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Structure of Intertidal Macroalgal Community at the Yeonpyeongdo Islets, Korea

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Intertidal benthic algal communities on the shores of Gujido and Daeyeonpyeongdo islets, Korea, were examined in October 2007. At both sites, 45 seaweeds including 7 green, 6 brown and 32 red algae were identified. The number of species at Gujido (38 species) was 1.5 times higher than at Daeyeonpyeongdo (25 species), but seaweed coverage was very similar with about 20%. Dominant seaweeds in terms of coverage and importance value were *Hildenbrandtia* sp., *Caulacanthus okamurae*, *Ulva pertusa*, and *Gelidium amansii* at Gujido and *U. pertusa*, *Hildenbrandtia* sp., *Gelidium divaricatum* at Daeyeonpyeongdo. The vertical distribution pattern of the seaweeds was *G. divaricatum* - *U. pertusa*, *Hildenbrandtia* sp. - *U. pertusa*, *Hildenbrandtia* sp., *Ishige okamurae* from upper to lower intertidal zone but seaweed zonations were not observed on the Gujido rocky shore. At both sites, coarsely-branched forms were the dominant functional group in species number and percent cover (among benthic algal species). The rocky shores of the two sites were dominated by crustose coralline and green algae, whose presence generally results in decreased seaweed biodiversity and community stability. Therefore, the shores of the Yeonpyeongdo islets are of considerable environmental concern and should be monitored for seaweed species composition and community structure.

Key words: Community structure, Coverage, Functional form, Seaweed, Yeonpyeongdo

Introduction

Seaweeds play an important role as primary producers in marine ecosystems and as habitat, spawning, feeding and nursery grounds of marine invertebrates and fishes (Terawaki et al., 2001; Choi et al., 2002). Intertidal seaweed community structures are mainly influenced by physical factors such as temperature, salinity and light (Levinton, 1982; Duxburg and Duxburg, 1991; Zhuang and Zhang, 2001; Wells et al., 2007). The pollution and disturbance of macroalgal habitats by human activities reduce species diversity and simplify its community structure (Díez et al., 1999). Thus, benthic macroalgal flora and community structures are good indicators for evaluating environmental conditions and monitoring coastal marine ecosystems (Vadas and Steneck, 1988; Wells et al., 2007).

Seaweeds can be classified into six functional forms based on their morphology, physiology, internal structure, photosythesis rate, and predation tolerant strategy (Littler and Littler, 1984). Green ephemeral algae, which include sheet and filamentous functional forms are generally prevalent in disturbed or eutropicated habitats (Littler and Littler, 1984; Pinedo et al., 2007). Conversely, late successional macroalgae including thick leathery and calcareous functional forms are dominant in stable environments. Biodiversity, which is high in stable habitats and unpolluted areas, is also a biological parameter that is indicative of environmental conditions (Piazzi and Cinelli, 2001; Arévalo et al., 2007). Thus, biodiversity and functional form composition of seaweed community are important indices representing environmental conditions.

Although the marine algal communities of the Gyonggiman (Gyonggi Bay) islets on the Western Sea of Korea have been studied extensively (Kang, 1966; Lee, 1971; Lee, 1973; Lee, 1980; Baek et al., 2007; Lee et al., 2007a), few studies have been conducted on intertidal seaweed communities of the

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Yeonpyeongdo islets, because of the time and cost of sampling (Lee et al., 1997; 2007b), and the data on these communities are very poor. For example, only six macroalgal species were identified during four seasons at Dangdo, which is near Daeyeonpyeongdo (Lee et al., 2007b), and other studies were conducted for only one or two seasons (Lee et al., 1997). Thus, the aim of the present study was to examine seaweed community structures using species composition and functional groups as descriptors to contribute to the knowledge of the macroalgal assemblages at Daeyeonpyeongdo and Gujido islets.

Materials and Methods

Seaweed community structure and their abundances were examined at intertidal zone of Daeyeonpyeongdo and Gujido, Incheon, Korea, in October 2007 (Fig. 1). The bottom is characterized by a rocky platform that extends through the entire intertidal zone. Five replicated quadrats (50 cm×50 cm) were placed at each of three tidal levels (upper, mid, and lower) and non-destructive collections were made after recording percent cover and frequency, using the method of Saito and Atobe (1970). Qualitative sampling was also conducted to examine the macroalgal flora at the two study sites. The samples were preserved in 5% formalin: seawater solution and transferred to the laboratory for identification.

