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Temporal Variations in Seaweed Biomass and Coverage in Korean Coasts: Ongdo, Chungnam

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Temporal variations of seaweed biomass and coverage were seasonally examined at Ongdo in the Yellow Sea, Korea from August 2006 to April 2008. Average seaweed biomass was 245.79 g/m^2 in wet weight and coverage was 16.49% with seasonal variations from 13.97% in spring to 18.55% in autumn. Seaweeds were distributed across the shore gradient from the high intertidal to 10m depth in the subtidal zone. Biomass was always higher in the subtidal zone (310.24 g/m^2) than in the intertidal zone (181.35 g/m^2). Of total seaweed biomass, 76.52% (first year) and 80.32% (second year) occurred from the low intertidal zone, down to depth of 1 to 5m. *Gelidium amansii* had the highest importance value and biomass, and subdominant species were *Chondrus ocellatus* and *Chondria crassicaulis*. Coarsely-branched seaweeds comprised the highest proportion of biomass (214.84 g/m^2, or 87.41% of the total biomss). Seasonal variations in algal biomass were largely explained by fluctuations in the biomass of coarsely-branched and thick-leathery forms. In conclusion, seaweed biomass of Ongdo shore was very low because of perennial *G. amansii* showing low biomass as compared to kelp or *Sargassum* spp. However, these results indicate Ongdo is good place to grow seaweeds because coarsely-branched form seaweeds including *G. amansii* are dominant at unpolluted and clean environment.

Key words: Biomass, Coverage, Functional form, Seaweed

Introduction

Seaweed beds play important roles as primary producers, habitat, feeding and nursery grounds of marine animals in coastal ecosystems (Terawaki et al., 2001; Choi et al., 2002; Eklof et al., 2005; Choi et al., 2008a). The biomass and species diversity of seaweeds are positively correlated with the abundance of marine animals (Eklof et al., 2005), and they can be used as basal indicators of ecosystem status (Díez et al., 1999; Neto, 2001). However, parameters of seaweed assemblages, including species richness, biomass, and coverage, are changing through anthropogenic habitat modification and alterations in physical factors such as seawater temperature, light, and sediment load (Zhuang and Zhang, 2001; Piazzi et al., 2002; Arévalo et al., 2007; Wells et al., 2007). These relationships allow us to use the benthic seaweed flora and assemblage structure as indicators to evaluate changes in environmental conditions and to monitor coastal marine ecosystems (Wells et al., 2007; Choi et al., 2008b).

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Seaweeds were classified into six functional forms based on morphology, primary production (photosynthetic rate), and thallus texture by Littler (1980); the scheme was later developed by several researchers (Littler and Littler, 1980; Littler and Arnold, 1982; Steneck and Dethier, 1994). Algal thallus structure is closely correlated with primary productivity (wet or dry weight basis); for example, coarsely-branched forms are more productive than thick-leathery, jointed-calcareous or crustose form seaweeds (Littler, 1980). Ecological and physiological characteristics of each seaweed functional form have been examined (Littler, 1980; Hanisak et al., 1988; Steneck and Dethier, 1994), and used to explain the changes in distribution patterns, abundances and diversities of seaweed assemblages (Phillips et al., 1997). Green ephemeral algae including sheet- and filamentous- functional forms are generally prevalent in disturbed or eutrophic habitats (Littler and Littler, 1984; Pinedo et al., 2007). Conversely, late-successional macroalgae such as thick leathery and calcareous functional seaweeds are dominant in stable environments. Thus, functional-form compositions of seaweed assemblages are useful indicators of environmental conditions.

In Korea, most studies on seaweed assemblages have involved the measurements of cover and biomass on rocky intertidal shores (Koh, 1990; Yoo and Kim, 1990; Kim et al., 1995), with only minor attention to the subtidal zone (Lee et al., 1990; Choi et al., 2008; Kang et al., 2008; Ko et al., 2008b). Because of the difficulties and costs of sampling, the seasonality of subtidal algae off western Korean coasts has re-mained largely unexplored. On rocky subtidal sub-strata, the seaweed community structure and vertical distribution are related to physical factors such as light and water movement, which are inversely correlated with seawater depth (Neto, 2001). Further-more, subtidal seaweed assemblage structures re-spond better to changing environmental conditions (including seawater quality) than intertidal assemblages because environmental stresses are weaker in the subtital zone (Kim et al., 1998). Thus, the aim of this study was to examine seaweed assemblage structure measured by seasonal and vertical biomass patterns and variations in seaweed functional-form group proportions; these are contributions to the knowledge on intertidal and subtidal seaweed vegetation at Ongdo, Korea.

