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Seasonal variations of marine algal community in the vicinity of Uljin nuclear power plant, Korea

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Abstract: *Three marine algal sites were examined seasonally in an area of thermal discharge from the Uljin nuclear power plant in Korea to assess possible impacts from thermal stress. Quadrat samples were taken at three sites: cooling water intake, outfall and Chukbyon. The degree of wave exposure increased from intake, outfall to Chukbyon. Percent cover and biomass were response variables. All sites were, by numbers red algae, followed by brown and green algae. Over the year, the maximum species diversity was also found at the Chukbyon (2.39), but the minimal one (1.67) was observed at the outfall. Seasonally, generally among algal form-functional groups, filamentous and coarsely branched algae were most abundant throughout the year at the three sites. The number of species in the jointed calcareous groups increased remarkably at the outfall. Based on these results, species richness appears to be strongly affected by wave exposure and thermal stress. The higher proportion of calcareous form groups at the outfall sites indicates that these species are better adapted morphologically to thermal stress such as high temperatures.*

Key words: *Algal community, Thermal discharge, Wave exposure, Power plant, Korea*

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Introduction

The survival and growth of marine organisms generally depend on the seawater temperature, although many species have a variety of physiological strategies which allow them to adapt to low or high seawater temperatures (Langford, 1990). Seawater has long been used as cooling water for some factories and power stations, and its usage has now rapidly increased with industrialization and urbanization (Langford, 1990). Following the cooling process, heated water is usually discharged into the aquatic environment, affecting the structures and distribution of marine plants and animal communities (Stockner, 1968; Forsyth and McColl, 1974; Brock, 1985). In particular, changes in the community structures of benthic algae are used as a biological indicator to represent the effects of thermal discharge (Trembley, 1960; Hellawell, 1986). Some effects of thermal effluents from nuclear power plants (NPP) on marine algal community have been reported (Roessler, 1971; Thorhaug, 1974; Vadas *et al.,* 1976). Frond bleaching and cell plasmolysis of algae found in those areas are directly caused by the thermal effluent (North, 1969; Lobban *et al*., 1985). These negative effects reduce the survival and growth of seaweeds, resulting in extensive reductions in the number of species of marine algae (Wood and Zieman, 1969). In addition, changes of algal morphology and functional form group are also one of the major effects of thermal stress in community structures (Littler, 1980; Littler and Littler, 1984a; Littler and Arnold, 1982). Many researchers previously suggested a distinct link between macro-algal form and its function, and argued that predictable growth forms of seaweeds may be found under given levels of environmental stress or disturbance (Steneck and Watling, 1982; Littler and Littler, 1984a; Dethier, 1994; Steneck and Dethier, 1994; Piazzi *et al.,* 2002). Thus, the functional form model has been used to understand the ecology of marine macroalgae (Littler, 1980; Norton *et al.,* 1982; Littler *et al*., 1983; Hanisak *et al*., 1988). Moreover, wave action is known to be one of the primary factors affecting community structures in benthic marine habitats (Gaylord, 1999).

Although several studies on algal community structures were carried out near nuclear power plants in Korea, most of them were focused on only seasonal change in species number and composition (Kim and Lee, 1980; Kim, 1986; Kim and Kim, 1991; Kim *et al*., 1992, 1998; Hwang *et al*., 1996; Kim and Huh, 1998; Kim *et al*., 2004).

Therefore, in this study, algal community structures at three sites in the vicinity of Uljin nuclear power plant (NPP) were examined seasonally to understand the effects of thermal discharge and wave exposure on the species composition and their relationship to functional forms.

Materials and Methods

Three study sites, intake and outfall of Uljin nuclear power plant (NPP) and Chukbyon were located on the middle of the eastern coast of Korea (Fig. 1). The intake was ca. 1.5 km apart from outfall site and Chukbyon was 6.6 km from outfall site. The degree of wave exposure increased from intake, outfall to Chukbyon. Particularly, the intake site is protected from wave action by artificial of breakwater. The slopes of the substrate of intake and outfall sites are somewhat steep, while that of the Chukbyon site is relatively gentle.

