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Seaweed Beds and Community Structure in the East and South Coast of Korea

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Abstract: This study conducted a community investigation via scuba-diving excursions into the subtidal regions of seven sea areas on the eastern coasts and three sea areas on the southern coasts, from October to December 2017, to determine the characteristics of seaweed communities and the current status of barren ground in natural seaweed beds in Korea. The results showed that species composition and average biomass in the sea area were 5–48 species and an average of 114.42 g/m^2 (0.29–273.60 g/m^2) in the eastern coasts, where red algae—an annual opportunity species—were dominant, and 21–48 species and an average of 1056.84 g/m^2 (53.03–2683.02 g/m^2) in the southern coasts, where perennial large brown algae were dominant. Using Orfanidis' EEI-c model, evaluations of the community states showed they varied significantly depending on the inclusion of melobesidean algae, and this model was determined to be inappropriate for direct application in sea areas with a low coverage of all macroalgae. A comprehensive review of the seaweed community characteristics of seaweed beds, the marine environment, the coverage of melobesidean algae, and the analysis results regarding the density of grazers showed that a decrease in the seaweed community, according to the barren ground phenomenon, was more severe in the eastern than southern coasts. Furthermore, there were also significant differences in seaweed community characteristics according to sea area and barren ground. Therefore, suitable countermeasures corresponding to the characteristics of each sea area are necessary; for example, the creation of growth substrates for the colonization of macroalgae in Deoksin and Saido Is., the transplantation of large brown algae in Gangyang and Daedurado Is., action plans for marine forest monitoring in Geomundo Is., and an improvement in substrates in Yeongjin, Mangsang, Daejin, Chogok, and Geundeok are possible countermeasures.

Keywords: barren ground; community state; EEI-c model; melobesidean algae; seaweed beds

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1. Introduction

Natural seaweed beds, also referred to as "sea forest," "kelp forest," and "marine forest," refer to communities of macroalgae that have been naturally formed [1–3]. Seaweed beds greatly contribute to coastal ecosystems as a habitat, spawning place, and food source for various marine organisms. However, the distribution of macroalgae communities around the world has recently been decreasing due to various causes, including climate change and ecological environment change [4,5].

In Korea, domestic barren ground phenomena started locally, occurring in the 1960s and 1970s [6,7], and the area of occurrence is continuously expanding. Since the report of a spreading area of 370 ha in 1997, it has expanded to 2413 ha in 2003–2004 and 10,518 ha in 2014 in the eastern coast. As a result, barren ground is becoming an increasingly serious problem, occurring across 62% of the entire rock mass area of 170,054 ha [8]. In the southern coasts, barren ground in the Yeosu sea area was reportedly 70 ha in 2006 [9], expanding to 962 ha across the entire southern coast in 2015, indicating that 30% of the entire rock mass area of 8234 ha is barren ground [10]. Thus, the spread of barren ground is expected to accelerate in both the eastern and southern coasts. This will result in increased damage, such as the destruction of coastal ecosystems and a reduction in fishery resources.

Ample quantitative research on the seaweed community in the eastern and southern coasts has been performed. This body of research began with Lee and Kang; Lee [11,12] studied the seaweed flora of Dongbaeksum, and this research continued with recent studies by Choi and Rho, Choi et al., Kim et al., Jeong et al., Kwon and Choi, Shin et al., and Han et al. [13–20], in the case of the eastern coasts. Studies on the southern coasts began with research by Song et al. [21], on the seaweed flora of Odongdo, and extends to recent studies by Park et al., Song et al., Oh et al., and Heo et al. [22–26]. However, most of these studies addressed seasonal changes in communities across certain sea areas, which is insufficient for handling the current status of barren ground phenomena.

Therefore, this study proposes a method for monitoring and managing seaweed beds suitable for the specific characteristics of seaweed communities in each sea area. This method was created by analyzing the structure of seaweed communities, evaluating the conditions of the communities, and identifying the current status of seaweed communities in natural seaweed beds among the seaweed habitats distributed in the eastern and southern coasts of Korea.

2. Materials and Methods

2.1. Marine Environment Survey

Marine environment data gathered from the nearby Marine Environmental Monitoring System were utilized for all sea areas except Geomundo Is. Since there are no Marine Environmental Monitoring System data on Geomundo Is., data, such as water temperatures, were collected at sites using a comprehensive water-quality measuring device (JFE-ADVANTECH, AAQ-RINKO, Victoria, Canada). Water temperature, salinity, pH, dissolved oxygen (DO), Chl-a, dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphate (DIP) were analyzed according to the maritime environment pollutant testing method after transporting the water collected from the site in a refrigerator.

