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Characteristics of Algal Succession Following Rock Scraping at Imwon Area in the East Coast of Korea

Young Dae Kim[1)], Jung Kwan Ahn[2), **], Myung Mo Nam[1)], Chu Lee[1)], Hyun Il Yoo[3)], Su Yeoung Yeon[4)], Young Hwan Kim[4)], Jang Kyun Kim[5), 6)], and Jae Suk Choi[7), *]

1) *East Sea Fisheries Research Institute*, *National Fisheries Research & Development Institute*, *Gangneung* 210-860, *Republic of Korea*
2) *Korea National Park Service*, *National Park Research Institute*, *Yeosu* 550-833, *Republic of Korea*
3) *Seaweed Research Center*, *National Fisheries Research & Development Institute*, *Mokpo* 530-831, *Republic of Korea*
4) *Department of Biology*, *Chungbuk National University*, *Chongju* 361-763, *Republic of Korea*
5) *Department of Marine Science*, *School of Natural Sciences*, *Incheon National University*, 22012, *Yeonsu-gu*, *Incheon*, *Korea*
6) *Department of Marine Sciences*, *University of Connecticut* 06901, *Stamford* ,*Connecticut*, *USA*
7) *Division of Bioindustry*, *Silla University*, *Sasang-gu*, *Busan* 617-736, *Republic of Korea*

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Abstract This study was conducted to clarify the characteristics of algal succession following rock scraping using hoe or high-pressure water sprayer in the period from June 2010 to April 2011. We divided the research area off the eastern coast of Korean near Imwon into 3 categories depending upon the severity of the barren ground, *i.e*., the urchin barren-affected, urchin barren-ongoing and urchin barren-free areas. In April 2011, in the urchin barren-affected area with 25 seaweed species, the cover percentage and importance value (IV) of crustose coralline algae were higher than those of other species. In the urchin barren-ongoing area with 33 seaweed species, crustose coralline algae (mean IV = 62%) as well as *Sargassum* sp. (mean IV = 28%), and *Gelidium amansii* (mean IV = 19%) were observed following rock scraping. In the urchin barren-free area where seaweed communities were relatively abundant with 42 species, a variety of algal species including *G. amansii* (mean IV = 32%) underwent algal succession. Overall, it was observed that, as an aspect of algal succession, the weaker the barren ground severity was, the more frequent and diverse the seaweeds were, and the more complex the succession pattern was in the study. As an aspect of recovering algal community, rock scraping using hoe was shown to be superior to the method using high-pressure water spraying. Therefore, we conclude that rock scraping using hoe is a very effective strategy for recovering the algal community in urchin barren-ongoing area.

Key words algal succession; sea-urchin barren ground; rock scraping; subtidal zone

1 Introduction

Seaweed delivers important ecological services, providing habitats, nurseries and food for marine fauna (Lindstrom, 2009). It serves as an important primary coastal producer (Graham and Wilcox, 2000) and has a variety of applications for medicines as well as being used for both human and animal food (Worm *et al*., 2000). Being affected by various causes like water temperature change, grazers and pollution, seaweed is continuously dying and being depleted. This depletion has been defined as 'barren ground' (also known as 'sea-urchin barrens' and 'algal whitening' in Korea) (Kim *et al*., 2012). The barren ground is characterized by a thin layer of pink-colored crustose coralline algae, which turn white after dying, consequently attracting an excess population of grazers (Kim *et al*., 2007). It was reported that the excessive increase of grazers serves as a main culprit of marine deforestation (Fujita, 2010; Humphries *et al*., 2014). Data released by the Japanese Fisheries Agency (Fisheries Agency, 2007) indicate that grazers are responsible for 55% of the barren ground, while an increase in water temperature accounts for 10% and other various causes occupy another 10% of the barren ground. It was reported that the algal barren ground affected an average of 16.1% of the coast of the Korean East Sea in 1999 with the medial coastal area not affected (NFRDI, 2004). But, in 2004, 7.0% of the medial area and 31.0% of the south of the coastal area were affected, indicating an increasing trend of barren ground along the Korean East Sea (NFRDI, 2004). A 2011 research of the entire Korean coastline showed a severely-high level of barren ground along the eastern coast, with 42.4% of the marine area being affected (KFRA, 2011).

