한국해양환경공학회지
Journal of the Korean Society
for Marine Environmental Engineering
Vol. 12, No. 3. pp. 157-164, August 2009

슬래그 매립장 해역의 인공해조장에 서식하는 저서생물 군집의 천이

김진만 · 곽석남[1,†]
부경대학교 생태공학과
[1]해양생태기술연구소

Monitoring in Succession of Benthic Communities on Artificial Seaweed Beds in the Slag Dumping Area

Jin Man Kim and Seok Nam Kwak[1,†]
Department of Ecological Engineering, Pukyong National University, Namgu, Busan 608-737, Korea
[1]Marine Eco-Technology Institute Co., Ltd. 485-1, Namgu, Busan 608-830, Korea

요 약

슬래그 매립장 배출구 인근해역에 곰피(*Ecklonia stolonifera*)를 이식한 소규모 인공해조장을 건설하여 해조장에서 서식하는 저서생물 군집의 천이 양상을 2004년 4월부터 2005년 6월까지 모니터링 하였다. 첫 번째 이식 후 조사(2004년 4월부터 10주간 실험)에서는 솜말(*Acinetospora critina*)이 인공해조장에서 가장 우점하였다. 두 번째 조사(2004년 6월 이식 후 51주간 실험)에서는 총 15종의 해조류가 발견되었는데, 이 중 창자파래(*Enteromorpha intestinalis*)와 파래류(*Enteromorpha* sp.)가 가장 우점하였다. 그 외 초록털말(*Urospora penicilliformi*), 초록실(*Ulothrix flacca*), 대마디말류(*Cladophora* sp.), 그리고 구멍갈파래(*Ulva pertusa*)가 곰피의 잎에 나타났다. 동시에 곰피의 잎에 부착하여 서식하는 저서동물, 연체동물 그리고 작은 크기의 어류 등도 출현하였다. 부착 저서동물은 주로 단각류(Amphipods)였으며, 연체동물은 진주담치(*Mytilus edulis*), 대수리(*Thais clavigera*), 그리고 어류는 숭어(*Mugil cephalus*), 베도라치(*Pholis nebulosa*) 등이 우점하였다. 이와 같은 결과는 곰피를 이용하여 조성된 인공해조장이 생물들이 성장할 수 있는 서식처 역할을 수행함과 동시에 스스로의 천이 과정을 통하여 저서생물 군집이 형성되는데 기여하였음을 알 수 있다.

Abstract – In order to rehabilitate habitats for marine organisms in the slag dumping area, succession of benthic communities was monitored on artificial seaweed beds with transplantation of *Ecklonia stolonifera* from April 2004 to June 2005. *Acinetospora critina* was only primary dominated on steel frame in the first experiment (April 2004). A total of 15 species of seaweed were identified in the second experiment (June 2004). *Enteromorpha intestinalis* and *Enteromorpha* sp. were dominated, and *Urospora penicilliformis, Ulothrix flacca, Cladophora* sp., and *Ulva pertusa* were found on *Ecklonia stolonifera* fronds gradually with increasing time. This time was coincided with occurrence of benthic macrofaunas, molluscans and small fish species. The epiphytic benthic macrofaunas were dominated on amphipods, molluscans were *Mytilus edulis, Thais clavigera,* and fish species were *Mugil cephalus, Pholis nebulosa*. These results indicated that transplantation of *Ecklonia stolonifera* on artificial seaweed beds have been contributed on restoration habitats for benthic communities in the slag dumping area.

Keywords: *Ecklonia stolonifera*(곰피), Artificial seaweed beds(인공해조장), Monitoring(모니터링), Succession(천이), Benthic communities(저서생물 군집)

[†]Corresponding author: seoknam@hotmail.com

1. INTRODUCTION

Seaweed is among the most productive of marine photo-autotrophic communities in temperate coastal areas (Watanuki and Yamamoto[1990]). Higher productivity and structural components of seaweed beds increases habitat complexity and provides living space and shelter for marine animals (Largo and Ohno[1993], Terawaki *et al.*[2001]). In many parts of the world, however, unwise use and development of coastal area have often resulted the devastation causing the loss of natural populations of many marine animals and seaweeds. Some ecological studies have been undertaken regarding the re-establishment of seaweed beds with special attention to use of artificial seaweed reefs to recover lost seaweed beds (Odum and Odum[2003], Mitsch[1988], Mitsch and Jorgensen[1989]), whereas those of the studies on artificial seaweed beds in Korea were few despite of fluctuations of fish community (Lee and Kang[1994]).

