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Macroalgal Community at Floristic Boundary Area between South and West Sea in Korea

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This study was conducted to provide marine algal community and floristic boundary of Gageo–do and nearby islands in the southwest coast of Korea from August 2013 to March 2015. There were 136 marine algae species collected in this study, including 11 green algae (8.09%), 30 brown algae (22.06%), and 95 red algae (69.85%). This study confirms that the current number of marine algae species in 277. According to the functional form group and ESG analysis, the ESG Ⅱ ratio for sheet–like species, filamentous species, and coarsely–branched species was 86.03%, in which most functional groups were composed of opportunistic species. The value of C/P, R/P, and (R+C)/P were 0.44, 2.54 and 2.99, respectively, indicating the characteristics of a temperate mixed marine algal flora. Based on the species reported in this study and previous studies, the appearance rates of subtropical and warm tolerant benthic marine algae showed no correlations an increase of water temperature. The cluster analysis of marine algae of 13 islands divided the West Sea and South Sea at a similarity of 40% in species composition. Notably, the presence of *Ecklonia cava*, *Rugulopteryx okamurae*, and *Corallina crassissima* was important to distinguish the marine algae of the West Sea and South Sea. It is assumed that the southwestern coastal area acts as a transition zone between the West Sea and South Sea floristic regions. Therefore, marine ecological research and monitoring of the change in water temperature and marine organisms at Gageo–do are urgently needed, as the island is important not only for its geography but also in relation to its surrounding ocean currents, water temperature, and marine biodiversity.

Key words: Floristic boundary, Gageo–do, Functional form group, Warm tolerant species, Biodiversity

INTRODUCTION

In South Korea, the early studies on marine algae were carried out by Rho (1958), Kang (1962, 1965, 1966), Lee (1974), Kim (1978), and Yoo and Lee (1979); these followed research by Chyung and Park (1955), who developed a species list of marine algae, after the original one by Okamura (1892).

The first study on the marine algae of the southwest coast of Korea is the subject of the book *Jasan–eobo*, written by Yak–jeon Jeong, which lists 35 marine algae species from Heuksan–do, Korea (Seo, 2014; Choi, 1992). Since then, Kang (1966), Uhm (1968), Kang and Song (1984), Lee and Park (1986), Lee *et al*. (1987a), Kang *et al*. (1993a, 1993b), and Oh *et al*. (2013) carried out similar studies.

Since Kang (1966) reported 15 marine algae species at Gageo–do, Kang and Song (1984), Lee *et al*. (1987a), Choi and Lee (1988), and Choi *et al*. (1993) also studied marine algae. Oh and Jung (1999), Kim and Choi (2002), Oh and Choi (2009) carried out ecological studies on marine algae in intertidal zones, as part of an environmental investigation. The poor development algae in intertidal zones led researchers to study algae in subtidal zones, but there has been no research in these zones for about 20 years since research conducted by Choi *et al*. (1993).

Since Kang (1966) divided the Korean coast into five distinct algal floristic regions, Lee and Yoo (1978), Yoo and Lee (1979), Kang *et al*. (1980), Lee (1980), Lee and Boo (1981), and Lee and Lee (1981) conducted additional floristic research, specifically of the country's marine algae distribution. Kang (1966), based on oceanic currents and characteristics, defined the north of Heuksan–do as a regional boundary between the West Sea and South Sea and based on algae presence defined the south of Baengnyeong–do as the regional boundary. Lee and Yoo (1978) argued that Gyeokryeolbi–yeol–do is the northern floristic regional boundary of the South Sea. Sohn (1987) studied the distribution of 447 marine algae species along the coast and showed results consistent with about floristic region those of Kang (1966). Sohn (1987) broadly subdivided the region into the East Sea, South Sea, West Sea, and Jeju–do and furthermore subdivided the region into the western and eastern areas of the South Sea, the central and southern areas of the West Sea, and Dokdo. Sohn (1987) also characterized the marine algae according to their habitat. In conclusion, previous studies demonstrate inconsistencies in floristic boundaries between the West Sea and the South Sea.