* Corresponding author. Tel: 0082-61-640-2311
E-mail: jungkwanahn@gmail.com; jsc1008@silla.ac.kr

Seaweed succession, in general, can be referred to as a process in which seaweed communities set on artificial substratum to undergo seasonal changes (Tsuda and Kami, 1973; Kim, 1987; Han, 2012; Kwak, 2014). The process also demonstrates how seaweed communities are recovered after having been artificially removed (Kain, 1975; Murray and Littler, 1978; Niell, 1979; Kim *et al*., 1992). Rock scraping has long been conducted by fishermen on a small scale to improve chances for commercially-useful seaweed species to settle upon rocks. Removing useless seaweed species and/or grazing animals, the method has been widely applied for projects involving marine forest enhancement aimed at overcoming the rapidly expanding phenomenon of algal barren ground along the Korean coast (Kim *et al*., 2012; Gim *et al*., 2013; Kwak *et al*., 2014a; Kwak *et al*., 2014b). It has been reported that rock scraping is to induce changes, or succession, in seaweed communities through artificial disturbances on the seaweed communities and this type of succession is classified as the second stage of succession where stabilized seaweed communities are artificially disturbed and recovered (Kim and Yoo, 1994). There were no available scientific data on effects of traditional methods using hoe for rock scraping. Therefore, in this study, we have applied both of the rock scraping methods (a traditional method using hoe and modern high-pressure sprayer) to the three research areas with different levels of barren ground severity. In addition, we have also conducted both quantitative and qualitative analyses on seaweed community and succession after rock scraping using hoe and high-pressure sprayer.

2 Materials and Methods

We have conducted experiments over a period from June 2010 to April 2011 at NFRDI (National Fisheries Research & Development Institute) fishing grounds research facility located in Imwon-ri, Wonduk-eup, Samchuk-si, Gangwon province, South Korea (37˚13.6′N, 129˚21.0′E). Its substratum is constructed with evenly-distributed rocks. On the coastline, some breakwaters forme a bay with an effective flow between the open sea and the research facility. We selected three trial groups at 6–10 m depth in the research area depending on the severity of the barren ground: (a) urchin barren-affected area (over 90% of which was barren), (b) urchin barren-ongoing area (over 50% of which was barren), and (c) urchin barren-free area (with natural vegetation of various abundantly growing seaweeds). We installed permanent quadrats and studied via the following process (Fig.1). We installed 4 permanent quadrats in the different research areas to conductexperiment using two different methods of rock scrapping. To set up a permanent quadrat, we drilled holes in a rock at a distance of 1 m × 1m, connected the holes with eye-nuts and tied a 18 mm rope to the nuts. We implemented rock scraping in the permanent quadrats using a traditional hoe and water sprayer with 400–500 bar pressure (High water pressure gun, DIVE Korea, Bucheon, Korea; Gim *et al*., 2013; Kwak *et al*., 2014a). After rock scrapping on the permanent quadrats, a diver placed a 0.5 m × 0.5 m portable quadrat at the center of the permanent quadrat to take pictures of seaweed communities using a digital camera (D800, Nikon, Japan). To ensure that seaweed covered by macroalgae was not to be missed, the diver took a second shot by moving the macroalgae. As for species which are considered difficult to be observed on the screen, we sampled a small quantity of the species nearby. Every two months after scraping, we conducted image analysis on species composition, frequencies and cover percentages of each seaweed species. To this end, we put a 0.5 m × 0.5 m sized quadrat with 25 segments of 0.1 m × 0.1 m in the permanent quadrat and measured values of cover percentage and frequency. As for coverage, we obtained a relative coverage, or ratio of a coverage of each species to the total coverage of all species combined. As for frequency, we also obtained a relative frequency in the same way as in calculating relative coverage values. Mean values of relative coverage and frequency values were adopted as importance values (Brower *et al*., 1998; Kim *et al*., 2011).

