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EFFECTS OF SHORE HEIGHT AND VISITOR PRESSURE ON THE DIVERSITY AND DISTRIBUTION OF FOUR INTERTIDAL TAXA AT LABRADOR BEACH, SINGAPORE

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ABSTRACT. **–** To date, the majority of research on the rocky intertidal has focused on temperate rocky shore communities whereas study sites in the tropics have been relatively distant from the equator. We examined four key groups of marine organisms, i.e. macroalgae, anthozoans, decapods and gastropods, in relation to shore height and visitor pressure, at Labrador beach, Singapore (just 1°16.0'N). To reveal any vertical zonation the shore was divided into four 10m-wide zones, parallel to shore, approximately spanning high to low spring tide marks. To determine the effects of visitor pressure, the shore was also divided horizontally into three 60m long sectors; representing a gradient in distance from the public entrance to the beach. Sampling data from quadrats positioned randomly within these zones and sectors were converted into Shannon-Wiener and Margalef diversity index scores. The number of visitors to each horizontal sector was monitored, and the substrate composition in the sampled areas was assessed using point intercept transects. A total of 28 genera of macroalgae, 14 genera of anthozoans, 20 genera of decapods and 25 genera of gastropods were identified. Diversity scores for macroalgae, anthozoans and decapods were highly significantly different among the different shore heights, with the highest diversity found in the lower shore zones. Anthozoan diversity in the sector closest to the entrance of the beach, where the highest numbers of visitors were recorded, was significantly lower than the sectors further away. It requires further work, however, to identify the extent to which visitor pressure may affect marine organism diversity and distribution in the intertidal zone at Labrador Park.

KEY WORDS. **–** Intertidal, rocky shore, zonation, visitor pressure, Labrador beach, Singapore.

INTRODUCTION

Rocky shore communities experience a wide range of emersion-related abiotic and biotic stresses associated with tidal range and wave action. The ecological consequence of this unique environment is a vertical zonation of taxa that reflects their specific adaptations (Purchon & Enoch, 1953; Vohra, 1971; Benson, 2002). Physical stresses due to emersion, e.g. heat exposure and desiccation, typically create extreme conditions in the higher intertidal and are therefore considered most important in defining the upper distribution limit of marine organisms (Newell, 1970; Taylor, 1982; Raffaelli & Hawkins, 1996). Lower down the vertical gradient, where abiotic conditions become increasingly stable due to longer immersion periods, ecological and biological factors such as interspecific competition predominate and determine the lower distribution limit of intertidal species. At a geographical scale, different shores have different climatic conditions, wave and sun exposure, and substratum type, and are therefore inherently dissimilar. Consequently, even though vertical zonation patterns are driven by similar factors, resultant biological stratification can vary considerably from shore to shore.

Research on rocky shores has contributed substantially to the general development of intertidal ecological theory (Underwood & Denley, 1984; Roughgarden et al., 1988; Menge & Branch, 2001; Benson, 2002). Rocky shores have been intensively studied, partly because of their presence along many coastlines, accessibility, and the relative ease with which manipulative experiments can be conducted (Roughgarden et al., 1988; Farrell et al., 1991; Lively et al., 1993). The majority of intertidal research has been carried out on temperate communities, e.g. Oregon, USA (Menge, 2000), Western Europe (Jenkins et al., 2001; O'Riordan et al., 2004), while quantitative and experimental studies in the tropics have been confined to Central America (e.g. Lubchenco et al., 1984), Hong Kong (e.g. Williams, 1994) and Australia (e.g. Coates, 1995) — all relatively distant from the equator. There have been published accounts of rocky shores at lower latitudes, e.g. Malaysia and Singapore (Purchon & Enoch, 1953; Chuang, 1961; Chow, 1966; Lee, 1966; Vohra, 1971; Leong, 1984) but, although these studies noted general zonation schemes similar to those of temperate shores, the descriptions were qualitative.

