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# Macroalgal species composition and seasonal variation in biomass on Udo, Jeju Island, Korea

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Macroalgae are important primary producers in marine ecosystem. They don't only play an important role as bio-indicators but also provide economic resources for humans. Seasonal and vertical variations in seaweed species composition and biomass were examined to determine the ecological status of seaweed beds around Udo, near Jeju Island. We obtained samples at two sites in the high-intertidal to subtidal zones using the quadrat method between June 2010 and May 2011. A total of 262 species were collected, including 31 green, 61 brown, and 170 red algae. The composition of algal species revealed a decrease in species growing in cold water in comparison with the list 20 years ago. The macroalgal mean biomass (g wet wt $m^{-2}$) was 3,476 g and 2,393 g from the two sites, respectively. *Ecklonia cava* had the greatest biomass at both sites. The seasonal dominant species by biomass at site 1 from the low-intertidal to 1-3 m depth of the subtidal zone was mostly comprised of thick-leathery form, such as *Sargassum hemiphyllum*, *S. coreanum*, and *Ecklonia cava*, whereas site 2 was comprised of the turf form, such as *Chondrophycus intermedius*, *Chondracanthus intermedius*, *Dictyopteris prolifera*, and *Gelidium elegans*. The current ecological status of the seaweed community in Udo is stable based on diversity and dominance indices.

**Key Words:** biomass; *Ecklonia cava*; macroalgae; seasonal variation; species composition; Udo

## INTRODUCTION

Macroalgae, key primary producers in marine ecosystem, play important ecological roles such as providing spawning grounds and habitat for fish and shellfish. They also provide medicinal and industrial materials, including feed, fertilizer, and bioenergy resources (Graham et al. 2009). Algae-based biofuels are receiving attention as an alternative to petroleum and grain-based fuels (Aresta et al. 2005). The reasons for this interest are that 1) marine algae have a very high productivity level by fixing $CO_2$ and 2) they are not a staple food. Additionally, annual productivity of macroalgal community on rocky shores exceeds that of tropical rain forests (Dawes 1998). Investigations into macroalgal biomass have been undertaken to determine whether macroalgae have a role in $CO_2$ reduction along Korean coasts (Choi et al. 2008, Kim et al. 2008, Ko et al. 2008).

Furthermore, the pharmaceutical industry is investigating the use of seaweed polysaccharides to develop better and safer drugs with fewer side effects than synthetic drugs (Athukorala et al. 2007). Marine algae have been explored as a resource for treating various medical conditions due to their antihypertensive, antioxidant, antibiotic, and antiinflammatory properties (Aoun et al. 2010, Tierney et al. 2010). Despite the vast potential ben-



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efits of seaweeds, collecting target algal species is complicated. The process requires a detailed understanding of algal life patterns, including habitat, seasonal or vertical variations, and life history. The macroalgal vertical distribution is mainly controlled by exposure to moisture in intertidal zones and light intensity in subtidal zones. Moreover, temperature is one of the most important factors controlling latitudinal distribution (Dawes 1998). Expansion and retreat of marine species along coastlines during temperature changes have been documented. For example, seaweed distribution changes along the British Coast were documented during the first half of the twentieth century (Lüning 1990, Hiscock et al. 2004, Müller et al. 2009).

Kang (1966) divided the Korean coast into five sections based on water temperature and other hydrological conditions. He designated Jeju Island as an independent section. Jeju Island is comprised of 2% boreal, 74% temperate, 10% subtropical, and 15% cosmopolitan macroalgal species. After his study, more than 340 macroalgal species were added to the list of algae, and about 860 species are currently present along the Korean coastline (Lee and Kang 2001, Lee 2008). However, little published information is available on long-term macroalgal variations associated with changes in seawater temperature in specific regions of the Korean coastline.

Udo is one of the most popular tourist spots in Korea. Many important commercial seaweeds occur along this coast, such as *Sargassum fusiforme*, *Sargassum fulvellum*, *Gelidium elegans*, *Meristotheca papulosa*, and *Grateloupia elliptica*. Woman divers in Udo collect these seaweeds and sell or use them as food. In 2010, a new water supply facility from Jeju to Udo was constructed to address the shortage of residential water caused by increasing tourism. Because of this construction, the natural habitat of seaweeds around Udo is endangered. Therefore, it is imperative to begin investigating the macroalgal species composition and seasonal variations in seaweed biomass in this region.

The macroalgal community serves as a valuable bioindicator, because macroalgal species respond rapidly to environmental changes in the coastal ecosystem (Tribollet and Vroom 2007). This study of the Udo area provides baseline data needed for long-term monitoring of the macroalgal community that serves as a bioindicator for the region. The specific objectives of this study were (1) to document the macroalgal species composition to elucidate the relationship between algal composition and seawater temperature due to global climate change, (2) to identify the seasonal variations in biomass to estimate the annual productivity of the macroalgal community, and (3) to determine the ecological characteristics that are useful for evaluating the ecological health of the macroalgal community prior to any increase in sewage volume.

