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INTERTIDAL ASSEMBLAGES ON COASTAL DEFENCE STRUCTURES IN SINGAPORE I: A FAUNAL STUDY

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***ABSTRACT*. –** Seawalls are a ubiquitous part of the Singapore coastline, providing a novel habitat for a suite of intertidal species. In this study, the diversity and community patterns of intertidal organisms of twelve seawalls located along the coasts of Singapore and its offshore islands were examined and described. Although the seawalls are made of similar material and are fairly uniform in physical attributes, the biological assemblages that occupy this habitat markedly differ at different locations. Species richness ranged from 26 to 51 intertidal taxa, total abundances varied from as low as 700+ individuals to an excess of 10,000 individuals and algae cover ranged from as low as 3% to almost 50%. Most of the intertidal organisms were common and several were found on all 12 surveyed seawalls (e.g. cyanobacteria, chthamalid barnacles, and gastropods *Echinolittorina malaccana, Patelloida saccharina* and *Siphonaria guamensis*), although there were a number of species that were only present on a single seawall (e.g. the rhodophyte *Asparagopsis taxiformis* on the seawall at Marina South and the bivalves *Trapezium* sp. and *Irus* sp. which were only observed at Pasir Ris). At each location, seawall communities were numerically dominated by a few taxa, which were usually siphonariid limpets or barnacles. This study provides detailed information on the diversity and community structure of intertidal communities inhabiting seawalls in Singapore in relation to location and shore height.

***KEY WORDS.* –** intertidal, artificial, coastal defence, tropical, Singapore.

INTRODUCTION

Extensive coastal urbanisation has been on-going in Singapore for the last three decades (Chua & Edwards, 1992). Much of Singapore's coastline now consist of primarily artificial habitat such as man-made beaches and hard coastal defence structures(seawalls and breakwaters) which have replaced natural rocky shores as the most prevalent hard-substratum intertidal habitat. In the absence of natural rocky shores, these artificial structures provide an alternative, though not necessarily surrogate, habitat for intertidal organisms dependent on hard substrata. These seawalls are constructed primarily of granite boulders fitted together, which serve to prevent erosion of the reclaimed shoreline. Apart from this obvious functionality, intertidal seawalls also provide habitats for the organisms that typically occupy natural intertidal rocky shores. Seawalls are also common in other countries, and could be said to be a distinctive feature of developed coastal cities (Davies et al., 2002; Chapman & Bulleri, 2003). The diversity, species dominance, and spatial patterns of abundance of intertidal organisms inhabiting tropical seawalls are practically unknown.

Marine waters surrounding Singapore and its outlying islands are increasingly utilised for numerous socio-economic activities, including shipping, port maintenance, industrial cooling and potable water production through desalination. As a result, the marine environment faces numerous anthropogenic pressures and disturbances. Potential impacts include increased occurrences of alien species introductions through ballast water and hull fouling (Ruiz et al., 2000; Gollash, 2002; Hewitt et al., 2004), increases in contamination or pollution through spills or resuspension of contaminated material through dredging.

The community structures observed on these artificial habitats should then be catalogued and described in detail as this will provide a basis for future comparative studies for these specific environments. The biological assemblages that occupy intertidal seawalls in the tropics have not been described in detail, although comparisons have been made between assemblages on these structures and adjacent natural rocky shores (Sydney, Australia: Chapman & Bulleri, 2003; California, USA: Davies et al., 2002).

The single published study to date on intertidal breakwaters in Singapore monitored molluscan assemblages on intertidal seawalls following an oil spill (Tan et al., 1999), but had little information on undisturbed community structure or natural fluctuations in space and time. In general, there is a dearth of published studies on the intertidal rocky habitats of Singapore, due in no small part, to the fact that extensive stretches of rocky shores are rare (Chuang, 1961; Todd & Chou, 2005). Many rocky intertidal habitats in Singapore tend to be isolated rocky patches along a sandy shore, or rocky upper littoral shores that gradate into sand banks or coral reef flats (Chuang, 1961; Lim et al., 1994). The first published study of intertidal rocky shores in Singapore (Purchon & Enoch, 1954) was conducted on an offshore island 12 km south of the main island of Singapore. Later, Lee (1966) described the distribution of organisms along the shore at Tanjong Teritip in Singapore. These studies were purely qualitative, with Lee (1966) making no estimates of even relative abundance, whilst Purchon & Enoch (1954) provided subjective estimates of abundance. Subsequent research focused on the natural rocky shore at Labrador Park, which described the remaining natural rocky shore communities (Todd & Chou, 2005) present on the single marine Nature Reserve in Singapore, as well as describing and the effects of visitor pressure on these rocky shores (Huang et al., 2006).

In this study we examine intertidal biological assemblages on seawalls at 12 locations around Singapore. These locations span a wide range of environmental conditions ranging from estuarine to coastal to offshore islands. The primary objective was to examine and document the distribution, diversity and abundances of intertidal organisms on seawalls in Singapore, providing a detailed description for each location.

MATERIAL AND METHODS

Site Description. **–** The following terms will be used to describe the physical features of seawalls. The term “slope length” (short or long) refers to the distance of the wall measured along the slope of the seawall perpendicular to the water’s edge from the bottom to the top of the seawall, while “wall width” refers to the length of the seawall parallel to the water’s edge and “wall height” (low or tall) describes the vertical height of the seawall perpendicular to the surface of the sea above chart datum (see Fig. 1). Seawalls generally have three main features, a flattened top, central sloping section and a base (Fig. 1). This base may sit directly on the substratum, or may extend for some distance as a roughly horizontal revetment. In some instances, an additional horizontal terrace/revetment may be present midway along the slope length. Most seawalls in Singapore are constructed from granite boulders. Differences may arise in the general angle of the slope, height above chart datum, presence of revetment and terraces, boulder size, and in the presence of concrete grouting between boulders. For most of the seawalls examined, no distinct organism zonation (sensu Stephenson & Stephenson, 1949, 1972) was noted. Most of the organisms generally occupied a range of tide

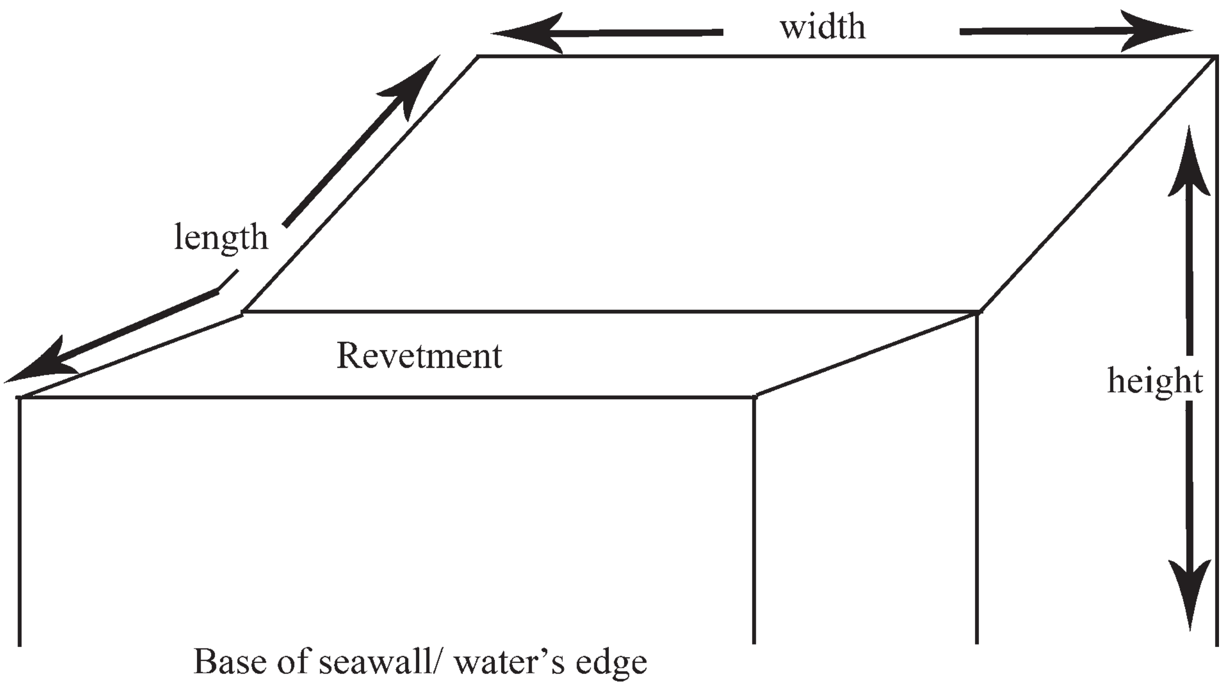

Fig. 1. Terms used to describe the dimensions of the seawalls examined. Height denotes the vertical height of the seawall above chart datum, width denotes the length of the seawall, measured along the horizontal surface and length, the slope length of the seawall.