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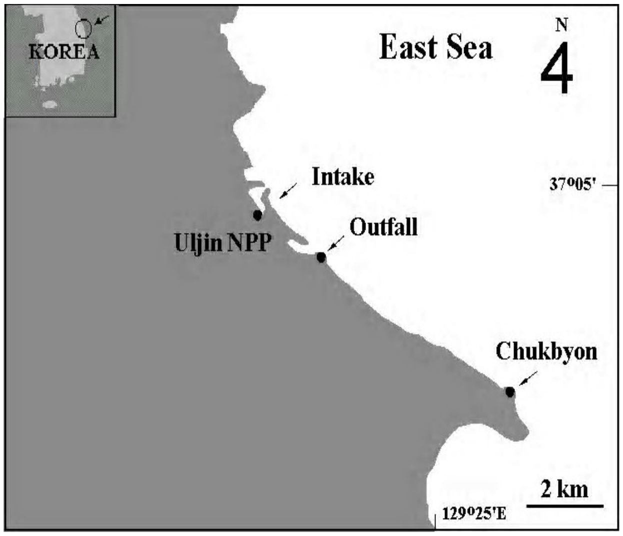

Fig. 1: Map of study area and location of collection site near Uljin nuclear power plant in eastern coast of Korea

Study sites are under the influence of the cold water mass of the North Korean cold current (Koh and Shin, 1990) and an average tidal range is ca. 40 cm (Sohn, 1998). The temperature of Chukbyon ranges between 11 and 23 °C during four seasons (Anonymous, 1995, 1996). Differences (ΔT) of seawater temperature between intake and outfall sites were approximately 6-7 °C in 1996 (Kim *et al.,* 2004).

Seaweeds were collected at three study sites from autumn to summer (Sep. 1994 - Aug. 1995). For quantitative data collection, five replicate quadrats (50 x 50 cm) were randomly placed between littoral and sublittoral zones, where the vertical range was about 2 m. Percentage cover was estimated in the field by the method of Saito and Atobe (1970), and all seaweeds within the quadrat were destructively sampled. In addition, all seaweeds occurred at each site were collected for algal flora analyses.

The seaweeds were transported to the laboratory and identified using standard taxonomic keys. All seaweeds occurred were classified into six functional form groups (sheet-group, filamentous-group, coarsely branched-group, thick leathery-group, jointed calcareous-group and crustose-group) by the methods of Littler and Arnold (1982) and Littler and Litter (1984b). The samples of each quadrat were identified and the biomass were obtained after drying to a constant weight at 70°C. Species diversity indices were used to assess community changes (Shannon and Weaver, 1949). Statistical analyses were done using STATISTICA v. 5.0. A one-way ANOVA was used to test significant differences of mean biomass among the three sites. When significant differences between means were detected, the Tukey test was applied (Sokal and Rohlf, 1995). Homogeneity of variance was tested using Cochran's test (Underwood, 1997).