On the basis of seaweed coverage and frequency, relative coverage (RC), relative frequency (RF), and importance value (IV) were assessed using the methods of Saito and Atobe (1970). Dominance index was calculated in terms of seaweed coverage using the method of McNaughton (1967). Diversity, rich-ness and evenness indices were assessed using PRIMER version 6.0. We followed the seaweed classification and nomenclature of Lee and Kang (2002). Seaweeds were classified into six functional-form groups (sheet, filamentous, coarsely branched, thick leathery, jointed calcareous, and crustose form) based on thallus morphology and internal structure (Littler and Littler, 1984). K-dominance curves using seaweed coverage were used to compare diversity patterns for the two study sites (Lambshead et al., 1983).

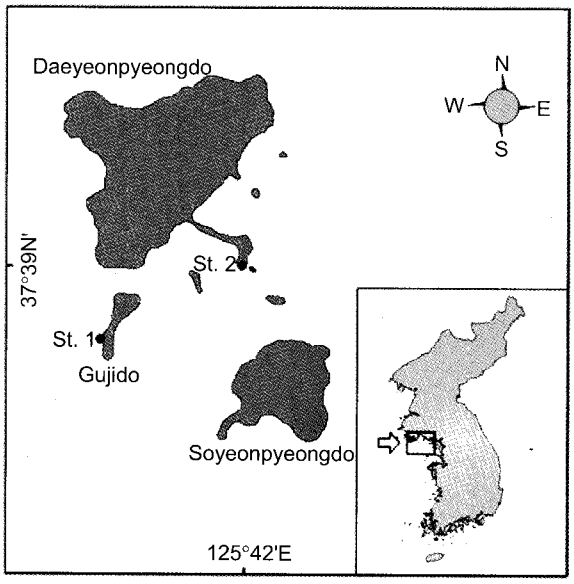

Fig. 1. A map of sampling sites at Yeonpyeongdo, western coast of Korea.

Coverage data were analysed using one-way and two-way ANOVA (analysis of variance). Before ANOVA test, homogeneity of variances was tested by Cochran's test (Sokal and Rohlf, 1981). The significance of the differences was evaluated with the Tukey HSD test.

Results

A total of 45 species including 7 green, 6 brown and 32 red algae were identified at two islands of Yeonpyeongdo, Korea (Table 1). However, the total number of species differed significantly between Gujido and Daeyeonpyungdo. In total, 38 species (5 green, 6 brown, and 27 red) were found on Gujido rocky shore, whereas 25 seaweeds (4 green, 2 brown, 19 red) were identified at Daeyunpyungdo. Red algae were the qualitatively dominant group (ca. 71%) at both study sites. Two green (*Ulva pertusa*, *Bryopsis maxima*), two brown (*Ishige okamurae*, *Ralfsia verrucosa*), and 14 red algae were most common on the rocky shores of Yeonpyungdo islets (Table 1). Brown algae, *Sargassum* spp. were found only at Gujido shore. The macroalgal coverage of the two study sites was very similar at about 20% (Table 1). The coverage of seaweed taxon groups varied from 19.09% (red algae) to 1.00% (brown algae) at Gujido and from 12.58% (red), 7.67% (green) to 1.37% (brown algae) at Daeyeonpyeongdo. Red algal group was dominant in terms of coverage, accounting for about 80% of total seaweed coverage (23.87%) at Gujido and 58% at Daeyeonpyeongdo.

At Gujido, the seaweed coverage at each tidal level ranged from 15.23% to 32.85%, with the number of species varying from 10 to 14 species (Fig. 2). The percent cover of seaweeds was significantly different at three tidal levels (ANOVA, $F_{2,12}=7.09$, $P<0.01$) and it was greater at mid shore than at upper shore levels (Fig. 2). The vertical distribution of seaweeds on the

Table 1. Intertidal macroalgal lists, coverage (%) and functional (F) form in Yeonpyeongdo, Korea. S, Sheet form; F, Filamentous form; CB, Coarsely Branched form; TL, Thick Leathery form; JC, Jointed Calcareous form; C, Crustose form