In Singapore, biodiversity of shores and the spatial variability of assemblages have not been quantified. One site previously surveyed is Labrador beach (Chow, 1966) — the only remaining natural shore on the southern coast of mainland Singapore (Lim et al., 1994; Todd & Chou, 2005). The beach is a sheltered rock and coral rubble shore with a fringing coral reef (Lim et al., 1994) and supports a convergence of organism groups typical to different environment types, e.g. rocky shore species, reef species and even some mangrove species, which endow the beach with a structural complexity that may translate into a unique zonation pattern (Lohrer et al., 2000).

Labrador beach has been recognised for its rich flora and fauna (Lim et al., 1994; Tan & Ng, 2001; Todd & Chou, 2005; Huang et al., in press) but, despite being part of a nature park, there is no stringent regulation of public conduct and visitors have been observed to trample organisms, unaware of the damage they are causing. Beach materials, living or otherwise, are also collected by visitors, and possibly poachers. Previous studies of human impact on the intertidal zone indicate a wide range of effects, for instance, human disturbance and trampling can actually enhance the densities and sizes of several molluscan taxa, especially limpets (Keough et al., 1993; Addessi, 1994; Keough & Quinn, 1998), while adversely affecting coral colonies, algal cover and the density of mussels (Woodland & Hooper, 1977; Hawkins & Roberts, 1993; Brosnan & Crumrine, 1994).

The present study has two primary objectives, (1) to provide a quantitative description of the diversity and distribution of gastropods, decapods, anthozoans and macroalgae at Labrador beach, and (2) to determine whether visitor numbers are related to the results of objective (1). The findings should further the understanding of Singapore's coastal ecology and, importantly, contribute to the limited amount of information available on equatorial rocky shores. Results may also be useful in devising regulations that can ameliorate negative effects of visitor pressure on Labrador beach's flora and fauna.

MATERIALS AND METHODS

Sampling site. **–** Labrador beach (1°16.0'N, 103°48.0'E) is a rocky shore at the western edge of Labrador Park, Singapore, a national Nature Reserve since 2002 (Fig. 1). Previously, the site had been impacted by an oil tanker jetty built in the middle of the beach and thermal effluent from a nearby power plant (Todd & Chou, 2005). Both these installations are now disused, however, the area is still affected by heavily sedimented waters (Chou, 1996). Labrador beach is only 300m wide, but it represents the last remaining natural shoreline along the dramatically modified southern coast of mainland Singapore (Todd & Chou, 2005).

Study species. **–** This study focuses on four key groups of marine organisms, i.e. macroalgae, anthozoans, decapod crustaceans and gastropod molluscs. Macroalgae is acknowledged as an ecologically important group in the marine environment, being a major primary producer and forming much of the basis for intertidal food webs (Littler et al., 1989; Trono, 1997). The anthozoan community around Singapore grows at the lower intertidal zone due to the longer periods of immersion, but the species structure varies among shores (Chuang, 1973) and little is known about the community at Labrador beach. Decapods and gastropods play a wide range of ecological roles including parasite, predator and scavenger (Menge, 1983; Boglio & Lucas, 1997; Ray-Culp et al., 1999), often exhibiting complex intra- and interspecific relationships (Tsuchiya & Yonaha, 1992; Stachowicz & Hay, 1996; Keppel & Scrosati, 2004).

Sampling design. **–** All taxa were collected using a stratified random sampling design (Chalmers & Parker, 1989) between December 2004 and March 2005. To determine the relationship between vertical position and taxa present, the shore was divided into four height zones, approximately spanning high to low spring tide marks. All four zones were 10m wide and, using the cross-staff method (Hawkins & Jones, 1992), the mean shore height of each was identified as: High (H) 1.0-1.9m, Middle (M) 0.3-1.0m, Low (L) 0.2-0.3m and Very low (VL) 0.1-0.2m (Maritime and Port Authority of Singapore, 2003, 2004). To examine the effects of visitor pressure, the shore was also divided horizontally into three 60m long sectors; representing a gradient in distance from the public entrance to the beach. The vertical zones were separated from each other by an unsampled 1m buffer area; similarly, each of the horizontal sectors, i.e. A, B and C (with A closest to the beach entrance), were separated from their adjacent sector by a 10m buffer.

