Waimea Estuary State of Environment Monitoring: Fine-scale Benthic Assessment, April 2006

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Waimea Estuary State of Environment Monitoring: Fine-scale Benthic Assessment, April 2006

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EXECUTIVE SUMMARY

Background

Through a Ministry for the Environment Sustainable Management Fund (SMF) grant, with support from 11 councils throughout New Zealand, Cawthron developed a standardised protocol for the assessment and monitoring of New Zealand estuaries. The initial development of the estuary monitoring protocol (EMP) included baseline surveys of fine-scale benthic characteristics of representative sites in nine estuaries ranging from Northland to Southland. This provided a comparative database that councils use to facilitate interpretation of State of Environment (SOE) and consent-related estuarine monitoring data. The Waimea Estuary was one of the original estuaries studied during the protocol development. During the past five years, a number of additional estuaries have been surveyed using the protocol and some have been (or are scheduled to be) resurveyed in order to monitor any change in condition.

Study aim/objectives

Cawthron Institute was commissioned by the Tasman District Council and the Nelson City Council to undertake the first repeat of the Waimea Estuary fine-scale benthic baseline survey carried out 5-8 March 2001. The present report describes the results of the repeat survey and comments on any obvious changes in estuary condition that may have occurred since the 2001 baseline survey.

Estuary condition

Results of the 2006 benthic monitoring survey indicate that the four sand-dominated study sites remained in a similar condition to that observed during the 2001 baseline survey. Although individual sites showed some indications of mild enrichment, all seemed to be in a relatively healthy condition and all observed changes between 2001 and 2006 may be attributed to natural variation.

Visual and physico-chemical characteristics

Visual characteristics at the four study locations were typical of moderately productive sandflat habitat. Core profiles showed no indications of sediment anoxia and no obvious signs of pollution (*e.g*. sulphide odours, fats, oils, unnatural debris *etc*.) were noted.

Indicators of sediment nutrient and organic enrichment (total nitrogen, total phosphorus, organic content, chlorophyll *a* and total N:P ratios) were within ranges typical for previously assessed New Zealand estuaries.

Sediment concentrations of cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn), were well below ANZECC (2000) ISQG-Low trigger values and within ranges reported for a variety of other unpolluted estuaries. Average nickel (Ni) and, to a lesser extent, chromium (Cr) concentrations were elevated due to erosional input from natural mineral deposits in the upper catchment. Ni levels were

above ANZECC (2000) ISQG-High trigger values and considerably higher than those reported for most other New Zealand estuaries.

Biological characteristics

The composition of macrofauna in the Waimea Estuary, as described by a variety of community descriptors/indices, was consistent with a range of other New Zealand estuaries that have been similarly assessed. Macrofaunal species richness at the four representative locations indicated relatively diverse and healthy sandflat habitats containing a broad range of feeding types (*e.g.* grazers, suspension feeders, deposit feeders, scavengers and carnivores).

At one study location (Site D), slight to moderate organic enrichment was indicated by the density of polychaete worms belonging to the Capitellidae family. These results were not consistent with other enrichment indicators (*e.g.* sediment organic content, total N and total P) and are therefore not particularly alarming. However further increases during subsequent surveys (or comparative consent monitoring) could be indicative of pockets of long-term cumulative enrichment.

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1. INTRODUCTION

1.1. Background

Through a Ministry for the Environment Sustainable Management Fund (SMF) grant, with support from 11 councils throughout New Zealand, Cawthron developed a standardised protocol for the assessment and monitoring of New Zealand estuaries (Robertson *et al.* 2002). The initial development of the estuary monitoring protocol (EMP) included baseline surveys of fine-scale benthic characteristics of representative sites in nine estuaries ranging from Northland to Southland. This provided a comparative database that councils use to facilitate interpretation of State of Environment (SOE) and consent-related estuarine monitoring data. The Waimea Estuary was one of the original estuaries studied during the protocol development. During the past five years, a number of additional estuaries have been surveyed using the protocol and some have been (or are scheduled to be) resurveyed in order to monitor any change in condition.

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1.2. Study aim/objectives

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1.3. Study Area

Waimea Inlet is a shallow, bar-built estuary bordering southern Tasman Bay adjacent to the city of Nelson (Figure 1). Covering an area of about 34.6 km^2, it is one of New Zealand's largest estuaries with respect to intertidal seabed habitat. The estuary is predominantly unvegetated (77%) and dominated by a soft mud habitat. The catchment has a total area of 812 km^2 and includes the Dun Mountain "mineral belt" region, which contains rock formations particularly high in metals such as nickel, chromium and copper (Grindley & Watters 1965). The Waimea River, with a mean flow of 20.8 $m^3 s^{-1}$, is the main freshwater inflow to the estuary, however nine small streams (<1 $m^3 s^{-1}$ in total) also contribute with the potential for localised impacts. The water quality of freshwater inflows is reported to be variable (Gillespie *et al*. 2001).

Waimea Inlet is of significant regional, national and international value. Due to its large size and complex heterogeneous physical and biological structure, it has been classed as a wetland of national importance by the Department of Conservation (Robertson *et al*. 2002) and has also been ranked as an estuary of international importance for migratory birds (Schuckard 2002).

Recreational and aesthetic values of the estuary are numerous and it is also used for wastewater discharge. For a more detailed description of Waimea Estuary and the surrounding regions see Davidson & Moffat (1990) and Robertson *et al.* (2002).

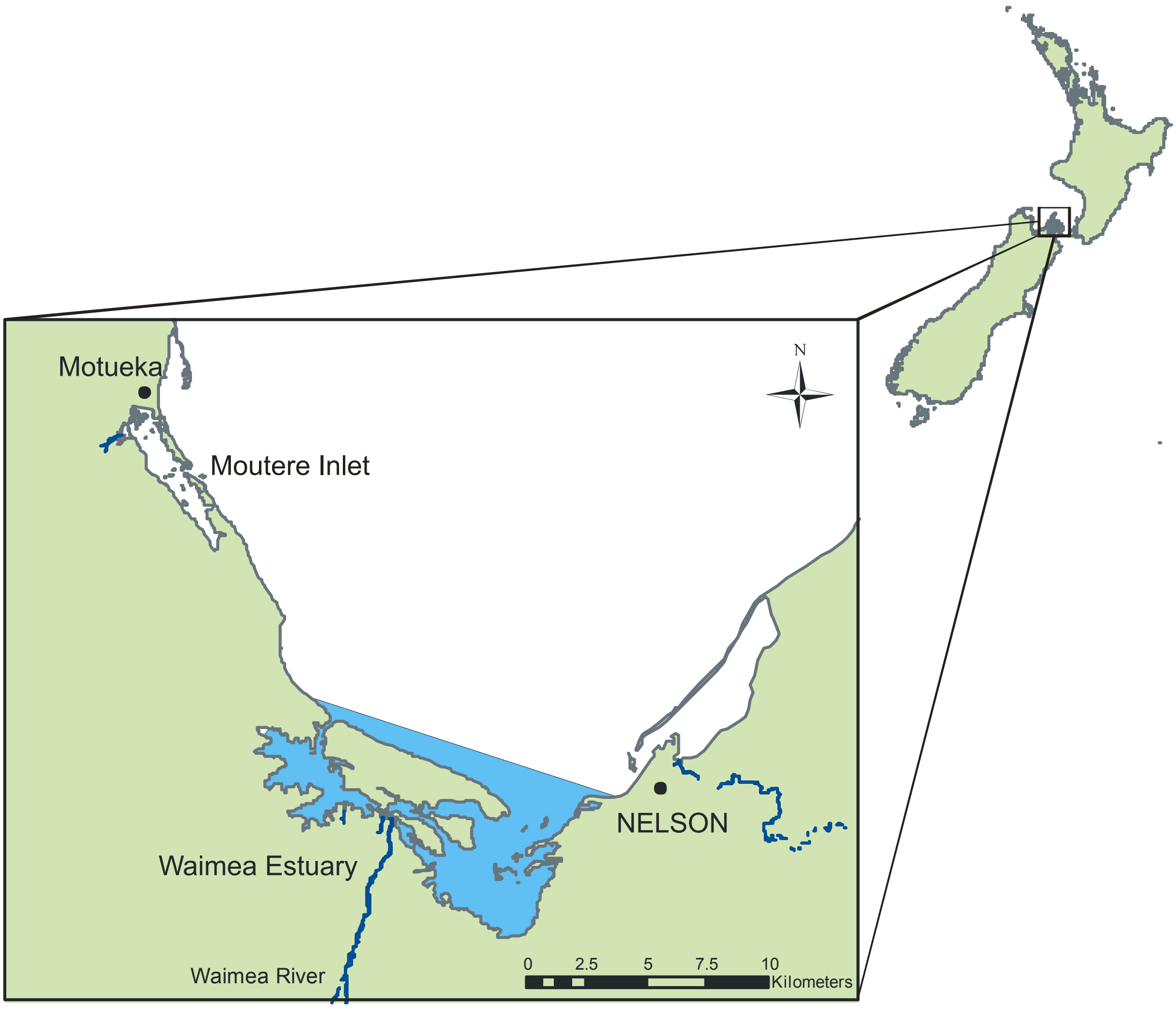


Figure 1. Waimea Estuary and surrounding area.

2. METHODS

2.1. Sampling procedures

Fine-scale sampling in Waimea Inlet followed the EMP procedures described by Robertson *et al*. (2002). The four study locations previously surveyed (Figure 2, Table 1) were revisited (±10 m) for the present survey using a hand held Global Positioning System. The four site locations were originally selected to be representative of unvegetated mud/sand habitat within the lower intertidal reaches of contrasting regions of the estuary. Sampling was carried out between 14 and 27 of April 2006.

Table 1. Coordinates (New Zealand Map Grid) of the four corners of Waimea Inlet sampling locations.