Species	Gujido	Daeyeonpyeongdo	F-form
Chlorophyta			
Ulva conglobata	0.98		S
Ulva pertusa	2.80	7.19	S
Ulva sp.		0.23	S
Cladophora sakaii	+		F
Cladophora sp.		0.25	F
Bryopsis maxima	+	+	F
Codium fragile	+		CB
Phaeophyta			
Ectocarpus confervoides	+		F
Ralfsia verrucosa	0.36	0.03	C
Ishige okamurae	0.51	1.34	CB
Sargassum fulvellum	+		CB
Sargassum horneri	+		CB
Sargassum sp.	0.13		CB
Rhodophyta			
Gelidium amansii	3.25	0.73	CB
G. divaricatum	1.83	3.78	CB
G. pusillum	+	+	CB
Pterocladiella capillacea	0.46	0.69	CB
Fosliella zostericola	+	+	C
Lithophyllum okamurae	+		C
L. cyctocarpideum	+		C
Hildenbrandia sp.	5.48	4.24	C
Corallina officinalis	+	+	JC
C. pilulifera	0.28	1.10	JC
Jania arborescens	+	+	JC
Carpopeltis affinis	1.37	0.30	CB
Grateloupia filicina	0.03		CB
G. sparsa	+		S
G. turuturu		0.13	TL
Grateloupia sp.		+	TL
Cruoriella japonica	+		C
Caulacanthus okamurae	5.43	0.69	F
Gracilaria textorii	0.11		TL
Ahnfeltiopsis flabelliformis		+	CB
Chondrus ocellatus	0.59	0.80	CB
Total species number	38	25	
Total Coverage (%)	23.87	21.62	

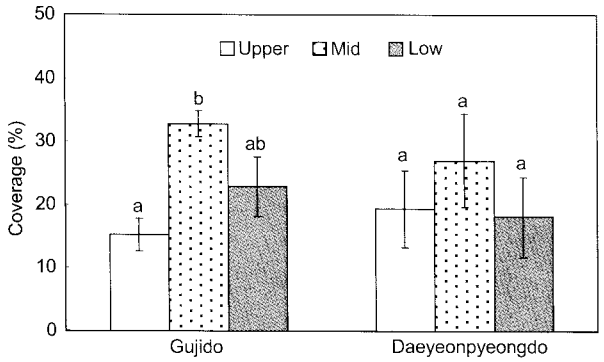

Fig. 2. Average seaweed coverage (%) of three tidal levels at Gujido and Daeyeonpyeongdo rocky shores, Incheon, Korea. Bars are standard errors (n=5).

Gujido shore was not clear because *Hildenbrandtia* sp., *Caulacanthus okamurae* and *Ulva pertusa* were extensively distributed from high to low shores. The dominant seaweeds at each tidal level were *Hildenbrandtia* sp. (4.16%), *C. okamurae* (3.15%) in the upper zone, *Hildenbrandtia* sp. (9.68%), *C. okamurae* (7.65%), and *U. pertusa* (4.80%) in the mid zone, and *Gelidium amansii* (6.41%), *C. okamurae* (5.48%), and *U. pertusa* (3.34%) in the lower zone.

At Daeyeonpyeongdo, the percent cover of seaweeds was between 18.08% and 27.04%, with maximal coverage in the mid zone and minimal coverage in the lower intertidal zone. Also, the number of species occurring in the five quadrats was similar,

Table 2. Average macroalgal coverage (C), frequency (F), relative coverage (RC), relative frequency (RF), and importance value (IV) in Yeonpyeongdo, Korea. Asterisk (*) denotes importance value (IV)>3

Site/Species	C	F	RC (%)	RF (%)	IV*
Gujido					
Hildenbrandtia sp.	5.48	19.73	22.96	18.97	20.97
Caulacanthus okamurae	5.43	15.73	22.75	15.13	18.94
Ulva pertusa	2.80	17.87	11.74	17.18	14.46
Gelidium amansii	3.25	14.40	13.63	13.85	13.74
Carpopeltis affinis	1.37	7.47	5.75	7.18	6.46
Gelidium divaricatum	1.83	4.53	7.65	4.36	6.01
Ulva conglobata	0.98	5.33	4.09	5.13	4.61
Chondrus ocellatus	0.59	6.13	2.46	5.90	4.18
Daeyeonpyeongdo					
Ulva pertusa	7.19	29.07	33.31	32.58	32.95
Hildenbrandtia sp.	4.24	14.67	19.64	16.44	18.04
Gelidium divaricatum	3.78	10.40	17.50	11.66	14.58
Corallina pilulifera	1.10	6.93	5.10	7.77	6.43
Ishige okamurae	1.34	5.23	6.20	5.86	6.03
Chondrus ocellatus	0.80	4.80	3.71	5.38	4.54
Gelidium amansii	0.73	3.73	3.36	4.18	3.77
Pterocladiella capillacea	0.69	3.73	3.19	4.18	3.69
Caulacanthus okamurae	0.69	3.20	3.19	3.59	3.39

