Optimum range 0-5% mud*, distribution range 0-80%**. Sensitive to changes in sediment mud content.	A small surface deposit-feeding spionid polychaete that lives throughout the sediment to a depth of 10cm. Although Aonides is free-living, it is not very mobile and prefers to live in fine sands. Aonides is very sensitive to changes in the silt/clay content of the sediment. **But is generally moderately tolerant of organically enriched situations.** Prey items for fish and birds.
Polychaeta	Capitellidae	V or IV	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%** based on *Heteromastus filiformis*.	Subsurface deposit feeder, occurs down to about 10 cm sediment depth. Common indicator of organic enrichment. Bio-turbator. Prey for fish and birds.
Polychaeta	*Heteromastus filiformis*	IV	I Optimum range 10-15%* or 20-40% mud**, distribution range 0-95%**.	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate to high organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species. Prey items for fish and birds.
Polychaeta	*Microspio maori*	III	S Expect optimum range in 0-20% mud.	A small, common, intertidal spionid. Can handle moderately enriched situations. Tolerant of high and moderate mud contents. Found in low numbers in Waiwhetu Estuary (black sulphide rich muds), Fortrose Estuary very abundant (5% mud, moderate organic enrichment). Prey items for fish and birds.
Polychaeta	Nereidae	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**. Sensitive to large increases in sedimentation.	Active, surface deposit feeder, scavenger, predator. Prefers reduced salinities. Usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter (Rasmussen 1973, Kristensen 1988). Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of high sulphide concentrations. Prey items for fish and birds.
Polychaeta	*Perinereis vallata*	III	M Optimum range 55-60%* or 35-55% mud**, distribution range 0-100%**.	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers sandy sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group ***	Tolerance to Mud****	Details
Polychaetes	*Scolecolepides benhami*	III	MM Optimum range 25-30% mud,* distribution range 0-100%*	A Spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. **Strong Mud Preference.** Prey items for fish and birds. Rare in Freshwater Estuary (<1% mud) and Porirua Estuary (5-10% mud). Common in Whareama (35-65% mud), Fortrose Estuary (5% mud), Waikanae Estuary 15-40% mud. Moderate numbers in Jacobs River Estuary (5-10% muds) and New River Estuary (5% mud). A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai arm, New River estuary.
Polychaetes	Spionidae (likely *Prionospio*)	IV	I Optimum range 65-70% mud* or 20- 50%**, distribution range 0-95%*. Sensitive to changes in sediment mud content.	Prionospio-group have many New Zealand species and are difficult to identify unless complete and in good condition. Common is *Prionospio aucklandica* which was originally *Aquilaspio aucklandica*. Common at low water mark in harbours and estuaries. A suspension feeding spionid (also capable of detrital feeding) that **prefers living in muddy sands (65-70% mud) but doesn't like higher levels.** But animals found in 0-95% mud. **Commonly an indicator of increase in mud content. Tolerant of organically enriched conditions.** Common in Freshwater estuary (<1% mud). Present in Waikawa (10% mud), Jacobs River Estuary (5-10% muds).
Oligochaeta	Oligochaetes	IV	MM Optimum range 95-100% mud*, distribution range 0-100%**.	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Gastropoda	*Cominella glandiformis*	NA	SS Optimum range 5-10% mud*, distribution range 0-10%**.	Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds. **Strong Sand Preference. Optimum mud range 5-10% mud.**
Gastropoda	*Potamopyrgus antipodarum*	III	M Tolerant of muds.	Endemic to NZ. Small snail that can live in freshwater as well as brackish conditions. In estuaries *P. antipodarum* can tolerate up to 17-24% salinity. Shell varies in colour (gray, light to dark brown). Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds but can tolerate organically enriched conditions. Tolerant of muds. Populations in saline conditions produce fewer offspring, grow more slowly, and undergo longer gestation periods.
Gastropoda	*Potamopyrgus estuarinus*	III	M Tolerant of muds.	Endemic to NZ. Small estuarine snail, requiring brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		Tolerance to Organic Enrichment - AMBI Group ***	Tolerance to Mud****	Details
Bivalvia	*Austrovenus stutchburyi*	II	S Prefers sand with some mud (optimum range 5-10% mud* or 0-10% mud**, distribution range 0-85% mud**).	Family Veneridae. The cockle is a suspension feeding bivalve with a short siphon - lives a few cm from sediment surface at mid-low water situations. Responds positively to relatively high levels of suspended sediment concentrations for short periods; long term exposure has adverse effects. Small cockles are an important part of the diet of some wading bird species. Removing or killing small cockles reduces the amount of food available to wading birds, including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns. In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, the evidence suggest that they struggle. In addition it has been found that cockles are large members of the invertebrate community that are responsible for improving sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).
	Paphies australis	II	SS (adults) S or M (Juveniles) Strong sand preference (adults optimum range 0-5% mud*, distribution range 0-5% mud**). Juveniles often found in muddier sediments.	The pipi is endemic to New Zealand. Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents. They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7m. **Optimum mud range 0-5% mud and very restricted to this range. Juveniles more tolerant of mud.** Common at mouth of Motupipi Estuary (0-5% mud), Freshwater Estuary (<1% mud), a few at Porirua B (Polytech) 5% mud.
Crustacea	Amphipoda sp.	NA	Uncertain	An unidentified amphipod.
	Exosphaeroma sp.	NA	Uncertain	Small seaweed dwelling isopod.
	Halicarcinus sp.	NA	Uncertain	A species of pillbox crab. Lives in intertidal and subtidal sheltered sandy environments.
	Helice crassa	NA	MM Optimum Range 95-100% mud (found in 5-100% mud)*.	Endemic, burrowing mud crab. *Helice crassa* concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.
	Macrophthalmus hirtipes	NA	I Optimum Range 45-50% mud (found in 0-95% mud)*.	The stalk-eyed mud crab is endemic to NZ and prefers water-logged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud.
	Paracorophium sp.	III	MM Optimum Range 95-100% mud (found in 40-100% mud)*.	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference. Optimum Range 95-100% mud (found in 40-100% mud) in upper Nth. Is. estuaries. In Sth. Is. and lower Nth. Is. common in Waikanae Estuary (15-40% mud), Haldane Estuary (25-35% mud) and in Fortrose Estuary (4% mud). Often present in estuaries with regular low salinity conditions. In muddy, high salinity sites like Whareama A and B (30-70% mud) we get very few.