Results and Discussion

A total of 116 algae, 11 green, 29 brown and 76 red algae were identified during the study period and red algae were the major taxon in species number. Algal species number varied in season and sites (Fig. 2). The number of algal species was the highest at Chukbyon in four seasons and the lowest was at outfall. During the study period, the total species number was 71 at intake, 60 at outfall, and 105 at Chukbyon indicating that algal species richness was the highest at Chukbyon. The differences in species number among the three study sites resulted from the number of red algae. That is, the species number of red algae was 49 at intake, 39 at outfall, and 67 at Chukbyon, respectively. At study sites, common species were *Cladophora* sp, *Enteromorpha compressa, Ulva pertusa*, *Dictyota dichotoma, Sargassum thunbergii, Ahnfeltiopsis flabelliformis, Audouinella* sp, *Bangia atropurpurea, Chondrus ocellatus, Corallina pilulifera* and *Peyssonnelia japonica.* Five red algal species (*Antithamnion densum*, *Chrysymenia wrightii*, *Grateloupia sparsa*, *Pterothamnion yezoense* and *Spyridia filamentosa*) were only found at intake, and 4 species (*Padina arborescens*, *Anotrichium furcellatum, Jania adharens*, *Tsengia nakamurae*) at outfall, and 25 species (*Codium arabicum, Agarum clathratum*, *Chordaria flagelliformis*, *Dictyopteris divaricata*, *Elachista* sp., *Hizikia fusiformis*, *Laminaria japonica, L. religiosa*, *Petalonia binghamiae, Sargassum filicinum*, *S. hemiphyllum, S. miyabei, Benzaitenia yenoshimenis, Callophyllis adhaerens, Ceramium japonicum, Champia compressa, Chondrocanthus tenellus*, *Grateloupia acuminata, G. divaricata, G. livida, Griffithsia japonica*, *Hypoglossum geminatum, Prionitis elata, P. crispata* and *P. patens*) at Chukbyon. A total of 21 red algae (5 intake, 3 outfall, and 13 Chukbyon) were site-specific among 34 site-specific species and 12 brown algae (11 Chukbyon, 1 outfall) and one green alga (Chukbyon) were also observed. Particularly, among site-specific species, *Codium arabicum, Agarum clathratum*, *Hizikia fusiformis*, *Laminaria japonica* and *L. religiosa* were found in all four seasons and restricted to the Chukbyon, while *P. arborescens* and *J. adhaerens* grew only at the outfall and observed over the study period.

As mentioned above, the lowest number of species was found at the outfall site, whereas the greatest number was observed at Chukbyon, which was more exposed to wave action. This regional pattern suggests that the species richness is primarily influenced by the extent of wave activity. Diez *et al.* (2003) noted that water motion has to enhance seaweed nutrient uptake by reducing or breaking the boundary layer (Wheeler, 1980; Hurd *et al*., 1996), and remove epiphytes and waste products (Kain and Norton, 1990). Recent studies also reported that species richness declines slightly towards more sheltered sites (Schils *et al*., 2001; Thongroy *et al*., 2007), whereas exposure to wind and waves possibly contributes to species diversity of the site (Lindstrom *et al*., 1999).

In seasons, the species number was the highest as 90 seaweeds in summer and the species richness values were 86 in winter, 84 in spring, and 76 in autumn. Among 116 algae, 4 species (*Sargassum filicinum, S. fulvellum, Anotrichium furcellatum*, *Grateloupia livida*) were only found in autumn, 4 species (*Acrosorium venulosum, Antithamnion densum, Laurencia intricata, Prionitis*