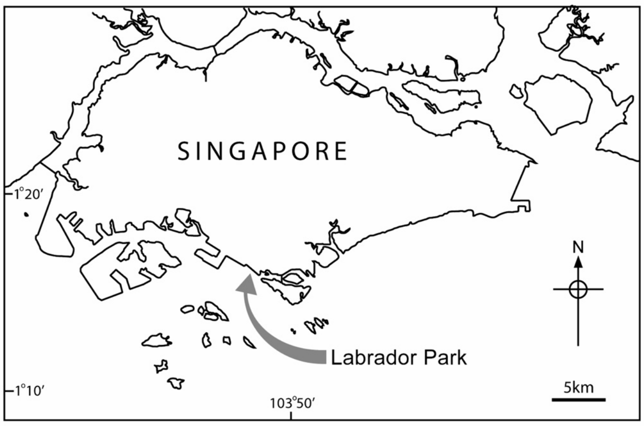

Fig. 1. Labrador Park is on the southern coast of Singapore.

Table 1. Categories and definitions of substrate types encountered.

Substrate	Definition
Boulder	Large immovable mass of hard material (>0.8m)
Rock	Movable mass of hard material (2mm–0.8m)
Sand	Small grains (0.2mm–2mm)
Silt	Fine grains (<0.2mm)
Cliff	Steep high rock face of hard material at the back of the shore
Artificial	Man-made materials, e.g. concrete, plastic, etc

The above design created 12 10m × 60m areas for sampling. Based on species accumulation curves, it was determined that 10 quadrats per sampling area, each 1.0m × 1.0m, were needed to capture a representative proportion of the macroalgae population, while 20, 7 and 10 quadrats, each 0.5m × 0.5m, were required for the anthozoan, decapod and gastropod populations respectively. The very low shore zone was only sampled for anthozoan diversity. Coordinates taken from random number tables and marked out with fiberglass tape measures were used to position all quadrats. The abundance of macroalgae and colonial anthozoans within each quadrat was quantified as percentage cover while that of solitary anthozoan polyps, decapods and gastropods was quantified as number of individuals.

The number of visitors in each horizontal sector was counted for two hours, one hour before and one after low tide, during each of 10 very low tide periods in February and March, 2005. Visitor pressure was determined by calculating the mean number of visitors per hour in each sector along the beach.

As substrate heterogeneity and resultant structural complexity are possible explanatory factors for the distribution and abundance of many intertidal species (Hawkins & Jones, 1992; Lohrer et al., 2000; Takeda & Murai, 2003; Bellgrove et al., 2004), substratum composition of the high, middle and low shore zones was estimated using point intercept transects (Aronson & Precht, 2000). Ten 10m transects perpendicular to the shore were placed randomly (using random number tables) in each sampling area and the substrate type encountered at each 2m interval was recorded (Table 1).

Statistical analysis. – For each of the four groups of marine organisms, diversity scores were calculated and genera richness summarised. These were entered into separate two-factor (shore height and horizontal sectors) univariate analyses of variance (ANOVA), with four tests of diversity and four of richness for all taxa. The Shannon-Wiener diversity index (modified to $H' = \sum p_i \log_e (p_i+0.0001)$ to accommodate zero values of p_i, fractional abundance of each taxon) was used to summarise count data of each quadrat into a single dependent variable for macroalgae, decapods and gastropods. Due to insufficient data for the Shannon-Wiener diversity index, a modified Margalef diversity index ($R=S / \log_e (N+1)$, where S and N represent taxonomic richness and abundance respectively) was used to determine anthozoan diversity in each quadrat. The total abundance of decapods and gastropods were also separately compared, each using a two-factor (shore height and horizontal sectors) univariate ANOVA. Visitor number data were analysed using a one-way ANOVA on the number of visitors per hour, treating horizontal sectors as the factor.

Cochran's test (Winer, 1971) was used to test for heterogeneity of variances and data were transformed when necessary. Post-hoc multiple comparisons were conducted using the Student-Newman-Keuls (SNK) tests. GMAV5 (Institute of Marine Ecology, Sydney, Australia) was used for all analyses.