Materials and Methods

Sampling was carried out seasonally during low tide from August 2006 to April 2008 at Ongdo Island (36°38′ N, 126°00′ E), Yellow Sea, Korea. During the study period, the average seawater temperature was 14.40°C±7.28 (SD), varying from 3.61°C±0.26 in February 2008 to 26.19 °C±1.15 in August 2007. The mean salinity was 29.64‰±1.68 and ranged from 27.16‰±1.79 in April 2006 up to 33.22‰±1.19 in October 2006.

For quantitative data collection, five replicate quadrats (50 cm×50 cm) were randomly placed at three intertidal levels (high, middle and low) and at three subtidal levels (1, 5, and 10 m depth). Subtidal collections were made by scientific SCUBA-diving. Seaweed cover and frequency were recorded for each species using the methods of Satio and Atobe (1970). Macroalgae within each quadrat were collected using a scraper, put into plastic bags, and preserved in formalin-seawater at 5-10%. Seaweeds were brought to the laboratory, rinsed with tap water, and identified following Lee and Kang (2001). Wet weights were measured first, followed by drying at 60°C to constant weight and weighing of dry mass to give total biomass (g/m^2) in wet and dry bases. We computed the average seaweed biomass for the five quadrats at each shore level. Based on coverage and frequency, the relative coverage (RC), relative frequency (RF), and importance value (IV) of each species were calculated. The dominant species in vertical distribution was determined by its IV. All seaweeds collected were classified into six functional-form groups (sheet, filamentous, coarsely-branched, thick-leathery, jointed-calcareous, and crustose) by the methods of Littler and Littler (1984), and the algal biomass in each group was calculated.

Results

Biomass

The average seaweed biomass was 245.79 g/m^2 wet weight (49.71 g/m^2 dry wt) at Ongdo during the survey period, and was about 10% higher in the first study year [Aug. 2006-Apr. 2007; 256.61 g/m^2 (54.32 g/m^2)] than in the second [Aug. 2007-Apr. 2008; 234.98 g/m^2 (45.10 g/m^2)].

In the first year, biomass ranged from 139.18 g/m^2 (41.48 g/m^2) to 415.07 g/m^2 (53.64 g/m^2) depending on season, and was maximal in summer and minimal in spring (Fig. 1). In the second study year, biomass ranged between 153.69 g/m^2 (26.50 g/m^2) and 430.80 g/m^2 (70.44 g/m^2), and was maximal in summer and minimal in winter. A clear seasonal pattern was seen with average biomass peaking in summer, decreasing in fall, declining to a minimum in winter, and increaseing from spring onward (Fig. 1).

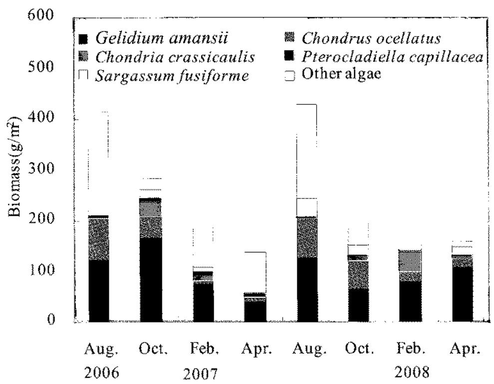

Fig. 1. Seasonal variations in mean biomass (wet weight g/m^2) of dominant seaweeds at Ongdo, Taean, Korea, from August 2006 to April 2008.

Seaweed biomass was significantly different between intertidal and subtidal levels, and always greater at lower on the gradient (1, 5, and 10 m; 310.24 g/m^2) than in the intertidal zone (high, mid, and low; 181.35 g/m^2; Table 1). The difference was especially marked in summer/autumn, particularly in August 2007. Seaweed biomass in the intertidal zone ranged from 171.66 g/m^2 to 326.88 g/m^2 during the first year and from 97.92 g/m^2 to 195.36 g/m^2 in the second year. Intertidal biomass was maximal in summer and minimal in winter in both years. In the subtidal zone, biomass ranged from 105.25 g/m^2 to 503.26 g/m^2 and from 182.81 g/m^2 to 666.24 g/m^2 in the first and second years, respectively (Table 1). Maximal biomass was found in summer, as in the intertidal zone, but was minimal in spring.