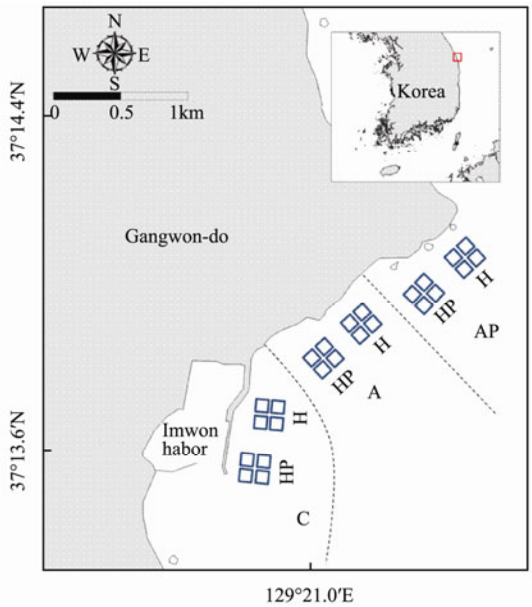

Fig.1 Locations of research area and permanent quadrats. C, urchin barren-free area; A, urchin barren-affected area; AP, urchin barren-ongoing area; H, Locations of quadrats scrapped by a hoe; HP, Locations of quadrats scrapped by high-pressure water spraying.

3 Results and Discussion

3.1 Qualitative Comparison of Seaweed Species Occurring in the Permanent Quadrats Between Pre- and Post-Rock Scraping

In the urchin barren-affected area, use of the traditional hoe showed no significant change in the cover percentages between pre- and post-rock scraping. The coverage of crustose coralline algae was 96% before rock scrapping and the number little changed after scrapping till February 2011. Ten months after scraping (April 2011), the cover percentage of crustose coralline algae significantly declined to 59% with small amounts of *Chorda filum* (cover 9%) and *Ulva pertusa* (2%) identified. In the same research area, the cover percentage of crustose coralline algae was 34% prior to use of high-pressure water spraying. In October, only four months after scraping, the cover significantly rose to 97%. Ten months after scraping, the cover percentage of crustose coralline algae significantly declined to 62% with small amounts of *Gelidim amansii* (cover 5%) and *C. filum* (2%) (Figs.2A and B). In the urchin barren-ongoing area, crustose coralline algae (33%), *G. amansii* (31%) and *Grateloupia filicina* (27%) were present on the permanent quadrats prior to rock scraping using a hoe. In October, four months after scraping, crustose coralline algae (95%) dominated the substratum, reducing *G. amansii* (1%). In the high pressure water spraying-treated area, most of crustose coralline algae (48%) and *G. amansii* (36%) were removed. In October, crustose coralline algae (48%) maintained the pre-rock scraping levels and *G. amansii* (8%) revived. In April 2011, 10 months after scraping, *S. horneri* (72%) became more abundant (Figs.2C and D). A comparison was also made for seaweed species in the permanent quadrats in the urchin barren-free area with relatively abundant seaweed forest. Prior to use of the traditional hoe, *Chondrus ocellatus* (42%) was dominant along with *G. amansii* (24%), crustose coralline algae (11%), *etc*. On the post-rock scraping substratum, all of seaweed species were removed except crustose coralline algae (32%). In December 2010, six months after rock scraping, massive occurrence of *G. amansii* (cover 52%) and decline of crustose coralline algae (22%) and *G. filicina* (5%) were observed. Prior to use of high-pressure water spraying, *G. amansii* (20%) and crustose coralline algae (15%) were growing. However, after scraping, all species were removed except crustose coralline algae (24%). Four months after scraping (October 2010), crustose coralline algae (82%) occupied most of the substratum and continued to until April 2011, 10 months after the scraping (Figs.2E and F).