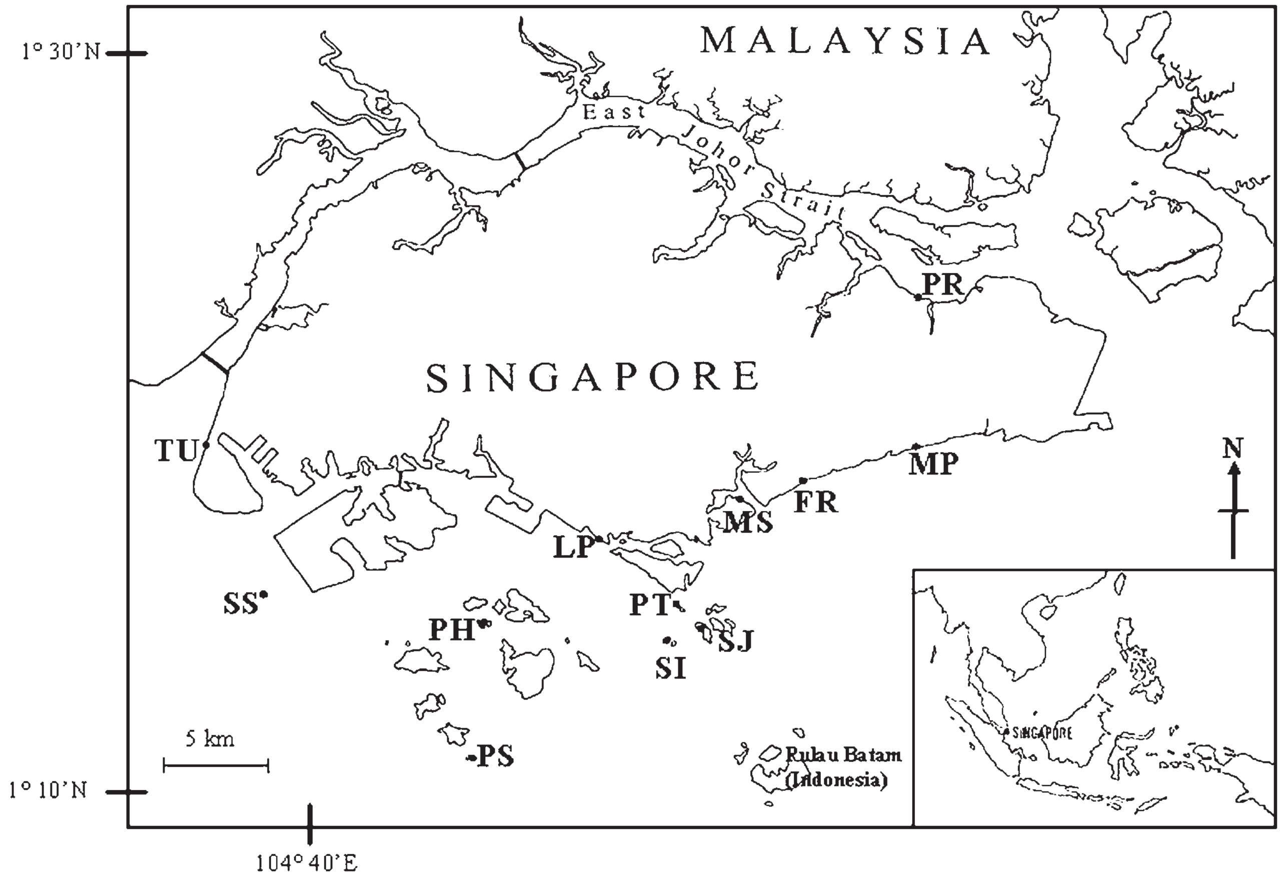

Fig. 2. Locations of twelve seawalls studied in the survey. Abbreviations used: PR, Pasir Ris; MP, Marine Parade; FR, Fort Road; MS, Marina South; SJ, Pulau Sakijang Bendera (St John's Island); PT, Pulau Tekukor; SI, Sister's Island; LP, Labrador Park; PH, Pulau Hantu; PS, Pulau Satumu; SS, Sultan Shoal; TU, Tuas. See also Table 4.

heights, which may span up to 3.1 metres vertically across all four defined shore heights (see below for definition of shore heights).

Twelve seawalls on the coastline of the main island of Singapore and its outlying islands were studied (Fig. 2) from Apr.2002 to Feb.2003. The physical attributes of each seawall were characterised by measuring the slope angle at 0.5 m intervals along the slope length. This allowed the calculation of absolute height at each with respect to chart datum. To avoid inconsistencies in tidal exposure due to different slopes and base heights of the seawalls, each seawall was divided into four parallel, horizontal sections along the width of the seawall corresponding to recognised tidal heights for Singapore (Maritime and Port Authority of Singapore, 2002). These were: Supralittoral (SP), > 1.1 m above mean sea level (MSL), High Shore (HS, 0.5 to 1.1 m above MSL), Upper Midshore (UM, from -0.5 to 0.5 m with respect to MSL) and Lower Midshore (LM, between -0.5 and -1.2 m with respect to MSL).

Sampling Methodology. – At each seawall location, sampling effort was stratified within these tidal sections (SP: 20 quadrats, HS: 20 quadrats, UM: 20 quadrats, LM: 32 quadrats) using 30 cm × 10 cm quadrats. A total of 92 replicate quadrats were haphazardly placed within a six metre wide area along the length of the sloping seawall. Quadrat size and number sampling effort were optimised for precision and accuracy based on results of a pilot study that consistently demonstrated higher variability at UM and LM habitats.

All visible organisms in each 30 × 10 cm quadrat were enumerated during spring low tides in daylight. Data consisted of visual estimates of percent cover for colonial organisms (algae and invertebrates) and numbers of individuals within each quadrat for motile animals. All organisms were identified to the highest taxonomic level possible. However, the difficulties of field identification necessitated the assignation of artificial groupings for some these organisms. A list of the groupings utilised in this study is provided in Table 1. These were treated as taxa in subsequent analyses. A limitation of the surveys was that nocturnally active animals, crevice fauna and juveniles were under-represented. Fast moving motile organisms (e.g. the isopod *Ligia*; nemerteans) were also excluded in the analyses.

Analyses. – Rank-abundance curves were plotted for all 12 locations to determine the gross patterns of dominance. The Shannon-Weiner diversity index and evenness was used as measures of species diversity and community structure of seawalls across locations. Correspondence Analysis (Greenacre, 1984) was used as an ordination method to examine the occurrences of intertidal organisms at two different spatial scales, across locations (kilometres) and within locations [across shore heights; (metres)]. The CA was performed on log(x + 1) transformed data compiled into two contingency tables: 1) Location × Species; 2) Zone × Species and analysed independently using the Correspondence Analysis module in Statistica (STATSOFT, ver. 5.1, 1997 edition). The results were then presented graphically using the first two dimensions of the analyses.

RESULTS

A total of 30 marine autotrophic taxa, comprising two cyanobacteria species, ten red algae taxa, six genera of brown algae, 11 genera of green algae and one mixed algae assemblage were observed from the surveys of the 12 seawalls around Singapore (Table 2). Total algal cover ranged from 18% at Pulau Hantu to ~ 60% at Marina South (Fig. 3). Most of the seawalls examined exhibited a fairly diverse and abundant algal assemblage, except at the estuarine locations Pasir Ris and Tuas, which had ≤ 5 algal taxa (Fig. 3). However, algal abundance was relatively high at Tuas (accounting for 48% of total cover) even though species richness was low, consisting almost entirely of cyanobacteria, possibly *Lyngbya* sp., as the dominant species (Fig. 3). Although Pulau Hantu exhibited relatively high species richness, algal abundance only accounted for 18% of the total cover and this also consisted primarily of cyanobacteria (Fig. 3). Taxon richness, but not cover, was greatest at Marina South and Labrador Park (Fig. 3), both mainland locations with relatively higher wave exposure close to the south coast. Algae taxa were generally widely distributed. Although no taxon was recorded from all sampling locations, most taxa were observed from at least three locations (Table 2). Only *Dictyosphaeria* spp. (green bubble algae) and the red alga *Asparagopsis taxiformis* were recorded from single locations (Table 2).

In addition to the algae, a total of 66 invertebrate taxa were also documented. The intertidal fauna was largely made up of molluscs, which contributed at least 60% of the total taxon richness observed at each location. Molluscs were also numerically dominant at each seawall, and these consisted primarily of siphonariid limpets and littorinid snails (Fig. 4, Table 3). Crustacean fauna were mostly represented by balanid and chthamalid barnacles, which together usually made up at least 10% of the total invertebrate abundance (Fig. 4). Motile crustaceans were relatively rare and comprised *Ligia* sp., hermit (Diogenidae) and grapsid crabs (Table 3). The gastropods *Siphonaria guamensis, Patelloida saccharina, Echinolittorina malaccana* as well as chthamalid barnacles were observed from all survey locations, while some species (e.g. *Musculista senhousia*, *Irus* sp. *Trapezium* sp., *Pyrene scripta*) were only observed from a single location (Table 3).

There was obvious spatial variation in the intertidal communities examined on the 12 surveyed seawalls. Total faunal abundances range from an excess of ten thousand individuals (Pasir Ris) to as little as 700+ individuals (Pulau Hantu), although differences in taxon richness were in the range of 10 taxa (Fig. 4). Species diversity as determined by the Shannon-Weiner diversity index, was fairly similar across all seawalls; exhibiting an index > 2.5 except at Pasir Ris and Tuas (Fig. 5). The assemblages on the seawalls also exhibited fairly comparable community evenness with evenness values ranging between 0.7 and 0.9 (except Pasir Ris (0.69), Fig. 5). Survey locations with low total abundances tended to exhibit relatively high species richness (e.g. Fort Road, Sister's Island, Pulau Hantu and Pulau Satumu, Fig. 4) and relatively higher community evenness (e.g. Pulau Hantu and Pulau Satumu, Fig. 5). The seawall assemblages at Pasir Ris and Tuas were characterised by high total abundances and relatively lower number of species and community evenness (Figs. 4, 5), indicating exceptionally marked patterns of numerical dominance by a very small range of species.