2.2. Collection and Analysis

Macroalgae were collected from October–December 2017 from the eastern coasts, including Yeongjin, Mangsang, Daejin, Geundeok, Chogok, Deoksin, and Gangyang, and southern coasts, including Saido Is., Daedurado Is., and Geomundo Is., to identify the characteristics of natural seaweed beds and the current status of barren ground distributed across 10 sea areas. After selecting stations representative of seaweed communities within a depth of 7–12 m for each sea area, qualitative and quantitative surveys were conducted through underwater scuba diving (Table 1). A quantitative survey was performed after taking photographs using a 50 × 50 cm quadrat, which was subdivided into 10 × 10 cm portions. The macroalgae were collected entirely using a scraper, and the coverage was simultaneously recorded at the sites. A 1 × 1 m quadrat was further utilized to record the density of grazers (sea urchins, turban shell, abalone, and aplysia) at the sites.

After the collected macroalgae were placed in an icebox at the site and transported to the laboratory, biological identification was performed with the naked eye and a microscope (Olympus SZX9, Olympus BX50, Tokyo, Japan). The wet weights of the quantitatively collected samples were measured with an accuracy up to 0.01 g for each species using an electronic balance (CAS, CBL3200H, Seoul, Korea). The names of each species and its list were identified following the method provided by Kim et al. [27]. The quantitative samples of macroalgae and the density of grazers were converted into biomass per unit area (g wet wt./m^2) and number of individuals per unit area (ind./m^2), respectively.

Samples were compared in terms of the diversity index [28], richness index [29], evenness index [30], and dominance index [31] to understand the community characteristics. The dominance depending on the biomass of the emerged macroalgae was compared with K-dominance curves. The community index was calculated, and K-dominance curves were plotted using Plymouth Routines Multivariate Ecological Research (PRIMER) version 6.0 and PERMANOVA+ [32].

Table 1. GPS coordinates at study sites.

Region	GPS Coordinates	
Yeongjin	37°52′19.72″ N	128°50′54.44″ E
Mangsang	37°35′38.21″ N	129°06′09.41″ E
Daejin	37°34′35.86″ N	129°07′05.22″ E
Geundeok	37°20′28.64″ N	129°16′03.49″ E
Chogok	37°18′50.16″ N	129°17′45.70″E
Deoksin	36°52′37.75″ N	129°25′20.20″ E
Gangyang	35°23′25.96″ N	129°21′16.68″ E
Saido Is.	34°40′03.76″ N	128°16′03.67″ E
Daedurado Is.	34°33′48.81″ N	127°43′18.89″ E
Geomundo Is.	34°03′26.71″ N	127°16′56.20″ E

Comparisons of macroalgae coverage between sea areas showed that most of the species that appeared were composed of large brown algae, melobesidean algae, and macroalgae < 10 cm in body, which were length classified into four groups: canopy forming, sub-canopy forming, turf forming, and crustose corallines, based on their compositional characteristics [33–35]. Large brown algae were classified into either canopy-forming or sub-canopy-forming groups according to the body length of each species; all macroalgae except melobesidean algae were classified into the turf-forming group and the coverage of each group was schematically compared (Figure 1).

