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The benthic ecology of expanding mangrove habitat, Tauranga Harbour, New Zealand

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Abstract

Over the last 40-50 years, mono-specific mangrove stands in New Zealand have expanded, and generally this expansion has been across previously unvegetated intertidal flats. In response to an increasing perception that mangroves present a negative ecological and aesthetic coastal change, coastal managers are sometimes opting to have some portion of them removed. The removal of this vegetation and the impacts on the macroinvertebrate community within these areas is largely unknown given that there have been relatively few studies of macroinvertebrate community structure undertaken in New Zealand's temperate mangrove habitats. To address these key questions and broaden our knowledge of New Zealand intertidal ecology, macroinvertebrates were collected within 3 sub-estuaries of Tauranga Harbour. Cores were collected from 3 transects within each estuary, each passing through mangrove habitat and unvegetated intertidal flats. Surface sediment grain size and organic content were also assessed. All sites monitored in this study were located in the upper half of the estuaries where surface sediments were either dominated by mud (all mangrove sites and some bare sites closest to the head of the estuary) or fine sand (mid-estuary). Species richness and species abundance were low at all sites, partly due to the exclusion of smaller organisms (e.g. oligochaetes). Abundance was generally greater in the bare flat habitat, being approximately < 6 individuals per core. Multivariate analyses indicate a significant difference in species richness between mangrove and bare intertidal habitats; however, within the overall suite of species identified, no species were exclusive to either habitat. These results suggest that catchment-based fine sediments entering the study sites are influencing benthic community composition more so than the presence of mangroves.

1 INTRODUCTION

The mono-specific stands of mangroves (*Avicennia marina* var. *australasica*) found in the estuaries of New Zealand, often represent young ecosystems. For example, much of the mangrove habitat found in Tauranga Harbour in 2008, where this study is centred, has established within the last 20 – 40 years. In the 1960s, most embayments in the harbour had fringing mangrove vegetation that totalled less than 1 hectare but by the late 1990s, mangrove colonisation had increased the canopy cover up to 30 ha (Park 2003). Similar vegetation changes have been documented at other estuarine sites in New Zealand (Burns and Ogden 1985; Young and Harvey 1996; Ellis et al. 2004; Swales et al. 2007) and some sites overseas (Allen 1998; Coleman 1998; Souza Filho et al. 2006; Thampanya et al. 2006). Increased sediment loads generated by changing land use practices have been considered the key driver of this mangrove expansion (Young and Harvey 1996; Ellis et al. 2004; Swales et al. 2007) as muddy sediments (clay and silt-sized sediment) provide a substrate more suitable to seedling establishment and survival. Climate cycles and increased nutrient loads are also possible mechanisms contributing to increased mangrove coverage (Lovelock, et al. 2007; Swales et al. 2007).

A growing public perception is that the expansion of mangroves reduces benthic biodiversity, and anecdotal evidence of decreased bivalve abundance is often connected to this vegetation change. As such, mangrove removal is being increasingly considered by coastal managers to improve the benthic ecosystem health of estuaries in New Zealand. However there is little information available that specifies the ecological consequences of mangrove colonisation.

Two general trends in estuarine geomorphology and ecology are well documented:

1. Once mangroves have established over intertidal flats, sedimentation rates increase and mud content of the surface sediment is likely to increase (Furukawa et al. 1997; Quartel et al. 2006).
2. Resident benthic communities that inhabit the intertidal zone are known to alter in response to increased terrestrial sediment loads (Cummings et al. 2003), with bivalves being particularly vulnerable (Norkko et al. 2006).

As such, it could be expected that as the intertidal habitat becomes colonised by mangroves, the benthic community composition will alter. Results of the few studies undertaken to date indicate low benthic macroinvertebrate diversity and abundance in mangrove habitat in New Zealand, however these findings are often coupled with a similarly low diversity of adjacent intertidal mudflats (Ellis et al. 2004), suggesting benthic communities are responding to increased silt/clay as a result of higher sedimentation rather than simply to the presence of mangroves.