Table 1. Functional categories of taxa and its corresponding components identified from the seawalls around Singapore.

Taxa	Components
Turfing algal assemblage (TAA)	A mixture of *Dictyota* sp., *Enteromorpha spp*. and Ceramiales
Bryopsis spp.	*Bryopsis harveyana*, *B. plumosa*
Ceramiales	Consists of either *Ceramium* spp. or *Centrocerus* spp. or combinations of both
Gracilaria spp.	*Gracilaria crassa*, *G. edulis*, *G salicornia*
Amphiroa spp.	*Amphiroa fragilis*, *A. foliacea*
Jania spp.	*Jania* cf. *tenella*, *J*. cf. *decussato-dichotoma*
Enteromorpha spp.	*Enteromorpha intestinalis*, *E. tubulosa*
Chthamalids	*Chthamalus malayensis*, *Euraphia caudata*, *E. withersi*
Crabs	*Myomenippe* sp., sesarmine crabs
Littoraria spp.	*Littoraria articulata*, *L strigata*, *L. ardouinana*
Peasiella spp.	*Peasiella lutulenta*, *P. patula*, *P. roepstorffiana*
Serpulids	*Pomatoleios* sp., *Hydroides* sp.

Table 2. List of algae observed at 12 seawalls around Singapore (see Fig. 2 for location abbreviations).

	Location											
Species	**PR**	**MP**	**FR**	**MS**	**SJ**	**PT**	**SI**	**LP**	**PH**	**PS**	**SS**	**TU**
Filamentous cyanobacteria	×	×	×	×	×		×	×	×	×	×	×
Encrusting cyanobacteria	×		×	×	×	×	×	×	×	×	×	×
Acanthophora spicifera (M. Vahl) Børgesen, 1910		×		×	×	×		×	×			
Amphiroa spp.				×		×						
Asparagopsis taxiformis (Delile) Trevisan de Saint Léon, 1845				×								
Polysiphonia spp.	×					×	×					×
Gracilaria spp.		×		×				×	×			
Jania spp.				×	×	×				×		
Encrusting Corallinacea		×		×	×	×		×	×	×	×	
Lithothamnium sp		×	×	×	×	×	×	×		×	×	×
Ceramiales		×	×	×		×			×		×	
Peysonnelia rubra (Greville) J. Agardh, 1851				×	×		×	×	×	×	×	
Colpomenia sinuosa (Mertens ex Roth) Derbès & Solier, in Castagne, 1851				×	×			×		×		
Dictyota spp.						×		×				
Lobophora variegata (Lamouroux) Womersley, ex Oliveira, 1977		×	×	×	×	×	×	×	×	×	×	×
Padina spp.		×	×	×	×	×		×	×	×		
Sargassum spp.			×	×	×	×		×		×		
Turbinaria spp.		×								×		
Acetabularia spp.								×				
Boergesenia forbesi (Harvey) Feldmann, 1938				×		×		×				
Bryopsis spp.					×			×		×		
Chaetomorpha spp.			×			×						
Codium geppiorum O.C. Schmidt, 1923						×		×				
Collinsiella cava (Yendo) Printz, 1927				×			×	×	×		×	
Dictyosphaeria spp.									×			
Enteromorpha spp.		×	×	×		×	×	×	×	×	×	
Neomeris spp.					×				×	×		
Phyllodictyon anastomosans (Harvey) Kraft & Wynne, 1996		×				×					×	
Ulva spp.		×	×	×	×			×				
TAA	×	×	×	×	×	×	×	×	×	×	×	

At each location, seawall communities were numerically dominated by two to five main taxa, which accounted for at least five percent of the total abundance at those locations. Exceptions were observed in the seawall communities at Pulau Satumu and Sultan Shoal, which were dominated by six or more intertidal taxa and at Tuas where only two taxa were numerically dominant (Fig. 6.1–6.12). Siphonariid limpets and barnacles (both balanids and chthamalids) were the most abundant taxa on seawalls except at Marine Parade, where patellogastropod limpets were numerically dominant (Fig. 6.2). All other taxa observed occurred at considerably lower abundances; usually less than ten individuals of each taxa were noted at each of the surveyed locations.

The ordination plot of the first two axes of the correspondence analysis (46.45% total variance) indicated that the seawall community at Pasir Ris was unique from the other locations primarily due to the presence of bivalves, in particular *Xenostrobus* sp. and *Saccostrea* spp. on the seawall at Pasir Ris (Fig. 7). Pulau Hantu was also unique from the other locations and was characterised by *Nerita chamaeleon* and *N. undata* (Fig. 7), where they occurred in high abundances (Fig. 6.9). Marine Parade, Fort Road and Tuas formed a fairly distinct grouping and this was characterised by the

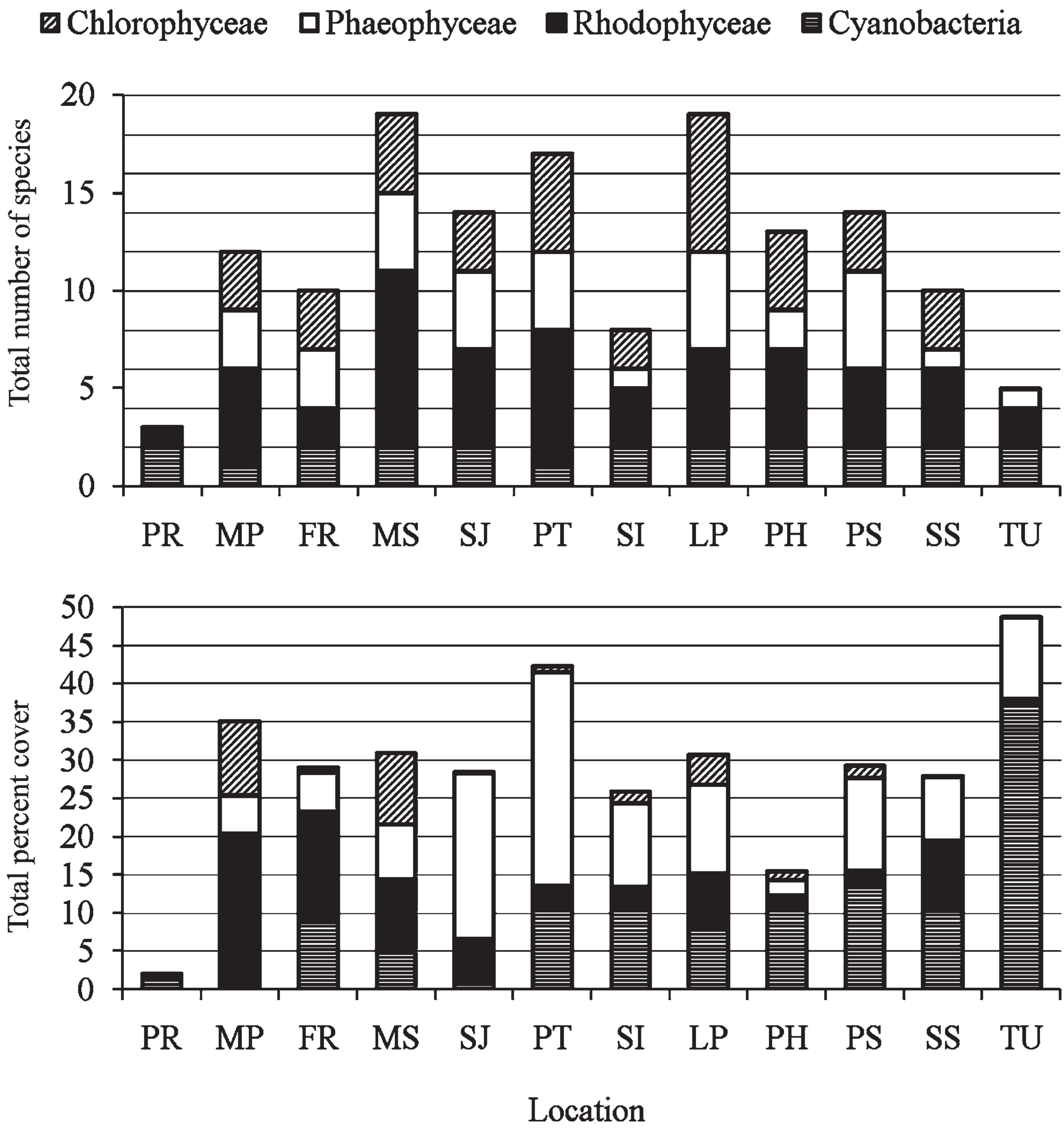

Fig. 3. Total abundance and number of algal species observed from 12 seawalls in Singapore. Abundance is expressed as percent cover. See Fig. 2 for location abbreviations.

presence of muricid gastropods (*Thais* spp.) at Marine Parade and Fort Road and the absence or low abundance of *Monodonta labio*, neritid snails and the muricid gastropod *Morula fusca* at all three locations (Fig. 7). Spatial patterns in the other locations arising from assemblage structure were less distinct; although offshore locations largely grouped together, there was some overlap with Labrador Park and Marina South, located on the south coast of the mainland (Fig. 7). This cluster was influenced by greater abundances of *Nerita undata*, the pulmonate limpets *S. atra*, *S. javanica* as well as *M. fusca* (Fig. 7).