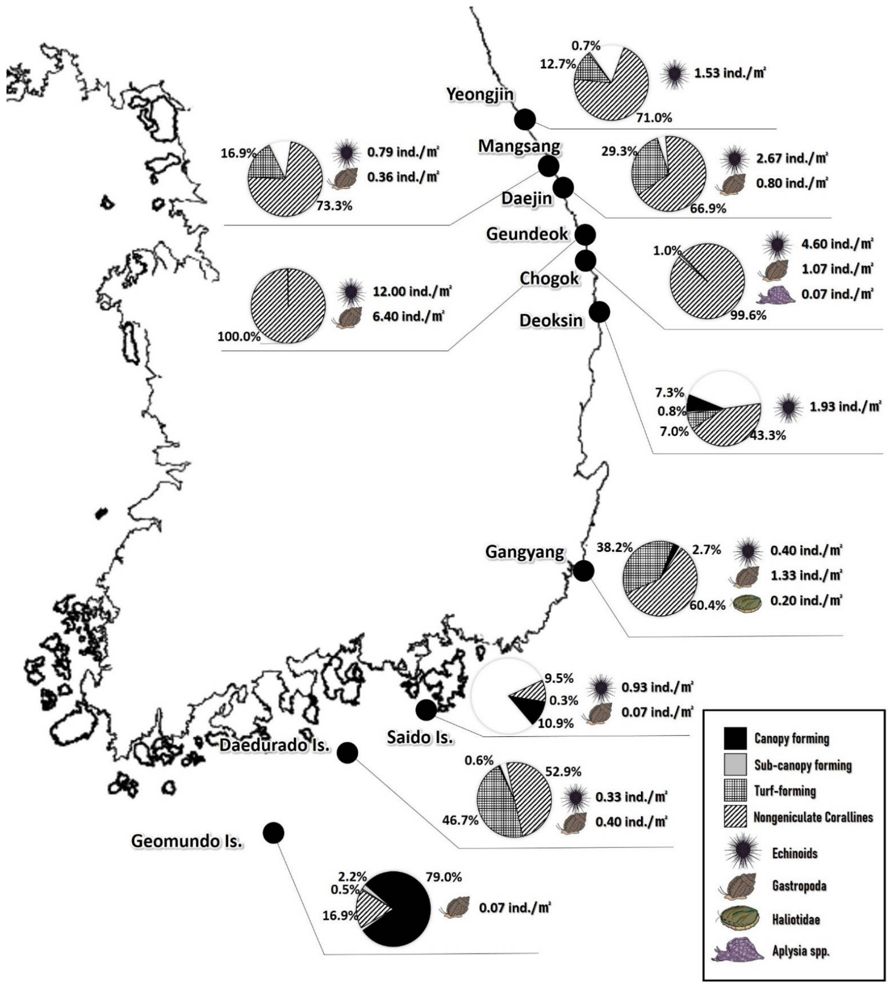

Figure 1. Coverage of seaweed group and grazer density at the study sites.

The EEI-c model from Orfanidis et al. [36] was applied to evaluate the community status. After the samples were classified into ESGI (subgroups: IA, IB, IC) and ESG II (subgroups: IIA, IIB) (comprising five groups) by species according to the macroalgae classification and ecological characteristics, the EEI-c was calculated using the sum of the coverage for each group.

3. Results

3.1. Marine Environment and Substrate Characteristics

The substrate characteristics for each sea area showed that although rock masses were predominant in most of the sea areas, such as Yeongjin, Mangsang, Daejin, Geundeok, Chogok, and Geomundo Is., sandy substrates were somewhat mixed, and Gangyang was composed of large and small rock masses and gravels. However, the surroundings of Deoksin, Saido Is., and Daedurado Is. were composed of sand or mudflats except for bedrock near the shorelines.

The survey of marine environmental data showed that transparency was ≥10 m in the central and northern parts of the eastern coasts. This figure lowered in the order of the southern part of the eastern coasts and the southern coasts. The sea surface temperature was 15.13–18.67 °C, salinity was 31.81–33.75 psu, and pH was 8.08–8.35, showing no significant differences. DO was generally high on the eastern coasts, showing 7.57–8.22 mg/L on the eastern coasts and 6.61–7.88 mg/L on the southern coasts. DIN, DIP, and chlorophyll a (Chl-a) values varied depending on the sea area. The water quality index (WQI) calculated by combining the water quality items was determined as Grade 1 in Youngjin, Mangsang, and Daejin, Grade 2 in Deoksin, Gangyang, Saido Is., and Geomundo Is., and Grade 3 in Geundeok, Chogok, and Daedurado Is. (Table 2).

Table 2. Marine environmental data at the study sites.

Region	Dominated Substrate	Transparency (m)	SST (°C)	Salinity (psu)	pH	DO (mg/L)	DIN (μg/L)	DIP (μg/L)	Chl-a (μg/L)	WQI
Yeongjin	rock	11.9	15.13	33.75	8.27	8.04	72.1	19.1	0.77	1
Mangsang	rock	12.1	16.01	33.66	8.20	7.94	57.2	18.7	0.71	1
Daejin	rock	12.7	16.39	33.65	8.21	7.90	71.7	19.5	0.77	1
Geundeok	rock	16.5	16.23	33.69	8.20	8.22	59.8	16.4	0.63	3
Chogok	rock	12.3	16.86	33.63	8.21	7.78	55.5	17.8	1.10	3
Deoksin	sand	8.0	17.54	33.73	8.23	7.75	47.6	17.3	0.92	2
Gangyang	gravel	4.7	16.83	33.64	8.14	7.57	83.0	21.6	1.03	2
Saido Is.	sand	4.5	18.67	33.11	8.13	7.88	39.6	19.2	0.76	2
Daedurado Is.	sand & mud	2.8	16.57	33.06	8.08	6.61	75.4	21.5	0.68	3
Geomundo Is.	bedrock	3.5	17.54	32.81	8.35	6.68	140.1	12.0	0.64	2

3.2. Species Composition

In total, 111 species of macroalgae appeared during the study period: 8 green algae, 16 brown algae, and 87 red algae, including 85 species in the eastern coasts and 72 species in the southern coasts. The proportion of red algae was very high, at 81–100% in the eastern coasts and 77–88% in the southern coasts. By sea area, 48 species appeared around Daedurado Is., which was the most, and 5 species appeared around Samcheok Chogok, which was the fewest (Figure 2). Melobesidean algae appeared in all sea areas. The frequency of *Symphyocladia marchantioides* and *Plocamium telfairiae* was high throughout the sea areas, and about half of all species appeared as fine-sized filamentous algae, such as Bryopsidaceae, Derbesiaceae, Cladophoraceae, Erythrotrichiaceae, Bonnemaisoniaceae, Ceramiaceae, Dasyaceae, Stylonemataceae, Colaconemataceae, and Callithamniaceae.

