Physical and biological characteristics of a rare marine habitat: sub-tidal seagrass beds of offshore islands

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ABSTRACT

Permanently submerged beds of seagrass (Zosteraceae) in coastal waters are rare in New Zealand, where most seagrass beds are confined to the intertidal zone of estuaries. This study describes some environmental conditions associated with submerged seagrass beds at Slipper and Great Mercury Islands. Field work was carried out in May–June 2004. The seagrass bed in South Bay, Slipper Island, is permanently submerged, grows to 4–5 m below chart datum, and covers an area of approximately $0.03 \, km^2$. In contrast, seagrass in Huruhi Bay, Great Mercury Island, was estimated to cover an area of approximately $0.07 \, km^2$, and the bed was more characteristic of mainland estuaries, with an intertidal component and a sub-tidal fringe to 1 m below chart datum. At Slipper Island, long leaves (up to 47 cm) combined with high percentage cover and biomass (74–229 g dry weight/m^2) provided a substantial three-dimensional habitat, supporting a higher macroinvertebrate abundance and diversity than Huruhi Bay or any of the Coromandel Peninsula sites previously reported. The two island locations supported fish assemblages that differed substantially from their mainland, intertidal counterparts. Huruhi Bay supported high abundances of exquisite goby (*Favonigobius exquistes*) and sand goby (*F. lentiginosus*), juvenile yellow-eyed mullet (*Aldrichetta forsteri*) and snapper (*Pagrus auratus*), with juvenile snapper densities being the highest ever recorded over seagrass in New Zealand. In contrast, South Bay supported a substantial population of an undescribed pipefish (*Stigmatopora* cf. *macropterygia*), but only low numbers of other fish species. The Slipper Island site is an excellent example of the high potential ecosystem value of sub-tidal seagrass beds.

Keywords: seagrass, *Zostera*, marine habitat, macroinvertebrates, juvenile fish

1. Introduction

Permanently submerged beds of seagrass (Zosteraceae) in coastal waters are rare in New Zealand, where most seagrass beds occur in the intertidal zone of estuaries. The degree to which submerged seagrass beds existed historically is uncertain, but there is evidence to suggest that their extent in many New Zealand estuaries and harbours has decreased over time (Inglis 2003). Evidence from elsewhere in the world would suggest that such reductions may be linked to environmental changes resulting from catchment and in-harbour development, including reduced water clarity, increased sedimentation and increased epiphyte growth. (Walker & McComb 1992; Short & Wyllie-Echeverria 1996; Kirkman 1997).

Permanently submerged seagrass has been reported at a small number of locations in New Zealand, predominantly on offshore islands such as the Bay of Islands, Slipper Island, the Cavallis and Great Mercury Island (Grace & Whitten 1974; Grace & Grace 1976; Grace & Hayward 1980; Hayward et al. 1981). Prior to this study, we knew that seagrass at Slipper Island at least was still present in 2004 (National Institute of Water & Atmospheric Research (NIWA), unpubl. data). The occurrence of isolated beds of submerged seagrass in the relatively high-clarity water at Slipper Island attests to the potential for New Zealand seagrass to form extensive sub-tidal beds, and allows us to test hypotheses about the environmental conditions required to support these.

The New Zealand seagrass flora is represented only by the genus *Zostera*. There have been a number of revisions to the number and names of species of *Zostera* in New Zealand (for discussion see Turner & Schwarz 2006b), but recently Les et al. (2002) recommended the taxonomic merger of Australian/New Zealand *Zostera* within a single species, *Zostera capricorni*; therefore, we have adopted *Z. capricorni* for the purpose of this report. Subsequent genetic and morphological analysis of Australian seagrass has also indicated that *Z. capricorni* and *Z. muelleri* should be considered synonymous (Waycott et al. 2004).

Seagrass beds perform a variety of functions in estuarine and coastal ecosystems, including primary production, the trapping and stabilisation of bottom sediment, nutrient cycling, and the provision of habitat. van Houte-Howes et al. (2004) showed that macroinvertebrate diversity within and adjacent to intertidal seagrass beds in New Zealand was variable, and differed at a range of scales. In general, sediments with low seagrass biomass supported similar macroinvertebrate assemblages to those with no vegetation; however, these assemblages were distinct from those found in high-seagrass-biomass areas. There is evidence that sub-tidal seagrass beds in New Zealand may be of much greater importance as juvenile fish habitat than either bare sediment or intertidal seagrass beds (Morrison & Francis 2001), as has been found elsewhere in the world (e.g. Hemminga & Duarte 2000).

The absence of submerged seagrass from New Zealand harbours has largely been attributed to the poor light climate (Inglis 2003; Schwarz 2004) and for the purpose of this study we hypothesised that submerged seagrass has persisted around Slipper Island due to the expected near-oceanic water clarity. This study

aimed to determine the extent and biomass of the known sub-tidal seagrass beds around Slipper Island, and the historically reported sub-tidal seagrass beds around Great Mercury Island, both of which fall within the boundary of Waikato Conservancy, Department of Conservation (DOC).

This study describes characteristics of the seagrass beds and some relevant environmental conditions where the beds are found, and assesses the diversity of associated fish and macroinvertebrates. Results are compared with historical data and with existing knowledge of habitat characteristics of intertidal beds in nearby Coromandel estuaries. The aim is to increase our understanding of the role that these rare habitat types play in the ecosystem, which in turn will enhance our ability to set environmental targets for the restoration of sub-tidal seagrass at locations where it is thought to have existed previously.

2. Methods

2.1 SITE DESCRIPTION

South Bay, Slipper Island, was visited on 4 May 2004 and 10 June 2004, and Great Mercury Island was visited on 5 May 2004. The sub-tidal seagrass beds reported for Great Mercury Island by Grace & Grace (1976) were in Huruhi Bay (Mercury Cove). We revisited this site, with the intention of confirming its existence and sampling it, using the methods outlined below. Time constraints precluded an extensive survey of bays other than those where submerged seagrass had previously been reported. However, the combined local knowledge of the divers on the boat, the charter skipper and other local divers suggest that South Bay at Slipper Island, and Huruhi Bay and the adjacent bay, Parapara Bay, at Great Mercury Island are the only places where submerged seagrass is currently known to occur on these two islands.

All collections for this study were made within the seagrass bed in South Bay (Fig. 1) and at the northern end of Huruhi Bay (Fig. 2). All subsequent references to 'Slipper' and 'Great Mercury' refer to these bays unless otherwise stated.

2.2 SEAGRASS AND MACROINVERTEBRATE CHARACTERISTICS

The area of the seagrass beds could only be estimated in this study owing to limited time and weather constraints on the work. Surface GPS positions and water depths of the shallow and deep boundaries of the seagrass beds were marked on bathymetric charts. Maximum depth boundaries were determined by snorkel or SCUBA divers as the point where seagrass cover exceeded 5%. This decision rule underestimates the potential niche available for seagrass growth (i.e. some plants will extend beyond this point). An additional source of error in this estimate is the fact that observing minimum and maximum depths alone does not account for bare patches within the bed.

Figure 1. Map of Slipper Island on the Coromandel Peninsula showing the location of the seagrass bed in South Bay (black area).
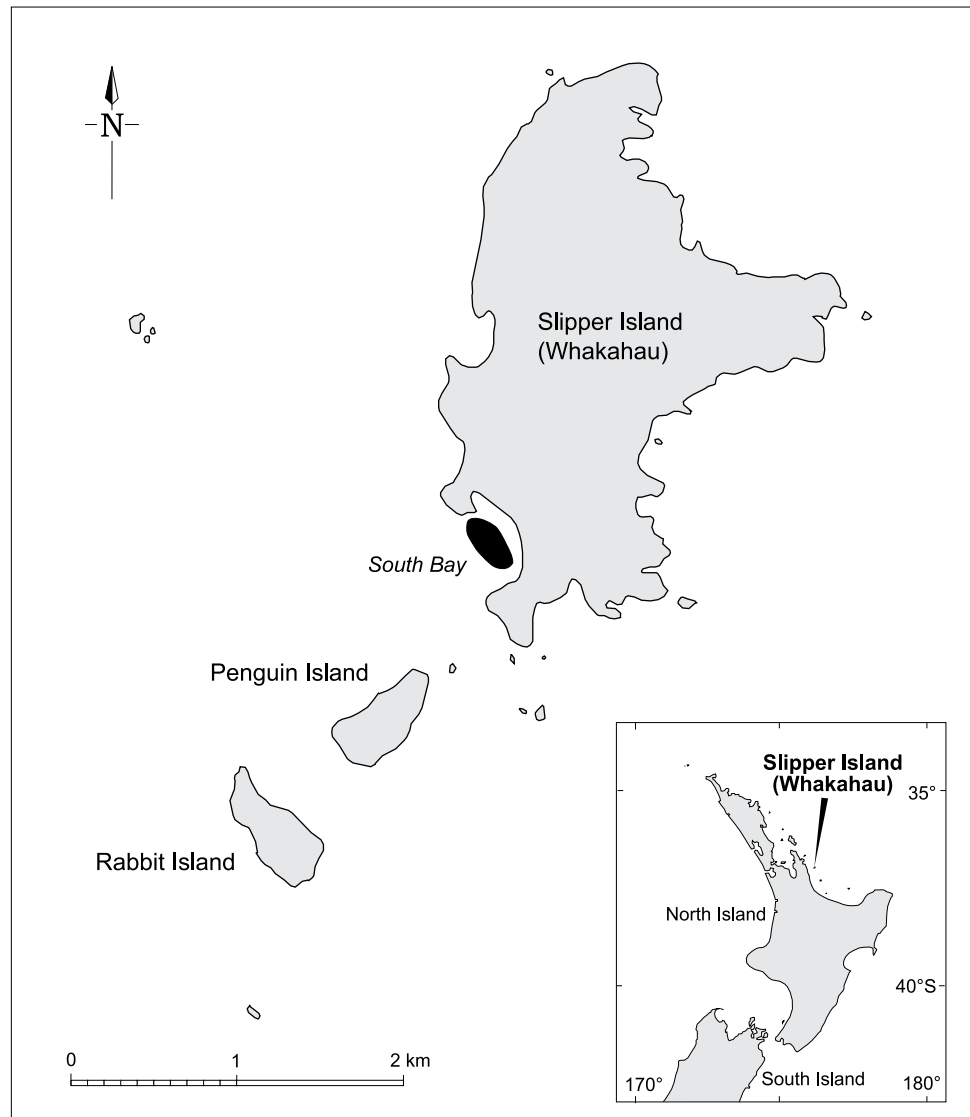
Three temporary 50-m-long transects were laid within each seagrass bed. The start point of each transect was chosen haphazardly, and transects were laid perpendicular to the shore (i.e. along the depth gradient). At Slipper Island, percentage cover of seagrass was estimated within a 1-m² quadrat at 2-m intervals along the transect by a SCUBA diver. In addition, where visibility was sufficiently high, each transect was videoed using a diver-held digital video camera at a fixed height of 70 cm above the bottom. The video footage was used to confirm cover estimates, and still images were captured to provide a reference for cover estimates in any future work. In Huruhi Bay, no deep seagrass beds were found, so measurements were made in shallow (< 0.5 m) water using snorkel or by wading and no video footage was made. These beds were more similar in appearance to sub-tidal fringes seen in mainland estuaries.