Gageo–do, the southwesternmost island in South Korea at lat 34°04,'N and long 125°07'E, is a typical island and marine fisheries resource, surrounded by deep and highly transparent water (Choi *et al*. 1993). In

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addition, its marine life is comparably healthy, as it is less influenced by man–made disturbances than neighboring islands close to the mainland. Gageo–do is in the channel of the Tsushima Current of the West Sea; its water is highly saline and warm, which is good for marine algae study, making this area important for algae flora monitoring (Oh *et al*. 1998).

In this study, we investigated changes in marine algae species composition by collecting marine algae data at Gageo–do and comparing the results with previous investigations of marine algae in intertidal and subtidal zones at islands surrounding Gageo–do. We also identified the suitability of the Gageo–do floristic boundary (located in the southwest) as habitat for algae by analyzing the similarity of algae species living at the boundary and algae species living at the nearby islands and Gageo–do. The purpose of this study was to provide marine algae scientific data, and in the process, clear criteria for the definition of the marine algae floristic boundary between the West Sea and South Sea.

MATERIALS AND METHODS

Research methodology

Qualitative research data were collected on the marine algae growing in the intertidal and subtidal zones by scuba diving at nine sampling points in the spring, summer, and autumn from August 2013 to March 2015. Sampling was conducted at three points (Gamujakji, Gaerinyeo, and Janggatsal) in August 2013, at four points (Sinyeo, Janggatsal, 3–gu, Hangri) in October 2014, and at three points (Nokdo, Hang 1 point, Hang 2 point) in March 2015 (Fig. 1).

The collected marine algae were immobilized in a 5–10% formalin–seawater solution in the field, placed in an icebox, and transported to the laboratory. Species were identified using a dissecting microscope (Olympus SZX9), and if necessary, an optical microscope (Olympus BX50), in which reproductive organ or other tissue sections were prepared by freehand section, and slides were mounted with glycerin water. Depending on taxon, we referred to the different studies of Okamura (1907–1909, 1909–1912, 1913–1915, 1916–1923, 1923–1928), Kang (1968), Chihara (1970), Abbott (1976), Yoshida (1998), and Lee (2008) for species identification.

Analysis of marine algae flora characteristics and distribution

We used the Segawa (1956) C/P ratios, Feldmann (1937) R/P ratios, and Cheney (1977) (R+C)/P ratios to analyze the marine algae flora composition according to climatic and geographic conditions. The functional form classification according to Littler and Littler (1984), and the ecological state group (ESG) ratio according to Orfanidis *et al*. (2001; 2003), were used to analyze the marine algae flora characteristics.

To analyze the changes in marine algae flora due to changes in water temperature, annual average surface water temperature data of the National Fisheries Research and Development Institute were used. The change in marine algae flora appearance rate was analyzed by using the subtropical climate species data summarized by Kang (1966) and the warm tolerant benthic marine algae data summarized by Kim (2000).

The analysis of the marine algae flora distribution was based on the results of this study, and the species composition analysis in previous studies carried out on neighboring islands of Gageo–do (Heuksan–do, Hong–do, Sangtae–do, Jungtae–do, and Hatae–do), islands in the West Sea (Baengnyeong–do, Gyeokryeolbi–yeol–do, Oeyeon–do, and Eocheong–do), and islands in the South Sea (Geomun–do, Cheongsan–do, Yeoseo–do, and Chuja–do). Differences in species composition between