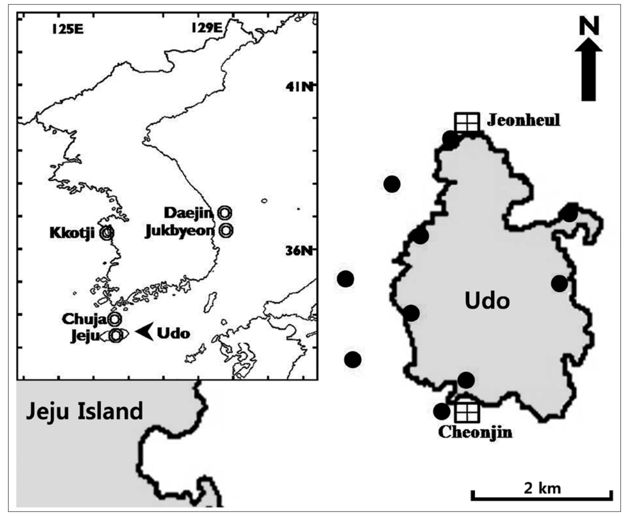


**Fig. 1.** Map showing the collecting sites (qualitative analysis [dark circles], quantitative analysis [squares]) of macroalgal samples at Udo and the comparison sites (double circles) from references.

## MATERIALS AND METHODS

Udo is an elliptical islet extending north to south in the easternmost part of Jeju Island. We selected the southern (Cheonjin) and northern (Jeonheul) parts of Udo to investigate macroalgal community structure. The Cheonjin site is situated on a concave coastline that is protected from strong winds and waves by both a seawall and Jeju Island itself. In contrast, the Jeonheul site protrudes into the sea and is exposed to strong wave action (Fig. 1). The distance between the two sites is about 3.7 km. At both sites, the substrate consists mostly of basaltic bedrock covered with sand in a depression of bedrock 7 m below the surface.

Macroalgal flora collections were conducted 17 times from June 2009 to May 2010 along the Udo coastline, including five subtidal sites and six intertidal sites (Fig. 1). For the analysis of species composition, 1-5 individuals of each species were collected and fixed in 5% formalin-seawater. The samples were identified using a microscope based on the descriptions of Lee (2008), and Yoshida (1998). All identified species were divided into four regions (W, warm; T, temperate; C, cold; B, broad) and

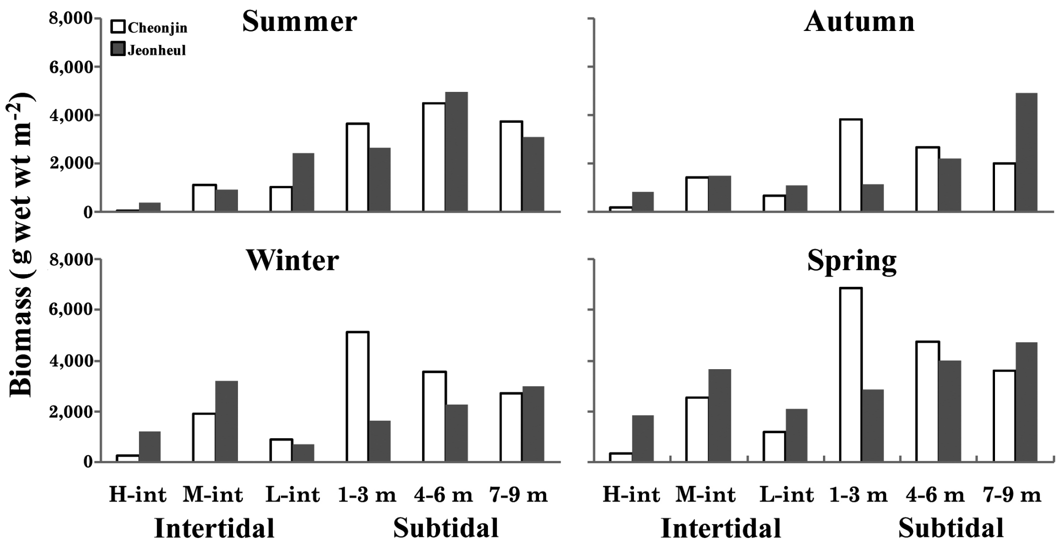


**Fig. 2.** Seasonal and vertical variation of total macroalgal biomass (g wet wt $m^{-2}$) during a year from two sites at Udo, Jeju Island. H, high; M, middle; L, low; int, intertidal.

then the species composition was compared with previously published studies of other coastal regions in Korea (Lee and Lee 1982, Lee and Ko 1991, Lee et al. 2007, Kim et al. 2008, Shin et al. 2008). Four regions were sectioned based on the geographical distribution of the macroalgal species (http://www.algaebase.org, Guiry and Guiry 2011), and the seven groups of biogeographical regions in the world seas as defined by Lüning (1990). We used the species composition data and annual mean sea surface temperature from the Korea Hydrographic and Oceanographic Administration for the correlation analyses (http://www.khoa.go.kr/). The C/P, R/P, and (R+C)/P ratios were also compared (Kim et al. 2008).

