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Spatial and temporal variability of seaweeds at Hwadang-ri, Jinhae Bay, Korea

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Summary

The study describes seasonal patterns and spatial distribution of seaweeds at five stations at Hwadang-ri, Jinhae Bay (Korea) in 2013. The seaweed community at Hwadang-ri was very diverse, with 44 taxa identified, representing three phyla: brown algae (phylum Ochrophyta), red algae (phylum Rhodophyta), and green algae (phylum Chlorophyta). Red algae exhibited the greatest diversity (26 taxa), followed by brown algae with 11 taxa, and green algae (represented by 7 taxa). The near seaside stations were characterized by the relatively higher individual density or abundance across areas than the stations in the open sea. Five species (*Ulva pertusa, Sargassum fulvellum, Sargassum horneri, Sargassum thunbergii*, and *Undaria pinnatifida*) dominated in terms of relative abundance. For the entire community, the values of temporal heterogeneity were low at the open sea stations and higher at the others. Overall, the results indicate that spatial heterogeneity in species composition among the replicates was not high. However, distribution of abundance of seaweeds showed statistically significant north-south differences at the studied sampling sites.

Key words: seaweeds, size-frequency distribution, spatial patterns

Introduction

Marine macroalgae, or seaweeds, are macroscopic, multicellular autotrophs that occupy bottom habitats. Seaweeds are plant-like organisms that generally live attached to rocks or other hard substrates in the coastal areas. They belong to three different groups empirically distinguished since the mid-nineteenth century on the basis of thallus color: brown algae (phylum Ochrophyta, class Phaeophyceae), red algae (phylum Rhodophyta), and green algae (phylum Chlorophyta, classes Bryopsidophyceae, Chlorophyceae, Dasycladophyceae, Prasinophyceae, and Ulvophyceae). Some of these groups encompass a number of unicellular eukaryotic species, or the protists.

Seaweeds are crucial part of marine ecosystems and are essential for their sustainability (Kim, 2012). Macroalgae are ecologically and economically important, providing valuable ecosystem services and biomass for foods, phycocolloids, soil additives, animal feeds and neutraceuticals (Chopin and Sawhney, 2009). They are also very important primary producers. Seaweeds play significant role not only in the marine food web which they are part of, but also on a more global scale (Benedetti-Cecchi et al., 2006; Hurd et al., 2014).

I surveyed seaweeds in the intertidal communities at Hwadang-ri, Georyu-meon, Goseng-gun, Jinhae Bay, Korea. This is the very important industrial area of the marine farming such as sea weeds (tangle, kelp, agar, and brown seaweed), sea squirts, and oysters in Korea. Red tides often occur along the south coasts near to this area in late summer and autumn (Lee et al., 2002; Lee, 2008). Therefore, farm industrial damages may be very serious when red tide outbreaks in the studied region. Thus, any new data on red tide organisms and their impacts on seaweeds, including their temporal and spatial heterogeneity and biodiversity are of significant importance.

The present study aimed at examining the taxonomic structure of seaweeds' assemblages and their spatial and temporal variability at Hwadang-ri, Jinhae Bay which is characterized by tidal regimes ensuring high openness and short water turnover times at high tides.

Material and methods

Sampling of seaweeds

Seaweeds samplings were conducted at five intertidal and subtidal stations at Hwadang-ri, Georyu-meon, Goseng-gun, Jinhae Bay (Fig. 1). The geographic location of the five sampling sites were as follows: Station A - 34°993′402″N/ 128° 458′216″E; Station B - 34°992′534″N/ 128°458′ 156″E; Station C - 34°992′758″/128°458′838″E; Station D - 34°988′064″N/128°457′115″E; Station E - 34°986′480″N/128°462′141″E. Sampling periods were February, May, August, and November 2013.

Major sampling depths were surface (<1 m) and 10 m. A boat/canoe or catamaran was used for designating each sampling point at the greater depth (down to 35 m). At the same time, the vertical distance of the sampling points from the baseline was recorded with the help of sextant. To examine the possible effect of deviations from the exact sampling position, the modified van-Veen grab (4 sample replicates of 1×1 m^2) was used for sampling macroalgae in the vicinity of the central position of all four permanent stations for 5 areas (A, B, C, D, E).

