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INTERTIDAL ASSEMBLAGES ON ARTIFICAL STRUCTURES AND NATURAL ROCKY HABITATS ON TAIWAN'S NORTH COAST

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ABSTRACT. — Differences in intertidal assemblages between artificial structures and natural rocky habitats require further investigation, so that the potential effects of artificial structures on coastal intertidal community can be better understood. We examined the intertidal assemblages on breakwaters, seawalls, and natural rocky shores in the Linshanbi and Houcuo fishing ports on the northern coast of Taiwan. Nine seawater parameters were measured at each sampling site in Dec.2010, Mar.2011, and Jun.2011. Intertidal assemblages on seawalls were largely distinct from those on breakwaters or natural rocky shores. The taxa that contributed most to the differences among habitats were algae, barnacles, oysters, and limpets. Limpets, red algae, and green algae were less abundant on seawalls compared to breakwaters or the natural rocky shore. Fewer intertidal organisms existed on seawalls than on breakwaters and natural rocky shores. The mobile organisms on breakwaters were similar to those on natural rocky shores. However, during the growing season, a greater number of mobile organisms were found on natural rocky shores than on breakwaters. We suggest that differences in seawater quality, which might relate to the presence of artificial structures, could affect the abundance of intertidal organisms. Further information is required on important factors in artificial structures that affect intertidal assemblages, in various coastal areas, to help conserve intertidal biodiversity.

KEY WORDS. — intertidal rocky shore, coastal infrastructure, intertidal assemblages, seawall, Taiwan

INTRODUCTION

Coastal areas in Asia tend to be rich in biodiversity and natural resources, rendering them economically important yet ecologically vulnerable. Such areas are densely populated and severely threatened by human activities and climate change. Consequently, the construction of coastal infrastructure is becoming an increasingly popular practice in coastal management. Built structures can protect shorelines from both wave erosion and land reclamation. However, the creation of new hard substrate habitats displays a potentially negative effect on intertidal organisms in coastal areas (Chapman, 2003). Previous studies have examined the differences between intertidal assemblages on artificial versus natural rocky habitats in temperate coastal areas (Connell, 2001; Bulleri & Chapman, 2004; Knott et al., 2004; Airoldi et al., 2005; Bulleri et al., 2005; Chapman, 2006; Blockley, 2007; Martins et al., 2009), but few studies have investigated the differences in intertidal assemblages among artificial structures in the intertidal zone of the Asian tropics and subtropics (Lin & Shao, 2002; Lam et al., 2009; Lee & Sin, 2009).

Artificial habitats often harbour less abundant and diverse intertidal assemblages compared to those of natural rocky coasts. This difference is ascribed to alterations in physical conditions such as the circulation and flow of nearshore seawater (Zyserman et al., 2005), sediment transportation and grit distribution (Cuadrado et al., 2005), and water quality (Airoldi et al., 2005). Furthermore, vertical artificial structures usually provide unsuitable habitats for intertidal assemblages, especially mobile benthic invertebrates (Airoldi et al., 2005; Chapman, 2006). In addition, the lack of surface complexity on artificial substrates affects intertidal assemblages, because such surfaces lack crevices in which intertidal organisms can seek refuge when the tide recedes (Fairweather, 1988; Underwood, 2004; Jackson et al., 2008; Chapman & Blockley, 2009). Alterations to these attributes of artificial structures would be expected to affect their habitability by organisms; in turn, this would affect the distribution and abundance of intertidal assemblages in intertidal zones (Abelson, 1997).

Taiwan is home to more than 23 million people and has the second highest population density worldwide. Two-thirds of the country consists of mountainous areas, and the majority of the human population is distributed along the coastal regions. Population growth and intensive human activity have caused rapid changes in the coastlines of Taiwan; at present, approximately 50% of the coastline comprises various artificial structures. A greater understanding of the differences in intertidal assemblages between artificial structures and natural rocky habitats would enable an improved assessment of the potential effects of artificial structures on coastal intertidal communities. We examined such differences by comparing the intertidal assemblages at two study sites on the northern coast of Taiwan. We investigated intertidal assemblages on fishing port seawalls, breakwaters, and natural rocks under different shading conditions in different seasons.

MATERIAL AND METHODS

Study sites. — We selected two sites, Houcuo fishing port and Linshanbi fishing port and their adjacent natural rocky coasts, for this study. The intertidal assemblages and water quality of these respective habitats were examined (Fig. 1A, B). Houcuo fishing port lies adjacent to Qianshui Bay, and Linshanbi fishing port is located to the west of Linshanbi cap, which was formed by volcanic activity from the Datun volcano systems. These fishing ports are located on the northern coast of Taiwan and are situated approximately 4 km apart. The ports were built more than 10 years ago, and the present intertidal assemblages on the seawalls have not been disturbed by any large construction activity during the past decade (Taiwan Fisheries and Marine Technology Consultants, Inc, 2003). Both ports are surrounded by rocky outcrops, which would assist in protecting the habitats inside the port from seawater pollution and external wave action.

Sampling methodology. — The intertidal assemblages of three different habitats in each of the two ports were investigated: seawalls, breakwaters, and natural rocky shores. We examined the mean tidal zones 0.5–1.0 m above the mean low water of the vertical walls of internal seawalls, the vertical planes of external breakwaters, and the vertical planes of the periphery andesites in each fishing port. The sampled seawalls comprised cement blocks inside the ports, the breakwaters comprised cement blocks measuring 2–3 m outside the ports, and the natural blocks were andesite blocks measuring 1–3 m.

We used two sampling sites for each habitat at each port (Fig. 1C, D). Ten quadrats, each measuring 10×10 cm, were photographed at each site by using a digital camera (FujiFilm F40). Among the 10 quadrats at each site, five were sampled at shaded areas and the other five at unshaded areas receiving at least five (winter) to seven (summer) hours of sunshine per day. Intertidal assemblages were sampled during autumn (Sep.) and winter (Dec.) of 2010, and in spring (Mar.) and summer (Jun.) of 2011.