We estimated percentage cover to the nearest 5%, and subsequently placed estimates into the cover scale of Braun-Blanquet (Braun-Blanquet 1932). This is an international standard for estimating seagrass cover and has the advantage of reducing observer bias. The technique involves estimating percentage cover within five cover classes: 1 = 1%-5%; 2 = 6%-25%; 3 = 26%-50%; 4 = 51%-75%; 5 = > 75% (Appendix 1).

Figure 2.   North end of Great Mercury Island on the Coromandel Peninsula. Seagrass, fish and macroinvertebrate samples were collected in Huruhi Bay, Mercury Cove (black areas).
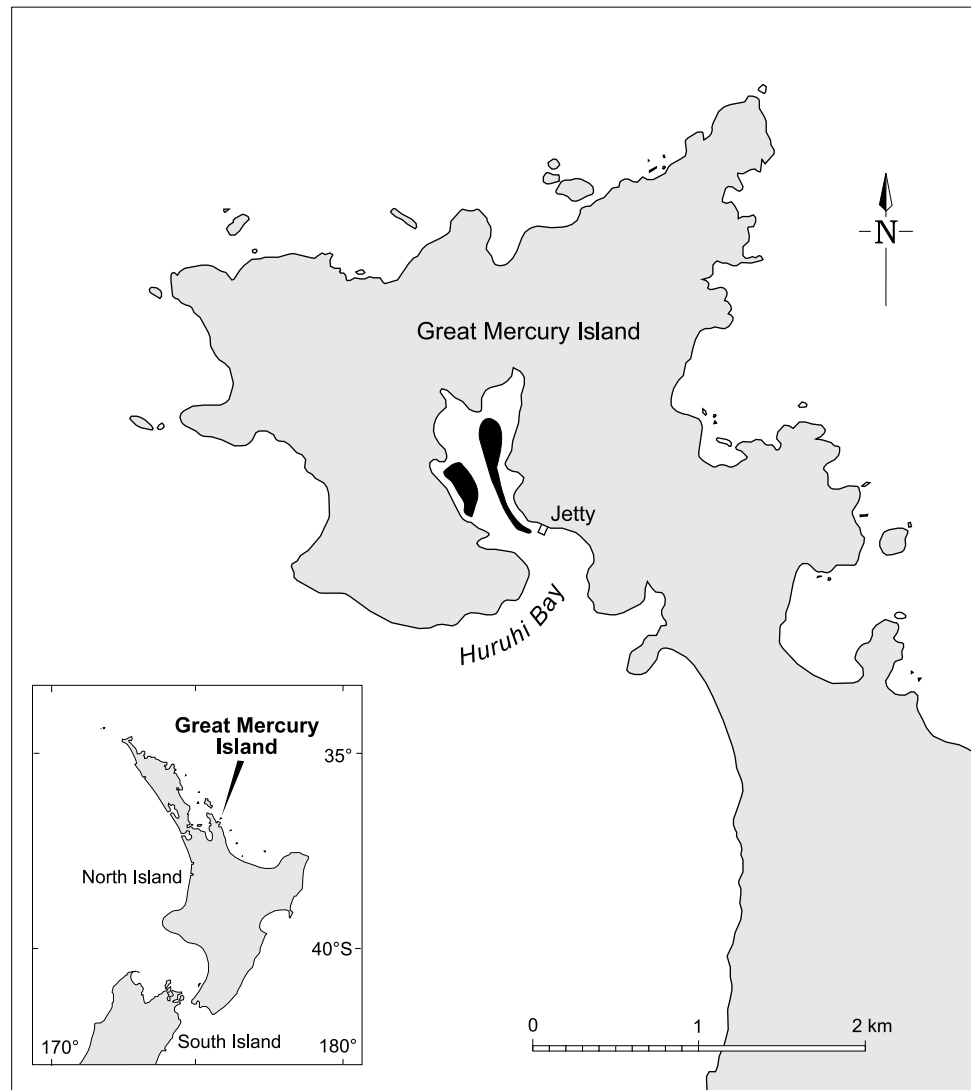
Once cover had been estimated, four cores (10-cm diameter, 15-cm deep) were placed at random intervals along each transect where seagrass occurred (+SG). One additional core was placed adjacent to, and within 1 m of, a +SG collection site in an area with no seagrass (−SG). Cores were pushed into the sediment by divers, ensuring that all leaf material within the area of the core was included. All material within the core was collected and intact cores were returned to the surface for processing.

A small sub-sample of the top 2 cm of sediment was removed from the core for later grain-size analysis. Sediment grain size, determined on a Galai particle analyser (Galai Cis–100; Galai Productions Ltd, Midgal Haemek, Israel), was then used to calculate percentage volumes for the sand (63 µm–2 mm), silt (4–63 µm) and clay (< 4 µm) fractions.

Seagrass material was separated from the sediment and thoroughly rinsed through a 1-mm sieve to ensure the removal of attached sediment and invertebrates. The maximum length of the first three plants haphazardly selected from within each core was recorded. In the laboratory, plant material was separated into above- and below-ground plant parts, oven dried for 48 h at 80°C and weighed. Biomass was expressed as g dry weight (DW)/m^2.

The remainder of the core material was sieved through the 1-mm mesh and preserved in 70% isopropyl alcohol and 0.1% Rose Bengal for return to the laboratory and subsequent enumeration and identification of macroinvertebrates. Resource constraints have precluded the counts and identification of all macroinvertebrate samples to date, as the numbers of individuals collected were higher than expected. We have taken the approach of fully processing one +SG and –SG pair from each of the three transects. One additional +SG sample was processed from Slipper, resulting in a total of 13 samples. The remaining three +SG samples from each transect have been sorted and are stored at NIWA, Hamilton. For each of the 13 fully processed samples, the total number of individuals in each sample was enumerated and each individual was identified to the lowest taxonomic level possible. Similarity in macroinvertebrate abundance between sites was examined through multidimensional scaling ordination (MDS) (Field et al. 1982) using PRIMER. The abundance data were not transformed and were based on Bray-Curtis similarities.

During the field work at both Slipper and Great Mercury Island, C. Duffy (DOC) recorded macrofaunal taxa that were observed incidentally within the seagrass bed. These observations are appended to this report (Appendix 2).

2.3 FISH

2.3.1 Beach seine (Slipper Island and Great Mercury Island)

The small-fish assemblages present at the two locations were sampled using a standardised beach seine (Morrison et al. 2002). This involved the deployment of a small-mesh beach seine: 11-m wide, with 9-mm mesh, a 2.3-m drop, and a 4-m-long cod-end. This net was set parallel to the shoreline (from an inflatable boat for Slipper Island and by hand for Great Mercury Island), and then hauled straight to the shore. During the initial trip to Slipper Island on 4 May 2004, four beach-seine shots were completed before deteriorating weather conditions forced us to abandon this location in the late afternoon and head north to Great Mercury Island. The seagrass-bed edge started at c. 30–40 m from the shore; since only c. 50 m of warp (the rope by which the net is towed) was available, only the edge of the seagrass bed was sampled, along with a significant area of shallow sandy beach.

We returned to Slipper Island 5 weeks later on 10 and 11 June, and completed a further eight beach-seine tows using a longer warp length of c. 150 m. These tows sampled a substantially greater area of seagrass habitat than the previous tows in May.

At Great Mercury Island, the seagrass bed was much more localised and patchy in extent. On 5 May, eight beach-seine tows were completed around inner Huruhi Bay, within a 3-hour time window either side of low tide. Since no aerial photographs or seagrass distribution maps were available, tow placement was made adaptively in the field, and effectively followed the U-shaped low-tide contour. For each tow, an estimate was made of the distance towed, the water

depth at the start of the tow, and the percentage cover of seagrass across the overall extent swept by the beach seine. Tow lengths ranged from 35 m to 70 m, and were placed across the limited area available so that no two tows overlapped in their spatial extent.

For all beach-seine tows, the catch was sorted in the field, identified to species, measured to the nearest millimetre, and released alive where possible. Any remaining catch was bagged, labelled and frozen, and processed back in the laboratory in the same manner. For catches of individual species exceeding 100 fish, sub-samples of at least 50 fish or 25% of the catch were measured.

