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Variations in Intertidal Assemblages and Zonation Patterns between Vertical Artificial Seawalls and Natural Rocky Shores: A Case Study from Victoria Harbour, Hong Kong

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Nelson W.Y. Lam, Richard Huang, and Benny K.K. Chan (2009) Variations in intertidal assemblages and zonation patterns between vertical artificial seawalls and natural rocky shores: a case study from Victoria Harbour, Hong Kong. *Zoological Studies* **48**(2): 184-195. Development of coastal cities often results in destruction of natural coastlines, which are consequently replaced by artificial coastal urban structures, commonly including smoothly surfaced vertical seawalls. Artificial seawalls can create novel habitats which may affect the diversity, abundances, and distribution patterns of intertidal assemblages. In the present study, the intertidal assemblages on 3 vertical artificial seawalls and 3 natural rocky shores were studied in Victoria Harbour, Hong Kong. Both artificial seawalls and natural rocky shores shared similar assemblages of common species, but the species abundance and percentage cover of certain taxa differed between the 2 habitat types. Artificial seawalls supported a greater abundance of the chiton *Acanthopleura japonica* and greater percentage coverage of the oyster *Saccostrea cucullata* and barnacle *Amphibalanus* (=*Balanus*) *amphitrite*. In contrast, a greater abundance of the false limpet *Siphonaria laciniosa* and a greater percentage cover of the barnacle *Tetraclita squamosa* occurred on natural rocky shores. Some species were found exclusively on only one of the habitats. The green mussel *Perna viridus*, tube worms *Hydriodes* spp., and sea squirt *Styela* sp. were only found on artificial seawalls, while the black mussel *Septifer virgatus* was exclusively recorded on natural rocky shores. Artificial seawalls had different zonation patterns compared to natural rocky shores. The barnacle *Tetraclita squamosa* and chiton *Acanthopleura japonica* were commonly low on natural rocky shores but they became abundant on the mid-shore of artificial seawalls. Differences in zonation patterns of species could be due to the vertical orientation of artificial seawalls leading to different temperature and humidity profiles compared to natural rocky shores. Spatial variability of the assemblage structure at the scale of tens of meters was greater on natural rocky shores than on artificial seawalls. Greater horizontal spatial variation in species assemblages on natural rocky shores may be associated with greater habitat diversity (e.g., rock pools, crevices, and vertical and horizontal surfaces) on natural shores than on smooth vertical seawalls.
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Key words: Intertidal, Artificial habitats, Rocky shores, Zonation.

With the global increase in human population, natural coastlines have been extensively urbanized with the development of coastal cities. Urbanization of coastlines destroys natural habitats, and the coastlines are modified into various artificial structures (Chapman 2003), including seawalls, ports, piers, wharf piles, pontoons, and artificial boulders, which serve different purposes (see Walker 1988, Thompson et al 2002, Bacchiocchi and Airoldi 2003, Airoldi et al 2005, Moschella et al 2005). Seawalls are often associated with port development and land reclamation, and have become one of the most common man-made habitats on modified coastlines

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(Alder and Robert 1999). Seawalls come in many forms but generally have smooth surfaces, and they are the most common urban coastal structure.

Coastal urban structures create novel habitats which affect the diversity and abundance of both subtidal and intertidal assemblages (Chapman 2003, Bulleri et al. 2005). Compared to natural rocky shores, vertical artificial seawalls have smaller surface areas and fewer microhabitats (Chapman and Bulleri 2003), in turn supporting lower species diversity. In Sydney Harbour, Australia, subtidal assemblages of epibiota varied among natural rocky shores, pier pilings, floating pontoons, and artificial seawalls (Connell and Glasby 1999, Glasby and Connell 1999). In Australia and Italy, for example, artificial seawalls supported fewer species than natural rocky shores, and the proportion of rare species was lower on artificial seawalls than on natural rocky shores (Bulleri and Chapman 2004, Bulleri 2005a b).

Hong Kong has a tropical climate (below the Tropic of Cancer), but it is strongly influenced by seasonal patterns (Morton et al. 1996). Summer (Apr.-Sept.) is hot and wet, while winter (Oct.-Mar.) is colder and dry (Kaehler and Williams 1996, Morton et al. 1996). In Hong Kong, tides are mixed semi-diurnal with a mean tidal range of ~2 m, and a maximum tidal range of ~2.5 m (Morton et al. 1996).

Victoria Harbour in Hong Kong is an international shipping port with a long and heavy reclamation history since 1880 (Lumb 1976). Nearly 95% of the coastline in Victoria Harbour has been reclaimed and replaced by smooth vertical artificial seawalls (see Morton and Morton 1983). There are, however, remnants of natural rocky shores located in the eastern and western regions of Victoria Harbour. The present study used natural rocky shores and artificial seawalls in Victoria Harbour, Hong Kong as examples to test whether tropical intertidal assemblages and their vertical distribution patterns differ between natural rocky shores and vertical artificial seawalls and whether the spatial heterogeneity of the assemblage structure is greater on natural rocky shores than on artificial seawalls.

MATERIALS AND METHODS

Study sites

Three natural rocky shores (at Heng Fa Chuen, Lei Yu Mun, and Green I.) and 3 vertical seawalls at Chai Wan, Tsim Sha Tsui, and Central (Fig. 1) were studied, during July-Sept. 2003. All of the natural rocky shores and seawalls are located inside Victoria Harbour and experience similar hydrographic regimes. The mean temperature and salinity of the inshore seawater at the study sites were about 26°C and 31‰ in summer and ~17.5°C and 33‰ in winter, respectively, during the study period (Lam, unpubl. data).