Studies of mangrove and mudflat habitat have mostly identified the same functional groups of benthic macroinvertebrates. However, the species found often vary, as do the estuarine sediment regimes of the sites investigated (Alfaro 2005; Morrisey et al. 2003; Ellis et al. 2004), As such, further investigation is required to identify the response of benthic community to the spread of mangrove ecosystems. This research aims to quantify and compare benthic invertebrate populations within both mangrove habitat and adjacent unvegetated intertidal flats. The results identify the potential consequence of mangrove expansion in upper estuarine environments where increased inputs of terrestrial sediments are influencing the present-day geomorphology.

2 STUDY AREA DESCRIPTION

Tauranga Harbour is located in the Bay of Plenty region, on the North Island of New Zealand (Figure 1). The harbour is a meso-tidal, barrier enclosed estuarine lagoon with a total area of ~200 km^2 (Park 2003). The harbour is predominantly shallow with around 80% of its total area exposed at low tide. Sediments of the harbour are predominantly sandy, but finer catchment-derived sediments accumulate in the upper reaches of many of the adjoining embayments (Park 2003). The surrounding catchments support considerable horticultural and agricultural activity, with a residential population of around 100,000 in the city of Tauranga. Urban development continues along the margins of many of the embayments along the landward (western) flanks of the harbour.

Sampling for this study was undertaken in 3 sub-estuaries, namely, Welcome Bay, Waikareao Estuary and Waikaraka Estuary. Transect 1 was located closest to the head of the estuary, and Transect 3 toward the middle of the system, with Transect 2 roughly halfway between (Figure 1). The two study sites of Welcome Bay and Waikareao Estuary were chosen for their hydrodynamic differences (Table 1). Welcome Bay represents a lower energy system, and Waikareao estuary a more open, higher energy environment with considerably greater terrestrial sediment inputs. Waikaraka Estuary, which is also a narrow, low-energy embayment, was included in the study to monitor sedimentological and topographical changes after council-approved removal of above-ground mangrove vegetation.

Mangroves and nearby unvegetated flats of Transects 2 and 3 in both Welcome Bay and Waikareao are exposed for around 5 hours over most low tides, while Transect 1 at both sites is inundated roughly 30 minutes later. Spring tide inundation height, based on observation of markings on the fringe mangroves, does not exceed ~0.75 m. In comparison, Waikaraka estuary experiences reduced inundation periods, with the monitoring locations of Transects 1 and 2 generally exposed for up to 8 hours per semi-diurnal tide (Hope 2002) and Transect 3 is exposed for around 7 hours. Spring tidal inundation ranges from < 0.5 m at Transects 1 and 2 to ~ 0.75 m at Transect 3 (see Figure 1 for transect locations).

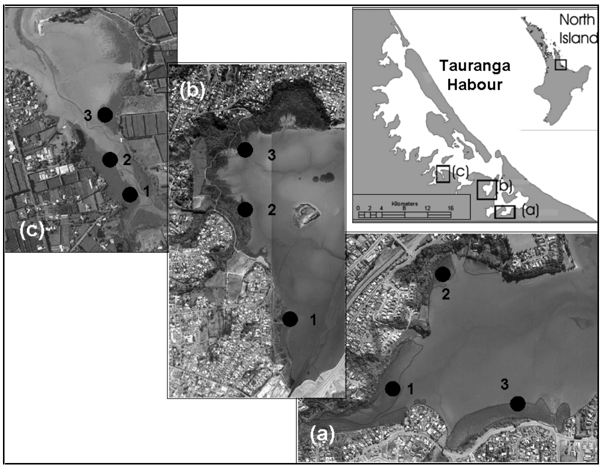

Fig. 1. Transect locations marked on 2003 aerial photos of Welcome Bay (a), Waikareao Estuary (b) and Waikaraka Estuary (c), North Island, New Zealand. Photo's courtesy of Environment Bay of Plenty.