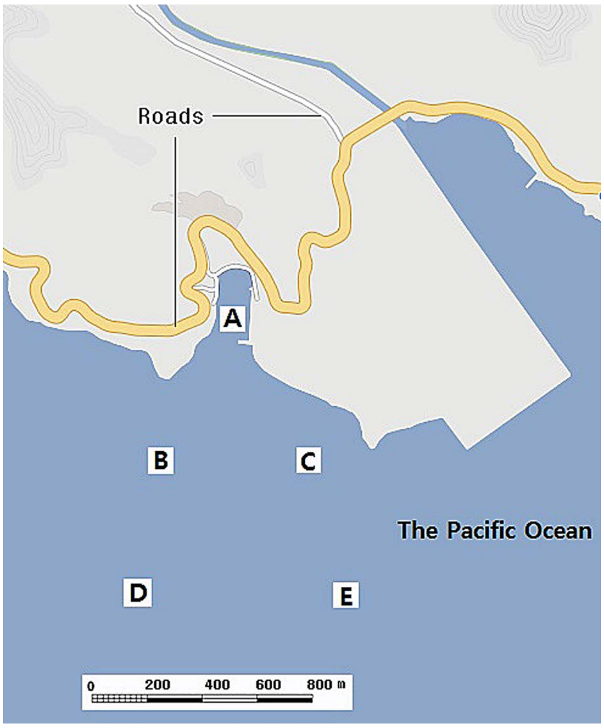

Fig. 1. The location of five stations (A, B, C, D, and E) at Hwadang-ri, Georyu-meon, Goseng-gun, Jinhae Bay (Korea).

Identification of seaweeds

Taxonomic identification of seaweeds was made with the help of published keys and taxonomic references (Dawes, 1998; Lee and Kang, 2002; Lee, 2008).

Biotic indices

Shannon–Weaver index of species diversity (Shannon and Weaver, 1963) was calculated using the formula:

$$H' = -\Sigma\, p_i \ln p_i$$

where p_i is the proportion of the i-th species in terms of abundance.

Species richness is a measure of the number of species found in a sample (Pielou, 1966). The species richness of seaweeds was calculated by using Berger-Parker's index (BPI) and Margalef's indices (R1 and R2) of richness (Magurran, 1988):

$$BPI = N_{max}/N$$

where N_{max} is the number of individuals of the most abundant species, and N is the total number of individuals in the sample.

$$R1 = \frac{S-1}{\ln(n)}$$

$$R2 = \frac{S}{\sqrt{n}}$$

where S is the total number of species in a community and n is the total number of individuals observed.

Evenness index was calculated using the important value index of species (Hill, 1973; Pielou, 1966). N1 measures the number of abundant species in the sample and N2 is the number of very abundant species:

$$N1 = e^{H'}$$

$$N2 = 1/\lambda$$

where H' is Shannon index and λ is Simpson's index.

Other common evenness indices used in the study were E1~E5 (Alatato, 1981):

$$E1 = \frac{H'}{\ln(S)}$$

$$E2 = \frac{e^{H'}}{S}$$

$$E3 = \frac{e^{H'}-1}{S-1}$$

$$E4 = \frac{1/\lambda}{e^{H'}}$$

$$E4 = \frac{1/\lambda-1}{e^{H'}-1}$$

The temporal heterogeneity index was calculated using the method of Tuomisto (2010):

$$ß = \gamma/\alpha$$

where γ is the total species diversity of five stations, and α is the mean species diversity per habitat.

Results

Community composition and abundance of species

The seaweed community at Hwadang-ri in 2013 contained 44 taxa below the genus level, representing three phyla (Table 1). Red algae (Rhodophyta) exhibited the greatest diversity with 26 taxa identified, followed by brown algae (Phaeophyta) with 11 taxa, and green algae (Chloro-phyta) represented by 7 taxa.

Seaweeds were abundant at five stations of Hwadang-ri, ranging from 1,003 sampled individuals in the fall to 1,684 individuals in spring (Table 2). Mean number of the sampled seaweeds per season was 1,440 individuals.

