

Research Article

Algae 2015, 30(2): 139-146

<http://dx.doi.org/10.4490/algae.2015.30.2.139>

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Changes in macroalgal assemblage with sea urchin density on the east coast of South Korea

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Urchin barrens have been a major issue of rocky coastal ecosystems in temperate regions. In South Korea, the east coast and Jeju Island have especially been a focus because the area of barren ground increases in spite of continual efforts to install artificial reefs. This study approached the urchin barrens issue in South Korea, by focusing on a correlational analysis of urchin and macroalgal abundance. Urchin density and algal species coverage were obtained using a quadrat image analysis. Subtidal sites were then classified into three groups according to the average densities of urchins to evaluate the characterization of the macroalgal community: no urchin (NU) zone; transition (TR) zone, 4 inds. m⁻²; and urchin (UR) zone, ≥8 inds. m⁻². The average urchin density in the study site was 4.7 inds. m⁻² and 57 macroalgal species were found in the study site. From the NU zone to UR zone, total species number, species diversity index and evenness gradually decreased, whereas the dominance index increased. The algae species with negative correlations were *Grateloupia divaricata*, *Polysiphonia morrowii*, *Chondracanthus intermedius*, *Delesseria violacea*, *Desmarestia viridis*; and those with positive correlations were the crustose corallines, *Sargassum horneri*. Other species were not significantly correlated with urchin density. The significant correlations indicate that the abundance of some macroalgal species is proportionally regulated by sea urchin density. This study also shows how macroalgal vegetation changes in response to an urchin's density gradient in a natural condition; and there is a TR zone that existed with respect to an intermediate level of algal abundance.

Key Words: barren ground; diversity; macroalgae; rocky; sea urchin; transition zone

INTRODUCTION

Urchin barrens have been a major coastal environmental issue in temperate regions (Klumpp et al. 1993, Guidetti and Dulčić 2007, Privitera et al. 2008, Agnetta et al. 2013). Various factors have been raised for the reasons of the barren ground phenomena, such as climate changes, marine pollutions, intensive herbivory, etc. (Arai and Arai 1984, Watanabe and Harrold 1991). Regarding herbivory actions, a magnitude of sea urchin density has been closely related with the severity of barrens in many parts of coastal beds (Mann 1982, Guidetti and Dulčić

2007, Privitera et al. 2008, Agnetta et al. 2013).

In general, the standing biomass of erect and fleshy macroalgae is low where urchins remain in a substantial density, and sometimes algal-rich beds have distinctively separated from those barren spots, even though the distance is only a few meters (Choat and Schiel 1982, Mann 1982, Dean et al. 2000, Wright et al. 2005, Stewart and Konar 2012). Despite strong grazing pressure, insufficient food supply has been proved in those biologically unprotected habitats because of low recruitment success and



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Received April 12, 2015, Accepted June 2, 2015

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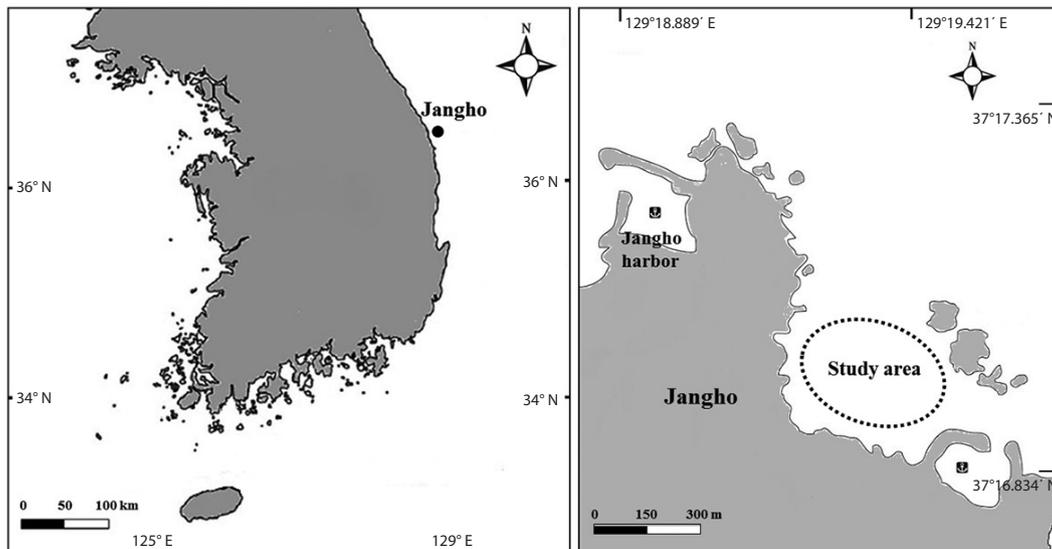