The macroalgal community structures were investigated seasonally for 1 year. Three 0.25 $m^2$ quadrats were randomly placed on the high-, mid-, and low-intertidal zones at each site. In the subtidal zone, nine 0.25 $m^2$ quadrats were placed at interval depths of 1 m at each site. All marine algal species except melobesioidinean algae, were collected in the quadrats, and the biomass of each species was recorded (g wet wt $m^{-2}$) in the laboratory. To examine the variations in the macroalgal community structure along the shore gradients, we divided the shore into three intertidal (high, mid, low) and three subtidal (1-3 m, 4-6 m, and 7-9 m depths from the mean sea level) zones and placed three quadrats at each vertical shore zone. We performed cluster analysis using Pearson's method (SPSS version 17.0; SPSS, Inc., Chicago, IL, USA) based on the macroalgal species lists. The diversity ($H'$) and dominant (DI) indices were calculated using Shannon-Weaver indices (Shannon and Weaver 1949).

## RESULTS

A total of 262 macroalgal species, including 31 Chlorophyta, 61 Phaeophyta, and 170 Rhodophyta were collected from Udo from June 2009 to May 2010. The C/P, R/P, and (R+C)/P ratios were 0.51, 2.79, and 3.30, respectively. The compositions of macroalgal species classified within the four climate affinities were 18 cold (7.09%), 119 temperate (42.91%), 96 warm (37.80%), and 31 broad (12.20%) species (Table 1).

The annual mean biomasses (g wet wt $m^{-2}$) of seaweeds were 3,476.4 from Cheonjin and 2,392.8 from Jeonheul. *Ecklonia cava* was the dominant species by biomass at the two sites (Cheonjin, 965.9; Jeonheul, 783.9). The seasonal and vertical variations in the total macroalgal biomass from the two sites are shown in Fig. 2. The highest values for biomass were recorded in spring (Cheonjin, 5,771.3; Jeonheul, 3,196.2), and the lowest values were found in autumn (Cheonjin, 1,806.5; Jeonheul, 1,954.3). Seaweed biomass fluctuated with season and vertical shore level. Biomass increased gradually from autumn to spring and decreased from summer to autumn. The biomass at the mid-intertidal displayed higher values than those at the other levels of the intertidal zone at both sites during the year. Jeonheul showed higher macroalgal biomasses with increasing depth in the subtidal zone compared to those at Cheonjin.