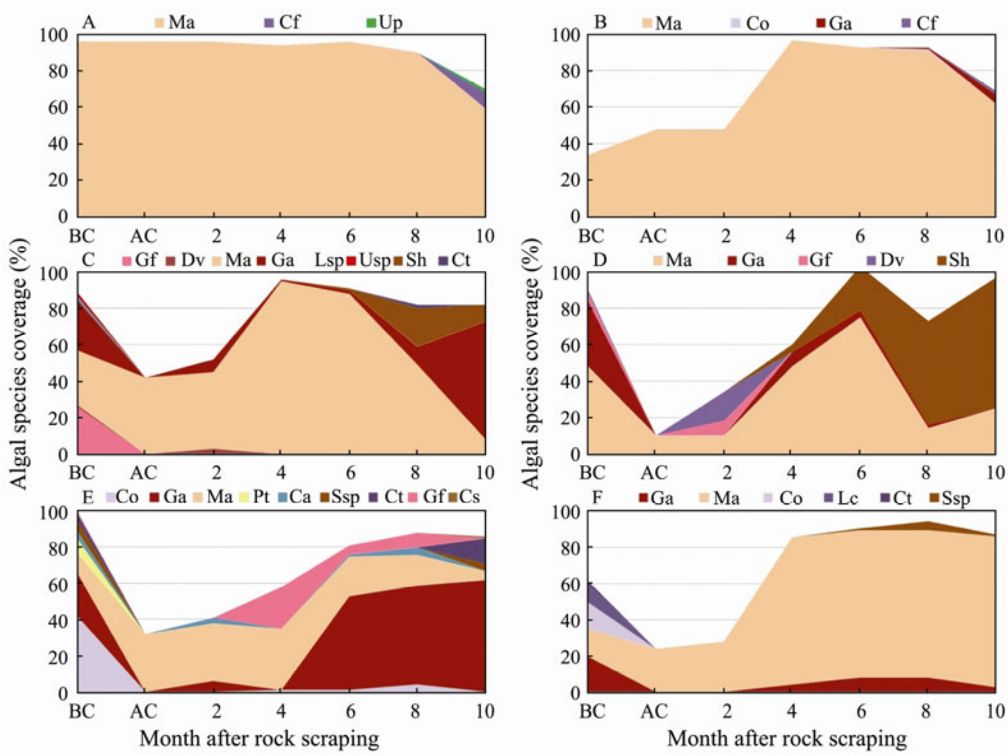

Fig.2 Algal species coverage of each research areas from June 2010 to April 2011. A, urchin barren-affected area scrapped by a hoe; B, urchin barren-affected area scrapped by high-pressure water spraying; C, urchin barren-ongoing area scrapped by a hoe; D, urchin barren-ongoing area scrapped by high-pressure water spraying; E, urchin barren-free area scrapped by a hoe; F, urchin barren-free area scrapped by high-pressure water spraying; BC, pre-rock scraping; AC, post-rock scraping; Ma, melobesioidean algae; Cf, *Chorda filum*; Up, *Uiva pertusa*; Co, *Chondrus ocellatus*; Ga, *Gelidium amansii*; Gf, *Grateloupia filicina*; Dv, *Desmarestia viridis*; Lsp, *Laurensia* sp.; Usp, *Ulva* sp.; Sh, *Sargassum horneri*; Ct, *Chondracanthus tenellus*; Pt, *Plocamium telfairiae*; Ca, *Codium arabicum*; Ssp, *Sargassum* sp.; Cs, *Colpomenia sinuosa*; Lc, *Lomentaria catenata*.

Seaweed succession patterns varied depending on the investigation areas; in the urchin barren-affected area, after rock scraping using a hoe and a high pressure water sprayer, seaweeds experienced succession stages in which crustose coralline algae maintained high percentages of cover or was greatly enriched and subsequently reduced the following winter (rock scraping was conducted in August) with a small number of other seaweed species; in the urchin barren-ongoing area, rock scraping removed all of seaweed species except crustose coralline algae which subsequently became greatly enriched in the summer and autumn and then *Sargassum horneri* and *G. amansii* appeared; in the urchin barren-free area, the succession pattern was different between the hoe-treated and sprayertreated area. In the rock substratum scrapped with a hoe, plenty of various seaweed species were observed; meanwhile, in the rock substratum scrapped with a high pressure water sprayer, explosively grown crustose coralline was observed. These results indicate that high pressure water spraying is effective in removing fleshy seaweed but is ineffective in removing crustose coralline algae.