Shore height had large and distinct effects on the structure of the intertidal assemblages; the first two dimensions of the Correspondence Analysis explained 86.67% and 8.44% respectively of the total variance. The supralittoral shore was characterised by assemblages that composed of littorinid gastropods (*Littoraria* spp. and *Echinolittorina* spp.) while the high shore was characterised primarily by *Littoraria* spp. and to a lesser extent by chthamalid barnacles, Siphonariid and patellagastropod limpets, as well as neritid snails, in particular *Nerita undata* (Fig. 8). The upper and lower midshore was primarily characterised by grazing molluscs and predatory whelks, however, there appeared to be a distinct difference in the assemblages occupying these two shore heights. At the upper midshore, grazing molluscs such as *Nerita albicilla*, *N. chamaeleon* and *Monodonta labio* were more abundant, along with the barnacles *Balanus*

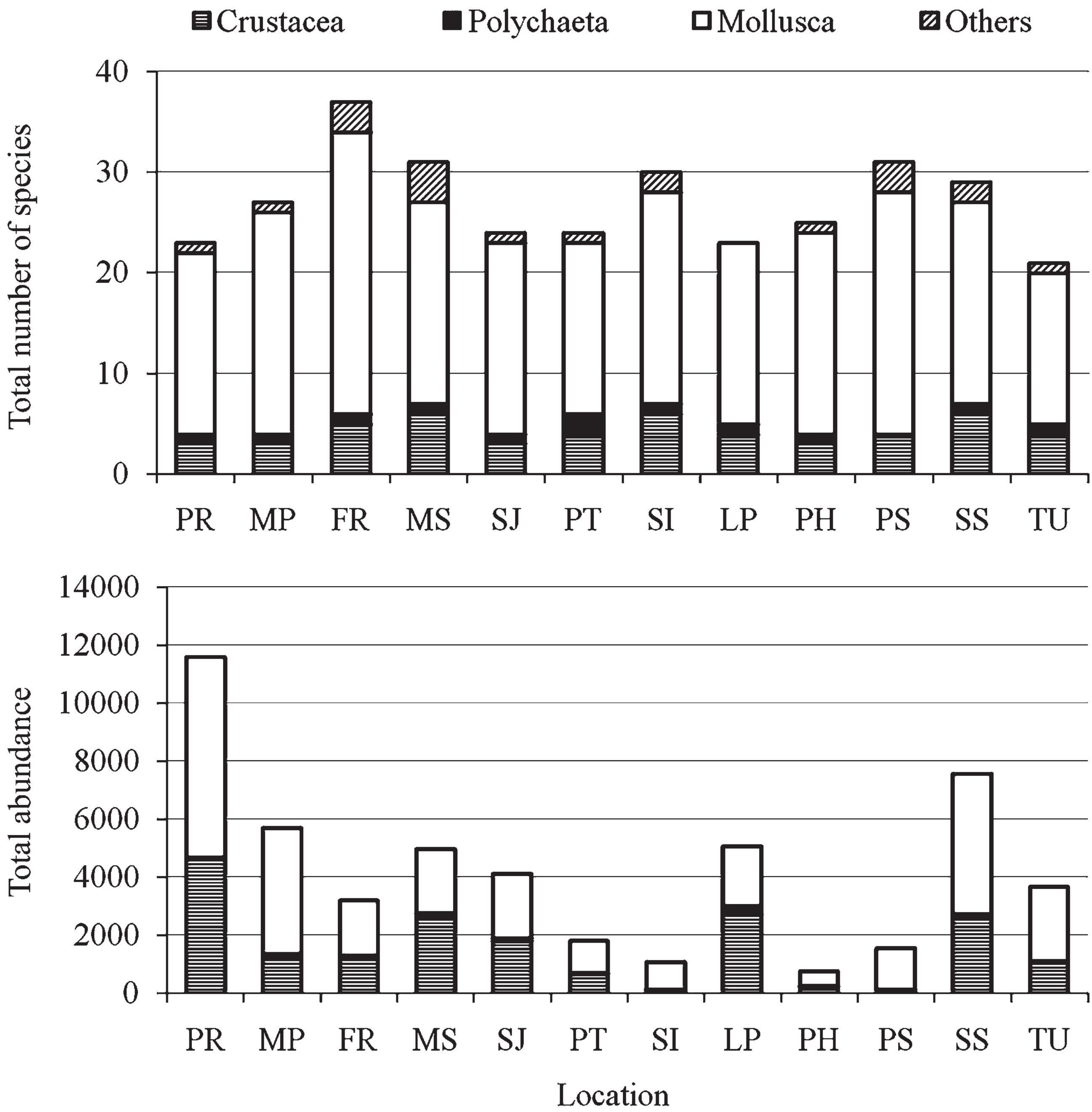

Fig. 4. Total abundance (as total number of individuals at each location) and number of intertidal invertebrates observed from 12 seawalls in Singapore. See Fig. 2 for location abbreviations.

spp. and *Tetraclita* spp. The predatory whelks that occupy this shore height in higher abundances were *Thais jubilaea* and *Morula fusca* (Fig. 8). The lower midshore, on the other hand, was characterised by grazing molluscs such as *Trochus bruneus*, *Pictocollumbella ocellata* and *Siphonaria atra*. The predatory molluscs that occupy this shore height consisted predominantly of *Thais bitubercularis* and *Morula margariticola*. In addition to these species, tubeworms and bivalves were also noted at the lower midshore.

Seawall descriptions. – The physical characteristics and biological assemblages of 12 seawalls examined in the present study are described below. A summary of the physical properties of the seawalls in this study is provided in Table 4.

1. **Pasir Ris.** This seawall is located on a reclaimed beach fronting the Eastern Johore Straits and is on the edge of an intertidal mud flat exposed at 1.2 m below MSL on the seaward side of the seawall. The biological assemblage here was characterised by a large number of estuarine bivalves *Perna viridis* and *Xenostrobus* sp., which were not found at the other locations. A wide band of the cosmopolitan barnacle *Balanus amphitrite* extended from 1 m below MSL to 1.4 m above MSL. At LM, most of the barnacles were dead, and their empty tests were used by organisms such as *Xenostrobus* sp. The LM was dominated by *Ulva pertusa*, turfing algal

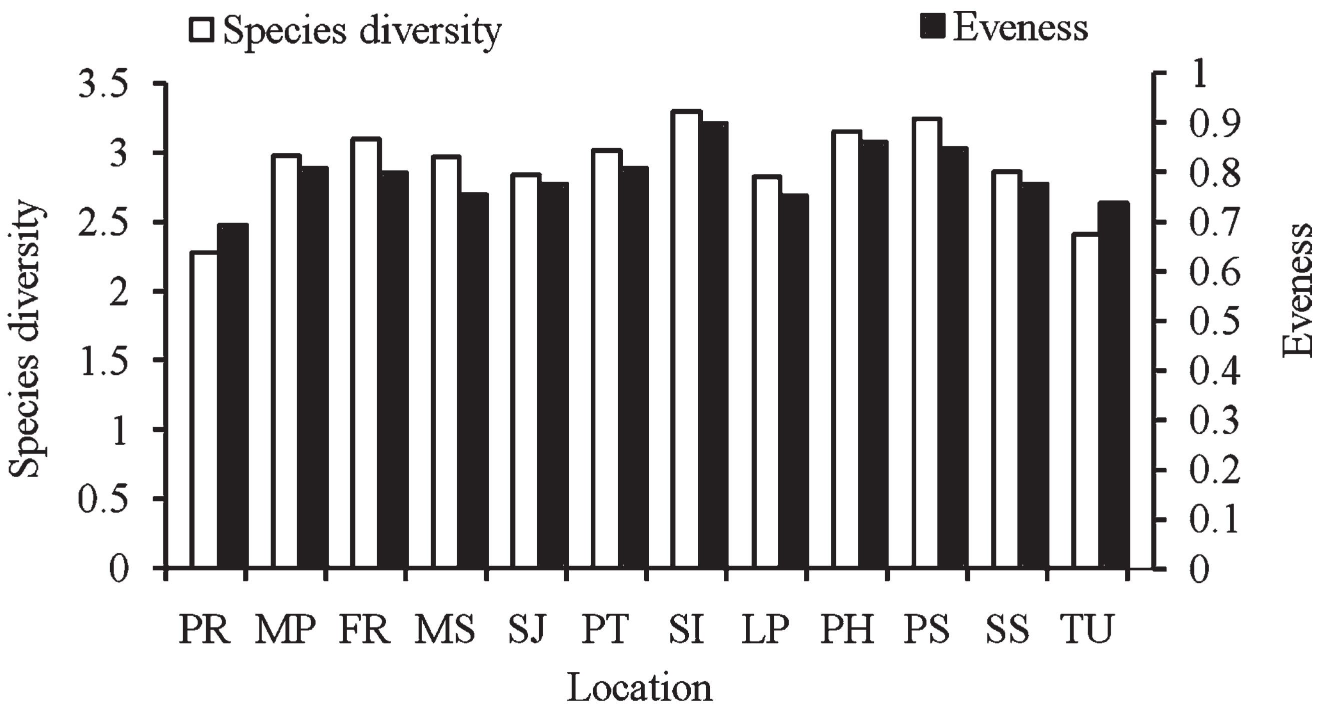

Fig. 5. Measures of species diversity and evenness for 12 study locations. See Fig. 2 for location abbreviations.

assemblages consisting of grazed *Enteromorpha spp.* and *Centrocerus* sp., the bivalves *Modiolus metcalfei*, *Xenostrobus* sp., *Perna viridis*, *Trapezium* sp. *Irus* sp. and *Anomia* sp. and predatory muricids (*Thais gradata* and *T. clavigera*). At UM, the seawall was dominated by *Balanus amphitrite*, *Siphonaria guamensis*, *Musculista senhausia* and undetermined brown solitary sea anemones living within dead barnacle tests. Encrusting algae (*Lobophora variegata*) appeared in substantial cover at HS. The SP zone was occupied by littorinid gastropods (*Littoraria articulata*, *L. strigata*, and *Echinolittorina malaccana*).

