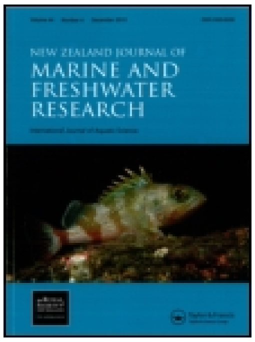

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Late summer hyperbenthic estuarine communities: comparing permanently open and intermittently closed systems along the Otago coastline

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Few studies have compared hyperbenthic communities among estuaries, in either New Zealand or elsewhere. This study presents the results of a single late summer survey of the lower reaches of 26 estuarine systems along the Otago coastline from the Clutha River to Oamaru, comparing hyperbenthic communities among both permanently open and intermittently closed estuaries. Intermittently closed estuaries are periodically closed from the ocean because of the formation of a berm across the mouth. A total of 33 taxa were captured with mysids and amphipods, the most widespread hyperbenthic taxa, being common in both permanently open and intermittently closed Otago estuaries. The mysid, *Tenagomysis novae-zealandiae*, and amphipod, *Paracalliope fluviatilis*, were widespread, found in 74% and 68% of all estuaries sampled, respectively. In contrast, most other taxa were present in relatively few estuaries, with 17 species recorded from only 10% of estuaries. There was a significant difference in the community composition among permanently open and intermittently closed estuaries. The results highlight the potential sensitivity of New Zealand estuarine communities to management regimes that may alter their open/closed status.

Keywords: intermittently closed; lagoon; hyperbenthos; New Zealand; estuaries; Mysidae

Introduction

While a large number of ecological studies have been conducted in estuaries, studies of single large permanently open estuaries located close to centres of human habitation are over-represented in the literature (Edgar et al. 1999; Teske & Wooldridge 2001; Hirst 2004). However, a large proportion of estuarine systems are very small. For example, along the Australian NSW coastline, the majority of the 950 estuarine systems are small and intermittently closed from the sea (Roy et al. 2001), while in South Africa 70% of estuaries are open only temporarily (Nozais et al. 2001; Perissinotto et al. 2002; Froneman 2004). Although large river estuaries are relatively common in New Zealand, there is also an abundance of small and intermittently closed estuaries that have received relatively limited attention.

Consequently, few studies worldwide have examined the distribution and spatial variation of biota among different types of estuaries. For example, comparisons of estuarine systems completed to date suggest that there can be significant differences among hyperbenthic communities in different estuary types (e.g. Mees et al. 1995; Teske & Wooldridge 2001; Desmond et al. 2002; Dye & Barros 2005a,b). Whether an estuary is permanently open or intermittently closed, in particular, can cause marked physico-chemical variation among estuaries including differences in salinity, temperature, inundation, nutrients and production (Kozlowski-Suzuki & Bozelli 2004; Thomas

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et al. 2005). Consequently, significant differences in the hyperbenthic communities present in permanently open or intermittently closed systems have been observed; for example in Australia (e.g. Hirst 2004; Dye & Barros 2005a,b) and South Africa (e.g. Teske & Wooldridge 2001). It is presumed that this pattern is also likely to occur in New Zealand.

Worldwide, estuarine hyperbenthic communities have also received only limited study (Mees et al. 1995). These species occupy a critical niche, providing linkages between the planktonic and detrital food webs and larger secondary consumers (e.g. Webb 1973; Fockedey & Mees 1999; Cabral & Ohmert 2001; Maes et al. 2003). Mysid shrimps are typically the most abundant hyperbenthos in temperate hyperbenthic estuarine communities, dominating the estuarine fauna in many regions (Azeiteiro & Marques 1999; Roast et al. 1999; San Vicente & Sorbe 1999; Mouny et al. 2000). The distribution of mysids is relatively unknown in New Zealand (Chapman & Lewis 1976; Jones et al. 1989), but it is likely that they are abundant in many estuaries.