During the sampling in February 2013, a total of 41 taxa were identified (Table 2). The stations A, B, and C were characterized by high diversity of seaweeds. The dominant species were *Sargassum fulvellum, Sargassum horneri, Sargassum thunbergii*, and *Ulva pertusa* at five stations.

In May, a total of 43 taxa were identified at five stations: Chlorophyta – 7 taxa, Phaeophyta – 11 taxa, and Rhodophyta – 25 taxa. The stations A, B, C, and D were characterized by high abundance of seaweeds. The relatively dominant species belonged to the genus *Sargassum* (*S. fulvellum, S. hemiphyllum, S. horneri*, and *S. thunbergii*).

In August, a total of 43 taxa were identified at the surface layer: Chlorophyta 7 taxa, Phaeophyta 11 taxa, and Rhodophyta 25 taxa. The dominant species were *Ulva pertusa, Sargassum fulvellum, Sargassum horneri*, and *Undaria pinnatifida*.

In November, a total of 42 taxa were identified at five stations: Chlorophyta – 7 taxa, Phaeophyta – 11 taxa, and Rhodophyta – 24 taxa. The stations A and B were characterized by high abundance of seaweeds, while at station E it was the lowest. The dominant species were *Ulva pertusa, S. fulvellum, S. horneri, S. thunbergii*, and *Undaria pinnatifida*.

The species composition of seaweeds demonstrated significant patterns from the nearshore station (stations A, B, and C) to remote seaside stations (stations D and E). Winter season was characterized by the minimum seaweed concentrations and *Sargassum thunbergii* was the dominant species. During spring season, *Sargassum fulvellum* was most abundant ($p<0.01$) at all stations (Table 1). During summer season, *Sargassum horneri* was the most abundant species ($p<0.01$) at all stations (Table 2). During winter season, *Undaria pinnatifida* was the most common seaweed ($p<0.01$) at stations A and B. The species abundance decreased seaward ($p<0.01$). *Sargassum horneri* was the second dominant species at station C. *Sargassum fulvellum* was also abundant at stations D and E.

Abundance of species in February varied from 116 to 452 individuals per 4×4 m^2. The station A was

Table 1. The composition of seaweeds in the intertidal community (units: Individuals per four 1×1 m^2 quadrates).