2.3.2 SCUBA visual counts (Slipper Island)

Until recently, few species and low abundances of small fishes have been found using visual searches over seagrass and other shallow-water soft-sediment habitats in New Zealand, despite quantitative evidence from other sampling methods (beach seines and beam trawls) showing that fish are present in relatively high abundances (MM, unpubl. data). However, recent night-diving work has found that many fish species not visible during the day can be counted and their size estimated while sleeping on the seafloor during the hours of darkness (MM, unpubl. data).

Visual SCUBA fish counts were undertaken at Slipper Island on 10 June. Belt transects of 50 m × 5 m were deployed across both seagrass ($n = 8$) and bare-sand ($n = 6$) sites during the day, and repeated during the hours of darkness (when the transect extents were effectively reduced to 50 m × 3 m, due to reduced visibilities when using dive torches to search under the seagrass canopy). All fish encountered were identified to species and, based on their size, placed into juvenile or adult categories. For snapper (*Pagrus auratus*) and red mullet (*Upeneichthys lineatus*), these size classes were 0+ (< 100 mm); 1+ (100–150 mm); and sub-adult/adult individuals (> 150 mm).

2.4 WATER CLARITY

Depth profiles of photosynthetically available radiation (PAR) were made using a PUV500 profiler (Biospherical Instruments Inc.) on 4 May 2004 at Slipper and 5 May 2004 at Great Mercury. To further characterise water clarity in the region, depth-profiles of PAR were measured at six locations between Tairua Harbour and Slipper Island on 24 August 2004. The locations of these were Tairua Harbour; south of Pauanui; west of Slipper Island; South Bay, Slipper Island; Home Bay, Slipper Island; and east of Slipper Island. In general, PAR entering the water is attenuated exponentially with increasing depth; therefore, from the PUV500 data, the rate of attenuation (attenuation coefficient for downwelling irradiance (K_d)) of PAR can be calculated by log-linear regression of irradiance values with depth (Kirk 1994). Water samples were collected from the mixed surface layer and filtered through GFF filters in the laboratory for analysis of total suspended solids (TSS) and Chlorophyll-*a* (Chl-*a*) concentration, two primary determinants of water clarity (Davies-Colley et al. 1993).

3. Results

3.1 SEAGRASS CHARACTERISTICS

South Bay, Slipper Island, is sheltered to the east (Fig. 1) and has a sandy bottom and clear water. Seagrass covered an area of c. $0.03\,km^2$ within the bay at a depth of up to 4–5 m below chart datum. Areas of physical disturbance were clearly visible within the South Bay seagrass beds.

Huruhi Bay, Great Mercury Island, is sheltered from winds from a northerly quarter and has a maximum depth of < 5 m at the entrance to the bay (Fig. 2). Seagrass beds occurred as fringes in the intertidal region around the bay, in some places extending into the sub-tidal region to a maximum depth of 1 m below chart datum, and covered an area of c. $0.07\,km^2$ (Fig. 2).

Seagrass at both Great Mercury and Slipper has the same morphological characteristics as *Zostera capricorni*; investigation of the genetic similarity between the submerged Slipper seagrass and Coromandel estuary seagrass is pending (T. Jones, University of Waikato, pers. comm.).

Above-ground biomass at Slipper ranged from $65.4\,g\,DW/m^2$ to $298.8\,g\,DW/m^2$ (mean ± SEM = $154.5 ± 27.1\,g\,DW/m^2$) over the three transects; samples were taken in areas that ranged from 30% to 95% cover. Below-ground biomass ranged from $131.4\,g\,DW/m^2$ to $615.9\,g\,DW/m^2$ (mean ± SEM = $298.3 ± 48.6\,g\,DW/m^2$). The overall above- to below-ground ratio was 0.53. In contrast, the above- to below-ground ratio at Great Mercury was only 0.21, primarily due to a lower above-ground biomass. Both above- and below-ground biomass were significantly less at Great Mercury than at Slipper (two-sample t-test; above: $t = 5.08$, df = 21, $P < 0.001$; below: $t = 1.943$, df = 22, $P < 0.001$). Above-ground biomass at Great Mercury ranged from $17.6\,g\,DW/m^2$ to $59.3\,g\,DW/m^2$ (mean ± SEM = $35.5 ± 4.3\,g\,DW/m^2$), which is c. 23% of that at Slipper. Below-ground biomass at Great Mercury ranged from $53.3\,g\,DW/m^2$ to $425.9\,g\,DW/m^2$ (mean ± SEM = $197.9 ± 34.6\,g\,DW/m^2$).

Leaf length at Slipper ranged from 17.5 cm to 48 cm (mean ± SEM = $28.8 ± 1.7$ cm), which was significantly longer than at Great Mercury (range = 6–13 cm; mean ± SEM = $7.8 ± 0.3$ cm) (two-sample t-test; $t = 12.24$, df = 70, $P < 0.001$). Where seagrass occurred, percentage cover ranged from cover class 1 to 4 (5%–60%) at Great Mercury, and from cover class 2 to 5 (10%–95%) at Slipper (Appendix 3).

3.2 MACROINVERTEBRATES

In total, 77 taxa, belonging to at least 57 different families, were identified from the macroinvertebrate core samples (Appendix 4). By far the greatest number of taxa and the most abundant invertebrates were found within the Slipper Island seagrass: twice as many taxa and more than three times the number of individuals were found within Slipper seagrass compared with bare adjacent sediments and +SG or –SG samples from Great Mercury (Fig. 3).

The greater number of taxa in Slipper +SG samples was due to an increase across all taxonomic groups, but especially in the Amphipoda, Bivalvia and Decapoda. Markedly higher abundances were notable for Polychaeta and Amphipoda. The multidimensional scaling ordination (MDS) plot (Fig. 4) indicates that there was a difference in macroinvertebrate community composition between the Slipper sites, and that the Slipper sites also differed from Great Mercury; the +SG Slipper samples were more similar to each other than any of the other samples. There was no evidence of any differences between the Great Mercury sites with and without seagrass; further statistical analysis has not been attempted because of the small sample size.

Figure 3. Number of macroinvertebrate taxa (A) and abundance of all taxa (B) at Slipper (S) and Great Mercury (GM) Islands with (+SG) and without (–SG) seagrass (*Zostera capricorni*). Data are means (±SEM) per 0.01-m^2 core.
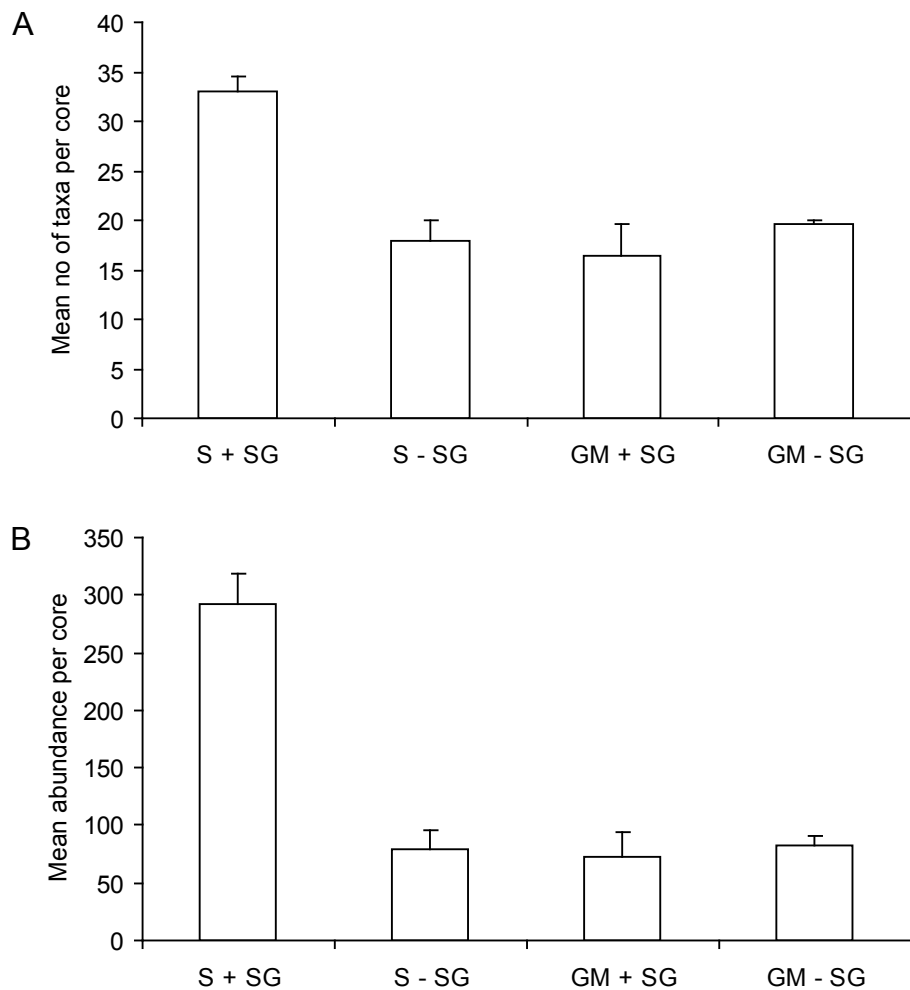
Figure 4. Multidimensional scaling ordination (MDS) of macroinvertebrate abundance data from samples taken from Slipper Island (S) and Great Mercury Island (GM) with (+SG) and without (-SG) seagrass (*Zostera capricorni*). Positions are based on Bray-Curtis similarities of untransformed data (stress = 0.1). The distance between samples is proportional to their relative similarity. Slipper Island plus seagrass (S+SG) samples are grouped to the left.
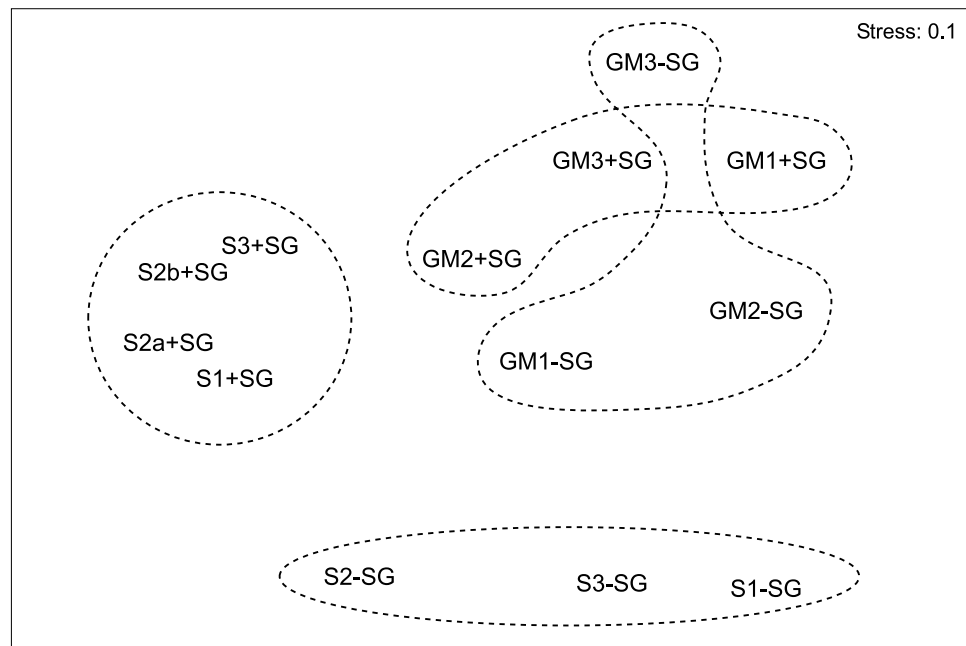
3.3   FISH

