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Ecological evaluation of marine macroalgal communities on five islands of Korea in the Yellow Sea

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Abstract

Macroalgae have long been used as biological indicators of marine ecosystem health worldwide due to their ecological importance and sensitivity to environmental stress. A number of previous studies have utilized macroalgal communities in monitoring surveys of environmental conditions. This study examined the characteristics and patterns of marine macroalgal communities in the Yellow Sea off the western coast of Korea. Macroalgae were analyzed for the number of species, biomass, and coverage ratio by macroalgal type. During the study period, 82 macroalgal species (10 green algae, 17 brown algae, and 55 red algae) were identified at the five study sites, with the highest number of species found at Gwanrido and Uido (both containing 41 species) and the lowest at Daeijakdo (27 species). The average biomass (via dry weight) was 98.63 g/m^2, consisting of green algae (8.39 g/m^2), brown algae (35.08 g/m^2), and red algae (55.16 g/m^2). The dominant macroalgae species in terms of biomass were *Corallina pilulifera*, *Sargassum thunbergii,* and *Ulva australis* in the intertidal zones, and *Botryocladia wrightii* and *Gelidium elegans* in the subtidal zones. Richness, evenness, and diversity indices based on the biomass of abundant species were 5.08, 0.65, and 2.30, respectively, over the entire study area. Based on the evaluation of the environmental states by the community indices, overall, the Ecological Evaluation Index of macroalgae communities in the study area was marked as “Good-Moderate”, but was determined as “Moderate-Low” at several sites during summer. The results can be a direct approach in the assessment of coastal habitats in which anthropogenic as well as climate change influences persist.

Key words: macroalgae, Yellow Sea, ecological state groups, ecological index, Ecological Evaluation Index (EEI), community variable

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1 Introduction

Macroalgae are primary producers in marine environments and provide important ecological services in coastal ecosystems (Whitaker et al., 2010; Liang et al., 2014). They also serve as biofilters owing to their capacity to remove organic and inorganic pollutants dumped in the coastal sea area from inland areas. Thus, they are considered to be an indicator organism for monitoring the coastal environment (Wells et al., 2007; Scherner et al., 2013; Vale et al., 2021), while they can also cause algal blooms (Liu et al., 2021a, 2021b, 2022; Sun et al., 2022). Ecological information of macroalgae such as species diversity, distribution range, and abundance data can be easily utilized to obtain the current status and environmental conditions of coastal ecosystems (Choi and Rho, 2010; Roleda et al., 2012; Akrong et al., 2021).

Evaluation of coastal environmental conditions using macroalgae has previously been attempted by analyzing the composition of functional groups of macroalgae (e.g., Wells et al., 2007; Juanes et al., 2008). Generally, macroalgae are divided into six functional groups (sheet, filamentous, coarsely branched, thick-leathery, jointed-calcareous, and crustose) according to their survival strategies. Since each group thrives under different environmental conditions, functional composition has been used to evaluate the level of environmental stress caused by artificial disturbance and pollution in surveyed areas (Littler and Littler, 1984; Padilla and Allen, 2000). Recently, the ecological evaluation index continuous formula (EEI-c) has been developed by classifying five functional types of macroalgae in consideration of body shape, life cycle, growth rate, phenotype adaptability, and transition rate, in order to grade the environmental status of coastal habitats based on the Ecological Status Class (ESC) (Orfanidis et al., 2001, 2003, 2011).

The coastal region of western Korea has been developed into numerous bays, estuaries, complex shorelines, and islands that are covered with spacious tidal flats along the rias of the coast. These areas often have high tidal ranges, which can lead to turbidity caused by high concentrations of suspended particles in the water (Yang and Kim, 2009; Jung et al., 2010). Since Kang (1966) formed a record of the 140 Korean algal species in “geo-

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graphical distribution of Korean macroalgae”, various ecological studies measuring features such as macroalgal flora, biomass, vertical distribution, community structure, and functional composition have been attempted. Most research aiming to evaluate environmental conditions through macroalgal communities was focused on only some coastal areas and islands (Yoo et al., 2007; Choi et al., 2008; Kim et al., 2010, 2013a; Ahn et al., 2017). However, such research is still scarce in the outlying islands of the western sea of Korea.