Phyla and Species	Plot																			
	A				B				C				D				E			
	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov
Chlorophyta																				
Bryopsis hypnoides	1.0	2.5	3.6	1.5			2.4	1.2												
Cladophora sp.	1.5	5.5	6.5	4.6	1.0	2.5	3.9	4.1	2.4	2.5			2.3	5.5						
Codium fragile	4.5	2.6	5.4	3.1	10.3	12.6	3.5	2.8	1.9	5.3	8.4	2.6								
Enteromorpha compressa	3.0	5.7	6.1	4.2	5.5	3.2	6.1	4.2	1.5	2.3			1.2				1.0			2.6
Enteromorpha intestinalis	2.5	1.3	4.6	2.8	6.8	6.6	2.2	3.2	3.3		4.2		3.6	2.0	3.5	1.0	4.4	1.2	3.0	
Enteromorpha linza	2.4	4.6	2.3	2.5	3.5	4.5	4.0	3.6	6.5	1.0	5.2	4.1								
Ulva pertusa	40.2	30.6	25.9	12.5	30.9	43.5	21.5	10.3	30.1	20.8	36.9	20.4	22.9	30.5	40.1	23.1	8.0	18.9	15.4	15.4
Phaeophyta																				
Colpomenia sinuosa	7.0	13.2	14.6	5.8	8.5	23.9	3.2	4.4	6.9	5.9	11.2	6.3	3.6	6.2	8.9	5.4	3.9	3.5	6.3	3.5
Dictyota dichotoma	1.5	2.6	3.0	2.0			1.8	4.6			2.0									
Hizkia fusiformis	11.4	2.5	3.7	1.5	6.9	2.4	3.2	2.2	5.6											
Myelophycus simplex	5.0	14.8	25.3	4.6	7.1		3.2	6.4	12.3	2.9	4.7	5.6								
Ralfisia verrucosa	2.5		2.0		1.5		1.7	1.2		3.6	5.1		1.0							
Sargassum fulvellum	60.9	35.0	41.6	39.4	85.0	87.0	34.2	22.5	45.6	105.6	59.2	17.8	23.7	56.7	60.4	45.2	14.6	15.5	10.5	32.6
Sargassum hemiphyllum	28.4	25.1	18.3	31.0		45.1	11.4	23.5	3.0	15.6	5.8	2.7		12.3	15.4	3.2		8.2	1.3	3.6
Sargassum horneri	62.5	50.2	27.7	16.8	57.3	47.8	20.2	13.5	46.2	50.5	78.9	43.5	20.3	56.3	60.2	14.5	15.2	22.9	20.1	10.2
Sargassum thunbergii	98.5	88.4	76.9	55.4	70.2	32.3	56.3	54.0	66.7	44.8	20.1	20.6	15.4	15.5	14.7	10.7	10.1	6.4		
Scytosippon lomentaria		2.5	3.6		20.3	15.6	2.5		15.8	20.5	34.4	12.3		22.8	20.1	2.9		8.9	7.3	3.4
Undaria pinnatifida	50.2	85.6	78.4	65.5	31.4	45.2	29.6	30.6	5.5	6.7	11.2	5.8		3.5	4.4					
Rhodophyta																				
Acrosrium flabellatum		1.2		1.0										4.2	5.9	2.3		2.3	2.1	
Amphiroa beauvoisii	3.2	2.6	17.1	5.5	5.5	2.1	12.3	7.2	3.9	8.8	5.9		3.3				1.0	2.6	1.0	
Carpopeltis affinis	4.2	4.6	5.6	4.7	7.0	1.3	4.4	2.0	2.3	2.0	1.6	1.1			2.2			2.2	1.4	
Caulacantjus cornea			2.5		2.6		1.2	1.9									2.5	1.8	2.7	
Caulacantjus okamurae	2.0	4.0	3.2	1.6	3.0	2.3	4.5	2.2		2.3			1.4		3.9		1.5	1.0	2.7	

Table 1. (Continuation).

Chondracanthus intermedia											3.0		2.1				1.0			
Chondracanthus tenellus													2.5				5.8	6.3	7.0	1.2
Chondria crassicaulis	8.5	10.2	11.6	14.2	5.7	6.6	8.4	11.0	5.2	6.6	7.0	1.5	3.6	7.8	14.2	2.5	1.3	3.5	2.1	
Chondrus ocellatus	10.7	8.9	5.8	8.4	12.3	7.8	7.6	9.1	1.9		2.0		3.0	3.7	4.5					
Corallina officinalis	3.4	2.0	4.0	2.9	1.6	5.3	2.4	2.4	2.3	3.5	1.3									
Corallina pilulifera					1.7	3.2	1.6	2.0	1.5	2.2	1.3		2.6	3.2	4.0	2.0	6.8	6.4	8.0	7.1
Gelidium amansii	6.9	3.3	2.6	2.5	8.4	11.2	15.5	10.4	5.6	7.6	12.6	4.5	5.7	8.7	11.4	6.8				
Gelidium divaricatum	1.5	1.0	3.1	1.2	3.0	4.4	5.2	4.5	4.8	2.3	4.4	7.1	1.5	3.8	4.5	3.6				
Gloiopeltis tenax	2.3	5.3	6.8	6.0	1.0		3.0				2.9									
Gracilaria verrucosa	1.6	2.3	3.6	2.0		2.6	6.4	1.7	5.5	2.1	5.4	1.0	14.0	15.6	18.9	5.5	5.2	3.6	6.4	5.0
Grateloupia elliptica	14.5	18.2	20.3	11.4	8.8	10.2	15.6	3.6	7.9	13.5	11.3	2.7		4.4	5.6	2.1				
Grateloupia filicina		2.5	1.4		2.1	3.5	2.0	1.1					6.1	7.8	4.6	2.8	3.5	6.5	3.2	
Hildenbrandtia rubra		1.5	1.0	1.1																
Hypnea charoides	5.5	6.9	10.3	4.0	2.9	3.9	5.4	2.7	10.6	2.7	2.6	2.2	5.9	6.5	8.9	4.1	1.2	2.5	3.9	2.0
Hypnea saidana	4.1	5.6	8.7	3.3	2.6	3.3	5.5	3.0	3.2	3.0	2.0	1.5	15.6	3.0	5.0	2.6	20.2	2.1	3.3	1.5
Lithophyllum cystocarpideum																		2.0	3.1	
Lithophyllum okamurae																	2.2	2.8	4.5	3.4
Lommentaria catenata		2.5	2.9		5.6	6.9	3.4	2.7	2.3	5.5	8.8	3.3	2.3	5.4	6.2	2.8				
Pachymenipsis elliptica					1.2	2.0	3.5	6.1		1.2	4.6	4.5					2.7	1.2	2.0	
Polysiphonia morrowii					1.2	3.3	4.0	2.5	1.0	2.8	5.8	2.0	2.7		2.6		1.3	2.4	3.1	2.0
Symphyocladia latiuscula																	2.5	2.8	2.0	1.4
Total	451	455	460	323	422	452	323	268	311	354	370	173	166	285	330	143	116	138	122	95