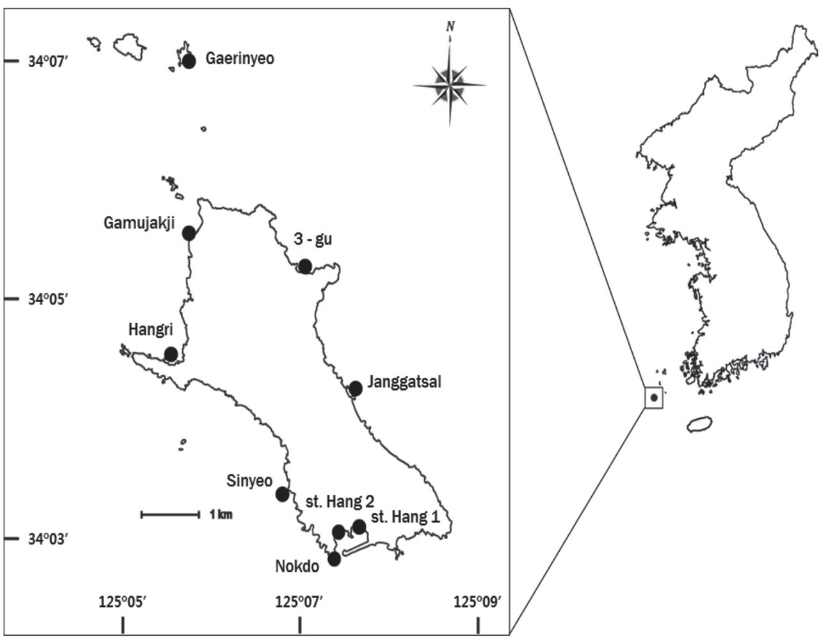

Fig. 1. Collecting sites of Gageodo Island on the West–southern coast of Korea.

island regions were analyzed using the similarity index (Bray and Curtis, 1957), and the data were analyzed using Plymouth Routines Multivariate Ecological Research (PRIMER) software (version 6.0). The group–average was utilized to connect the regions with the species composition based on the similarity index matrix. Data were also analyzed by dendrogram and MDS ordination for similarity.

RESULTS

Species composition

There were 136 marine algae species collected in this study, including 11 green algae species (8.09%), 30 brown algae species (22.06%), and 95 red algae species (69.85%) (Table 1). The highest number of species collected based on study period was 94 in October 2014, with 6 green algae species (6.38%), 17 brown algae species (18.09%), and 71 red algae species (75.53%). In August 2013, 76 species were collected, including 4 green algae species (5.26%), 20 brown algae species (26.32%), and 52 red algae species (68.42%). In March 2015, 19 species were collected, including 4 green algae species, 4 brown algae species, and 11 red algae species. The highest number of species collected among sampling points was 64 at Sinyeo in October 2014, whereas Hang 2 had the lowest with 4 species in March 2015.

Marine algae flora characteristics

Functional form groups and ESG analysis

As a result of the marine algae analysis based on functional form group according to Littler and Littler (1984), the algae species could be classified into the following groups: 25 sheet–like species (S) (18.38%); 34 filamentous species (F) (25.00%); 58 coarsely–branched species (CB) (43.65%); 8 thick leathery species (TL) (5.88%); 8 jointed calcareous species (JC) (5.88%); and 3 crustose species (C) (2.21%). Thus, CB species were the most abundant, whereas C species were the least abundant. In addition, 19 species (13.97%) were classified as belonging to ESG I, and 117 species (86.03%) as belonging to ESG Ⅱ.

Marine algae flora composition analysis

The study with the highest number of marine algae species recorded was conducted by Choi *et al.* (1993), whereas 136 species were collected in this study. Of a total of 233 species reported across previous studies at Gageo–do, 44 new species were added in this study, including 3 green algae species, 9 brown algae species, and 32 red algae species. Thus, this study confirms that the current number of marine algae species is 277.

The Segawa (1956) C/P ratios, Feldmann (1937) R/P ratios, and Cheney (1977) (R+C)/P ratios were applied to the data of this study and previous studies, to analyze the characteristics of and identify the changes in marine algae species composition. The values of C/P, R/P, and (R+C)/P were 0.44, 2.54, and 2.99, respectively, indicating the characteristics of a temperate mixed marine algal flora. Comparing the results with previous studies, the highest C/P value (0.80) was recorded by Oh and Jung (1999), whereas Kang and Song (1984) recorded an R/P value of 3.35 and an (R+C)/P value of 3.80.