Therefore, this study was conducted to identify the characteristics of macroalgal communities inhabiting the intertidal and subtidal habitats of five islands off the western coast and to evaluate environmental conditions by calculating the EEI-c based on functional groups of macroalgae occurring in the study area. The results may be highly beneficial both for management purposes of coastal ecosystem and for recognizing future human- and climate- induced influences on coastal environments locally and globally.

2 Materials and methods

2.1 *Sample collections and laboratory procedure*

In this study, macroalgal samples were collected from both intertidal and subtidal zones of five islands along the western coast of Korea (part of the Yellow Sea off western Korean waters). The islands were: Daeijakdo (DJD) in Incheon, Gyeokryeolbiyeoldo (GBD) and Hodo (HD) in Chungcheongnam-do, Gwanrido (GD) in Jeollabuk-do, and Uido (UD) in Jeollanam-do (Fig. 1). All study islands are located far from the inland and have little anthropogenic influences such as pollution, river discharge and sewage. Only the study sites on GD and UD are located near ports which may have been influenced by moving passenger ships and/or fishing vessels. Nitrate, dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) were lower on HD and GD than on the other islands, whereas both particulate organic carbon (POC) and particulate organic nitrogen (PON) were higher (unpublished data). Overall, benthic community structures were similar among the study islands, but the abundances of filter bivalves (e.g., oysters and mussels) potentially influencing macroalgal growth tended to be higher on DJD and GBD (unpublished data).

Samplings of macroalgae were conducted during May (spring) and August (summer) of 2017, and macroalgae samples were collected from rocky substrates. In total, ten quadrats were installed on each island during low tide; two quadrats (50 cm × 50 cm) were randomly installed on the ground in each of the upper, middle, and lower parts of the intertidal zone and the two stations in the subtidal zone (at depths of 1–4 m and 5–8 m). Quadrats were first photographed before all macroalgae existing within the quadrats collected using chisel knives (Tajima, TJM Design Corp., Japan). Analysis of these data was used to record the percentage coverage of each macroalgal type in each zone (Saito and Atobe, 1970).

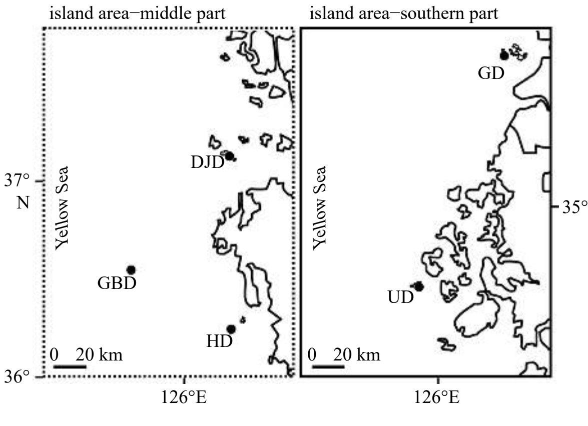

Fig. 1. Map showing the five study sites located along the western coasts of Korea. DJD: Daeijakdo; GBD: Gyeokryeolbiyeoldo; HD: Hodo; GD: Gwanrido; UD: Uido.

Immediately after collection, macroalgae samples were fixed in the field with seawater-diluted formalin solution (5%–10%, Samchun Pure Chemical Co., Ltd., Korea) and transported to the laboratory. The samples were then washed with fresh water and identified at the species level using a combination of naked eye and microscope (Olympus CX31, Olympus Corp., Japan) observations. Following this, they were dried in a drying oven (Lab House Co., Korea) at 105℃ for 2 d before measuring the dry weight (0.01 g). The dry weight value was used to determine biomass per unit area (g/m^2).

The list of macroalgal species based on scientific names followed the *National List of Species of Korea* [*Marine Algae*] (Kim et al., 2013b) and the AlgaeBase classification system (www.algaebase.org; Guiry and Guiry, 2021).

2.2 *Analyses of community indices and macroalgae community status*

To understand the ecological characteristics of macroalgal communities, the richness index, Shannon-Wiener diversity index, and evenness index were calculated based on the current status of macroalgae (species number and biomass) at each site (Margalef, 1958; McNaughton, 1967; Cohen and Fowler, 1990). The ecological indices were calculated using the PRIMER v6 statistical software (Clarke and Gorley, 2006; PRIMER-e, New Zealand).

