TEMPORAL VARIATIONS IN COMMUNITY STRUCTURE IN AND AROUND INTERTIDAL BARNACLE (*Chthamalus challengeri* Hoek) PATCHES ON A PLEBBY SHORE IN JAPAN

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(With 6 figures)

ABSTRACT

The community structure in and around two barnacle (*Chthamalus challengeri* Hoek) patches (sites A and B) which extended from the middle to the upper intertidal zone on a pebbly shore in Magarisaki (Amakusa, Kyushu, Japan), was studied during summer and winter of 1995 and 1996. The results show a significant decrease in the proportion of substrate covered by barnacles from January 1995 to July 1996. The number of species, number of individuals, and biomass also decreased in the patch areas through time. There were significant differences between inside and outside the patches for percentage of substrate covered by barnacles, number of individuals, number of species, and biomass during the first year. Numbers of some gastropods were significantly higher in the barnacle patches, suggesting that the presence of barnacles create favorable microhabitat for the other taxa.

Key words: barnacles, *Chthamalus challengeri*, community structure, intertidal, Japan.

RESUMO

Estrutura de comunidades dentro e fora de agregações de cracas no litoral de Amakusa, Japão

Durante o verão e o inverno de 1995 e 1996, foram realizados estudos de estrutura das comunidades dentro e ao redor de duas agregações de cracas (*Chthamalus challengeri Hoek*), nas áreas A e B, que se estendem das regiões do supra ao médio litoral em Magarisaki (Amakusa, Kyushu, Japan). Os resultados mostram um declínio significativo na proporção de substrato coberto por cracas desde janeiro de 1995 até julho de 1996. O número de espécies, número de indivíduos e biomassa também diminuíram dentro dos "patches" de cracas no decorrer do tempo. Houve significativas diferenças entre as comunidades de dentro e fora dos "patches" para porcentagem de substrato coberto por cracas, número de espécies, número de indivíduos e biomassa durante o primeiro ano de estudo. Os números de alguns gastrópodos foram significativamente maiores dentro dos "patches" de cracas, sugerindo que a presença das cracas cria um microambiente favorável a outros taxa.

Palavras-chave: cracas, *Chthamalus challengeri*, estrutura de comunidades, região entre-marés, Japão.

INTRODUCTION

Physical features or biological variables such as competition and predation commonly explain spatial differences and temporal changes in patchness. Differences in community structure among patches of dominant related species occur at many scales of resolution, with the smallest being the space occupied by a single organism (Sauer Machado *et al.*, 1992). Differences in substrate also influence the structure of a community, making comparison of the results obtained by different authors difficult. For example, there is abundant literature on community structure and interactions on hard intertidal substrata, such as rocky shores, and vertical walls (Paine, 1974;

Menge, 1976; Lubchenco & Menge, 1978; Menge & Lubchenco, 1981, Cubit, 1984; Underwood & Denley, 1984; Garrity & Levings, 1987; Sauer Machado *et al*., 1992, 1996), but little on boulder or pebble shores (Sousa, 1979a, e 1979b; Petersen *et al*., 1986; Takada & Kikuchi, 1990, 1991; Rocha, 1995).

Benthic patchness can also be caused and/ or maintained by unpredictable factors operating in the plankton. There may be temporal variation in the larval supply (Gaines *et al*., 1985; Roughgarden *et al*., 1985, 1987) threatening the maintenance of a population.

In this work a comparison of community structure within and outside intertidal barnacle (*Chthamalus challengeri* Hoek) patches on a pebbly shore over time, is done by using multivariate analysis of variance (MANOVA).

MATERIAL AND METHODS

Study site

The sand spit of Magarisaki, located in Amakusa Shimoshima, West Kyushu, Japan (lat. 32°32'N, long. 130°02'E) (Fig.1) is formed by oval pebbles, with an average diameter of 20 cm, on corse sand (Takada & Kikuchi 1990, 1991). The patches observed along the shore were of irregular size, extending from the middle to the upper intertidal zone.

The shore is relatively protected in summer (June-September), with winds predominantly from south, but exposed during winter when winds are from the north (November-February). Tidal amplitudes vary between 0 and 300 cm, with the middle intertidal defined as 150 to 200 cm, and the upper intertidal at 100 to 150 cm below mean high tide level. Mean air and surface seawater temperature range from 6° to 33°, and 13° to 26°C, respectively (Fig.2).