2. **Marine Parade.** Located along the eastern coast of Singapore, this reclaimed coastline is protected by a series of short seawalls (average wall length of 30 m).. The biological assemblages here tended to occupy a wide range of shore heights. At LM and UM levels, the algal assemblage consisted of *Ulva petusa*, *Gracilaria* spp., *Acanthophora spicifera* and *Padina* sp. as well as red turfing algae. The LM was also dominated by sessile organisms (*Balanus amphitrite*, vermetids and serpulids), with smaller densities of herbivorous gastropods (*Trochus maculatus*) and predatory muricids (*Thais rufotincta*). Other muricid species (*T. jubilaea* and *Morula musiva*) were less abundant and inhabited the UM levels, where *B. amphitrite* was still abundant. The HS was covered by traces of encrusting algae. The limpets *Siphonaria guamensis* and *Patelloida saccharina* ranged from the UM to the SP, with highest densities at HS. Commonly found at HS were oysters (*Saccostrea cucullata*) and chthamalid barnacles (*Euraphia withersi*, *Chthamalus malayensis*). Littorinids (*Littoraria articulata*, *L. strigata*, *Echinolittorina malaccana*, *E. vidua* and *Peasiella* spp.) were extremely abundant at HS and SP.

3. **Fort Road.** This seawall is located on the east coast of Singapore, and forms the northern entrance of a tidal monsoonal canal. The gently sloping wall extends vertically up to 2.4 m above MSL and although a revetment is absent, it is topographically more complex than most of the other walls examined in this study. The upper reaches of the wall is made up of large granite boulders grouted with cement. Towards the base, the boulders are smaller and grouting is absent (Table 4). The algal assemblage at LM consisted almost entirely of red turfing algae, interspersed with small patches of cyanobacteria, *Enteromorpha* spp., *Sargassum* spp., *Padina* spp. and encrusting algae (mainly *Peyssonnelia rubra*). The site was unusual in that a high diversity of muricid predators (*Thais clavigera*, *T. rufotincta*, *T. jubilaea*, *T. bitubercularis*, *Morula musiva* and *M. margariticola*) co-occurred (see also Marine Parade). These predators extended throughout the midshore, but were most abundant in the LM zone, where sessile organisms such as barnacles, vermetids and serpulids were also common. Cyanobacteria and encrusting algae covered much of the UM and HS areas. *Siphonaria guamensis* and *Balanus amphitrite* inhabited a wide intertidal range, spanning 0.5 m below MSL to 1 m above and 1 m below MSL to 0.5 m above MSL, respectively. Both species were most abundant at UM. *Patelloida saccharina* was also common at UM and

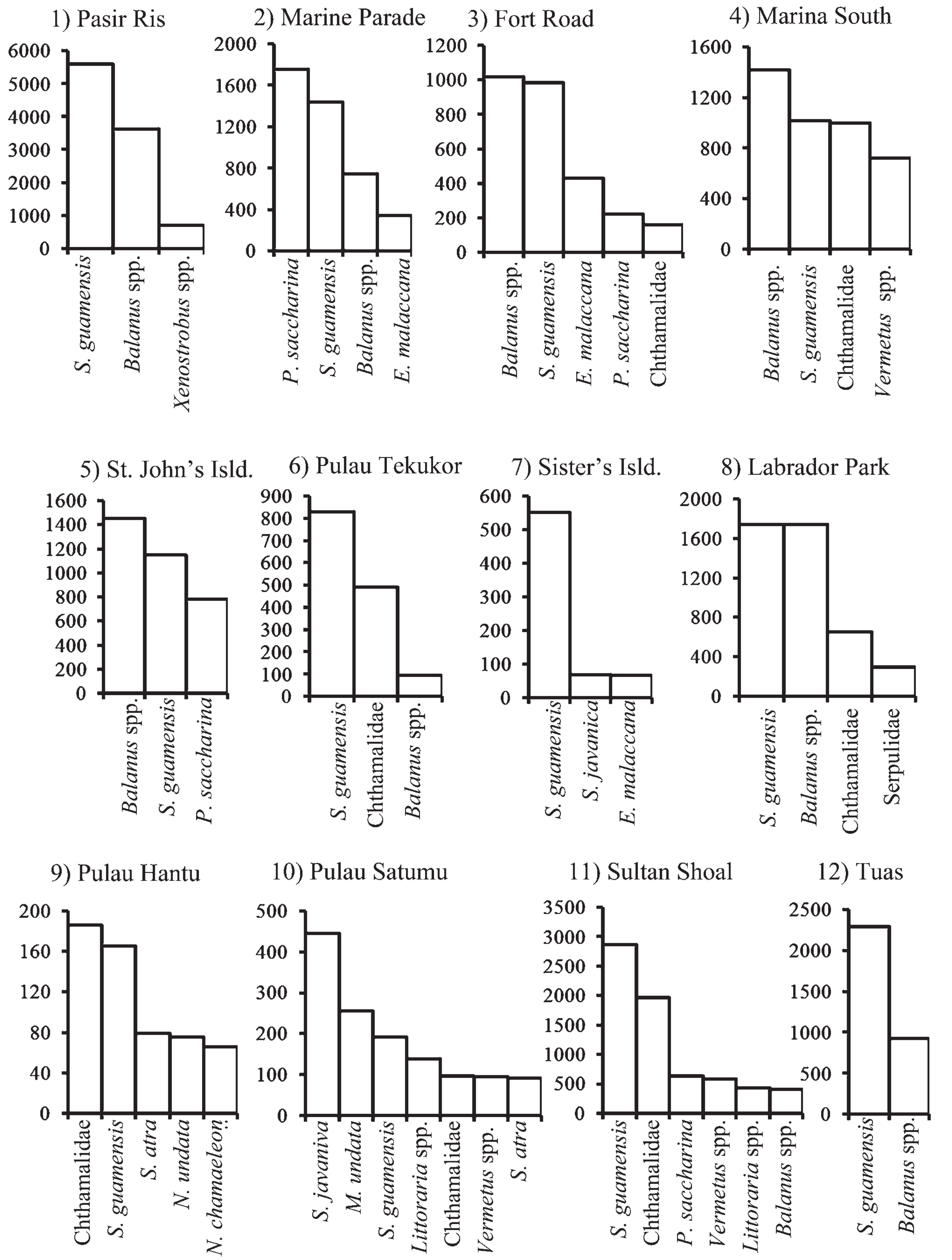

Fig. 6.1–6.12. Rank abundance graphs for the 12 study locations. Data shown is only for taxa that contribute more than 5% of the total abundance in each location. See Table 3 for full names of taxa.

Table 3. List of intertidal fauna observed at 12 seawalls around Singapore. See Fig. 2 for location abbreviations.

Species	Location											
	PR	MP	FR	MS	SJ	PT	SI	LP	PH	PS	SS	TU
Balanus spp.	×	×	×	×	×	×	×	×		×	×	×
Chthamalidae	×	×	×	×	×	×	×	×	×	×	×	×
Ibla sp.			×	×			×		×		×	
Tetraclita spp.			×	×	×	×		×		×	×	×
Tetraclitella sp											×	
Grapsidae		×	×	×			×				×	
Diogenidae							×					
Ligia sp.	×			×		×	×	×	×	×		×
Serpulidae	×	×	×	×	×	×	×	×	×		×	×
Spirorbidae						×						
Patelloida sp. A	×	×	×	×	×	×		×	×	×	×	×
Patelloida saccharina	×	×	×	×	×	×	×	×	×	×	×	×
Cellana radiata (Born, 1779)				×	×	×		×		×	×	
Turbo bruneus Linn., 1758				×	×		×	×	×	×	×	
Trochus maculatus (L., 1758)		×	×	×	×	×		×		×		
Monodonta labio (L., 1758)			×	×	×	×	×	×	×	×		×
Euchelus sp.								×		×		
Nerita albicilla L., 1758			×		×	×			×	×		
N. chamaeleon L., 1758		×	×				×		×	×		
N. lineata Gmelin, 1791												×
N. squamulata Le Guillou, 1841									×			
N. undata L., 1758			×		×	×	×		×	×	×	
Echinolittorina malaccana (Philippi, 1847)	×	×	×	×	×	×	×	×	×	×	×	×
E. vidua (Gould, 1859)	×	×	×	×	×		×	×	×	×	×	
E. melanacme (Smith, 1876)	×	×	×	×	×	×	×			×	×	
Littoraria spp.	×	×	×	×	×	×	×	×	×	×	×	
Peasiella spp.	×	×	×	×				×			×	×
Vermetus cf. *alii*		×	×	×	×	×	×	×	×	×	×	×
Dendropoma sp.											×	
Gyrineum natator (Röding, 1758)		×										
Lataxiena bimucronata (Reeve, 1846)	×				×							
Morula musiva (Kiener, 1835)		×	×	×		×	×	×	×	×	×	×
M. fusca (Küster, 1858)			×	×	×	×	×	×	×	×		×
M. margariticola (Broderip, 1833)			×	×	×	×	×	×	×	×	×	×
*Thais bituberculari*s (Lamarck, 1822)			×			×	×			×		
T. clavigera (Küster, 1858)	×	×	×									
T. echinata (Blainville, 1832)									×		×	
T. jubilaea Tan & Sigurdsson, 1990		×	×									
T. squamosa (Pease, 1868)										×		
T. rugosa (Born, 1778)				×								
T. rufotincta Tan & Sigurdsson, 1996		×	×									
T. gradata (Jonas, 1846)	×											
Pictocollumbella ocellata	×			×			×					

Table 3 (continued).