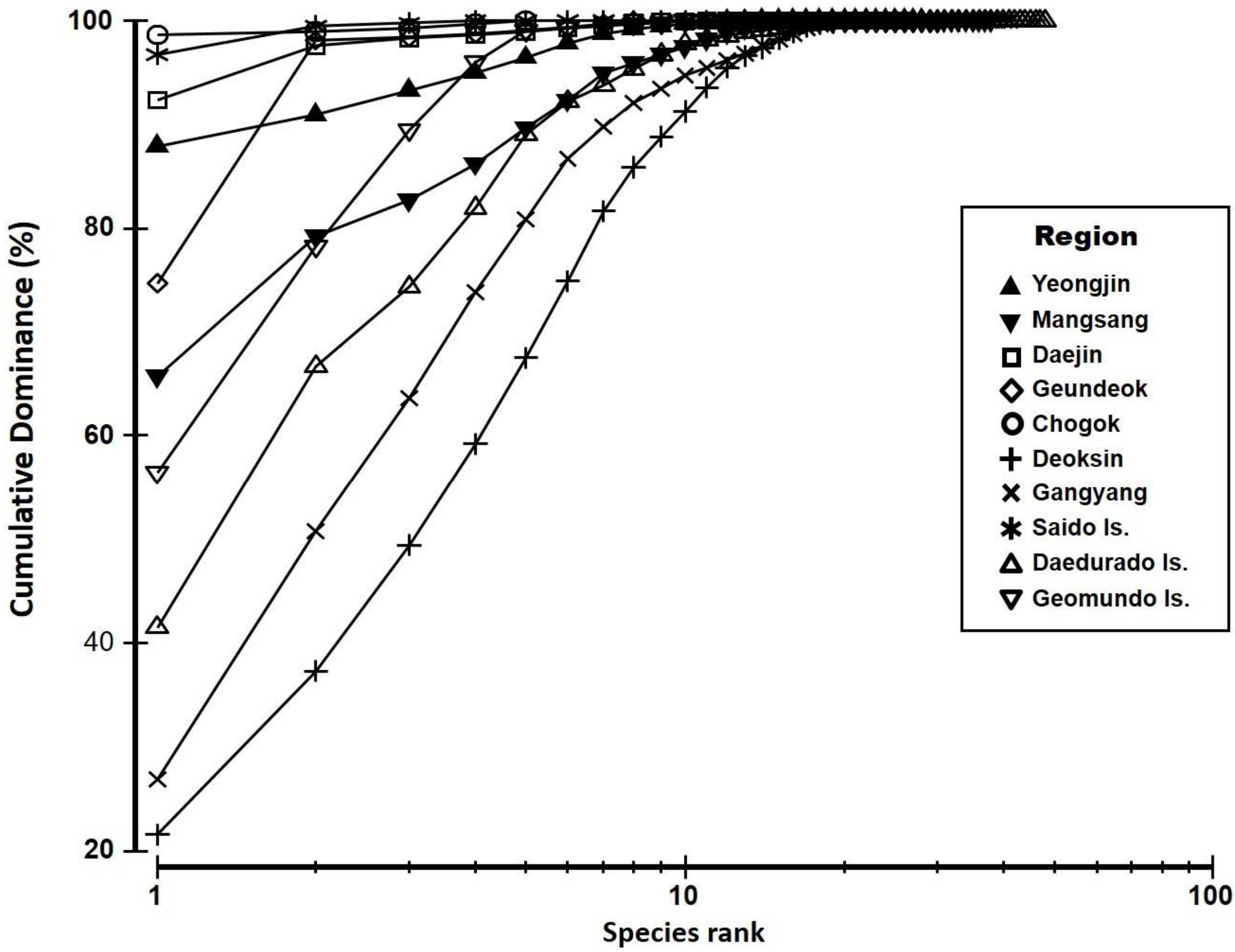

Figure 2. K-dominance curve of seaweed beds at the study sites.

3.3. Biomass, Dominant Species, and Ecological Index

The average biomass in the seven sea areas on the eastern coasts was 114.42 g/m^2, including 29.18 g/m^2 for green algae, 10.64 g/m^2 for brown algae, and 104.60 g/m^2 for red algae. That in the three sea areas on the southern coasts were 1056.84 g/m^2, including 60.63 g/m^2 for green algae, 907.60 g/m^2 for brown algae, and 88.60 g/m^2 for red algae. The results showed that the biomass of red algae was high in the eastern coasts and that of brown algae was high in the southern coasts. By sea area, the biomass around Geomundo Is. was remarkably high, at 2683.02 g/m^2, and that at Geundeok (0.33 g/m^2) and Chogok (0.29 g/m^2) were very low, due to the severity of the barren ground phenomenon (Figure 2).

The dominant species in each sea area were 197.73 g/m^2 (87.9%) of *Codium fragile* in Yeongjin, 61.41 g/m^2 (65.7%) of *P. telfairiae* in Mangsang, 252.62 g/m^2 (92.3%) of *P. telfairiae* in Daejin, 0.24 g/m^2 (74.7%) of *Acrosorium ciliolatum* in Geundeok, 0.28 g/m^2 (98.6%) of *A. ciliolatum* in Chogok, 21.85 g/m^2 (21.6%) of *Sargassum horneri* in Deoksin, 85.00 g/m^2 (26.8) of *Gelidium elegans* in Gangyang, 51.29 g/m^2 (96.7%) of *S. horneri* in Saido Is., 180.43 g/m^2 (41.5%) of *Ulva australis* in Daedurado Is., and 1513.83 g/m^2 (56.4%) of *S. macrocarpum* in Geomundo Is. Examining the top dominant species by sea area, r-selection species (annual opportunistic species) dominated the remaining seas except that around Geomundo Is.