In total, 25 fish species were sampled from the beach-seine and dive-count surveys, although only nine of these species were represented by more than ten individuals (Table 1). The presence of juveniles (less than 1 year old) of several commercial species was a feature of the samples collected by beach seine at both Slipper Island and Great Mercury Island.

3.3.1   Beach seine

In the Slipper Island samples collected during May, there was a very limited fish assemblage, consisting of large adult garfish (piper, *Hyporhamphus ihi*), along with modest numbers of juvenile kahawai (*Arripus trutta*), broad squid (*Sepioteuthis bilineata*) and snapper (Table 1, Fig. 5). It is likely that the garfish and kahawai were encountered while the net swept the sandy beach area that was inshore of the edge of the seagrass bed, as these species are often a common feature of such beaches, irrespective of the presence of seagrass (MM, pers. obs.).

During June, we used much longer tow warps when sampling Slipper Island, and swept substantial areas of sub-tidal seagrass. These samples were dominated by a pipefish species (*Stigmatopora* cf. *macropterygia)* that is known to taxonomists but has not yet been formally described (M. Francis, NIWA Wellington, pers. comm.; Paulin & Roberts 1992), and that may be a hybrid between *S. macropterygia* and an Australian species *Stigmatopora argus*, which may have relatively recently invaded New Zealand waters. Both juveniles and adults were present (Fig. 5), with an average overall estimated density of 0.76 ± 0.25 fish per $100\,m^2$. However, densities of this species were likely to have been greatly underestimated. Observations of the cod-end made on snorkel showed that at least half of the individuals of this slender-bodied species managed to escape through the meshes during towing. In addition, the strong benthic

TABLE 1.   FISH-SAMPLING CATCH SUMMARY FROM BEACH-SEINE AND SCUBA FISH COUNTS.

Beach-seine samples were taken from Te Huruhi Inlet, Great Mercury Island, during May, and from South Bay, Slipper Island, during May and June. SCUBA fish counts were only taken from South Bay, Slipper Island, during May and June. Separate counts from samples taken during the day and night from areas with and without seagrass (*Zostera capricorni*) are shown.

COMMON NAME	SCIENTIFIC NAME	BEACH SEINE			VISUAL UNDERWATER COUNTS			
		GREAT MERCURY	SLIPPER		SLIPPER			
					SEAGRASS		NO SEAGRASS	
		MAY	MAY	JUNE	DAY	NIGHT	DAY	NIGHT
Exquisite goby	*Favonigobius exquistes*	765						
Sand goby	*Favonigobius lentiginosus*	761						
Yellow-eyed mullet	*Aldrichetta forsteri*	502	7	1				
Snapper	*Pagrus auratus*	249	6	7		7		
Triplefin	*Grahamina capito*	16						
Kahawai	*Arripus trutta*	9	29	6				
Sand flounder	*Rhombosolea plebeia*	9						
Trevally	*Pseudocaranx dentex*	6						
Spotty	*Notolabrus celidotus*	5						
Parore	*Girella tricuspidata*	4						
Clingfish sp.	Gobiesocidae	3						
Gurnard	*Chelidonichthys kumu*	1		1				
Red mullet	*Upeneichthys lineatus*	1		7	1	54		3
Broad squid	*Sepioteuthis bilineata*		10	1		6		4
Garfish	*Hyporhampus ihi*		128					
Speckled sole	*Peltorhamphus latus*		1					
Brown topknot	*Notoclinus compressus*			1				
Triplefin	*Grahamina nigripenne*			1				
Pipefish sp.	*Stigmatopora* sp.			82				
Northern bastard red cod	*Pseudophycis breviuscula*					5		
Triplefin sp.	*Grahamina* sp				2	1		
Short-finned eel	*Anguilla australis*					2		
Snake eel	*Ophisurus serpens*				1	1		
Eagle ray	*Myliobatis tenuicaudatus*					1		
Leatherjacket	*Parika scaber*					1		
Slender roughy	*Optivus elongatus*							1
Total fish sampled		2331	181	107	4	78	0	8

association of this fish with the seagrass canopy was also likely to have reduced its susceptibility to capture by the net's lead-line. Other species caught in low abundances included juvenile snapper, kahawai, and red mullet.

The second beach-seine event (June) was undertaken to rectify the issue encountered in the May event of only being able to sample the very inner fringe of the seagrass bed, due to insufficient net warp lengths. These two beach-seine sampling events (May and June) are thus not directly comparable, as not only were they undertaken in different months, but they sampled different proportions of the seagrass bed. However, overall they showed that the small-fish fauna of the Slipper Island sub-tidal seagrass bed was quite limited (at least during May–June), with the exception of a substantial population of the undescribed *Stigmatopora* pipefish species.
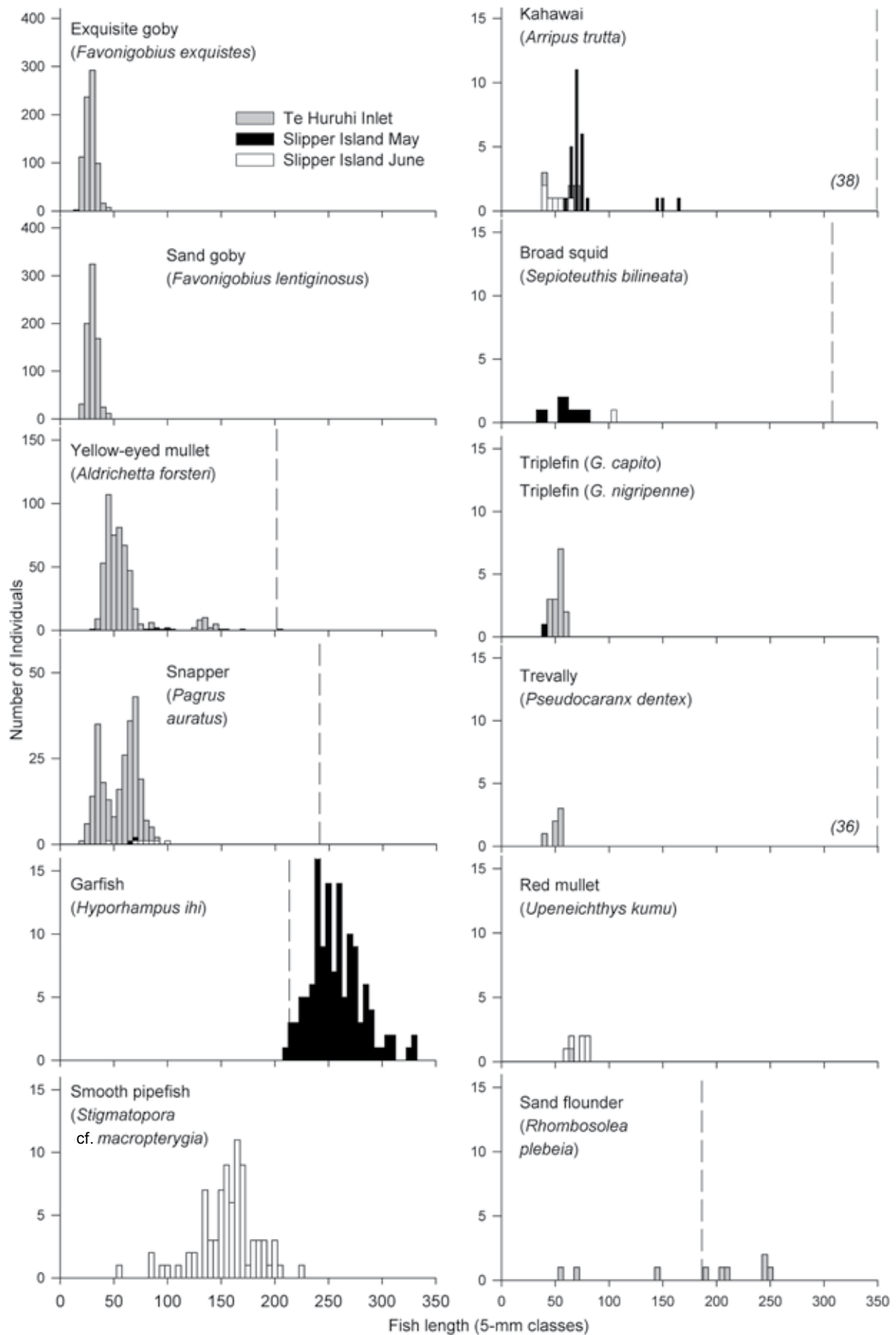
Figure 5. Size frequencies of 12 species of fish sampled by beach seine from South Bay, Slipper Island, and Huruhi Bay, Great Mercury Island. Dotted vertical lines denote length at maturity where known; taken from a range of primary sources, cited in Hurst et al. (2000).