LOCATION	NZMG-E (m)	NZMG-N (m)
A	2525273.1	5987710.5
	2525301.4	5987719.0
	2525306.9	5987659.7
	2525278.3	5987650.2
B	2517342.2	5993604.6
	2517368.9	5993592.1
	2517340.5	5993539.5
	2517313.3	5993552.0
C	2524854.3	5989674.9
	2524912.6	5989686.2
	2524910.0	5989715.9
	2524851.4	5989704.3
D	2518888.2	5991761.7
	2518917.3	5991753.8
	2518928.5	5991810.8
	2518899.1	5991819.5

At each site location, a 30 x 40 m area containing twelve 10 m^2 grids was marked out. Sediment samples for physical and chemical analyses were scraped from the top 25 mm within each of 10 randomly selected grid squares (*i.e*. 10 replicates per site), returned to the laboratory and stored at either +4ºC or -20ºC until analysed. A 0.25 m^2 quadrat was placed randomly within each grid square and photographed. Any visible epibiota (animals or macroalgae) on the sediment surface within the quadrat were identified and counted. Samples for chlorophyll *a* (chl *a*) analyses were collected from five grid squares at each site in order to determine the potential for development of nuisance microalgal blooms. The top 5 mm of sediment was sliced from four 15 mm diameter syringe barrel cores. These were mixed to provide a single composite for each grid square. Animals buried within the sediment matrix (infauna) were collected by inserting a 131 mm diameter core to a depth of at least 150 mm into the sediment. The core contents were gently washed through a 0.5 mm mesh sieve attached to one end of the core and the residual was preserved with 50% ethanol (in seawater and 1% glyoxal) for later sorting, identification and counting. Additional sediment cores were collected with 62 mm diameter Perspex tubes. These were extruded onto a white viewing tray and photographed. Sediment colour profiles were described and the depth of any visible redox discontinuity layer (RDL) was recorded. Any obvious signs of pollution (*e.g*. sulphide odours, fats, oils, unnatural debris *etc*.) were noted.

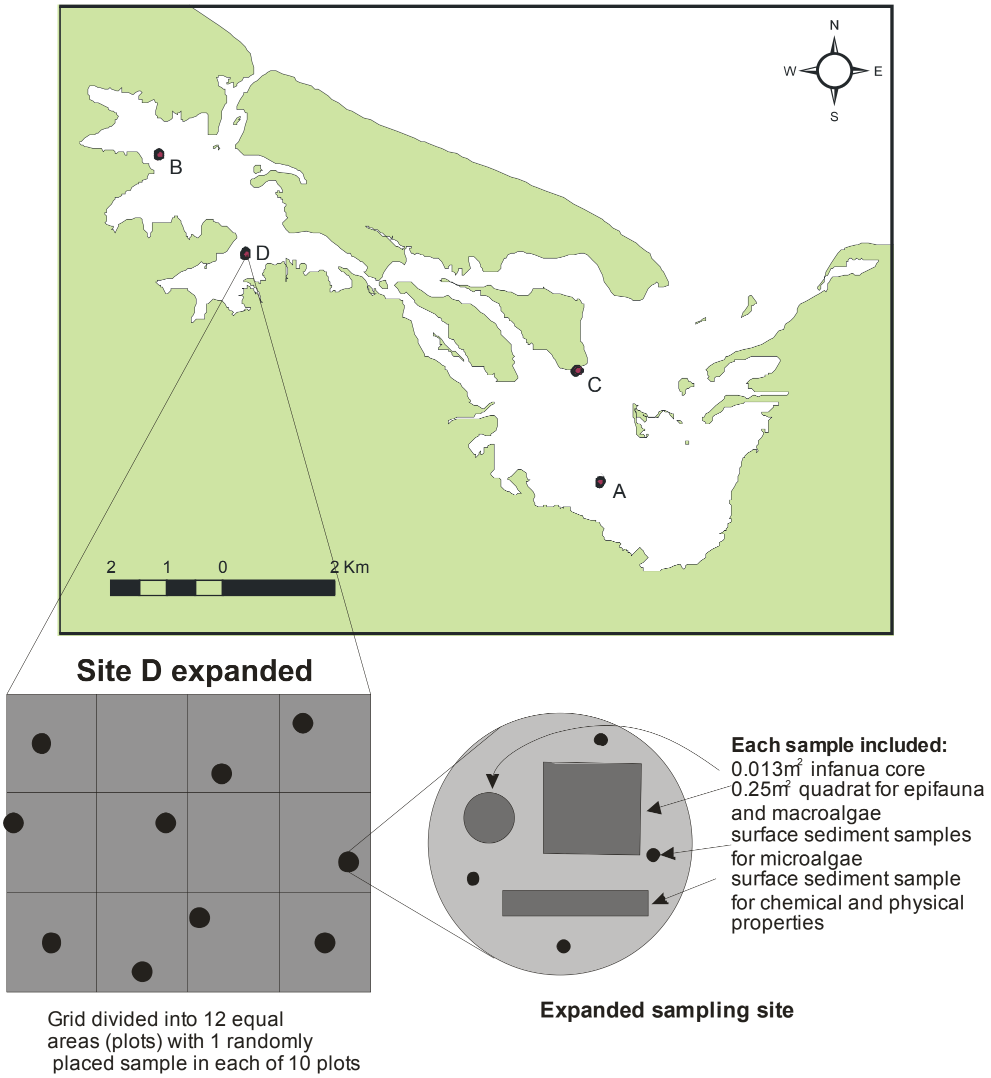


Figure 2. Map of Waimea Estuary showing locations of the study sites and the sampling strategy**.**

2.2. Analytical methods

Sediments were analysed for a range of properties to reassess the environmental condition of the estuary. Table 2 summarises the parameters assessed and the analytical methods and detection limits used.

Table 2. Analytical methods and detection limits for sediment indicators.

Parameter	Method	Detection Limit
Metals	Perchloric/nitric acid digestion and flame atomic absoption spectrometry	
Cadmium	ASTM 3974 Dig A	0.1 mgkg $^{-1}$
Chromium	ASTM 3974 Dig A	1.0 mgkg $^{-1}$
Copper	ASTM 3974 Dig A	0.5 mgkg $^{-1}$
Nickel	ASTM 3974 Dig A	2.0 mgkg $^{-1}$
Lead	ASTM 3974 Dig A	0.5 mgkg $^{-1}$
Zinc	ASTM 3974 Dig A	0.2 mgkg $^{-1}$
Ash Free Dry Weight	Dry sediment weight loss after combustion at 550 ^{o}C (APHA 1999, 20th Edn, modified 2540D + E).	-
Chlorophyll *a*	Limnology & Oceanography 1967 No 12	
Grain Size	Wet sieving and calculation of dry weight percentage fractions	-
Total Nitrogen	APHA 20th Edn 4500N C	0.1 gm $^{-3}$
Total Phosphorus	ICP-MS Aqua Regia Digest	20 mgkg $^{-1}$
Macroinvertebrates	Microscope enumeration of species retained on a 0.5mm sieve	n/a

When results were below or equal to the analytical detection limit, site and estuary averages were calculated using the detection limit, providing a conservative measure of potential sediment contamination. In this case a "<" symbol was placed in front of the average to indicate that the actual value will be less than the average value calculated. Standard deviations were only calculated where all data were above the analytical detection limit.

The ANZECC (2000) Sediment Quality Guidelines were used (where appropriate) to assess and interpret the results of the sediment sampling. These guidelines present Interim Sediment Quality Guideline-Low (ISQG-Low) and -High (ISQG-High) as two threshold levels under which biological effects are predicted (ANZECC 2000). The lower threshold indicates a possible biological effect while the upper threshold (ISQG-High) indicates a probable biological effect. These trigger values are essentially conservative criteria (*e.g.* for water or sediment quality) that, if complied with, will ensure that specified environmental values are protected. Note, however, that the converse is not necessarily true (*i.e.* exceeding of trigger values does not necessarily suggest environmental damage) hence the intent of these values is to act as a trigger for more intensive assessment if they are not met.

2.3. Benthic biological community structure

Epifauna data were used only as a general descriptor of habitat type while the more comprehensive infauna data was evaluated according to a variety of statistical procedures.

The number of infauna taxa, and their density, evenness and diversity were calculated for each site as described in Table 3. The maximum value for the diversity index (H) is dependent on the number of categories or species sampled for a given data set. Values typically range between 0 (indicating low community complexity) and 4 (indicating high complexity). The evenness value (E) ranges from 0 (highly irregular distribution) to 1 (regular distribution).

Table 3. Descriptors of macro-invertebrate community characteristics.

Descriptor	Equation	Description
No. species (S)	Count (taxa)	Total number of species in a sample.
No. individuals (N)	Sum (n)	Total number of individual organisms in a sample.
Evenness (J')	$J' = H'/Log_e(S)$	Pielou's evenness. A measure of equitability, or how evenly the individuals are distributed among the different species. Values can theoretically range from 0.00 to 1.00, where a high value indicates and even distribution and a low value indicates an uneven distribution or dominance by a few taxa.
Diversity (H' log_e)	$H' = -SUM(Pi*log_e(Pi))$	Shannon-Wiener diversity index (log_e base). A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of species and the relative distribution of individual organisms among the species. The index ranges from 0 for communities containing a single species to high values for communities containing many species and each with a small number of individuals.

The infauna assemblages recorded were then contrasted using non-metric multidimensional scaling or MDS (Kruskal & Wish. 1978) and ordination and cluster diagrams based on Bray-Curtis similarities (Clarke & Warwick. 1994)). Abundance data were fourth-root transformed to de-emphasise the influence of the dominant species (by abundance).

A two-factor crossed analysis of similarity (ANOSIM) was performed to identify significant differences in community composition between sites and between years.