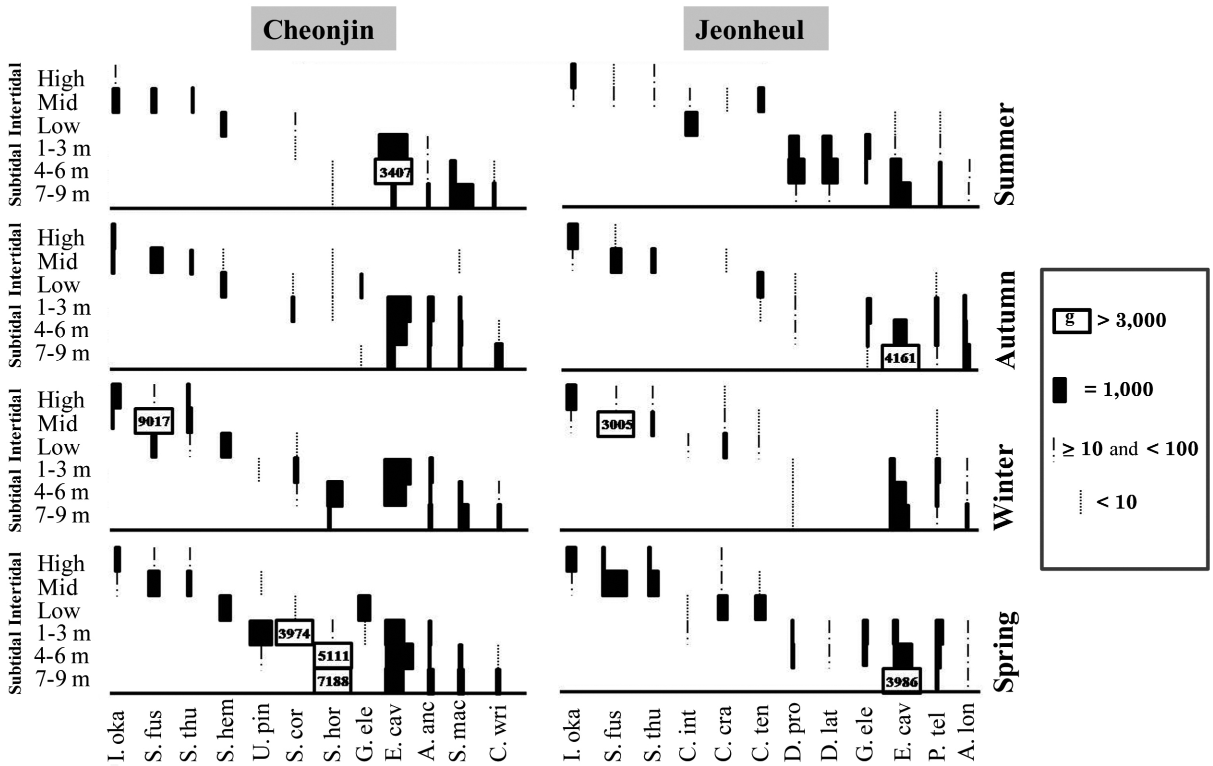


**Fig. 3.** Seasonal and vertical variation in the major species biomass with more than 50 g wet wt m$^{-2}$ from two sites. I. oka, *Ishige okamurai*; S. fus, *Sargassum fusiforme*; S. thu, *Sargassum thunbergii*; S. hem, *Sargassum hemiphyllum*; U. pin, *Undaria pinnatifida*; S. cor, *Sargassum coreanum*; S. hor, *Sargassum horneri*; G. ele, *Gelidium elegans*; E. cav, *Ecklonia cava*; A. anc, *Amphiroa anceps*; S. mac, *Sargassum macrocapum*; C. wri, *Cladophora wrightiana*; C. int, *Chondrophycus intermedius*; C. cra, *Chondria crassicaulis*; C. ten, *Chondracanthus tenellus*; D. pro, *Dictyopteris prolifera*; D. lat, *Dictyopteris latiuscula*; P. tel, *Plocamium telfairiae*; A. lon, *Acanthopeltis longiramulosa*.

**Table 1.** Comparisons of species composition (%) based on the habitat climate zone and flora characteristics at several localities from the coasts of Korea

| Contents | | This study | Udo (Lee and Ko 1991) | Jeju (Lee and Lee 1982) | Chuja (Kim et al. 2008) | Jukbyeon (Shin et al. 2008) | Daejin (Shin et al. 2008) | Kkotji (Lee et al. 2007) |
|---|---|---|---|---|---|---|---|---|
| Climate affinity | W | 37.80 | 35.34 | 41.46 | 40.79 | 34.33 | 36.96 | 32.43 |
| | T | 42.91 | 36.21 | 29.27 | 30.92 | 31.34 | 26.09 | 17.57 |
| | C | 7.09 | 11.64 | 11.22 | 12.50 | 14.93 | 17.39 | 18.92 |
| | B | 12.20 | 16.81 | 18.05 | 15.79 | 19.40 | 19.57 | 31.08 |
| Floristic characteristics | C/P | 0.51 | 0.56 | 0.32 | 0.35 | 0.33 | 0.39 | 0.72 |
| | R/P | 2.79 | 2.76 | 2.80 | 2.19 | 2.10 | 2.30 | 2.67 |
| | (R+C)/P | 3.30 | 3.31 | 3.12 | 2.53 | 2.43 | 2.68 | 3.39 |
| AST (°C) | | 17.7 | 17.2 | 16.5 | 16.6 | 15.1 | 14.0 | 12.8 |
| Year | | 2009 | 1990 | 1980 | 2006 | 2006 | 2006 | 2005 |
| Spatial range | | Inter / Sub | Inter / Sub | Inter | Inter | Inter / Sub | Inter / Sub | Inter |
| Temporal range | | Four seasons | Spring / Summer | Four seasons | Four seasons | Four seasons | Four seasons | Four seasons |

W, warm; T, temperate; C, cold; B, broadwater species; AST, annual sea water temperature; Inter, intertidal; Sub, subtidal.