Water temperature data in the region from 1983 to 2015 showed an increase of 0.5°C over the last 30 years, which is similar to the global rate of increase (Fig. 2). Based on the species reported in this study and previous studies, the appearance rates of subtropical and warm tolerant benthic marine algae species were between 8.6%–26.9% and showed no correlations in appearance rates among survey years. Therefore, we conclude that there has been no significant change in the appearance rate of subtropical or warm tolerant benthic algae species since the 1990s.

Marine algae flora distribution analysis (cluster analysis) for Gageo–do, West Sea, and South Sea

Cluster analysis was carried out based on the species composition for Gageo–do, the five islands near Gageo–do (Heuksan–do, Hong–do, Sangtae–do, Jungtae–

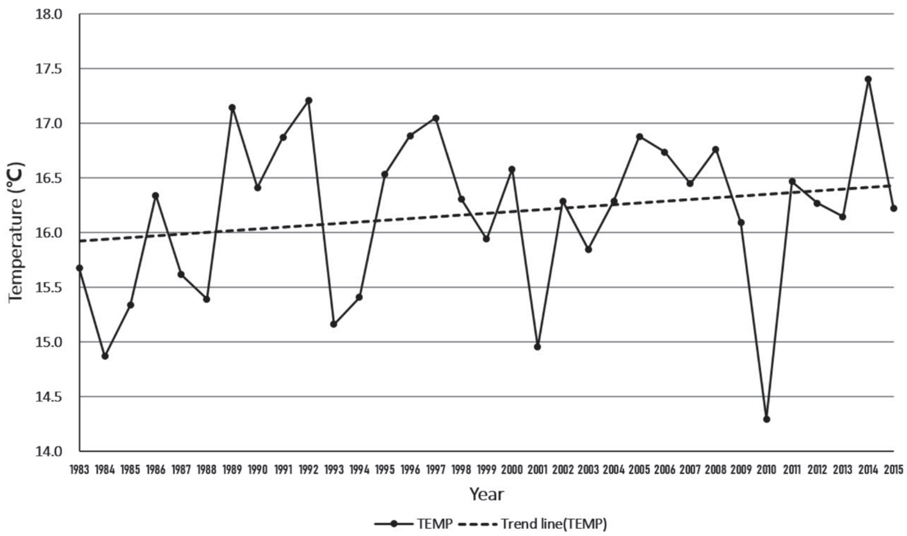

Fig. 2. Sea Surface Temperature from February 1983 to December 2015 in Gageodo island.

Table 1. Regions and references used for Bray–Curtis cluster analysis

Location	Number of species				Reference
	C*	P*	R*	T*	
Gageodo	29	60	144	233	Kang (1966), Lee *et al*. (1987a) Kang and Song (1984) Choi and Lee (1988) Choi *et al*. (1993) Oh and Jung (1999) Oh and Choi (2009)
	11	30	95	136	This study
Hongdo	14	52	124	190	Kang and Song (1984) Lee and Park (1986) Kang *et al*. (1993a, b)
Chujado	19	59	133	211	Kim *et al*. (2008), Kim (2009)
Heuksando	19	33	100	151	Kang (1966), Lee *et al*. (1987a) Oh and Lee (1989)
Sangtaedo	7	12	53	72	Oh and Lee (1989)
Jungtaedo	6	12	38	56	Oh and Lee (1989)
Hataedo	5	12	37	54	Oh and Lee (1989)
Oeyeondo	15	25	72	112	Cho and Boo (1996)
Eocheongdo	10	19	57	86	Kim *et al*. (2013)
Baengnyeongdo	10	28	86	125	Lee (1973), Lee *et al*. (1987a) Baek *et al*. (2007)
Gyeokryeolbiyeoldo	7	13	28	48	Han and Lee (2006)
Cheongsando	9	25	59	93	Lee *et al*. (1990)
Yeoseodo	7	27	84	118	Kang *et al*. (1993a, b) KNPS (2015)
Geomundo	19	50	140	209	Koh (1990a, b), KNPS (2015)