Fig. 1. The study site, Jangho, Gangwon Province, South Korea.

high mortality of young thalli (Harrold and Reed 1985, Agatsuma 2007, Yoo et al. 2007). Hence, the pattern often persists for a long time. Nevertheless, with regard to sea urchins distributional patterns, they tend to be gregarious in those barren spots with little food (Mann 1982, Vadas et al. 1986, Nakabayashi et al. 2006, Guidetti and Dulčić 2007, Stewart and Konar 2012); this leads to some further questions. Is it a group protection from predators? A good shelter from wave action? A certain behavioral pattern of sea urchins? (Mann 1982, Vadas et al. 1986, Dean et al. 2000, Dumont et al. 2006, Stewart and Konar 2012, Morse and Hunt 2013). Vadas (1977) and Mann (1982) claimed that macroalgae-herbivore interactions have led to important adaptations and strategies by both the sea urchins and algae, emphasizing algae's temporal (e.g., short-lived) and spatial (e.g., patchy) escape and urchin's efficient search and mobility for available prey. From another point of view, Agnetta et al. (2013) explained that sea urchin grazing often determined the formation and maintenance of two alternative states (coralline barrens and erect algal forests) of a macroalgal community in temperate rocky reefs. However, except for many researches dealing with urchin's feeding experiments, field distributional patterns of sea urchins and their prey are still remained quite conceptual.

This non-manipulative experiment was carried out to understand the relationship between macroalgal abundance and sea urchin density in a natural habitat, where both coralline barrens and an erect algal forest exist with a transition zone between the two types. The present

study provides a layout of the natural field conditions and further questions on feeding patterns and behavior of urchins in the particular barren subtidal habitat.

MATERIALS AND METHODS

The study site is located in Jangho village, Samcheok City, Gangwon Province, South Korea (37°17.025' N, 129°19.358' E) (Fig. 1). The subtidal zone (6-10 m in depth) of this area, where the experiment was conducted, represents a typical urchin barrens habitat on the east coast of South Korea. The field data were collected from April 12 to May 23, 2013, using by means of SCUBA diving. Two species of sea urchin, *Strongylocentrotus nudus* and *S. intermedius*, dominate the grazer populations with an occasional occurrence of erect foliose macroalgal beds.

The ratio of the relative percent coverage of crustose coralline algae and erect foliose algae is 60 : 40 in average, with more foliose algae appearing in the shallower zone and more corallines in the deeper zone (Jeon 2013). The sea urchin density and macroalgal percent cover were obtained from a random quadrat (0.5 m × 0.5 m, n = 170), using a transect line marked with random points, which was placed along the urchin density gradient. The subdivided areas (0.25 m × 0.25 m) of a quadrat were photographed and analyzed for the quantification of organisms using an image-analyzing program (Image J, National Institute of Mental Health). The algal percent cover and urchin density and size were obtained via an analysis of the im-

ages. Additional photos were taken to better estimate the percent coverage of understory species where canopy-forming macroalgae were predominant in the quadrat. An individual entity appearing on the border was taken into account if 50% of its holdfast was inside of a quadrat; the same rule was applied to sea urchins.

To examine the difference in the macroalgal assemblage according to urchin density gradient, we divided the habitat into 3 zones: 1) no urchin zone (NU zone): no sea urchin found; 2) transition zone (TR zone): average 4 inds. m⁻²; and 3) urchin zone (UR zone): ≥8 inds. m⁻². Then, there was a comparison of the number of algal species, percent coverage of each macroalgal species, diversity ($H_s = -\sum p_i \ln p_i$), evenness ($E = H_s/H_{s_{\max}}$), and dominance ($D_s = \sum p_i^2$). There was no manipulation of the urchin density. Pearson's correlation analysis was carried out using log-transformed percent coverage of macroalgae, since the normality assumption was not met for most variables.