Community structure

The community structure was monitored within and outside the barnacle patches at sites A and B (see Fig. 1), at the two intertidal levels during winter and summer (January-July) of 1995 and 1996 using four 0.25 m^2 quadrats, placed randomly on 10 m^2 horizontal transect line. All organisms inside the quadrats were collected, fixed in 10% formalin, identified and measured in the laboratory.

Percentage of substrate covered by barnacles

The sites were photographed just before sampling the quadrats. In the laboratory, the photographic slides were projected onto a 0.90 m^2 screen, filled with 225 evenly –spaced dots, to calculate the proportion of substrate covered by barnacles (= % cover of barnacles). Only living individuals were included in my calculations.

Data Analysis

Multivariate analysis of variance (MANOVA), formed the base of the data analysis, using date (time), site (A, B), tidal height, and patch – non-patch (space) as the four factors. The % cover of barnacles, number of species, number of individuals, and biomass were monitored as the community indexes. The numbers of the most dominant species (gastropods) were also included in the analyses. Kendall's coefficient of rank correlation (t), was used to examine the relationship between the mean % cover of barnacles on the four sampling dates (n = 4), the mean number of species, individuals and biomass (g), and the mean numbers of the most abundant gastropods within the barnacle patches (4 replicates) given in Burr (1960). Shannon's diversity index (H') was also calculated for data from within (P) and outside (OP) the barnacle patches, to assess variation in the diversity index over time.

RESULTS

The fauna sampled during this study belongs to the following groups: Annelida: Polychaeta (1 specie); Arthropoda: Crustacea, Malacostraca (4 species); Mollusca: Polyplacophora (1 specie), Gastropoda (16 species); and Echinodermata: Holothuroidea (1 specie) (Table 1). Gastropods represented 70% of the total number of species; their abundance and biomass represented 95% of the total fauna sampled. There was a significant decline in the community indexes over time. The MANOVA calculated for sites (A, B), intertidal levels (upper, middle), and patches (P, OP), against time, showed significant differences for the % cover of barnacles. The differences between sites A and B, as well as upper and middle intertidal levels, were caused by the decline of the % cover of barnacles at the middle intertidal patch in site B. Variations in the number of species had a similar pattern between the two sites, with greatest numbers at the middle intertidal, and inside the patch areas. The number of individuals did not vary significantly between the two intertidal levels. See Fig. 3 and Table 2 for the patterns of variation and the MANOVA results.