Species	Location											
	PR	MP	FR	MS	SJ	PT	SI	LP	PH	PS	SS	TU
P. duclosiana	×											
P. scripta			×									
Haminoea sp.										×		
Siphonaria atra Quoy & Gaimard, 1833		×	×		×	×	×	×	×	×	×	
Siphonaria guamensis Quoy & Gaimard, 1833	×	×	×	×	×	×	×	×	×	×	×	×
Siphonaria javanica (Lamarck, 1819)		×		×	×		×	×	×	×	×	×
Onchidiidae			×									×
Septifer excisus (Wiegmann, 1837)		×										
Perna viridis (L., 1758)	×			×								
Xenostrobus sp.	×	×										
Musculista senhousia (Benson, 1842)							×					
Isognomon legumen Gmelin, 1791			×				×		×		×	
Saccostrea cuccullata (Born, 1778)	×	×	×				×			×	×	×
Ostrea sp.	×	×										
Anomia sp.	×	×										
Trapezium sp.	×											
Irus sp.	×											
Chiton	×	×	×									×
Hydroida		×	×	×	×	×	×			×	×	
Anemone	×		×				×					
Ascidiacea				×								×
Porifera				×								
Zoanthidae			×	×					×	×		
Favia spp.											×	
Platygyra spp.										×		

neritids (*Nerita chamaeleon*, *N. albicilla* and *N. undata*) occurred between the UM and HS regions. *Monodonta labio* and chthamalids were occasionally found at the HS levels. Littorinids (*Littoraria*, *Echinolittorina malaccana*, *E. vidua* and *E. melanacme*) were common in the SP. *Echinolittorina malaccana* was very abundant and has a fairly wide intertidal range between 3.4 to 3.9 m above chart datum.

4. **Marina South.** Situated at the mouth of Kallang Basin and Marina Bay, the seawall defining the coastal outline of the northern mouth of Marina Bay spans a total distance of approximately 3.1 km and stands 2 m above MSL. This is a gently sloping grouted seawall, consisting of large granite boulders. A distinct ungrouted revetment is present at the lower limit of the LM zone which was covered by extensive mats of *Enteromorpha* spp., a marked turfing algal assemblage (consisting of *Ceramium* spp., *Dictyota* sp. and *Microdictyon* sp.), *Ulva petusa* and *Gracilaria crassa*. The fauna on the revetment included substantial populations of *Vermetus* cf. *alii* and *Pictocolumbella ocellata*. Unlike the previous two locations, predatory muricids were not as commonly observed. The distributions of *Morula margariticola*, *M. musiva* and *M. fusca* extended from this region to UM, with *M. fusca* being the most common of the three species. The algal assemblage between LM and HS was comprised almost entirely of cyanobacteria. On the seawall, *Balanus amphitrite* ranged between -1 to 1 metres above MSL. The UM was also characterised by the presence of gastropods *Siphonaria javanica*, *Patelloida* sp. A, *Monodonta labio* and *Nerita chamaeleon*. *S. guamensis* and chthamalids occur in a wide tidal range, both spanning between -0.7 m to 1.1 m above MSL. On the HS, littorinids (*Littoraria articulata*, *L. strigata*, *Echinolittorina malaccana*, *E. vidua* and *E. melanacme*) were present in the HS region. The SP zone was inhabited by considerable numbers of *E. malaccana* and the occasional *Littoraria* sp. and *Peasiella* sp.

5. **St John's Island (Pulau Sakijang Bendera).** Seawalls line a greater part of the island and along one northern shoreline, they protect sandy lagoons. The seawall in

this survey is situated along the south-west shoreline which faces a major shipping lane where a strong tidal current runs close to the shore. It is a fairly high and steep seawall, composed of non-grouted large granite boulders and no revetment. The algal assemblage on the seawall between LM and HS comprised almost entirely of encrusting algae such as *Lobophora variegata* and *Lithothamnion* sp. Neritids (*Nerita albicilla, N. chamaeleon,* and *N. undata*), muricids (*Morula musiva*, *M. decussata*) and the trochid *Monodonta labio* were common across the intertidal region, whilst *Siphonaria guamensis*, *Patelloida saccharina* and *Balanus amphitrite* dominated the LM and HS regions. Chthamalids were also found in the same range, but in lower numbers. The upper part of the slope was dominated by littorinids.

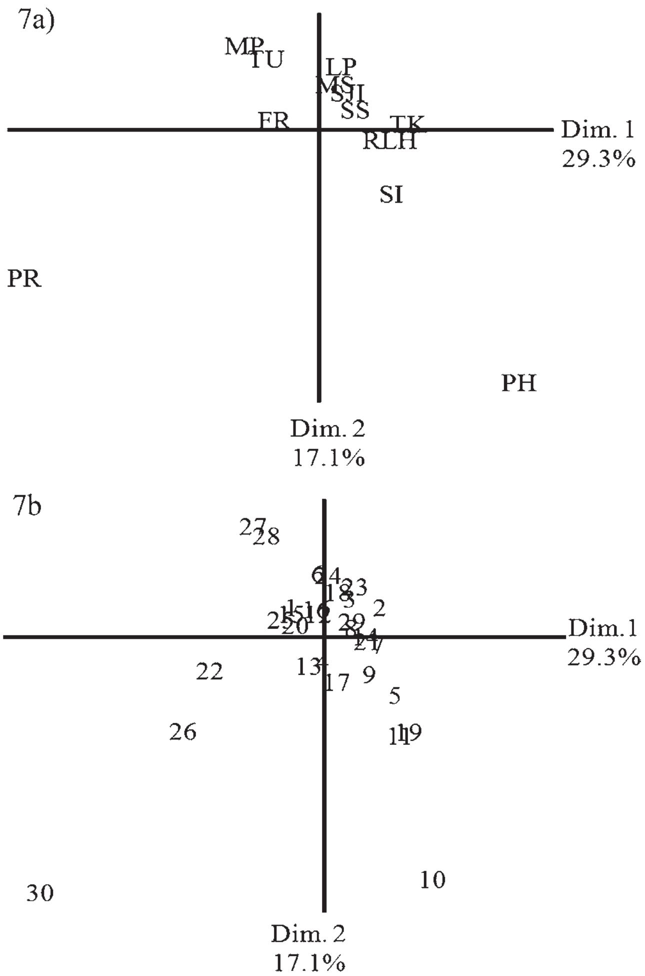

Fig. 7. Biplot of: a, Location × b, Species of the Correspondence Analyses. Data plotted on dimensions 1 and 2. Location codes as per Fig. 2. Species codes are: 1, *Balanus* spp.; 2, *Cellana radiata*; 3, Chthamalids; 4, *Littoraria* spp.; 5, *Monodonta labio*; 6, *Morula musiva*; 7, *M. fusca*; 8, *M. margariticola*; 9, *Nerita albicilla*; 10, *N. chamaeleon*; 11, *N. undata*; 12, *Echinolittorina malaccana*; 13, *E. vidua*; 14, *E. melanacme*; 15, *Patellioda* sp. A; 16, *P. saccharina*; 17, *Pictocolumbella ocellata*; 18, Polychaete; 19, *Siphonaria atra*; 20, *S. guamensis*; 21= *S. javanica*; 22, *Saccostrea cucullata*; 23, *Tetraclita squamosa*; 24, *Trochus maculatus*; 25, *Thais bitubecularis*; 26, *T. clavigera*; 27, *T. jubilaea*; 28, *T. rufotincta*; 29, *Vermetus* sp.; 30, *Xenostrobus* sp.

6. **Pulau Tekukor.** This island is located south of Singapore, north-west of St. John's Island. The seawall, built along the southern perimeter of the island, is the tallest and one of the steepest in the survey. It is made up of large, non-grouted granite boulders, with a distinct revetment at the LM zone. LM areas were extensively covered by *Sargassum* sp., *Enteromorpha spp.*, *Lithothamnion* sp., encrusting algae (*Peyssonnelia rubra* and *Lobophora variegata*) and turfing algae assemblages (*Ceramium* sp. and *Gracilaria* sp.). Other algae such as *Microdictyon* sp., *Jania* sp., *Boergesenia forbesii*, *Codium arabicum* and *Acanthophora spicifera* were also present. The faunal community here was not numerically dominated by any single species but comprised of a variety of sessile animals (serpulids, *Balanus amphitrite*, *Tetraclita squamosa* and chthamalids), grazers (*Siphonaria guamensis*, *S. atra*, *Cellana radiata*, *Trochus maculatus*, *Monodonta labio*, *Nerita undata*, *N. albicilla*), and predators (*Morula fusca* and *M. margariticola*). Encrusting algae extended well into the HS regions. Chthamalids were very abundant and occupied a wide tidal range (-0.5 m to 2.3 m above MSL). *Nerita undata* was also quite common, occupying the range between -1.1 m to 2.3 m above MSL. Grazing molluscs such as *S. guamensis* and *Monodonta labio* were also present in low numbers from the UM to SP regions. Littorinids (*Littoraria* spp., *Echinolittorina malaccana*, *E. vidua* and *E. melanacme*) occurred at 3.6 m above chart datum, of which *E. malaccana*, a high shore species, extended well into the SP.