RESULTS

A total of 28 genera of macroalgae, 14 genera of anthozoans (including 11 genera of hard corals), 20 genera of decapods and 25 genera of gastropods were recorded within quadrats during the study. Although the data on macroalgal diversity had heterogeneous variances and transformations did little to reduce the departure from homogeneity, ANOVA was still applied as the test is robust to such departures (Underwood, 1997). The analysis, however, has to be treated with some caution as there is an increased probability of type I error. The data on anthozoan diversity and genera richness, as well as gastropod abundance had homogeneous variances only after transforming to $\log_e (x+0.0001)$, while an operation of $\log_e (x+0.01)$ was necessary to normalise variances of decapod abundance.

There were highly significant differences in the diversity score (ANOVA, *d.f.*=2, F=10.17, P=0.0001) and genera richness (ANOVA, *d.f.*=2, F=55.38, P=0.0000) of macroalgae among shore heights but not between horizontal sectors. For macroalgal richness, ANOVA indicates a significant interaction between shore height and horizontal sector (*d.f.*=4, F=3.26, P=0.0158); thus the effects on genera richness of these factors cannot be generalised. SNK tests of shore heights detect significant trends of increasing macroalgal diversity and richness with decreasing shore height (low>middle; middle>high; low>high). A non-significant pattern among the horizontal sectors from A to C at each shore height, with exception of diversity in sector C at the low shore zone, is also suggested (Figs. 2b and 3b). *Bryopsis* sp. was the most abundant macroalgae at every zone on the beach.

For the transformed data on anthozoan diversity, ANOVA describes highly significant differences in the Margalef diversity index and genera richness for the main effects of shore height (index, *d.f.*=3, *F*=6.29, *P*=0.0004; richness, *d.f.*=3, *F*=5.51, *P*=0.0011) and horizontal sectors (index, *d.f.*=2, *F*=3.90, *P*=0.0217; richness, *d.f.*=2, *F*=3.59, *P*=0.0292). Multiple comparisons using the SNK procedure show that the diversity of the very low shore was significantly higher than high (*P*<0.01) and middle (*P*<0.05) shore zones, while the low shore zone had significantly higher diversity than the high shore zone (*P*<0.05). A similar trend was registered for anthozoan richness, but the very low and middle shore zones did not differ significantly. *Epiactis* sp. was the only anthozoan found at the high shore; almost all of the 11 species of hard corals were found at the low and very low shore zones. The SNK procedure also shows that the mean index for sector A, the one nearest to the entrance of the beach, was significantly lower than sectors B and C (*P*<0.05), which did not differ significantly from each other. The richness of sector A was significantly lower than sector B (*P*<0.05) (Figs. 2a and 3a). At the former, only the genera *Epiactis*, *Goniopora*, *Leptastrea*, *Platygyra*, *Porites*, *Turbinaria* and *Zoanthus* were sampled, whereas other sectors contained, additionally, *Favia*, *Favites*, *Galaxea*, *Goniastrea*, *Montipora*, *Oulastrea* and *Phymanthus*.