In the beach-seine samples collected at Great Mercury Island during May, there was a very different small-fish assemblage, with 13 fish species being encountered. Of these, four species dominated the catch (exquisite goby (*Favonigobius exquistes*), sand goby (*F. lentiginosus*), yellow-eyed mullet and snapper), making up 97% of all individuals (Table 1). The goby populations consisted of both juveniles and adults, while the yellow-eyed mullet and snapper were all juveniles (Fig. 5). Low numbers of other species were also present, including triplefins (*Grahamina nigripenne*), kahawai, sand flounder (*Rhombosolea plebia*), trevally (*Pseudocaranx dentex*), spotty (*Notolabrus celidotus*) and parore (*Girella tricuspidata*).

Perhaps the most significant finding was the presence of very high densities of juvenile 0+ snapper (less than 1 year old). These fish had a bimodal distribution, with peaks around 35 mm and 70 mm fork length; this bimodal recruitment is a consistent feature of north-eastern-coast snapper populations.

As the seagrass bed in Huruhi Bay was relatively patchy, each beach-seine shot encountered a different set of habitat elements, resulting in differing relative fish contributions from seagrass and sand habitats (along with the added variable of differing water depths). Thus, it is not appropriate to calculate 'average' abundances across the bay. Instead, we present abundances for each beach-seine shot, expressed as the number of individuals per 100 m^2 swept (Fig. 6).

Of the eight beach-seine shots, two had no seagrass present (M1 and M2); the remaining six tows (M3–M8) broadly represented a gradient of increasing water depth and had a variable degree of associated seagrass cover.

Exquisite and sand gobies were present in all beach-seine tows, with the highest abundance being found in tows M4 and M5 (associated with high seagrass cover in very shallow water). Yellow-eyed mullet were very common over tows M1–M6, but were largely absent from tows M7 and M8, which represented deeper water sites with relatively extensive sub-tidal seagrass strips. Snapper were absent from tows lacking seagrass (M1 and M2) and those with seagrass cover in very shallow water (less than 20 cm; M3 and M4), but rapidly increased in abundance with increasing water depth and associated seagrass cover (M5–M8). These 0+ snapper abundances are the highest we have ever encountered during our sampling of both seagrass and other soft-sediment habitats in estuaries around northern New Zealand (NIWA, unpubl. data). Other species were only present in very modest abundances, but species that appeared to favour the deeper water/seagrass tows included juvenile trevally, red mullet, and spotties. Kahawai and triplefins showed no apparent pattern. MDS of the eight beach-seine sites indicated that sites M7 and M8 were different from the preceding sites (Fig. 7); this result is likely to have been driven by the very low abundance of yellow-eyed mullet and high abundance of snapper, along with the lesser contributions of some other species.
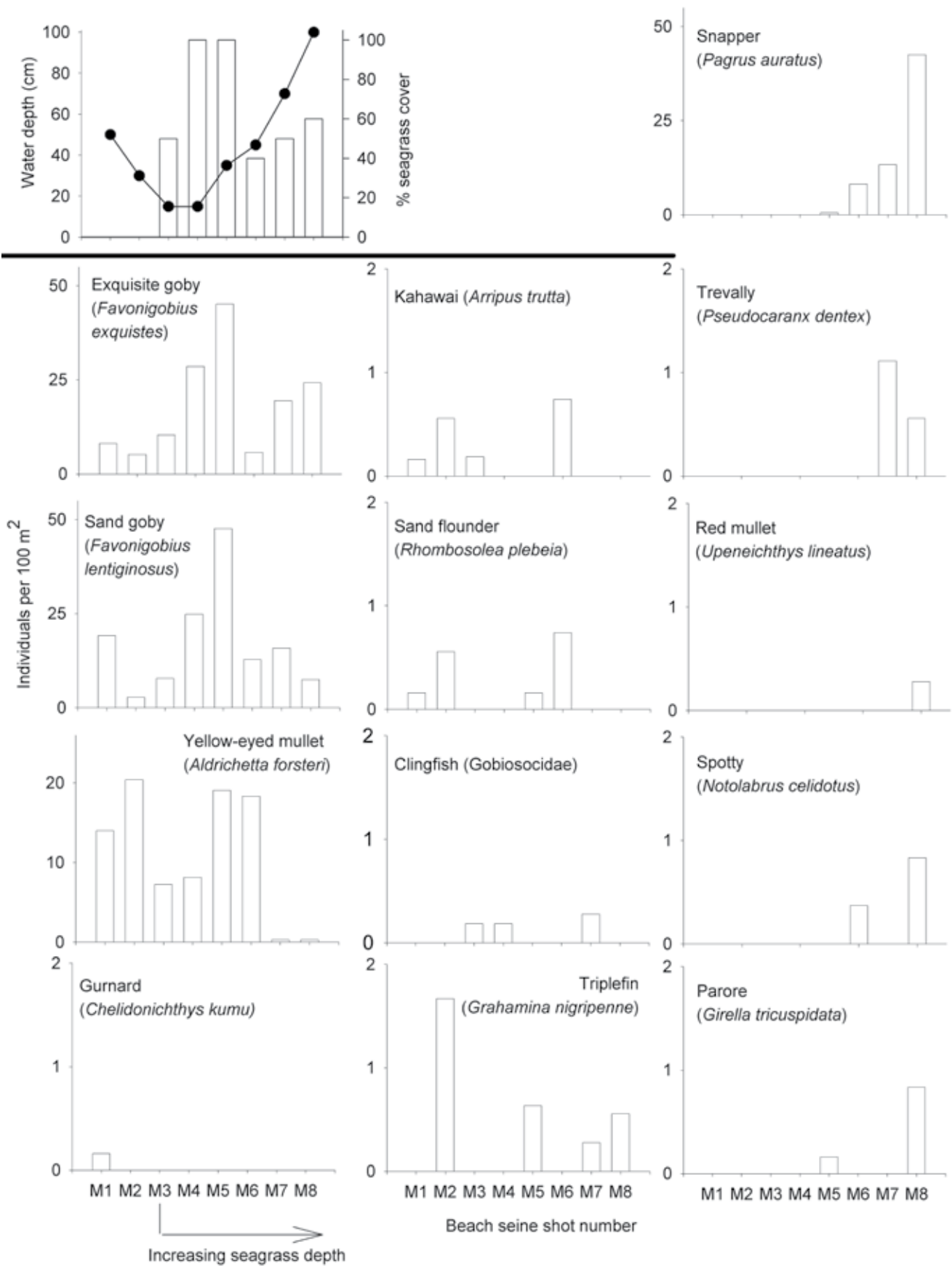
Figure 6. Density of 13 fish species found in each beach-seine shot at Huruhi Bay, Great Mercury Island. The upper left-hand graph shows estimated water depth (line) and seagrass (*Zostera capricorni*) cover (bars) for each tow.

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A comparison can be made between the May beach-seine samples from Great Mercury and Slipper Islands. MDS showed that these two locations have fundamentally different small-fish assemblages (Fig. 8). This was probably driven by the complete absence of the two goby species from the Slipper Island sites, along with very few yellow-eyed mullet and snapper, compared with high abundances of these species at the Great Mercury Island sites. In contrast, large numbers of garfish were sampled at the Slipper Island sites but were not sampled at Great Mercury Island (although large numbers were seen in the shallow waters of the bay during the hours of darkness, suggesting that diurnal behavioural patterns accounted for their absence from low-tide day samples, rather than this being a true absence).