The abundance of sessile species was estimated by the percentage of coverage for each quadrat. A photograph of each 10×10 cm quadrat was divided into 25 cells measuring 2×2 cm each, and then the coverage by sessile organisms was identified and scored. Each cell was visually allocated 0–4 percentage points for the coverage score; the sum of 25 cell coverage scores was calculated to determine the coverage of an organism in a quadrat (Bacchiocchi & Airoldi, 2003; Bulleri & Chapman, 2004; Martins et al., 2009). In addition, the abundance of mobile organisms was counted in each quadrat and was converted to density values (numbers/100 cm^2). Fast-moving organisms such as crabs and Ligiidae were excluded in this study.

Water quality analysis. — We collected water samples at 12 sampling sites in Dec.2010 and in Mar. and Jun.2011, and measured the water quality in each sample. The temperature, salinity, dissolved oxygen, and conductivity were measured using a YSI model 85 handheld system. The pH and turbidity were measured using a portable Knick Portamess® 911 pH meter and a portable Orbeco-Hellige® TB200 turbidimeter, respectively. In each sampling site, water grab samples were collected from approximately 50 cm below the water surface using 500-ml plastic bottles to obtain measurements of chlorophyll a, suspended solids, and silicate. All water samples were maintained in an icebox during transportation and stored at 4°C before analysis. For chlorophyll a measurements, water samples were analysed within 24 h according to a standard test method (NIEA E508.00B) established by the Taiwan Environmental Protection Administration (EPA). For suspended solid and silicate measurements, all water samples were analysed within 3 days according to the standard test methods established by the Taiwan EPA (NIEA W210.57A and NIEA W450.50B, respectively).

Statistical analysis. — We used two-way nonparametric multivariate analysis of variance (NPMANOVA; Anderson, 2001) on untransformed data. We tested the hypotheses that differences would exist in the assemblages among different habitats at the two fishing ports during each season. The analysis was conducted using the free PAST (PAleontological STatistics) programme (version 2.15; Hammer et al., 2001). We also analysed similarities in data for the assemblages among various sampling sites, using the Bray-Curtis similarity coefficient and a nonmetric multidimensional scaling (n-MDS) graph. The variations in taxa abundance were examined by three-way ANOVA to test the effects of time, habitat, and shade. The abundance data were transformed by log (x + 1) to reduce the effects of dominant species on the statistical results. If ANOVA yielded a significant result, we conducted a post hoc Student-Newman-Keuls test (SNK). The water quality data were also normalised to avoid the potential problems of

Table 1. Summary of taxa found in three habitats of two fishing ports. (S: seawalls; B: breakwaters; N: nature rocky shores; x: taxa present).

Season	Autumn			Winter			Spring			Summer		
Habitat	S	B	N	S	B	N	S	B	N	S	B	N
Chitons												
Acanthopleura japonica	x			x		x	x	x	x	x		x
Whelks												
Batillaria sordida		x										
Nerita undata												x
Thais spp.	x	x	x	x	x	x	x	x	x	x		x
Tenguella granulata	x		x									
Limpets												
Cellana toreuma	x		x	x	x	x	x	x	x	x	x	x
Collisella heroldi				x	x	x	x	x	x			
Notoacmea schrenckii	x	x		x	x	x	x	x	x	x	x	x
Patella flexuosa		x	x	x	x		x	x	x	x	x	x
Patelloida pygmaea	x	x	x	x	x	x	x	x	x			
Patelloida saccharina	x	x	x	x	x	x	x	x	x			
Siphonaria japonica	x		x	x	x	x			x	x	x	x
Siphonaria laciniosa	x	x	x	x	x	x		x	x	x	x	x
Oysters												
Saccostrea mordax	x	x	x	x	x	x	x	x	x	x	x	x
Barnacles												
Amphibalanus amphitrite	x			x	x							
Chthamalus challenger	x			x	x		x			x	x	x
Tetraclita squamosa	x	x	x	x	x	x	x	x	x	x	x	x
Red Algae												
Bostrychia tenella					x							
Centroceras clavulatum		x	x	x	x	x	x	x	x	x	x	x
Chondracanthus intermedia		x	x		x	x		x	x		x	x
Green Algae												
Ulva conglobata								x	x		x	
Ulva lactuca	x	x	x	x	x	x	x	x	x	x	x	x
Valoniopsis pachynema								x	x		x	
Number of Species	14	12	13	15	16	13	13	16	17	12	13	14
Total		18			17			18			16	

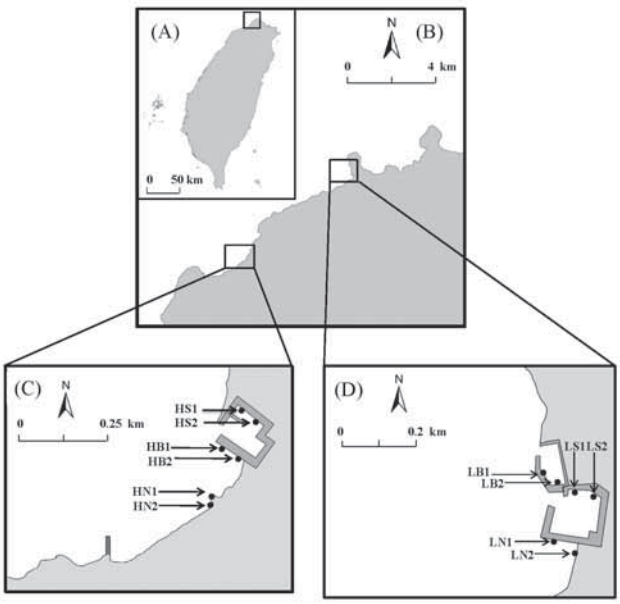

Fig. 1. Location of study sites. (A) Taiwan, (B) the northern coast of Taiwan, (C) Houcuo fishing port, and (D) Linshanbi fishing port.

using divergent data scales. Principal component analysis (PCA) was applied to elucidate the contribution of water quality in the chemical properties of seawater from the 12 sampling sites. Pearson correlation analysis was conducted to examine the relationships between water quality and taxa abundance. The similarity percentage (SIMPER) procedure was used to determine which taxa contributed the most to the recorded differences between the habitats in each season. The Bray-Curtis similarity coefficient, n-MDS, PCA, and SIMPER values were analysed using PRIMER 5.0 software. The ANOVA, SNK post hoc test, and Pearson correlation analysis were performed using the SPSS PASW Statistics v18 programme.