The ecological index was excluded because the biomass in Geundeok and Chogok were significantly low. The species richness, evenness, diversity, and dominance indices were in the ranges of 3.67–8.16, 0.05–0.69, 0.16–2.40, and 0.12–0.94, respectively. The species richness index was highest in Mangsang, the evenness and diversity indices were highest in Deoksin, and the dominance index was highest in Saido Is., respectively (Table 3).

Table 3. Ecological indices of seaweed beds at the study sites.

Region	Richness	Eveness	Diversity	Dominance
Yeongjin	4.99	0.18	0.62	0.78
Mangsang	**8.16**	0.37	1.35	0.46
Daejin	4.46	0.11	0.37	0.86
Deoksin	6.93	**0.69**	**2.40**	0.12
Gangyang	6.95	0.57	2.12	0.17
Saido Is.	5.04	0.05	0.16	**0.94**
Daedurado Is.	7.74	0.46	1.78	0.25
Geomundo Is.	3.67	0.37	1.25	0.38

The K-dominance curves for the eight stations—excluding Geundeok and Chogok, whose biomass was significantly low—varied slightly, depending on sea areas (Figure 3). The three sea areas, Saido Is., Daejin, and Yeongjin, had 5–6 dominant species, and the dominance index of the top dominant species was significantly high as "severe". The dominance index of the top dominant species was $\geq$60% in Mangsang. However, the dominance index of subdominant species was not as large as "major". The dominance index of the top five dominant species in Geomundo Is. was almost 100%, showing the "major" state with a relatively steep slope in the curve. The species in the three sea areas—-Daedurado Is., Gangyang, and Deoksin—were relatively evenly distributed in a "moderate" state.

3.4. Current Status of Barren Ground and Community States

Macroalgae coverage by each sea area was 84.50% in Yeongjin, 90.35% in Mangsang, 96.31% in Daejin, 100.14% in Geundeok, 100.65% in Chogok, 58.31% in Deoksin, 101.22% in Gangyang, 20.70% in Saido Is., 103.26% in Daedurado Is., and 98.69% in Geomundo Is., the coverage of which was mostly close to 100%. The coverage of Deoksin and Saido Is. was relatively low compared to other sea areas; in particular, the coverage of Saido Is. was significantly low at 20%.

According to the hierarchical structure of the species appearing in each sea area, the species were classified into four groups: canopy-forming, sub-canopy-forming, turf-forming, and non-geniculate corallines. The results showed the coverage of melobesidean algae in Geundeok and Chogok reached 100%. The coverage of melobesidean algae in the five sea areas of Youngjin, Mangsang, Daejin, Deoksin, and Gangyang and Daedurado Is. was high, at 43.27–73.30%, and turf-forming and canopy-forming species were mixed. The coverage of melobesidean algae around Geomundo Is., unlike other sea areas, was low, and the coverage of canopy-forming and sub-canopy-forming species was significantly higher.

Analysis of the ecological status class (ESC), which represents the ecological state of the community, was conducted using the ecological evaluation index continuous formula (EEI-c). The results showed that as a cover of macroalgae species, when melobesidean algae were included, the ESC was high in Mangsang, Daejin, Geundeok, Chogok, Geomundo Is., good–high in Yeongjin, Deoksin, Gangyang, and Saido Is., and good–moderate in Daedurado Is.. When melobesidean algae were excluded, the ESC was high in Geomundo Is., good–high in Daejin, good–moderate in Mangsang, Deoksin, and Saido Is., moderate–low in Yeongjin and Gangyang, and bad in Daedurado Is. As a result, the ESC was evaluated as 1–2 grades lower in all sea areas, except Geomundo Is. (Table 4).