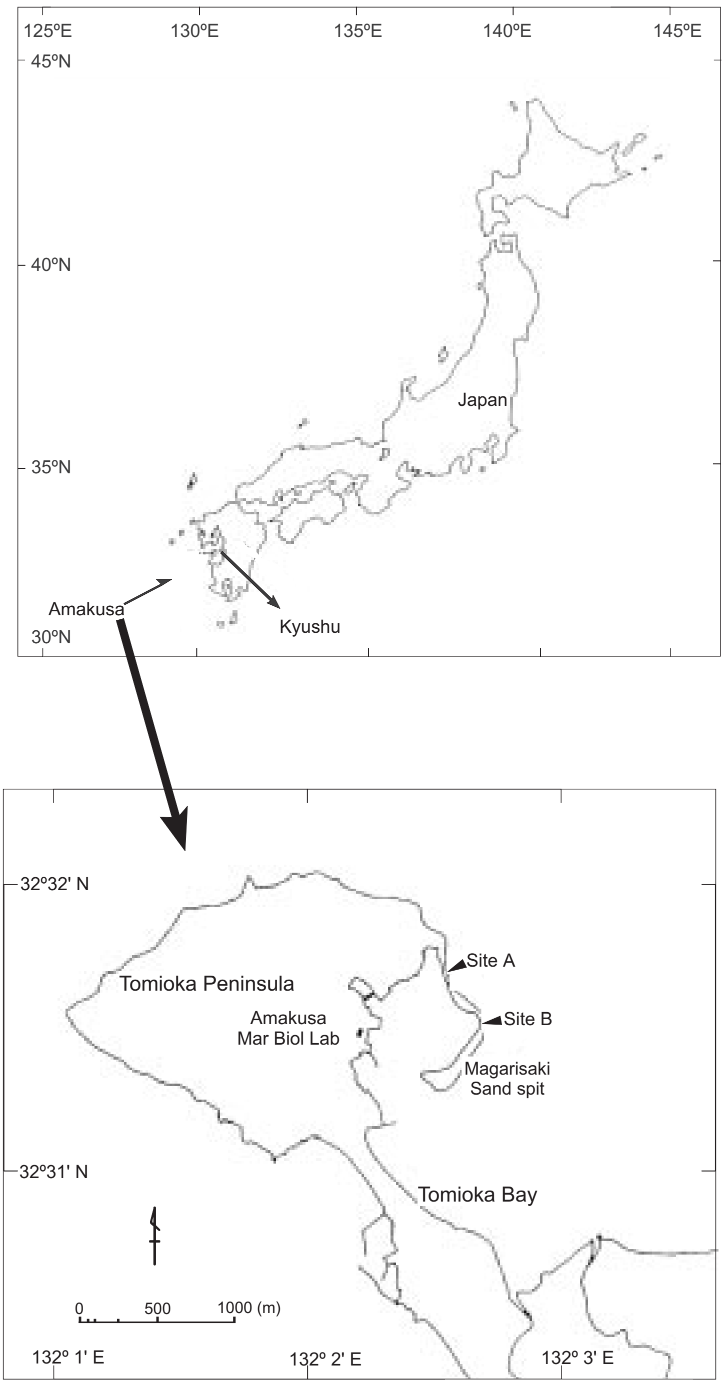

Fig 1 — Maps showing the Amakusa Islands, in Kyushu, Japan (upper), and the Magarisaki Sand Spit at Tomioka Peninsula, Amakusa (lower).

TABLE 1

Relative frequency of species in samples from sites A and B, at the upper and middle intertidal levels through time. P and OP represent samples from inside and outside the barnacle patches, respectively. 0 = absence of species, + = sampled on just one date, ++ = sampled more than once, but not on all dates, and +++ = sampled on all dates.

	Site A				Site B			
	upper		middle		upper		middle	
	P	OP	P	OP	P	OP	P	OP
Phylum Annelida								
Class Polychaeta								
Order Phyllodocida								
Family Polynoidae								
Harmathoe imbricata	0	+	0	0	0	0	++	++
Phylum Arthropoda								
Subphylum Crustacea								
Class Malacostraca								
Order Decapoda								
Suborder Anomura								
Pagurus laguginosos	0	0	0	0	0	0	0	+
P. samuellis	0	0	+	0	0	0	+	0
Petrolisthes japonicus	0	0	0	0	0	0	0	+
Suborder Brachyura								
Gaetice depressus	++	++	+++	+++	++	+++	+++	++
Phylum Mollusca								
Class Polyplacophora								
Order Acanthochitonidae								
Family Acanthochitonidae								
Acanthonchiton defilippi (Tapparone-canefori)	++	++	++	++	++	++	++	++
Class Gastropoda								
Subclass Prosobranchia								
Order Archeogastropoda								
Family Acmaeidae								
Notoacmea concinna (Lischke)	++	++	0	0	++	0	0	0
N. fuscoviridis teramachii	++	++	++	++	++	++	++	++
N. nigrans (Lischke)	++	++	++	++	++	++	++	++
N. schrenckii (Lischke)	0	0	++	++	0	++	0	++
Patelloida pygmea (Dunker)	++	++	++	++	++	++	++	++
Family Trochidae								
Monodonta labio (Linnaeus)	+++	+++	+++	+++	+++	+++	+++	+++
Omphalius rusticus (Gmelin)	0	+	++	0	+	0	+	0
Family Turbinidae								
Lunella cronata coreensis (Récluz)	+++	+++	+++	+++	+++	+++	+++	+++
Family Neritidae								
Nerita spp.	+++	+++	+++	+++	+++	+++	+++	+++
Order Mesogastropoda								
Family Littorinidae								
Littorina brevicula (Philipi)	+++	++	+++	++	+++	++	+++	++
Peasiella roepstorfiana (Nevill)	+++	++	+++	++	+++	++	+++	++
Order Neogastropoda								
Family Muricidae								
Cronia fusca (Küster)	0	0	0	0	0	0	0	+