In this study, macroalgal species were classified into two ecological status groups (ESGs) and five subgroups, namely, ESG I (subgroups IA, IB, and IC) and ESG II (subgroups IIA and IIB), based on their morphology, growth rate, phenotype adaptability, lifespan, and transition rate (Orfanidis et al., 2011). The EEI-c was calculated using the coverage of macroalgal species in each group. The coastal environmental conditions were evaluated according to the ecological evaluation class (ESC) (Table 1; Orfanidis et al., 2011). The characteristics of each group and the equation for calculating the EEI-c are as follows:

ESG I: thick perennial (IA), thick plastic (IB), shade-adapted plastic (IC).

ESG II: fleshy opportunistic (IIA), filamentous sheet-like opportunistic (IIB).

$$\text{ESG I (\% coverage)} = [(\text{IA} \times 1) + (\text{IB} \times 0.8) + (\text{IC} \times 0.6)]\ (x\text{-axis}).$$

$$\text{ESG II (\% coverage)} = [(\text{IIA} \times 0.8) + (\text{IIB} \times 1)]\ (y\text{-axis}).$$

$$\text{EEI-c}\ (x, y) = a + b(x/100) + c(x/100)^2 + d(y/100) + e(y/100)^2 + f(x/100)(y/100),\ a=0.468\ 0,\ b=1.208\ 8,\ c=-0.358\ 3,\ d=-1.128\ 9,\ e=0.512\ 9,\ f=-0.186\ 9.$$

Table 1. Ecological Status Class (ESC) boundaries of transitional and coastal waters based on the Ecological Evaluation Index continuous formula (EEI-c)

ESC	EEI-c (mean±SD)
High (H)	9.72±0.46
Good-High (G-H)	8.09±0.74
Good-Moderate (G-M)	5.84±0.70
Moderate-Low (M-L)	4.04±0.68
Bad (B)	2.34±0.78

3 Results

3.1 *Species composition*

During the study period, 82 macroalgal species (10 species of green algae (Chlorophyta), 17 species of brown algae (Ochrophyta-Phaeophyceae), and 55 species of red algae (Rhodophyta)) were recorded at five study sites, with six species (*Ulva australis*, *Sargassum thunbergii*, *Gelidium elegans*, *Chondrus ocellatus*, *Polyopes affinis,* and *Symphyocladia latiuscula*) occurring at all study sites (Table S1). In total, 57 and 62 species were found in the intertidal and subtidal zones, respectively. Spatially, 27 species occurred on DJD, 34 on HD, 35 on GBD, and 41 on both GD and UD (Table 2). The frequency of the occurrence of macroalgal species by taxonomic group ranged from 7.32% to 19.51% for green algae, 11.76% to 26.83% for brown algae, and 53.66% to 78.05% for red algae. The mean occurrence of red algae was the highest on UD compared to the other sites, and the lowest on GD, where the occurrence of brown algae was the highest. Overall, the occurrence of green algae was relatively low in all study sites regardless of the season and tidal zone.

3.2 *Biomass and dominant species*

The mean biomass (dry weight) of all macroalgae was 98.63 $\mathrm{g/m^2}$, including green algae (8.39 $\mathrm{g/m^2}$), brown algae (35.08 $\mathrm{g/m^2}$), and red algae (55.16 $\mathrm{g/m^2}$). The total mean biomass of brown algae was the highest (110.00 $\mathrm{g/m^2}$) on GD, and that of red algae was the highest (85.96 $\mathrm{g/m^2}$) on GBD (Fig. 2). Overall, the mean biomass was higher in the intertidal zones of GBD and GD, while it was higher in the subtidal zones of DJD, depending on the tidal level (Fig. 2). The site showing the largest difference in mean biomass between the intertidal and the subtidal zone was DJD (163.61 $\mathrm{g/m^2}$ vs. 19.09 $\mathrm{g/m^2}$, respectively), while the lowest difference in mean biomass between intertidal and subtidal zones was on HD (95.14 $\mathrm{g/m^2}$ vs. 63.44 $\mathrm{g/m^2}$, respectively).