Table 1. Estuary and catchment characteristics of Waikareao Estuary (Waik), Welcome Bay (WB) and Waikaraka Estuary (TP), taken from Park, 2003 *; Surman, 1999 ** and Hope, 2002^.

	Waik	WB	TP
Estuary area (km^2)	3.25	1.6	0.5
Mangrove coverage 1980 (ha)	2.2	8.3	3
Mangrove coverage 2003 (ha)	16	11.6	11.5
Catchment size (km^2) *	74	20	10
% catchment urban *	8	16	1
% catchment horticulture or pasture *	54	84	86
% scrub/forest *	40	1	13
Distance from harbour entrance km	4.5	10	12
Freshwater inflow yields - mean of recorded flows in L/s	2450**	179**	92^

3 METHODS

Three transects were marked out at each of the three study sites. The seaward fringe of mangrove vegetation was marked as '0 m'. Sampling of mangrove habitat was undertaken 20 and 10 m landward of the mangrove/tidal flat boundary (labelled as -20 m and -10 m). Stations on the unvegetated intertidal flats were positioned 10 m and approximately 40 m from the mangrove fringe. Sampling was undertaken in February 2006 (southern hemisphere summer), July 2006 (winter), and February 2007 at Waikareao

Estuary and Welcome Bay, and July 2006 and February 2007 at Waikaraka Estuary.

Benthic macrofauna were collected in 3 replicate 13 cm diameter x 20 cm cores. The cores were taken roughly 1 m apart, at each location. All samples were sieved on-site during high tide through a 1000 µm mesh. Collected organisms were preserved in isopropyl alcohol and later stained with Rose Bengal and all organisms were enumerated and identified to the lowest possible taxonomic level.

Environmental variables examined in this study were sediment grain size and organic matter content. Surface samples were collected in triplicate from the top 1-2 cm of the substrate surface. Grain size was measured with a Malvern Mastersizer-S Longbed after 48 hours in hydrogen peroxide and 24 hours in Calgon. Organic content was determined by weight lost after ignition (500° C for 5 hours). Surface elevation changes at the study sites, reported in detail in Stokes et al. (2009) and Stokes et al. (in press), are included in this paper to demonstrate sedimentation rates.

Similarities in community structure were established using non-metric multi-dimensional scaling (MDS) based on Brays Curtis similarity matrices, square-root transformed where required, using PRIMER software. Community composition and species diversity was further investigated using PERMANOVA techniques, written in C++ script (available on request) and performed using R software. A nested approach was used, with factors 'mangrove/non-mangrove'; 'station' 'transect' and 'estuary'; nested within 'season' and 'year'. Homogeneity of variance was checked using Levene's test, and although the result indicated variance across groups of the species composition data, highly significant results from the PERMANOVA test (< 0.001) were supported by MDS, and as such were included in the data interpretation. Univariate indices and benthic community composition are described using data associated with the 2007 (summer) sampling.

4 RESULTS

Environmental Parameters

The mangrove and bare habitats were distinguishable by their sediment characteristics. Fine sand was dominant on the unvegetated flats, while mud (silt and clay) was abundant in mangrove at Welcome Bay, and all except Transect 2 at Waikareao, where fine sand was measured at all stations. Mud still constituted up to 50% of the unvegetated intertidal locations (Figure 2).