The seawater landfill by the slag dumping using by-product in P's company, Korea was 1,400 tons from 1987 to 1995, and will be reclaimed 524 thousands m^2 ('97~2010), and 705 thousands m^2 (2011~) because iron production have been increased every year. These slag dumping brought high pH value with the combination of Ca^{2+} and seawater in the slag dumping area. The technologies to reduce higher pH values which can be lethal for the exposed marine animals shown in the slag dumping area are not available to date. Recently it has been suggested to recover high pH value in the slag dumping area with the injection of carbon dioxide from the LNG exhaust gas in P's company after establishing artificial seaweed beds with regard of ecological restoration. Laboratory experiment using 3 algal species (*Undaria pinnatifida, Sargassum horneri* and *Ecklonia stolonifera*) for ecological restoration showed that *Ecklonia stolonifera* was the best species among 3 algal species for transplantation on artificial seaweed beds in the study area (Kim and Kwak, in press).

The aims of this study was to monitor succession of benthic communities in transplantation of *Ecklonia stolonifera* on artificial seaweed beds. It is a fundamental part of a wider study aimed at understanding the pH neutralization of slag dumping area as well as suitable marine organisms by using carbon dioxide from LNG combustion process. It is also first approach for ecological restoration on carbon dioxide reduction in the slag dumping area with the monitoring on succession of benthic communities in transplantation of *Ecklonia stolonifera* on artificial seaweed beds.

2. MATERIALS AND METHODS

The artificial seaweed beds were located in the end of spillway close to seawater near P' company in Korea (Fig. 1a). To determine the environmental characteristics in the study area, temperature, salinity, pH, and dissolved oxygen were monitored on each sampling occasion with YSI 6600 instrument. The chemical oxygen demand, inorganic nutrient concentrations, and metal concentrations samples were also taken from the study area, and then were measured in the laboratory with Korea Standard Methods for the Examination of Water & Wastewater Manual (Ministry of Maritime Affairs and Fisheries[2002]). The degree of pH recovery was measured by the injection of carbon dioxide from the LNG exhaust gas in the study site. The LNG exhaust gas system was composed of constant pressure, and distribution facilities for suitable gas amount. The entrance of them was also consisted of ten 20A pipe (ϕ 20 mm) with hole, and located in the middle of spillways. The pH sensors were in P1, P2, P3, and P4 and controlled the fluctuation of pH