with macroalgal coverage as follows: 12 species at mid shore, 11 species at upper shore, and 8 species at lower shore. The dominant seaweeds of Daeyeonpyeongdo rocky shore were *G. divaricatum* - *U. pertusa*, *Hildenbrandtia* sp. - *U. pertusa*, *Hildenbrandtia* sp., *Ishige okamurae* from the upper to lower intertidal zone. Abundant species (IV>5) were crustose *Hildenbrandtia* sp., *C. okamurae*, *U. pertusa*, *G. amansii*, *Carpopeltis affinis*, and *G. divaricatum* at Gujido shore, and *U. pertusa, Hildenbrandtia* sp., *G. divaricatum*, *Corallina pilulifera*, and *I. okamurae* at Daeyeonpyeongdo (Table 2). Three taxa, *Hildenbrandtia* sp., *U. pertusa*, *G. divaricatum* were dominant seaweeds at both rocky shores. K-dominance curves based on coverage and species were slightly different between the two rocky shores (Fig. 3). At Gujido, the shape of the curve suggested high dominance by the four most common species comprising more than 71% of the total seaweed coverage. Three species (*Ulva pertusa*, *Hildenbrandtia* sp., and *Gelidium divaricatum*) dominated, accounting for 70% of total macroalgal coverage at Daeyeonpyeongdo (Fig. 3).

Six functional-form algae were observed at two sites of Yeonpyeongdo islets. The most dominant group in species number was coarsely-branched form with 19 species (42.00%). Coarsely-branched group seaweeds were also major group in species number at Gujido (44.74%) and at Daeyeonpyeongdo (44.00%). The coarsely-branched form also had maximum coverage (Gujido, 8.43%; Daeyeonpyeongdo, 7.76%), whereas the thick-leathery form had minimum coverage (Fig. 4). Sub-dominant algal groups in terms of seaweed coverage were filamentous and crustose forms at Gujido and sheet form algae including *Ulva pertusa*, which had the highest percent cover (34.32% of total coverage) at Daeyeonpyeongdo (Fig. 4). Community indices generally reflected by coverage and the number of species. The coverage of two most important species for total seaweed coverage contributed 52.87% at Daeyeonpyeongdo and 45.71% at Gujido in Table 2. Thus, the dominance index (DI) was greater at Daeyeonpyeongdo (0.53) than at Gujido (0.45). However, diversity index (H') and richness index (R) were higher at Gujido (H', 2.23; R, 11.63) than Daeyeonpyeongdo (H', 2.03; R, 7.80) because the two community indices were calculated from the number of species and percent cover of

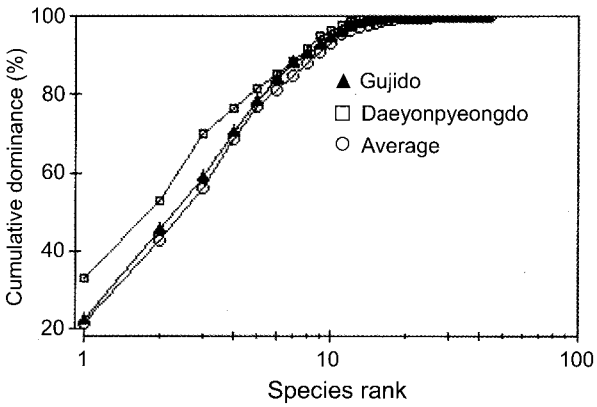

Fig. 3. K-Dominance curves (x-axis logged) for mean coverage at Gujido and Daeyeonpyeongdo rocky shores, Incheon, Korea.

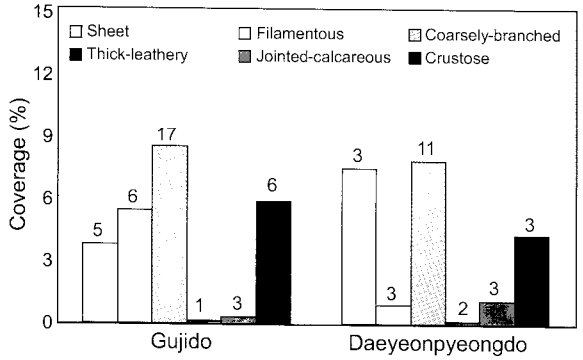

Fig. 4. Average seaweed coverage of six functional-form groups at Gujido and Daeyeonpyeongdo rocky shores, Incheon, Korea. The number presented species number of each functional form group.

Table 3. Distributional patterns of the benthic seaweeds and various community indices for coverage (%) at two study sites in Yeonpyeongdo, Korea

Community indices	Gujido	Daeyeonpyeongdo	Average
Dominance index (DI)	0.45	0.53	0.43
Diversity index (H')	2.23	2.03	2.30
Richness index (R)	11.63	7.80	14.03
Evenness index (J')	0.61	0.63	0.60

seaweeds. However, evenness index (J') was similar at both sites, with 0.61 and 0.63 at Gujido and Daeyeonpyeongdo, respectively (Table 3).