Based on the macroalgal biomass content, the dominant species were *Corallina pilulifera*, *Sargassum thunbergii,* and *Ulva australis* in the intertidal zone, and *Botryocladia wrightii* and *Gelidium elegans* in the subtidal zone (Table 3). In the intertidal zone, *Sargassum thunbergii* was the most abundant macroalgal species on HD (48.13%) and GD (66.85%), whereas *Ulva australis*, *Gelidiophycus freshwateri*, and *Corallina pilulifera* were common macroalgal species on DJD (51.41%), GBD (27.99%), and UD (45.46%), respectively. In contrast, in the subtidal zone, *Botryocladia wrightii* dominated the macroalgal communities of GBD and HD. Two *Geldium* species (*Gelidium elegans* and *Gelidium vagum*) were the most abundant macroalgae on DJD and UD, and *Myagropsis myagroides* dominated only in the intertidal zone of GD among all study sites.

Table 2. Number of macroalgal species observed at the five study sites along the western coast of Korea

Site	Taxon	Intertidal zone		Subtidal zone		Total
		Spring	Summer	Spring	Summer	
DJD	Chlorophyta	2	1	2	1	3
	Ochrophyta	–	–	4	3	5
	Rhodophyta	5	6	5	13	19
	Subtotal	7	7	11	17	27
GBD	Chlorophyta	4	–	–	–	4
	Ochrophyta	5	2	1	1	6
	Rhodophyta	12	7	8	13	25
	Subtotal	21	9	9	14	35
HD	Chlorophyta	4	2	1	–	5
	Ochrophyta	3	2	1	1	4
	Rhodophyta	8	8	9	10	25
	Subtotal	15	12	11	11	34
GD	Chlorophyta	4	4	3	1	8
	Ochrophyta	5	2	4	5	11
	Rhodophyta	7	5	16	8	22
	Subtotal	16	11	23	14	41
UD	Chlorophyta	2	1	1	2	3
	Ochrophyta	2	4	–	3	6
	Rhodophyta	18	17	13	19	32
	Subtotal	22	22	14	24	41

Note: DJD: Daeijakdo; GBD: Gyeokryeolbiyeoldo; HD: Hodo; GD: Gwanrido; UD: Uido. – represents no data.

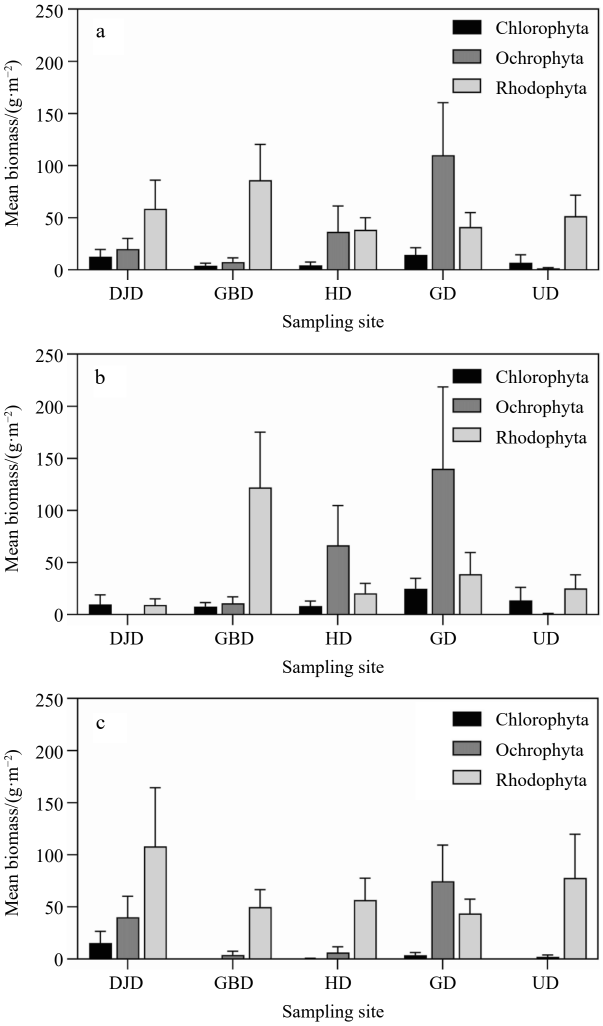

Fig. 2. Mean biomass (dry weight) of macroalgae in each taxonomic group across the five study sites along the western coast of Korea. a. Mean biomass combining intertidal and subtidal zones; b. mean biomass in the intertidal zone; c. mean biomass in the subtidal zone. DJD: Daeijakdo; GBD: Gyeokryeolbiyeoldo; HD: Hodo; GD: Gwanrido; UD: Uido. Error bars indicate standard deviation.