Across the subtidal shore gradient, seaweed biomass ranged between 60.62 g/m^2 and 444.80 g/m^2, and was minimal at 10 m depth and maximal at 1m depth in the first year (Table 1). In the second year, seaweed biomass ranged from 79.42 g/m^2 at the upper inter-tidal shore to 611.32 g/m^2 at 1m depth in the subtidal zone (Table 1). Significant seasonal fluctuations in biomass occurred in the low intertidal, and at 1 and 5 m subtidal depths. About 76.52% and 80.32% of the annual seaweed biomasses in the first and second years, respectively, were in this section of the vertical gradient (Table 1). In both years, the greatest values occurred at 1m depth in the subtidal zone in summer, and were mainly attributable to increased biomass accretions in *Gelidium amansii* (507.37 g/m^2) and *Chrysymenia wrightii* (482.94 g/m^2) in the first year and *Undaria pinnatifida* (730.64 g/m^2), *G. amansii* (485.42 g/m^2), and *Chondrus ocellatus* (360.76 g/m^2) in the second year.

Coverage

Macroalgal coverage averaged 16.49%, with seasonal variations from 13.97% in spring to 18.55% in autumn over the study period (Fig. 2). The proportion of red algal cover varied from 83.37% in summer to 95.47% in fall and across all sampling time, red algae made up 89.14% of total cover (16.49%). Seasonal variations in seaweed cover were between 0.67% and 2.87% (from 3.61% to 15.80% in proportion) in brown algae and between 0.003% and 0.18% (from 0.02% to 0.97% in proportion) for green algae.

In the first year, the annual seaweed coverage was 15.94% (from 12.20% in spring to 18.65% in summer) and species richness consisting of seaweed coverage were from 17 (autumn) to 25 species (summer, winter, and spring; Fig. 2). Seaweed cover on the gradient varied between 8.28% and 25.47%; it was maximal at 5 m and minimal at 10 m depth. About 60% of the seaweed cover occurred from the low intertidal zone down to 5 m depth in the subtidal zone. Seaweed cover fluctuated seasonally from 5.57% to 24.42% at the low intertidal shore level, from 11.44% to 30.34% at 1 m, and from 22.24% to 29.89% at a 5 m depth.

In the second year, the average annual algal cover was 17.04% (from 14.11% in winter to 20.63% in autumn) with species richness consisting of coverage varying from 14 in winter to 26 species in summer (Fig. 2). Seaweed cover varied on the shore gradient from 11.35% to 29.94%, with maximal values at 1m in the subtidal and lowest values on the upper intertidal shore. Most of the seaweed cover (67.61%) occurred at the low intertidal and at subtidal depths from 1 to 5 m. Seaweed cover varied seasonally from 11.10% to 26.21% in the lower intertidal zone, from 19.39% to 45.94% at 1 m in the subtidal zone, and from 13.55% to 44.35% at a 5 m depth in the subtidal zone.

Vertical distribution and dominant species

Over the study period, the vertical distribution of dominant species based on important value (IV) was

Table 1. Seasonal variations in mean seaweed biomass (wet weight g/m^2) at Ongdo, Taean Korea, from August 2006 to April 2008

Shore level	2006		2007				2008	
	Aug.	Oct.	Feb.	Apr.	Aug.	Oct.	Feb.	Apr.
Intertidal zone								
High	130.10	155.14	110.46	123.43	138.18	89.88	44.68	44.95
Mid	201.97	184.86	165.69	131.70	64.73	91.31	125.28	72.34
Low	648.58	316.82	238.83	264.18	383.18	216.55	123.81	285.71
Mean	326.88	218.94	171.66	173.10	195.36	132.58	97.92	134.33
Subtidal zone								
-1 m	1,160.38	271.01	234.28	113.52	1,660.77	226.96	324.08	233.70
-5 m	281.14	679.23	361.20	143.64	301.18	455.18	127.86	190.78
-10 m	68.26	87.09	28.55	58.60	36.78	101.18	176.46	123.95
Mean	503.26	345.78	208.01	105.25	666.24	261.10	209.47	182.81
Total mean	415.07	282.36	189.84	139.18	430.80	196.84	153.69	158.57