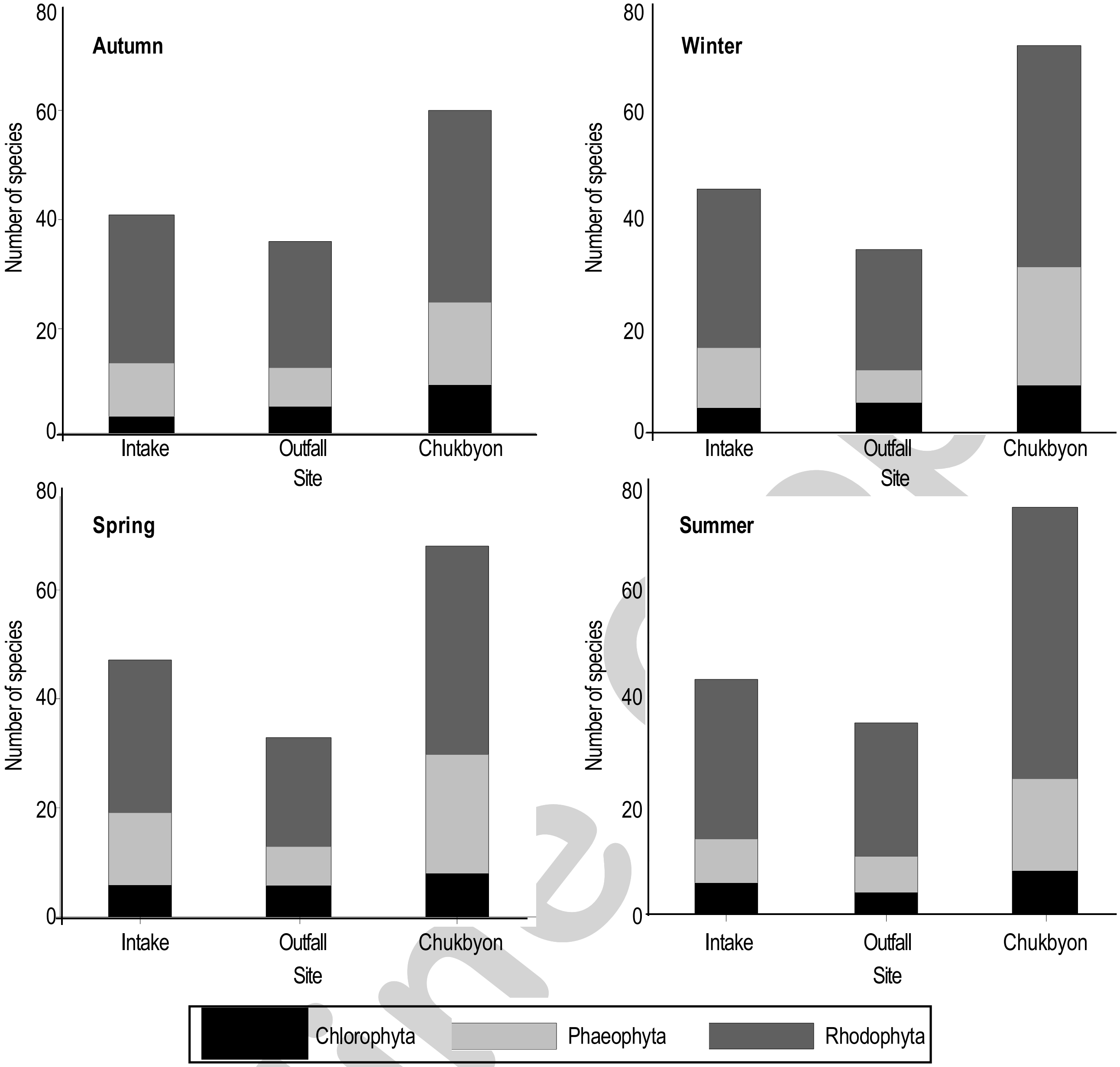

Fig. 2: Seasonal variation of number of algal species in each division in the vicinity of the Uljin nuclear power plant

patens) in winter, 5 species (*Sargassum hemiphyllum, Benzaitenia yenoshimensis, Pterothamnion yezoense*, *Spyridia filamentosa*, *Tsengia nakamurae*,) in spring, and 11 species (*Chordaria flagelliformis*, *Sargassum patens, Callophyllis adhaerens, Champia compressa, Chondrocanthus tenellus, Chrysymenia wrightii*, *Griffithsia japonica, Heterosiphonia japonica, Nemalion vermiculare*, *Neosiphonia decumbens* and *Prionitis crispata*) in summer. The seaweeds found only in summer were the greatest as 11 algae compared to other seasons. In autumn, several green algae (*eg. Bryopsis pulmosa, Codium adhaerens* and *C. fragile*), large sized brown algae (*eg. Agarum clathratum, Laminaria* spp. *Hizikia fusiformis* and *Sargassum filicinum*) and thick leathery red algae (*eg. Grateloupia acuminata*, *G. divaricata* and *G. livida*) were occurred at Chukbyon site.

There are conspicuous seasonal fluctuations of biomass in this study (Fig. 3). Mean biomass of the three sites was 96.2 g/m^2 in dry weight. Over the study period, mean biomass of four seasons was the greatest at the Chukbyon site (112.2 g/m^2), followed by intake (93.7 g/m^2) and outfall sites (82.7 g/m^2). Seasonally, the maximum biomass was recorded at the Chukbyon (159.3±30.5 SE g/m^2) in summer and the minimum biomass at the outfall (25.8±2.6 g/m^2) in autumn. The maximum variation in mean biomass among these sites occurred in the winter. In this season, at the Chukbyon site mean biomass was 101.1 g/m^2, whereas it was 36.1 g/m^2 at the outfall site. Spatially, biomass was influenced by several algae (*U. pertusa, G. amansii* and *P. arborescens*) at the intake and outfall sites. At the outfall site, in particular, *P. arborescens* was accounted for 30-76%