RESULTS

A total of 57 macroalgal species were found at the study site of the Jangho subtidal area: 6 Chlorophyta, 13 Phaeophyta, and 38 Rhodophyta. The indices of species diversity, evenness, and dominance were 1.73, 0.43, and 0.36, respectively (Table 1). The average density of sea urchins was 4.7 inds. m⁻², consisting of 3.5 inds. m⁻² for *S. nudus* and 1.2 inds. m⁻² for *S. intermedius*. The average diameters of the two species were 6.9 ± 1.8 cm (n = 147) and 4.9 ± 1.9 cm (n = 54), respectively. It was often found that sea urchins were gregarious depending on the habitat condition, such as a crack on a rock bed, and reached a maximum density of 32 inds. m⁻², including many juveniles in this study.

With regard to the three urchin zones, the NU zone had the highest number of macroalgal species, which was 50

species that was composed of 5 green, 11 brown, and 34 red, followed by the TR zone (44 species with 4 green, 10 brown, and 30 red), and the UR zone (40 species with 2 green, 12 brown, and 26 red). The NU zone also had the highest index value in species diversity (2.36) and evenness (0.62), followed by the TR zone (1.95 and 0.52, respectively) and the UR zone (1.74 and 0.47, respectively). However, the dominance index showed the opposite pattern; 0.37 for the UR zone, 0.28 for the TR zone, and 0.16 for the NU zone (Table 1).

The relative frequency of macroalgal species was calculated, based on the field data from the total 170 quadrats surveyed (Fig. 2). Twelve species, of the 57 species, appeared in >40 quadrats. Crustose coralline algae (167 quadrats) showed the highest frequency, followed by *Dellesseria violacea* (116 quadrats) and *Ulva pertusa* (112 quadrats). Among brown algae, *Desmarestia viridis* (60 quadrats) was ranked as sixth. Except for these species, 8 species among the top 12 groups consisted of red algae.

Among the species with higher frequency ranks from each urchin zone, crustose coralline algae had 25.15% coverage in the NU zone, but they increased up to 40% in both the TR and UR zones (Fig. 3). *U. pertusa* appeared in about 10% coverage in the NU and TR zones, but was reduced to 4.97% in the UR zone. *Acrosorium polyneurum* showed an even distribution of about 2% in all three zones. *Sargassum horneri* showed a lower percent coverage in the NU zone than in both the TR and UR zones, hence representing a similar pattern to crustose coralline algae. In general, most species tended to be reduced in their coverage as sea urchin density increased (from the NR to TR to UR zones).

Table 2 summarizes various changes in percent coverage at the algae species-level, along with urchin density gradient, regardless of the three zonation schemes. Crustose coralline algae showed an even distribution (around 40% coverage), except for the no urchin condition. Some foliose species (e.g., *Acrosorium polyneurum*, *Grateloupia*

Table 1. Macroalgal community characteristics and number of species in the 3 urchin zones

		Total (n = 170)	NU zone (n = 77)	TR zone (n = 41)	UR zone (n = 52)
No. of species	Chlorophyta	6	5	4	2
	Phaeophyta	13	11	10	12
	Rhodophyta	38	34	30	26
Index	Diversity (H')	1.73	2.36	1.95	1.74
	Evenness (E)	0.43	0.62	0.52	0.47
	Dominance (D _s)	0.36	0.16	0.28	0.37

NU, no urchin; TR, transition; UR, urchin; n, number of quadrats.