* C: Chlorophyta, P: Phaeophyta, R: Rhodophyta, T: Total

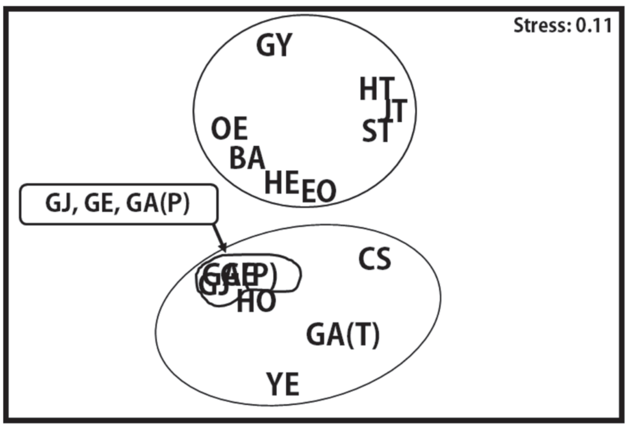

Fig. 3. Bray–Curtis cluster analysis multidimensional scaling (MDS) configuration generated on the basis of recorded species of 14 regions. BA. Baengnyeongdo; GY. Gyeokryeolbiyeoldo; EO. Eocheongdo; OE. Oeyeondo; CJ. Chujado; CS. Cheongsando; YE. Yeoseodo; GE. Geomundo; HE. Heuksando; ST. Sangtaedo; JT. Jungtaedo; HT. Hataedo; HO. Hongdo; GA (T). Gageodo (this study); GA (P). Gageodo (previous studies).

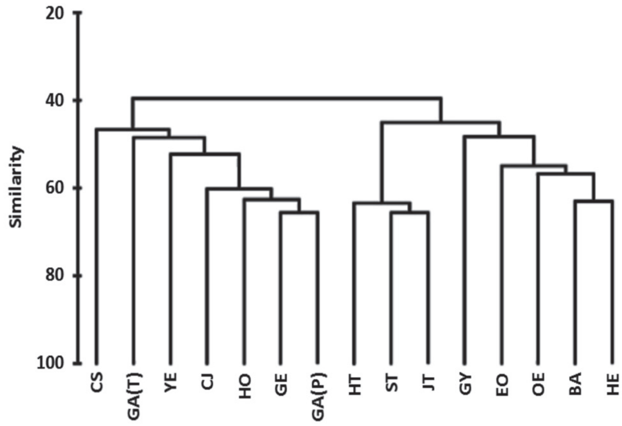

Fig. 4. Bray–Curtis cluster analysis dendrogram generated on the basis of recorded species of 14 regions. BA. Baengnyeongdo; GY. Gyeokryeolbiyeoldo; EO. Eocheongdo; OE. Oeyeondo; CJ. Chujado; CS. Cheongsando; YE. Yeoseodo; GE. Geomundo; HE. Heuksando; ST. Sangtaedo; JT. Jungtaedo; HT. Hataedo; HO. Hongdo; GA (T). Gageodo (this study); GA (P). Gageodo (previous studies).

do, and Hatae–do), the four islands of the southwest coast (Geomun–do, Cheongsan–do, Yeoseo–do, and Chuja–do) and the four islands of the West Sea (Baengnyeong–do, Gyeokryeolbi–yeol–do, Oeyeon–do, and Eocheong–do) (Table 1, Figs. 3–5).

As a result of the cluster analysis, two groups (West Sea and South Sea) were distinguished at 40% similarity in species composition. The West Sea group included Baengnyeong–do, Gyeokryeolbi–yeol–do, Oeyeon–do, Eocheong–do, Heuksan–do, Sangtae–do, Jungtae–do, and Hatae–do and had a 50.84% similarity in species composition among islands. The South Sea group included Hong–do, Gageo–do, Chuja–do, Cheongsan–do, Yeoseo–do, and Geomun–do and had a 52.50% similarity in species composition among islands (Fig. 4). Considering both groups, no species only appeared in the area of the West Sea group, whereas the species *Ecklonia cava*, *Rugulopteryx okamurae*, and *Corallina crassissima*, only appeared in the area of the South Sea group. Because these three species have not been reported in areas of the West Sea group, they are presumed to be endemic to areas of the South Sea group.