3.3 *Ecological indices*

Ecological indices based on species number and biomass of the macroalgae community ranged from 2.32 to 5.31 in richness, from 0.42 to 0.75 in evenness, from 1.39 to 2.35 in diversity, and from 0.41 to 0.80 in dominance (Table 4). The richness index was higher in the subtidal zone on DJD and GD, whereas it was high-

Table 3. Dominant (⩾30%) and subdominant (10%–30%) species in terms of percentage of average biomass at both the intertidal zone and subtidal zone of five study sites along the western coast of Korea

Site	Intertidal zone	Subtidal zone
DJD	*Ulva australis* (51.41%) *Chondrus pinnulatus* (13.46%) *Polyopes affinis* (13.01%)	*Gelidium elegans* (32.02%) *Chondrus pinnulatus* (13.75%)
GBD	*Gelidiophycus freshwateri* (27.99%) *Corallina pilulifera* (24.88%) *Chondria atropurpurea* (24.67%)	*Botryocladia wrightii* (27.44%) *Gelidium elegans* (21.29%) *Rhodymenia intricata* (14.49%)
HD	*Sargassum thunbergii* (48.13%) *Myelophycus simplex* (12.85%)	*Botryocladia wrightii* (22.46%) *Rhodymenia intricata* (18.47%) *Gelidium elegans* (14.67%) *Chondracanthus tenellus* (11.37%)
GD	*Sargassum thunbergii* (66.85%)	*Myagropsis myagroides* (23.40%) *Sargassum miyabei* (22.37%) *Campylaephora hypnaeoides* (13.00%)
UD	*Corallina pilulifera* (45.46%) *Ulva australis* (34.63%)	*Gelidium vagum* (57.23%) *Haraldiophyllum bonnemaisonii* (12.16%)

Note: DJD: Daeijakdo; GBD: Gyeokryeolbiyeoldo; HD: Hodo; GD: Gwanrido; UD: Uido.

Table 4. Community indices in each intertidal and subtidal zone of five study sites in the western coast of Korea

Community indices	DJD		GBD		HD		GD		UD	
	Inter	Sub	Inter	Sub	Inter	Sub	Inter	Sub	Inter	Sub
Richness	2.32	3.24	3.71	3.17	3.62	2.89	2.80	4.52	5.31	5.03
Evenness	0.64	0.75	0.57	0.70	0.60	0.73	0.46	0.70	0.42	0.45
Diversity	1.59	2.33	1.85	2.04	1.91	2.06	1.39	2.35	1.44	1.53
Dominance	0.65	0.46	0.53	0.49	0.61	0.41	0.75	0.46	0.80	0.69

Note: DJD: Daeijakdo; GBD: Gyeokryeolbiyeoldo; HD: Hodo; GD: Gwanrido; UD: Uido; Inter: intertidal zone; Sub: subtidal zone.

er in the intertidal zone on GBD, HD, and UD. Evenness and diversity were higher in the subtidal zone in all sites, while dominance was higher in the intertidal zone in all sites.

3.4 *Evaluation of community status*

ESCs were evaluated based on EEI-c derived using the coverage of macroalgae present and the current status of macroalgal communities at the five sites in the western sea (Table 5). As a results, ESCs in the intertidal zones were evaluated as "Moderate-Low" or "Good-Moderate" except for GD during spring, which was "Good-High"; additionally, ESCs in the subtidal zones were all either "Moderate-Low" or "Good-Moderate" except for UD during summer, which was "Bad". During spring, overall ESCs were determined as "Good-Moderate" in all sites except UD. During summer, ESCs were "Good-Moderate" in two sites (HD and GD) and "Moderate-Low" in three sites (DJD, GBD and UD). Therefore, the environmental conditions based on ESC tended to be better during spring than during summer.