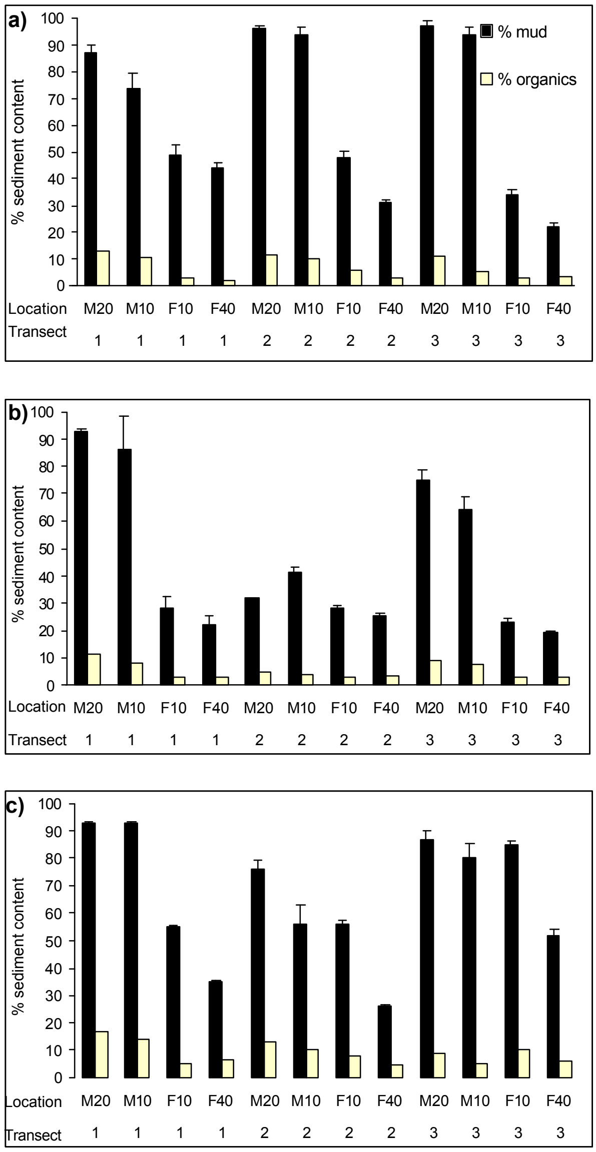

Fig. 2. Average (± SE) percent mud content and total organic content of sediments collected in mangrove (M20 and M10) and unvegetated sampling locations (F10 and F40) at Welcome Bay (a), Waikareao Estuary (b) and Waikaraka Estuary (c), February 2007.

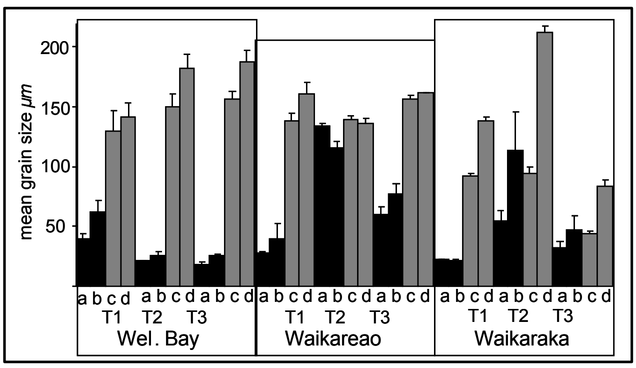

Fig. 3. Mean grain size (± SE) of sediments collected in February 2007 in mangrove (black) and unvegetated sampling locations (grey) at Welcome Bay, Waikareao Estuary and Waikaraka Estuary.

Organic content was generally higher in mangrove sediments, with the highest values found in Waikaraka, which may reflect the abundant decaying root material resulting from mangrove removal (Figure 3).

Increased surface topography was found to occur at most locations in the upper estuary locations of Waikareao and Welcome Bay with maximum increases in surface elevation of 18 mm yr^{-1}. More sediment appears to be accumulating on the bare flats of Transects 1 and 2 at Welcome Bay, compared to the adjacent mangroves. Erosion, or a fall in surface elevation, is occurring on the bare flats at Waikareao in the vicinity of Transect 3. Erosion rates of over 20 mm yr^{-1} were recorded at Waikaraka due to release of some sediment fines and the decomposition and collapse of mangrove roots after above-ground mangrove vegetation was removed (Table 2).

Table 2. Surface elevation changes measured in mangrove (black) and unvegetated sampling locations (grey) at Welcome Bay, Waikareao Estuary and Waikaraka Estuary. ** Measurements not recorded at these locations.