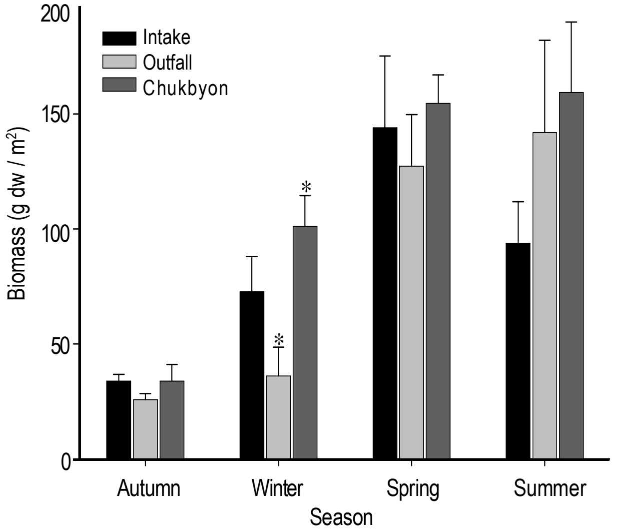

Fig. 3: Seasonal variation of mean biomass (g/m^2±SE) in the vicinity of the Uljin nuclear power plant. Asterisks indicate significant difference between two sites, $p < 0.05$

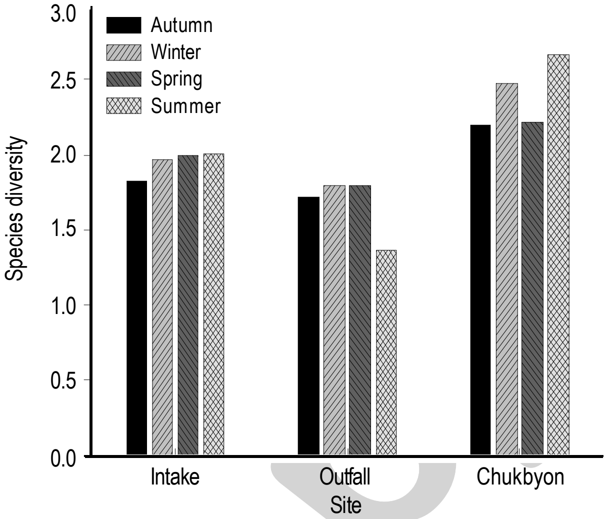

Fig. 4: Spatial variation of algal species diversity in the vicinity of the Uljin nuclear power plant during each season

Table - 1: Number of species and percentage (%) of total species recorded for each functional form group at three sites in the vicinity of the Uljin nuclear power plant in Korea

Site	Functional form group	Number of species			
		Autumn (%)	Winter (%)	Spring (%)	Summer (%)
Intake	S	5 (12.2)	6 (14.0)	9 (19.0)	9 (20.9)
	F	15 (39.6)	14 (32.0)	10 (21.0)	10 (23.3)
	CB	13 (34.0)	14 (32.0)	16 (34.0)	15 (34.9)
	TL	5 (7.6)	7 (16.0)	8 (17.0)	6 (14.0)
	JC	1 (1.9)	1 (2.4)	1 (2.1)	1 (2.3)
	C	2 (3.8)	2 (4.6)	3 (6.4)	2 (4.7)
	Total	**41 (100)**	**44 (100)**	**47 (100)**	**43 (100)**
Outfall	S	4 (11.1)	7 (21.2)	7 (21.2)	6 (17.7)
	F	15 (41.7)	9 (27.3)	9 (27.3)	12 (35.3)
	CB	7 (19.4)	10 (30.3)	8 (24.2)	8 (23.5)
	TL	5 (13.9)	3 (9.1)	5 (15.2)	4 (11.8)
	JC	3 (8.3)	3 (9.1)	3 (9.1)	3 (8.8)
	C	2 (5.6)	1 (3.0)	1 (3.0)	1 (2.9)
	Total	**36 (100)**	**33 (100)**	**33 (100)**	**34 (100)**
Chukbyon	S	9 (15.0)	13 (18.8)	12 (17.7)	9 (12.0)
	F	20 (33.3)	16 (23.2)	16 (23.5)	23 (30.7)
	CB	12 (20.0)	22 (31.9)	21 (30.9)	23 (30.7)
	TL	13 (21.7)	12 (17.4)	13 (19.1)	13 (17.3)
	JC	2 (3.3)	2 (2.9)	2 (2.9)	2 (2.6)
	C	4 (6.7)	4 (5.8)	4 (5.9)	5 (6.7)
	Total	**60 (100)**	**69 (100)**	**68 (100)**	**75 (100)**