4 Discussion

In this study, 82 species of macroalgae were identified (10 species of green algae, 17 species of brown algae, and 55 species of red algae). Each study site contained between 27–41 species, and each tidal level contained between 57–62 species. Previous studies have shown higher or similar numbers of macroalgal species (from 21 to 122 species) occurring in the intertidal and subtidal zones of the western coast of Korea (Table 6). However, we should be cautious in making direct comparisons between differ-

Table 5. Ecological Status Class (ESC) evaluation results of macroalgal community using Ecological Evaluation Index continuous formula (EEI-c) based on ground coverage of macroalgal species

Content	DJD		GBD		HD		GD		UD	
	Inter	Sub	Inter	Sub	Inter	Sub	Inter	Sub	Inter	Sub
Spring										
ESG I	0.00	4.80	10.43	2.10	8.70	3.40	30.18	7.05	3.88	8.54
ESG II	2.78	8.90	12.05	12.05	11.50	10.00	9.88	10.18	5.04	45.08
EEI-c	5.50	5.42	5.67	4.91	5.56	5.20	7.50	5.52	5.67	3.25
ESC	G-M	G-M	G-M	M-L	G-M	G-M	G-H	G-M	G-M	B
EEI-c per site	5.46		5.29		5.38		6.51		4.46	
ESC per site	G-M		G-M		G-M		G-M		M-L	
Summer										
ESG I	2.00	16.20	3.43	2.57	5.33	1.50	5.80	11.60	7.92	11.63
ESG II	18.40	29.45	34.13	6.80	3.73	6.20	7.57	10.90	13.88	41.02
EEI-c	4.41	4.86	3.45	5.39	5.92	5.34	5.63	5.87	5.30	3.74
ESC	M-L	M-L	M-L	G-M	G-M	G-M	G-M	G-M	G-M	M-L
EEI-c per site	4.64		4.42		5.63		5.75		4.52	
ESC per site	M-L		M-L		G-M		G-M		M-L	

Note: DJD: Daeijakdo; GBD: Gyeokryeolbiyeoldo; HD: Hodo; GD: Gwanrido; UD: Uido; Inter: intertidal zone; Sub: subtidal zone; G-H: Good-High; G-M: Good-Moderate; M-L: Moderate-Low; B: Bad.

Table 6. Comparison of the number of species in each macroalgae taxonomic groups along the western sea of Korea

Tidal level	Site	Season	Species				Reference
			C	O	R	Total	
Inter+Sub	Bunjeomdo[a]	Wi, Sp, Su, Au	9	8	37	54	Yoo and Kim (2003)
	Ongdo[a]	Wi, Su	2	4	26	32	Heo et al. (2011)
	Jusamdo[b]	Wi, Su	4	9	32	45	Heo et al. (2011)
	Woejodo[b]	Wi, Su	2	6	36	44	Heo et al. (2011)
	Eocheongdo[a]	Wi, Sp, Su, Au	12	23	66	101	Kim et al. (2013a)
	Daeijakdo[a]	Sp, Su	3	5	19	27	this study
	Gyeokryeolbiyeoldo[a]	Sp, Su	4	6	25	35	this study
	Hodo[a]	Sp, Su	5	4	25	34	this study
	Gwanrido[b]	Sp, Su	8	11	22	41	this study
	Uido[b]	Sp, Su	3	6	32	41	this study
Inter	Bagryoungdo[a]	Wi, Sp, Su, Au	6	6	29	41	Baek et al. (2007)
	Sapsido[a]	Wi, Sp, Su, Au	12	30	58	100	Yoon and Boo (1991)
	Oeyondo[a]	Wi, Sp, Su, Au	16	27	79	122	Cho and Boo (1996)*
	Sinangun UI.[b]	Su	11	16	36	63	Oh et al. (2005)
	Dochogundo[b]	Su	10	14	29	53	Park et al. (2007)
	Deokjeokdo[a]	Wi, Sp, Su, Au	2	2	17	21	Lee et al. (2007)
	Gogunsangundo[b]	Wi, Sp, Su, Au	10	16	32	58	Kim et al. (2011)

Note: *Monthly basis sampling; superscripts of a and b indicate the study sites of middle and southern parts, respectively. Inter: intertidal zone; Sub: subtidal zone; Wi: winter; Sp: spring; Su: Summer; Au: Autumn; C: Chlorophyta; O: Ochrophyta (Phaeophyceae); R: Rhodophyta.

ent studies at different sites. The number of recorded macroalgal species can differ according to elements of the survey method such as sampling season, replication, and geographic range. Furthermore, environmental conditions such as water temperature, salinity, turbidity, exposure to air, and substrate features can greatly impact the number of species present (Choi et al., 1994; Best et al., 2001; Park and Hwang, 2011; Kim et al., 2013a; Kong and Kim, 2015; Park et al., 2013). Therefore, comparing total macroalgal species counts between different sites may not provide very meaningful insights.