The major taxa contributing to the similarities at each site were identified using analysis of similarities (SIMPER; Clarke & Warwick 1994). All multivariate analyses were performed with PRIMER v6 software.

3. RESULTS

3.1. General site characteristics

Representative photographs of replicate quadrats and core profiles from each site are shown in Appendix 3, while the complete set may be found on the accompanying CD. Core profiles at all sites were medium-grey throughout with no obvious redox discontinuity layers or dark patches indicative of oxygen depletion. Although surface sediments generally showed patchy, slightly olive-green colouration due to a diatom film, there were no signs of significant microalgal mat development. Visual characteristics overall were typical of relatively unenriched sandflat habitat. No obvious signs of pollution (e.g. sulphide odours, fats, oils, unnatural debris etc.) were noted.

3.2. Physico-chemical characteristics

Average grain size distributions and chemical characteristics of sediments from the four Waimea Inlet monitoring sites are shown in Table 4 along with overall estuary averages. The complete data set is included in Appendix 1.

Table 4. Average sediment physical and chemical properties of Waimea Estuary sites.

Property		Site A	Site B	Site C	Site D	Estuary Average	SD	ISQG[a] Low	ISQG[a] High
Mud	(<63µm)	33.8	19.9	21.6	33.39	27.2	7.1	-	-
Sands	(<2 mm & >63µm)	65.2	80.0	77.61	64.39	71.8	7.7	-	-
Gravel	(>2 mm)	1.1	0.1	0.76	2.22	1.1	1.4	-	-
AFDW	% w/w	1.9	1.4	2.06	2.19	1.9	0.5	-	-
TN	mg/kg	468.0	353.0	550	487	464.5	90.2	-	-
TP	mg/kg	457.8	516.4	375.6	508.7	464.6	59.8	-	-
TN/TP	molar ratio	2.2	1.5	3.2	2.1	2.2		-	-
Chl a	mg/kg	2.3	2.0	5.0	1.8	2.7	1.4	-	-
Cd	mg/kg	<0.01	<0.01	<0.01	<0.01	<0.1	-	1.5	10
Cr	mg/kg	48.6	32.0	42.3	55.1	44.5	9.3	80	370
Cu	mg/kg	7.9	6.7	7.83	9.42	8.0	1.1	65	270
Ni	mg/kg	64.8	69.4	60.6	89.2	71.0	11.7	21	52
Pb	mg/kg	6.4	5.1	5.88	6.35	5.9	0.6	50	220
Zn	mg/kg	34.7	27.9	28.2	34.5	31.3	3.7	200	410

[a] - ANZECC (2000) Interim Sediment Quality Guidelines

The monitoring sites were, on average, dominated by sand (72%) and mud (28%) with very little gravel (1%). This is typical of many New Zealand estuaries and was expected as the four sites were chosen to be representative of the dominant substrate type (sand) in the estuary.

Indicators of sediment nutrient and organic enrichment (total nitrogen, total phosphorus, organic content, chlorophyll *a* and total N:P ratios) were within ranges typical for New Zealand estuaries. Table 5 provides a comparison of these characteristics along an enrichment continuum extending from the relatively natural Delaware Inlet (largely native and exotic forestry catchment), through moderately enriched sites affected by a variety of nutrient sources and a highly enriched site affected by a freezing works waste discharge.

Table 5. Comparison of average sediment mud content and organic indicators of enrichment of Waimea Estuary (2006) with other New Zealand estuarine sites. Sites with mud content 10-30 are shaded.

	Mud %	TN mg kg^{-1}	TP mg kg^{-1}	TN/TP molar ratio	AFDW %
Waimea Estuary (2006)	**27.2**	**465**	**465**	2.1	**1.9**
Other NZ estuaries					
Moutere (2 sites, 2006)[a]	11.6	339-	530	1.4	1.6
Waimea (4 sites)[b]	25	506	433	2.6	2.0
Otamatea Arm of Kaipara (3 sites)[b]	56	1630	526	6.8	7
Ohiwa (4 sites)[b]	20	650	278	5.2	3
Ruataniwha (3 sites)[b]	9	263	458	1.3	1
Havelock (2 sites)[c]	19	421	330	2.8	2
Avon-Heathcote (3 sites)[b]	5	301	327	2.0	1
Kaikorai (1 site)	27	1650	799	4.6	5
New River (2001) (4 sites)[b]	2	<250	268	<2.1	1
Tauranga Hbr (10 m from outfall)[c]	15	650[h]	275	5.2	
Tauranga Hbr (1 km from outfall)[c]	15	460[h]	175	5.9	
Delaware (4 sites)[d]	7	303	540	1.2	2
Nelson Haven (6 sites)[e]	23	347	403	3.9	2
Moutere (2 sites, 1991)[f]	18	567	424	3.0	2.5
Waimea (enriched site)[g]	83	4340	1063	9.0	9

a Slightly modified estuary near Motueka (Gillespie & Clark 2006)
b EMP estuary sites (Robertson *et al.* 2002)
c Subtidal on open coast (Roper 1990)
d Largely undisturbed estuary near Nelson (Gillespie & MacKenzie 1990)
e Slightly modified estuary near Nelson; affected by urban stormwater runoff, roading, marina development (Gillespie & MacKenzie 1990)
f Slightly enriched estuary near Motueka (Gillespie *et al.* 1995)
g Highly enriched site affected by a freezing works discharge (Gillespie & MacKenzie 1990)
h Total Kjeldahl Nitrogen does not include nitrate/nitrite

In terms of potentially toxic contaminants, all sites showed low sediment levels of cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn), with values well below ANZECC (2000) ISQG-Low trigger values (Table 6). These metal concentrations were within ranges reported for a variety of other New Zealand estuaries, and much lower than values reported for some overseas estuaries (Table 6). Average chromium (Cr) concentrations, although below guideline trigger values, were slightly elevated due to erosional input from natural mineral deposits in the upper catchment (Grindley&Watters 1965). Nickel (Ni) levels were above ANZECC (2000) ISQG-High trigger values. Nickel levels were much higher than most other New Zealand estuaries but comparable to those of the nearby Moutere Inlet (Figure 1), suggesting a shared catchment source. A previous study in Waimea Estuary (Robertson *et al.* 2002) found nickel levels similar to those in the present study. The high nickel concentrations were attributed to natural mineral deposits within the catchment.

Table 6. Comparison of average concentrations of trace metals in sediments from the Waimea sites (2006) with the eight estuaries examined in the EMP study (Robertson *et al*. 2002) and a selection of New Zealand and overseas estuaries that have been contaminated to varying degrees.

		Cd mg kg-1	Cr mg kg-1	Cu mg kg-1	Pb mg kg-1	Ni mg kg-1	Zn mg kg-1
	ANZECC ISQG-Low	*1.5*	*80*	*65*	*50*	*21*	*200*
	ANZECC ISQG-High	*10*	*370*	*270*	*220*	*52*	*410*
Present survey 2006	**Waimea**	**<0.1**	**44.5**	**8**	**5.9**	**71.0**	**31.3**
EMP baseline surveys (2001)	Waimea	0.3	67.7	9.6	7.4	72.5	41.8
	Otamatea Arm	0.4	20.5	13.8	11.4	9.4	54.5
	Ohiwa	0.1	7.4	4	3.4	3.9	27.7
	Ruataniwha	0.1	24	7.1	4.7	13.7	37.5
	Havelock	0.3	48.8	10.7	5.6	26.5	43
	Avon-Heathcote	0.1	15.6	3.2	6.3	6.6	38.3
	Kaikorai	0.1	48.4	16.8	45.3	15.6	184.2
	New River	0.1	11.1	3.8	0.7	5	17.1
Other NZ sites	Tamaki A (E1) [a]		14.5	27.8	132.1	56.9	136.1
	Tamaki B (E2) [a]		20.6	26.1	72.9	6.6	167
	Tamaki C (E3) [a]		17.3	29.4	69.7	9.3	173
	Tamaki D (E4) [a]		35.9	38.5	145.2	12.8	233
	Manukau (rural catch) [b]	0.03		20	9	15	114
	Manukau (industrial catch) [b]	0.25		90	58	14	285
	Otago (mid-upper harbour) [c]	0.26	21	17	19	9.7	110
	Lampton Harbour, Wellington [d]		91	68	183	21	249
	Poriora Harbour, Wellington [e]		20	48	93	20	259
	Moutere Inlet (2 sites) [f]	<0.01	31.7	6.1	4.2	67.3	25.9
Overseas sites	Delaware Bay, USA [g]	0.24	27.8	8.3	15		49.7
	Lower Chesapeake Bay, USA [g]	0.38	58.5	11.3	15.7		66.2
	San Diego Harbour, USA [g]	0.99	178	218.7	51		327.7
	Salem Harbour, USA [g]	5.87	2296.7	95.1	186.3		238
	Rio Tinto Estuary, Spain [h]	4.1		1400	1600		3100
	Restronguet Estuary, UK [h]	12	1060	4500	1620		3000
	Sorfjord, Norway [h]	850		12000	30500		118000
	Nervión Estuary, Spain [i]	0.2-15	50-300	50-350	50-400	20-100	200-2000

Sources: a. Thompson (1987), b. Roper *et al.* (1988), c. ORC (1998), d. Stoffers *et al.* (1986), e. Glasby *et al.* (1990), f. Gillespie & Clark (2006), g. Kennish (1997), h. quoted by Robertson (1995) from other sources, i. Belzunce *et al.* (2001).

3.3. Benthic biological characteristics

A complete list of infauna (animals living within the sediment matrix) and epifauna (animals living on the sediment surface) may be found in Appendix 2.

The composition of infauna in the Waimea Estuary (Table 7) was fairly typical of many New Zealand estuaries as it was numerically dominated by polychaete worms and bivalves. Gastropods (snails), decapods (crabs) amphipods and anthozoa (anemones) were also common. These taxa included a broad range of feeding types (*e.g.* grazers, suspension feeders, deposit feeders, scavengers and carnivores) indicating a relatively healthy estuarine condition.