The seasonal and vertical variations of the dominant seaweed biomasses are shown in Fig. 3. The annual dominant species of each six vertical levels at Cheonjin were *Ishige okamurai*, *Sargassum fusiforme*, *Sargassum hemiphyllum*, *Ecklonia cava*, *Ecklonia cava*, and *Sargassum macrocarpum*, whereas the dominant species of the six vertical levels at Jeonheul were *Ishige okamurai*, *Sargassum fusiforme*, *Chondracanthus tenellus*, *Gelidium elegans*, *Ecklonia cava*, and *Ecklonia cava*. At Cheonjin, the intertidal zone always had three dominant species, *Ishige okamurai*, *Sargassum fusiforme*, and *Sargassum hemiphyllum*, but the subtidal zone showed some seasonal changes, such as *Ecklonia cava* (summer to winter) and *Sargassum coreanum* (spring) at 1-3 m depth, *Ecklonia cava* (summer to winter) and *Sargassum horneri* (spring) at 4-6 m depth, *Sargassum macrocarpum* (summer and winter), *Sargassum horneri* (spring), and *Ecklonia cava* (autumn) at the 7-9 m depth level. The macroalgal community at Jeonheul showed more fluctuations than that of Cheonjin. In Jeonheul, the high-intertidal zone was dominated by *Ishige okamurai* during all seasons; at the mid-intertidal zone by *Sargassum fusiforme* (autumn to spring) and *Chondracanthus tenellus* (summer); and at the low-intertidal zone by *Chondrophycus intermedius* (summer), *Chondracanthus tenellus* (autumn and spring), and *Chondria crassicaulis* (winter). In the subtidal zone at Jeonheul, the 1-3 m depth was dominated by *Dictyopteris prolifera* (summer), *Gelidium elegans* (autumn and winter), and *Plocamium telfairiae* (spring), at the 4-6 m depth by *Ecklonia cava* (autumn to spring) and *Dictyopteris prolifera* (summer), and at the 7-9 m depth by *Ecklonia cava* throughout the year. *Chondria crassicaulis*, *Cladophora wrightiana*, *Dictyopteris prolifera*, *D. latiuscula*, *Ishige okamurai*, *Sargassum fusiforme*, *S. hemiphyllum*, *S. coreanum*, *S. macrocarpum*, and *Undaria pinnatifida* demonstrated higher biomass in a relatively narrow vertical level, whereas *Acanthopeltis longiramulosa*, *Ecklonia cava*, *Amphiroa anceps*, and *Plocamium telfairiae* had broad vertical distribution. Great forests of *Sargassum horneri* were observed during the springtime at 4-9 m depth at Cheonjin. The community near the 5 m depth of the subtidal zone at Jeonheul consisted mostly of *Dictyopteris prolifera* and *D. latiuscula* during the summer and then abruptly changed to *Plocamium telfairiae* growing on the infirm stipes of *Dictyopteris* spp. in autumn.

Fig. 4 shows a cluster analysis dendrogram based on macroalgal species compositions. The dendrogram is divided into two groups corresponding to the intertidal (I) and subtidal (II) regions. Group I was divided into three subgroups and Group II into two subgroups (Fig. 4).

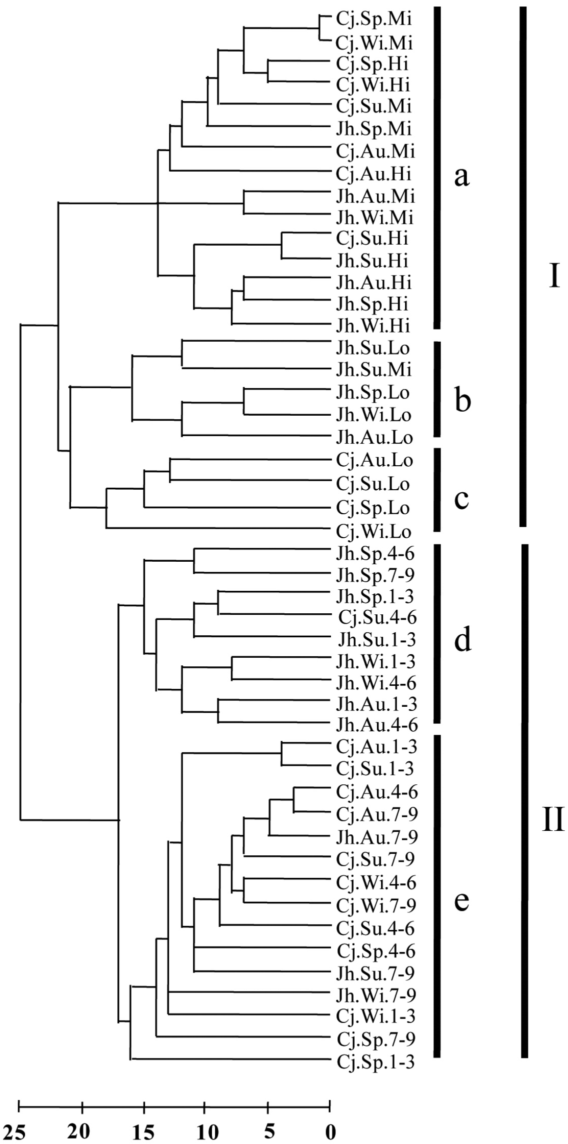


**Fig. 4.** Dendrogram of cluster analysis based on the macroalgal species composition at Udo. Scale bar, rescaled distance cluster combine; Cj, Cheonjin; Jh, Jeonheul; Sp, spring; Su, summer; Au, autumn; Wi, winter; Hi, high intertidal; Mi, mid intertidal; Lo, low intertidal; 1-3, 1-3 m depth; 4-6, 4-6 m depth; 7-9, 7-9 m depth level.