Each taxonomic group of macroalgae (green, brown, and red algae) shows different survival responses to environmental changes (Romdoni et al., 2018). In this study, the proportion of the macroalgal community made up of green algae, brown algae, and red algae ranged from 7.3%–19.5%, 11.8%–26.8%, and 53.7%–78.0%, respectively. In previous studies at nearby marine locations, the values obtained were similar to ours, being 4.5%–18.9% for green algae, 9.5%–30.0% for brown algae, and between 54.7%–81.8% for red algae (see also Table 6). Except for UD, the proportion of green algae, which is known for excellent environmental adaptability and rapid transition and growth in contaminated environments, was higher in this study area than in the nearby previously studied areas. On DJD, GBD, and GD, the proportion of brown algae, which tend to dominate in uncontaminated environments, was similar to or higher than those of the nearby areas, implying differences in environmental conditions between our study sites and nearby areas.

Cheney (1977) proposed the (R+C)/P value (each letter indicates the number of species in each Chlorophyta (C), Phaeophyceae (P) and Rhodophyta (R)) as an indicator of the geographical characteristics of the macroalgal flora based on the number of species in each macroalgal taxonomic group; he classified the flora as temperate or Arctic if the (R+C)/P value was 3 or lower, tropical if it was 6 or higher, and hybrid if it was intermediate. In our study areas, the (R+C)/P values ranged from 2.73 for GD to 7.50 for HD, displaying a wide range from temperate to tropical macroalgal flora. Although GD was located in the middle latitudes among the study areas, it was classified as having a temperate macroalgal flora, while islands at both higher and lower latitudes had hybrid or tropical macroalgal flora. This trend of Cheney's index in this study was not in accordance with the general climate trend of macroalgal communities suggested by Cheney (1977), but at least, it can be explained by distinct coastal environments in the western waters of Korea. Generally, seawater in the Yellow Sea region is turbid, and the bottom layers are mostly covered with mud, providing unfavorable environmental conditions for the growth of macroalgae, so that more diverse red algae occur in such environments (Hwang et al., 1996). In contrast, the macroalgal community in GD is dominated by brown algae, which reflects its cleaner waters compared to other more turbid sites (Koh and Oh, 1992). Our results could explain variations in macroalgal composition on a global scale, while local environmental conditions (such as turbidity) can sometimes override the influence of climate, providing unexpected results.

Community indices of marine biota, such as diversity and dominance, are quantitative indicators for determining the characteristics of the biological community and partial environmental conditions. Park et al. (2006) suggested that a higher diversity and lower dominance indicate a more stable community structure and good environmental conditions. In the present study, diversity was lower and dominance was higher in the intertidal zones as compared to the subtidal zones, indicating that the algal community of the intertidal zone was less stable and the environmental conditions were poorer. This pattern is probably due to the difference in the growing environment for macroalgae between the intertidal and subtidal zones; due to its permanent submergence below water, the subtidal zone has relatively stable environmental conditions; in contrast, the intertidal zone undergoes large environmental changes between low tide and high tide, experiencing swings in temperature, salinity, dryness, and humidity, which can have a destabilizing effect on the ecosystem. Among the study sites, DJD, GBD, and HD indicated little or almost no impact from human interference. However, GD and UD were located near ports and piers which entail frequent arrival and departures of vessels, and occasional coastal reclamations by port constructions and modifications. These human activities may affect environmental factors such as seawater flow, sediment realignment, and water quality (Song et al., 2003). Such an environment in the latter study sites resulted in the dominance of a small number of species with excellent environmental adaptability and rapid growth (Park et al., 2013). In addition, the subtidal zone of UD was at a depth of 3 m, compared to the other islands where the water depth was 6–8 m. Therefore, abiotic factors such as the intensity and quality of light and competition for substrate may result in low macroalgal diversity in this habitat (Koh and Oh, 1992; Edwards and Connell, 2012).