DISCUSSION

There were 136 marine algae species collected and identified in this study, with 11 green algae species (8.1%), 30 brown algae species (22.1%), and 95 red algae species (69.9%). No species appeared in all sampling areas during the study period, but *Codium arabicum*, *Symphyocladia marchantioides*, *Griffithsia japonica*, and *Plocamium telfairiae* were distributed relatively evenly throughout the region.

According to the functional form group and ESG analyses, the ESG II ratio for S, F, and CB, was 86.03%, in which most functional groups were composed of opportunistic species. As mentioned in previous studies (Choi and Lee, 1988; Choi *et al*. 1993; Kim, 1997), Gageo–do is the southwesternmost island, located far from the mainland. It is a difficult place to conduct a study because of its unique geographical and geomorphological characteristics, such as its steep sea cliffs created by vertical jointing. According to Oh *et al*. (1998) and Yang *et al*. (1998), the ocean current near Gageo–do is influenced by the proper water of the West Sea from the late autumn to spring. From spring to summer, a high–temperature, high–salinity, and turbulent ocean current flows northwest of Jeju, which has an effect on algae populations.

A total of 277 marine algae species have been reported at Gageo–do, which accounts for about 30% of the 908 marine algae species recorded in the *National List of Species* by Kim *et al*. (2013) and represents the highest marine algae species diversity among the islands of the West Sea. Thus, Gageo–do is a major habitat for marine algae and requires continuous research on marine algae conservation and management.

Compared with the number of species recorded in previous studies by Choi and Lee (1988) and Choi *et al*.

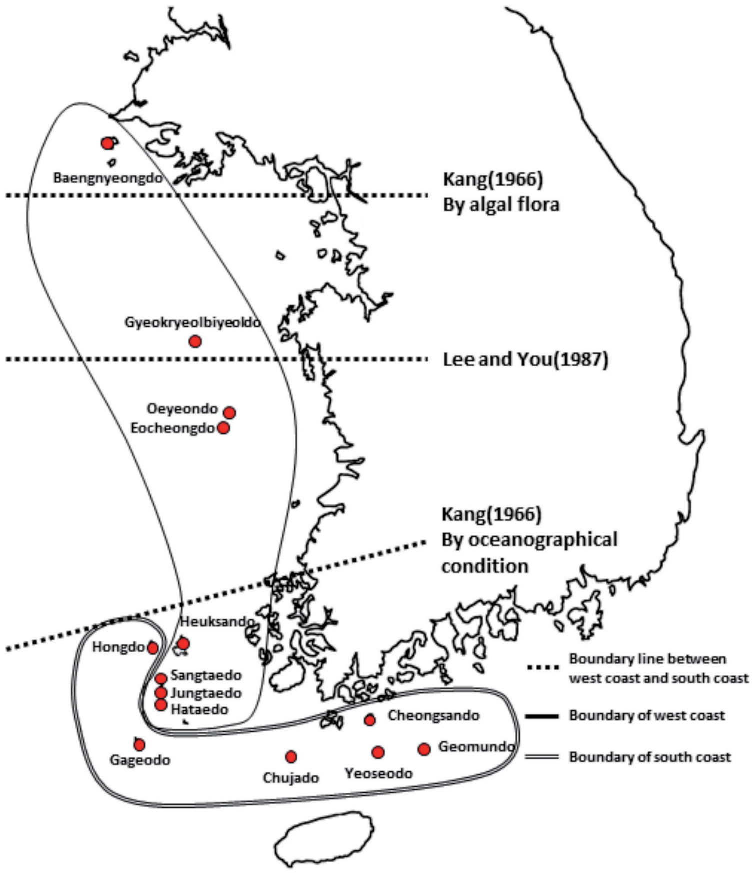

Fig. 5. The location of 14 regions and the boundary of the south coast and west coast.