It has been reported that various different patterns of the process of seaweed community enrichment were observed depending on location of sea, season, initial seaweed community, *etc*. (Pacheco *et al*., 2010; Chung *et al*., 1998; Niell, 1979; Lodge, 1948). According to the results of Pacheco *et al*. (2010), the seaweed community in the subtidal zone of the northern coast of Chile undergoes 2 phases of succession of benthic diatoms film and custose red corallines. It was also observed that crustose red corallines thrived 3 months after rock scraping in the waters off Jeju Island (Gim *et al*., 2013). This tendency was also observed in the barren-affected area scraped with a hoe or a high pressure water sprayer and in the barren-free area scraped with a high pressure water sprayer in this study (Figs.2A, B and F). Though pioneer species of an early phase could not be identified (like benthic diatoms in Chilean coast), crustose red corallines which occurred in later phase indicated that the research areas underwent similar phases of succession to those of the Chilean coast and Jeju. As another pattern, it was reported that algal barren ground off the coast of Seogwipo, Jeju, South Korea experiences 3 stages of succession; 1) early stage loss of thallus algae; 2) middle-stage loss of geniculate algae; 3) late stage loss of crustose coralline algae (Chung *et al*., 1998). Generally, seaweed succession is studied to monitor temporal changes in how a seaweed community is composed after installation of an artificial substratum or removal of seaweed grazers from a natural substratum; it takes at least 3 years to conduct such a study (Kim, 1987, 1994; Kim *et al*., 1992; Kim and Yoo, 1994; Kim and Park, 1997). With a relatively short period (about 10 months), this study cannot provide a complete process of seaweed succession. Nevertheless, the number of species in the seaweed community declined after rock scraping and the seaweeds experienced seasonal changes in autumn (October), winter (February), and spring (April) in the urchin barren-ongoing area scraped with both a hoe and a high pressure water sprayer and in the urchin barren-free area scraped with a hoe in this study.

3.2 Importance Value (IV) of Seaweed Species in Each Experimental Area

We calculated importance value (IV) of seaweed species based upon cover percentages and frequencies of observed seaweeds in the permanent quadrats installed in each experimental area (Fig.3). The results are as follows:

