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Algal Succession on Different Substrata Covering the Artificial Iron Reef at Ikata in Shikoku, Japan

Chang Geun Choi[1]*, Masao Ohno[2] and Chul Hyun Sohn[3]

[1]*Research Institute of Marine Science and Technology, Korea Maritime University, Busan 606-791, Korea*
[2]*Usa Marine Biological Institute, Kochi University, Inoshiri, Usa, Tosa, Kochi 781-1164, Japan*
[3]*Department of Aquaculture, Pukyong National University, Busan 608-737, Korea*

Succession of artificial seaweed communities in an artificial iron reef at Ikata, southern Japan was studied based on monthly or bimonthly observations from February 1999 to August 2000. Communities were associated with different substrata (40 cm x 60 cm: steel, concrete, wood and stone) as the cover on artificial iron reefs (4.5 m x 4.1 m x 2.5 m, 45.38 m^3 and 3.2 ton), which were placed on a sandy substratum at 8 m depth. Within one month diatoms dominated on all substrata with cover of approximately 100%. *Enteromorpha intestinalis* and *Colpomenia sinuosa* dominated on the reef within three months after the placement in the spring. Seaweed communities on the reef decreased during the summer. In the winter, the seaweeds on the reef recovered. *Sargassum* spp., *Ecklonia kurome* and *Padina arborescens* dominated on each substratum after one year. Seaweed communities on the artificial reef were similar to those on the rocky substratum around the artificial reef and also similar on different substrata covering the iron artificial reef. These results indicate that seaweed succession was impacted by season and the recruitment of spores and propagules from mature algae around the artificial reefs.

Key Words: artificial reef, seaweed community, substratum, succession

INTRODUCTION

Devastation on coasts worldwide has led to barren grounds (Isoyake, Japanese) resulting in the loss of the natural population of many marine organisms and seaweeds (Serisawa *et al*. 1998; Choi *et al*. 2000a). In such coastal area, useful fishery resources such as abalone, fish and seaweeds have been depleted remarkably. In the 1970s technical studies on the restoration of Isoyake area (barren ground) to rich seaweed beds were begun under the leadership of the Fisheries Agency in Japan. Several studies on the succession of seaweeds have been carried out on artificial seaweed beds in subtidal zone by placing artificial substrata on the sea bottom since 1980s (Hirata 1986; Serisawa and Ohno 1995a, b; Choi *et al*. 2000b). Most of these artificial seaweed beds have been constructed by the purpose of growing only larger seaweeds (Tsuda and Kami 1973). On the other hand, artificial iron reefs are commonly used to increase the fishery resources on the deeper bottom more than 20-30 m depth in many coastal areas where there is no seaweed community. The artificial iron reefs, which have placed on the sandy bottom at 5-10 m depths, have been supposed to form good nursery ground for juvenile. The fishes come together with good feed on the seaweeds. But there are not reports on the seaweed bed cover on the artificial iron reef yet. Various substrata such as stone, concrete, wood and steel have made the artificial algal beds cover on the artificial reef in this study. These structures also act as artificial substrata for marine algae. The algal community colonizes on the artificial reefs and serves as the primary food source for herbivores (Watanuki and Yamamoto 1990).

Choi *et al*. (2000a) has reported on early stage of algal succession on artificial reefs. This study has surveyed on marine algae on the climax succession growing *Sargassum* and *Ecklonia* at the different substrata cover on the artificial iron reef during the period of two years, where were placed on the sandy bottom, and such special seaweed beds were also compared to the seaweed beds near the rocky shore.

*Corresponding author (changgeuni@hanmail.net)