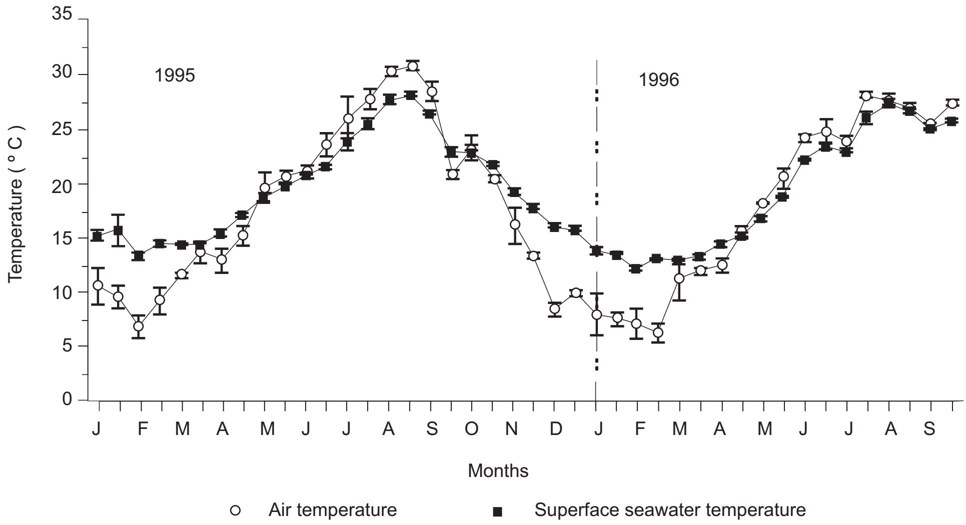

Fig. 2 — Mean (SD) air and surface seawater temperatures for January 1995 to September 1996.

TABLE 2

Summary of the MANOVA results for 4 dependent variables (% cover, number of species, number of individuals, and biomass) calculated for sites (A, B), intertidal levels (upper, middle), and patches (P, OP) against time.

Source	DF	F	P
For % cover			
Sites (A,B) vs. Time	3	2.89	0.0386 *
Int. levels (upper, middle) vs. Time	3	2.88	0.0393 *
Patches (P, OP) vs. Time	3	130.96	0.0001 ***
For No. of species			
Sites (A, B) vs. Time	3	7.38	0.0001 ***
Int. levels (upper, middle) vs. Time	3	2.98	0.0347 *
Patches (P, OP) vs. Time	3	7.06	0.0002 ***
For No. of individuals			
Sites (A, B) vs. Time	3	1.03	0.3831 NS
Int. levels (upper, middle) vs. Time	3	3.58	0.0167 *
Patches (P, OP) vs. Time	3	32.77	0.0001 ***
For biomass			
Sites (A, B) vs. Time	3	1.84	0.1448 NS
Int. levels (upper, middle) vs. Time	3	7.99	0.0001 ***
Patches (P, OP) vs. Time	3	2.15	0.0974 NS