There is growing concern in New Zealand over the impact of both deteriorating water quality and climate change on our aquatic ecosystems (Larned et al. 2004; McDowell and Wilcock 2008). Estuaries are vital to our understanding of these impacts, as they potentially integrate these impacts from over the whole catchment and often transport pollution to the ocean because of their role as the conduit of freshwater run-off (Scharler & Baird 2003; Davies & Eyre 2005). In particular, intermittently closed estuaries are thought to be especially vulnerable because of longer residence times and limited opportunities for flushing (Haines et al. 2006; Schallenberg et al. 2010). Hence it is important to gain a baseline understanding of estuarine taxa and how estuarine communities vary among systems.

The aim of this paper is to (1) provide a late-summer spatial comparison of hyperbenthos composition among representative estuaries along the Otago coastline; and (2) focus on mysid distribution and variation in relative abundance between permanently open and intermittently closed estuarine systems. It is hypothesised that the presence of a barrier across the estuary mouth will create physicochemical differences that will lead to distinct hyperbenthic communities among these two estuarine types.

Methods

Study sites

Twenty-six estuaries were chosen using 1:50,000 topographic maps in a stratified design in order to obtain representatives from a wide variety of estuary types and sizes over a large spatial scale along the Otago coastline (refer to Table 1 for name and location of estuaries sampled). Estuaries were sampled along approximately 250 km of the south east coast of the South Island of New Zealand from the Clutha River (46.33775°N, 169.80696°E) in the south to Awamoa Creek (45.14268°N, 170.93506°E) near Oamaru in the north. All the types of estuarine systems in Otago are represented in the study including large river estuaries (e.g. Clutha River), drowned river estuaries (e.g. Taieri River), coastal lagoons (e.g. Reids Stream) and coastal inlets (e.g. Hoopers Inlet). Sixteen estuaries sampled were known to close frequently or were closed by sand bars at the time of sampling and were thus identified as intermittently closed systems.

Sampling protocol

Sampling was conducted at night on 17–20 February 2004 during a period of settled weather with no significant rainfall. Night-time sampling is known to maximise both catch per unit effort and the number of species caught, and is important in order to avoid any crepuscular bias in invertebrate activity (Guest et al. 2003). While such a short sampling period offers only a snapshot of the distribution and variation in estuarine fauna, it was conducted in order to avoid seasonal or significant climatic variation confounding patterns of spatial variation among estuaries. Furthermore, as the analyses treated each estuary as an individual sampling unit, an attempt was made to maximise the number of estuaries sampled over as short a time span as possible. All intermittently closed estuaries apart from Awamoa were closed during sampling.

The following environmental variables were recorded at each estuary: connection to the sea (open versus closed), salinity, temperature, latitude and longitude. In order to maximise the number of estuaries sampled and to increase the spatial extent of the study, only one hyperbenthos sample was collected in each estuary. A qualitative sample was taken at each estuary using a 240 mm width by 200 mm height handheld sweep net with 500-µm mesh. Each sample was collected over 2 min with the net swept in front of the sampler and constantly moving over new area, and covered approximately 15 m^2. Sampling was limited to locations by the estuary mouth, allowing for a standardisation of habitat type across estuaries with areas only of soft sand/mud substrates sampled and in water greater than 20 cm deep. Only the water column just above the benthos was sampled and areas of fast-flowing water were avoided. After collection, all samples were preserved in 70% ethanol.

In the laboratory, the presence/absence of all invertebrate taxa collected was recorded for each sample. Because of their dominance, the number of each mysid species by sample was also counted to allow comparison of relative abundance across estuaries. PRIMER 5 was used to investigate patterns in the data. Two Bray–Curtis similarity matrices were created with standardised presence/absence data. One measured the similarities in taxa present among estuaries. The other measured the similarities among the taxa in which estuary they were present. Multidimensional scaling (MDS) with 1000 restarts was used to compare assemblage structure among estuaries. MDS was also used to compare the differences in estuary occupation among taxa. Differences among communities in temporarily open/closed and permanently open estuarine systems, and between high and low salinity communities, were examined in detail. ANOSIM (1000 permutations) comparing estuarine communities was conducted to test the *a priori* hypothesis that there was a difference between temporarily open/closed and permanently open estuaries.