Macrofaunal species richness was moderately high with a total of 45 taxa sampled overall in the estuary. This represents a relatively diverse sandflat habitat compared to those studied by Robertson *et al.* (2002) which were found to range from 13 (Kaikorai) to 53 (Ohiwa) species in total. The average across all eight estuaries studied by Robertson *et al.* (2002) was 37 species.

The density of polychaete worms belonging to the Capitellidae family, often referred to as capitellids, has commonly been used as an indicator of biotic 'health' or state of enrichment of a given seabed habitat (ANZECC 2000). These opportunistic species (*e.g. Capitella capitata*) rapidly respond to organic enrichment often reaching very high densities. The relationship between capitellid densities and anthropogenic enrichment, however, is tenuous at best, and the guidelines are therefore generally used in combination with other indicators of enrichment, or to evaluate known contaminant sources. When the density of capitellids reaches the suggested trigger level of 1000 m^{-2}, further investigation may be warranted. Capitellid densities at Sites A, B and C were all well below the trigger level, however densities of *Heteromastus filiformis* approaching 1800 m^{-2} were observed at Site D. *H. filiformis*, although often associated with productive estuarine habitats like Waimea Inlet, is less indicative of anthropogenic enrichment than *C. capitata*. These results are therefore not particularly alarming but further increases during subsequent surveys (or comparative consent monitoring surveys) could be of concern.

Table 7. Summary of the top 15 infaunal taxa, in order of abundance, from the four sampling sites in Waimea Estuary. Estuary and individual site data are presented as average species abundance per core ($0.0133m^2$).

Group	Taxon	Common Name	Feeding Type	Estuary	SiteA	SiteB	SiteC	SiteD
Polychaeta: Spionidae	*Prionospio sp.*		Surface deposit feeder	10.2	8.5	0	19	13.1
Polychaeta: Nereididae	*Nicon aestuariensis*	Rag worm	Omnivorous	8.3	14.5	1.1	10.7	6.7
Polychaeta: Capitellidae	*Heteromastus filiformis*		Infaunal deposit feeder	8.0	3	0.1	4.9	23.9
Bivalvia	*Arthritica bifurca*	Small bivalve	Infaunal deposit feeder	7.8	16.2	1.7	11.4	1.7
Bivalvia	*Austrovenus stutchburyi (0-5mm)*	Cockle	Infaunal deposit feeder	5.6	2.1	4.3	12.3	3.6
Bivalvia	*Austrovenus stutchburyi (11-20mm)*	Cockle	Infaunal deposit feeder	2.7	4.1	0.2	3.5	3.1
Bivalvia	*Austrovenus stutchburyi (21-30mm)*	Cockle	Infaunal deposit feeder	1.9	0.9	0.3	4.7	1.6
Amphipoda	Amphipoda b	Amphipods	Epifaunal scavenger	1.3	0.9	0.4	1.2	2.7
Bivalvia	*Macomona liliana*	Wedge shell, Hanikura	Infaunal suspension feeder	1.1	0.6	0.4	2.1	1.3
Decapoda	*Macrophthalmus hirtipes*	Stalk-eyed Mud Crab	Deposit feeder & scavenger	1.0	1.3	0	1.4	1.4
Gastropoda	*Cominella glandiformis*	Mud Flat Whelk	Carnivore & scavenger	0.8	1.3	0.3	0.6	1
Anthozoa	*Anthopleura aureoradiata*	Mud flat anemone	Filter feeder	0.7	0.7	0	0.5	1.6
Polychaeta: Spionidae	*Scolecolepides benhami*		Surface deposit feeder	0.6	0.8	0.9	0.3	0.2
Gastropoda	*Zeacumantus lutulentus*	Spireshell	Microalgal & detrital grazer	0.4	0	0.3	1	0.1
Bivalvia	*Nucula hartvigiana*	Nut Shell	Infaunal deposit feeder	0.4	0	0.1	1	0.3

A total of seven epifaunal taxa were present amongst the four sites (Table 8). The surface-living animals were dominated by cockles and a variety of gastropods (snails) with anemones also present but only in low numbers. This reflects a pattern commonly found in sand habitat of other New Zealand estuaries (Robertson *et al*. 2002).

Table 8. Summary of epifaunal species, in order of abundance, sampled in Waimea Estuary. Data are presented as average abundance per quadrat (0.25m^2).

Group	Taxon	Common Name	Feeding Type	Estuary	Site A	Site B	Site C	Site D
Bivalvia	*Austrovenus stutchburyi*	Cockle	Infaunal deposit feeder	6.93	4	0.7	6.4	16.6
Gastropoda	*Zeacumantus lutulentus*	Spire shell	Microalgal & detrital grazer	1.75	0.1	1.8	3	2.1
Gastropoda	*Diloma surostrata*	Mudflat topshell	Microalgal & detrital grazer	0.65	0.2	0.1	0	2.3
Gastropoda	*Micrelenchus huttoni*	Topshell	Microalgal & detrital grazer	0.22	0	0	0.9	0
Gastropoda	*Cominella glandiformis*	Mudflat whelk	Microalgal & detrital grazer	0.15	0.1	0	0.2	0.3
Anthozoa	*Anthopleura aureoradiata*	Mudflat anemone	Filter feeder	0.08	0.2	0.1	0	0
Gastropoda	*Amphibola crenata*		Microalgal & detrital grazer	0.03	0	0	0	0.1
		Total		9.8	4.6	2.7	10.5	21.4

4. DISCUSSION

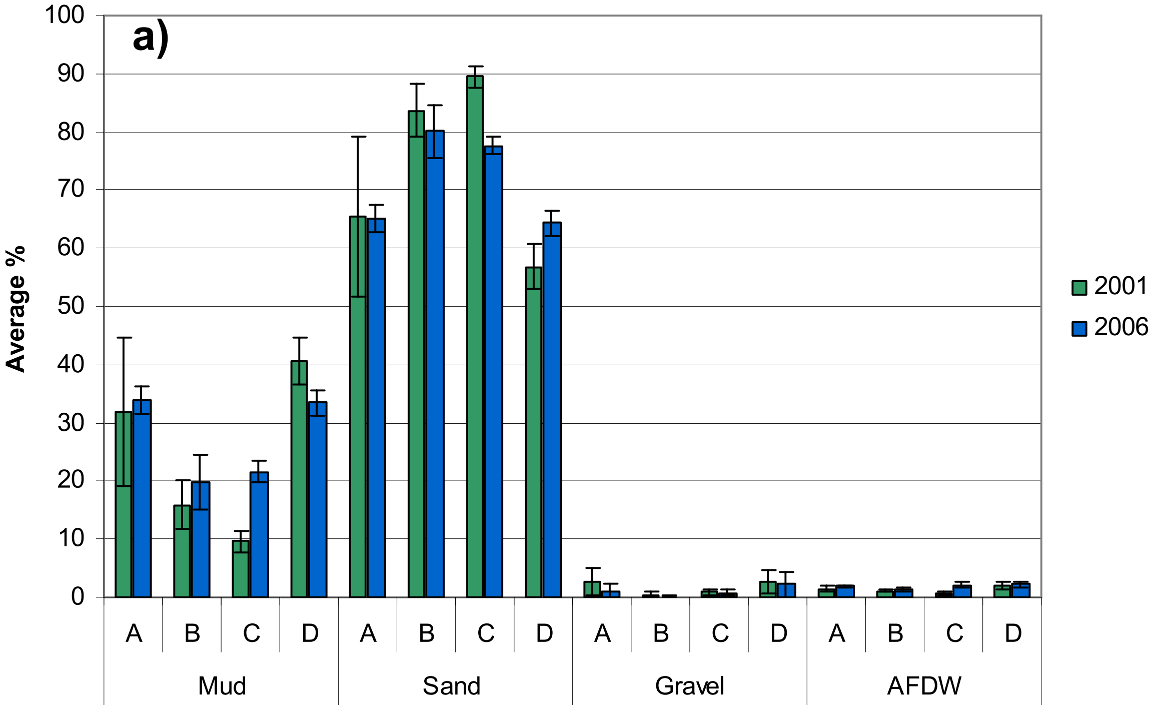
4.1. Comparison of 2001 and 2006 survey results

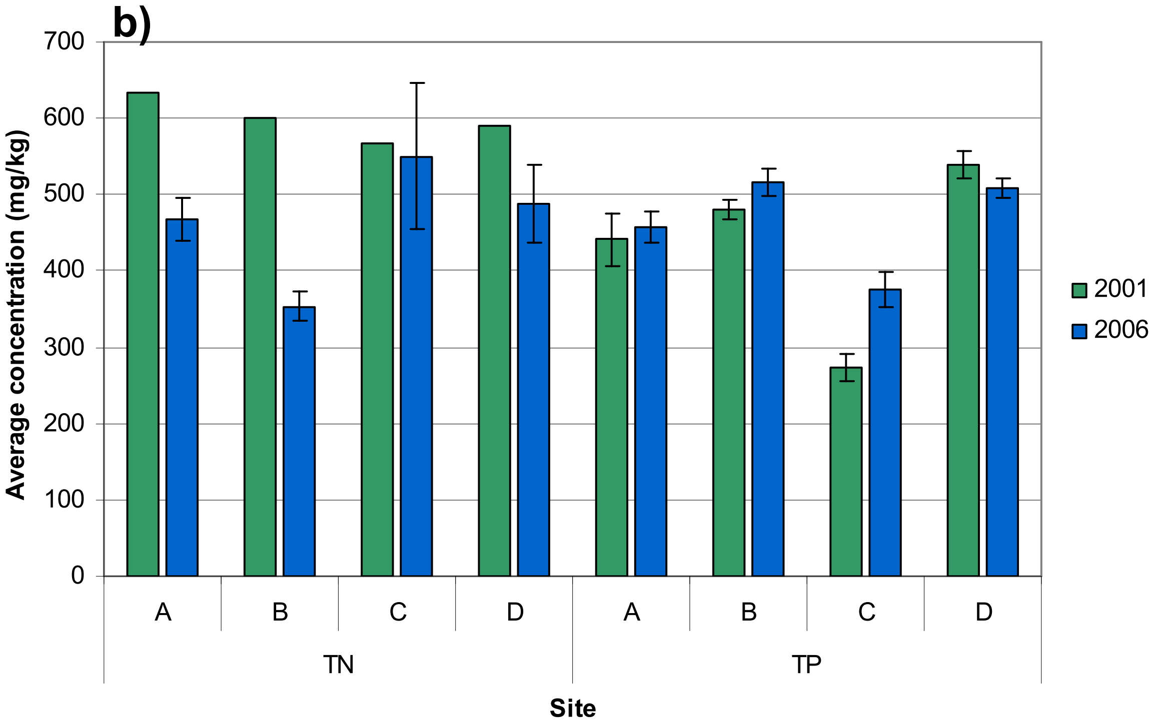
4.1.1. Visual and physico-chemical characteristics