Figure 7. Multidimensional scaling ordination (MDS) of fish beach-seine data from Huruhi Bay, Great Mercury Island. Positions are based on Bray-Curtis similarities of square-root transformed data (stress = 0.04). The distance between samples is proportional to their relative similarity. The deeper seagrass (*Zostera capricorni*) tows M7 and M8 are grouped to the right.
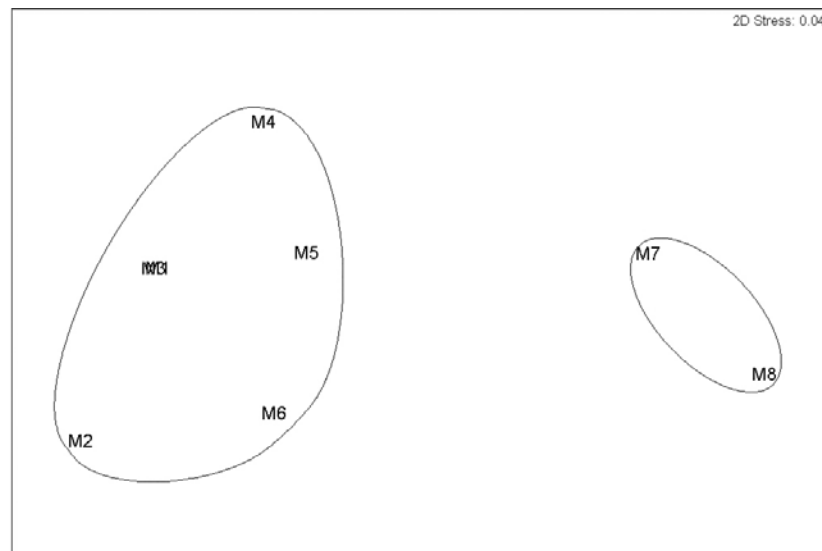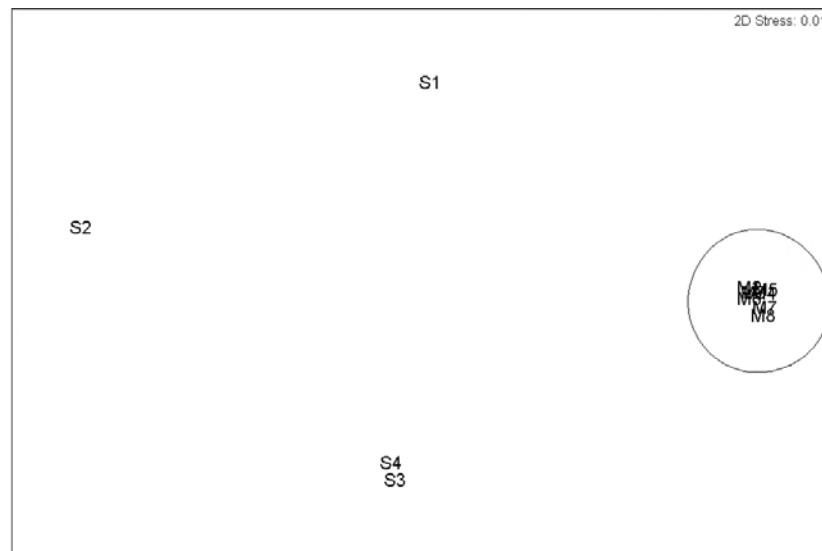

Figure 8. Multidimensional scaling ordination (MDS) of fish beach-seine data from Huruhi Bay, Great Mercury Island (M), and South Bay, Slipper Island (S). Positions are based on Bray-Curtis similarities of square-root transformed data (stress = 0.01). The distance between samples is proportional to their relative similarity.

3.3.2   SCUBA fish counts

Ninety-three percent of the fish observed during the SCUBA fish counts were seen at night; the majority of these were sleeping within the seagrass bed (Table 1, Fig. 9). A number of these species were not detected during beach-seine sampling, including adult and 1+ red mullet, northern bastard red cod (*Pseudophycis breviuscula*), short-finned eel (*Anguilla australis*), snake eel (*Ophisurus serpens*), eagle rays (*Myliobatis tenuicaudatus*), leatherjacket (*Parika scaber*) and a slender roughy (*Optivus elongates*). Overall, abundances were very low, with only red mullet being relatively common.

Figure 9.   Abundances of fish encountered during day and night SCUBA dive counts at Slipper Island, over bare sand and seagrass (*Zostera capricorni*) habitats. The top graph gives overall fish densities (all species combined) by habitat and time of day, with night counts being represented by black shading. The middle and bottom graph show abundances by age class for red mullet (*Upeneichthys lineatus*) and snapper (*Pagrus auratus*) respectively.
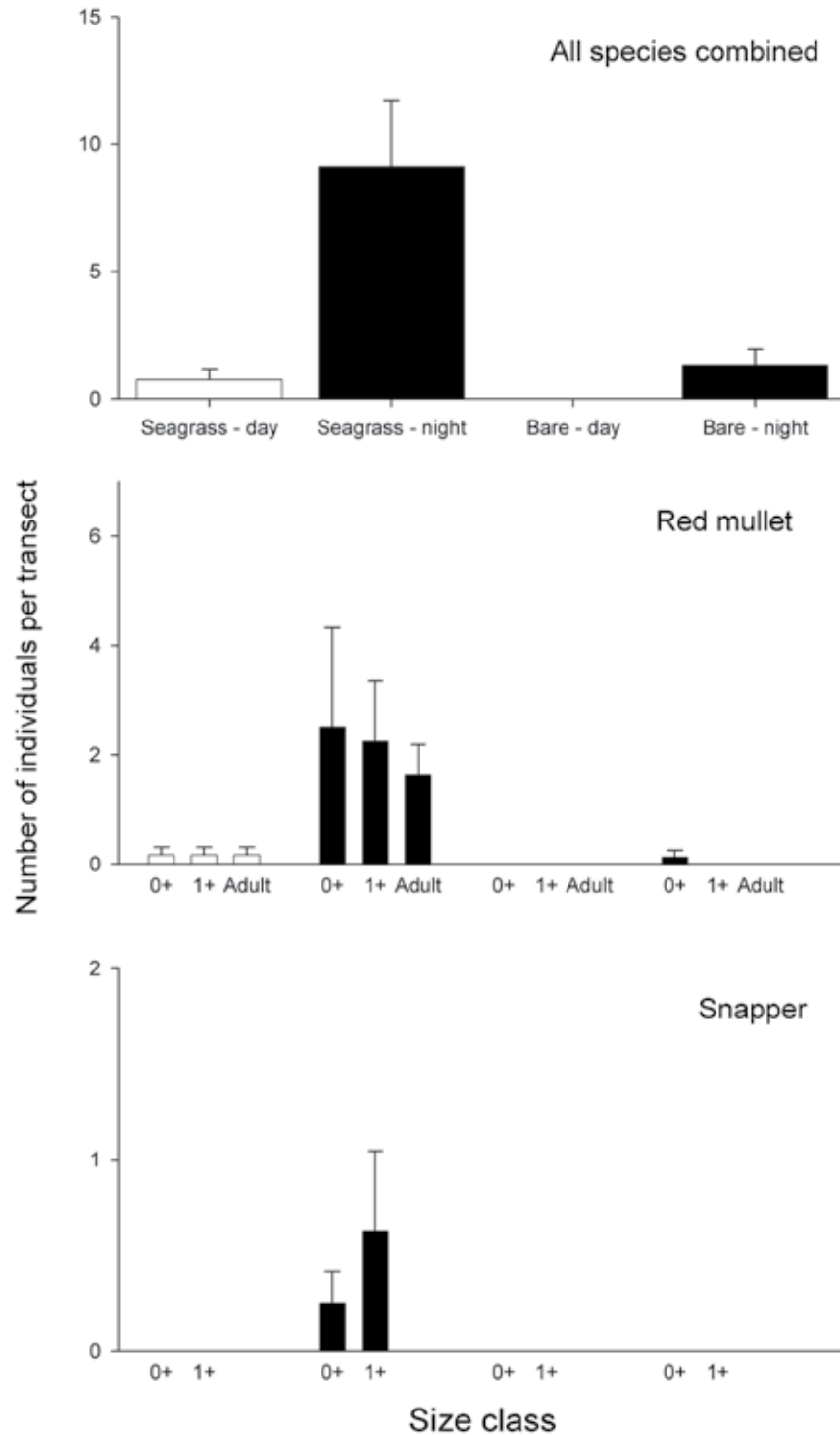
3.4   WATER CLARITY AND GRAIN SIZE

There were marked differences in water clarity between Slipper and Great Mercury Islands (Table 2). The attenuation coefficient (K_d) at Slipper was much lower than at Great Mercury, i.e. the water was clearer, and 10% of incident irradiance was able to penetrate to a water depth of 10 m. This was slightly less than the water clarity measured 1 month earlier at an offshore site near Hahei, as shown in Table 2 for comparison. In contrast, at Great Mercury a relatively high value for K_d of 0.67 resulted in 10% of incident irradiance penetrating to a depth of only 3.5 m.

In August, water clarity at Slipper was much higher than at the time of the May measurements (Table 2). Because of the exponential nature of the attenuation of PAR with depth, apparently small differences in K_d can have a large effect on the amount of light that reaches the bottom. For example, with a K_d of 0.05 in South Bay in August, the depth to which 10% of surface irradiance could potentially reach (were the bay deep enough) was 46 m, compared with only 10 m in May at the same site.

In August, K_d at sites between the east of Slipper Island and within Tairua Harbour ranged from 0.08/m in South Bay to 0.14/m in Home Bay. These values are indicative of extremely clear water at all sites and, when compared with the May values, illustrate some of the variability over time experienced by coastal sites. Phytoplankton Chl-*a* concentrations were low on all occasions, ranging from 0.4 mg/m³ to 1.9 mg/m³; however, total suspended-solid (TSS) concentrations were higher in May than in August, coincident with lower water clarity. This was especially so in Huruhi Bay, where TSS = 7.4 g/m³ compared with 0.7 g/m³ at Slipper (Table 2).

TABLE 2.   WATER CLARITY AT NINE SITES BETWEEN SLIPPER AND GREAT MERCURY ISLANDS.

Water clarity is represented by the attenuation coefficient for downwelling irradiance (K_d), the depth at which 10% of subsurface irradiance penetrated (10% SI), total suspended solids (TSS) and Chlorophyll-*a* concentration (Chl *a*) in surface waters on the dates indicated. The higher the value for K_d, the lower the water clarity.

SITE	DATE	DEPTH (m)	K_d/m	10% SI (m)	TSS (g/m³)	Chl *a* (mg/m³)
Slipper	May 2004	5	0.23	10.0	0.7	0.7
Great Mercury	May 2004	5	0.67	3.5	7.4	0.9
Slipper South Bay	August 2004	6	0.05	46.0	<0.5	1.3
Slipper Home Bay	August 2004	7	0.14	16.0	<0.5	1.5
Slipper west	August 2004	20	0.08	29.0	<0.5	1.1
Slipper east	August 2004	20	0.13	18.0	<0.5	1.9
Coromandel coastline south of Pauanui	August 2004	20	0.09	26.0	<0.5	0.9
Tairua Harbour	August 2004	4	0.11	21.0	<0.5	1.1
Coromandel coastline south of Hahei	April 2004	20	0.17	13.5	0.8	0.4

At both sites, sediments with and without seagrass were predominantly sand, with a small amount of silt and clay. However, the relative proportions of each of these differed between the two sites. Great Mercury samples had a significantly higher clay ($F = 15.94$, df = 1, 28, $P < 0.001$) and silt ($F = 31.15$, df = 1, 28, $P < 0.001$) fraction and a significantly lower sand content ($F = 31.33$, df = 1, 28, $P < 0.001$) by volume than the Slipper Island samples (Fig. 10). At both sites, there were no significant differences (ANOVA; $P > 0.05$: Table 3) in clay, silt or sand content between +SG and –SG samples.