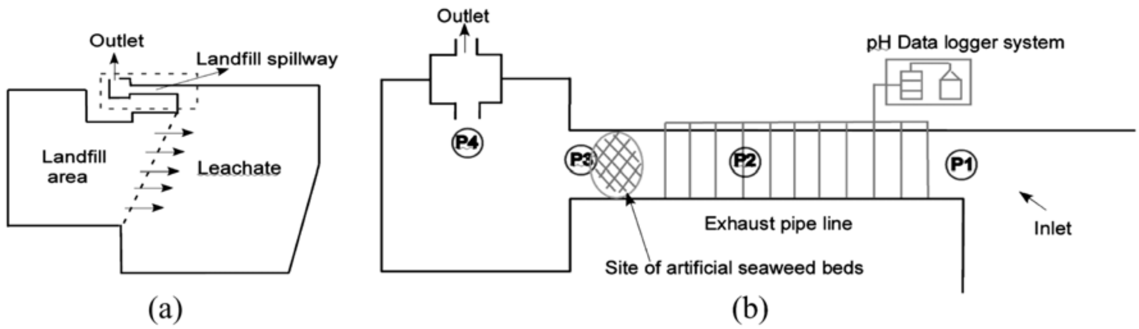
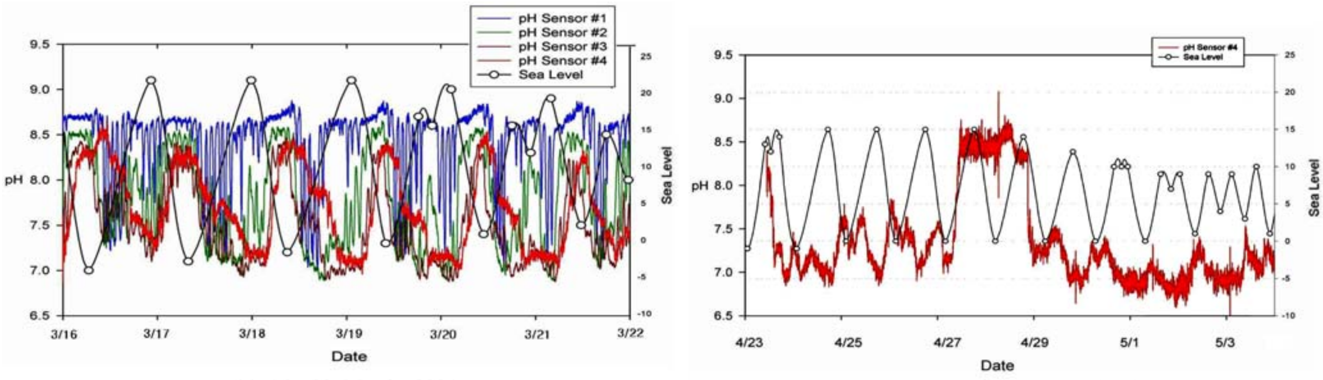


Fig. 1. The schematic diagram in the study area; (a) Landfill area (b) Pipe line for injection of LNG exhaust gas and station of pH sensor (P1: Spillway inlet zone, P2: Spillway middle zone, P3: Spillway the last zone, P4: Outlet zone).



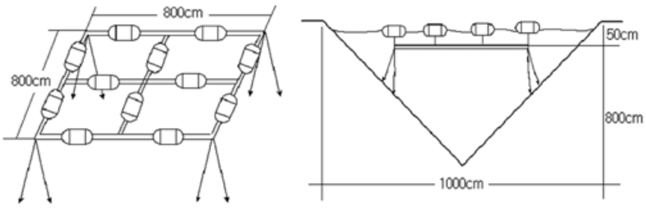
(a) 16~22 March, 2004 (b) 23 April ~ 3 May, 2004

Fig. 2. Temporal variation of pH values with injection of (a) 20 m^3/min and (b) 30 m^3/min by injection of LNG exhaust gas.

with continuous monitoring (Fig. 1b).

The CaO in the slag and seawater increases pH value with producing Ca^{2+} and OH^- in seawater ($CaO+H_2O=Ca^{2+}+2OH^-$). OH^- can be neutralized by CO_2 in LNG exhaust gas, producing HCO_3^- ($CO_2+OH^-=HCO_3^-$). At the field survey, the change in pH value has been monitored with injection of CO_2. The pH value decreased 8.5~9.0 from 16 March to 22 March 2004 with flow rate 20 m^3/min by injection of LNG exhaust gas (Fig. 2a), and 7.0~7.5 with flow rate 30 m^3/min from 27~29 April 2004. High difference of 7.0~8.5 was observed between high and low tide (Fig. 2b). The pH value of 7.0~7.5 was maintained with CO_2 continuous injection in the remaining periods.