RESULTS

Composition of intertidal assemblages. — Twenty-three taxa were identified in three different habitats in the two study sites (Table 1), as follows: 1 species of chiton,

Table 2. Two-way NPMANOVA of the coverage of mobile molluscs in three habitats in both ports; sampled between autumn 2010 and summer 2011, under shaded and unshaded conditions.

		Autumn		Winter		Spring		Summer	
	df	ms	F	ms	F	ms	F	ms	F
Unshaded area									
Port (P)	1	1.15	24.83***	0.99	5.13**	1.969	11.64***	0.934	5.28*
Habitat(H)	2	3.12	3.27**	0.61	3.16**	0.496	2.93**	0.486	2.75*
P × H	2	1.64	3.89**	0.42	2.21*	0.551	3.26**	0.137	0.77
Residual	54	16.74		0.19		0.169		0.177	
Shaded area									
Port (P)	1	2.398	11.38***	1.134	4.59***	0.696	3.94**	0.826	5.35***
Habitat(H)	2	1.474	7.00***	1.140	4.62***	0.773	4.38***	0.886	5.74***
P × H	2	0.490	2.33*	0.262	1.06	0.357	2.02*	0.187	1.21**
Residual	54	0.216		0.247		0.176		0.154	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3. Two-way NPMANOVA of the abundance of sessile species in three habitats of both ports; sampled between autumn 2010 and summer 2011, under shaded and unshaded conditions.

		Autumn		Winter		Spring		Summer	
	df	ms	F	ms	F	ms	F	ms	F
Unshaded area									
Port (P)	1	1.013	3.67***	0.562	1.46	1.148	3.71**	0.227	0.92
Habitat(H)	2	2.142	7.12***	0.547	1.42	1.561	5.04**	1.175	4.79***
P × H	2	0.663	2.20*	0.307	0.80	0.822	2.66**	0.531	2.16*
Residual	54	0.301		0.386		0.310		0.245	
Shaded area									
Port (P)	1	0.327	1.19	0.403	1.53	0.395	1.48	0.096	0.32
Habitat(H)	2	0.879	3.20**	0.380	1.47	0.652	2.44*	0.339	1.12
P × H	2	0.649	2.37*	0.289	1.10	0.170	0.64	0.331	1.06
Residual	54	0.274		0.263		0.267		0.303	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4 species of whelks, 8 species of limpets, 1 species of oyster, 3 species of barnacles, 3 species of red algae, and 3 species of green algae. We identified 22 and 21 taxa in Linshanbi and Houcuo fishing ports, respectively. Across all study sites and four seasons, 18 taxa were found on seawalls, 21 on breakwaters, and 20 on natural rock shores. The majority of species occurred across all three habitats, apart from *Amphibalanus amphitrite*, which was not found in natural rock habitats, and red algae (*Chondracanthus intermedia*) and two species of green algae (*Ulva conglobata* and *Valoniopsis pachynema*), which were not present on the seawalls inside the ports. Of the 23 taxa, eight were found in only one or two sampling sites during either one or two seasons only.

Differences in assemblages for different habitats. — For the percentage cover of mobile organisms, our results showed significant differences among the different habitats between the two fishing ports under both shaded and unshaded conditions and across all seasons (Table 2 and Fig. 2). There was no significant difference in the abundance of sessile species under shaded conditions between the two ports, whereas significant differences were found among the habitats during spring and autumn (Fig. 3). The abundance of sessile species also differed among the various habitats from spring to autumn under unshaded conditions, and between the two fishing ports in spring and autumn (Table 3).

The results of n-MDS plots revealed that the sampling sites were clustered into two major groups: shaded and unshaded sites (Fig. 4). In each season, the assemblages on seawalls showed greater diversity than those on breakwaters or natural rocky shores (Fig. 4). The assemblages on breakwaters and natural rocky shores were very similar to each other and clustered into the same group in each season according to the cluster analysis of the Bray-Curtis similarity index (Fig. 4). The SIMPER procedure identified five taxa that contributed the most to the differences between habitats (Table 4), including two species of red algae, two species of green algae, two species of barnacles, one species of oyster, and one species of limpet.

Comparisons of specific taxa. — Based on the SIMPER results, further analyses were conducted on the occurrence of limpets, oysters, barnacles, and red and green algae. The results of three-way ANOVA showed that limpets in both fishing ports differed significantly according to season, substrate, and shadow (Table 5). Limpets occurred in the greatest abundance on natural rocks; their numbers in this habitat were significantly higher than in the other two habitats comprising artificial structures (Table 5). In addition, the abundance of limpets was greater in unshaded areas than in shaded areas (Table 5). Three-way ANOVA on limpet numbers revealed significant interactions among seasons, habitats, and shade in Houcuo port, whereas no significant interactions among seasons, habitats, and shade in Linshanbi port (Table 5). The abundance of oysters differed significantly between the two ports. For Linshanbi, the abundance of oysters did not vary across seasons or between habitats. In Houcuo, barnacle coverage did not differ significantly between the shaded and unshaded areas (Table 5), and the oyster coverage on natural rocks and breakwaters was higher than that on seawalls (Fig. 3). The barnacles differed by seasons and habitats, with the coverage on seawalls and natural rock shores higher than on breakwaters (Table 5). Furthermore, we found no barnacle settlement on the breakwaters outside Houcuo fishing port during the period of study. The coverage of red algae was higher in shaded than in unshaded areas (Fig. 3). The red algae and green algae were abundant in spring and summer, and were especially abundant on breakwaters and natural rocks compared with seawalls (Table 6).