Results

Physical and chemical variation

There was no apparent relationship between geographic location (longitude and latitude) and type of estuarine system, with the 16 intermittently closed systems evenly dispersed amongst the 10 permanently open systems (Table 1). Similarly, there were no detectable relationships between geographic location and the suite of environmental variables recorded. Salinity was significantly different between permanently open and intermittently closed systems (two-sample *t*-test, t-stat $= 4.20$, $P < 0.01$, df $= 25$) with mean salinity of 23.9 PSU in open estuaries and 7.8 PSU in intermittently closed systems. No significant difference in mean temperature was observed among permanently and intermittently closed systems.

Community structure

Thirty-three taxa were collected across the sampled estuaries. However, only 16 taxa were recorded in 10% or more of the estuaries sampled (Table 2). The total number of taxa found in permanently open estuaries was 21, while 20 taxa were recorded in intermittently closed systems. Mean taxa richness was equivalent with 5.3 ± 0.6SE and 5.8 ± 0.7SE taxa for open and intermittently closed systems respectively (analysis of variance; ANOVA, $P > 0.05$, $F = 0.27$, df $= 1$). Mysid and amphipod taxa were widespread and accounted for 22.5% and 25.5% of taxa recorded, respectively. The two most widespread species were *Tenagomysis novae-zealandiae* and *Paracalliope fluviatilis*,

Table 1 Site number, estuary name, location of sample and typology as sampled on 17–20 February 2004.

Site no.	Estuary name	Latitude (S)	Longitude (E)	Estuary type
1	Clutha River	46.34779	169.80820	Open
2	Washpool Creek	46.27492	169.95604	Closed
3	Rock valley Creek	46.22356	170.04258	Closed
4	Tokomairiro River	46.21360	170.04556	Open
5	Nobles Stream	46.19225	170.10218	Closed
6	Akatore Creek	46.10610	170.17753	Open
7	Sawmill road Creek	46.06232	170.19511	Closed
8	Taieri River	46.05055	170.19031	Open
9	Reids Stream	46.00499	170.24579	Closed
10	Otokia Creek	45.94828	170.33131	Closed
11	Awamoa Creek	45.14268	170.93506	Closed
12	Kakanui River	45.18070	170.89358	Open
13	Orore Creek	45.21090	170.88334	Closed
14	Waianakarua River	45.23302	170.86458	Closed
15	Back Creek	45.41272	170.82524	Closed
16	Stony Creek	45.50834	170.77621	Closed
17	Pleasant River	45.54309	170.71668	Open
18	Hawkesbury Lagoon	45.60499	170.67882	Closed
19	Karitane	45.62742	170.64959	Open
20	Doctors Point	45.73400	170.59571	Open
21	Purakanui Inlet	45.74925	170.63166	Open
22	Drivers Creek	45.75586	170.64740	Closed
23	Murdering Beach	45.76344	170.67153	Closed
24	Tomahawk Lagoon	45.90536	170.54033	Closed
25	Tomahawk Creek	45.90582	170.56519	Closed
26	Hoopers Inlet	45.86902	170.66328	Open

being present in 74% and 68% of the estuarine systems sampled respectively (Table 2).

SIMPER analysis (Table 3) indicates that both *T. novae-zealandiae* and *P. fluviatilis* were widespread in both open and intermittently closed estuaries and contributed over 50% to the similarity across each estuary type. The amphipod *Paracorophium excavatum* was important in open systems being present in 64% of these systems compared with 31% of closed systems. Conversely, chironomid taxa were important in closed systems, being present in 63% of closed systems compared with 25% of open systems. These taxa collectively explained 75% of the similarity among open or among closed systems. The remaining taxa contributed to no more than 10% each of the similarity among permanently open or intermittently closed systems.

MDS ordination of taxa presence/absence arranged estuaries by estuarine type (permanently open/intermittently closed) (2D Stress 0.14) (Fig. 1A). Comparison of community composition in permanently open and intermittently closed estuaries by ANOSIM indicated that communities in these types of system were significantly different from each other (ANOSIM; Global $R = 0.249$, $P < 0.01$). Separation of estuarine types was less evident when ordered by high and low salinity (Fig. 1B). Along MDS axis 2, three significantly different groups of taxa could be distinguished determined by the presence of only *T. novae-zealandiae* or only *P. fluviatilis* or both species together (Fig. 1C).