The artificial seaweed beds were composed of steel frames (8 m×8 m) and placed under 50 cm water surface with 59 kg buoys (Fig. 3 and 4). This is due that transplanted *Ecklonia stolonifera* get more improvement of photosynthetic function on artificial seaweed beds. The matured *Ecklonia stolonifera* were transplanted on each steel frame with fixation of their holdfast by rubber band, and these samples were collected



(a) (b)

Fig. 3. Sketch of artificial seaweed beds in spillway; (a) size of a steel frame, (b) a front view of a steel frame in depth.

on natural rock in the coastal water off Young Island, Busan. In order to measure the degree of adaptability of *Ecklonia stolonifera* under controlled pH condition, 20 *Ecklonia stolonifera* were transplanted on steel frames in April 2004, and then monitored the successions of benthic communities for ten weeks as a pilot study. In the second experiment, 200 fronds were transplanted on them with 40~50 cm intervals in June 2004 based on the pilot study. The successions of benthic communities on artificial seaweed beds were observed by scuba diving from June 2004 to June 2005 three times (ten week, twenty four weeks, and fifty one weeks later).

(a) (b)

Fig. 4. Photographs of set up steel frames on artificial seaweed beds; (a) construction of steel frames, (b) set up steel frames in the spillway.

3. RESULTS AND DISCUSSIONS

3.1 The environmental characteristics

The concentrations of dissolved oxygen, nitrate, and phosphate were lower or similar, but pH and most of metal ion concentrations such as Cu and Ca were higher in the study area than those of in seawater nearby study area (Table 1).

3.2 Succession of benthic communities

3.2.1 The first experiment (April 2004)

For succession of benthic communities on artificial seaweed bed (Table 2), diatoms and coralline algaes colonization were almost 100% coverage in an initial stage. Two weeks later after placement (16 April 2004), *Acinetospora critina* was only colonized on steel frames. On the other hand, *Ulothrix flacca, Bryopsis plumosa, Sargassum* sp., and *Heterosiphonia japonica* were occurred on natural rocks nearby our study site. The four weeks later after placement (30 April 2004), abundance of genera *Acinetospora, Enterophorma*, and *Ulothrix* was increased on the fronds of *Ecklonia stolonifera* as well as on steel frames. Within ten weeks later after placement (18 June 2004), genera *Acinetospora* and *Enteromorpha* were appeared plentifully on the fronds of *Ecklonia stolonifera* although these were not in good condition (plate 2). The benthic macrofaunas (e.g. gammarid amphipods, caprellid amphipods, tanaids etc.) were increased to occur with succession of algaes, and small size fishes. *Mugil cephalus, Pholis nebulosa, P. fangi*, and some gobiid fishes were also occurred.

3.2.2 The second experiment (June 2004)

The similar succession patterns were occurred in an initial stage like coralline algaes were predominated in the first experiment (Table 2). A total of 15 species of seaweed (9 Chlorophyta, 1 Phaeophyta, and 5 Rhodophyta) were identified in the second experiment, and composed of *Urospora penicilliformis, Ulothrix flacca, Cladophora* sp., *Ulva pertusa, Enteromorpha intestinalis, E. linza, E. compressa, E. prolifera, Bryopsis plumosa, Undaria pinnatifida, Gracilaria textorii, G. verrucosa, Gigartina tenella, Heterosiphonia pulchra*, and *Polysiphonia morrowii*. Within ten weeks later after placement (3 September 2004), *Enteromorpha* sp. and *Heterosiphonia* sp. colonization on steel frames achieved about 100% coverage, and *Enteromorpha intestinalis* and *Enteromorpha* sp. were dominated on all of *Ecklonia stolonifera* fronds within twenty four weeks later after placement (3 December 2004, plate 3). Early colonization may have been due to the annual release cycle of their reproductive cells and then the spore of *Enteromorpha compressa* and *Enteromorpha* sp. were attached on the wide frond of *Ecklonia stolonifera* with current. Such conclusions were in agreements with other studies which reproductive periods of genus *Enteromorpha* were from April to July in the temperate areas (Kang and Koh[1977]). Yamada *et al*.[1992] and Choi *et al*.[2002] have reported that *Enteromorph* sp. especially *Enteromorpha intestinalis,* was found to be typical primary colonists on artificial reefs at Muronohana, Ikata, Japan, and colonization of small annuals and crustaceous algae were colonized in an initial stage. The succession of seaweed communities on artificial seaweed beds demonstrated here also showed similar patterns with other studies in other regions worldwide (Serisawa and Ohno[1995a,b], Ohno[1993]). On the other hand, most of algal species, benthic macrofaunas (e.g. gammarid amphipods, caprellid amphipods, tanaids, isopods, etc.) and barnacles (e.g. *Chthalamus*) were few in ten weeks after placement compared with those in first experiments. These differences seems to be due to seasonal variation of species composition and different reproductive periods. High epiphytic benthic macofauna in spring were related with increasing temperature, whereas Rhodophyta were dominated from winter to spring at seaweed beds (Ohno[1993], Choi[2001]).