Characteristics of water quality conditions. — PCA showed that 3 principal components explained 78.3% of the variance in water quality conditions in the two fishing ports (Table 7). The first component explained 38.3% of the variance and was strongly correlated with salinity, electrical conductivity, dissolved oxygen, chlorophyll, and temperature (Table 7). The second component accounted for an additional 23.3% of the variance, and correlated significantly with turbidity, suspended solids, and silicate (Table 7). The third and final principal component contributed an additional 16.6% of variance and showed a strong correlation with pH (Table 7).

Relationships between water quality and specific taxa. — Limpets were abundant in summer 2011, when the water temperature was high; the number of limpets was

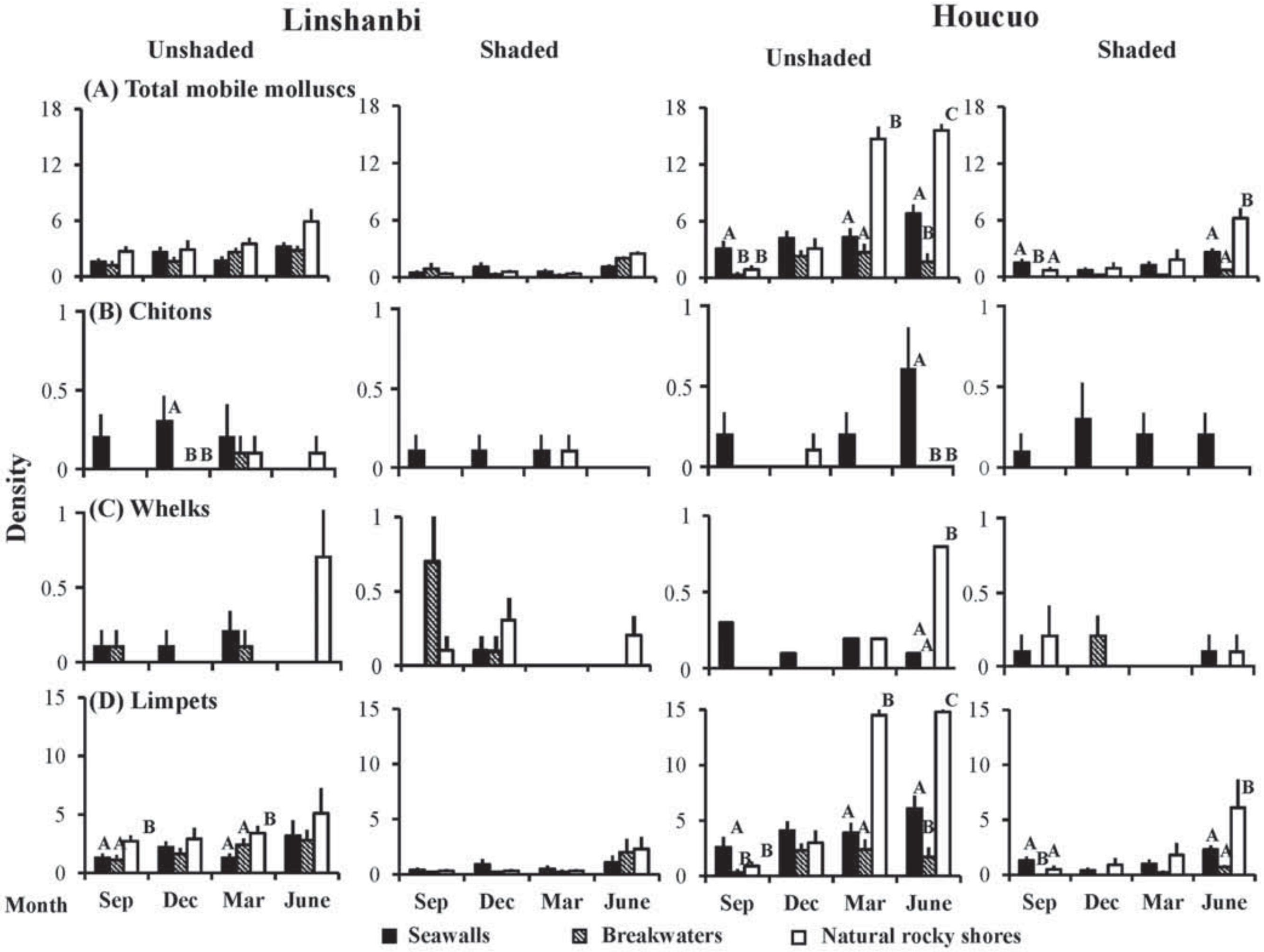

Fig. 2. Mean density (±SE) of mobile molluscs on seawalls, breakwaters, and natural rocky shores, at Houcuo and Linshanbi fishing ports between autumn 2010 and summer 2011. In the same season, means with different letters indicate significant differences according to Student-Newman-Keuls test ($p < 0.05$).

positively correlated with temperature (Table 8). Oyster coverage was positively correlated with chlorophyll a, whereas barnacle coverage was negatively correlated with chlorophyll a, turbidity, and suspended solids (Table 8). The red algae and green algae abundance was positively correlated with chlorophyll a, dissolved oxygen, and salinity (Table 8). Factor loadings for the abundance of taxa on the plots of the first two principal components (Fig. 5) showed that the abundance of red algae and green algae was positively correlated with the first principal component. Oyster occurrence was positively correlated with the second principal component, whereas barnacle occurrence was negatively correlated with the second principal component (Fig. 5).