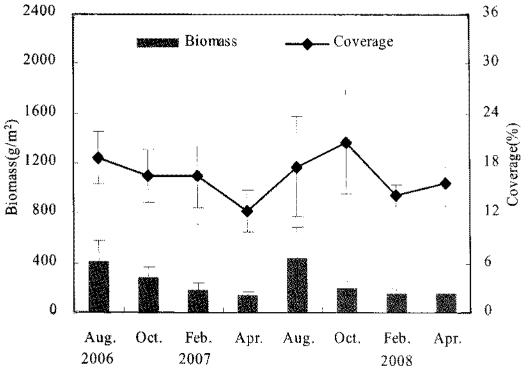

Fig. 2. Seasonal variations in percent cover (%) of seaweeds and number of species at Ongdo, Taean Korea, during the study period. Bars are standard errors.

recorded in Table 2. Dominant seaweeds in the intertidal zone were *Carpopeltis affinis* (from high to mid shores) and *Sargassum fusiforme* from the mid to low zones. The red alga, *Gelidium amansii* was the most dominant species from a tide pool in the high intertidal zone down to 10 m depth in the subtidal zone (Table 2). *Chondrus ocellatus*, a subdominant species, was widely distributed from the mid intertidal shore down to 10 m depth. *Chondria crassicaulis* was abundant in the low intertidal zone, and at 1 and 10 m subtidal levels. *Chrysymenia wrightii* was predominant at 1 and 5 m subtidal depths (Table 2).

Gelidium amansii was also dominant in measures of biomass and IV in all seasons of the study period at Ongdo (Fig. 1 and Table 2). Subdominant species were *C. ocellatus*, *C. crassicaulis*, *Pterocladiella capillacea*, and *S. fusiforme* (Table 2). Seasonal changes in seaweed biomass were observed. For example, *C. ocellatus* was abundant from summer to fall over the two study years and *C. crassicaulis* had the greatest biomass in October and February. On the basis of IVs, *Caulacanthus okamurae, C. wrightii, Gracilaria textorii* and *Undaria pinnatifida* were placed among dominant algae only in summer. *Laurencia okamurae* and *Scytosiphon lomentaria* predominated in spring and *Corallina pilulifera* did so in winter (Table 2).

Functional-form groups

Seaweeds of six functional-form groups (sheet, filamentous, coarsely-branched, thick-leathery, jointed-calcareous, and crustose) were observed and their proportions were found to fluctuate seasonally (Table 3). The coarsely-branched form was the most abundant in biomass measures (214.84 g/m^2, or 87.41% of the total biomass). Annual variations in seaweed biomass were also observed in the coarsely-branched and thick-leathery forms (Table 3). The biomass of the coarsely-branched form seaweeds was greater in the first year (233.54 g/m^2 = 91.01% of the total biomass) than in the second year (196.15 g/m^2 = 83.48% of the total biomass). The biomass of the thick-leathery form increased from 15.89 g/m^2 (6.19%) in the first year to 34.62 g/m^2 (14.73%) in the following

Table 2. Vertical distribution of dominant species based on importance value at Ongdo, Taean Korea, over the study period

Shore level		Dominant species (Importance value)	
Intertidal zone	High	*Gelidium amansii* (28.16) *Caulacanthus okamurae* (10.33) *Grateloupia prolongata* (8.56)	*Pterocladiella capillacea* (24.66) *Carpopeltis affinis* (10.38) *Myelophycus simplex* (5.76)
	Mid	*Gelidium amansii* (34.61) *Chondrus ocellatus* (9.41) *Laurencia okamurae* (5.77)	*Carpopeltis affinis* (17.29) *Sargassum fusiforme* (6.86)
	Low	*Chondrus ocellatus* (27.13) *Sargassum fusiforme* (13.90) *Chondria crassicaulis* (6.91)	*Gelidium amansii* (19.04) *Sargassum thunbergii* (9.49)
Subtidal zone	-1 m	*Chondrus ocellatus* (31.20) *Chondria crassicaulis* (8.11) *Chrysymenia wrightii* (5.54)	*Gelidium amansii* (30.79) *Undaria pinnatifida* (7.68)
	-5 m	*Gelidium amansii* (66.79) *Chrysymenia wrightii* (6.31)	*Chondrus ocellatus* (9.89)
	-10 m	*Gelidium amansii* (34.47) *Gracilaria textorii* (9.06) *Kallymenia crassiuscula* (5.05)	*Chondrus ocellatus* (11.27) *Chondria crassicaulis* (7.64)