(1993), the number of species recorded in this study was lower because species in the intertidal zone (*Monostroma* spp., *Ulva* spp., *Porphyra* spp., *Pyropia* spp., *Laurencia* spp., *Leathesia marina*, *Petrospongium rugosum*, and *Myelophycus simplex*) were not collected. The collection was not possible in this zone because the marine algae habitat has changed due to the construction of a breakwater and the Gageo–do port; most of the marine algae in this area of Gageo–do are not able to grow and have disappeared. Furthermore, marine algae did not appear in Gulseom, because of habitat disturbance from mining construction, even though Choi and Lee (1988) recorded a high algae species diversity (119 species) there.

Although increases in the appearance rate of subtropical and warm tolerant benthic algae species due to an increase in the ocean water temperature were not observed, ocean water temperature has been rising continuously on a global scale. Moreover, the increase in the rate of ocean water temperature in Korea is 2–3 times higher than the global average. Therefore, it is necessary to fully understand changes in marine algae species composition in response to the increase in water temperature; in addition, more accurate marine algae indicator species are needed to monitor these changes.

The cluster analysis of marine algae of 13 islands indicated divided the West Sea and South Sea at a similarity of 40% in species composition. Notably, the presence of *Ecklonia cava*, *Rugulopteryx okamurae*, and *Corallina crassissima* was important to distinguish the marine algae of the West Sea and South Sea. Six islands located along the southwest coast (Heuksan–do, Gageo–do, Hong–do, Sangtae–do, Jungtae–do, and Hatae–do) are geographically close to each other. Therefore, their algae species composition was expected to be similar to the marine algae species composition of the West Sea or South Sea or independently unique species composition. However, Hong–do and Gageo–do showed an algae species composition similar to that of the South Sea, while Heuksan–do, Sangtae–do, Jungtae–do, and Hatae–do showed a species composition like that of the West Sea. Therefore, as mentioned in Kang *et al*. (1993a, b), the presence of an *E. cava* community and turbidity because of the type of substrate greatly influenced the vegetation classification. It is assumed that the southwestern coastal area acts as a transition zone between the West Sea and South Sea floristic regions (Fig. 5).

Gageo–do is one of the outermost islands from the mainland and is geographically important. It has the unique geographical feature of well–developed, steep sea cliffs. In addition, among the islands of the West Sea, Gageo–do is located where the warm Yellow Sea Current and the Kuroshio Current meet (the former a tributary of the latter); thus, this region is expected to receive the greatest impacts from a change in water temperature. Previous studies and this study have shown that marine algae in its role as primary producers, consumers, and as habitat (e.g., spawning grounds) for organisms, that are highly diverse, promote the diversity of the entire marine ecosystem (Dawes, 1998; McCall *et al*. 1999; Worm *et al*. 2000; Kang and Kim, 2004; Choi *et al*. 2008). Therefore, it is presumed that the diversity of other marine organisms, such as zoobenthos and fish, is high in areas of high marine algae diversity. Myoung *et al*. (2003) revealed that diverse fish species were observed, even at relatively shallow water depths, along the Gageo–do coast, suggesting that *Ecklonia cava* provides great habitat for fish. Therefore, marine ecological research and monitoring of the change in water temperature and marine organisms at Gageo–do are urgently needed, as the island is important not only for its geography and topography but also in relation to its surrounding ocean currents, water temperature, and marine biodiversity.

AUTHOR CONTRIBUTIONS

S. W. Jung, Y. S. Oh, I. J. Kang, and C. G. Choi designed this study and drafted the manuscript. S. W. Jung, C. G. Choi, and I. J. Kang conceived and designed the study, and also revised the manuscript. Y. Shimasaki supervised the work. All authors read and approved the final manuscript.

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