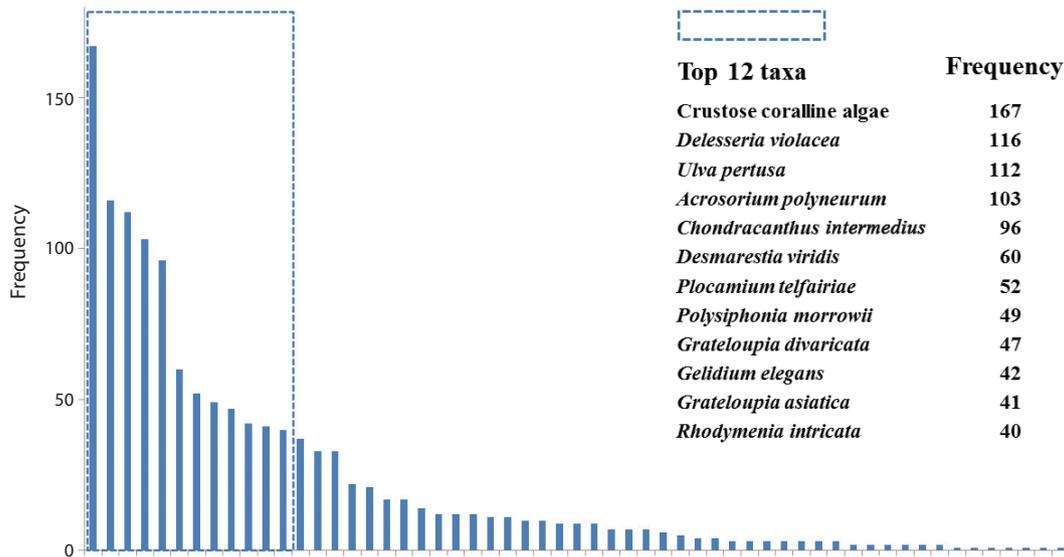


Fig. 2. Frequency counts (number of quadrat out of 170 quadrats) of all species in the Jangho subtidal.

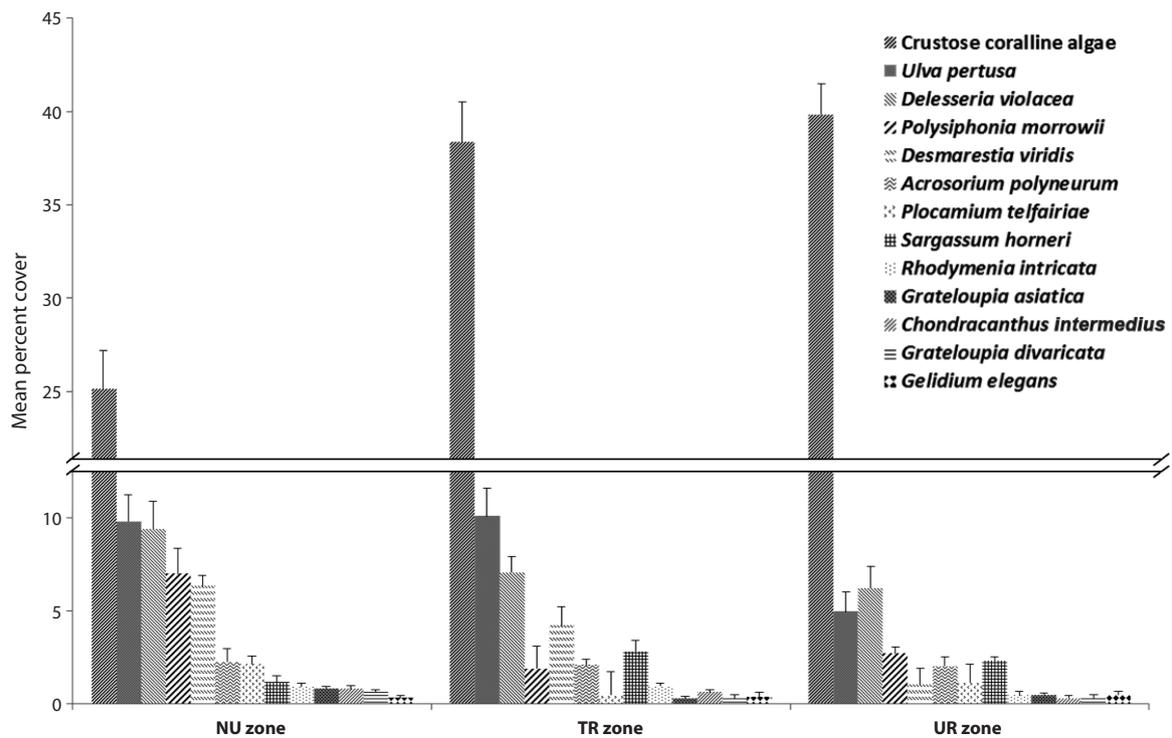


Fig. 3. Mean percent cover (\pm standard error) of the major algal species in the 3 urchin zones. NU, no urchin; TR, transition; UR, urchin.

divaricata, *G. asiatica*, *Rhodymenia intricata*), showed a similar substantial coverage at the range of 0-8 urchins m^{-2} , however, the coverage dropped suddenly when the urchin density exceeded 8 inds. m^{-2} . This urchin density making a turning point represented 12 inds. m^{-2} for three species: *U. pertusa*, *Plocamium telfairiae*, *Gelidium elegans*. *D. viridis* was marked at 4 inds. m^{-2} and *Chondracanthus intermedius* was at 16 inds. m^{-2} .