Within one year later after placement (3 June 2005), more

Table 1. The environmental characteristics in the study area, which are compared to those of natural seawater

Locations/items	Temp. (℃)	Sal. (psu)	pH	DO	TSS	COD	DIN	PO_4^{3-}-P	Cl^-
				(mg/L)					
Study area	9.8	31.9	9.25	7.6	25.3	3.2	0.20	0.02	16.5
Seawater	9.8	32.5	8.18	8.2	14.3	2.5	0.45	0.05	18.3
Locations/items	Cr^{6+}	As	Cd	Pb	Cu	Na	Ca	K	Mg
			(μg/L)				(mol/L)		
Study area	2.3	4.5	0.1	2.0	9.5	0.400	0.120	0.008	0.00005
Seawater	1.8	3.8	0.1	1.8	5.6	0.468	0.013	0.010	0.00005

Table 2. Succession of benthic communities on artificial seaweed beds with transplantation of *Ecklonia stolonifera*

Organisms/periods	The first experiment (April 2004)			The second experiment (June 2004)		
	two weeks (16 Apr. 2004)	four weeks (30 Apr. 2004)	ten weeks (18 Jun. 2004)	ten weeks (3 Sep. 2004)	twenty four weeks (3 Dec. 2004)	fifty one weeks (3 Jun. 2005)
Diatoms	●	●	●	●	●	●
Coralline algae	●	●	●	●	●	●
Algae						
Chlorophyta						
Urospora penicilliformis		●	●	●	●	●
Ulothrix flacca		●	●	●	●	●
Cladophora sp.			●		●	●
Ulva pertusa		●	●	●	●	●
Enteromorpha compressa		●	●	●	●	●
E. linza		●	●	●	●	●
E. intestinalis		●	●	●	●	●
E. prolifera		●	●	●	●	●
Bryopsis plumosa			●		●	●
Phaeophyta						
Undaria pinnatifida		●	●		●	●
Acinetospora crinita	●	●	●	●	●	●
Rhodophyta						
Gracilaria textorii		●	●		●	●
G. verrucosa		●	●		●	●
Gigartina tenella		●	●		●	●
Heterosiphonia pulchra		●	●		●	●
Polysiphonia morrowii					●	●
Benthic macrofauna						
Crustacea						
Gammarid amphipods	●	●	●	●	●	●
Caprellid amphipods	●	●	●	●	●	●
Tanaidacea		●	●		●	●
Isopoda			●		●	●
Cirripedia						
Chthalamus sp.			●		●	●
Mollusca						
Mytilus edulis			●		●	●
Thais clavigera			●		●	●
Septifer virgatus			●		●	●
Serpulorbis imbricatus			●		●	●
Chlorostoma lischkei			●		●	●
Fish						
Mugil cephalus	●	●	●	●	●	●
Pholis nebulosa	●	●	●	●	●	●
P. fangi	●	●	●	●	●	●
Sebastes schlegeli		●	●		●	●
Acanthogobius flavimanus			●			
Engraulis japonicus		●			●	●
Hexagrammos otakii			●			●
Acentrogobius pflaumii			●			●
Repomucenus valenciennei			●			●
Hypodytes rubrippinis						●