The five subgroups are characterized as follows: subgroup a) represents the high- and mid-intertidal zones at both sites, b) contains most of the low-intertidal zone at Jeounheul, c) includes all of the low-intertidal zone at Cheonjin, d) includes generally the 1-6 m depth level of the subtidal zone at Jeonheul, and e) contains most of the subtidal zone at Cheonjin and the 7-9 m depth level of the subtidal zone at Jeonheul.

Ecological community indices from the two sites are shown in Table 2. The DI ranged from 0.15 to 0.25 at Cheonjin, and from 0.17 to 0.24 at Jeonheul. The highest DI was measured at both sites in autumn when the biomass of the two major species (*Ecklonia cava* and *Sargassum fusiforme*) comprised 56.92 and 55.62% of the total biomass, respectively. At both sites, the highest value of the evenness index ($J'$) was recorded in summer and the lowest value was recorded in autumn. In contrast, the highest richness (R) and diversity ($H'$) indices were recorded in spring and the lowest were recorded in autumn. Generally, the ecological community indices were similar at both sites, whereas the richness (R) and diversity ($H'$) indices were somewhat higher at Jeonheul than Cheonjin.

## DISCUSSION

Seawater temperature is thought to be one of the important physical factors determining seaweed distribution (Druehl 1981). Macroalgal floras have been classified by the ratio of Chlorophyta and Rhodophyta species relative to Phaeophyta species (C/P, R/P, [C+R]/P), and the ratios increase as the tropical zone is approached (Cheney 1977). The macroalgal species composition at Jeju Island compared to the east coast of Korea is characterized by a higher proportion of Rhodophyta. This observation is believed to be a consequence of the Tsushima Current throughout the winter and spring, and the Yellow Sea Warm Water Current during summer and autumn (Kang 1966, Lee and Kim 1999). Korean seaweed flora belong to the warm temperate (Van den Hoek 1984, Lüning 1990) or cold temperate (Michanek 1979) region. It is clear from Table 1 that our results contrast with these earlier reports. The C/P ratio of our study was lower than that reported 19 years ago from Udo at Jeju (Lee and Ko 1991) and more recently on the western coast of Korea by Kkotji (Lee et al. 2007). The C/P ratio is somewhat higher than that documented 28 years ago at Jeju (Lee and Lee 1982), Chuja on the southern coast of Korea (Kim et al. 2008), and Jukbyeon and Daejin on the eastern coast of Korea (Shin et al. 2008). The R/P and (R+C)/P ratios are similar to the pattern of the C/P ratio except for the R/P ratios of Jeju (Lee and Lee 1982) and Kkotji (Lee et al. 2007). In our study, Udo had a greater proportion of Chlorophyta and Rhodophyta species than those on other Korean coasts. The C/P, R/P, and (R+C)/P values were directly proportional with latitude, although exceptions were observed, such as the C/P and (R+C)/P ratios for Kkotji (Lee et al. 2007). These exceptions could be related to local environmental factors or some unexplained spatio-temporal investigation variance such as the intertidal / subtidal, depth, period, or periodicity. Notably, the C/P, R/P, and (R+C)/P values obtained at Udo in this study were very similar to those reported about 20 years ago (Lee and Ko 1991).

In this study, the macroalgal species compositions from Udo were classified into four climate affinities: 7.09% cold, 42.91% temperate, 37.80% warm, and 12.20% broadwater species (Table 1).The cold and broadwater species comprised the lowest percentages in comparison with the ratio of other studies from Korea (Lee and Lee 1982, Lee and Ko 1991, Lee et al. 2007, Kim et al. 2008, Shin et al. 2008). The temperate-water species ratio trended in

**Table 2.** Seasonal variations in ecological macroalgal community indices from two sites at Udo

| Site | Community indices | Summer | Autumn | Winter | Spring | Mean |
|---|---|---|---|---|---|---|
| Cheonjin | Richness index (R) | 8.45 | 6.75 | 9.98 | 13.00 | 13.99 |
| | Diversity index ($H'$) | 3.43 | 2.87 | 3.33 | 3.75 | 3.67 |
| | $H'$max | 4.04 | 3.81 | 4.23 | 4.49 | 4.74 |
| | Evenness index ($J'$) | 0.85 | 0.75 | 0.79 | 0.84 | 0.78 |
| | Dominant index (DI) | 0.15 | 0.25 | 0.21 | 0.16 | 0.22 |
| | No. of species | 57 | 45 | 69 | 89 | 114 |
| Jeonheul | Richness index (R) | 9.12 | 8.43 | 11.32 | 13.67 | 15.97 |
| | Diversity index ($H'$) | 3.42 | 3.09 | 3.45 | 3.71 | 3.72 |
| | $H'$max | 4.14 | 4.08 | 4.37 | 4.57 | 4.89 |
| | Evenness index ($J'$) | 0.83 | 0.76 | 0.79 | 0.81 | 0.76 |
| | Dominant index (DI) | 0.17 | 0.24 | 0.21 | 0.19 | 0.24 |
| | No. of species | 60 | 58 | 79 | 96 | 131 |