Correlational analyse revealed that seven algal species showed a significant relationship between algal coverage and urchin density. Crustose coralline algae and *S. horneri* had a positive correlation and their correlation coefficients (r) were 0.258 ($p < 0.01$) and 0.409 ($p < 0.05$), respectively. Four species (*Polysiphonia morrowii*, *Grateloupia divaricata*, *D. viridis* and *Delesseria violacea*) showed a negative correlation ($r = -0.490, -0.458, -0.407$, and -0.247 , respectively; $p < 0.01$ for all). *C. intermedius* had $r = -0.228$ ($p < 0.05$) (Fig. 4).

DISCUSSION

The study area has been frequently investigated by other researchers (Choi et al. 2006, Shin et al. 2008a, 2008b). The total number of macroalgal species found in this study was 57 species, which seemed a slight increase, compared with 28-53 species found in previous studies of the same season data. This was probably due to the

number of quadrats used. In this study, we used a set of 5 quadrats placing randomly on many different zones, depending on the sea urchin density gradient, thus a total 170 quadrats, which was much more sampling than used in the previous studies that were 5 or less quadrats. In addition to the sampling size used, the coverage of crustose coralline algae and sea urchin density in the Jangho subtidal area were decreased for over last 10 years. The average percent cover of the crustose coralline algae was 33% and sea urchin density was 4.7 inds. m^{-2} , as opposed to 60-80% and 12-16 inds. m^{-2} in the 2001-2002 survey (Park 2008). The results of this study, along with the previous reports, indicate that the percent coverage of crustose coralline algae decreased as sea urchin density decreased during last 10 years.

As hypothesized about the 3 zonation category of urchin density in this study, the macroalgal species diversity and the mean coverage decreased as urchin density increased within the field survey scale of $\sim 40,000 m^2$. This study did not manipulate the sea urchin density and distribution during the study, but nevertheless this negative correlation could be deduced by considering sea urchin's slow moving speed about 4 $cm m^{-1}$ (Morse and Hunt 2013), relatively narrow home range of mean 0.40 to 1.72 $m d^{-1}$ (Harrold and Reed 1985, Dumont et al. 2006), and habitat limitation that is confined to rocky beds (Agatsuma 2007). However, taking into account the urchin's nocturnal foraging behavior, further investigations are still

Table 2. Mean percent cover (\pm SE) of major algal species along with the urchin density gradient

	Sea urchin density (inds. m^{-2})					
	0 (n = 77)	4 (n = 41)	8 (n = 23)	12 (n = 17)	16 (n = 4)	≥ 20 (n = 8)
Crustose coralline algae	25.15 \pm 2.12	38.39 \pm 3.74	40.31 \pm 6.05	38.36 \pm 5.50	46.26 \pm 14.69	38.45 \pm 5.50
<i>Delesseria violacea</i>	9.37 \pm 1.44	7.06 \pm 1.48	7.45 \pm 1.95	4.86 \pm 1.26	9.16 \pm 4.44	4.15 \pm 1.99
<i>Ulva pertusa</i>	9.79 \pm 2.05	10.09 \pm 2.14	5.94 \pm 3.15	6.29 \pm 2.73	0.81 \pm 0.62	1.44 \pm 0.98
<i>Acrosotium polyneurum</i>	2.25 \pm 0.56	2.10 \pm 1.00	3.51 \pm 1.90	1.03 \pm 0.25	1.60 \pm 0.99	0.14 \pm 0.12
<i>Chondracanthus intermedius</i>	0.81 \pm 0.10	0.65 \pm 0.10	0.32 \pm 0.21	0.37 \pm 0.14	0.48 \pm 0.37	0.08 \pm 0.06
<i>Desmarestia viridis</i>	6.33 \pm 1.36	4.22 \pm 1.21	0.55 \pm 0.36	1.54 \pm 0.85	1.84 \pm 1.44	1.08 \pm 0.58
<i>Plocamium telfairiae</i>	2.14 \pm 0.71	0.48 \pm 0.31	1.55 \pm 0.97	1.11 \pm 0.65	0.53 \pm 0.53	0.40 \pm 0.27
<i>Polysiphonia morrowii</i>	6.99 \pm 1.50	1.89 \pm 0.86	4.15 \pm 2.31	1.39 \pm 1.10	4.02 \pm 4.02	0.78 \pm 0.74
<i>Grateloupia divaricata</i>	0.66 \pm 0.16	0.31 \pm 0.11	0.60 \pm 0.36	0.17 \pm 0.09	-	-
<i>Gelidium elegans</i>	0.36 \pm 0.10	0.42 \pm 0.21	0.65 \pm 0.34	0.58 \pm 0.34	-	0.16 \pm 0.12
<i>Grateloupia asiatica</i>	0.85 \pm 0.18	0.29 \pm 0.15	0.88 \pm 0.47	0.30 \pm 0.30	0.08 \pm 0.08	-
<i>Rhodymenia intricata</i>	0.92 \pm 0.34	0.98 \pm 0.59	0.97 \pm 0.53	0.04 \pm 0.03	-	0.12 \pm 0.12
<i>Sargassum horneri</i>	1.17 \pm 0.45	2.82 \pm 1.26	2.15 \pm 1.81	2.40 \pm 1.51	-	3.73 \pm 2.46
Sum of foliose algae	41.64	31.31	28.72	20.08	18.52	12.08