The natural rocky shores are sloping granite platforms while the artificial seawalls were composed of cemented granite blocks (Figs. 1B, C). The type of rock of the substratum of both natural rocky shores and artificial seawalls was therefore similar. Artificial seawalls were constructed during 1981-1985 (Survey Division 1985, Survey and Mapping Office 1992 1996). Yip (1979) studied artificial boulder shores in Hong Kong and concluded that new shores needed about 8-10 yr to reach a climax community. Based on this, it is likely that the communities studied had reached a climax stage.

Distribution of intertidal assemblages

Distribution patterns of intertidal assemblages on the natural rocky shores and artificial seawalls (hereafter called the habitat factor) were investigated using a hierarchical sampling design (see Bulleri and Chapman 2004). At each site (hereafter called the site factor), three 10 m stretches of shoreline (hereafter called transects; transects were at least 10 m apart) were chosen. At each transect, the epibiota was surveyed at 3 tidal levels: low shore, 1.25-1.50 m above chart datum (CD); mid shore, 1.50-1.75 m above CD; and high shore, 1.75-2.00 m above CD, as these 3 levels cover the vertical distribution of most intertidal organisms on Hong Kong coasts (Morton and Morton 1983). At each tidal level, ten 25 × 25 cm quadrats were randomly photographed using a photo-framer (Chan et al. 2001) with a digital camera (Nikon COOLPIX 995, Nikon, Japan). Only the epibiota of the primary cover (directly attached to the substratum) in the photographs was scored and identified, if possible, to lowest possible taxonomic level. Algae and sessile species were scored as the percentage cover under a 576 point grid layer (24 × 24 points), while mobile species were counted as the number of individuals in a quadrat. This sampling design allowed us to study variations in intertidal assemblages between habitats, among sites, and among transects within each habitat. Sampling was conducted during low

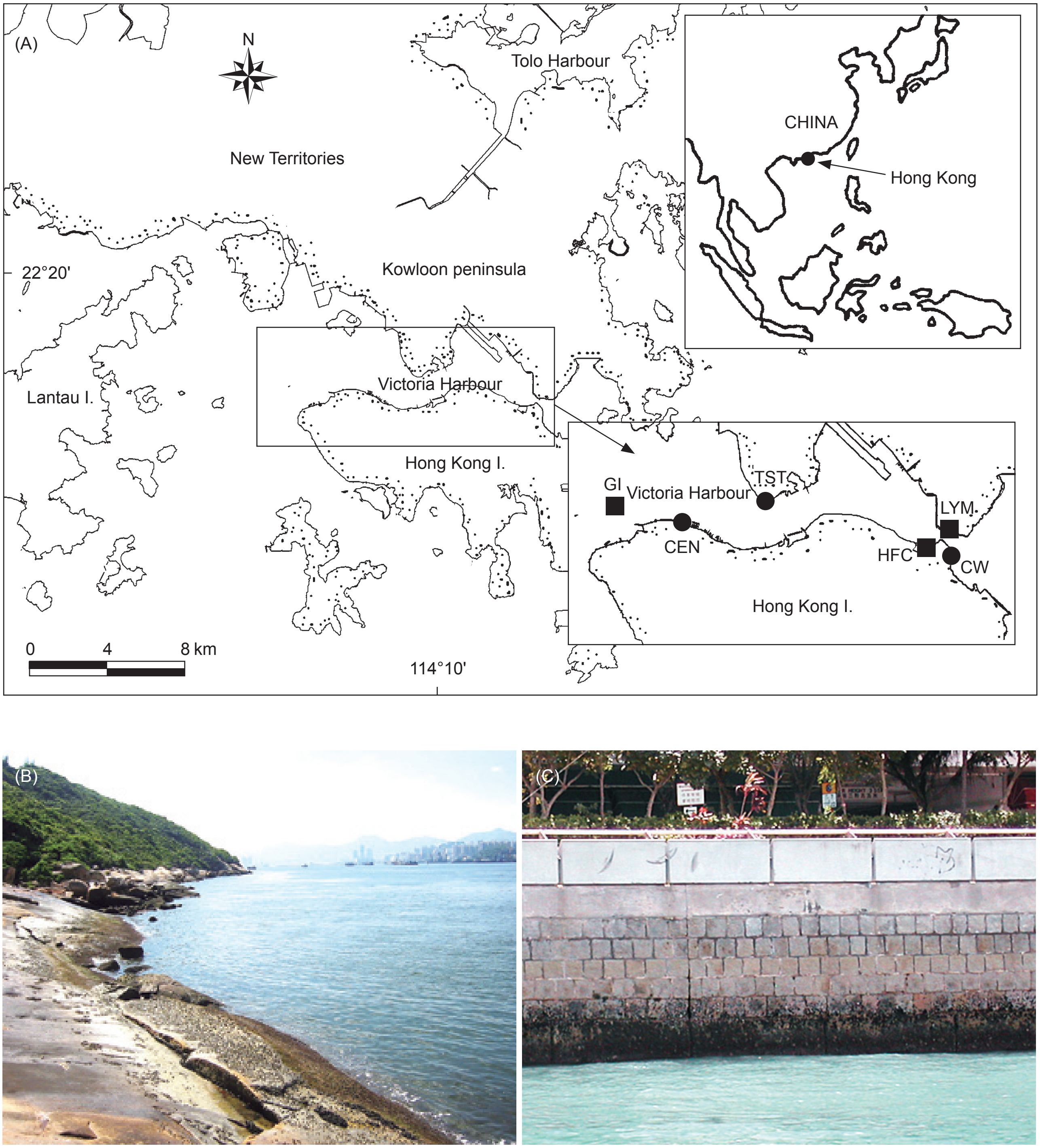

Fig. 1. (A) Victoria Harbour, Hong Kong showing the locations of the study sites on natural rocky shores (squares) and artificial seawalls (circles). Sites names are abbreviated for clarity: CW, Chai Wan; HFC, Heng Fa Chuen; LYM, Lei Yue Mun; CEN, Central; TST, Tsim Sha Tsui; and GI, Green I. (B) Remnants of Victoria Harbour natural rocky shores in the present study and (C) common seawalls in Victoria Harbour, showing that the substratum is made of rectangular granite blocks jointed by cement.

spring tides in July-Sept. 2003.