7. **'Sisters' Islands.** This is a collective term for two small islands, Pulau Subar Darat and Pulau Subar Laut, separated by a deep channel less than 100 m wide and located 5 km off the southern tip of Singapore mainland. The grouted seawall studied on Pulau Subar Laut was fairly low and steep, and constructed of granite boulders of varying sizes. A non-grouted revetment is clearly visible at LM. The LM was dominated by *Enteromorpha* spp., *Lithothamnion* sp., encrusting algae and turfing algal assemblages. *Nerita chamaeleon*, *N. undata*, vermetids, *Morula fusca*, *M. margariticola*, *M. musiva* and serpulids were common on the revetment and at the base of the slope. *Nerita undata* however, extended well into the HS zone. Pulmonate limpets (*Siphonaria guamensis*, *S. javanica* and *S. atra*) occurred in moderate numbers at UM. Other molluscs such as *Turbo bruneus*, *Isognomon legumen* and *Saccostrea* sp. were also present here but in lower abundance. *Morula fusca,* and *Monodonta labio* were quite common in both the UM and HS regions. Chthamalids were present at HS but appear to be found primarily in rock crevices. The littorinids (*Littoraria* spp., *Echinolittorina malaccana*, *E. vidua* and *E. melanacme*) were present on the HS region. The vertical range of *Littoraria* and *E. malaccana* extended to the SP zone.

8. **Labrador Park.** The seawall located at the southern tip of Singapore island is fairly extensive, stretching for a distance of some 500 m. In some sections the seawall had collapsed, giving rise to large crevices. The seawall

is moderately high and possesses a gentle slope, lacking a distinct revetment with boulders devoid of grouting. The algal assemblage in the LM consisted primarily of encrusting algae and *Enteromorpha* spp. The more common organisms observed at this tidal level consisted of *Balanus amphitrite*, *Pomatoleios* sp. and *Monodonta labio*. Predatory muricids such as *Morula fusca* and *M. musiva* were also present, albeit in low numbers. *Morula musiva* was also common at UM, which also has a substantial cover of encrusting algae. HS and SP areas were devoid of macroalgal cover. *Siphonaria guamensis* occupied a wide tidal range on the seawall (from −0.6.to 0.4 m above MSL) although they occurred in small numbers. Chthamalid barnacles were perhaps the most common organisms on this seawall and they occurred between UM and HS (−0.4 to 0.7 m above MSL). Littorinids were evident at the upper limit of the UM zone. The range of *E. malaccana* extended up to the SP zone.

9. Pulau Hantu. The seawalls examined on this reclaimed reef flat are built along the perimeter of the two islands. They are fairly short and steep and are constructed of granite boulders of varying sizes grouted with cement. No revetment is present. This is the steepest seawall in the survey, varying between 41º at the SP zone to 28º at the LM zone (Table 4). The algal assemblage of the LM consists of grazed-down *Lobophora variegata*, *Mesospora* sp. and *Collinsiella cava*. The barnacles *Euraphia* sp. and *Ibla* sp. were quite common at LM, residing on the vertical rock surfaces and rock crevices respectively. This seawall was characterised by its high diversity and abundance of neritids (*Nerita undata*, *N. chamaeleon* and *N. albicilla*), particularly between the UM and HS. *Nerita undata* and *N. chamaeleon* inhabited a wider tidal range (−0.5 to 0.8 m above MSL) than *N. albicilla* (from MSL to 0.4 m above MSL). The littorinids (*Littoraria articulata*, *L. strigata*, *Echinolittorina malaccana*, and *E. vidua*) resided near the upper limit of the SP zone.

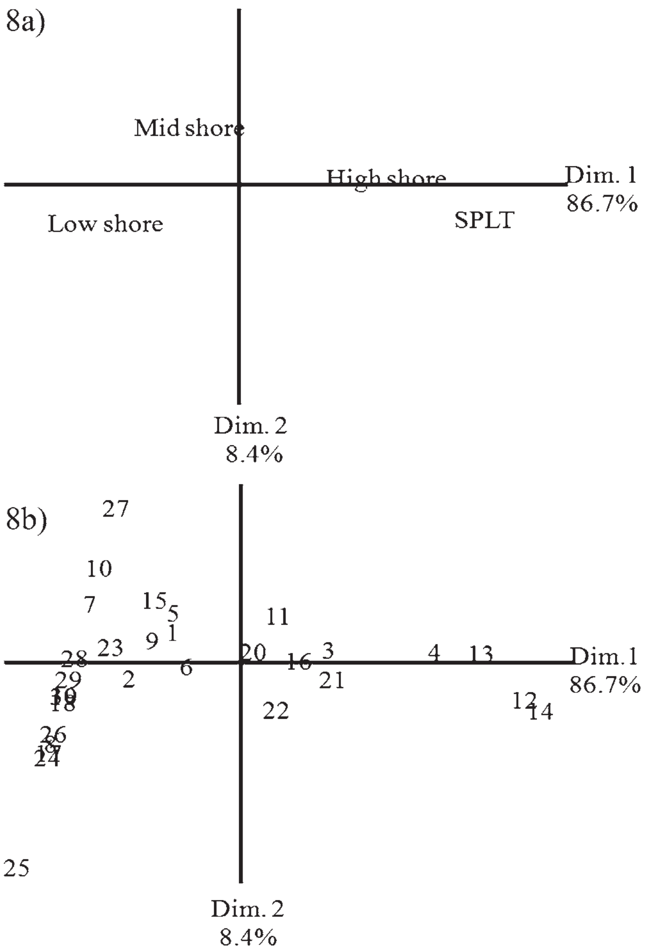

Fig. 8. Biplot of: a, Tidal zone × b, Species of the Correspondence Analyses. Data plotted on dimensions 1 and 2. Location and species codes as per Fig 7.

10. Pulau Satumu (Raffles Lighthouse). Located 12 km away from the main island of Singapore at the southern-most limit of Singapore port waters, the grouted seawall on Pulau Satumu is built along the western and eastern perimeter of the island, comprising of granite and sandstone boulders without a revetment. The seawall extends to 3.1 metres above MSL. The LM was characterised by a diverse algal assemblage, comprising green (*Bryopsis* spp., *Enteromorpha* spp.), brown (*Sargassum* spp., *Turbinaria* spp., *Padina* spp.) and red algae (*Acanthophora spicifera*, *Lithothamnion* and small turfing red algal assemblages). Other inhabitants in the LM include patellogastropod and pulmonate limpets (in particular *Siphonaria atra*), neritids, grazing gastropods (*Monodonta labio*, *Turbo bruneus*), predatory muricids (*Thais squamosa*), vermetids (*Dendropoma* sp.) and barnacles. Encrusting algae and occasional mats of filamentous cyanobacteria were observed at the UM levels, as well as large numbers of pulmonate limpets (*Siphonaria guamensis* and *S. javanica*) and *Nerita undata*. Muricid gastropods including *Morula fusca*, *M. margariticola* and *M. musiva* were also present between UM and LM levels. HS areas were covered almost entirely by encrusting algae, which thins out at the SP. Chthamalid barnacles and littorinids (*Littoraria* spp., *Echinolittorina malaccana*, *E. vidua* and *E. melanacme*) were present in the HS and SP levels.

11. Sultan Shoal. Located to the south west of Singapore Island, Sultan Shoal Lighthouse, till recently, marked the west entry into Singapore port waters until overtaken by reclaimed land. The seawalls line the perimeter of the island, which are more or less continuous. These grouted seawalls have a shallow gradient with the tops reaching 2.2 metres above MSL and has no revetment. Much of the LM was covered by encrusting algae (principally *Lobophora variegata* and *Lithothamnion* sp.), turfing algae assemblages and false limpets (*Siphonaria guamensis*, *S. javanica* and *S. atra*). Encrusting alga and true limpets (*Patelloida* sp. A and *P. saccharina*) characterised the UM. The algal component was further reduced in the HS and eventually disappeared in the SP zone. Littorinids (*Echinolittorina malaccana*, *E. vidua*, *E. melanacme* and *Peasiella* spp.) were found in substantial numbers in the SP levels.

Table 4. General description of the physical properties of the 12 seawalls surveyed. See Fig. 2 for location map.

Seawall location	Coordinates	Mean Slope (± S.D.)	Grouting present	Height (m above mean sea level)	Slope Length (m)	Mean boulder size in cm (±S.D.)
Pasir Ris	1°23.N 103°56'E	22.9 ± 12.2°	No	3.04	17	0.7 ± 0.3
Marine Parade	1°18.4'N 103°56.4'E	25.8 ± 8.6°	Yes	1.38	5.5	1.0 ± 0.2
Fort Road	1°17.6'N 103°53.8'E	17.2 ± 6.7°	Yes	2.42	11	0.8 ± 0.2
Marina South	1°17.6'N 103°53.8'E	15.6 ± 7.7°	Yes	2.03	13	0.9 ± 0.2
St. John's Island	1°16.8'N 103°52.2'E	25.4 ± 8.8°	No	2.8	9	0.9 ± 0.1
Pulau Tekukor	1°17.6'N 103°53.8'E	27.9 ± 16.9°	No	4.15	11.5	0.9 ± 0.2
Sisters' Island	1°12.8'N 103°50.0'E	29.9 ± 14.6°	Yes	2.36	6.5	1.1 ± 0.3
Labrador Park	1°15.8'N 103°48.2'E	17.3 ± 9.2°	No	1.41	11	0.4 ± 0.2
Pulau Hantu	1°13.5'N 103°44.8'E	35.8 ± 12.9°	Yes	1.82	5	0.5 ± 0.1
Pulau Satumu	1°09.6'N 103°44.4'E	21.1 ± 13.9°	Yes	3.05	13	0.7 ± 0.3
Sultan Shoal	1°14.37'N 103°38.8'E	23.9 ± 12.6°	Yes	2.17	9.5	0.9 ± 0.1
Tuas	1°17.6'N 103°53.8'E	14.1 ± 10.0°	No	2.67	14.5	1.0 ± 0.2

12. Tuas. This seawall is located on the reclaimed western coastline of Singapore, at the mouth of the West Johore Straits. This is one of the longest continuous seawalls (> 1 km) in the survey, with a slope length of 14.5 metres, but with a relatively shallow gradient. As with the seawall at Pasir Ris, there is a fair amount of freshwater influence from the West Johore Straits as evidenced by the salinity of the water which ranged between 24 and 26 ppt. Filamentous cyanobacteria covered a wide expanse of the seawall at UM levels. *Siphonaria guamensis* was the dominant invertebrate, occurring in high abundances at this shore height. Also common at UM were predatory muricids (*Morula musiva*, *M. fusca* and *M. margariticola*) and algal grazers such as *Siphonaria javanica*, *Patelloida* sp. A, *Monodonta labio*, *Nerita lineata* and *N. chamaeleon.* Balanid and chthamalid barnacles were present at UM and HS levels. As with most other locations, littorinids dominated the HS while the SP appeared devoid of any lifeform. Unlike other locations, *E. malaccana* was not common at this location.