Table 3. Seasonal variations in mean biomass (wet weight g/m^2) of functional (F)-form groups at Ongdo during the study period

F-Form	2006		2007				2008		Mean
	Aug.	Oct.	Feb.	Apr.	Aug.	Oct.	Feb.	Apr.	
S	8.99	-	-	4.90	7.02	4.17	0.05	0.15	3.16
F	-	0.30	0.14	0.40	-	0.27	-	1.22	0.29
CB	343.50	273.30	186.64	130.71	289.55	187.26	153.64	154.16	214.84
TL	61.09	8.76	0.08	2.37	131.87	3.59	-	3.00	25.25
JC	1.50	-	2.92	0.80	2.37	1.56	0.01	0.04	2.24
C	-		0.05	-	-	-	-	-	0.01

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

year (Table 3). Seasonal biomasses of the other seaweed functional-form groups fluctuated by ±10.00 g/m^2 during the two survey years. These results indicate that seasonal variations in algal biomass were principally linked to fluctuations in the biomass of the coarsely-branched and thick-leathery forms of algae. As described in Fig. 1, five dominant algae (*Gelidium amansii, Chondrus ocellatus, Chondria crassicaulis, Pterocladiella capillacea, Sargassum fusiforme*) were in the coarsely-branched category. *Undaria pinnatifida* (thick-leathery form) was abundant in summer and *Corallina pilulifera* (jointed-calcareous form) was so in winter. Crustose algae, including *Ralfsia verrucosa* and *Lithophyllum okamurae*, were found in winter with low biomass and coverage.

Vertical biomass distributions of seaweed functional forms were directly linked to the identity of dominant species. In the coarsely-branched category, *G. amansii* and *C. ocellatus* were distributed from the high intertidal zone to 10 m depth in the subtidal zone, but *Caulacanthus okamurae* only on the high shore. The thick-leathery form algae, *U. pinnatifida* (from low to 10 m) and *Gracilaria textorii* (5-10 m) were mainly found on the lower shore levels at Ongdo.

Discussion

The abundance and diversity of seaweeds growing on intertidal and subtidal rocky shores have a fundamental role in determining the productivity of coastal systems in temperate seawaters (Díez et al., 1999; Piazzi et al., 2002; Kim et al., 2007). In western coastal areas of South Korea, seaweed biomass was greater at mid latitudes (mean, 135.51 g/m^2) than in the northern (29.51 g/m^2) and southern parts (99.68 g/m^2; Table 4). Differences in seaweed biomass are positively related to species richness (Neto, 2000, 2001; Zhuang et al., 2004), and accordingly, species richness was greater at mid latitudes than in the northern and southern parts (Table 4). These differences in diversity and biomass of seaweeds along the west coast of Korea may result from water turbidity caused by sediment suspension (Kim et al., 1995). Seaweed biomass ranged from 80.63 to 173.43 g/m^2 around three offshore Yellow Sea islands (Korea); assemblages on these islands were more stable than those in coastal areas (Table 4). Our measured seaweed biomass of 39.52 g DW/m^2 in the Ongdo intertidal zone is remarkably lower than that on other islands with very similar water turbidity. Thus, low seaweed biomass at Ongdo may not be explained by seawater turbidity.

Seaweed biomass is also a function of the taxonomic and functional group composition of dominant algae (Johnston, 1969; Littler and Littler, 1980; Prathep, 2005). Generally, seaweed biomass is greater in assemblages of brown algae such as kelps and *Sargassum* species than in stands of green and red algae (Johnston, 1969; Nam, 1986; Prathep, 2005). On the rocky shores of islands in the Yellow Sea, dominant seaweeds are mainly brown algae, *Laminaria japonica* (at Bagryoungdo), *Sargassum horneri* (at Deokjeokdo), and *S. thunbergii* (at Sapsido, Woejodo, and Jusamdo), or/and jointed-calcareous group algae (*Corallina pilulifera* at Woejodo). In the western coastal area of Korea, *S. thunbergii* and *C. pilulifera* are the dominant seaweeds (Yoo and Kim, 1990; Kim and Yoo, 1994; Kim et al., 1995; Lee et al., 2000; Lee et al., 2007a,b; Choi et al., 2008c). In particular, *S. thunbergii* accounts for 57.83% of the seaweed biomass at Muchangpo, 56.88% at Maryangri (Yoo and Kim, 1990), and 54.64% at Jusamdo (Choi et al., 2008b). In our study, however, the more diminutive *Gelidium amansii* and *Chondrus ocellatus* were the dominant species, representing 55.23% of the total seaweed biomass at Ongdo during the survey period. Also, Littler and Littler (1980) reported that *Gelidium purpurascens/robustum* weighs less than *Corallina officinalis*, whose biomass is 81.70% $CaCO_3$. Thus, low seaweed biomass at the Ongdo shore may result