algae, *Urospora penicilliformis, Ulothrix flacca, Cladophora* sp., *Ulva pertusa, Enteromorpha prolifera, Bryopsis plumosa, Undaria pinnatifida, Gracilaria textorii, G. verrucosa, Gigartina tenella, Heterosiphonia pulchra,* and *Polysiphonia morrowii* were appeared plentifully on the steel frames and frond of *Ecklonia stolonifera.* Some molluscans started to colonize in the study area. A total of 5 molluscan species were identified. These were composed of *Mytilus edulis, Thais clavigera, Septifer virgatus, Serpulorbis imbricatus*, and *Chlorostoma lischkei*. A significantly high occurrence of epiphytic benthic macrofaunas and molluscans in the our study site confirmed that these species were also likely to be dependent on seaweed beds for food resources or nursery functions. Broad-scale surveys of benthic communities at artificial seaweed beds from other regions suggest a similar community structure (Hawkins and Hartnoll[1983], Bohnsack and Sutherland [1985], Ohno[1993], Choi *et al*.[2002]).

Small sized 10 fish species were also found (Table 2), and these were *Mugil cephalus, Pholis nebulosa, P. fangi, Sebastes schlegeli, Acanthogobius flavimanus, Engraulis japonicus, Hexagrammos otakii, Acentrogobius pflaumii, Repomucenus valenciennei,* and *Hypodytes rubrippinis*. Some fish species, e.g., *Mugil cephalus, Pholis nebulosa, P. fangi,* and *Sebastes schlegeli,* were feeding epiphytic benthic macrofauna and seaweed on the artificial seaweed beds (plate 4). Probably it might be regarded artificial seaweed beds as nursery area for these fish species with their prey organisms (e.g., seaweed, benthic macrofauna, and molluscan). *Pholis nebulosa* consumed on caprellid amphipods, and fish species in the algal and eelgrass bed fed on epiphytic benthic macrofaunas worldwide (Gerking[1994], Huh and Kwak[1997]). Choi[2001] demonstrated that commercially valuable molluscans and fishes were appeared on the artificial seaweed beds after one month of establishment because these animals grazed on the small sized epiphytic benthic macrofauna and seaweed on the beds. Most of fish species might have been moved on artificial seaweed beds through spillways because these fish species were also occurred in Youngil Bay nearby the study site (Hwang *et al*.[1997], Lee[1999], Han *et al*. [2002]). Especially *Pholis nebulosa, P. fangi, Sebastes schlegeli, Acanthogobius flavimanus, Hexagrammos otakii,* and *Hypodytes rubrippinis* have been inhabited on seaweed and eelgrass beds on rocky shore during most of their life history, and *Mugil cephalus* was distributed widely in the coastal waters around Korean peninsula including polluted waters (Huh and kwak[1997], Kwak and Huh[2007], Yoon[2002], Kwak *et al*.[2008]).

Thus we would like to suggest that transplantation of *Ecklonia stolonifera* on aritificial seaweed beds in the slag dumping area can provide good habitats on small scale ecosystems for seaweed, benthic macrofaunas, and even small sized fishes although *Ecklonia stolonifera* has been found to decay with increasing periods after placement.

4. CONCLUSION

Succession of benthic communities were monitored on artificial seaweed beds with transplantation of *Ecklonia stolonifera* from April 2004 to June 2005 in order to rehabilitate the slag dumping area as small scale ecosystem for marine organisms. In the first experiment (April 2004), *Acinetospora critina* was only primary dominated. A total of 15 species of seaweed (9 Chlorophyta, 1 Phaeophyta, and 5 Rhodophyta) were identified in the second experiment (June 2004). *Enteromorpha intestinalis* and *Enteromorpha* sp. were dominated, and *Urospora penicilliformis, Ulothrix flacca, Cladophora* sp., and *Ulva pertusa* were found on *Ecklonia stolonifera* fronds gradually with increasing time. Benthic macrofaunas, molluscans and small fish species were also occurred. The epiphytic benthic macrofaunas were dominated on amphipods, molluscans were *Mytilus edulis, Thais clavigera,* and fish species were *Mugil cephalus, Pholis nebulosa*. Overall these results demonstrated that transplantation of *Ecklonia stolonifera* on artificial seaweed beds could contribute to the habitat restoration for benthic communities in the slag dumping area.