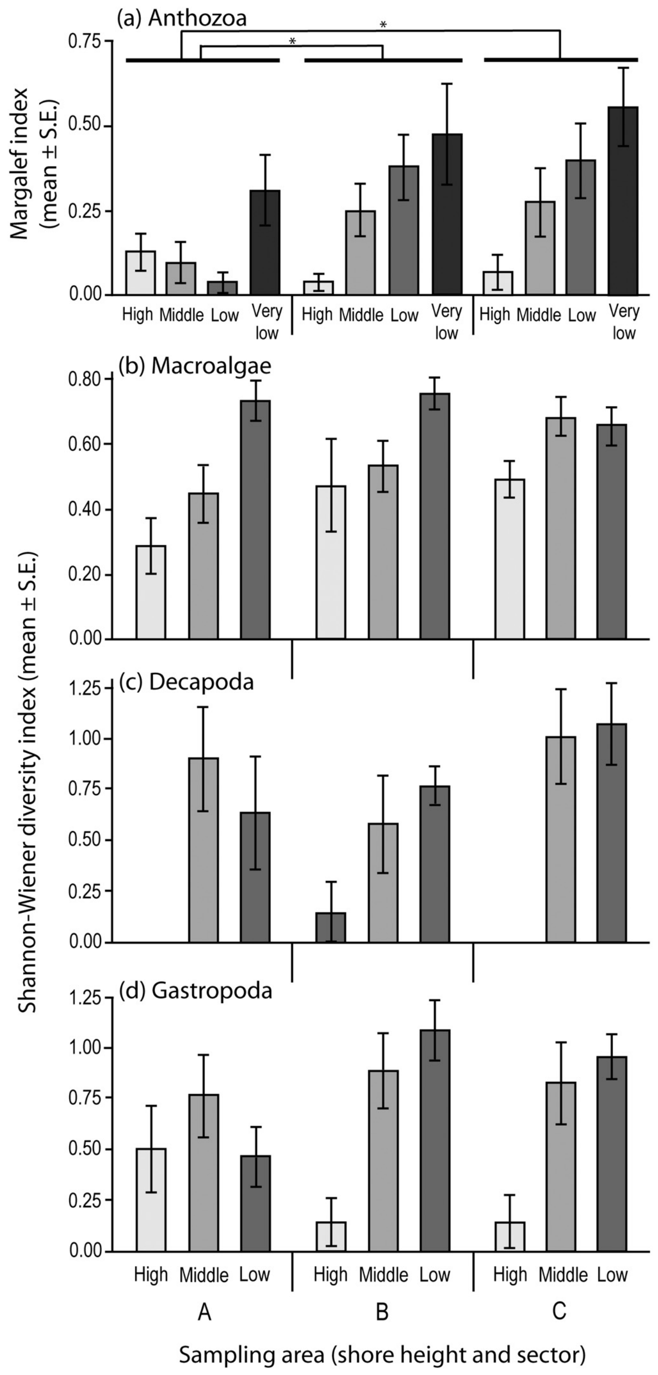

Fig. 2. Bar charts showing mean Margalef index scores of anthozoans (a), and Shannon-Wiener index scores of macroalgae (b), decapods (c), and gastropods (d), at each sampling area. Error bars denote standard errors. Differences between sectors, as revealed by Student-Newman-Keuls tests, are indicated above each graph.