APPENDIX 3. INFAUNA CHARACTERISTICS

* Preferred and distribution ranges based on findings from the Whitford Embayment in the Auckland Region (Norkko et al. 2001).
** Preferred and distribution ranges based on findings from 19 North Island estuaries (Gibbs and Hewitt 2004).
*** Preferred and distribution ranges based on findings from Thrush et al. (2003)

**** Tolerance to Mud Codes are as follows (from Gibbs and Hewitt 2004, Norkko et al. 2001) :

1 = SS, strong sand preference.

2 = S, sand preference.

3 = I, prefers some mud but not high percentages.

4 = M, mud preference.

5 = MM, strong mud preference.

***** AMBI Sensitivity to Organic Enrichment Groupings (from Borja et al. 2000)

Group I. Species very sensitive to organic enrichment and present under unpolluted conditions (initial state). They include the specialist carnivores and some deposit-feeding tubicolous polychaetes.

Group II. Species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.

Group III. Species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations). They are surface deposit-feeding species, as tubicolous spionids.

Group IV. Second-order opportunistic species (slight to pronounced unbalanced situations). Mainly small sized polychaetes: subsurface deposit-feeders, such as cirratulids.

Group V. First-order opportunistic species (pronounced unbalanced situations). These are deposit-feeders, which proliferate in reduced sediments.

The distribution of these ecological groups, according to their sensitivity to pollution stress, provides a Biotic Index with 5 levels, from 0 to 6.