ACKNOWLEDGEMENT

We are grateful to Dr. C. G. Choi in KIOS, Pukyong National University as research scientist for assistance with sampling and data analysis. We also thank Dr. David W Klumpp (AIMS) for his constructive comments in structure of English.

REFERENCES

[1] Bohnsack, J. A. and Sutherland, D. L., 1985, Artificial reef research: A review with recommendations for future priorities. Bull. Mar. Sci., Vol. 37, 11-39.

[2] Choi, C. G., Takeuchi, Y. Ohno, M., and Sohn, C. H., 2002, "Succession of seaweed communities on artificial reefs at Muronohana, Ikata, Japan", Fish. Sci., Vol. 68, 1755-1758.

[3] Choi, C. G., 2001, "Marine communities around the experimental artificial reefs", Pukyong National University. Ph. D. Thesis., 1-190.

[4] Gerking, S. D., 1994, "Feeding Ecology of Fish", Academic Press, Inc, U.S.A, 1-416.

[5] Han, K. H., Kim, J. H., and Baek, S. P., 2002, "Seasonal variation of species composition of fishes collected by set net in coastal waters of Ulsan, Korea", Kor. J. Ichthy., Vol. 14, 61-69.

[6] Huh, S. H. and Kwak, S. N., 1997, "Species composition and seasonal variations of fishes in eelgrass (*Zostera marina*) bed in Kwangyang Bay", Kor. J. Ichthy., Vol. 9, 202-220.

[7] Hwakins, S. J. and Hartnoll, R. G., 1983, "Grazing of intertidal algae by marine invertebrates", Oceanogr. Mar. Biol. Ann. Rev., Vol. 21, 195-282.

[8] Hwang, S. D., Park, Y. J., Choi, S.H. and Lee, T. W., 1997, "Species composition of fish collected by trammel net off Heunghae, Korea", J. Korean Fish. Soc., Vol. 30, 105-113.

[9] Huh, S. H. and Kwak, S. N. 1997, "Feeding habits of *Pholis nebulosa*", Kor. J. Ichthyol., Vol. 9, 22-29.

[10] Kang, J. W. and Koh, N. P. 1977, "Algal Mariculture", Taehwa Publ. Co., Pusan, Korea, 1-294.

[11] Kim, J. M. and Kwak, S. N., "Experimental design in laboratory for ecological restoration in the slag dumping area", J. of the Environ. Sci., Vol. 17, 1195-1201. (on submitted)

[12] Kwak, S. N. and Huh, S. H. 2007, "Temporal Variation in Species Composition and Abundance of Fish Assemblages in Masan Bay", Kor. J. Ichthy., Vol. 19, 132-141.

[13] Kwak, S. N., Huh, S. H. and Kim, H. W., 2008, "Seasonal Variation in Species Composition and Abundance of Fish Assemblage in the Coastal Water off Namhae Island", Kor. J. Ichthy., Vol. 20, 303-312.

[14] Largo, D. B. and Ohno, M., 1993, "Construction an artificial seaweed bed", In: Ohno M, Critchley A.T. (eds). Seaweed Cultivation and Marine Ranching. JICA, Tokyo. 113-130.

[15] Lee, J. W. and Kang, Y. S., 1994, "Variation of fish community and fish density on artificial reefs", Bull. Korea Fish. Soc., Vol. 27, 535-548.

[16] Lee, T. W., 1999, "Seasonal variation in species composition of demersal fish in Yongil Bay, East Coast of Korea", J. Korean Fish. Soc., Vol. 32, 512-519.

[17] Ministry of Maritime Affairs and Fisheries, 2002, "Korea Standard Methods for the Examination of Seawater Manual", 347pp.

[18] Mitsch, W. J., 1988, "Ecological engineering and ecotechnology with wetlands: applications of systems approaches", In: A. Marani, eds Advances in Environmental Modelling, Elsevier, Amsterdam, 565-580.