S - Sheet, F - Filament, CB - Coarsely branched, TL - Thick leathery, JC - Jointed calcareous, C - Crustose

Table - 2: Mean coverage of major algal species(>1.0) in four seasons at three sites in the vicinity of the Uljin nuclear power plant in Korea

Species	Site											
	Intake				Outfall				Chukbyon			
	Season											
	Au	Wi	Sp	Su	Au	Wi	Sp	Su	Au	Wi	Sp	Su
Dictyota dichotoma (S)	*	*	*	5.5	*	*	*	*	*	*	*	*
Enteromorpha compressa (S)	*	12.6	6.6	*	4.9	11.0	*	*	9.8	6.8	*	12.1
Enteromorpha linza (S)			*	*		*	*	*	*	*	6.1	*
Porphyra sp (S)		*	*	*		*	*	*	*	7.6	*	
Scytosiphon lomentaria (S)			4.3	*						*	2.3	
Ulva pertusa (S)	4.5	3.2	6.9	17.3	*	*	*	*	*	*	8.5	*
Bangia atropurpurea (F)	*	*	2.8	*	*	*	*	*	*	*	*	*
Centroceras clavulatum (F)				*	*	3.5	*	*	*	*		
Ceramium paniculatum (F)	*	*		*	*			2.5	*	*	*	*
Chaetomorpha sp (F)		*			*				4.3	*	7.6	*
Ectocarpus sp (F)	*	6.6	*		3.9	8.6	21.5	*	*	*	*	
Neosiphonia japonica (F)	*	*	*	*				*	*	*	*	7.0
Chondracanthus intermedia (CB)			*	*	*				*	*	3.2	*
Chondrophycus intermedia (CB)					*	*	*	4.3		*		*
Chondrus ocellatus (CB)	1.8	*	*	6.1	*	*	*	*	*	*	*	4.6
Colpomenia bullosa (CB)		*	4.5							*	*	
Colpomienia sinuosa (CB)	*	*	*	7.4			*	*	*	*	*	*
Gelidium amansii (CB)	6.6	21.9	13.8	9.5			*	*			*	*
Gloiopeltis furcata (CB)			*							8.8	*	
Leathesia difformis (CB)	*		6.8							*	*	*
Grateloupia elliptica (TL)	*	*	*	*	*	*	*	*	3.3	*	8.7	13.8
Hizikia fusiformis (TL)									*	7.8	*	*
Padina arborescens (TL)					23.9	35.4	25.7	41.6				
Sargassum filicinum (TL)									4.9			
Sargassum hemiphyllum (TL)											5.5	
Sargassum horneri (TL)	*	*	7.5						*	*	*	
Sargassum patens (TL)								6.3				5.6
Corallina pilulifera (JC)	*	*	*	*	*	14.0	2.7	9.4	4.4	5.1	2.6	*
Jania adhaerens (JC)					*	*	4.0	*				

Au - Autumn, Wi - Winter, Sp - Spring, Su - Summer, * - < coverage 1%

of the total mean biomass during each season. Whereas, at Chukbyon site, *C. pilulifera* and *G. elliptica* were found with relatively as higher biomass values of 16.1-26.7 g/m^2 and 2.3-74.7 g/m^2, respectively.