*** Significantly different at 0.001 level, * significantly different at 0.05 level, and NS not significantly different.

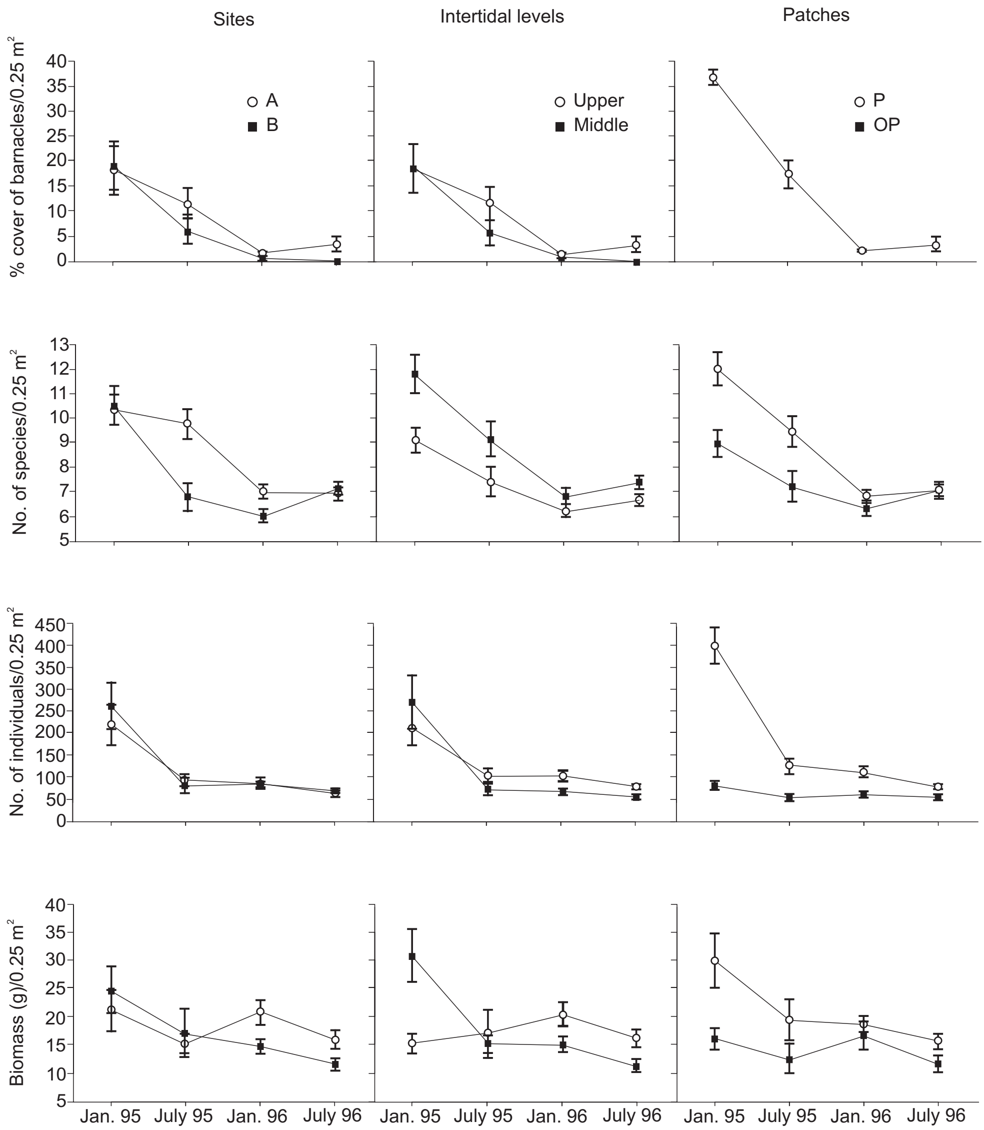

Fig. 3 — Mean (SD) % cover of barnacles, number of species, number of individuals, and biomass (g) at sites A and B; upper and middle intertidal levels; and inside (P) and outside (OP) the barnacle patches over time.

The most abundant species associated with the barnacle patches, the gastropods, showed the following patterns of variation. The number of *Littorina brevicula* was significantly greater inside than outside the barnacle patches before the decline of the % cover of barnacles. The numbers of *Peasiella roepstorfiana*, were significantly greater in site A than in site B, and inside than outside the barnacle patches, during the first two sampling dates. The numbers of carnivorous *Thais clavigera* varied significantly between the two intertidal levels and patches. The above three species showed a similar pattern of temporal variation as that of the % cover of barnacles inside the patches. See Fig. 4, and Table 3 for patterns of variation, and the Kendall's coefficient of rank correlation (t) results.

The three other abundant species of gastropods showed no clear association with the barnacle patches. For example, the numbers of *Lunella cronata coreensis* were significantly greater at the middle intertidal, but showed no relationship with patches or sites. The numbers of *Monodonta labio* were significantly greater in site

B as well as at the middle intertidal level. Numbers of *M. labio* in the patch areas ranged from significantly greater outside to significantly greater inside the patches inside the patches over time. *Nerita spp.* showed the most significant differences amongst all the abundant gastropods. They were numerically greater in site A at the upper intertidal and inside the patches. Their numbers in the patches increased when the % cover of barnacles declined (Fig. 5). Se Table 4 for the summary of the MANOVA results.