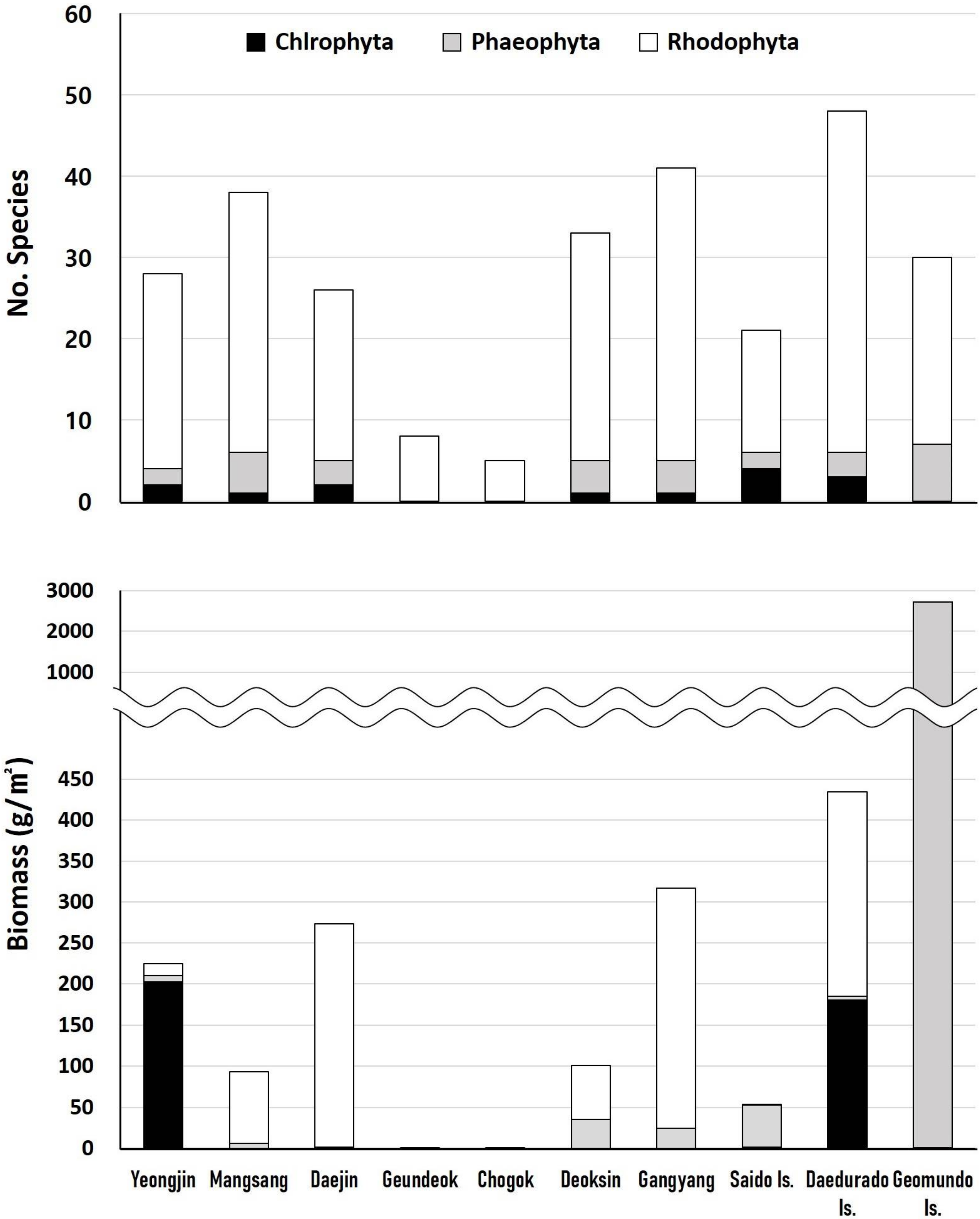

Figure 3. Species composition and biomass of seaweed beds at the study sites.

Table 4. Evaluation of the status of seaweed beds using EEI-c model at the study sites.

Contents	Yeongjin	Mangsang	Daejin	Geundeok	Chogok	Deoksin	Gangyang	Saido Is.	Daedurado Is.	Geomundo Is.
ESG IA	0.45	0.00	0.00	0.00	0.00	0.64	0.18	0.00	0.45	1.45
ESG IB	1.36	13.42	25.89	0.07	0.00	9.08	9.17	10.91	3.69	79.77
ESG IC	71.08	73.58	66.94	100.01	99.64	44.76	60.64	9.49	53.64	18.66
ESG IIA	1.43	3.35	3.30	0.04	1.00	4.95	31.12	0.05	28.18	0.09
ESG IIB	10.22	0.21	0.18	0.02	0.00	0.09	0.12	0.28	17.99	0.25
Including non-geniculate coralline										
ESG I	44.19	54.88	60.88	60.06	59.78	34.76	43.90	14.42	35.59	76.47
ESG II	11.36	2.89	2.82	0.05	0.81	4.05	25.01	0.32	40.53	0.33
EEI-c	8.41	9.91	10.00	10.00	10.00	8.38	7.27	7.05	5.62	10.00
ESC	G-H	High	High	High	High	G-H	G-H	G-H	G-M	High
Excluding non-geniculate coralline										
ESG I	1.65	11.03	20.73	Not applicable		8.79	7.68	8.75	3.85	66.30
ESG II	11.36	2.89	2.82			4.05	25.01	0.32	40.53	0.33
EEI-c	4.93	6.51	7.37			6.21	4.44	6.54	3.10	10.00
ESC	M-L	G-M *	G-H *			G-M *	M-L *	G-M *	Bad	High

* G-H, Good-High; G-M, Good-Moderate; M-L, Moderate-Low.