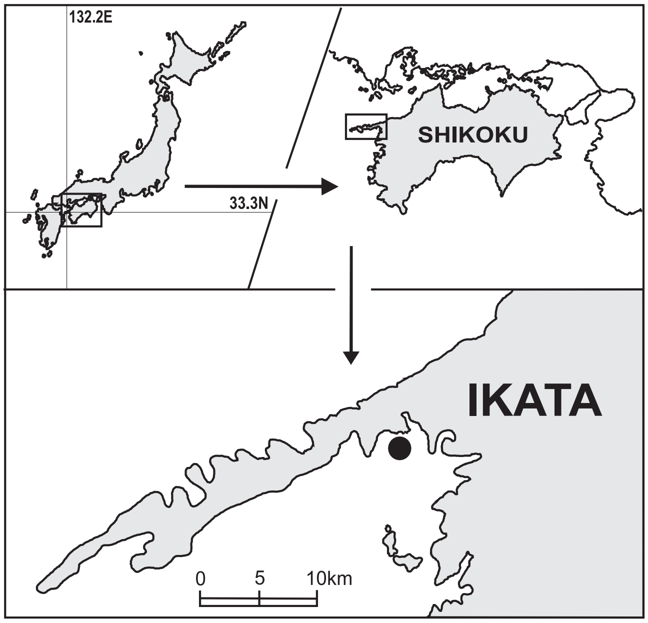

Fig. 1. Study site (●) in Muronohana, Ikata, Japan.

MATERIALS AND METHODS

The experimental artificial iron reef was placed on the sandy bottom at the depth of 8 m at Muronohama, Ikata, in Shikoku, southern Japan, on 16th February 1999 (Fig. 1). The artificial iron reef placed on the sandy area at short distance of 2-3 m from the rocky area, where are large number of brown seaweeds such as *Sargassum horneri*, *S. macrocarpum* and *Ecklonia kurome* shown in the shape artificial iron reef, which was 4.5 m x 4.1 m x 2.5 m, 45.38 m^3 and 3.2 ton. Twelve different types of substrata (40 cm x 60 cm) made up with the materials of steel, concrete, wood and stone, and those were fixed on the roof of artificial iron reef (Fig. 2, Table 1).

The ecological survey on marine algae on the artificial reefs and around rocky shore were carried out monthly or bimonthly by scuba diving during period of March 1999 to August 2000. The photographs by 35 mm camera were taken from right overhead about 80 cm on each substratum. The photographs by digital video camera were also taken for identifying species in detail at same parts. The coverage (%) of algal species growing on the plates was measured by the photos and data of video.

Water temperature, salinity and turbidity were measured as environmental factors at the study site. Salinity was measured with a digital salinometer (Model 3-G, Tsurumi Seiki, Yokohama).

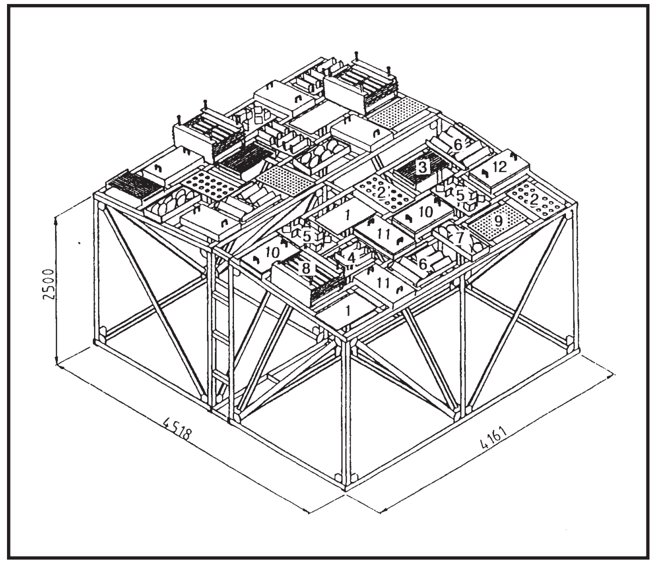

Fig. 2. Illustration of experimental plate which were fixed on the experimental artificial iron reef. 1: steel plate, 2: steel plate with big hole, 3: plate shaped an iron bar, 4: steel plate with irregularity, 5: steel plate with a triangle shaped irregularity, 6: steel plate with a irregularity of A shaped, 7: plate fixed pebble, 8: plate to accumulated wood, 9: steel plate with small hole, 10: concrete plate, 11: concrete plate of water permeability, 12: concrete plate of coal fry-ash.