There were no large temporal changes in Shannon's diversity index (H') for the fauna inside the barnacle patches. Outside the patches, diversity decreased from January 1995 until January 1996, but had recovered by July 1996 (Fig. 6). With the decline of the barnacle patches, the pattern of aggregation showed by some species within the patches disappeared and more homogeneous distribution of the species within the same intertidal level was observed at the end of the study.

DISCUSSION

The barnacle patches collapsed by the end of the first year. Species composition did not differ greatly between inside and outside patch areas, but the abundance of some species did exhibit significant differences in this respect. In the first year, when the barnacle patches were clearly delimited, three species of gastropods were significantly correlated with the patches. Amongst them, were the herbivorous *Littorina brevicula* and *Peasiella roepstorfiana*. These species are known to be abundant at the upper intertidal level of boulder and rocky shores (Takada & Kikuchi, 1990).

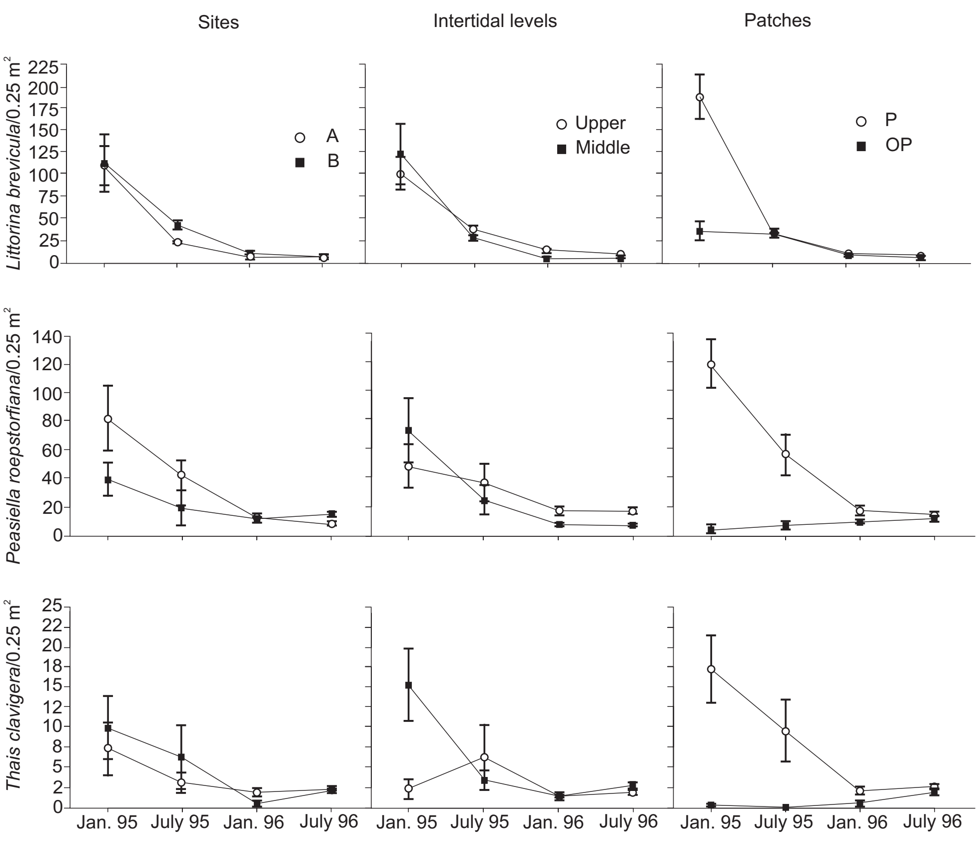

Fig. 4. — Mean (SD) numbers of three species associated with the barnacles *patches (Littorina brevicula, Peasiella roepstorfiana* and *Thais clavigera*) for sites A and B; upper and middle intertidal levels; and inside (P) and outside (OP) the barnacle patches over time.

TABLE 3

Summary of results from Kendall's coefficient rank of correlation (τ) between the mean % cover of barnacles during the 4 sampling dates (n = 4); the mean number of species, individuals, and biomass (g); as well as the mean numbers of the most abundant gastropods inside the barnacle patches during the 4 sampling dates (4 replicates).