SE, standard error; n, number of quadrats.

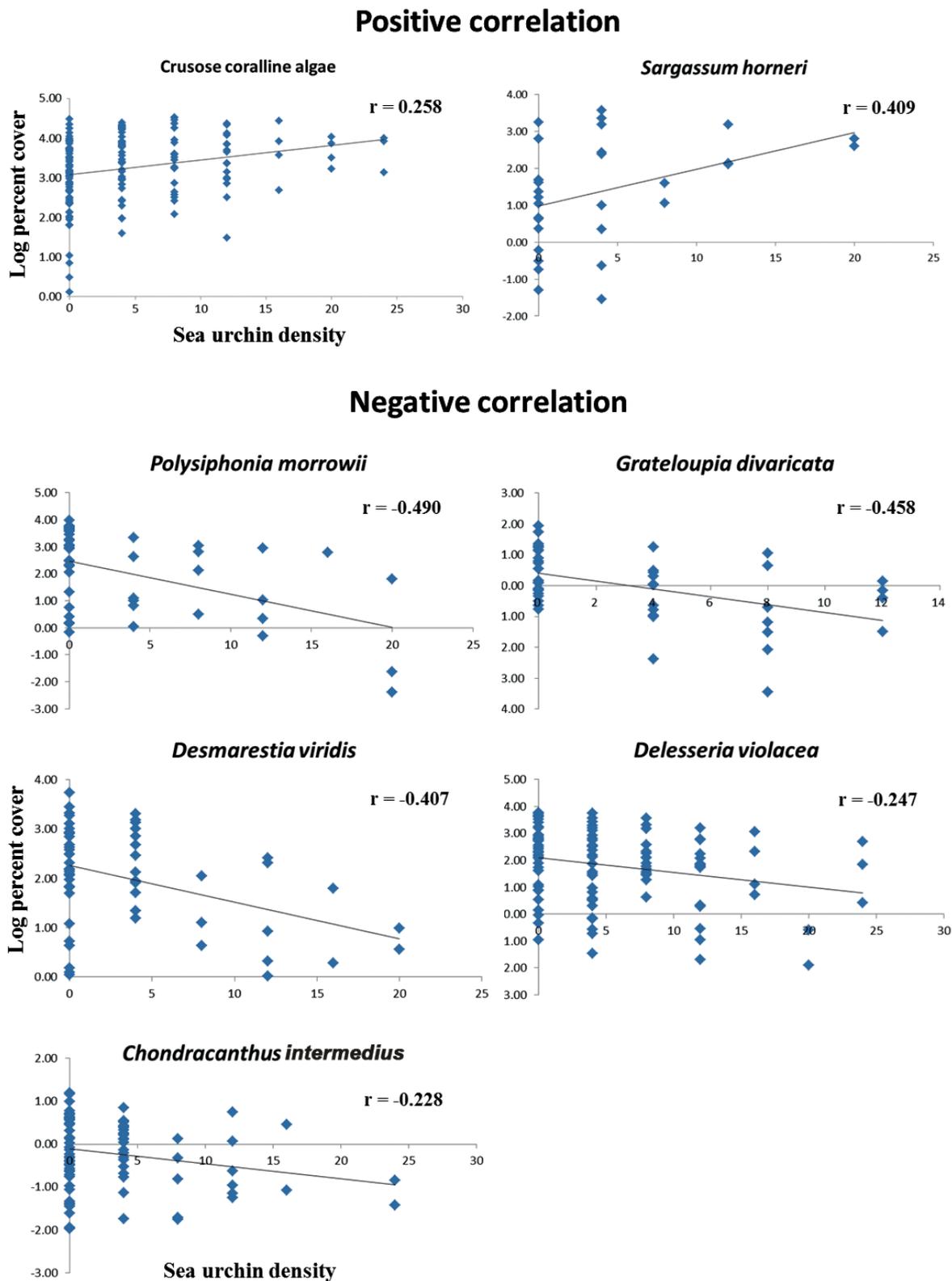


Fig. 4. Correlations between macroalgal coverage (log transformed) and sea urchin density (inds. m⁻²).

needed about their timely (i.e., hourly) moving patterns and behavior in the field, especially because this SCUBA survey was only done in the daytime.

In many temperate regions, the rocky subtidal areas are often distinctively separated into macroalgal beds and urchin barrens, and thus much more urchins are found in barren grounds. This phenomenon has been known as a defensive behavior of sea urchins against predators (Mann 1982, Vadas et al. 1986, Stewart and Konar 2012). However, since there seems no natural predators (such as sea otter, sheephead fish, crab, lobster, etc.) of sea urchins, except starfish, on the east coast of South Korea, it is assumed to be a certain kind of foraging-related behavior, rather than defense. The gregarious tendencies of adult sea urchins in barren ground could be either an after-feeding phenomenon on foliose macroalgae or an on-going feeding stage of other types of foods, such as crustose coralline algae, filamentous algae, or capsulated eggs. If the former is the case, then further questions arise: Why do they crowd in the foodless spot of barren ground? Why don't they move to food-rich algal beds nearby? Do they move to algal beds at night time and come back? No clear answers or evidence have yet been suggested.

The results of the urchin's feeding preference tests in previous studies indicate that sea urchins usually prefer brown algae to other macroalgal groups (Vadas 1977, Seymour et al. 2013). However, a gut analysis of sea urchins, collected from natural habitats, revealed that there was a similar ratio of food contents between major preferred food species and crustose coralline algae (Vadas 1977, Harrold and Reed 1985, Lee et al. 1998, Nakabayashi et al. 2006, Seymour et al. 2013). Although some differences exist, depending on the sea urchin species and location, it is obvious that sea urchins do consume crustose coralline algae in substantial amounts. In the results of this study, *Sargassum horneri* (brown algae) showed a positive correlation; it is assumed that there must be some difficulties for sea urchins to feed on this particular alga because of its long and thin stipe and structural characteristics.