DISCUSSION

This study demonstrates that seawalls in Singapore support a relatively high diversity of intertidal organisms, which ranged between 26 and 51 species of invertebrates and algae. The dominant species observed from artificial seawalls from this study appear to be similar with previously recorded studies of natural rocky shores in Singapore (Purchon & Enoch, 1954; Lee, 1966, Chuang, 1973). Other reported studies from tropical locations were comparable in terms of the number of species present. A total of 23 species of fauna was reported from Cape d'Aguilar, Hong Kong (Harper & Williams, 2001) and at least 34 species from San Diego Bay (Davies et al., 2002). Previous studies of local natural rocky shore environments showed only a total of 19 intertidal animal species (Purchon & Enoch, 1954; Lee, 1966). In a study of intertidal fauna on artificial seawalls, Tan et al. (1999) recorded 18 species of molluscs from Pulau Hantu and 17 species from Labrador Park, as opposed to 20 species in Pulau Hantu and 18 species from Labrador Park in this present study. Huang et al. (2005) reported a total of 14 genera of anthozoans, 20 genera of decapods and 25 genera of gastropods from the natural rocky shores at Labrador Park. This represents a significant increase in the intertidal fauna from this study, which is partly due to the habitat complexity of natural shores not observed in artificial habitats such as seawalls. Artificial structures generally appear to support only a subset of the assemblages present at comparable natural habitats (Bulleri & Chapman, 2004, Chapman, 2004), and assemblage structure consistently differed between these two habitat types (Chapman & Bulleri, 2003). In particular, mobile fauna was found be relatively depauperate (Chapman, 2003). This is possibly a result of the uniformity of seawall construction material and the lack of microhabitats such as holes, cracks, crevices and rock pools, which can harbour habitat specialised organisms (Chapman, 2003; Moreira et al., 2007).

There was greater variability in assemblage among locations than among heights on shore. The first two axes of the CA for location only accounted for 46.5% of the variance compared to 95.1% in the analyses for tide height. Species composition could not be adequately explained by environmental conditions alone. Study locations on the south coast, which experienced more coastal conditions, differed compositionally from those in more estuarine systems (e.g. Pasir Ris and Tuas), and showed some affinities with offshore locations. However, assemblages at Tuas and Pasir Ris also had demonstrable differences in composition. For example, *Nerita lineata* was only recorded from Tuas, while the bivalves *Xenostrobus* sp. and *Perna viridis* were common components of the assemblage at Pasir Ris. Although both seawalls are located along the Johore Straits, East and West Johore Strait are effectively two separate water bodies with differing environmental conditions (Lim, 1983). Some distinctions in assemblage structure were also observed between offshore and mainland locations, and these are examined in greater detail by Lee & Sin (2009).

This study also demonstrates that the intertidal assemblages on seawalls are very strongly structured by shore height. Similarly, shore heights were distinguishable not only by abundance but also by species composition, although, this is restricted to only a small suite of taxa. These results are similar to that for natural rocky shores in Australia where even fewer species could be used to discriminate between shore heights (Underwood & Chapman, 1998). Supralittoral areas were primarily characterised by *Echinolittorina malaccana* as is typical of many Indo-Pacific rocky shores (Mak & Williams, 1999; Chapman, 1994; 1999—on a congeneric species *N. pyramidalis*). Balanid barnacles, *Patelloida* sp. A, *Monodonta labio* and *Nerita albicilla* were primarily found in the upper midshore area. The lower midshore was distinguished by various limpets, muricids, and *Trochus bruneus.*

Locally, several studies have described the vertical distribution of organisms on natural and artificial rocky shores (see Purchon & Enoch, 1954; Lee, 1966; Chuang, 1961; Tan et al., 1999; Huang et al., 2005). These studies were conducted predominantly on only one or two locations, and some of these studies established vertical zonation based on distribution of dominant oganisms (see Lee, 1966; Chuang, 1961). Their findings indicated that higher regions were occupied by littorinid gastropods, balanid and chthamalid barnacles, whilst the mid-shore was dominated by grazing molluscs (e.g. *Monodonta labio*, neritid gastropods, siphonariid limpets), barnacles (balanids and chthamalids) and predatory gastropods (*Drupa* (= *Morula*) *musiva*). The lower shore was characterised by macroalgae, *Pictocollumbela* spp. true and pulmonate limpets and cerithiid snails.

While vertical distributions elucidated in this study show some concordance with previously described patterns (*Littoraria* spp and *Echinolittorina* spp. located primarily in the supralittoral and high shore zones; neritids in the mid to high shore zones; *Siphonaria atra, Pictocollumbela ocellata (= Pyrene fulgurans)* at low shore levels), other species show somewhat variable vertical distributions. In this study, muricids were found in greater abundances in the low shore levels and also in the mid shore levels, albeit in lower numbers. Chthamalid and balanid barnacles were observed to occupy a wide tidal range, extending from supralittoral zones to low shore zones, although previous studies (Purchon & Enoch, 1954; Chuang, 1961; Lee, 1966) documented the vertical distribution of these barnacles to be between the highest tidal zone and the mid shore zone.

Patterns of vertical distribution of intertidal organisms on shore have been attributed to a combination of physical and biological factors. Temperature, exposure and dessication stress tend to increase with height on shore (e.g. Chapman & Underwood, 1996), and this is probably more so in the tropics, where temperatures in excess of 45ºC have been recorded (Garrity, 1984). However, predation by fish during high tide can exert controlling effects (Bertness et al., 1981; Garrity & Levings, 1981; 1983; Levings & Garrity, 1983). The upper limits of species distribution are hence likely to be defined by biological tolerances and behavioural adaptations to physical conditions (Garrity, 1984). The physical conditions particular to a shore may be mediated somewhat by extrinsic factors, but the effects of these are not always clear. Wave exposure and frequent boat wakes may extend the upper limit by reducing temperature levels at high-shore habitats (Whorff et al., 1995), but on the other hand, may increase mortality due to physical duress (Connell, 1961; Wolcott, 1973; McMahon & Russell-Hunter, 1977; Garrity & Levings, 1984). This study also suggests that wave exposure can extend the upper limits of some organisms on the shore. Seawalls at Sultan Shoal, Pulau Satumu and Pulau Tekukor are subject to waves created by ship wakes from commercial vessels. The distribution of chthamalid barnacles at these locations extended into supralittoral habitats, although many were located under overhangs and in small crevices.

This study has provided a quantitative assessment of the variability on seawalls around Singapore, with a view to identifying general patterns for further examination. The data demonstrates that seawalls support a fairly diverse assemblage, although lower than the 50 species per shore height figures obtained for seawalls in New South Wales, Australia (Chapman & Bulleri, 2003) and at the natural shore at Labrador Park, Singapore (Huang et al., 2005). Although species richness on the seawall is comparable to the natural shore (Purchon & Enoch, 1954) at Pulau Satumu, there appear to be some difference in species suites between the two habitats on the same island. This appears consistent with the findings in temperate Australian shores that artificial habitats are poor surrogates of equivalent natural ones, the former only supporting a subset of species suites present on natural ones (Chapman & Bulleri, 2003; Chapman, 2003). A relative lack of microhabitats has been cited as the reason for the lower diversity on seawalls (Chapman & Bulleri, 2003), but the effects of this have yet to be demonstrated. Habitat partitioning on seawalls may occur at smaller spatial scales than that on natural shores. This is supported in part by the high variability encountered within locations. Field observations suggest that the pertinent spatial scale may be smaller than 10 centimetres; organisms were seen to aggregate based on small variations in the substratum such as uneven grouting, fracture edges, pits and vertical faces of rocks, as well as biogenic habitats such as empty barnacle tests (Lee et al., in prep.).

Across locations, assemblages may differ considerably although the basic construction material is identical. Variability across locations is high, and cannot be attributed solely to physical and chemical environments. These results are similar to those obtained in other urban coastal habitats such as Sydney Harbour (Connell, 2001; Chapman & Bulleri, 2003). The next logical step is to elucidate the mechanisms underlying these observed patterns. Identification of general mechanisms between these artificial and natural intertidal rocky habitats would be highly towards developing general ecological theories.

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