Table 2. Species numbers and density of seaweeds in the intertidal zone at Hwadang-ri.

Season	Number of species	Density (ind/16 m²)	Dominant species
Winter	41	1,467	*Sargassum thunbergii*
Spring	43	1,684	*Sargassum fulvellum*
Summer	43	1,605	*Sargassum horneri*
Fall	42	1,003	*Sargassum fulvellum*

characterized by the highest seaweed density among the five stations.

Spatial and temporal variability

Assessment of the spatial and seasonal variability of structure of the seaweed community is presented in Table 3. Although the numbers of species with absolute occurrence varied at different stations and seasons, mean paired similarity between the species composition within both, stations and seasons, were high. For the community as a whole, the values of Tuomisto's ß-diversity index were low (1.125 for station D) or high (1.333 for station C). The parameters of paired similarity between seasons and stations were tested. The high taxonomic homogeneity of the seaweed community between four seasons was discovered, and the similar trend in seasonal development of seaweeds at the same stations was registered.

In order to assess macro-scale spatial variability of the seaweed community at Hwadang-ri, the distribution of species richness and diversity of large taxonomic groups as well as seaweed composition along a longitudinal gradient were analyzed. Margalef's index gradually decreased from northern area (near inland) to southern area (open waters). This trend conformed to a linear regression model, which described 82% of the spatial variability for mean species density (R^2=0.61).

Seaweed community composition from the western areas near the Hwadang-ri was more diverse than that of the eastern areas. The mean number of species in the northern waters was 34, and in the southern – 22.

The near seaside stations (A, B, and C) from an inland sea demonstrated the relatively higher abundance of seaweeds across areas than the stations D and E in the open sea (Tables 1 and 2). However, Shannon-Weaver index of diversity at station E was lower than at the other stations (Table 4). In addition, evenness indices at station E were higher than those at the other stations. The three stations (A, B, and C) had high number of species. Shannon-Weaver index of diversity also varied among the seasons. BPI values for five stations and four seasons were low at A and B regions, meaning dominant species were different according to stations or seasons.

During the winter months, the southern area (station E) was characterized by the lowest concentrations of seaweeds (116 individuals per 4×4 m^2 in February and 95 – in November) (Table 1). Spatial variability of seaweed communities and the dominant species of seaweeds at different stations are illustrated by Figure 2.

For the five community locations as a whole, the values of temporal heterogeneity were low (from 0.270 to 0.372) (Fig. 3). They indicated that, respectively, heterogeneity in species compositions among the replicates was high.

Discussion

Temporal heterogeneity of seaweeds at five intertidal and subtidal stations at Hwadang-ri, Jinhae Bay (Korea) was calculated using the method of Tuomisto (2010) and analyzed. Forty four seaweed species were registered in the intertidal, shallow and deep sea areas down to 35 meter depth. During the

Table 3. Space-time variability of the seaweed community structure.