Statistical analysis

Assemblage differences

Variations in the assemblage structure between natural rocky shores and artificial seawalls were investigated using a multivariate analysis (PRIMER 6, Plymouth Routine in Multivariate Analysis, PRIMER-E; Clarke 1993), using species abundance (mobile species) and percentage cover (sessile species) as variables. The species abundance and percentage cover data were square root-transformed, and the matrix of similarity between each pair of sampled quadrats was calculated using the Bray-Curtis similarity index (Bray and Curtis 1957). Non-metric multidimensional scaling (nMDS) plotted the 2-dimensional ordinations of the ranked orders of similarity among the quadrats from the transect and habitat (artificial seawalls and natural rocky shores) levels (Clarke 1993). Two-way nested-analysis of similarity (ANOSIM) (with factors of habitat and site (habitat)) and a global R test were used to test for significant differences in the assemblage structures between habitats. R values from the global test usually range 0-1, which can reflect the degree of similarity between the factors compared (0 indicates high similarity while 1 indicates low similarity).

Scales of horizontal variability

Horizontal variations of the assemblages at the scale of tens of centimeters (within a transect) and of tens of meters (among transects) were compared between the natural rocky shores and artificial seawalls by calculating the Bray-Curtis similarity index among replicate quadrats within each transect (n = 5 per transect) and among replicate quadrats among transects within each site (n = 15 per site). All quadrat pairs were randomly selected and used once so that data were independent of each other (Bulleri and Chapman 2004). Similarities of paired quadrats within transects and among transects between natural rocky shores and artificial seawalls at each tidal level were compared using a mixed-model analysis of variance (ANOVA; within a transect using the factors of habitat (fixed factor), site (random factor), and transects (random factor, nested in sites); and among transects using the factors of habitats (fixed factor) and sites (random factor)).

Vertical distribution, abundances, and cover of specific taxa

Variations in the abundances (mobile taxa) and percentage cover (sessile taxa) of common and widespread taxa among tidal levels and habitats were analyzed using a 4-factor mixed-model ANOVA (with the factors of habitat (fixed), tidal level (fixed and orthogonal), site (random and nested within habitat x tidal levels), and transect (random, nested within habitat x tidal levels x sites)). Data were transformed to satisfy the homogeneity of variance (tested using Cochran's C test). Significant factors were tested using the Student-Newman-Keuls (SNK) test.

RESULTS

During the entire study period, total numbers of taxa recorded on the natural rocky shores and the artificial seawalls ranged from 15 to 19 taxa (Table 1). The natural rocky shores and artificial seawalls shared similar major sets of common species assemblages. A few taxa, however, such as the green mussel *Perna viridus*, barnacle *Amphibalanus amphitrite* (=*Balanus amphitrite*), tube worms *Hydroides* spp., and sea squirt *Styela* spp. were recorded almost exclusively on the artificial seawalls, while the black mussel *Septifer virgatus* was only recorded on natural rocky shores (Table 1).

Multivariate analysis of intertidal assemblages

From the nMDS ordination plots of species abundances, the ordinations of the natural rocky shores and artificial seawalls were clearly separated at each of the 3 tidal levels (Fig. 2). From the ANOSIM, species assemblages between the natural rocky shores and artificial seawalls significantly differed at all 3 tidal levels (Table 2). There were, however, no differences in assemblages between sites within each habitat (Table 2). The degree of discrimination of the artificial seawalls and natural rocky shores was greatest at the mid-shore level (with the highest R-value) compared to the high- and low-shore levels (Table 2).

Scales of horizontal variability

Percentages of similarity of assemblages at the scale of 10s of centimeters (between paired quadrats within each transect) on artificial seawalls and natural rocky shores were similar except for the low-shore assemblages on artificial seawalls, which had greater similarity than natural rocky shores (Fig. 3, Table 3). The assemblages on artificial seawalls, however, were more homogeneous at the scale of 10s of meters (among quadrats among transects) on the high shore and

Table 1. Summary of taxa found on natural rocky shores and artificial seawalls in Victoria Harbour. For abbreviation of site names (HFC, LYM, GI, CW, TST, and CEN), refer to the legend of figure 1. x, taxon present; *, diagnostic species between natural rocky shores and artificial seawalls as indicated by the univariate analysis; *Perna viridus*, *Hydroides* spp., *Septifer virgatus*, and *Amphibalanus amphitrite* were not included in the statistical analysis because they were almost exclusively found in 1 habitat only