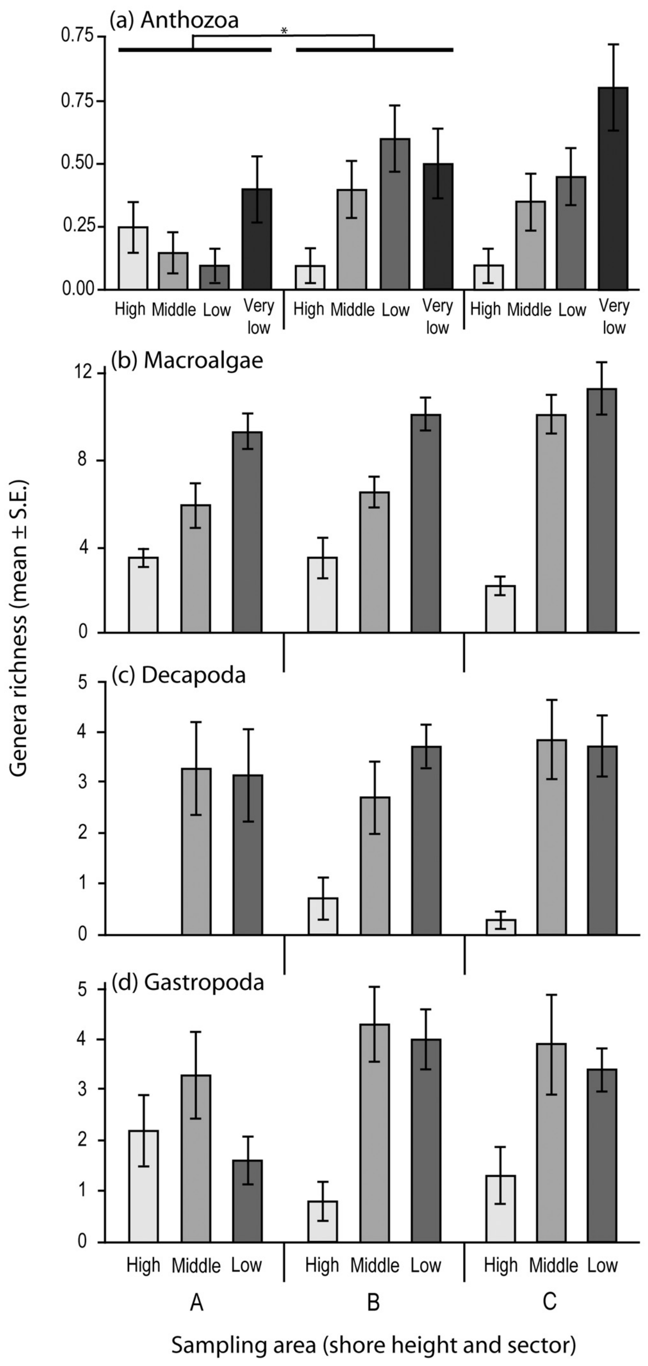

Fig. 3. Bar charts showing mean genera richness of anthozoans (a), macroalgae (b), decapods (c), and gastropods (d), at each sampling area. Error bars denote standard errors. Differences between sectors, as revealed by Student-Newman-Keuls tests, are indicated above each graph.

Among shore heights, there were highly significant differences in decapod diversity (ANOVA, *d.f.*=2, *F*=16.87, *P*=0.0000), genera richness (ANOVA, *d.f.*=2, *F*=23.83, *P*=0.0000) and abundance (ANOVA, *d.f.*=2, *F*=37.03, *P*=0.0000), but not among the horizontal sectors. SNK procedure reveals that all three parameters calculated for the high shore zone were highly significantly lower than the middle and low shore zones ($P<0.01$), while the latter two zones were comparable. There was a general trend of increasing mean index, richness and abundance with decreasing shore height in sector B (Fig. 2c, 3c and 4a). Sectors A and C had slightly differing patterns, but the lowest scores for all measures were invariably derived from the high shore zone.

Analysis of variance indicates a significant interaction between shore height and horizontal sector for gastropod diversity (*d.f.*=4, *F*=2.66, *P*=0.0383); therefore the effects of these factors cannot be generalised. No interaction was present for genera richness and abundance, which differed significantly among shore heights (ANOVA on richness, *d.f.*=2, *F*=9.99, *P*=0.0001; ANOVA on abundance, *d.f.*=2, *F*=4.97, *P*=0.0092). The SNK procedure reveals that gastropod diversity and richness at the high shore zone were highly significantly lower than the middle ($P<0.01$) and low ($P<0.01$) shore zones; tests on the abundance data yielded similar results. There appears to be a trend of increasing mean index with decreasing shore height in sectors B and C but not in A (Fig. 2d). Within each sector, genera richness and abundance were generally highest in the middle shore (Figs. 3d and 4b); but Sector C had an overwhelmingly large number of gastropods at the high shore zone due to high density of *Siphonaria* sp.