Table 1. Abbreviations of experimental plates for seaweed attached on the artificial iron reef

Plate	Material	Size
Plate 1	Steel plate	40 cm×60 cm
Plate 2	Steel plate with big hole	″
Plate 3	Plate shaped an iron bar	″
Plate 4	Steel plate with irregularity	″
Plate 5	Steel plate with a triangle shaped irregularity	″
Plate 6	Steel plate with a irregularity of A shape	″
Plate 7	Plate fixed pebble	″
Plate 8	Plate to accumulate wood	″
Plate 9	Steel plate with small hole	″
Plate 10	Concrete plate	″
Plate 11	Concrete plate of water permeability	″
Plate 12	Concrete plate of coal fly-ash	″

RESULTS

Environmental factor

Seasonal changes of water temperature, salinity and transparency at the survey site are shown in Table 2. The differences of water temperatures were less than 1.0°C between surface layer and bottom through the year. In winter season, temperature ranged between 10.0°C to

Table 2. Seasonal changes of environmental factors in water at the survey site

Environmental factors		1999								2000					
		Mar.	May	Jun.	Jul.	Aug.	Oct.	Nov.	Dec.	Feb.	Mar.	Apr.	Jun.	Jul.	Aug.
Temperature (°C)	Surface	10.0	19.7	22.5	25.3	28.3	24.9	19.8	16.0	12.6	12.8	16.8	21.8	27.0	27.3
	Bottom		19.1	21.8	23.0	26.8	24.0	18.9	15.8	12.5	12.7	16.7	21.2	23.2	26.4
Salinity (‰)	Surface	34.4	34.4	33.8	34.9	33.0	33.1	33.9	33.8	34.3	34.4	35.0	35.1	35.0	35.0
	Bottom		34.4	34.2	35.0	33.0	33.6	34.1	34.0	34.3	34.4	35.3	35.2	35.1	35.2
Transparency (m)				6.0	6.0	8.0	7.0	7.0	8.0	8.0	8.0	8.0	6.0	8.0	7.3

13°C. In summer season, the water temperature attained to 28.3°C, and became to damage growing seaweeds. Salinity varied little between surface layer and bottom. The seasonal variation of salinity ranged slightly among 32.96‰ to 35.49‰ through the year, though the heavy rain occurred at survey. The transparency changed higher transparency of 6 m at waving condition and in summer seasons. The higher temperature in summer season might damage growing *Ecklonia* plants and many seaweeds.

Algal succession at different substrata

There are rich seaweed communities with *Sargassum* and *Ecklonia* plants on the natural substrata adjacent to the artificial reefs, and that total of 23 species of algae was found growing on the natural rocky substrata around the artificial reef (Table 3).

Fig. 3 shows the relative coverage (%) of algae at the different substrata on the artificial iron reefs over the study period. This experimental survey has made several substrata (iron bar, triangle plates, holed plate etc.) of each material. The data of their coverage of algae showed the average of all substrata of each material, as the algal coverage of them were similar among the different shapes. The surface of each artificial iron reef turned to brown within one month after the placement. Diatoms colonization was observed in the brown parts of different substrata. Diatoms on all substrata attained 100% relative coverage.

Remarkably *Enteromorpha intestinalis* and *Colpomenia sinuosa* appeared at all of the substrata on the artificial reefs within three months after the placement, although *E. intestinalis*, which grew luxuriously on the artificial iron reefs, did not grow on the natural rocks in the area. The relative coverage algal division during the study period was almost similar at each substratum on the iron artificial reef (Fig. 3).

At the early stage of seaweed community, within 3 months of the placement of the reefs *E. intestinalis* covered approximately 60-75% of the artificial reefs. In June, the coverage of *E. intestinalis* was nearly 100%. The relative coverage of *C. sinuosa* was less than that of *E. intestinalis* on most substrata on June 1999. The thalli of *E. intestinalis* and *C. sinuosa* found to have decayed in the

Table 3. A list of marine benthic algal species found growing on the natural rocky substrata around the artificial reef at the study site

Division	Species
Chlorophyta	*Enteromorpha intestinalis*
	Ulva pertusa
	Codium adhaerens
	C. coarctatum
	C. cylindricum
Phaeophyta	*Colpomenia sinuosa*
	Hydroclathrus clathratus
	Ecklonia kurome
	Dictyota dichotoma
	Pachydictyon coriaceum
	Padina arborescens
	Spatoglossum pacificum
	Sargassum giganteifolium
	S. horneri
	S. macrocarpum
	S. patens
	S. piluliferum
	S. sp.
	Undaria undarioides
Rhodophyta	*Scinaia latifrons*
	S. moniliformis
	Palmaria palmata
	Gelidium amansii
	Peyssonelia caulifera
	Lithothamnion japonicum
	Amphiroa dilatata
	Jania arborescens
	J. sp.
	Marginisporum crassissima
	Prionitis angusta
	Plocamium leptophyllum
	Gracilaria incurvata
	Lomentaria catenata