Figure 10. Percentage of A. clay, B. silt and C. sand at Slipper Island (S) and Great Mercury Island (GM) sites with (+SG; $n = 12$) and without (-SG; $n = 3$) seagrass (*Zostera capricorni*). Note the different *y*-axis scales on each graph.
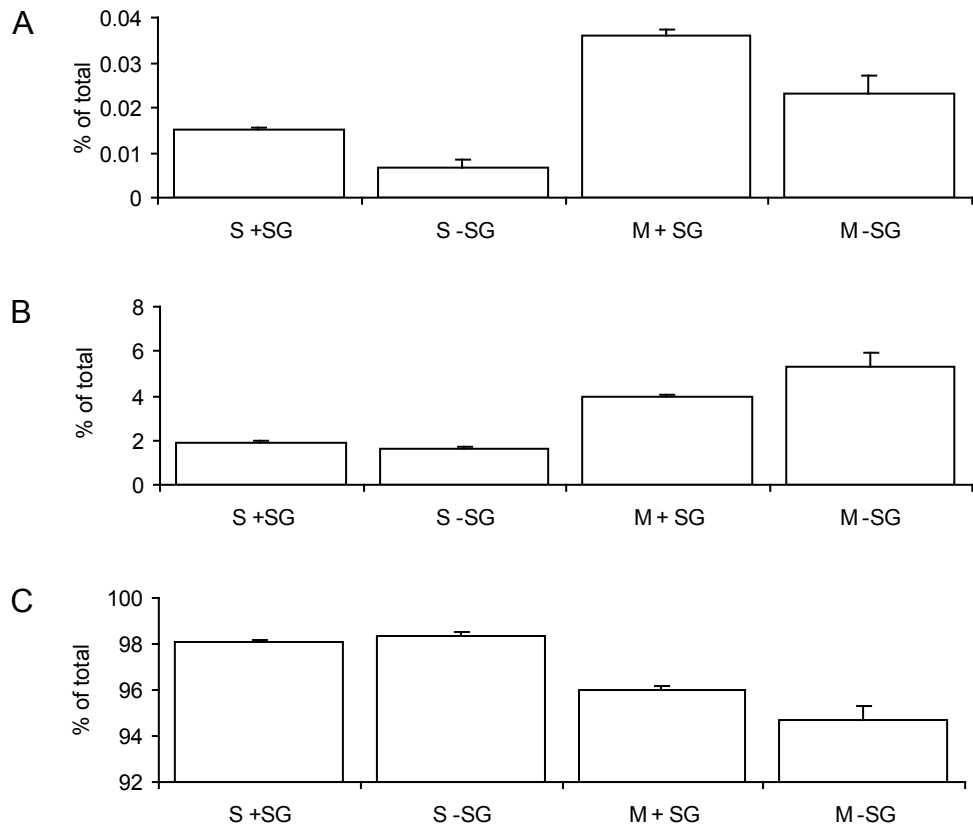
TABLE 3. ANALYSIS OF VARIANCE OF GRAIN-SIZE ANALYSIS FOR SAMPLES WITH AND WITHOUT SEAGRASS (*Zostera capricorni*) FROM SLIPPER AND GREAT MERCURY ISLANDS.

LOCATION	TREATMENT	F RATIO	df	P
Slipper	Clay	2.83	1, 13	0.117
	Silt	0.439	1, 13	0.519
	Sand	0.448	1, 13	0.514
Great Mercury	Clay	1.23	1, 13	0.287
	Silt	2.37	1, 13	0.147
	Sand	2.28	1, 13	0.154

3.5 COMPARISONS WITH MAINLAND COROMANDEL SITES

Seagrass characteristics were compared with measurements made at three mainland Coromandel Peninsula sites (Whangapoua, Wharekawa and Whangamata) during 2001 and 2002. Above-ground biomass at Slipper was around twice that recorded for intertidal beds in Coromandel estuaries in January 2001 (Turner & Schwarz 2006a), but only half that recorded for the same group of estuarine sites in January 2002 (van Houte-Howes et al. 2004) (Table 4), with the exception of Whangamata. In this study, biomass at Great Mercury was less than that recorded in any of the mainland estuaries in January 2001 or 2002 (Table 4). Average leaf length at Slipper was more than three times greater than at any of the other sites (Table 4).

There is insufficient long-term data on New Zealand seagrass to be definitive about the relative importance of interannual v. seasonal fluctuations in biomass. In some North Island estuaries, there is evidence to suggest that the former can at times be greater than the latter (Turner & Schwarz 2006a). This means that comparisons between biomass measurements made on the offshore islands during 2004 can only be compared in a general way with measurements made in other years on the Coromandel Peninsula. Nevertheless, in general the sub-tidal bed at Slipper appears to be more similar to the high-biomass sites of Wharekawa and Whangapoua, consistent with the appearance of the beds, while the seagrass bed at Great Mercury is more similar to Whangamata.

Both offshore-island sites had a much lower silt/clay fraction by volume than the mainland estuary sites (Table 4).

TABLE 4. COMPARISON OF SOME CHARACTERISTICS OF SEAGRASS (*Zostera capricorni*) BEDS ON SLIPPER AND GREAT MERCURY ISLANDS (MAY 2004; THIS STUDY) WITH THE COROMANDEL ESTUARIES WHANGAPOUA, WHAREKAWA AND WHANGAMATA (JANUARY 2001 AND JANUARY 2002).

The following characteristics are compared: above- and below-ground biomass; seagrass leaf length; substrate silt/clay content (% of fraction $<63\,\mu$m); average number of macroinvertebrate taxa per $0.01\,m^2$; and average macroinvertebrate abundance per $0.01\,m^2$. Data are for within seagrass beds only and are averages of all samples; n.d. = not reported in the study.

SITE	BIOMASS (g DW/m²)		LEAF LENGTH	SILT/CLAY	MACROINVERTEBRATES	
	ABOVE	BELOW	(cm)	(%)	NO. TAXA	ABUNDANCE
Slipper	155	298	29.0	1.9	33	293
Great Mercury	36	198	7.8	3.9	16	73
Whangapoua upper*	75	331	7.0	n.d.	n.d.	n.d.
Whangapoua upper[†]	270	1262	n.d.	29.0	8	35
Whangapoua lower*	81	663	7.1	n.d.	n.d.	n.d.
Whangapoua lower[†]	391	1203	n.d.	27.0	10	56
Wharekawa*	69	256	6.2	n.d.	n.d.	n.d.
Wharekawa[†]	522	464	n.d.	32.0	11	80
Whangamata*	50	100	5.6	n.d.	n.d.	n.d.
Whangamata[†]	87	116	n.d.	23.0	12	35

*   Turner & Schwarz (in press).

[†]   van Houte-Howes et al. (2004).

A notable difference between these sites was the high abundance and number of macroinvertebrate taxa in the Slipper +SG beds compared with Great Mercury and any of the intertidal beds. The abundance and number of taxa at Great Mercury was at the high end of those recorded for the Coromandel estuaries. However, Slipper had at least twice as many taxa and 4–8 times the number of individuals for a given area.

There were substantial differences between the small-fish assemblages at the two study sites compared with the four adjacent mainland estuaries (Table 5). The numbers of exquisite and sand gobies were relatively high at Greater Mercury Island (up to an order of magnitude higher than at some mainland-estuary sites), and the two species occurred in equal numbers, whereas the mainland estuaries tended to be dominated by only one of these species. The snapper abundances at Great Mercury Island were more than four times greater than the next highest snapper-catch total (Whangapoua Estuary). Detailed fish and seagrass sampling at Whangapoua Harbour has shown that higher snapper catches within that estuary are associated with small patches of sub-tidal seagrass, which are much less extensive than those encountered in Huruhi Bay (MM, pers. obs.). Several species were present at much lower abundances around Great Mercury Island than in the mainland estuaries, especially the triplefin *G. nigripenne*. The Slipper Island seagrass bed held only modest numbers of fish compared with the mainland estuaries, with the exception of the undescribed *Stigmatopora* pipefish species, which has not been encountered during any of our previous estuarine habitat sampling.

TABLE 5. COMPARISON OF THE TOTAL ABUNDANCES OF SOME SELECTED FISH SPECIES BETWEEN THE COASTAL SEAGRASS (*Zostera capricorni*) SITES SAMPLED AT GREAT MERCURY AND SLIPPER ISLANDS, AND THE ADJACENT MAINLAND ESTUARIES.

See Table 1 for scientific names of fish.