a manner different than those of broad and coldwater species. We could not discern any pattern in the warmwater species. The ratio of coldwater species showed a tendency to increase in relation to the annual sea surface temperature and latitude. In particular, the coldwater species in this study were considerably less abundant than those in previous studies of 19 years ago at Udo (Lee and Ko 1991) and 28 years ago at Jeju (Lee and Lee 1982). Lee and Ko (1991) reported some coldwater species from Udo, such as *Capsosiphon fulvescens*, *Desmarestia viridis*, *Saccharina japonica*, *Campylaephora hypnaeoides*, *Mazzaella japonica*, *Nemalion vermiculare*, and *Odonthalia corymbifera* (Table 3). Although these species are comparatively large in size and have obvious characteristics useful for identification, we did not find or collect any of these species in this study (Table 3). Instead, we were able to find and collect *Gloiosiphonia capillaris*, *Neosiphonia japonica*, and *Polysiphonia morrowii*, even though Lee and Ko (1991) did not report finding these species at Udo. Changes in seawater temperature can have an effect on the biogeographical distribution patterns of seaweed (Breeman 1988, Hiscock et al. 2004, Müller et al. 2009). Thus, it is important to document the changes in macroalgal species compositions brought about by increasing seawater temperature using long-term investigations. Furthermore, these investigations are very useful to mon-

**Table 3.** Comparisons of the appearance of coldwater species between this study and previous studies at Udo

| Division | Species | This study | Udo (Lee and Ko 1991) |
|---|---|---|---|
| Chlorophyta | *Bryopsis australis* | + | |
| | *Capsosiphon fulvescens* | | + |
| Phaeophyta | *Acinetospora crinita* | + | |
| | *Desmarestia viridis* | | + |
| | *Sccharina japonica* | | + |
| | *Undaria pinnatifida* | + | + |
| Rhodophyta | *Acrochaetium plumosum* | | + |
| | *Acrosorium yendoi* | + | + |
| | *Alatocladia modesta* | + | + |
| | *Bonnemaisonia hamifera* | + | + |
| | *Bossiella cretacea* | | + |
| | *Callophyllis rhynchocarpa* | | + |
| | *Campylaephora crassa* | + | + |
| | *Campylaephora hypnaeoides* | | + |
| | *Ceramium japonicum* | + | + |
| | *Ceramium kondoi* | | + |
| | *Chondrus pinnulatus* | | + |
| | *Chrysymenia wrightii* | + | |
| | *Delisea pulchra* | + | |
| | *Gelidium elegans* | + | + |
| | *Gelidium pacificum* | | + |
| | *Gelidium vagum* | | + |
| | *Gloiopeltis furcata* | + | + |
| | *Gloiosiphonia capillaris* | + | |
| | *Heterosiphonia japonica* | + | + |
| | *Hydrolithon sargassi* | | + |
| | *Hypnea japonica* | + | + |
| | *Mazzaella japonica* | | + |
| | *Nemalion vermiculare* | | + |
| | *Odonthalia corymbifera* | | + |
| | *Polysiphonia morrowii* | + | |
| | *Schizymenia dubyi* | + | + |
| | *Symphyocladia latiuscula* | + | + |

itor the impact of climate change by documenting the expansion or contraction of macroalgal species, which are highly temperature-sensitive, along the Korean coast line.

Macroalgal and periphyton ecologists are interested in defining the factors that influence species occurrence and distribution patterns (Graham et al. 2009). Coastal marine communities have proven valuable as ecological models for determining the relative importance of physical factors, algal morphological and physiological adaptations, and biotic factors that structure macroalgal communities (Taylor et al. 1990, Orfanidis et al. 2001, Graham et al. 2009). Tide and light attenuation are the most important determinants of intertidal and subtidal zonation patterns of macroalgal assemblages. As the intertidal region is submersed at high tide and exposed at low tide, the upper intertidal region is exposed significantly for longer periods than that of lower areas (Doty 1946, Graham et al. 2009). Clear vertical zonation patterns were observed in the macroalgal communities at both Udo sites (Figs 3 & 4). The macroalgal communities at the high and mid levels of the intertidal zone were composed of *Ishige okamurai*, *Gloiopeltis* spp., *Myelophycus simplex*, *Sargassum fusiforme*, and *S. thunbergii*, as characterized by desiccation resistance (Fig. 4a). In contrast, below 6 m of the subtidal zone, the community was comprised of species such as *Ecklonia cava*, *Sargassum macrocarpum*, and *S. horneri* that have a wide surface (Fig. 4d & e), and was dominated by *E. cava* (Fig. 3).