3.5. Density of Grazers

The average density of grazers was 0.07 ind/m^2 in Geomundo Is., which was the lowest, 0.73 ind/m^2 in Daedurado Is., 1.00–1.93 ind/m^2 in Youngjin, Mangsang, Deoksin, Gangyang, and Saido Is., and 3.47 ind/m^2 and 5.73 ind/m^2 in Daejin and Chogok, respectively, and 18.40 ind/m^2 in Geundeok, which was the highest. The density of sea urchins was high in most sea areas and that of snails was high in Gangyang, Daedurado Is., and Geomundo Is. Nearly no abalone or aplysia were observed (Figure 1).

4. Discussion

According to the results of species composition and average biomass by sea area analyses, the eastern coasts had 5–48 species and an average biomass of 114.42 g/m^2 (0.29–273.60 g/m^2), while the southern coasts had 21–48 species and an average biomass of 1056.84 g/m^2 (53.03–2683.02 g/m^2), showing a significant difference by sea area. Regarding the ratio of occurrence by taxon, red algae showed the highest ratio, which was common across the surveyed sea areas. The biomass ratio of red algae was high on the eastern coasts, while that of brown algae was high in the southern coasts. To identify the change in seaweed flora, a comparison was made with previous studies on seaweed communities. In the case of the eastern coasts, previous studies [13–20,37] reported that the number of species was 12–152 and the average biomass was 1355.67 g/m^2 (155.89–7349.56 g/m^2), which was significantly lower in this study. In the case of the southern coasts, previous studies [25,38–41] reported the number of species was 21–118, and the average biomass was 1140.62 g/m^2 (548.96–2230.00 g/m^2). By comparison, this study showed that the number of species has decreased, while biomass remains similar. These results are similar to those from the recent FIRA [8,10] analysis on the occurrence of barren ground areas, which confirmed that the decrease in seaweed communities due to barren ground is more severe on the eastern than southern coasts.

Regarding the community structure analyzed by species biomass, biomass was low, and opportunistic species were dominant in all sea areas, except Geomundo Is., whose cluster state suggested disturbance was severe in each sea area [33,42–44]. These results suggest that the community state can vary rapidly, depending on surrounding environment or seasonal changes. Furthermore, because the biomass in the community constituent species, excluding the dominant species, is poor in most sea areas, a rapid change in the dominant species or the severe extinction of macroalgae could occur. The biomass of these major dominant species is also shown in the results of the ecological index and K-dominance curve analysis. Since Saido Is., Daejin, and Yeongjin seas are in a “severe” state, changes in communities would be severe because of disturbances. Although Mangsang, Daedurado Is., Gangyang, and Deoksin are in "major" or "moderate" states, considering that the community is composed mainly of opportunistic species, changes to communities would be significant, depending on seasonal transitions. K-dominance was evaluated to appropriately reflect the current state. This is because k-dominance was determined as a "major" state, despite the dominance of perennial large brown algae, such as *Sargassum* spp. and *Ecklonia cava* surrounding Geomundo Is. This is in consideration of the change in the biomass of large brown algae, depending on the season effects on the entire community [45,46].

Comparisons of the coverage of the species that appeared showed all macroalgae were low in Deoksin and Saido Is. due to the predominantly sandy substrate characteristics. Turf-forming macroalgae were mixed in the central and north-eastern coasts, with melobesidean algae covering the entire bedrock. The coverage of melobesidean algae was relatively low in Gangyang, in the southern part of the eastern coasts, and around Daedurado Is. in the southern coasts, and the coverage of turf-forming algae tended to increase. The coverage of melobesidean algae was high at stations located in the eastern coasts, and that of other macroalgae was low, indicating the severe state of barren ground [3,47]. Moreover, the state of barren ground was determined to be severe in Geundeok and Chogok, where few macroalgae other than melobesidean algae were growing. The coverage of the K-selection canopy-forming and sub-canopy-forming algae was high in Geomundo Is., while that of opportunistic turf-forming algae was low. The biomass also showed similar characteristics to the coverage and ecological indices; for example, the species richness and diversity indices were also low. Geomundo Is. may provide favorable conditions for large brown algae to grow because it is less affected by external pressures, such as the influx of pollutants from land or artificial disturbances induced by human activities, due to its geographical characteristics of being far from the coasts [33]. Large brown algae, such as *S. macrocarpum*, *S. fulvellum*, and *S. horneri*, form a canopy to block light, thereby inhibiting the growth of turf-forming algae that constitute the understory [48,49].

Analysis results of the ecological state of the community, using the EEI-c model from Orfanidis et al. [36], showed that because melobesidean algae are classified as ESG IC due to their transitional characteristics, a difference of 1–2 grades occurred for each sea area, depending on the presence of melobesidean algae. When conducting an analysis excluding melobesidean algae, Mangsang, Daejin, Deoksin, and Saido Is., which had poor seaweed community states, showed "good–moderate" or "good–high" states. Gangyang, where the seaweed flora were the richest on the eastern coasts, showed a "moderate–low" state, indicating different results from the average biomass and total coverage of the community. The EEI-c indicated the community state only by the relative ratio of ESG I and ESG II, without considering the total coverage rate of macroalgae, and showed the community state of "good–moderate", with a default value of 5.74. Thus, obtaining clear results on the community state when applying the EEI-c is difficult for a sea area with a low coverage of total macroalgae.