	Natural rocky shores			Artificial seawalls		
	HFC	LYM	GI	CW	TST	CEN
Taxon						
Chitons						
*Acanthopleura japonica**	x	x	x	x	x	x
Whelks						
Thais spp.	x	x	x	x	x	x
Limpets						
Cellana grata	x	x	x	x	x	x
Cellana toreuma	x	x	x	x	x	x
Patelloida pygmaea	x	x	x	x	x	x
Patelloida saccharina	x	x	x	x	x	x
*Siphonaria japonica**	x	x	x	x		x
*Siphonaria laciniosa**	x	x	x	x	x	x
Littorinids						
Nodilittorina spp.	x	x	x	x	x	x
Bivalves						
*Septifer virgatus**	x	x	x			
*Perna viridus**				x	x	x
*Saccostrea cucullata**	x	x		x	x	x
Barnacles						
Capitulum mitella	x	x	x	x	x	x
Tetraclita japonica	x	x	x	x	x	x
*Tetraclita squamosa**	x	x	x	x	x	x
*Amphibalanus amphitrite**	x			x	x	x
Tube worms						
Hydroides spp.*				x	x	x
Algae						
Pseuduvella applanata	x	x	x	x	x	x
Others						
Styela spp.*				x	x	x

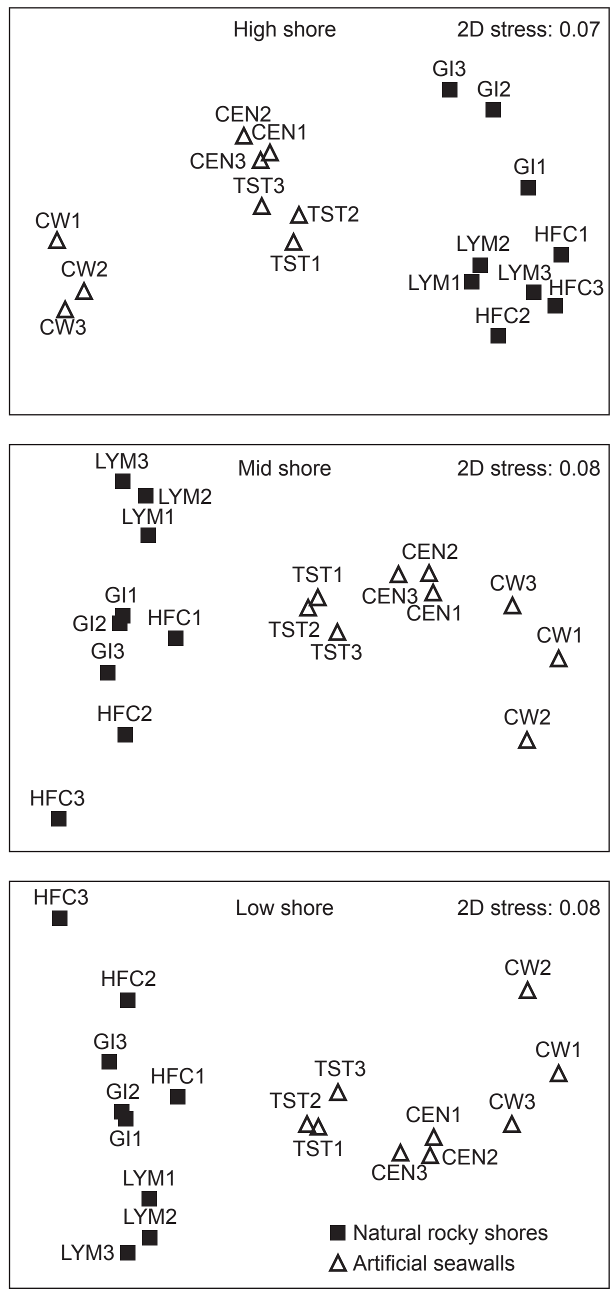

Fig. 2. Two-dimensional non-metric multidimensional scaling ordination plots comparing species assemblages between natural rocky shores (black squares) and artificial seawalls (open triangles). Sites names are abbreviated for clarity and are explained in the legend of figure 1. Numbers adjacent to the site names indicate the transect number within each site.

mid shore than they were on natural rocky shores (Fig. 4, Table 3).

Vertical distribution, abundances, and cover of specific taxa

The artificial seawalls and natural rocky shores shared similar major common assemblages (Figs, 5, 6). From the univariate analysis, the chiton *Acanthopleura japonica* was more abundant on artificial seawalls than on natural rocky shores (Fig. 5, Table 4). The zonation pattern of *A. japonica* varied between artificial seawalls and natural rocky shores. *Acanthopleura japonica* was abundant in both the mid and low zones of the artificial seawalls, while it had a greater abundance low on natural rocky shores (Fig. 5, Table 4). The false limpet *Siphonaria laciniosa* was more abundant on natural rocky shores than on artificial seawalls (Fig. 5, Table 4). The barnacle *Tetraclita squamosa* and oyster *Saccostrea cucullata* were more abundant on artificial seawalls than on natural rocky shores (Fig. 6, Table 5). The zonation pattern of *T. squamosa* differed between artificial seawalls and natural rocky shores (Fig 6, Table 5). *Tetraclita squamosa* was abundant on the mid shore of artificial seawalls, which contrasts to its maximum abundance low on natural rocky shores (Fig. 6, Table 5).