Abundances compared		τ	p
% cover of barnacles			
	vs. No. Species	1.00	0.042 *
	vs. No. Individuals	1.00	0.041 *
	vs. Biomas	1.00	0.041 *
	vs. *Littorina brevicula*	1.00	0.042 *
	vs. *Peasiella roepstorfiana*	1.00	0.041 *
	vs. *Thais clavigera*	0.91	0.174 NS
	vs. *Lunnela cronata coreensis*	0.33	0.496 NS
	vs. *Monodonta labio*	0.55	0.264 NS
	vs. *Nerita spp.*	0.54	0.263 NS

*significantly different at 0.05 level, and NS not significantly different.

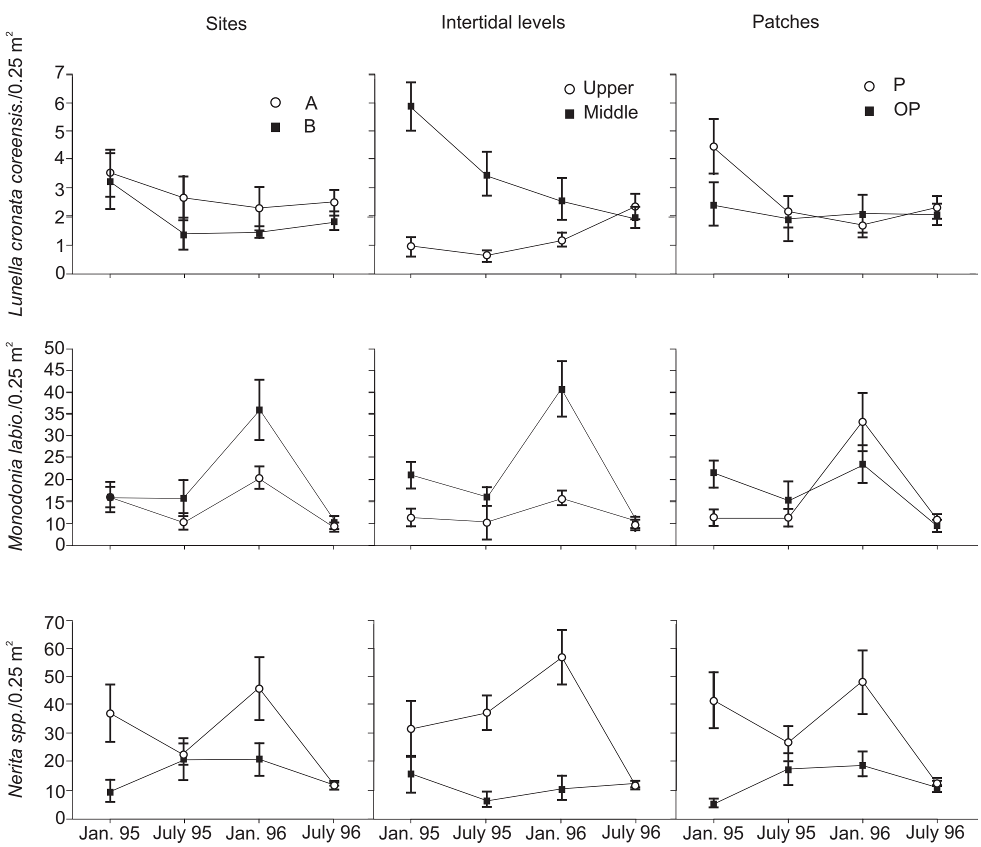

Fig. 5 — Mean (SD) numbers of abundant mobile mollusks (*Lunella cronata coreensis, Monodonta labio,* and *Nerita spp.*) for sites A and B; upper and middle intertidal levels; and inside and (P) and outside (OP) the barnacle patches over time.