Macroalgae classified into ESG I consist of perennial species (late successional species) that respond sensitively to environmental changes from natural or artificial disturbances. Meanwhile, ESG II is composed of fast-growing opportunistic species that show excellent adaptation to environmental changes based on morphological, physiological, and ecological characteristics (Orfanidis et al., 2001). Because the species belonging to ESG I dominate in the pristine state, and ESG II species become abundant in degraded environmental conditions (Orfanidis et al., 2001), changes in the composition of the macroalgae functional group over time can closely reflect changes in the habitat environment (Littler and Littler, 1984; Pinedo et al., 2007; Wells et al., 2007). Orfanidis et al. (2001, 2003) divided species into five grades based on an EEI model to evaluate the habitat environmental conditions using the characteristics of macroalgal communities and suggested the necessity for ecosystem restoration for habitats with EEI values lower than six. Subsequently, Orfanidis et al. (2011) supplemented the existing EEI model to present EEI-c because even species within the same ESG category may show different responses to similar stressors. Several studies have evaluated the environmental conditions of ecosystems along the western coast of Korea using the EEI model. For example, Yoo et al. (2007) evaluated the habitat environment of the summer macroalgal flora in the western Taean Peninsula, and determined its condition to be "Bad-Low" based on EEI values of 0.80–2.29. Ahn et al. (2017) determined the habitat condition as "Low-Moderate" based on EEI values ranging from 3.77 to 7.33 in the coastal region of the Taean Peninsula. Furthermore, Oh et al. (2016) determined that the coastal habitat condition was "Moderate" from EEI values of 5.15–6.11 in three regions of a marine national park in the western Korean waters. As a result, higher EEI values indicate better environmental condition of the coastal habitat such as in marine national parks where habitats are well protected by the national government, whereas the coastal habitat of the western Taean Peninsula showed a poorer habitat environment during summer based on lower EEI values.

Evaluations of environmental conditions on the western coast of Korea have previously been conducted using either the composition of macroalgal functional groups (Littler and Littler, 1984) or EEI values (Orfanidis et al., 2001). However, no studies have evaluated environmental conditions using an improved EEI-c model. The present study is the first to evaluate habitat environmental conditions using EEI-c values in western Korean waters. However, Jung et al. (2020) evaluated coastal habitats on the eastern coast of Korea by applying EEI-c, determining the environmental conditions at Hupo Bank as "Good-High" (G-H). They reported that canopy-forming brown algae belonging to ESG I dominated in spring, while turf-forming red algae belonging to ESG II dominated in summer. In a study applying EEI-c along the Algerian coastline, Chabane et al. (2018) reported that habitats not impacted by environmental pollution were dominated by the ESG I species *Cystoseira amentacea* var. *stricta*, *Lithophyllum incrustans*, and *Jania rubens*, whereas ESG II species such as *Ulva rigida*, *Ulva intestinalis*, and *Caulerpa cylindracea* were abundant at polluted sites. In the present study, the environmental conditions of GD and HD were evaluated as "Good-Moderate" (G-M) due to the dominance of *Sargassum thunbergii* and *Myagropsis myagroides* belonging to ESG I. However, the environmental conditions of DJD, GBD, and UD, were evaluated as "Moderate-Low" (M-L), due to the dominance of *Corallina pilifera* (ESG I), *Ulva australis*, *Botryocladia wrightii*, *Gelidium vagum*, and *Gelidium elegans* (ESG II). The evaluation of macroalgal communities by applying EEI-c cannot only be a good protocol for monitoring the ecosystem, but also contribute to the coastal management plan (Caldeira et al., 2017). Therefore, it will be necessary to secure more data on macroalgal biota to evaluate the environmental conditions for the entire coast of Korea in the future.

5 Conclusions

Changes in the environmental conditions of marine habitats due to coastal development, marine pollution, and increasing water temperatures can act as stressors for macroalgal communities (Russell et al., 2009). In this study, the EEI-c of macroalgal communities in five islands along the western coast of Korea were evaluated as "Moderate-Low" or "Good-Moderate". The coastal habitats of HD and GD were better for inhabiting macroalgae, whereas the other sites were judged to be in poor environmental conditions. Analyses of biological communities in marine ecosystems can be a direct approach in coastal habitats where anthropogenic as well as climate change influences persist. Therefore, to maintain a sustainable marine ecosystem, it is necessary to accumulate ecological data through continuous monitoring and prepare a management plan for ecosystem restoration in the western waters of R. O. Korea.

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Supplementary information

Table S1. List of macroalgal species and average biomass (g/m^2) investigated at the study sites.

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