DISCUSSION

Our study data showed a great variation between the two fishing ports for the type and number of intertidal assemblages. No clear pattern emerged for the differences among assemblages on natural rocks versus breakwaters or seawalls. Limpets, red algae, and green algae were less abundant on seawalls than on breakwaters or natural rocks. By contrast, the number of chitons was higher on seawalls than on breakwaters or natural rocky coasts. These differences may be related to the surface roughness, texture, and orientation of these three habitats as well as the chemical and physical conditions of their surroundings. The chitons typically inhabited the seawalls inside ports, whereas algae were abundant on the breakwaters and natural rock faces outside the ports. The taxa that contributed the greatest variance among habitats were algae, barnacles, oysters, and limpets and are discussed in greater detail below.

The coverage of red algae and green algae on the seawalls was less dense than on the breakwaters and natural rocks in this study. Previous studies have suggested that the algae coverage on natural rocks and breakwaters exposed to a strong flow of seawater is higher than on the seawalls inside ports (Underwood & Jernakoff, 1984; Blockley & Chapman, 2008). The hydrodynamic settings of fishing ports usually limit seawater circulation, which may result in the accumulation of rainwater or pollution inside the port. In addition, the level of dissolved oxygen around breakwaters or natural rocks outside ports are usually higher than at the seawalls inside the port because of

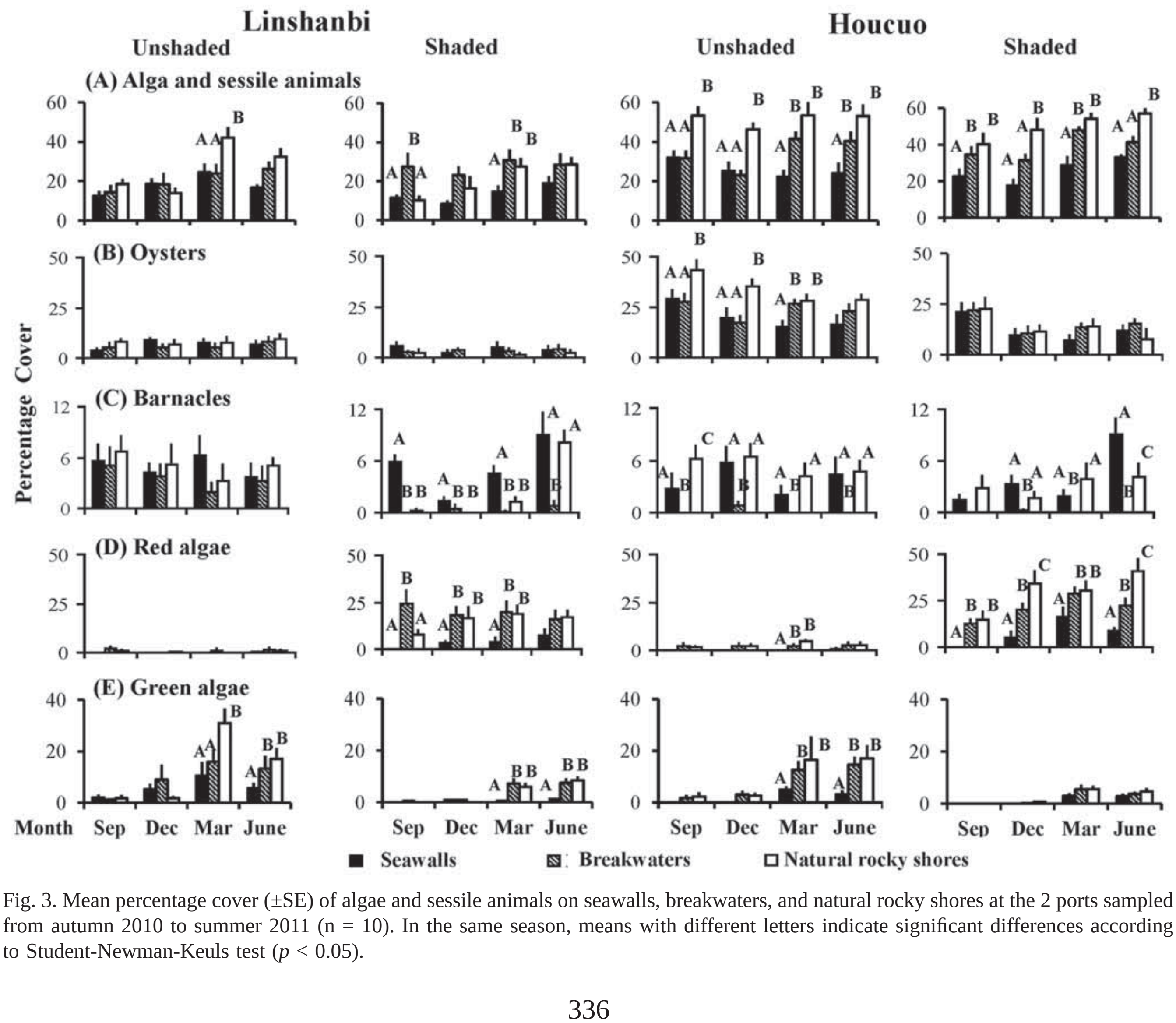

Fig. 3. Mean percentage cover (±SE) of algae and sessile animals on seawalls, breakwaters, and natural rocky shores at the 2 ports sampled from autumn 2010 to summer 2011 (n = 10). In the same season, means with different letters indicate significant differences according to Student-Newman-Keuls test ($p < 0.05$).

Table 4. SIMPER results for each species that contributed at least 10% in variance (dissimilarity) between habitats from autumn 2010 to summer 2011.