Ordination by MDS of similarity among species taxa distribution also indicated separation of estuary communities by their permanently open or intermittently closed status (2D Stress 0.07). Three significantly different groups of taxa could be distinguished in Fig. 2, with species present exclusively in intermittently closed estuaries to the right side of MDS axis 1 and species present exclusively in open estuaries to the left side of MDS axis 1, while species present in both estuary types occupied the middle of MDS axis 1. These three groups are significantly different from each other (ANOSIM Global $R = 0.33$, $P < 0.01$). No relationships between taxa and habitat variables were apparent along MDS axis 2. Whether a taxa is present exclusively in permanently open,

Table 2 Taxa list with percentage prevalence in 26 Otago estuaries, and presence of taxa in permanently open, intermittently closed or both estuarine systems.

Taxon	Order	% Prevalence	Distribution
Isopoda sp.	Isopoda	3	Open
Paramoera fasciculata	Amphipoda	3	Open
Amphipod sp.	Amphipoda	3	Open
Parawaldeckia kidderi	Amphipoda	3	Closed
Atyidae sp.	Decapoda	3	Closed
Coleoptera sp. 1	Coleoptera	3	Open
Coleoptera sp. 2	Coleoptera	3	Open
Limonia sp.	Diptera	3	Closed
Paroxyethira sp.	Trichoptera	3	Closed
Hirudinea sp.	Arhynchobdellida	3	Open
Hymenosomatidae sp.	Decapoda	3	Open
Daphnia sp.	Diplostraca	6	Closed
Liodessus plicatus	Coleoptera	6	Closed
Stratiomyidae sp.	Diptera	6	Closed
Culex sp.	Diptera	10	Closed
Collembola sp.	Collembola	10	Both
Gastrosaccus australis	Mysida	10	Open
Gobiomorphus sp.	Perciformes	13	Both
Melita awa	Amphipoda	13	Open
Microvelia sp	Hemiptera	13	Closed
Anisops sp.	Hemiptera	13	Closed
Pseudosphaeroma cambellensis	Isopoda	16	Open
Isocladus armatus	Isopoda	16	Open
Parathemisto sp.	Amphipoda	16	Both
Sigara sp.	Hemiptera	16	Closed
Copepoda sp.	Copepoda	19	Open
Neoscatella	Diptera	19	Both
Tenagomysis chiltoni	Mysida	19	Both
Tenagomysis macropsis	Mysida	29	Both
Chironominae	Diptera	39	Both
Paracorophium excavatum	Amphipoda	45	Both
Paracalliope fluviatilis	Amphipoda	68	Both
Tenagomysis novae-zealandiae	Mysida	74	Both

intermittently closed or in both types of systems is indicated in Table 2.

Numerically, *T. novae-zealandiae* was the dominant mysid in both systems, comprising about 75% of mysids in temporarily open/closed systems and 85% of mysid numbers in open systems (Fig. 3). *T. chiltoni* was relatively less abundant or absent in open systems, whilst *T. macropsis* and *Gastrosaccus australis* were relatively more abundant in open systems.

Discussion

Species distribution and richness

This study provides a late summer baseline survey of hyperbenthic species that inhabit the lower reaches of Eastern Otago estuaries. The broad spatial extent of this study enabled sampling from a wide range of estuarine types, but precluded examination of spatial or temporal variation within estuaries. Despite the limited

Table 3 Output of SIMPER analysis comparing the contributions of species similarities among (A) permanently open estuaries and the similarities among (B) intermittently closed estuaries.