DISCUSSION

Table 2 Two-way nested analysis of similarity (with the factors of habitat and site (habitat)) showing the global test for the similarity of species abundances between natural rocky shores (consisting of sites HFC, LYM, and GI) and artificial seawalls (consisting of sites CW, TST, and CEN). *R* values in the global test (ranging 0-1) indicate the degree of similarity, with *R* = 0 indicating high similarity and *R* = 1 indicating low similarity. For abbreviations of site names, refer to the legend of figure 1

Artificial seawalls vs. Natural rocky shores						
	High shore		Mid shore		Low shore	
Global test	*R*	*p*	*R*	*p*	*R*	*p*
Habitat	0.70	0.001*	0.90	0.001*	0.75	0.001*
Site (habitat)	0.037	0.6	0.2	0.8	0.07	0.6

* $p < 0.05$

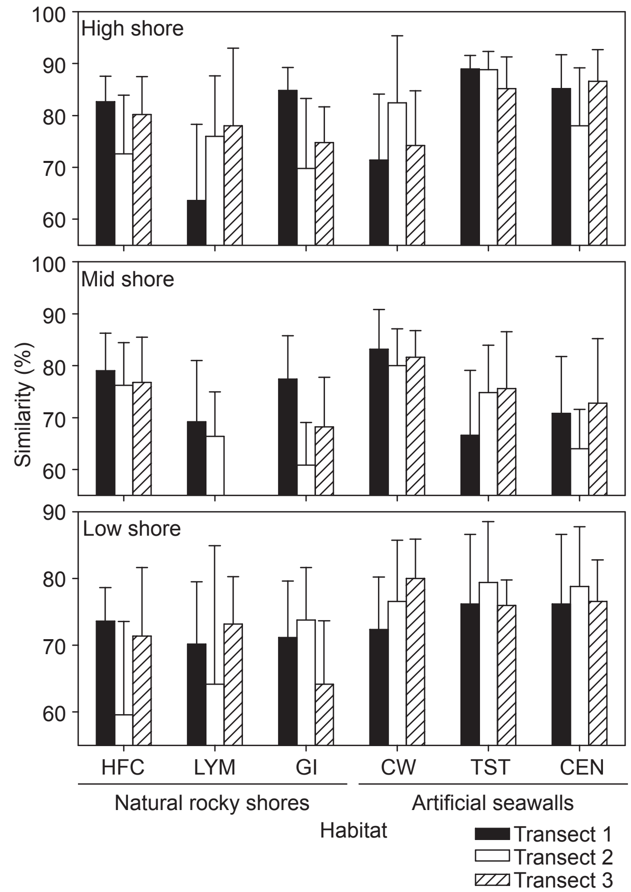

Fig. 3. Percentage of similarity (Bray Curtis) of assemblage abundances and percentage cover between paired quadrats (mean + 1 S.D.) within each transect (*n* = 5 quadrat pairs per transect) at the study sites of natural rocky shores and artificial seawalls.

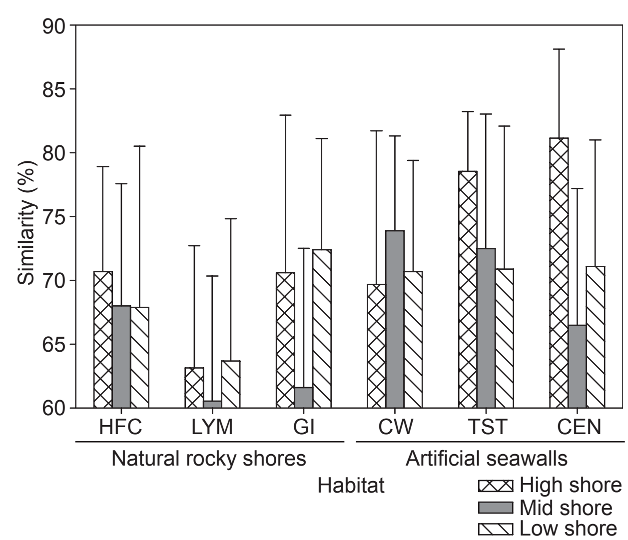

Fig. 4. Percentage of similarity (Bray Curtis) of assemblage abundances and percentage cover between paired quadrats (mean + 1 S.D.) among transects (*n* = 15 quadrat pairs) within each site of natural rocky shores and artificial seawalls.

In the present study, natural rocky shores and artificial seawalls in Victoria Harbour, Hong Kong shared similar sets of main space occupiers, but 47% of the taxa showed significant variation in abundance and percentage cover between the 2 habitat types. Differences in patterns of assemblage structure between natural and artificial shores addressed in the present study contrast with findings in Australia and Italy. In Sydney, artificial seawalls supported 50% fewer mobile species and rare taxa than did natural shores. In Italy (Bulleri and Chapman 2004), artificial seawalls and natural rocky shores supported different sets of major taxa, and additionally, artificial seawalls supported fewer species than did natural rocky shores. Variations in the species assemblages between natural rocky shores and artificial seawalls may be due to the substratum of artificial seawalls and the degree of wave exposure (Bulleri and Chapman 2004). In Australia (Bulleri and Chapman 2004) and Hong Kong, artificial seawalls and natural rocky shores had the same rock type and degree of exposure, but artificial seawalls contain no cracks or pools, and such differences can result in differences in mobile taxa. In Italy, artificial seawalls were constructed from stone blocks joined by concrete but were sheltered by breakwaters, and great assemblage variations between natural rocky shores and artificial seawalls were found (Bulleri and Chapman 2004).

There were a few diagnostic species which solely occurred in one of the habitats. The green mussels *Perna viridus* and barnacle *Amphibalanus amphitrite* only occurred on artificial seawalls, while the black mussel *Septifer virgatus* only occurred on natural rocky shores. Differences in water transport patterns on artificial seawalls and natural rocky shores can result in different assemblage structures (Bulleri and Chapman 2004). When a wave approaches an artificial seawall (smooth and vertical in nature), it is generally deflected towards the other direction without breaking (pers. obs.). In contrast, waves approaching natural rocky shores (heterogeneous sloping platforms) break, and the energy is dissipated onto the shore. The false limpet *Siphonaria laciniosa* and black mussel are common on habitats with great wave exposure (Morton and Morton 1983), and this may account their absence on artificial seawalls.