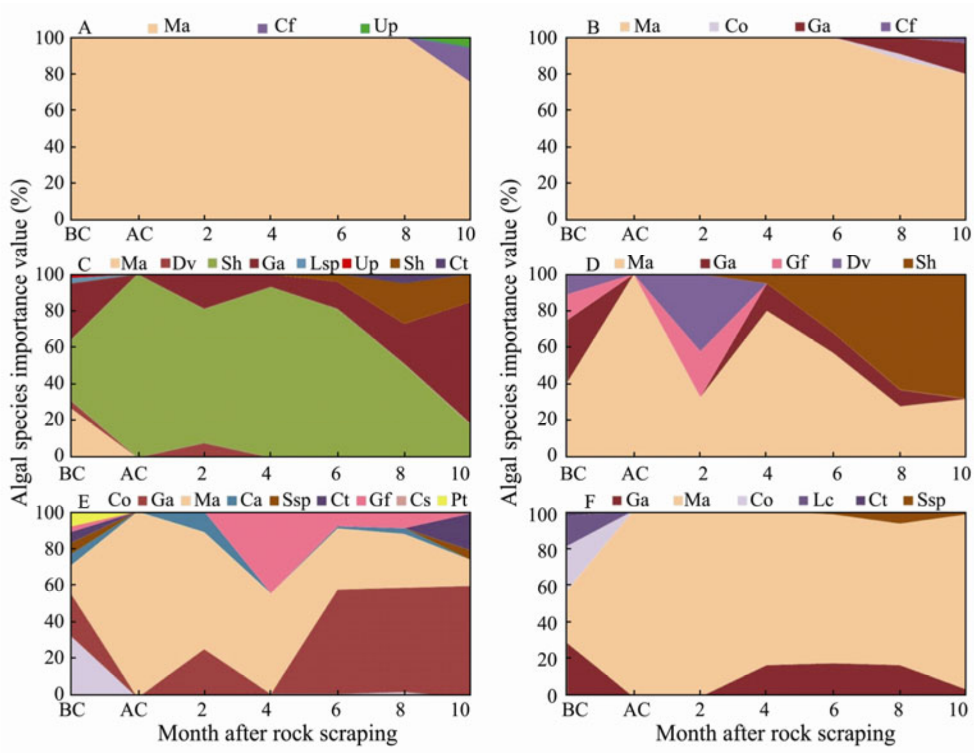

Fig.3 Algal species importance value of each research areas from June 2010 to April 2011. A, urchin barren-affected area scrapped by a hoe; B, urchin barren-affected area scrapped by high-pressure water spraying; C, urchin barren-ongoing area scrapped by a hoe; D, urchin barren-ongoing area scrapped by high-pressure water spraying; E, urchin barren-free area scrapped by a hoe; F, urchin barren-free area scrapped by high-pressure water spraying; BC, pre-rock scraping; AC, post-rock scraping; Ma, melobesioidean algae; Cf, *Chorda filum*; Up, *Ulva pertusa*; Co, *Chondrus ocellatus*; Ga, *Gelidium amansii*; Gf, *Grateloupia filicina*; Dv, *Desmarestia viridis*; Lsp, *Laurensia* sp.; Usp, *Ulva* sp.; Sh, *Sargassum horneri*; Ct, *Chondracanthus tenellus*; Pt, *Plocamium telfairiae*; Ca, *Codium arabicum*; Ssp, *Sargassum* sp.; Cs, *Colpomenia sinuosa*; Lc, *Lomentaria catenata*.

In quadrats scrapped by a hoe in the urchin barren- affected area, crustose coralline algae maintained IV 100% until February 2011, 8 months after scraping. In April 2011 (10 months after scraping), crustose coralline algae also remained IV 95% with other seaweed species rarely observed. In quadrats scrapped by high pressure water spraying, crustose coralline algae also remained IV 91-100% during the research period with other seaweed species rarely observed (Figs.3A and B). In quadrats scrapped by a hoe in the urchin barren-ongoing area, *U. pertusa* (IV 2%) rose in its importance value and *G. amansii* (IV 15%) were newly colonizing after scraping. In quadrats scraped by high pressure water spraying, IV of crustose coralline algae reached 100%. In August, two months after scraping, *D. viridis* (IV 42%), *G. filicina* (IV 25%) and crustose coralline algae (IV 33%) were observed. In October, crustose coralline algae (IV 80%) and *S. horneri* (IV 5%) appeared and then the IV changed inversely to 32% of coralline algae and 57% of *S. horneri* (Figs.3C and D). Overall, in the urchin barren-free area, relatively more diverse seaweed species were growing before rock scraping. In quadrats scrapped by hoe, *G. amansii* and *Codium arabicum* gained 26% and 11% of IV, respectively and then the value (14%) of crustose coralline algae was sharply reduced. In quadrats scrapped by high- pressure water spraying, crustose coralline algae almost reached IV 100% after rock scraping (Figs.3E and F).

3.3 Species Composition

A total of 48 seaweed species, including 6 Chlorophyta, 15 Phaeophyta and 27 Rhodophyta, were identified during the period of June 2010 to April 2011 (Table 1). Results from the investigation area showed the urchin barren-free area with the most diverse species of 42 (Chlorophyta 3, Phaeophyta 12, and Rhodophyta 27), the urchin barren-ongoing area with 33 species (Chlorophyta 4, Phaeophyta 9, and Rhodophyta 20) and the urchin barren-affected area with 25 species (Chlorophyta 4, Phaeophyta 7, and Rhodophyta 14). Having excluded crustose coralline algae which were not clearly identified through image analysis, 21 commonly found species were identified in the urchin barren-affected area, the urchin barren-ongoing area scrapped by both the scraping tools and the urchin barren-free area scrapped by a hoe (at the thick of the seaweed forest). The commonly found species were identified as follows: 2 Chlorophyta species (*Cladophora albida* and *Ulva pertusa*), 6 Phaeophyta (*Colpomenia sinuosa*, *Desmarestia viridis*, *Dictyota dichotoma*, *Leathesia difformis*, *Sargassum horneri*, and *Undaria pinnatifida*) and 13 Rhodophyta (*Acrosorium polyneurum*, *Amphiroa zonata*, *Caulacanthus ustulatus*, *Chondracanthus intermedia*, *C. tenellus*, *Chondrus ocellatus*, *Gelidium amansii*, *Grateloupia filicina*, *Laurencia okamurae*, *Lithophyllum okamurae*, melobesioidean algae, *Peyssonnelia japonica*, and *Plocamium telfairiae*) (Table 1). We identified a total of 48 seaweed species during the research period, 19 of which were commonly observed in all of the experimental areas. Meanwhile, some species were unique depending upon the area observed. For instance, *Codium fragile*, *Chorda filum* and *Derbesia* sp. were observed in the urchin barren-affected area, while *Bryopsis maxima*, *Cladophora albida*, *Papenfussiella kuromo* and *Scytosiphon lomentaria* were observed in the urchin barren-ongoing area. In the urchin barren-free area where seaweeds grew relatively abundantly, 5 Phaeophyta species (*Dictyopteris divaricata*, *D. undulata*, *Ecklonia cava*, *Laminaria japonica*, and *Sargassum confusum*) and