Taxa	% Prevalence	Mean sim	Sim/SD	Cum%
(A) Open estuaries				
Tenagomysis novae-zealandiae	86	14.69	1.35	35.74
Paracalliope fluviatilis	71	8.69	0.95	56.88
Paracorophium excavatum	64	7.12	0.76	74.21
Copepoda sp	43	2.76	0.43	80.93
Tenagomysis macropsis	36	2.06	0.34	85.95
Isocladus armatus	36	1.95	0.34	90.70
(B) Closed estuaries				
Paracalliope fluviatilis	69	9.54	0.83	28.78
Tenagomysis novae-zealandiae	69	8.9	0.82	55.62
Chironominae	63	6.02	0.73	73.78
Sigara sp.	31	1.55	0.28	78.46
Paracorophium excavatum	31	1.53	0.27	83.09
Tenagomysis chiltoni	31	1.52	0.28	87.68
Neoscatella	31	1.31	0.29	91.65

Including the percentage of sites where the species is present (% prevalence), the mean similarity contributed by each species to the overall group similarity (mean sim), the standardised similarity (sim/SD), as well as the contribution as a cumulative percentage of the overall similarity (cum%).

extent of sampling within estuaries, some clear patterns were evident in Otago hyperbenthic estuarine communities that inhabit the mouth regions of estuaries. Mysids (*G. australis*, *Tenagomysis chiltoni*, *Tenagomysis macropsis* and *T. novae-zealandiae*) and amphipods (*Melita awa*, *Paracorophium* sp. and *P. fluviatilis*) were widespread among estuaries. Geographically, mysids were the most widespread group of hyperbenthic fauna in the Otago estuaries with only three estuaries having no mysids recorded. This pattern of mysid and amphipod dominance appears to be a common feature of hyperbenthic communities in temperate estuaries worldwide (e.g. Mees et al. 1995; San Vicente & Sorbe 1999; Mouny et al. 2000; Hirst 2004).

Relatively few taxa sampled were widely distributed across the sampled estuaries, with only two species, *P. fluviatilis* and *T. novae-zealandiae*, being recorded from >50% of estuaries sampled. On average, each taxon was recorded from only 15% of sites sampled. Hyperbenthic estuarine communities dominated by the presence of rare taxa was also reported by Hirst (2004) who found that nearly 50% of species collected in south east Australian estuaries were found at only one site. Drake et al. 2002 reported 134 fish and hyperbenthic species in the Guadalquivir Estuary (Spain) and concluded that over half (72) were present at only a few sites. Whilst it is unlikely that most hyperbenthic taxa are restricted to only a few estuaries in Otago, it is likely that as estuaries harbour temporally dynamic communities, only a few estuaries along the same coastline will harbour similar communities at any one time.

Open versus intermittently closed estuaries

Over half of the estuaries studied were closed at the time of sampling highlighting the significance of this estuarine type along the Otago coastline. As hypothesised *a priori*, a significant difference in hyperbenthic communities between open and intermittently closed estuaries was observed, with significant differences in overall community composition and in the relative