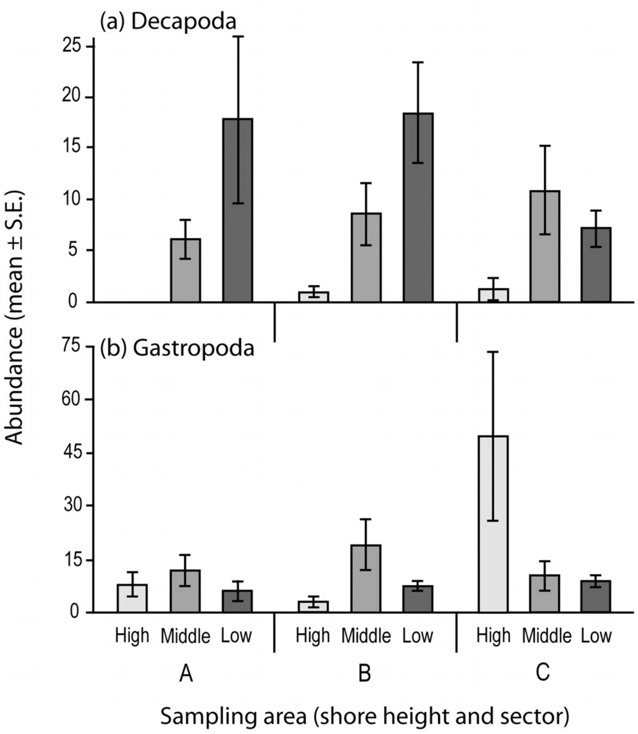

Fig. 4. Bar charts showing mean abundance of decapods (a), and gastropods (b), at each sampling area. Error bars denote standard errors.

The number of visitors to the beach was highly significantly different among the three horizontal shore sectors (ANOVA, *d.f.*=2, *F*=9.46, *P*=0.0008). The SNK procedure indicates that the mean number of visitors per hour at sector A (11.90 ± S.E. 1.95) was significantly greater than the same at sector B (7.35 ± S.E. 1.59; $P<0.05$), which was in turn significantly greater than that at sector C (2.80 ± S.E. 0.48; $P<0.05$).

The results of the point intercept transect study of substrate composition at the beach are presented in Fig. 5. Sand was the most abundant substrate in the high shore zones of sectors A and B, while rocks dominated all the other sampling areas. Most of the large boulders were found in the high shore zone as well as in sectors A and B of the middle shore. Silt was well-represented in the middle and low shore zones; the artificial substrata observed at sector C were parts of a concrete pillar left from an oil installation at the beach that had discontinued operations since 1995 (Lim et al., 1994; Lim, 1997). The uneven spread of the immovable and movable beach materials gave rise to a heterogeneous distribution of microhabitats of rock pools and crevices on the beach.

DISCUSSION

The main objectives of this study were to identify the spatial distribution of four major groups of organisms in relation to shore height and visitor numbers which, in this case, decreased with increasing distance from the beach entrance. Diversity scores and genera richness for all the organisms were highly significantly different among the shore heights, except for gastropod diversity and macroalgal richness, for which there were significant interactions between the factors shore height and sector. Only anthozoan diversity and richness showed

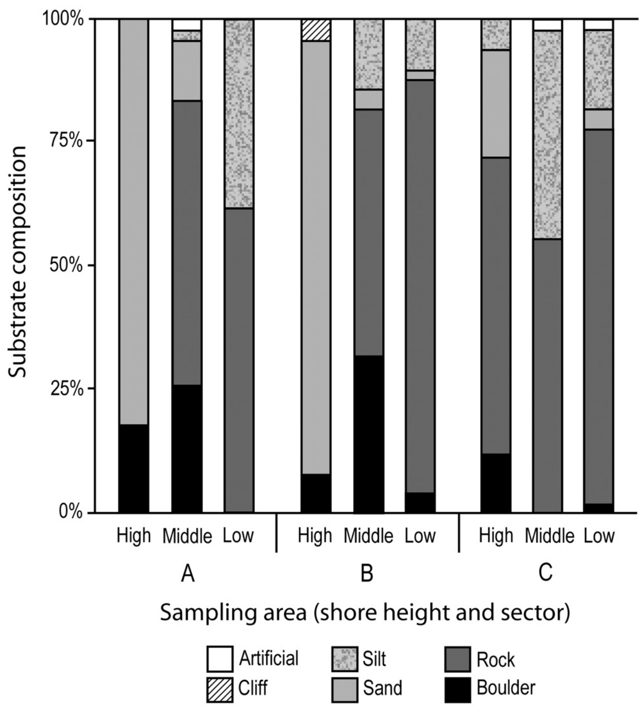

Fig. 5. Substrate composition at each of nine sampling areas.

significant heterogeneity among the three horizontal shore sectors. As expected, data analyses on the diversity, richness and abundance of each taxa generally gave similar results — the indices used are combined measures of richness and abundance (Hamilton, 2005).