Barren ground refers to a phenomenon in which sheet-form macroalgae become extinct due to various causes, such as an increase in water temperature, artificial disturbances, and environmental pollution. Melobesidean algae cover rock mass, and excessive grazing pressure by grazers is also known to have certain effects [50,51]. In addition, melobesidean algae, a major causative organism, have an antifouling characteristic that limits the attachment of other macroalgae spores onto the surface through sloughing [52–54]; this mechanism acts species specifically [55]. Thus, although the correlations between marine environment by sea area, the average biomass of macroalgae, the coverage of melobesidean algae, and the density of grazers were analyzed, the correlations among marine environment factors are not clear, except for the fact that Geomundo Is., which had the highest biomass, had a significantly higher DIN value of 140.1 μg/L compared to other sea areas and that its DIP value was low at 12.0 μg/L. Although the coverage of melobesidean algae showed positive correlations ($r^2 = 0.641$, $p < 0.05$) with sea surface temperature and the density of grazers, these correlations were not significant (Table 5). Future long-term monitoring studies are necessary to closely understand the relationship between the condition of seaweed beds and the actual status of barren ground based on physical and ecological factors.

Table 5. Results of Pearson's correlation analysis for marine environment and seaweed beds.

	Transparency	SST	Salinity	pH	DO	DIN	DIP	Chl-a	Grazer Density
Mean Biomass	−0.281	−0.374	0.022	0.125	−0.025	−0.026	−0.138	−0.182	−0.309
Coverage of Non-geniculate corallines	0.365	0.641 *	−0.223	−0.015	0.118	−0.252	−0.334	−0.142	0.641 *

*, $p < 0.05$.

Based on a comprehensive review of the above results, since sea areas, such as Deoksin and Saido Is., are unsuitable for macroalgae growth due to their predominantly sandy characteristics, it is necessary to establish a growth base for the recruitment and growth of macroalgae. Gangyang and Daedurado Is. have a low coverage of melobesidean algae, which are mostly composed of turf-forming macroalgae. Although these turf-forming algae contribute greatly to the production and circulation of [56], these algae, as an opportunistic species, are subjected to disturbances by seasonal or environmental changes. Therefore, they lower the stability of the entire seaweed community. Thus, it is necessary to perform seasonal monitoring to more closely analyze the characteristics of sea areas. Furthermore, the transplantation of large perennial brown algae, such as *Sargassum* spp. and *Ecklonia* spp., can be considered to increase the stability of communities. Despite Geomundo Is.'s stable community, formed by dense seaweed forests made of large brown algae, Geomundo Is. has low species variety, as its canopy-forming macroalgae inhibit the growth of other microalgae. If this phenomenon continues, melobesidean algae populations could expand, as these species adapt well to where the light is inhibited] [57,58]. Thus, continuous monitoring and action plans to manage seaweed forests are required. The five sea areas—Yeongjin, Mangsang, Daejin, Chogok, and Geundeok—exhibited the characteristic of distributing only some turf-forming algae in the state where melobesidean algae covered the entire rock mass. In this sea area, it is necessary to consider an improvement in substrates, such as rocky cleaning, out of consideration for the antifouling mechanism of widely distributed melobesidean algae [59]. In particular, in the case of Geundeok and Chogok, it is necessary to reduce the density of sea urchins to increase the recruitment and early growth of macroalgae [60,61]. In relation to the species-specific antifouling mechanism characteristic of melobesidean algae on the eastern coasts, practical ecological restoration is necessary to overcome barren ground by conducting ecological community studies on species composition and the species-inhibiting actions of melobesidean algae.

5. Conclusions

This study conducted a community investigation to find out the characteristics of seaweed communities and the current status of barren ground in natural seaweed beds. The characteristics of seaweed communities differed by sea area, and red algae, an annual opportunistic species, dominated the eastern coasts, and perennial large brown algae dominated the southern coasts. As a result of the evaluation on community status using the EEI-c model, the status of the community differed, depending on the inclusion of melobesidean algae, and the model application was not suitable in habitats with low seaweed coverage. As a result of the study, the seaweed community showed a tendency to gradually decrease according to the barren ground phenomenon, and there was a significant difference in the characteristics of seaweed community in the seaweed beds and barren ground area. The seaweed bed areas were less affected by external pressures or disturbances, so it was a place where large brown algae could grow in a good marine environment. Barren ground refers to a phenomenon in which macroalgae become extinct due to various causes, such as an increase in water temperature, artificial disturbance, and environmental pollution, and excessive grazing pressure by grazers is also known to have certain effects. Therefore, it seems necessary to introduce a marine ecological restoration and management system, incorporating the concept of ecological engineering in the sea area where barren ground is serious.

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