Table 1 List of algal species observed in research areas, from June 2010 to April 2011

Species	Site		
	Urchin barren-affected area	Urchin barren-ongoing area	Urchin barren-free area
Chlorophyta			
Bryopsis maxima		+	
Cladophora albida	+	+	+
Codium arabicum		+	+
Codium fragile	+		
Derbesia sp.	+		
Ulva pertusa	+	+	+
Phaeophyta			
Chorda filum	+		
Colpomenia sinuosa	+	+	+
Desmarestia viridis	+	+	+
Dictyopteris divaricata			+
Dictyopteris undulata			+
Dictyota dichotoma	+	+	+
Ecklonia cava			+
Leathesia difformis	+	+	+
Papenfussiella kuromo		+	
Saccharina japonica			+
Sargassum confusum			+
Sargassum horneri	+	+	+
Sargassum sp.		+	+
Scytosiphon lomentaria		+	
Undaria pinnatifida	+	+	+
Rhodophyta			
Acrosorium polyneurum	+	+	+
Acrosorium yendoi		+	+
Ahnfeltiopsis flabelliformis			+
Amphiroa beauvoisii	+	+	+
Caulacanthus ustulatus	+	+	+
Chondracanthus intermedius	+	+	+
Chondracanthus tenellus	+	+	+
Chondria crassicaulis			+
Chondrus ocellatus	+	+	+
Corallina pilulifera		+	+
Gelidium amansii	+	+	+
Grateloupia elliptica		+	+
Grateloupia filicina	+	+	+
Heterosiphonia japonica			+
Laurencia okamurae	+	+	+
Lithophyllum okamurae	+	+	+
Lomentaria catenata			+
Lomentaria hakodatensis			+
melobesioidean algae	+	+	+
Peyssonnelia caulifera			+
Peyssonnelia japonica	+	+	+
Plocamium telfairiae	+	+	+
Polysiphonia morrowii		+	+
Prionitis cornea			+
Pterocladiella capillacea		+	+
Rhodymenia intricata			+
Symphyocladia latiuscula			+

10 Rhodophyta species (*Ahnfeltiopsis flabelliformis*, *Chondria crassicaulis*, *Corallina pilulifera*, *Heterosiphonia japonica*, *Lomentaria catenata*, *L. hakodatensis*, *Peyssonnelia caulifera*, *Prionitis cornea*, *Rhodymenia intricata*, and *Symphyocladia latiuscula*) were observed (Table 1).

Lee and Kim (1999) reported that in the waters off the coast of the eastern village of Jangho, South Korea, seaweed communities were composed of 12% of Chlorophyta, 25% of Phaeophyta, and 63% of Rhodophyta. Choi *et al*. (2006) also reported that the subtidal seaweed communities off the coast of the eastern village of Uljin, South Korea were composed of 13% Chlorophyta, 33% Phaeophyta, and 54% Rhodophyta. In the subtidal zone of Daejin, Gangwon province, located near the research facility used in this study, the seaweed communities were composed of 12% of Chlorophyta, 28% of Phaeophyta, and 61% of Rhodophyta (Shin *et al*., 2008). In this study, the percentages of seaweed composition found in all research areas during research periods were 13% of Chlorophyta, 31% of Phaeophyta, and 56% of Rhodophyta. The results on the composition of seaweed community showed similar tendency to previous results on seaweed communities in the Korea eastern coast (Lee and Kim, 1999; Choi *et al*., 2006; Shin *et al*., 2008). The study was conducted over a period from June 2010 to April 2011 to reveal the monthly changes in seaweed communities following rock scraping in the subtidal zone of Imwon area, Korea. Rock scraping by a traditional method using a hoe induced changes in various species of seaweed while scraping using a high pressure water sprayer resulted in explosive colonization of crustose coralline algae. In April 2011, the seaweed community composition in the urchin barren-ongoing area and urchin barren-free area scraped by a hoe showed similar tendency to what previous results showed in the Korean eastern coast. Therefore, we conclude that the rock scraping using a hoe is a very effective strategy for recovering the algal community in urchin barren-ongoing area.

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