The diversity within the four groups was significantly higher in the lower shore zones than in the high shore zone, an observation consistent with previous rocky shore studies (Chuang, 1973; Lubchenco et al., 1984; Raffaelli & Hawkins, 1996). These findings are also consistent with the hypothesis that physical and biological factors respectively determine the upper and lower limit of the distribution of organisms in the intertidal region. In the physically stable and resource-rich environment of the lower shore, a greater range of organisms were able to survive. In the harsh conditions of the upper shore, with increased levels of desiccation, temperature changes and salinity fluctuations, well-adapted organisms such as the banded bead anemone *Epiactis* sp. and the false limpet *Siphonaria* sp. dominated (Chuang, 1973; Tan & Ng, 2001).

The heterogeneous substrate composition is another potential modifier for the difference in diversity between the high and lower shore zones. For instance, the low shore zones were characterised by rocks and silt. Silt has a larger surface area than sand that supports higher numbers of micro-organisms and bacteria, providing a rich food resource for deposit feeders (Raffaelli & Hawkins, 1996). The undersides of rocks, serving as discrete habitat units, provide protection from desiccation during periods of low tide and refuge from subtidal predators during tidal inundation. Crevices formed by spaces between adjacent rocks and the sediment trapped in interstices add an additional habitat dimension for organisms such as molluscs to hide in, increasing their abundance (McGuiness & Underwood, 1986). In the high shore zone, high density of rocks and boulders at sector C that served as habitats for *Siphonaria* sp. could have contributed to the large number of gastropods recorded.

Anthropogenic activities also have an effect on intertidal biodiversity (Addessi, 1994; de Boer & Prins, 2002; Thompson et al., 2002; Pinn & Rodgers, 2005). In a study of corals at Labrador beach in 1968, only eight monospecific genera of hard corals were found (Chuang, 1973) as opposed to 11 identified in the present study. The increase in genera richness could be due to the discontinued operation of the oil installation in 1995 (Lim, 1997). The installation had caused silting and oil pollution at the beach, reducing the number of coral species from pre-operation numbers of ~30 to eight in 1968 (Chuang, 1973). Our results also show an inverse relationship between anthozoan diversity and visitor numbers. The diversity of sector A, the one closest to the entrance of the beach, was significantly lower than the sectors further away. Anthozoans, especially corals, are very sensitive to the effects of human trampling (Woodland & Hooper, 1977) and this may explain the observed pattern. Alternatively, the pier pilings adjacent to sector A could have slowed down the rate of water flow in this area, leading to a decrease in nutrient influx important for the growth of anthozoans (Muscatine et al., 1989; Bongiorni et al., 2003a; Bongiorni et al., 2003b).

There were no significant differences between the different horizontal sectors for the macroalgae, decapod and gastropod groups. The positive and negative effects of trampling recorded for molluscs (Keough & Quinn, 1998) and macroalgae (Brosnan & Crumrine, 1994) respectively were not found in this study. For instance, Keough and Quinn (1998) observed that trampling led to an increase in the density of several herbivorous molluscs, especially limpets, while another study by Brosnan and Crumrine (1994) revealed that macroalgae, in particular foliose algae, were susceptible to trampling. As most decapods are highly mobile and molluscs are more often dislodged than crushed (Povey & Keough, 1991), it is more difficult to identify the impacts of trampling for these groups than it is for the sessile anthozoans. Future studies should examine the effects of visitor numbers in more detail in an effort to elucidate any deleterious effects.

In conclusion, the diversity of macroalgae, anthozoans and decapods varied significantly among shore heights and this may be attributed to different tolerances to emersion. Anthozoans showed a significant decrease in diversity near the beach entrance, the area where the highest numbers of visitors were observed. There is a need to further explore the extent to which visitor pressure affects diversity and distribution in the intertidal zone at Labrador Park.

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