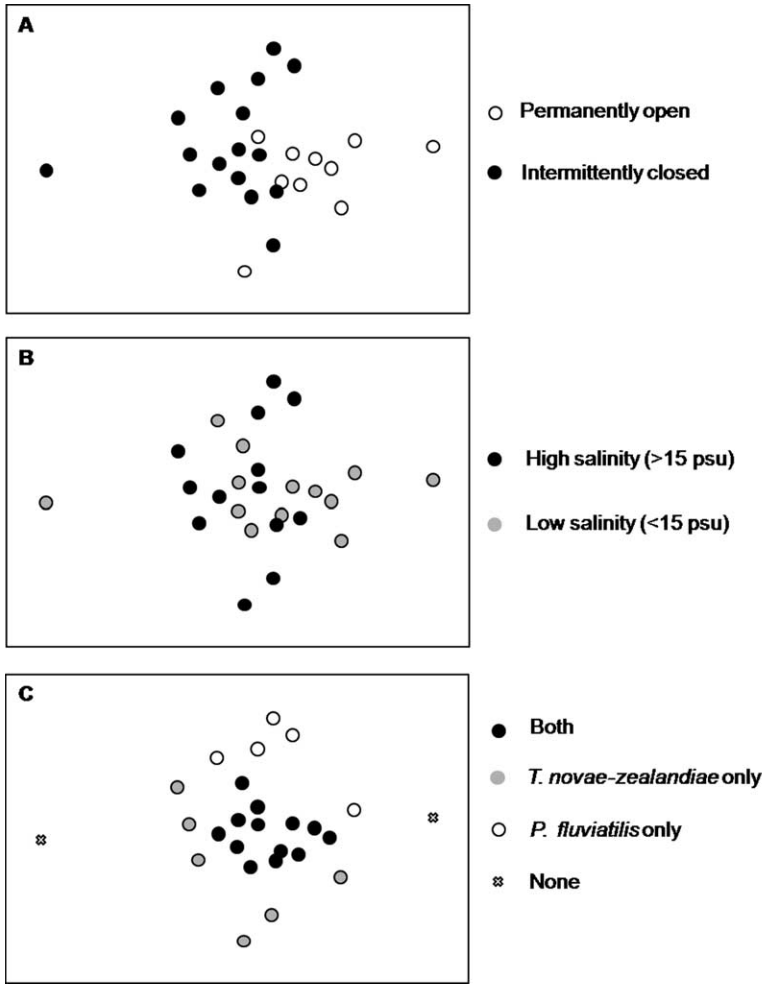

Figure 1 Multidimensional scaling (MDS) ordination of the similarity among estuaries sampled based on presence/absence of taxa. **A**, Key indicates whether estuary is classified as permanently open or intermittent closed. **B**, Key indicates whether estuary is classified as high (> 10 ppt) or low (< 10 ppt) salinity. **C**, Key indicates estuaries classified by the presence of *Tenagomysis novae-zealandiae* or *Paracalliope fluviatilis* or both.

abundance of mysid species. Species more typically associated with marine environments, such as *T. macropsis* (Chapman & Lewis 1976; Sutherland & Closs 2001a), were recorded more frequently from permanently open estuaries, whereas taxa generally associated with freshwater habitats, particularly various insects and *T. chiltoni* (Chapman & Lewis 1976), were recorded more frequently in the intermittently closed estuarine systems. Mysids were recorded from all estuarine types; four species were present in open estuaries, whereas only *T. chiltoni* and *T. novae-zealandiae* were recorded from intermittently closed estuaries. The occurrence of only these two species in intermittently closed systems is consistent with records of mysid abundance collected over one annual cycle in the intermittently closed Kaikorai

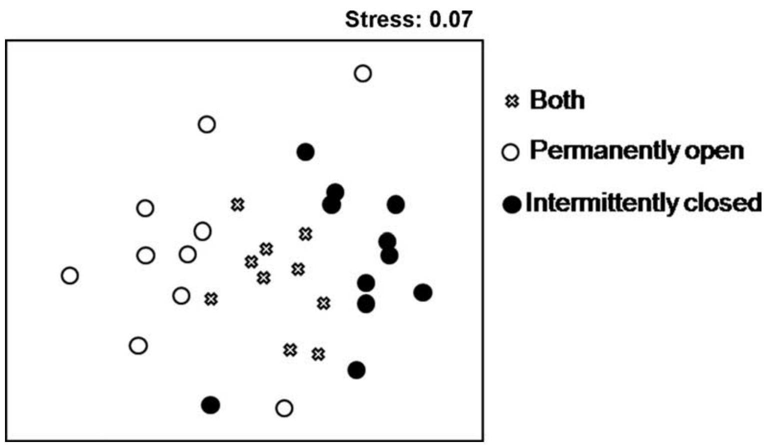

Figure 2 Multidimensional scaling (MDS) ordination of similarity among all taxa sampled based on presence or absence in estuaries. Key indicates whether taxa is present in: both permanently open and intermittently closed estuaries, exclusively in intermittent closed estuaries or exclusively in open estuaries.

Lagoon, where only *T. chiltoni* and *T. novae-zealandiae* were abundant and observed to reproduce during 2004 (Lill et al. 2010).