Water movement is one of the most important variables influencing marine macroalgae, because it regulates nutrient availability, turbidity, and light penetration (Nishihara and Terada 2010). In many studies of the wave-exposure effect on macroalgal communities, an intermediate level of water motion improves the diversity and abundance of seaweeds by accelerating nutrient and gas exchange, whereas a high level of water motion either decreases diversity or promotes the abundance of certain species such as short clump turfs and kelps (Prathep 2005, Thongroy et al. 2007, Nishihara and Terada 2010). In the present study, the macroalgal community at the sheltered Cheonjin site showed high biomass and more stable characteristics, whereas that in the exposed Jeonheul site contained various dominant species influenced by season (Fig. 3). Kelps (*Sargassum* spp., *Undaria pinnatifida*, and *Ecklonia cava*) were the dominant species in the subtidal region of Cheonjin and at the 7-9 m depth level of Jeonheul. Distribution of kelp may be caused by physical disturbances such as water motion and wave action, and they may be able to withstand more water movement than other functional formed algae because of their large thalli. The dominant species was turf-form algae from the low-intertidal zone to the 4-6 m depth level of Jeonheul, which is less able to withstand water movement than kelp. In contrast, Cheonjin has a bay-like shoreline and showed a high abundance of kelp species within the same vertical range. Villaça et al. (2010) documented a similar pattern: the reef front of Atol das Rocas is also dominated by turf species such as *Caulerpa verticillata*, *Dictyota* spp., and *Dictyopteris* spp., but the largest proportion of brown algal species was found at depths below 6 m. Our dendrogram also supports the contention that environmental differences influence macroalgal species composition (Fig. 4). In the shallow part of the shore (low intertidal to 6 m depth of the subtidal zone), turf-formed algae such as *Chondria crassicaulis*, *Chondracanthus tenellus*, *Grateloupia cornea*, and *Chondrophycus* spp. were the most common species on the exposed Jeonheul site, whereas kelp species such as *Myagropsis myagroides*, *Sargassum corneum*, *S. hemiphyllum*, *S. horneri*, and *S. macrocarpum* were comparatively common on the sheltered Cheonjin site.

A comparison of the mean biomass between this study and recently published studies (Table 4) indicates that the mean biomass at Udo was similar with that of the subtidal zone of Munseom, Jeju Island (Ko et al. 2008). However, it was higher than that of other coastal regions of Korea, such as Yokjido and Ilkwang Bay, Gyeongnam (Choi et al. 2008, Kang et al. 2008), Daejin, Gangwon (Shin et al. 2008), and Woejodo and Jusamdo, Jeonbuk (Choi et al. 2008). The ecological community indices indicate that

**Table 4.** Comparisons of mean biomass among this study and previous studies from other Korean Peninsula coasts

| | Udo (This study) | Munseom (Ko et al. 2008) | Yokjido (Choi et al. 2008) | Ilkwang (Kang et al. 2008) | Daejin (Shin et al. 2008) | Woejodo (Choi et al. 2008) | Jusamdo (Choi et al. 2008) |
|---|---|---|---|---|---|---|---|
| Shore level | Inter / Sub | Sub | Inter / Sub | Inter / Sub | Inter / Sub | Inter / Sub | Inter / Sub |
| Biomass (g wet wt $m^{-2}$) | 2,934.5 | 2,784 | 576.8 | 78.5-731.8 | 1,292 | 198.27 | 417.34 |

Inter, intertidal; Sub, subtidal.

Udo has stable macroalgal communities (Lee et al. 2007).

In conclusion, Udo on Jeju Island maintains a higher macroalgal diversity level and biomass than other coastal regions of Korea. However, due to the construction of new water supply facilities from Jeju Island to Udo in 2010, it is possible that the overflow of fresh water or other pollution from these facilities could damage the uncontaminated sea areas of Udo. In contrast to a previous report (Lee and Ko 1991) on macroalgal species composition, we found that the number of species growing in cold water at Udo had decreased, whereas the number of high-temperature resistance species had increased. We speculate that this result is related to the increase in annual sea surface temperatures caused by the greenhouse effect. Additional studies involving continuous long-term monitoring of water quality, sea temperature, and species composition of seaweeds are needed. The differences in the compositions of the macroalgal communities at the two sites suggest that the huge artificial construction along the shoreline could affect seaweed species composition due to changes in physical factors. The results of the present study indicate that the ecological status of the seaweed community at Udo is stable for now, and provide a baseline database to begin long-term monitoring studies to protect the abundant macroalgal beds of Udo.

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