Visual characteristics, as evidenced by comparison of quadrat and core profile photographs (Appendix 3) and other field observations with those from the 2001 baseline survey (Robertson *et al.* 2002) showed no obvious indication of change over the 5-year monitoring interval.

Sediment particle size distributions and organic contents at the four sites (Figure 3a) did not change dramatically, however a noticeable increase in mud content was noted at Site C. Total nutrient concentrations of the sediments (Figure 3b) were also similar in 2006 and 2001, although slight decreases in TN concentrations were seen at all sites. The minor changes observed were probably within the range of expected normal fluctuation. The results suggest that no significant change in the general state of enrichment of the estuary had occurred.

No noticeable increases in sediment metals concentrations were observed during the monitoring interval (Figure 3c), however the slight reduction in chromium was probably due to variation in natural catchment input from the Dun Mountain mineral belt region.


a)
Average %
100
90
80
70
60
50
40
30
20
10
0
A
B
C
D
Mud
Sand
Gravel
AFDW
2001
2006


b)
Average concentration (mg/kg)
700
600
500
400
300
200
100
0
A
B
C
D
TN
TP
Site
2001
2006

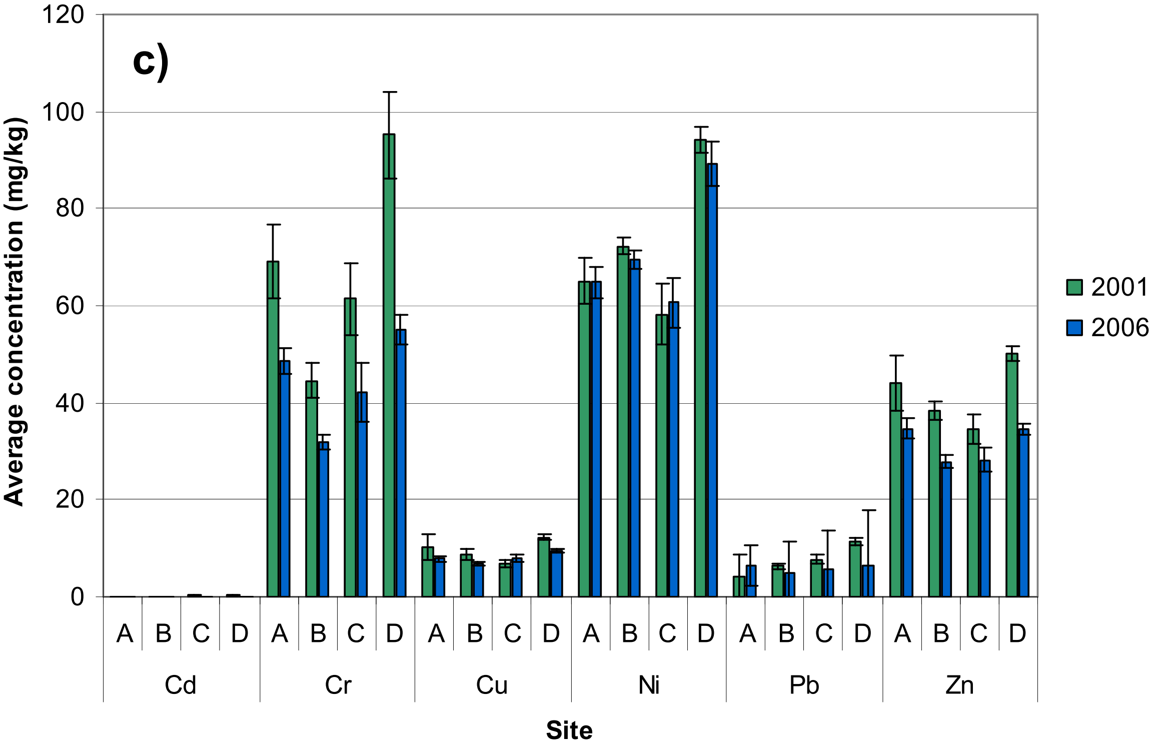


Figure 3. Comparison of sediment physical and chemical indicators of estuarine condition at four representative Waimea Estuary sites in 2006 and 2001; a) particle size and organic matter, b) total nitrogen and total phosphorus, c) trace metals.

4.1.2. Benthic biological community structure

Diversity Indices

There were no major changes in infauna diversity indices at individual sites between 2001 and 2006 (Figure 4), however species richness and density were slightly lower at Site B in 2006 compared to the 2001 record. The community composition was uniform between sites and years, indicating that the no single species was dominant (Evenness range ~0.7-0.9). The Shannon-Weiner diversity scores were moderate to high (1.3-2.4), indicating a uniform spread of individuals amongst the taxa.

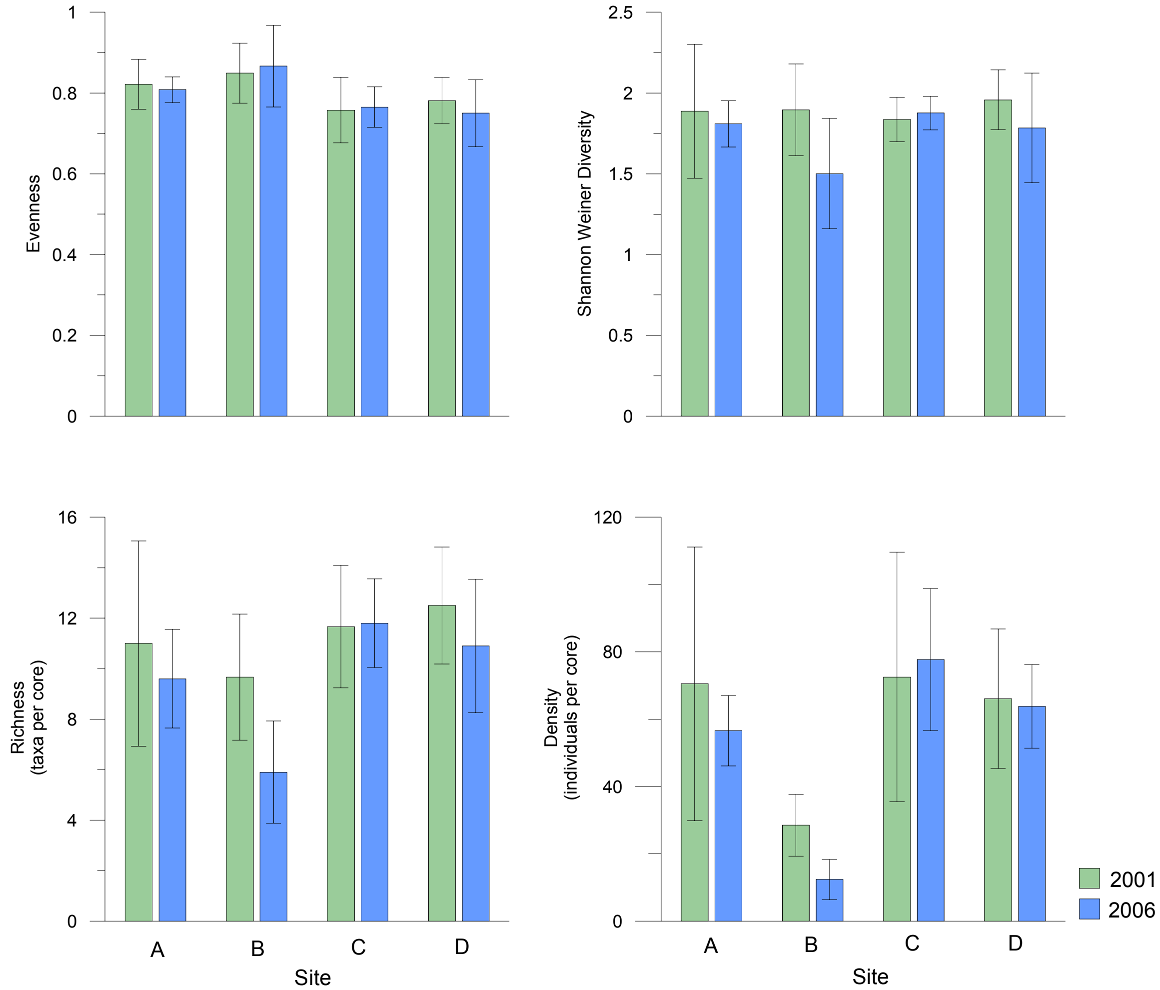


Figure 4. Average infauna species density, species richness, diversity and evenness at each site between 2001 and 2006. Data are mean values ± standard deviation.