The greater separation of the sampled estuaries into groups based on estuarine type (permanently open versus intermittently

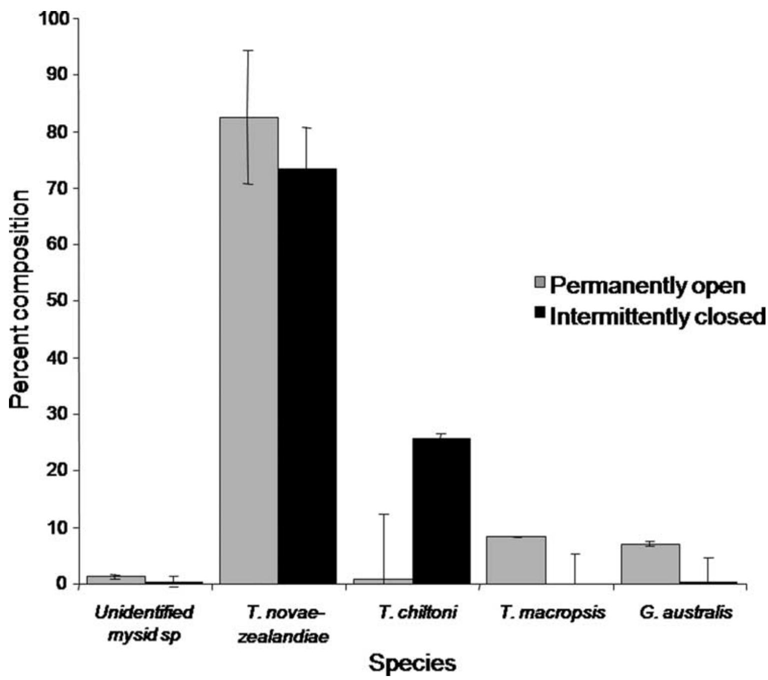

Figure 3 The mean relative abundance (±SE) of mysid species recorded in open and temporarily open/closed estuaries along the Otago coastline, 17–20 February 2004, $n = 28$.

closed), rather than by salinity, indicate community differences are most likely driven by a number of inter-related factors related to estuarine closure, rather than a single factor (Hirst 2004; Dye & Barros 2005a,b). Communities in intermittently closed estuaries are influenced by isolation from marine environments and the wide fluctuations in various physico-chemical factors associated with the occasional and irregular intrusion of seawater, compared with the cyclical tides that occur in permanently open estuaries (Edgar et al. 1999; Teske & Wooldridge 2001; Kibirige & Perissinotto 2003b; Kozlowski-Suzuki & Bozelli 2004; Dye & Barros 2005a,b). The degree of isolation because of barriers across the mouth of an estuarine system has consequences for its trophic and community structures (Dye & Barros 2005a,b; Thomas et al. 2005), as well as the size and genetic make-up of populations of species present (Carr et al. 2003). In the permanently open Taieri River estuary, a system sampled in this study, *T. macropsis* were recorded drifting into the estuary on incoming tides (Sutherland & Closs 2001a) and juveniles of fish with marine adult life-history stages have also been recorded (Sutherland & Closs 2001b), indicating that tidal exchange is important for maintaining the presence of certain species. Tidal conditions in intertidal creeks have been shown to be a major factor structuring hyperbenthic communities, especially mysid and amphipod assemblages (Hampel et al. 2003). Also, freshwater inflow is limited in intermittently closed estuaries and the rate of freshwater inflow has a major influence on community structure and diversity (Teske & Wooldridge 2001; Gillanders & Kingsford 2002).

The difference between permanently open and intermittently closed estuarine communities observed in this study is consistent with studies conducted overseas. Desmond et al. (2002) conducted a long-term study of three Californian estuaries and suggested that the closure of estuaries might play an important role in estuarine community structure including increased invertebrate density and decreased fish numbers. Edgar et al. (1999) reported that the presence of a bar across the estuary is the factor most strongly correlated with community structure in Tasmanian estuaries. Kibirige & Perissinotto (2003b) found that the opening of a lagoon increased the zooplankton diversity and drastically altered the food web structure. Hirst (2004) compared 28 estuaries in south-eastern Australia and found a significant difference in macrofaunal assemblages between open and closed estuaries. Teske & Wooldridge (2001) describe high hyperbenthic density in intermittently closed estuaries while species diversity is highest in permanently open estuaries in thirteen estuaries in South Africa. The results of this study provide further support for the view that altering the open/closed status of an estuary, for example, by altering upstream flow regimes or artificially opening natural sand barriers, will have significant impacts on estuarine community structure and composition.

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