Species	Average abundance		Average dissimilarity	Contribution (%)	Cumulative (%)
Autumn, 2010	seawall	breakwaters	**59.83**		
Centroceras clavulatum	0.00	0.63	14.56	24.19	24.19
Chthamalus challenger	0.46	0.08	7.80	13.11	37.30
Saccostrea mordax	1.14	1.03	7.42	12.40	49.70
	seawall	natural rock	**60.52**		
Centroceras clavulatum	0.00	0.80	10.97	18.24	18.24
Saccostrea mordax	1.14	1.06	8.40	12.94	31.18
Chthamalus challenger	0.46	0.00	7.46	12.33	43.51
Tetraclita squamosa	0.32	0.47	6.58	10.88	54.39
	breakwater	natural rock	**44.67**		
Tetraclita squamosa m	0.15	0.47	8.94	20.04	20.04
Centroceras clavulatu	0.63	0.80	8.54	19.33	39.37
Saccostrea mordax	1.03	1.06	7.50	16.55	55.92
Chondracanthus intermedia	0.19	0.29	5.09	11.39	67.31
Winter, 2010	seawall	breakwaters	**49.43**		
Centroceras clavulatum	0.36	0.70	9.53	19.27	19.27
Ulva lactuca	0.29	0.47	6.66	13.47	32.74
Saccostrea mordax	0.88	0.94	5.60	11.32	44.06
	seawall	natural rock	**53.16**		
Centroceras clavulatum	0.36	0.82	10.29	19.35	19.35
Saccostrea mordax	0.88	1.03	9.22	17.35	36.71
Tetraclita squamosa	0.40	0.51	5.85	11.00	47.70
	breakwater	natural rock	**49.37**		
Centroceras clavulatum	0.70	0.82	10.49	21.24	21.24
Saccostrea mordax	0.94	1.03	8.70	17.64	38.86
Tetraclita squamosa	0.23	0.51	6.55	13.28	52.14
Ulva lactuca	0.47	0.29	6.25	12.71	64.85
Spring, 2011	seawall	breakwaters	**44.40**		
Centroceras clavulatum	0.48	0.87	9.65	21.72	21.72
Ulva lactuca	0.66	0.99	5.53	12.46	34.18
Chthamalus challenger	0.38	0.00	5.27	11.86	46.04
Tetraclita squamosa	0.46	0.12	5.03	11.32	57.36
	seawall	natural rock	**46.27**		
Centroceras clavulatum	0.48	0.86	8.01	17.30	17.30
Siphonaria laciniosa	0.00	0.49	5.08	10.99	28.29
Ulva lactuca	0.66	0.99	4.86	10.51	38.80
	breakwater	natural rock	**40.44**		
Centroceras clavulatum	0.87	0.86	7.05	17.44	17.44
Siphonaria laciniosa	0.19	0.49	5.38	13.31	30.75
Saccostrea mordax	1.01	1.00	4.86	12.01	42.76
Tetraclita squamosa	0.12	0.59	4.21	10.42	53.18
Ulva conglobata	0.14	0.39	4.17	10.32	63.50
Summer, 2011	seawall	breakwaters	**41.61**		
Centroceras clavulatum	0.53	0.87	7.46	17.93	17.93
Ulva lactuca	0.58	0.98	6.18	14.85	32.78
Saccostrea mordax	0.86	1.05	5.57	13.39	46.17
Chthamalus challenger	0.50	0.08	5.50	13.21	59.38
	seawall	natural rock	**40.30**		
Centroceras clavulatum	0.53	0.90	7.67	19.02	19.02
Siphonaria laciniosa	0.52	0.75	5.52	13.71	32.73
Ulva lactuca	0.58	1.03	5.38	13.36	46.09
Saccostrea mordax	0.86	0.96	5.23	12.97	59.05
	breakwater	natural rock	**34.78**		
Centroceras clavulatum	0.87	0.90	6.51	18.73	18.73
Siphonaria laciniosa	0.34	0.75	5.14	14.77	33.50
Tetraclita squamosa	0.16	0.52	4.91	14.13	47.63
Saccostrea mordax	1.05	0.96	4.49	12.92	60.55

seawater circulation and wave action (Guerra-Garcia et al., 2006). Higher levels of dissolved oxygen are advantageous for the growth and survival of algae (Blockley & Chapman, 2008). This may partly explain why the coverage of algae on breakwaters and natural rocks outside ports tends to be denser than on the internal seawalls.

Our data showed that limpets occurred in greater abundance on natural rocks than on breakwaters or seawalls. Temperature is known to be a major factor affecting limpet distribution (Branch, 1981). When the temperature rises in summer, the rough surface of natural rocks provides an increased number of microhabitats, such as neap pools and surface cracks, in which species can take refuge from unfavourable temperature conditions. Limpets seek out dents that match their shell sizes on the reef surface, and then hide in those cracks to reduce the dissipation of moisture (Fairweather, 1988; Underwood, 2004; Jackson et al., 2008). In addition, limpets can temporarily travel short distances to new areas if bottom habitats are overheated or short of water; they return to the unshaded area after the adverse conditions subside (Blockley & Chapman, 2006; Blockley, 2007).

Moreira et al. (2006) documented that limpet egg masses typically occurred less abundantly on artificial structures than on natural rocks, indicating a lower fertility of limpets on artificial structures compared with natural rocky shores. Similarly, Chapman & Bulleri (2003) and Bulleri et al. (2005) suggested that numerous intertidal weed eaters, including limpets, may inhabit environments in which green algae proliferate. Our data showed that limpets occurred in all three unshaded habitats. This finding might be related to the food source of limpets, namely green algae, having been abundant in these unshaded habitats during the seasons under study.