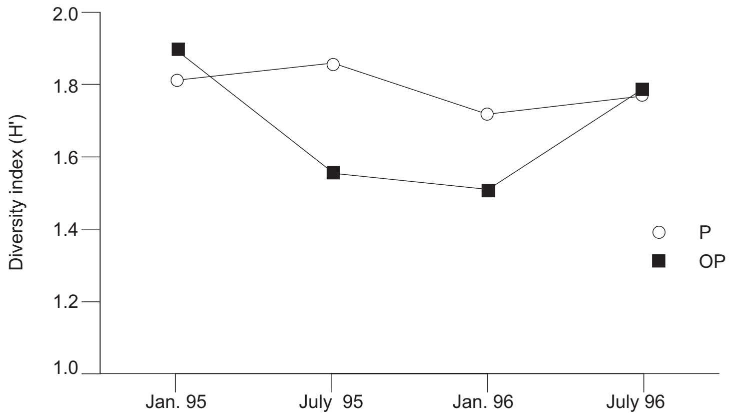

Fig. 6 — Temporal variation of Shannon's diversity index (H') for total numbers of fauna inside (P) and outside (OP) the barnacle patches.

TABLE 4

Summary of the MANOVA results for 6 dependent variables (*Littorina brevicula*, *Peasiella roepstorfiana*, *Thais clavigera*, *Lunella cronata coreensis*, *Monodonta labio*, *Nerita spp.*) calculated for sites (A, B), intertidal levels (upper, middle), and patches (P, OP) over time.

Source	DF	F	P
For *Littorina breviculla*			
Sites (A, B) vs. Time	3	0.51	0.7271 NS
Int. levels (upper, middle) vs. Time	3	0.82	0.5160 NS
Patches (P, OP) vs. Time	3	27.46	0.0001 ***
For *Peasiella roepstorfiana*			
Sites (A, B) vs. Time	3	5.42	0.0005 ***
Int. levels (upper, middle) vs. Time	3	2.21	0.0723 NS
Patches (P, OP) vs. Time	3	36.63	0.0001 ***
For *Thais clavigera*			
Sites (A, B) vs. Time	3	0.66	0.6190 NS
Int. levels (upper, middle) vs. Time	3	6.13	0.0002 ***
Patches (P, OP) vs. Time	3	12.97	0.0001 ***
For *Lunella cronata coreensis*			
Sites (A, B) vs. Time	3	1.18	0.3250 NS
Int. levels (upper, middle) vs. Time	3	15.06	0.0001 ***
Patches (P, OP) vs. Time	3	1.90	0.1157 NS
For *Monodonta labio*			
Sites (A, B) vs. Time	3	3.97	0.0047 **
Int. levels (upper, middle) vs. Time	3	11.01	0.0001 ***
Patches (P, OP) vs. Time	3	3.08	0.0190 *
For *Nerita spp.*			
Sites (A, B) vs. Time	3	10.72	0.0001 ***
Int. levels (upper, middle) vs. Time	3	12.49	0.0001 ***
Patches (P, OP) vs. Time	3	13.63	0.0001 ***

*** Significantly different at 0.001 level, ** significantly different at 0.01 level, *significantly different at 0.05 level, and NS not significantly different.

The littorinids tend to use the barnacle tests as a refuge, and so as a source of food by grazing on the microalgae associated with the barnacles' tests (Apolinário *et al*.). The other associated gastropod was *Thais clavigera*, a potential predator of the barnacles. Its abundance within the patches could be an important factor in patch formation, according to the predation hypothesis proposed by Paine (1974, 1977). However, the predation hypothesis was based on studies done on rocky shores, where zonation is well delimited, and competition for space amongst the sessile intertidal organisms (barnacles, mussels, and microalgaes) is very intensive. Also, *Chthamalus spp*. is less susceptible to either bulldozing or predation by gastropods (Dayton, 1971; Paine, 1966, 1981). In other hand, Connell (1961a), observed that predation by *Thais lapillus* influences the dynamics of natural populations of *Balanus ballanoides*. The scenario of our study is completely different, especially in the absence of space limitation on the Magarisaki Sand Spit, due to high tidal amplitude and low inclination profile.

The results from Kendall's coefficient of rank correlation must be interpreted carefully. A significant correlation per se does not mean a cause/effect relationship. For example, many factors such as timing of recruitment and mortality of these populations (Takada & Kikuchi, 1991) could be operating concurrently with the decreasing % cover of barnacles. However, considering the sequence of events from the beginning of the study, when there were well delimited barnacle patches, to the last sampling date, when the patches had disappeared, my suggestion is that factors operating on the barnacle population prior to their patchy recruitment were the principal causes of the observed patterns, i. e. the differences in the community structures were a consequence of and not the cause of the appearance of the barnacle patches.

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