In the present study, the zonation patterns and abundances of the chiton *Acanthopleura japonica* and barnacle *Tetraclita squamosa* differed between natural rocky shores and artificial seawalls. *Tetraclita squamosa* and *A. japonica* were mainly found at a low level on natural rocky shores, while they were found at mid level on artificial seawalls. In addition, artificial seawalls had greater abundances of *T. squamosa* and *A. japonica* than did natural rocky shores. The shore slope can affect variations in species abundances and zonation patterns between natural rocky shores and artificial seawalls (Glasby 2000, Knott et al. 2004). The vertical orientation of seawalls might result in a narrow gradient of physical

Table 3. Mixed model analysis of variance showing variations in the percentage of similarity between quadrats within transects (A, $\sum n$ = 5 quadrat pairs × 3 transects × 3 sites × 2 habitats = 90) and among transects within each site (B, $\sum n$ = 15 quadrat pairs × 3 sites × 2 habitats = 90). SW, artificial seawall; NR, natural rocky shore

		High shore		Mid shore		Low shore	
	d.f.	MS	*F*	MS	*F*	MS	*F*
A) Between quadrats within transects							
Habitat	1	1,259,418	-	4,121,361	-	3,126,426	40.54*
Site (habitat)	4	655,271	-	596,006	3.53*	817,132	-
Transect (site × habitat)	12	3,654,655	-	2,998,157	-	1,409,148	-
Residual	72	-	-	2,153,053	-	-	-
SNK test	-	-	-	-	-	-	SW > NR
B) Between quadrats among transects							
Habitat	1	8,127,769	-	9,879,427	11.36*	8,064,360	-
Site (habitat)	4	7,513,211	-	2,631,168	-	4,536,055	-
Residual	84	1,971,294	-	1,904,016	-	9,214,124	-
SNK test	-	-	-	-	SW > NR	-	-

* $p < 0.05$. SNK, Student-Newman-Keuls.

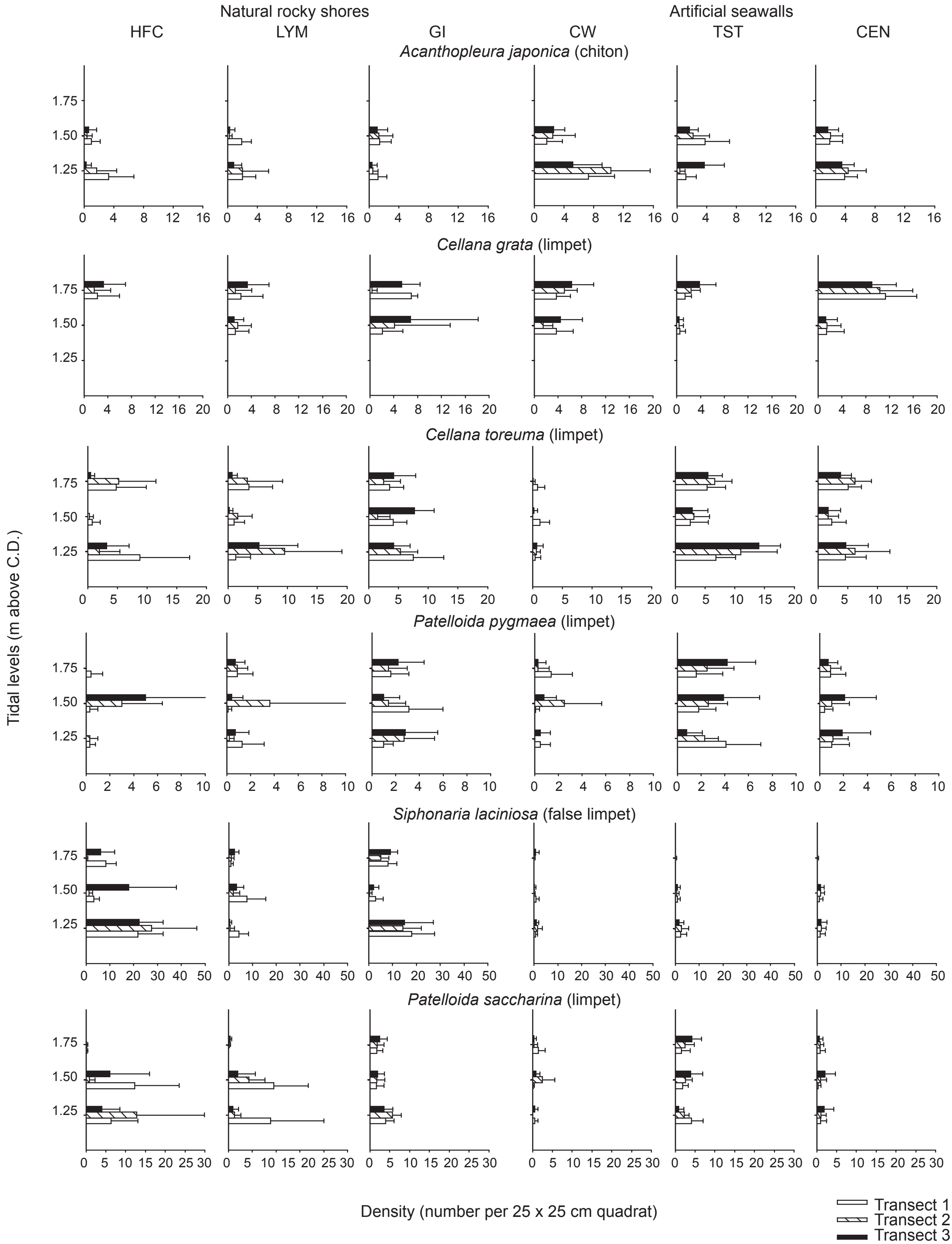

Fig. 5. Abundance (mean + 1 S.D., *n* = 10 for each transect) of mobile taxa on natural rocky shores and artificial seawalls. Site names are abbreviated for clarity and are explained in the legend of figure 1. Note: the change in scale of abundances among species. Rare species were not included for clarity.