Barnacles rarely occurred on the breakwaters outside Houcuo fishing port, whereas oysters were abundant on both the breakwaters and natural rocks. Barnacle larval dispersal is usually unaffected by the limitations of seawalls or breakwaters (Martins et al., 2009), and barnacle larvae easily attach themselves to hard bottom structures (Connell, 2001; Lam et al., 2009). Our data showed that barnacles existed on artificial structures but that they were sparse on the breakwaters outside Houcuo fishing port; this finding might also have been the result of the water quality at this site. The measurements of chlorophyll a, turbidity, and suspended solids were relatively high at the breakwaters outside Houcuo. The area surrounding Houcuo fishing port comprises a sandy beach, and the breakwaters on the coastline detain the drift sand carried by offshore currents; thus, the turbidity of seawater and suspended solids is high at the breakwaters. By contrast,

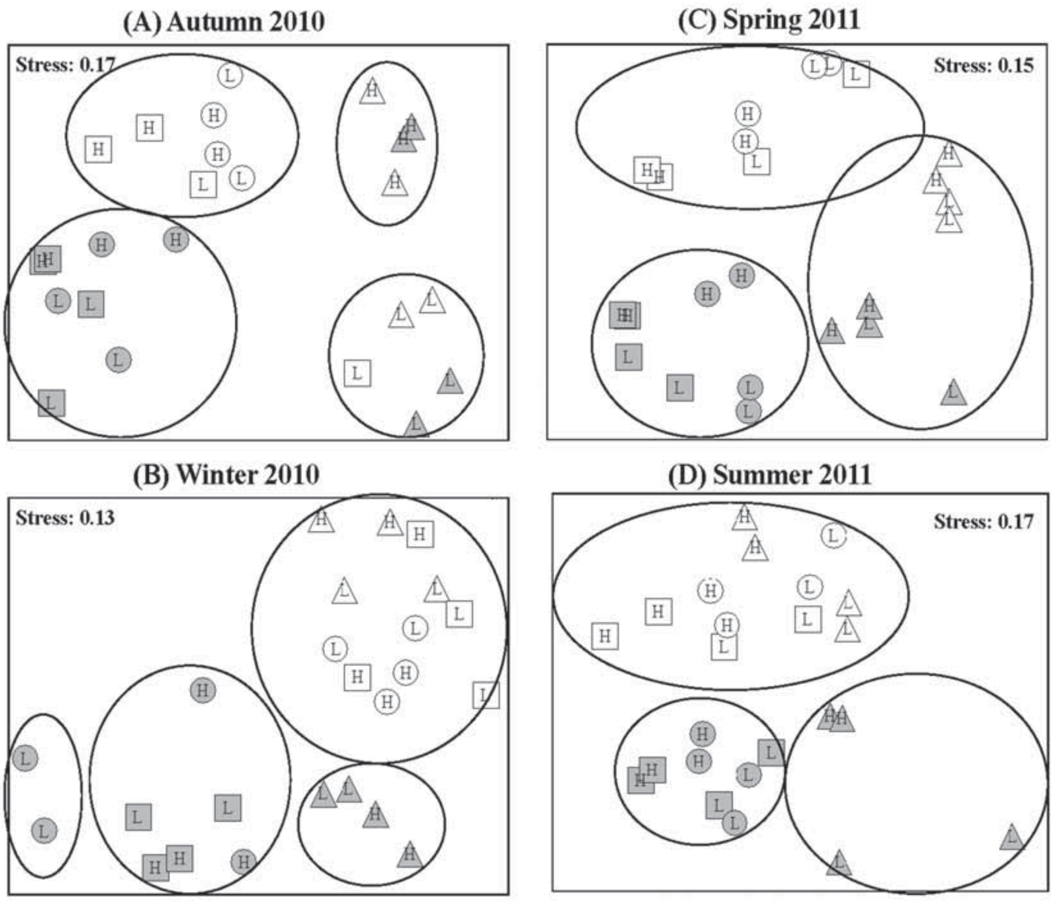

Fig. 4. The n-MDS plots for assemblages at various sampling sites from autumn 2010 to summer 2011. Symbols represent different habitats(: natural rocky shores; :seawalls; :breakwaters) and characters represent different fishing ports (H: Houcuo fishing port; L: Linshanbi fishing port). Shaded shapes represent shaded habitats, and unshaded shapes represent unshaded habitats. Ellipses represent the 60% similarity groups superimposed from the cluster analysis based on the Bray-Curtis resemblance matrix.

Table 5. Three-way ANOVA (time × habitat × shade) for the density of limpets and the percentage cover of sessile animals sampled in the two ports.

	df	Limpets		Oysters		Barnacles	
		ms	F	ms	F	ms	F
Linshanbi port							
Time (T)	3	0.48	7.16***	0.12	0.55	0.74	5.42**
Habitat (H)	2	0.31	4.57*	0.66	3.01	2.92	21.37***
Shade (S)	1	5.47	81.75***	6.89	31.42***	2.80	20.51***
T × H	6	0.04	0.64	0.32	1.47	0.14	1.03
T × S	3	0.04	0.56	0.50	2.30	1.20	8.79***
H× S	2	0.14	2.12	0.69	3.16*	0.86	6.29**
T × H × S	6	0.05	0.79	0.37	1.69	0.20	1.44
Residual	216	0.07		0.22		0.14	
SNK test		Time: Jun > Mar, Sep, Dec Habitat: N > S, B[1]					
Houcuo port							
Time (T)	3	1.65	21.62***	1.01	6.01***	0.33	2.69*
Habitat (H)	2	2.25	29.51***	1.11	6.62***	6.15	50.37***
Shade (S)	1	8.21	107.62***	6.84	40.59***	0.23	1.86
T × H	6	0.45	5.92***	0.22	1.29	0.23	1.91
T × S	3	0.54	7.14***	0.09	0.51	0.33	2.67*
H× S	2	0.27	3.53*	0.58	3.43*	0.67	5.50**
T × H × S	6	0.17	2.27*	0.18	1.07	0.11	0.87
Residual	216	0.08		0.17		0.12	
SNK test		Time: Mar, Jun >Dec >Sep Habitat: N > S, B[1]		Time: Sep > Mar, Jun, Dec Habitat: B, N > S[1]		Time: Sep > Mar, Jun, Dec Habitat: B, N > S[1]	

[1]S: seawalls; B: breakwaters; N: nature rocky shores
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

the area surrounding Linshanbi fishing port comprises reef rock, and the water quality was similar at both the breakwaters and the natural rocks outside this port.