Transect	habitat & distance (m)	W. Bay annual accretion (mm)	Waikareao annual accretion (mm)	Waikaraka annual accretion (mm)
1	M20	2	14	4
1	M10	0	7.5	4
1	F10	13	6	**
1	F40	1	0.6	**
2	M20	6	13	-5
2	M10	5	8	5
2	F10	12	-2.5	-31
2	F40	1	0.4	**
3	M20	18	5	4
3	M10	13	5	4
3	F10	6	-13	-14
3	F40	5	-13	**

Macrobenthic community composition

All locations sampled were found to have low macrofaunal abundance. Unvegetated sandflats often had slightly higher numbers of individuals (between 2 and 6 individuals per core) than the adjacent mangrove habitat (1 to 2.7). Similarly, sandflats mostly had slightly higher total taxa compared to mangrove habitat, though the average total taxa at all locations was always < 4 per 0.01 m^2 core (Table 4). Comparative differences in univariate indices between habitats was less evident within Waikaraka Estuary however.

The benthic macrofaunal community consisted of gastropods, polychaetes and decapods, with a similar suite of species found across both habitats, though with patchy abundance. Numerically dominant species (listed in Table 4) were mostly surface deposit feeders, with the exception of the predators *Perinereis nuntia* and *Cominella glandiformis*. Very few bivalves were found. One cockle (*Austrovenus stutchburyi*) was recorded for the tidal flats of Waikareao, and two individuals in Waikaraka, where one *Macomona liliana* was found at the 40 m station of each of the three transects. Interestingly, the crab *Helice crassa* was more abundant in mangroves compared to unvegetated sites, with the reverse trend found for *Macropthalmus* sp.

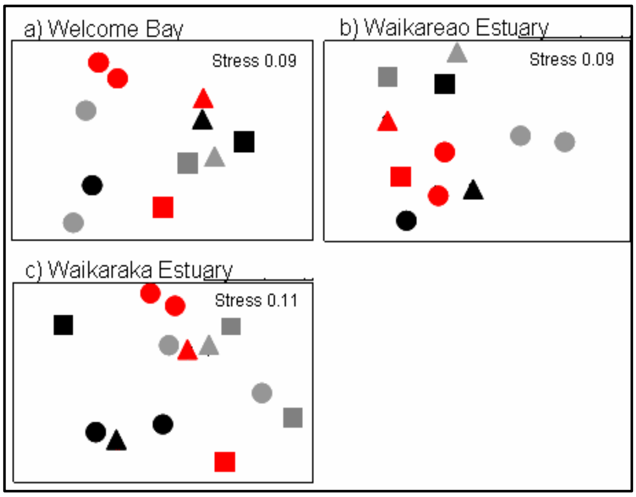

Fig. 4. Multidimensional scaling (MDS) ordination of macroinvertebrate data from all locations sampled in February 2007. Circles = mangroves; squares = 10 m bare flat station; and diamonds = 40 m bare flat station. Black = Transect 1; red = Transect 2 and grey = Transect 3.

Table 3. p values from nested PERMANOVA undertaken to assess differences in macrobenthic species composition and species richness amongst sampling locations. Significant p values (< 0.05) are indicated in bold.

Source	Observed	Expected	*p*
Species composition			
Year	1.3840284	0.9513149	0.127
Season	**2.7657315**	**1.7094688**	**0.045**
Estuary	11.086509	11.086509	1.0
Transect	**7.2007662**	**4.1303546**	**<0.001**
station/position	**2.5915253**	**0.7684976**	**<0.001**
Mangrove or flats	**5.1947285**	**0.7665717**	**<0.001**
Mean Taxa			
Year	0.1099169	0.8439526	0.775
Season	**9.4048788**	**0.9247281**	**<0.001**
Estuary	1.0446197	1.6081458	0.525
Transect	0.0015653	0.8557772	1.0
Station/position	**11.498686**	**0.9507795**	**<0.001**
Mangrove or flats	**29.097696**	**0.9441287**	**<0.001**

Multivariate analyses, displayed in Table 3, indicate that the presence of mangroves influenced macrofaunal community composition, as did sampling location and transect ($p < 0.001$). The significant seasonal effect on mean taxa was due to the presence of crab (*Halicarcinus cookii, Halicarcinus whiteii* and *Hemigrapsus edwardsii*) and polychaete species (*Hetermoastus filiformis* and *Aglophamus macroura*) in summer 2006 that were mostly not found during proceeding sampling events.