Table 4. Mixed model 4-factor analysis of variance showing variations in the abundances of mobile species between habitat types, and among tidal levels, sites, and transects. SW, artificial seawall; NR, natural rocky shore; NS, not significant, * $p < 0.05$; ** $p < 0.001$; *** $p < 0.0001$. Note: *Acanthopleura japonica* and *Cellana grata* were recorded at 2 tidal levels only, while the other mobile species covered all 3 tidal levels

Source of variation		*Acanthopleura japonica*		*Cellana grata*			*Cellana toreuma*		*Patelloida pygmaea*		*Siphonaria laciniosa*		*Patelloida saccharina*	
	d.f.	MS	*F*	MS	*F*	*d.f.*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Habitat	1	39.8	13.0*	33.8		1	2.0		5.9		180	15.38*	7.4	
Tidal level	1	8.3	12.1*	85.1	9.44**	2	21.6		0.04		22.8	15.3*	93.0	4.13*
Site (habitat × tidal level)	8	2.9		9.0	4.23***	12	13.2	10.1***	4.3	5.62***	11.7		22.5	9.6***
Transect (site × habitat × tidal level)	24	0.9	2.4***	2.1	2.1***	36	1.3	2.6***	0.76	2.23***	1.7	6.69***	2.34	3.3***
Habitat × tidal level	1	2.6	5.1*	17.1		2	0.6		0.31		5.6	4.08***	1.05	
Residual	324	0.4		1.01		486	0.49		0.34		0.4		0.71	
Transformation		Ln (x+1)		Ln (x+1)			Ln (x+1)		Ln (x+1)		Ln (x+1)		Ln (x+1)	
Cochran's C test		NS		NS			NS		NS		NS		NS	
Student-Newman-Keuls test		Habitat: SW > NR for all tidal levels Tidal level:SW: Mid = Low NR: Low > Mid		Tidal level: High > Mid > Low					Habitat: NR > SW for all tidal levels Tidal level: NR: Low > Mid > High SW: Low = Mid > High					

Table 5. Mixed model 4 factor analysis of variance showing variations in the percentage cover of sessile species between habitat types, and among tidal levels sites, and transects. SW, artificial seawall; NR, natural rocky shores; NS, not significant, * $p < 0.05$; ** $p < 0.001$; *** $p < 0.001$. Note: that *Tetraclita japonica* and *T. squamosa* covered 3 tidal levels only, while the other sessile species covered 2 tidal levels

Source of variation		*Tetraclita japonica*		*Tetraclita squamosa*			*Saccostrea cucullata*		*Pseuduvella applanata*	
	d.f.	MS	*F*	MS	*F*	*d.f.*	MS	*F*	MS	*F*
Habitat	1	18.9		354.7	5.89*	1	72.4	26***	70.1	
Tidal level	2	16,628.2	21.46***	2886.1	47.8***	1	0.6		8.9	
Site (habitat × tidal level)	12	774.9		60.2		8	2.7	2.18**	59.8	33.7***
Transect (site × habitat × tidal level)	36	395.3	6.61**	77.2	3.89***	24	1.2	2.14**	1.7	4.2***
Habitat × tidal level	2	1770.5		1820.2	30.2***	1	0.8		13.5	
Residual	486	59.8		19.8		324		0.4		
Transformation		none		none			Ln (x+1)		Ln (x+1)	
Cochran's C test		NS		NS			NS		NS	
Student-Newman-Keuls test		High = Mid > Low		Habitat: SW > NR for all tidal levels NR: High < Mid < Low SW: High < Mid = Low			Habitat: SW > NR			

stresses relative to sloping rocky shores over the entire intertidal range (~5 m on natural shores in the present study). Vertical intertidal surfaces often have reduced heat and desiccation stress (10°C cooler) than horizontal and sloping platforms (Williams and Morritt 1995, Chan et al. 2006), and thus reduced post-settlement mortality of settlers occurs (Chan and Williams 2003). Artificial