Table 4. Seaweed biomass (dry weight g/m^2) and species number at the intertidal zone of coastal and island areas along the western sea of Korea

Region	Station	Biomass	No. of species	References
Coast area				
Northern Part	Inchon dock	25.02	24	Yoo et al. (1996)
		34.00	30	Yoo et al. (1999)
Middle Part	Taean	279.71	97	Yoo and Kim (2003)
	Padori	254.25	84	Lee et al. (1997)
		123.23	50	Lee et al. (2000)
		54.54	79	Lee et al. (2007)
	Muchangpo	73.66	63	Kim and Lee (1985)
		90.42	86	Yoo and Kim (1990)
	Maryangri	72.76	73	Yoo and Kim (1990)
Southern Part	Yonggwang	99.68	61	Kim and Huh (1998)
Island area				
Northern Part	Bagryoungdo	119.43	41	Baek et al. (2007)
	Deokjeokdo	80.63	22	Lee et al. (2007)
Middle Part	Sapsido	173.43	100	Yoon and Boo (1991)
Southern Part	Jusamdo	97.46	ND	Choi et al. (2008)

ND, no data.

from the occurrence of the dominant rhodophyte seaweeds (*G. amansii* and *C. ocellatus*) in the coarsely-branched category.

Seaweed functional-form composition has been used as an indicator for interpreting community stability or disturbance patterns and it is applicable anywhere predominant algal bundances are known (Hanisak et al., 1988). Sohn (1987) reported that sheet- and filamentous-form seaweeds are common in shallow and highly turbid coastal areas, while coarsely-branched and thick-leathery forms are dominant at offshore coastal stations in Korea. Coarsely-branched seaweeds comprise 42.00% to 56.30% (from Yeonpyeongdo to Yonggwang) of the species richness in western areas of Korea (Hwang et al., 1996; Lee et al., 2007b; Yoo et al., 2007; Choi et al., 2008c). In the present study, the coarsely–branched form (including *G. amansii* and *C. ocellatus*) accounted for 52.73% and 87.41% of the species number and biomass, respectively. The abundance of perennial *G. amansii*, the representative species, may be related to the environmental conditions such as strong wave action and relatively clean water at the site because *Gelidium* spp. typically occur in turbulent habitats with rapid water movement, low sedimentation, and no pollution (Santelices, 1991; Díez et al., 2003).

Differences in the dominant seaweeds growing in the subtidal zone (1 m depth) were also found among islands positioned from northern to southern parts of the Yellow Sea (Baek et al., 2007; Choi et al., 2008b). The dominant seaweeds in terms of biomass were *L. japonica* and *Ulva pertusa* at Bagryoungdo (Baek et al., 2007) and *S. thunbergii* and *U. pinnatifida* at Woejodo (Choi et al., 2008b). In the present study, however, *C. ocellatus*, *G. amansii,* and *U. pinnatifida* were dominant at Ongdo.

In conclusion, seaweed biomass was very low, reaching 49.71 g dry wt./m^2 at Ongdo; the dominant species were *Gelidium amansii*, *Chondrus ocellatus*, *Chondria crassicaulis*, *Pterocladiella capillacea*, and *Sargassum fusiforme*. *Gelidium amansii* was the representative species. It was distributed from the high intertidal zone to 10 m depth in the subtidal zone. The abundance of the diminutive perennial *G. amansii* resulted in low seaweed biomass, but the species is nevertheless indicative of good environmental conditions because coarsely-branched forms including *G. amansii* are dominant at unpolluted and clean environments.

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