[19] Mitsch, W. J. and Jorgensen S. E., 1989, "Introduction to ecological engineering", In: Mitsch W. J., Jorgensen S. E. eds. Ecological Engineering: An Introduction to Ecotechnology, J. Wiley & Sons, Inc., New York. 3-12.

[20] Odum, H. T. and Odum, B., 2003, "Concepts and methods of ecological engineering", Ecol. Engin., Vol. 20, 339-361.

[21] Ohno, M., 1993, "Succession of seaweed communities on artificial reefs in Ashizuri, Tosa Bay, Japan", Algae. Vol. 8, 191-198.

[22] Serisawa, Y. and Ohno, M., 1995a, "Succession of seaweed communities on artificial reefs in the inlet of Tosa Bay, Japan", Suisanzoshoku Vol. 43, 437-443.

[23] Serisawa, Y. and Ohno, M., 1995b, "Succession of seaweed communities on artificial reefs in Tei, Tosa Bay, Japan", Nippon Suisan Gakkaishi Vol. 61, 854-859.

[24] Terawaki, T. Hasegawa, H., Arai, S. and Ohno, M., 2001, "Management-free techniques for restoration of *Eisenia* and *Ecklonia* beds along the central Pacific coast of Japan", J. Appl. Phycol., Vol. 13, 13-17.

[25] Watanuki, A. and Yamamoto, H., 1990, "Settlement of seaweeds on coastal structure", Hydrobio., Vol. 204/205. 275-280.

[26] Yamada, H., Kawamura, T., Asano, M. and Taniguchi, K., 1992, "Marine algal succession on artificial reefs in the sublittoral zone off Oshika peninsula, Japan", Bull. Tohoku Reg. Fish. Res. Lab., Vol. 54, 89-95.

[27] Yoon, C. H., 2002, "Fishes of Korea with Pictorial Key and Systematic List", Academy Publ. Co., Seoul, 1-782.

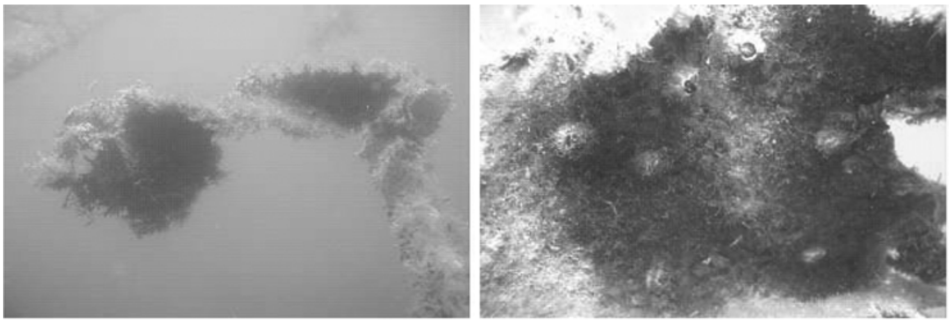
2009년 4월 22일 원고접수
2009년 6월 24일 심사완료
2009년 7월 20일 수정본 채택

(a) (b)

Plate 1. Photographs of the mature frond *Ecklonia stolonifera* was transplanted on each steel frame.

(a) (b)

Plate 2. Photographs of algae colonization within ten weeks after placement in the first experiment; (a) The dominated *Acinetospora critina* on steel frame, (b) *Enteromorpha* sp. colonized on the wide frond of *Ecklonia stolonifera*.



(a) (b)

Plate 3. Photographs of benthic communities within twenty four weeks after placement in the second experiment; (a) algal species and benthic macrofuanas, (b) barnacles were occurred on the wide frond of *Ecklonia stolonifera*.

(a) (b)

Plate 4. Photographs of benthic communities within one year after placement in the second experiment; (a) molluscans (*Mytilus edulis*), (b) small fishes (*Mugil cephalus*) colonized around frond of *Ecklonia stolonifera*.