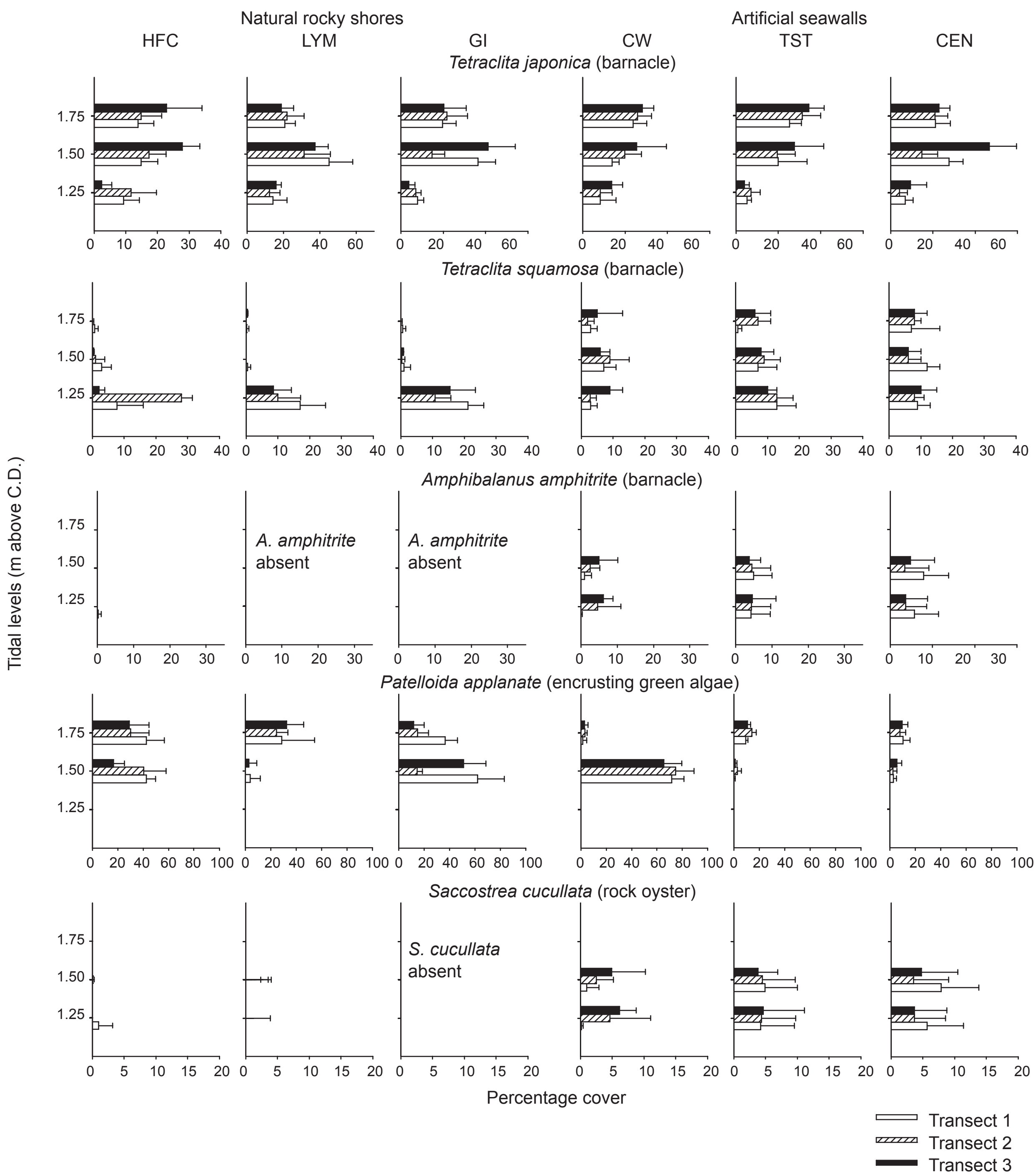

Fig. 6. Percentage cover (mean + 1 SD, *n* = 10 for each transect) of sessile taxa on natural rocky shores and artificial seawalls. Site names were abbreviated for clarity and are explained in the legend of figure 1. Note: the change in scale of abundances among species. Rare species were not included for clarity.

seawalls can therefore be a cooler and damper environment compared to natural rocky shores. Thus, physical stresses are probably reduced on artificial seawalls (all artificial seawalls were often shaded at noon until the afternoon, which is the hottest period of the day; pers. obs., Chan et al. 2006), and the mid and low shores of artificial seawalls supported greater abundances of species than those on natural rocky shores including the barnacle *T. squamosa* (see Chan et al. 2001) and chiton *A. japonica* (Morton and Morton 1983). Recruitment patterns and post-recruitment mortality can, however, vary between natural rocky shores and artificial seawalls, and this may result in different species abundances between these 2 types of habitats (Chapman 2003, Bulleri 2005b). On natural rocky shores, *T. squamosa* settles on a wide tidal range on shore, but settlers on the mid and high shores were killed by heat and desiccation, thus limiting their distribution to the low shore on natural rocky shores (Chan and Williams 2003). Reduction of heat stress using experimental roofs to provide shading on shores resulted in *T. squamosa* settlers surviving on the mid shore (Chan and Williams 2003). In the present study, the greatest abundance of *T. squamosa* was found on the mid shore of artificial seawalls, which is probably due to reduced heat stress on artificial seawalls resulting in settlers surviving higher up on the shore of artificial seawalls.

The percentage similarity of assemblages between the transects (on a scale of tens of meters) was lower among natural rocky shores compared to that of artificial seawalls, suggesting that the species composition was more heterogeneous on natural rocky shores than on artificial seawalls. Compared to artificial seawalls (with only smooth surfaces), natural rocky shores contain a greater diversity of microhabitats including large rock crevices, and vertical and horizontal surfaces. This may help explain the greater heterogeneity in species composition on natural rocky shores than on artificial seawalls at the same spatial scales (Bulleri and Chapman 2004, Bulleri et al. 2005, Moschella et al 2005). Similar to the present study, species compositions in northeastern Italy exhibited a greater degree of variation on natural shores (Bulleri and Chapman 2004, Bulleri et al. 2005) than on artificial shores.

In Hong Kong, similar species compositions were present on natural rocky shores and artificial seawalls in Victoria Harbour, but the abundances, percentage cover, and zonation of certain taxa differed between the 2 habitats. Such diagnostic patterns can result from variations in the larval supply, and settlement and post-settlement mortality of intertidal assemblages between natural and artificial habitats. Bulleri and Chapman (2004) revealed that differences in assemblages between natural rocky shores and artificial seawalls can exhibit temporal variations. In Australia, limpets on artificial seawalls had lower fecundity compared to those on natural rocky shores (Moreira et al. 2006). Further studies should focus on the long-term population dynamics and reproductive biology of intertidal assemblages between the 2 types of habitats to ascertain patterns and processes governing variations in the zonation and species assemblages on natural and artificial habitats along the coast of cities.

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