Barnacles use cirri to catch and filter food particles from seawater-suspended solids (Barnes, 1982). However, barnacles die if they are covered by a large quantity of suspended solids. These features explain the occurrence of barnacles inhabiting the cement surface of seawalls in both ports and on the breakwaters outside Linshanbi, but not outside Houcuo. By contrast, numerous oysters were found on the breakwaters outside Houcuo, with high levels of turbidity and suspended solids. This finding might have been the result of oysters' ability to absorb suspended solids and nutritive salt through their filter feeding mechanism (Dame, 1988).

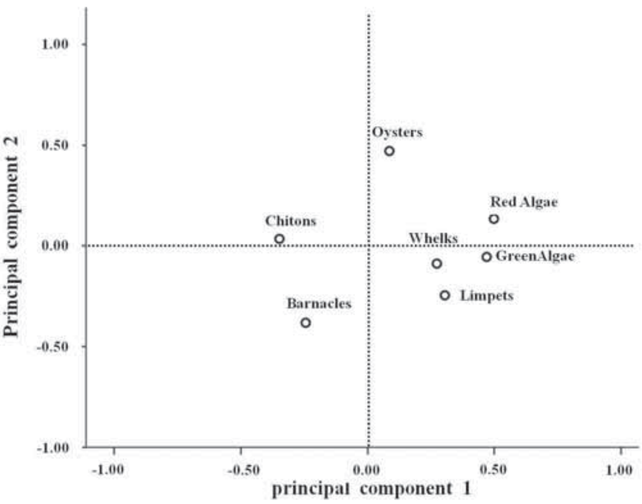

Fig. 5. Principal component scores for specific taxa at the two ports sampled between autumn 2010 and summer 2011.

In summary, the presence of intertidal assemblages on seawalls, breakwaters, and natural rocky coasts is affected by the interactions between local environmental factors. Such factors include wave action, water quality, and the abiotic aspects of the habitat such as the substrate type. For example, compared with the smooth concrete surfaces of seawalls, the rough surfaces of natural rocks and breakwaters retain more moisture in which intertidal organisms can flourish (McGuinness & Underwood, 1986; Anderson & Underwood, 1994). In addition, the ability of the larvae of intertidal organisms to adhere to various bottom substrates is influenced by the water's flow intensity and patterns (Qian, 2000). In general, the type of habitat affects the settlement, growth, and living

Table 6. Three-way ANOVA (time × habitat × shade) for the percentage cover of algae sampled in the two ports.

		Red algae		Green algae	
	df	ms	F	ms	F
Linshanbi port					
Time (T)	3	0.12	0.80	6.77	37.71***
Habitat (H)	2	4.86	31.82***	1.71	9.50***
Shade (S)	1	30.93	202.35***	4.91	27.38***
T × H	6	0.22	1.46	1.08	6.03***
T × S	3	0.23	1.48	0.25	1.42
H× S	2	2.96	19.33***	0.12	0.69
T × H × S	6	0.29	1.90	0.07	0.41
Residual	216	0.15		0.18	
SNK test		Habitat: B, N > S[1]		Time: Mar, Jun > Sep, Dec Habitat: B, N > S[1]	
Houcuo port					
Time (T)	3	1.54	13.88***	6.83	49.18***
Habitat (H)	2	8.06	72.52***	1.68	12.07***
Shade (S)	1	43.16	388.29***	2.65	19.07***
T × H	6	0.15	1.35	0.39	2.87*
T × S	3	0.72	6.48***	0.10	0.69
H× S	2	1.32	11.86***	0.39	2.80
T × H × S	6	0.38	3.46**	0.10	0.70
Residual	216	0.11		0.14	
SNK test		Time: Mar, Jun > Sep, Dec Habitat: B, N > S[1]		Time: Mar, Jun > Sep, Dec Habitat: B, N > S[1]	

[1]S: seawalls; B: breakwaters; N: nature rocky shores
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7. Principal component loadings, eigenvalues, and percentage variances computed for nine water quality parameters in the two ports, measured in Dec.2010 and in Mar. and Jun.2011.

	PC 1	PC 2	PC 3
Chlorophyll a	0.687	0.581	0.056
Silicate	–0.564	0.604	0.419
Temperature	0.564	–0.273	–0.027
Dissolved oxygen	0.722	0.168	0.514
Conductivity	0.905	–0.239	–0.104
Salinity	0.903	–0.186	–0.078
Turbidity	0.068	0.797	–0.292
pH	0.178	0.082	0.913
Suspended solids	0.387	0.750	–0.345
Eigenvalues	3.449	2.101	1.498
Variation (%)	38.325	23.348	16.639
Cumulative variation (%)	38.325	61.673	78.312

space of intertidal assemblages, whereas the water quality conditions influence larval drift, food source abundance, and the living environment (Pedersen et al., 2008). Because of the worldwide threat of rising sea levels, the need for coastal protection is increasing globally. However, the physical and ecological effects of artificial structures on the coastal environment remain poorly understood. Future studies should assess the physical and chemical properties of artificial structures that affect the function and structure of intertidal ecosystems in various coastal locations. Information on the factors and types of artificial structures affecting intertidal assemblages in different coastal areas could help conserve intertidal biodiversity.

Table 8. The correlation coefficients between specific taxa and water quality parameters in the two ports.

	Chl a	Silicate	Temp	DO	Cond	Salinity	Turbidity	pH	SS
Limpets	0.00	–0.05	0.55***	0.31	0.32	0.24	–0.21	0.34	–0.17
Oysters	0.43*	0.29	–0.01	0.14	–0.07	–0.05	0.31	0.39	0.38
Barnacles	–0.40*	0.17	0.37	–0.06	–0.15	–0.31	–0.46**	0.03	–0.41*
Red algae	0.48**	–0.10	0.04	0.58***	0.37	0.44**	–0.05	0.34	0.19
Green algae	0.43*	–0.06	0.11	0.44**	0.36	0.45**	–0.29	0.30	0.05

Chl a = chlorophyll a; Temp = temperature; DO = dissolved oxygen; Cond = conductivity; SS = suspended solids
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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