Attributes of community structure	Stations				
	A	B	C	D	E
Mean number of species per sample (±SD)	32.5±2.38	34.0±2.58	27.8±3.95	22.3±2.36	21.5±4.51
Number of species with absolute ocurence	1	0	5	7	1
Number of samples containing all species	29	26	21	15	12
Tuomisto's ß-diversity index	1.231	1.176	1.333	0.877	1.133

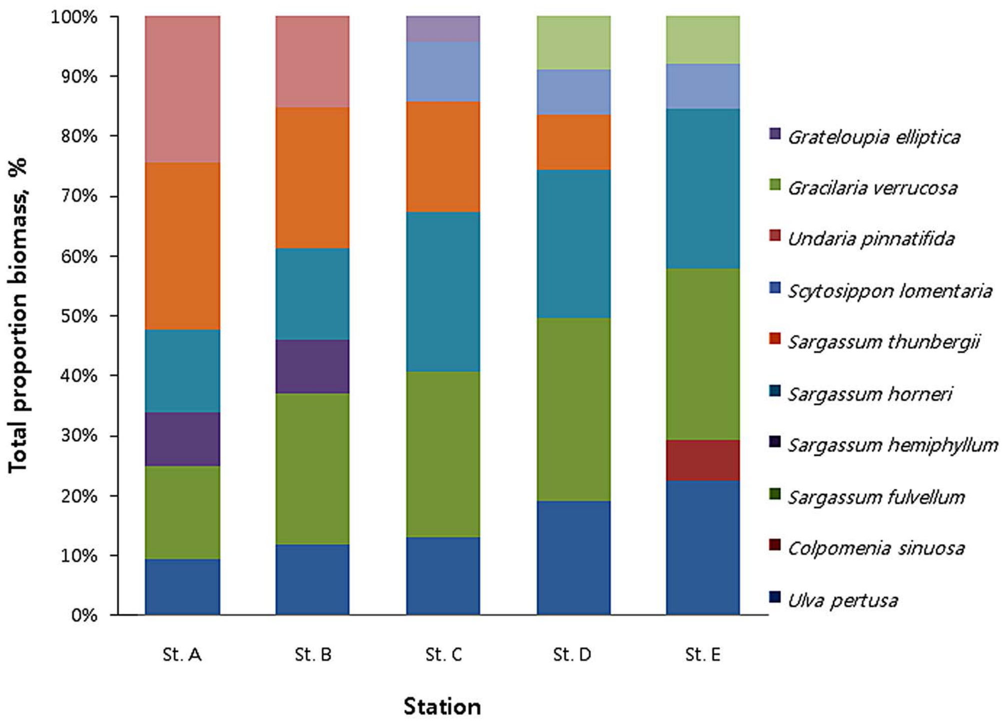

Fig. 2. Spatial variability of seaweed community. The composition of dominant species in different seaweed associations within stations.

winter months, the southern, deeper area (station E) was characterized by the lowest concentrations of seaweeds (Table 1). This is largely due to the greater depth at station E, and is in accord with the general concept that seasonality of macroalgal productivity is controlled by light penetration and nutrient availability, and in temperate regions irradiance and growth are usually low during the winter and early spring, while nutrient levels are high (Gagne et al., 1982).

Table 4. Biological diversity characteristics of seaweeds at Hwadang-ri (Mean±SD). For the description of biotic indices see "Material and methods".