Extensive researches have been carried out to understand the sea urchin's feeding preference by selectively supplying a food choice (Vadas 1977, Kim et al. 2007, Seymour et al. 2013), as well as gut analyses (Lee et al. 1998, Kim and Jang 2012). In addition to those studies, this research could be meaningful in clarifying some component species in the macroalgal community that gradually decreased as urchin density increased in a natural condition, vice versa. Furthermore, this study provides an answer as to how macroalgal vegetation changes in response to a density gradient of urchins; and there is a

transition zone (TR zone) that existed with respect to an intermediate level of algal abundance. However, there are still unanswered questions. For those 5 species (*Polysiphonia morrowii*, *Grateloupia divaricata*, *Desmarestia viridis*, *Delesseria violacea*, *Chondracanthus intermedius*) with negative correlations, are they scarce in the high urchin density places because it is an outcome of past grazing? Are those species actually preferred food? Are the 2 groups (crustose coralline algae and *Sargassum horneri*) with positive correlations non-preferred species? The possible answers to these questions can be found by conducting a direct feeding preference experiment with the component species, and then along with this field survey it will provide a solid description on urchin barrens and macroalgal community dynamics. This study is the first report on macroalgal community changes with relation to urchin density on the east coast of South Korea where severe barren ground problems occur, and can be a starting point for various functional ecological works in this particular subtidal habitat.

ACKNOWLEDGEMENTS

This research is a part of the project titled "Long-term change of structure and function in marine ecosystems of Korea", funded by the Ministry of Oceans and Fisheries, Korea. We thank Byong Su Kim and his SCUBA team for underwater photographing and helps in the fieldworks.

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