The MDS ordination for macroinvertebrate community data revealed no clear separation of habitats when all sites (estuaries) and locations were combined, consistent with the similar suite of organisms found across mangrove and unvegetated locations.

When sites were analysed separately, however, mangrove and unvegetated habitats separated clearly at Welcome Bay. The four locations along Transect 2 at Waikareao cluster closely, consistent with similarities in sediment characteristics of these locations (Figure 4).

Table 4. Macroinvertebrate taxa in each sampling location sampled at Welcome Bay, Waikareao Estuary and Waikaraka Estuary in February 2007. Values are average abundance per 0.01 m^2 core (n=3).

Species/taxa		Site	T1 M	T1 10 m	T1 40 m	T2 M	T2 10 m	T2 40 m	T3 M	T3 10 m	T3 40 m
Zeacumantus lutulentus	G	W Bay	0.5	1.0	2.7	0.3	1.3	0.7	1.0	1.3	2.0
		Waikareao									
		Waikaraka						2.0			
Eatoniella sp.	G	W Bay									
		Waikareao	1.7	1.0		1.2	1.0	2.0			0.3
		Waikaraka	1.7	1.2		0.5		1.0			
Amphibola crenata	G	W Bay									
		Waikareao							0.3		
		Waikaraka						1.0	1.0		
Cominella glandiformis	G	W Bay					0.7				0.0
		Waikareao					1.7				0.7
		Waikaraka							1.0	1.0	1.0
Helice crassa	D	W Bay	0.5			0.3			1.0		
		Waikareao		0.5			0.3		0.7		
		Waikaraka	0.3	0.3	1.3		1.0		1.3	1.0	
Macropthalmus sp.	D	W Bay		0.7	0.7	0.3	0.7			1.0	0.3
		Waikareao		0.5	0.3	0.3			0.3	0.7	
		Waikaraka				1.0	1.5		2.0	1.0	1.0
Nicon aestuariensis	P	W Bay		0.3	1.3			0.3		2.0	0.3
		Waikareao		0.5		0.3			0.3	0.3	
		Waikaraka	1.0				1.0	1.0	1.0	2.0	2.0
Family Nereidae	P	W Bay			0.7	0.3	0.3	0.7			
		Waikareao			0.3		2.3	0.3		1.0	2.0
		Waikaraka	0.7	0.3				1.0			
Ceratonereis sp.	P	W Bay			0.3						
		Waikareao			0.3	0.3	0.3	0.3	0.3	2.7	0.3
		Waikaraka	0.5	0.3							
Scolecolepides sp.	P	W Bay	0.5	0.3			0.3	1.7	0.7	0.7	0.7
		Waikareao			0.3	0.3				0.3	0.7
		Waikaraka			2.0						
Perinereis nuntia	P	W Bay							0.7		
		Waikareao			1.3	0.3	0.3			0.3	0.3
		Waikaraka	0.3	0.2		1.0					
Species Richness		W Bay	2.5	1.7	3.3	1.5	2.3	3.3	2.0	3.3	3.0
		Waikareao	1.3	2	2	2.2	3.3	1.3	2	3.7	3
		Waikaraka	1.6	2	2.7	1	2.3	2.3	1.5	1.3	1.7
Abundance		W Bay	1.7	2.7	6	1.5	3.3	5	2.7	5.7	4.7
		Waikareao	1	2.5	2.7	2.3	6	2.7	2	6	4.3
		Waikaraka	2.7	3.7	4.3	1	2.7	2.7	2	1.7	2

5 DISCUSSION

This study was designed to determine the differences in macrobenthic communities between mangrove habitat and adjacent unvegetated sandflats. A description of surface sediment characteristics was included to investigate the influence of mud accumulation on species diversity and abundance.