Dominant species in terms of biomass and coverage differed between sites and seasons. *P. arborescens* was the most conspicuous species throughout the year at the outfall site (Table 1). *G. elliptica, U. pertusa* and *C. pilulifera* were the most abundant species at Chukbyon site, while *G. amansii* was the most abundant species at the intake site. As mentioned above, this intake site is protected from wave action by artificial breakwater.

In general, *Gelidium sesuiipedale* thrives well at very exposed habitats for seawater movement (Santelices, 1991; Díez *et al*., 2003). In the present study, however, *G. amansii* was a dominant species at the sheltered intake site. Appearances of *Geliduum* spp. at different wave exposure sites may result from their physiological features. A similar phenomenon was also found between *Corallina mediterranea* and *C. elongata* in the response of pollution (Arevalo *et al.*, 2007).

Among the three sites sampled during the survey period, the mean species diversity (H') was the highest at the Chukbyon site as 2.39 and the lowest at the outfall site with 1.67 (Fig. 4). In summer, species diversity was at its maximum at the Chukbyon site (2.66) and minimum at the outfall site (1.36). Diversity indices have been used most extensively among community parameters, with varying degrees of success (Borowitzka, 1972, Littler and Murray, 1975). Seapy and Littler (1982) reported that, under conditions of extreme disturbance, species diversity is low and communities are composed mainly of opportunistic organisms. In the present study, among the three examined sites, outfall showed the minimum species diversity as outfall is affected by heating stresses of thermal discharge.

Functional form groups in species number ranged from highest to lowest as follows: filamentous-group (31.9%), coarsely branched-group (29.3%), thick leathery-group (19.0%), sheet-group (12.9%), jointed calcareous-group (2.6%) and crustose-group (4.3%). Overall, number of species of filamentous-group and coarsely branched-group were more abundant at three sites of four seasons (Table 2). Spatially, jointed calcareous-group was more abundant in number of species at the outfall site than the other sites except for summer, while thick leathery-group was more abundant at the Chukbyon site. Particularly, *G. amansii* of coarsely branched-group has a higher biomass value than the other groups at intake site. At the outfall site, however, *C. pilulifera* of jointed calcareous-group and *P. arborescens* of thick leathery-group have a higher value than the other groups.

In natural communities, there are many algal species with various morphological forms (Littler and Littler, 1984a). Algal succession has been interpreted from the perspective of the thallus form group. At the three sites examined in this study, the filamentous- and the coarsely branched-groups of the six functional form groups proposed by Littler (1980), showed general species abundance throughout the year.

In our study, proportion of sheet- and filamentous-groups at the outfall site was recorded 49-53%, whereas those at the intake site and at the Chukbyon site were 40-49% and 41-48%, respectively (Table 2). It is likely to be related to the disturbance such as thermal stress (Littler and Arnold, 1982).

However, the jointed calcareous-group such as *Corallina* and *Jania* was usually abundant at the outfall site of Uljin NPP. The calcification in this group may play an important role in survival under conditions of high temperature or desiccation, as suggested by several researchers (North, 1969; Kolehmainen *et al.,* 1975; Morgan and Grant, 1989). Also, *P. arborescens* of thick leathery-group together with *Corallina* of jointed calcareous-group, were found as the representative species throughout all seasons at the outfall site. According to the work of Phillips *et al.* (1997), jointed calcareous-group (as articulated calcareous group) and thick leathery-group (as leathery macrophyte group) were more abundant at higher levels of disturbance, because their structural complexity have a relatively high degree of resistance to physical damage. This distribution is likely to be related to the survival strategies of these species. In Korea, the genus *Padina* mainly is distributed in Jeju Island and South coast of Korea (Lee and Kang, 2002). It seems that warm temperature allows this species to grow in these areas. This genus has been reported previously as warm water-tolerant species in the vicinity of Uljin (Kim *et al.,* 1998, 2004).

In conclusion, the species richness appears to be importantly affected by the feature of sheltered or exposed site. The higher proportion of calcareous form groups at the outfall site indicates that these species are better adapted morphologically to thermal stress such as high temperatures. However, thermal stress substantially impedes the growth and species diversity of other functional forms.

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