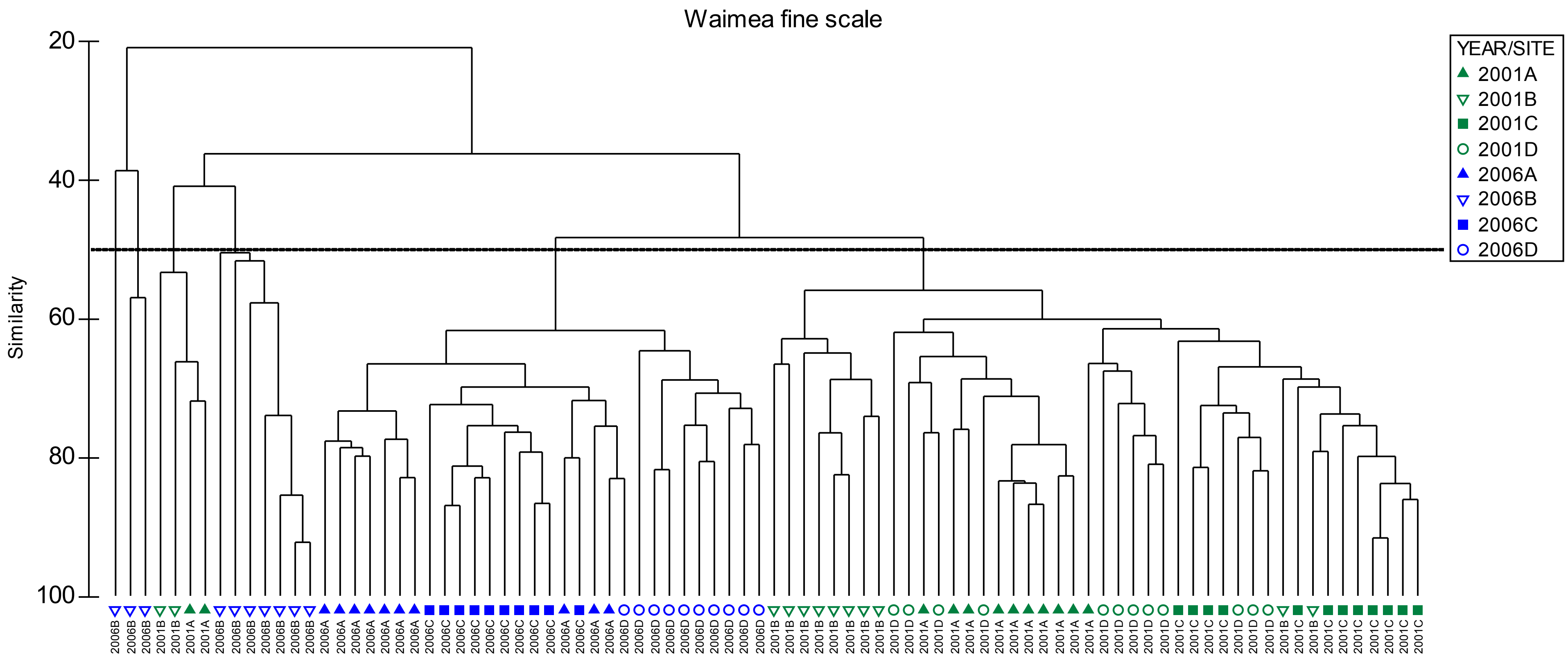
Multi-dimensional scaling (MDS) and Analysis of similarity (ANOSIM)

Bray-Curtis cluster analysis and multi-dimensional scaling, based on benthic infauna communities (Figure 5), indicate a distinct separation of assemblages between 2001 and 2006 at approximately the 50% level of similarity, with several exceptions. Several replicate samples from Site B in 2006, which showed significant separation from the remainder sites recorded in 2006 at ~20% level of similarity, were characterised by the lower abundance of bivalves (*Austrovenus stutchburyi*) and the absence of any polychaete taxa. Several replicate samples from Sites A and B also showed significant separation at ~40% level of similarity, with the assemblage characterised by low species richness, and low abundances of bivalves (A. stutchburyi, Arthritica bifurca), nereid polychaetes and the absence or low abundance of other key polychaete taxa (*e.g. H. filiformis*, *Prionospio* sp.).

The dominant species contributing to the infauna composition at Waimea sample sites were generally similar in 2001 and 2006; however some species either appeared or disappeared from the list (Table 9). Such changes are an indication of the natural fluctuations that occur within existing populations and do not necessarily indicate a change in estuary condition.

As shown by a two-way analysis of similarity (ANOSIM, Table 10) there was a significant shift in community assemblages between 2001 and 2006 (R=0.86, P=0.001), and also significant differences between sites (R=0.50, P=0.001). Pairwise comparisons between sites showed the greatest differences between Sites B and D, and the least difference between Sites A and D.

A.


Waimea fine scale
Similarity
20
40
60
80
100
YEAR/SITE
2001A
2001B
2001C
2001D
2006A
2006B
2006C
2006D

B.

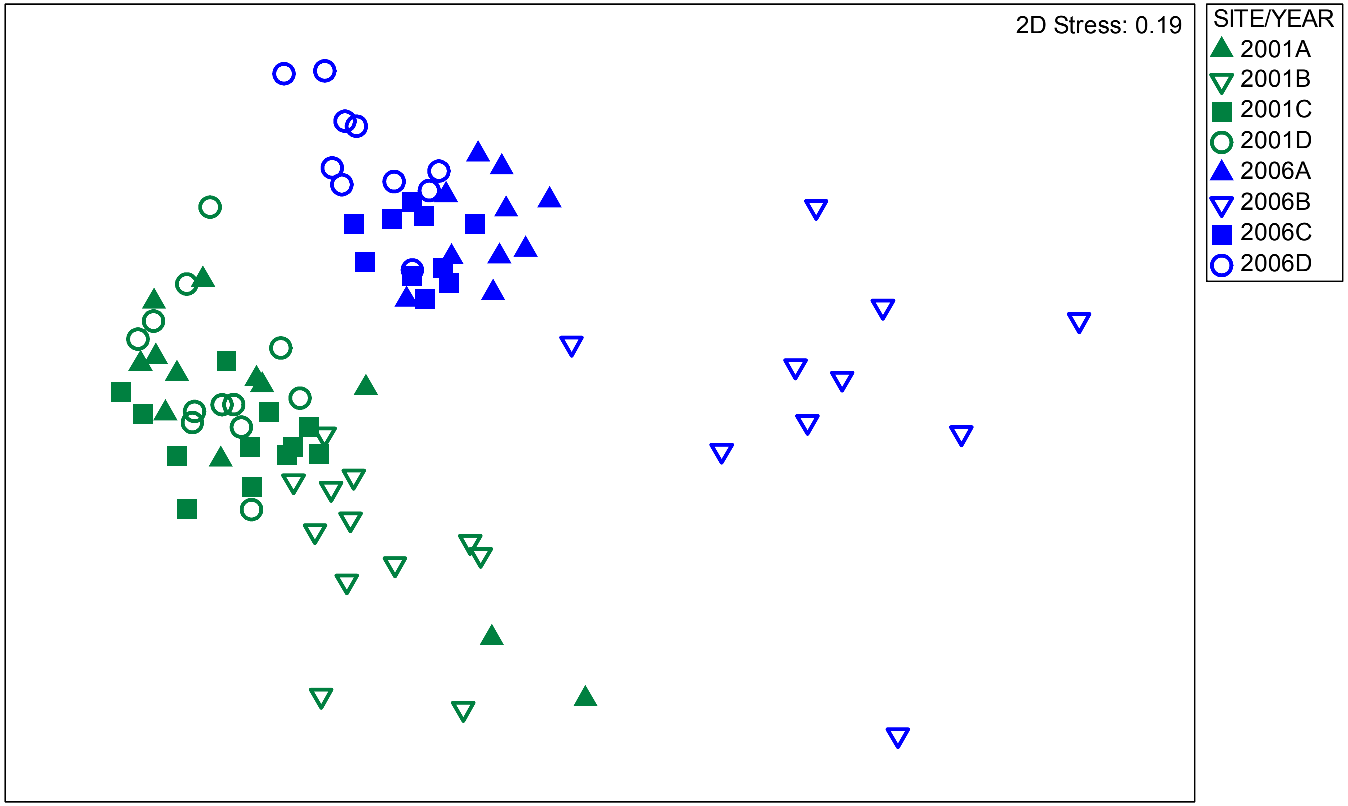


Figure 5. Cluster diagram (A) and multi-dimensional scaling plot (B) of infauna sampled at four sites in Waimea Estuary (2001 and 2006). Count data were fourth-root transformed.

For all of the sites, except Site B-2006, the presence of capitellid and spionid worms were recorded at levels that contributed to over 5% of the similarity. These results suggest that the sites were moderately productive. This slightly enriched condition is probably due to a combination of natural and/or anthropogenic nutrient sources. Although some changes in polychaete densities occurred between the two survey dates, these were likely due to natural variation rather than variation in enrichment status.

Similarity in species assemblage was highest at Site D in 2001 and highest at Site A in 2006, indicating that these sites had the highest homogeneity in the species assemblages sampled within each site. For Sites A, C and D, similarity in species assemblage increased by ~7-25% from 2001 to 2006, but decreased at Site B by 1.3%. For Sites A, C, and D, the similarity in species assemblages in 2001 ranged from ~49-63%, and in 2006 ranged from ~69-74%.

The main differences that distinguished Site B in 2006 from the other sites were the fewer species that contributed to assemblage similarity, and the presence of the tunnelling mud crab (*Helice crassa*) that contributed ~7% of the similarity.

Co-dominant species recorded in 2001 that were common between sites included several species of polychaete worms (*e.g. Prionospio* sp., *H. filiformis*), and several bivalve species (*e.g. Austrovensus stutchburyi, Arthiritica bifurca*).