The mud (clay and silt) content of mangrove sediments of Welcome Bay, Waikareao and Waikaraka estuaries, ranged from around 60% to 98%, while the adjacent flats were dominated by fine sand. Mud content of between 20 and 50% was found on the bare flats however, implying these locations also retain terrestrial sediments. Sediment surfaces are mostly experiencing accretion, as evidenced by positive surface elevation changes measured in both mangrove and bare flat habitats.

Benthic communities across both mangrove and bare flat habitats of the study were populated by mud-tolerant organisms, which were predominantly surface deposit-feeders such as polychaetes, decapods and gastropods. In contrast to high crab abundance and diversity documented in many tropical estuarine systems (Frusher et al. 1994), two decapods were commonly found (*Helice crassa* and *Macropthalmus hirtipes)*, however only in low numbers. Helice crassa tolerate increases in mud content (Thrush et al. 2003), although their preference for well-drained compact sediments (Jones and Marsden 2005) may go some way to explaining the low numbers counted in this study.

The numerical dominance of polychaetes is consistent with findings of other field studies that have identified a correlation between increased terrestrial sedimentation with greater abundance of this group of surface deposit-feeders (Pridmore et al. 1990; MacFarlane and Booth 2001; Morrisey et al. 2003; Thrush et al. 2003; Ellis et al. 2004). Annelids have differing habitat preferences, however, and the presence of *Nicon* and *Scolecolepides* species supports modeling predictions of a positive effect of increased mud content with these species (Thrush et al. 2003). The use of 1 mm sieves in this study is likely to have excluded smaller macroinvertebrates from the study and therefore underestimate the absolute abundance of some populations (James et al. 1995). The results of this study provide a good comparison between vegetated and bare intertidal habitats however.

Bivalves were mostly absent across all locations in this study. *Paphies australis* and *Austrovenus stutchburyii* have been found in mangrove habitat of other New Zealand estuaries (Alfaro 2005), however these were sites dominated by fine sand (with < 15% mud), as opposed to the mud-dominated sediments reported here. It is likely that the relatively high mud content of the bare flats and > 90% mud of the mangrove habitat in this study is a causal factor in the absence of bivalves as sensitivity to increased turbidity and sediment mud content of filter-feeding invertebrates is well documented (Ellison and Farnsworth 2000; Thrush et al. 2003; Norkko et al. 2006).

Differences in benthic communities were detected between the two key habitats, mostly as a result of slightly higher abundances of the same suite of organisms found in the unvegetated flats more so than the occurrence of habitat-specific taxa. The low benthic diversity and abundance documented for both the mangrove and bare flat habitats in this study is consistent with observations of declining diversity and abundance associated with increasing sediment mud content (Thrush et al. 2003; Ellis et al. 2004; Lohrer et al. 2004; Thrush et al. 2004; Rodrigues et al. 2006). Sedimentation of as little as 3 mm has been considered to have a deleterious effect on macrobenthic communities (Lohrer et al. 2004), so it is reasonable to assume that the sedimentation rates of up to 18 mm yr^{-1} reported in this study are sufficient to influence the composition of benthic fauna. Field observations of extensive bivalve beds (predominantly *Austrovenus stutchburyi*) buried 10 – 15 cm below the estuary surface indicate a large environmental change has occurred to shift the benthic community from one dominated by filter-feeding organisms to one now composed of macroinvertebrates with feeding strategies adapted to a mud-dominated environment.

6 CONCLUSION

This study has provided further evidence of the impacts of terrestrial sedimentation on benthic communities. The sediment characteristics of the mangrove and unvegetated intertidal habitat were markedly different. However it appears that the silt and clay content of the unvegetated habitat was still sufficient to limit macrofaunal species diversity and abundance, exclude bivalves and encourage a benthic community dominated by deposit-feeding polychaetes, gastropods and decapods. Any coastal management strategies employed to improve the ecosystem health of an estuary must therefore consider the negative effects of catchment-based sediment loads on the diversity of benthic communities that exist both in mangrove habitat and on adjacent bare intertidal surfaces.

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