	GREAT MERCURY	SLIPPER	TAIRUA	WHITIANGA	WHANGAMATA	WHANGAPOUA
Exquisite Goby	765	0	7	121	32	6
Sand goby	761	0	90	13	432	20
Yellow-eyed mullet	502	8	408	640	1057	766
Snapper	249	13	1	10	17	64
Trevally	6	0	0	12	7	13
Kahawai	9	35	0	0	0	0
Triplefin	0	1	12	106	23	1
Broad squid	0	11	0	0	0	0
Stigmatopora sp.	0	88	0	0	0	0

4. Discussion

A number of features differentiate the submerged seagrass bed at South Bay, Slipper Island, from other studied seagrass beds in estuaries on the Coromandel Peninsula. The three-dimensional structure of the above-ground biomass, resulting from a combination of high percentage cover, high biomass and long leaves of the seagrass, as well as the rhizosphere below ground, provides habitat to a macroinvertebrate community that is more diverse and abundant than that in nearby bare sediments and mainland estuarine intertidal seagrass-beds. Unexpectedly, the fish fauna of the submerged bed was quite modest, with the main finding being an abundant seagrass-associated population of a currently undescribed *Stigmatopora* pipefish species. This species appears to be absent from mainland estuarine seagrass sites. Since the fish sampling was undertaken much later in the summer season than was ideal, it is possible that the juveniles of a number of species might have already moved off into deeper water habitats (especially snapper, trevally, spotties and parore). Such ontogenetic movements have been previously observed in the nearby Whangapoua Estuary on the mainland (MM, pers. obs.). Night diving showed that the South Bay seagrass bed provides sleeping grounds for a number of fish species not encountered during the day, including adult red mullet and northern bastard red cod.

In 1973, Grace & Whitten (1974) described the sub-tidal seagrass beds at South Bay, Slipper Island, as extensive, and noted that seagrass was clearly visible from the dinghy and from aerial photographs. According to their map, Grace & Whitten (1974) found seagrass throughout the bay from the low-tide mark to a depth of c. 5 m. In 2004, it appears that the extent of the bed may have reduced to around 65% of that in 1973, largely due to an increase in patchiness at the south-eastern end of the bay. There is insufficient information to quantify this more accurately. Nevertheless, the bed remains a healthy example of a rare New Zealand habitat type, and it still extends to 4–5 m below chart datum, indicating that the water is still sufficiently clear for it to persist.

It is pertinent to identify potential future risks to the Slipper Island submerged seagrass bed. A reduction in water clarity might be expected to reduce the ability of the submerged beds to persist (Schwarz 2004) and changes in sediment regimes (i.e. turbidity, sedimentation rates or sediment textural characteristics), either as a result of land-based or coastal activities, have been identified as one of the most serious threats to the integrity of New Zealand's estuarine and coastal ecosystems (MfE 1997; Morrisey & Green 2000; Inglis 2003).

Slipper Island is a popular day trip from Tairua and a common anchorage. Elsewhere in the world, it has been shown that anchoring has a destructive impact on seagrass meadows (Walker et al. 1989; Hastings et al. 1995). For example, in their study on *Posidonia oceanica* seagrass beds in the Mediterranean, Francoeur et al. (1999) found that the degree of meadow fragmentation was positively correlated with moderate anchoring pressure, while meadow cover and shoot density were negatively associated with high anchoring pressure. Regardless of what damage may have occurred in the last 30 years, the increasing popularity of the Coromandel coast as a holiday destination may result in increased pressure on this small area of habitat in future years. More detailed investigation on

the effects of anchoring at this site would be needed before any management recommendations could be considered.

For Huruhi Bay, Great Mercury Island, Grace & Grace (1976) published a map indicating that in 1975 seagrass occupied the whole of the bay and extended out to the 5-m depth contour. Seagrass was also shown to occur in a small bay (Parapara Bay) to the east of the harbour entrance. According to local charter boat operators (Maurie Martin and John Neighbours, pers. comm.), seagrass can still be seen in Parapara Bay; however, unfortunately the weather during our field trip meant that confirmation of this was not possible. Our observations suggest that the extent of sub-tidal seagrass beds in Huruhi Bay has declined substantially since 1975, and that they no longer extend deeper than c. 1 m below chart datum, and do not occur within all potential areas shallower than that depth. Although this perceived change must be viewed with caution, as the 1975 map (Grace & Grace 1976) was extrapolated from five stations, those stations were in the middle of the bay where the water is deepest, and we did not find seagrass growing in this location in May 2004.

Fish sampling in Huruhi Bay indicated a small-fish assemblage dominated by high numbers of four species: exquisite and sand gobies, juvenile yellow-eyed mullet, and 0+ snapper. The snapper densities were the highest (at least four times higher) that we have ever encountered during sampling of seagrass beds (and other juvenile snapper habitats) over multiple estuaries spread throughout northern New Zealand (Francis et al. 2005). Those mainland estuaries in which we have found the next highest numbers of seagrass-associated 0+ snapper are those where some remnants of sub-tidal seagrass still remain (Rangaunu Harbour and Whangapoua Estuary), while intertidal seagrass beds support much lower densities.

Huruhi Bay is also a popular anchorage during summer; however, there are moorings available that reduce anchoring pressure during quiet times of the year. A notable difference from Slipper was the markedly lower water clarity under the same weather conditions. There has been some development of the shoreline of Huruhi Bay in the 30 years since the previous seagrass survey (Grace & Grace 1976). During that period, earthworks have been undertaken, and such activities may have exacerbated fine-sediment loadings in the bay. The rate at which PAR is attenuated with depth is dictated by particulate constituents (e.g. suspended solids and phytoplankton), dissolved constituents (yellow substance) and the water itself (Davies-Colley et al. 1993). Freshwater-derived yellow substance is a minor cause of absorption in estuarine and coastal waters, with phytoplankton and suspended solids usually playing a much greater role in attenuation in these environments (Gallegos et al. 1990; Vant 1990). At times, fine sediments are able to be re-suspended in the water column in Huruhi Bay, which has a shallow and relatively extensive intertidal zone, with a higher proportion of silt than Slipper. This was especially noticeable when a south-west wind was combined with an outgoing tide at the time of our visit. According to local knowledge (Maurie Martin, pers. comm.), water clarity in Huruhi Bay can fluctuate between being extremely clear and extremely turbid, the latter particularly on spring tides with winds from the south. Such fluctuations in water clarity are similar to the conditions experienced in Coromandel mainland estuaries (Vant 1990; Schwarz

2004). At Slipper, although water clarity can be reduced in westerly winds, it is not to the same extent as for the aforementioned sites, in part because of the lower fractions of silt and clay in the sediments.

Changes in the availability of light for seagrass photosynthesis are thought to have caused large-scale loss of seagrass in the natural environment in many places around the world. General relationships have been described to assess the depth to which seagrasses can grow based on the availability of light (Duarte 1991). Although there are exceptions, and different species do have different light requirements (Vermaat et al. 1997), seagrasses are generally confined to depths of less than 20 m, or c. 11% of surface irradiance (Duarte 1991). Water clarity can change markedly over different time-scales and so a value such as 11% represents an average over an ecologically meaningful time-scale. Over this time-scale (e.g. a year), there must be a net balance between photosynthesis and respiration enabling the plant to grow (Hemminga & Duarte 2000). According to our water-clarity measurements made on the sampling days in May, at both sites *Z. capricorni* was growing to a depth that was equivalent to 36% of surface irradiance. In marked contrast, according to water clarity at Slipper in August, the maximum depth for *Z. capricorni* was equivalent to 80% of surface irradiance. Given the depth at which plants grow at Slipper and Great Mercury, the average clarity at both sites is likely to be higher than that measured in May during this study. For Slipper, it is likely to be somewhere between the May and August measurements.

Since turbid events can markedly reduce the production of both intertidal and sub-tidal seagrass (Schwarz 2004), it is very likely that the much lower frequency of markedly turbid events at Slipper Island compared with those experienced in the mainland estuaries and Huruhi Bay is a major factor in enabling these deep seagrass beds to persist.

The physical structure of marine macrophytes (seagrass and macroalgae) not only provides shelter for larger organisms, such as fish, but also provides a large surface-area for the growth of epiphytes, thereby supporting invertebrate grazers, which in turn provide food for higher trophic levels. The close proximity of macroinvertebrate samples taken from within seagrass beds to those on bare sediments may reflect small-scale patchiness rather than large-scale differences. Nevertheless, invertebrate abundance was three times greater and there were more than twice as many taxa within Slipper seagrass beds than in adjacent bare-sand sites and intertidal beds in nearby mainland estuaries (van Houte-Howes et al. 2004). This suggests that there are certain characteristics of that particular habitat (its permanently submerged status and its very long leaf length are prime candidates) that enable it to provide higher ecosystem value.

There is historical evidence that more extensive sub-tidal seagrass beds existed in New Zealand estuaries prior to extensive land-clearance in associated catchments (e.g. Inglis 2003). The Slipper Island site is an excellent example of the high potential ecosystem-value of such beds; however, it is at least an order of magnitude smaller in area than intertidal and sub-tidal beds in Wharekawa, Whangamata or Whangapoua. Therefore, we suggest that it would be advantageous to undertake catchment and estuarine management that considers the reinstatement of sub-tidal beds as a positive outcome.

When determining the most appropriate method for monitoring seagrass beds, the values for which they are to be managed need to be considered (Turner & Schwarz 2006b). For example, while shoot density (for which cover estimates can provide a non-destructive proxy) is a key parameter in monitoring seagrass health, this is insufficient when aiming to characterise the structural role of seagrass, both as a habitat and as a refuge for animals. Canopy height, defined as the height of 80% of the shoots above the bottom, is considered to be directly comparable among seagrass species, thereby enabling nationwide and international comparisons. Shoot height and density are, therefore, two key parameters required to answer questions about ecosystem services of seagrass beds. Furthermore, to quantify the value of sub-tidal seagrass to fish populations, seasonality must be considered. Ideally, juvenile fish surveys would be conducted in February/March.

Finally, the small size of the Slipper bed means that the estimates of area are not accurate enough to track small changes in the extent of the seagrass bed. Therefore, now that the current scale of this bed has been determined, we recommend that an accurate base map be developed from aerial photography with appropriate ground truthing and rectification. This would enable anchor scars to be accurately mapped over time and could be complemented with the installation of permanent underwater markers to enable tracking of any expansion or retraction of the bed area over time.

5. Acknowledgements

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