The presence of several species that were responsible for the shift in community assemblage composition in 2006 included the nereid polychaete (*Nicon aestuuariensis*), the stalked-eye mud crab (*Macrophthalmus hirtipes*) and several gastropod species (*e.g. Zeacumantus lutulentis, Cominella glandiformis*).

Although the above community characteristics/comparisons do not add significantly to our understanding of habitat condition or health, they do provide a picture of subtle habitat variation that could become meaningful over the longer term.

Table 9. Average abundance and similarity of benthic infauna species within the Waimea Estuary. Includes the taxa contributing over 5% to the total similarity.

Site/Species	Av Abund	Av. Sim	Sim/SD	% Contrib	% Cum
2001 A					
Average similarity: 48.83					
Arthritica bifurca	14.25	12.74	2.06	26.10	26.10
Heteromastus filiformis	12.92	8.56	1.21	17.52	43.62
Austrovenus stutchburyi	5.75	7.44	1.39	15.24	58.86
Potamopyrgus estuarinus	12.92	6.71	0.98	13.75	72.61
Prionospio sp.	8.08	4.46	1.19	9.14	81.75
Nereidae	5.17	4.18	1.49	8.56	90.31
2006 A					
Average similarity: 73.99					
Arthritica bifurca	16.20	24.87	3.94	33.61	33.61
Nicon aestuariensis	14.50	20.29	5.24	27.43	61.04
Austrovenus stutchburyi	7.30	10.86	4.59	14.68	75.72
Prionospio sp.	8.50	10.74	2.40	14.52	90.23
2001 B					
Average similarity: 48.52					
Austrovenus stutchburyi	7.83	16.36	1.85	33.72	33.72
Arthritica bifurca	4.17	7.75	1.02	15.97	49.69
Nereidae	3.08	7.30	1.89	15.05	64.74
Heteromastus filiformis	2.83	4.73	0.98	9.75	74.49
Prionospio sp.	2.75	3.88	0.72	8.00	82.50
2006 B					
Average similarity: 47.2					
Austrovenus stutchburyi	5.20	29.90	3.02	63.36	63.36
Nicon aestuariensis	1.10	5.22	1.16	11.05	74.41
Arthritica bifurca	1.70	5.04	0.78	10.67	85.08
Helice crassa	0.60	3.22	0.67	6.82	91.90

Table 9. Continued

Site/Species	Av Abund	Av. Sim	Sim/SD	% Contrib	% Cum
2001 C					
Average similarity: 57.4					
Austrovenus stutchburyi	25.25	24.34	3.04	42.67	42.67
Prionospio sp.	15.83	11.17	1.71	19.58	62.25
Heteromastus filiformis	9.25	7.99	1.96	14.01	76.26
Arthritica bifurca	3.67	3.04	1.06	5.33	81.59
2006 C					
Average similarity: 69.30					
Austrovenus stutchburyi	21.60	21.52	2.94	31.06	31.06
Prionospio sp.	19.00	17.23	3.23	24.86	55.92
Arthritica bifurca	11.40	10.50	2.19	15.15	71.07
Nicon aestuariensis	10.70	9.87	3.16	14.24	85.31
Heteromastus filiformis	4.90	3.92	1.64	5.66	90.97
2001 D					
Average similarity: 62.67					
Austrovenus stutchburyi	16.42	20.38	4.96	32.52	32.52
Heteromastus filiformis	17.83	18.17	2.47	28.99	61.51
Prionospio sp.	9.50	9.38	2.47	14.97	76.49
Arthritica bifurca	5.50	4.95	1.19	7.90	84.39
2006 D					
Average similarity: 69.30					
Heteromastus filiformis	23.90	28.13	2.94	40.59	40.59
Prionospio sp.	13.10	15.52	3.72	22.40	62.99
Austrovenus stutchburyi	8.80	10.13	1.75	14.61	77.60
Nicon aestuariensis	6.70	8.46	3.44	12.21	89.81

Table 10. Results of analysis of similarity between site and year (based on 10,000 permutations).

	Global R	Significance level
Year (2001, 2006)	0.858	0.01%
Site (A, B, C, D)	0.495	0.01%
Pairwise tests		
A, B	0.516	0.01%
A, C	0.590	0.01%
A, D	0.441	0.01%
B, C	0.536	0.01%
B, D	0.637	0.01%
C, D	0.513	0.01%

5. CONCLUSIONS

5.1. Visual and physico-chemical characteristics

Visual characteristics at the four study locations were typical of moderately productive sandflat habitat. Core profiles showed no indications of sediment anoxia and no obvious signs of pollution (*e.g.* sulphide odours, fats, oils, unnatural debris *etc*.) were noted.

Indicators of sediment nutrient and organic enrichment (total nitrogen, total phosphorus, organic content, chlorophyll *a* and total N:P ratios) were within ranges typical for New Zealand estuaries.

Sediment concentrations of cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn), were well below ANZECC (2000) ISQG-Low trigger values and within ranges reported for a variety of other unpolluted estuaries. Average nickel (Ni) and, to a lesser extent, chromium (Cr) concentrations were elevated due to erosional input from natural mineral deposits in the upper catchment. Nickel (Ni) levels were above ANZECC (2000) ISQG-High trigger values and considerably higher than reported for most other New Zealand estuaries.

5.2. Biological characteristics

The composition of macrofauna in the Waimea Estuary, as described by a variety of community descriptors/indices, was consistent with a range of other New Zealand estuaries that have been similarly assessed. Macrofaunal species richness at the four representative locations indicated relatively diverse and healthy sandflat habitats containing a broad range of feeding types (*e.g.* grazers, suspension feeders, deposit feeders, scavengers and carnivores).

At one study location (Site D), slight to moderate organic enrichment was indicated by the density of polychaete worms belonging to the Capitellidae family. These results were not consistent with other enrichment indicators (*e.g.* sediment organic content, total N and total P) and are therefore not particularly alarming. However further increases during subsequent surveys (or comparative consent monitoring) could be indicative of pockets of long term cumulative enrichment.

5.3. Estuary condition (2006 versus 2001)

Results of the 2006 benthic monitoring survey indicate that the four sand-dominated study sites remained in a similar condition to that observed during the 2001 baseline survey. Although individual sites showed some indications of mild enrichment, all seemed to be in a relatively healthy condition and all observed changes from 2001 to 2006 may be attributed to natural variation.

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8. APPENDICES

Appendix 1. Physical and chemical properties of sediments.

Waimea Estuary A	AFDW % w/w	Chl a ug/kg	Mud (<63µm)	Sands (<2mm & >63µm)	Gravel (>2mm)	Cd mg/kg	Cr mg/kg	Cu mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	TN mg/kg	TP mg/kg
A-01	1.6	2200	36.5	63.4	0.1	<0.1	50	8.5	66	6.8	35	510	489
A-02	1.8	2700	36.1	63.3	0.6	<0.1	50	7.9	66	6.3	34	470	472
A-03	1.7	2700	34	62.4	3.6	<0.1	48	7.5	66	6.4	35	470	464
A-04	1.6	2200	28.9	69.6	1.5	<0.1	48	7.4	63	6.1	34	470	431
A-05	1.9	1900	31.9	66.2	1.9	<0.1	42	6.8	57	5.8	31	420	429
A-06	1.9	2400	31.9	67.7	0.4	<0.1	48	7.5	63	6	33	450	438
A-07	1.9	2200	33.1	66.9	<0.1	<0.1	51	8.4	67	6.4	35	440	484
A-08	2.1	2800	35.2	64.1	0.7	<0.1	48	7.8	64	6.5	35	460	460
A-09	2.1	1800	35.7	63.5	0.8	<0.1	50	8.7	68	6.7	38	500	460
A-10	2	2500	34.9	64.6	0.6	<0.1	51	8.2	68	6.7	37	490	451
Average	1.9	2340.0	33.8	65.2	1.1	<0.01	48.6	7.9	64.8	6.4	34.7	468.0	457.8
SD	0.2	340.6	2.4	2.3	1.1	0.0	2.6	0.6	3.3	0.3	1.9	27.4	20.8
Min	1.6	1800	28.9	62.4	0.1	-	42	6.8	57	5.8	31	420	429
Max	2.1	2800	36.5	69.6	3.6	<0.01	51	8.7	68	6.8	38	510	489

Waimea Estuary B	AFDW % w/w	Chl a ug/kg	Mud (<63µm)	Sands (<2mm & >63µm)	Gravel (>2mm)	Cd mg/kg	Cr mg/kg	Cu mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	TN mg/kg	TP mg/kg
B-01	1.6	1800	19.6	80.2	0.3	<0.1	30	6.6	67	4.9	29	360	524
B-02	1.5	1800	20.1	79.8	0.1	<0.1	33	6.6	73	4.8	29	320	505
B-03	0.94	2300	15.1	84.8	0.1	<0.1	34	7.7	71	5.5	30	340	523
B-04	1.1	2800	27.6	72.3	0.1	<0.1	34	7.1	69	5.5	29	380	551
B-05	1.1	2200	22.3	77.6	<0.1	<0.1	33	6.8	71	5.2	28	360	510
B-06	1.7	1800	20	79.9	0.1	<0.1	32	6.4	69	4.8	27	340	496
B-07	1.2	2000	13.5	86.4	0.1	<0.1	31	6.5	69	5	27	350	498
B-08	1.5	1700	17.4	82.6	<0.1	<0.1	31	6.5	70	5	26	360	538
B-09	1.7	1400	16.3	83.5	0.2	<0.1	30	6.2	67	5.2	26	340	523
B-10	2	1800	26.6	73.3	<0.1	<0.1	32	7	68	5.3	28	380	496
Average	1.4	1960.0	19.9	80.0	0.1	<0.01	32.0	6.7	69.4	5.1	27.9	353.0	516.4
SD	0.3	389.3	4.6	4.6	0.1	0.0	1.5	0.4	1.9	0.3	1.4	18.9	18.7
Min	0.94	1400	13.5	72.3	0.1	-	30	6.2	67	4.8	26	320	496
Max	2	2800	27.6	86.4	0.3	<0.01	34	7.7	73	5.5	30	380	551