Discussion

Rocky shores covered by crustose coralline algae become barren areas disappearing seaweed beds and such areas have been slowly expanding along the coastal areas of Korea (Choi et al., 2002; Baek et al., 2007). In Japan, these barren areas are called as Isoyake because of the colour of dead crustose corallines (Masaki et al., 1984; Terawaki et al., 2001). Masaki et al. (1981) found that a crustose coralline alga, *Lithophyllum yessoense* did not allow *Laminaria japonica* germlings to grow on the living crusts. The rocky shores of Yeonpyeongdo islets are widely covered by crustose coralline algae and barren areas can be expected to continue to increase. For example, the number of crustose algae that we found on the Gujido shore was five times greater that that observed in 1993 (Lee et al., 1997b). The coverage of *Hildenbrandtia* sp. at the two Yeonpyeongdo islets exceeded 20-23% in our study. The increase of barren areas reduces biodiversity and abundance of seaweeds and herbivorous invertebrates such as abalone and sea urchin. Thus, the restoration of seaweeds, which are primary producers in marine coastal ecosystems, is critical to the recovery of fisheries resources in the western coastal areas around the Yeonpyeongdo islets. Abundance of crustose coralline algae in species number and coverage influenced our method of quantitative data collection for the rocky shore seaweed communities of the Yeonpyeongdo islets. In seaweed community studies, biomass and coverage are generally estimated but crustose coralline algae sampling for biomass measurements is very difficult. Thus, we conducted a non-destructive coverage estimation using quadrats. Meese and Tomich (1992) reported that visual coverage estimation could contribute to rocky shore conservation and increase survey replicates during a low tide cycle. Thus, we suggest that using a coverage estimation method is superior to biomass measurement to present the seaweed community on barren rocky shores covered by crustose corallines. Although *Sargassum thunbergii* is a representative seaweed on the western coast of Korea (Lee et al., 2000; Baek et al., 2007; Lee et al., 2007b), we did not find it on the rocky shores of the Yeonpyeongdo islets. Dominant seaweeds in terms of importance value (IV) were *Hildenbrandtia* sp., *C. okamurae*, and *Ulva pertusa* at Gujido and *U. pertusa*, *Hildenbrandtia* sp., and *Gelidium divaricatum* at Daeyeonpyeongdo. The brown alga, *S. thunbergii* was identified at only three sites of 11 islands located in Gyonggi bay (Lee et al., 1997). At Gujido, it was not observed in either summer or winter samplings in 1993-1994. On the other hand, *S. thunbergii* was recorded at Daeyeonpyeongdo in 1994 but was absent in 2006- 2007 (Lee et al., 1997; Lee et al., 2007b). After an exhaustive but futile search for *S. thunbergii*, we suggest that *S. thunbergii* populations have disappeared or have declined in abundance because of the expansion of crustose coralline algae on the Yeongpyeongdo islets. Differences of the two study sites were mainly in species number and the coverage of functional form seaweeds. The number of species number at Gujido was 1.5 times higher than at Daeyeonpyeongdo. Although the percent cover of the dominant functional form, which was the coarsely-branched group, was the same at both sites, coverage of sheet form was two times higher at Daeyeonyeongdo (34.32%). Crustose coralline algae coverage was three times higher at Gujido than at Daeyeonpyeongdo. Generally, sheet-like and filamentous seaweeds, such as *Ulva* sp. and *Cladophora* sp., are dominant in unstable or polluted habitats, and thick-leathery and calcareous forms are conspicuous in more stable environments (Litter 1980; Littler and Littler, 1984). Daeyeonpyeongdo has the largest area (7.01 km^2) of the four Yeonpyeongdo islets and about 1,100 inhabitants, whereas Gujido is uninhabited.

Thus, human activities on Daeyeonpyeongdo are likely an important factor in the decline of the number of macroalgal species and the higher coverage of sheet form seaweeds compared to Gujido. However, more detailed studies are required to confirm whether the differences in seaweed community structure and species composition are originated from human activities. In conclusion, the rocky shores of Gujido and Daeyeonpyeongdo islets are dominated by green seaweeds occurring in polluted areas and by crustose coralline algae. The abundance of these seaweed groups is adversely affecting macroalgal species diversity and the extent of seaweed beds. Thus, the shores of the Yeonpyeongdo islets require attention and monitoring of seaweed species composition and community structure.

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