Indices	Station A	Station B	Station C	Station D	Station E
Diversity					
H′	2.259±0.063	2.330±0.052	2.228±0.092	2.588±0.165	2.174±0.260
N1	9.584±0.611	10.286±0.536	9.311±0.855	13.431±2.098	9.011±2.246
N2	10.404±1.535	12.710±2.696	9.168±1.271	9.760±2.295	13.657±5.501
Richness					
BPI	0.196±0.017	0.192±0.011	0.224±0.035	0.210±0.064	0.212±0.076
R1	5.218±0.347	5.628±0.633	4.699±0.435	3.951±0.392	4.288±0.832
R2	1.591±0.131	1.815±0.334	1.617±0.056	1.518±0.263	1.971±0.292
Evenness					
E1	0.649±0.011	0.661±0.021	0.672±0.020	0.835±0.025	0.712±0.039
E2	0.295±0.013	0.304±0.028	0.339±0.035	0.601±0.034	0.418±0.038
E3	0.273±0.013	0.283±0.027	0.314±0.033	0.582±0.038	0.388±0.041
E4	1.081±0.087	1.241±0.296	0.984±0.097	0.720±0.066	1.520±0.625
E5	1.090±0.096	1.268±0.330	0.982±0.110	0.696±0.075	1.587±0.716

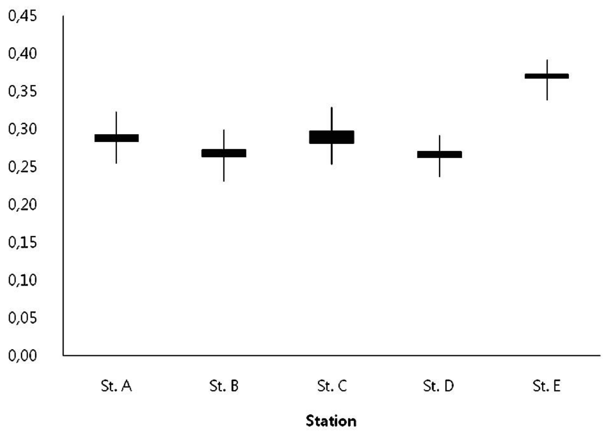

Fig. 3. The degree of heterogeneity of seaweed assemblages (calculated after Tuomisto, 2010) at five stations. Horizontal bars and vertical lines indicate ranges of mean and standard deviations, respectively, for the four seasons and five stations.

Although algal beds constitute nutrients-rich habitats, some species are not always forming the desirable sea habitats for vertebrates. Beds of some macroalgae, including *Ulva* spp. and *Gracilaria pacifica*, can form nuisance blooms in response to high nutrient concentrations and may overgrow eelgrass and interfere with their photosynthesis (Nichols and Cooke, 1979).

Nevertheless, seaweeds are the major food source for a wide variety of herbivores and are the basis of the reef food-web; they are major reef formers and create habitats for invertebrates and vertebrates of ecological and economic importance. Seagrass beds are essential components of coastal ecosystems, providing many valuable ecosystem functions and services (Barbier et al., 2011). These include sediment stabilization, particle trapping, shoreline protection, nutrient cycling, food production, and provision of habitat structure and biodiversity (Orth et al., 2006; Barbier et al., 2011).

The macroalgae of the Goseng-gun are represented by a very diverse and complex group of species and forms. Marine macroalgae play an important role in the everyday lives of the people of Korea. Several species are used as food (by humans and livestock) or for the extraction of agar and carrageenan in traditional medicine, others – as biofertilizers. Studies on microalgae culture in Korea began at the end of the 1960s for the purpose of utilizing them as live food in aquaculture (Hur, 2008). This area has been traditionally famous for the farming of marine fish, including finfish and shellfish like prawns, or oysters. However, the area under study is characterized by the toxic red tides. Thus, any new data on red tide organisms and their impacts on the biotic components, including seaweeds and their temporal and spatial heterogeneity in the coastal waters of Korea are of the utmost importance.

Aspects of global climate change, such as rising temperatures, increased UV radiation, extreme weather events and eutrophication can disrupt ecological processes that maintain the distribution of habitats and their associated biodiversity. The increased nutrient levels caused by effluent leakage from the inlands are considered to be a potential threat to seaweed habitats in those areas. Red tides often occur at a small area and then spread to wider areas. Recent mariculture in Korea attempts to shift the farming frames to the areas without red tides, whenever these stressful events occur. Therefore, results of the present study can serve a critical baseline for future comparisons of seaweed distribution and estimates of variability in potential monitoring parameters in the nearshore coastal waters of Korea affected by the red tides, and can contribute to decreasing and eliminating the farm industrial damages which may be very harmful when red tide outbreaks in the coastal area.

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