Waimea Estuary C	AFDW % w/w	Chl a ug/kg	Mud (<63µm)	Sands (<2mm & >63µm)	Gravel (>2mm)	Cd mg/kg	Cr mg/kg	Cu mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	TN mg/kg	TP mg/kg
C-01	1.2	4400	19.1	78.9	1.9	<0.1	35	7.2	53	5.5	25	450	350
C-02	2.1	4700	20.3	78.7	0.9	<0.1	57	7.6	65	6	32	580	411
C-03	2.2	5100	23.7	75.9	0.3	<0.1	41	7.2	57	5.7	26	770	373
C-04	1.6	5300	22.6	76.6	0.8	<0.1	38	7.4	56	5.7	26	540	368
C-05	2.3	3900	21.4	78	0.6	<0.1	39	7.1	57	5.7	27	510	353
C-06	2.6	5300	22.9	76.4	0.6	<0.1	46	8.4	66	6	29	550	366
C-07	2.1	4800	21.9	77.6	0.5	<0.1	41	7.7	60	5.8	28	430	359
C-08	1.9	4100	18.6	80.7	0.7	<0.1	39	7.8	58	5.8	28	530	364
C-09	1.8	5600	22.1	77.4	0.6	<0.1	43	8.5	66	5.8	29	520	407
C-10	2.8	5700	23.4	75.9	0.7	<0.1	44	9.4	68	6.8	32	620	405
Average	2.1	4890.0	21.6	77.6	0.8	<0.01	42.3	7.8	60.6	5.9	28.2	550.0	375.6
SD	0.5	617.3	1.8	1.5	0.4	0.0	6.1	0.7	5.2	0.4	2.4	95.2	23.2
Min	1.2	3900	18.6	75.9	0.3	-	35	7.1	53	5.5	25	430	350
Max	2.8	5700	23.7	80.7	1.9	<0.01	57	9.4	68	6.8	32	770	411

Waimea Estuary D	AFDW % w/w	Chl a ug/kg	Mud (<63µm)	Sands (<2mm & >63µm)	Gravel (>2mm)	Cd mg/kg	Cr mg/kg	Cu mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	TN mg/kg	TP mg/kg
D-01	2.5	2400	32.2	67.2	0.7	<0.1	58	9.3	96	6.1	33	400	506
D-02	2.5	1600	37.6	61.9	0.5	<0.1	60	9.7	92	6.4	37	490	522
D-03	2.4	1900	31.6	67.3	1.1	<0.1	55	9.2	87	6.3	33	510	495
D-04	2.4	1300	35.2	64.4	0.5	<0.1	51	8.9	83	5.9	33	450	510
D-05	2.3	3700	33.9	65.4	0.6	<0.1	52	9.4	85	6.2	35	520	532
D-06	2.6	900	35	63.3	1.7	<0.1	52	8.8	84	5.9	34	450	499
D-07	1.3	1500	32.7	62.1	5.1	<0.1	56	9.5	89	6.4	35	530	488
D-08	1	1200	31.7	66.8	1.5	<0.1	56	9.4	94	6.2	35	570	515
D-09	2.4	1800	33.8	61.7	4.5	<0.1	57	10	93	6.5	35	440	500
D-10	2.5	1400	30.2	63.8	6	<0.1	54	10	89	7.6	35	510	520
Average	2.2	1770.0	33.4	64.4	2.2	<0.01	55.1	9.4	89.2	6.4	34.5	487.0	508.7
SD	0.6	794.5	2.2	2.2	2.1	0.0	2.9	0.4	4.5	0.5	1.3	51.0	13.7
Min	1	900	30.2	61.7	0.5	-	51	8.8	83	5.9	33	400	488
Max	2.6	3700	37.6	67.3	6	<0.01	60	10	96	7.6	37	570	532

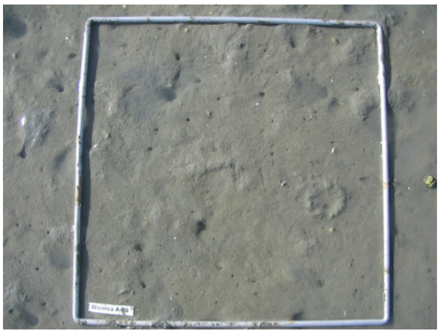
Appendix 2. List of infauna and epifauna sampled.

General group	Taxa	Common Name	Feeding Type
Anthozoa	*Anthopleura aureoradiata*	Mud flat anemone	Filter feeder
Anthozoa	*Edwardsia sp.*	Burrowing anemone	Filter and deposit feeder
Nemertea	Nemertea	Ribbon worms	Carnivorous
Nematoda	Nematoda	Roundworm	
Gastropoda	*Amphibola crenata*	Mudflat snail	Microalgal grazer
Gastropoda	*Cominella glandiformis*	Mudflat whelk	Carnivore & scavenger
Gastropoda	*Diloma zelandica*	Ridged topshell	Microalgal & detrital grazer
Gastropoda	*Micrelenchus hutton*[1]	Topshell	Microalgal & detrital grazer
Gastropoda	*Micrelenchus tenebrosus*	Topshell	Microalgal grazer
Gastropoda	*Notoacmea helmsi*	Estuarine limpet	Microalgal & detrital grazer
Gastropoda	*Potamopyrgus estuarinus*	Estuarine snail	Microalgal & detrital grazer
Gastropoda	*Zeacumantus lutulentus*	Spireshell	Microalgal & detrital grazer
Gastropoda	*Zeacumantus subcarinatus*	Small spireshell	Microalgal & detrital grazer
Bivalvia	*Arthritica bifurca*	Small bivalve	Infaunal deposit feeder
Bivalvia	*Austrovenus stutchburyi (0-5mm)*	Cockle (0-5mm)	Infaunal deposit feeder
Bivalvia	*Austrovenus stutchburyi (06-10mm)*	Cockle (6-10mm)	Infaunal deposit feeder
Bivalvia	*Austrovenus stutchburyi (11-20mm)*	Cockle (11-20mm)	Infaunal deposit feeder
Bivalvia	*Austrovenus stutchburyi (21-30mm)*	Cockle (21-30mm)	Infaunal deposit feeder
Bivalvia	*Austrovenus stutchburyi (31+mm)*	Cockle (>31mm)	Infaunal deposit feeder
Bivalvia	*Macomona liliana*	Wedge shell,	Infaunal suspension feeder
Bivalvia	*Nucula hartvigiana*	Nut shell	Infaunal deposit feeder
Bivalvia	*Paphies australis*	Pipi	Filter feeder
Bivalvia	*Soletellina sp.*	–	Infaunal suspension feeder
Oligochaeta	Oligochaeta	Oligochaete worms	Infaunal deposit feeder
Polychaeta: Capitellidae	*Heteromastus filiformis*	Worm (opportunist)	Infaunal deposit feeder
Polychaeta: Maldanidae	Maldanidae	Bamboo Worms	Infaunal deposit feeder
Polychaeta: Paraonidae	Paraonidae	Worm	Infaunal deposit feeder
Polychaeta: Glyceridae	Glyceridae	Blood worm	Infaunal carnivore & deposit feeder
Polychaeta: Nereididae	*Nicon aestuariensis*	Rag worm	Omnivorous
Polychaeta: Phyllodocidae	*Eulalia microphylla*	Paddle warm	Carnivorous
Polychaeta: Spionidae	*Aonides sp.*	Worm	Surface deposit feeder
Polychaeta: Spionidae	*Prionospio sp.*	Worm (opportunist)	Surface deposit feeder
Polychaeta: Spionidae	*Scolecolepides benhami*	Worm	Surface deposit feeder
Mysidacea	Mysidacea	Mysid shrimp	Filter and deposit feeder
Cumacea	Cumacea	Cumaceans	Infaunal filter or deposit feeder
Isopoda	Flabellifera	Sea louse	Epifaunal scavenger
Amphipoda	Amphipoda a	Amphipods	Epifaunal scavenger
Amphipoda	Amphipoda b	Amphipods	Epifaunal scavenger
Decapoda	*Callianassa filholi*	Ghost shrimp	
Decapoda	*Halicarcinus whitei*	Pill-box crab	Eats small organisms & some weed
Decapoda	*Helice crassa*	Tunnelling, mud crab	Deposit feeder & scavenger
Decapoda	*Macrophthalmus hirtipes*	Stalk-eyed mud crab	Deposit feeder & scavenger
Copepoda	Copepoda	Copepods	
Cirripedia	*Austrominius modestus*	Estuarine barnacle	Filter feeder
Insecta	Dolichopodidae larvae	Small fly larvae	Algal grazer
Rhodophyta	*Gracilaria sp.*	Agar weed	Photosynthetic

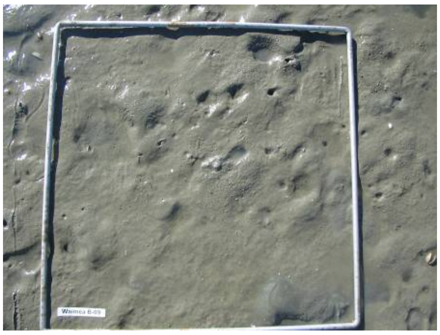
Note: *Micrelenchus huttoni* now recognised as an ecotype of *Micrelenchus tenebrosus.*

Appendix 3. Representative quadrat and core profile photographs; core upper surface on left.

Site A



Site B



Site C

Site D