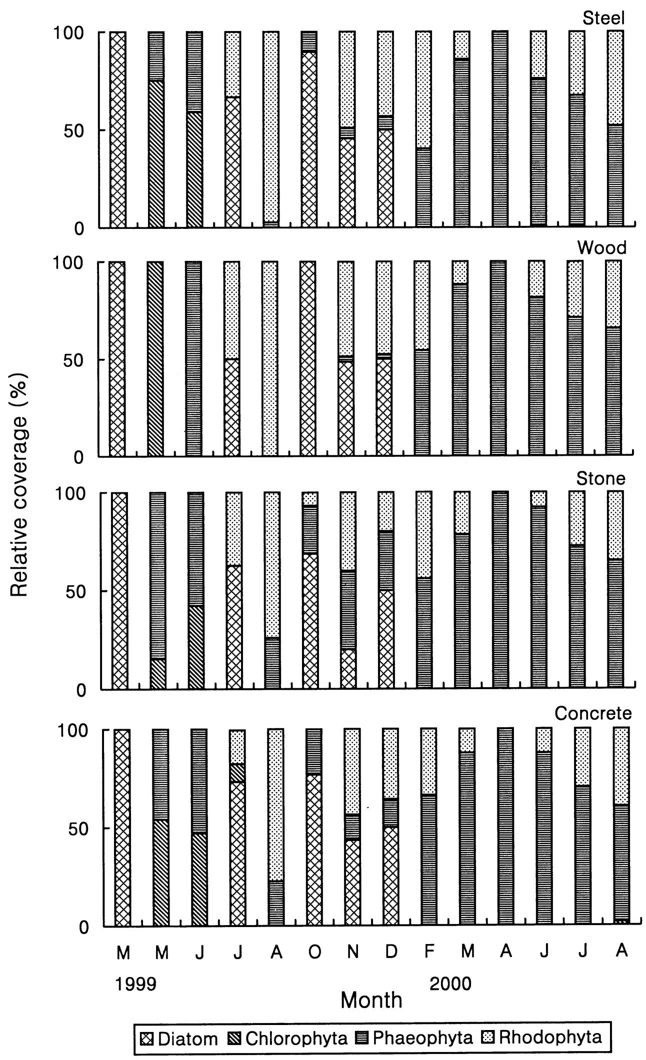

Fig. 3. Relative coverage of algal division on surface part of different experimental substrates.

month of July (summer season), i.e. after five months, whereas representative coralline red algal species started growing on the artificial iron reefs. The coverage at most substrata showed similar values at such early stage of the algal communities.

Within 6 months of the placement of the reefs, coralline algae covered approximately above 80% of the artificial reefs at the study site in summer season, August to November. The relative coverage of coralline algae on the reefs had 90 to 95% coverage. From October to December 1999, diatoms and coralline algae had greatly colonized on the surface all of substrata of the reefs. At the winter season relative coverage of brown algae, such as *Sargassum* spp. and *Ecklonia kurome*, was recorded above 50% at each substratum of the reefs. The relative coverage of brown algae at all of plates on the reefs placed and that covered approximately 100%. The number of species tended to be comparatively greater on the reefs during the winter and spring seasons during the periods of February 2000 to June 2000 (Table 4).

In February 2000, 12 months after the placement of the artificial reefs, *C. sinuosa* reappeared, and coverage was increasing on almost all reefs, about 10-80% coverage. *C. sinuosa* had decreased considerably on the reefs in June 2000, while *Padina arborescens*, *E. kurome* and *Jania adhaerens* gradually covered approximately 7-42% of the artificial reefs. The coverage of *J. adhaerens* tended to be comparatively greater, about 79% on the reefs from June.

The dominant species of the algal succession on the reefs during period of this survey changed from diatoms to *Sargassum* spp., *E. kurome* and *P. arborescens* on the each substratum as follows: diatoms → *E. intestinalis* and *C. sinuosa* → coralline algae → *C. sinuosa* → *Sargassum*

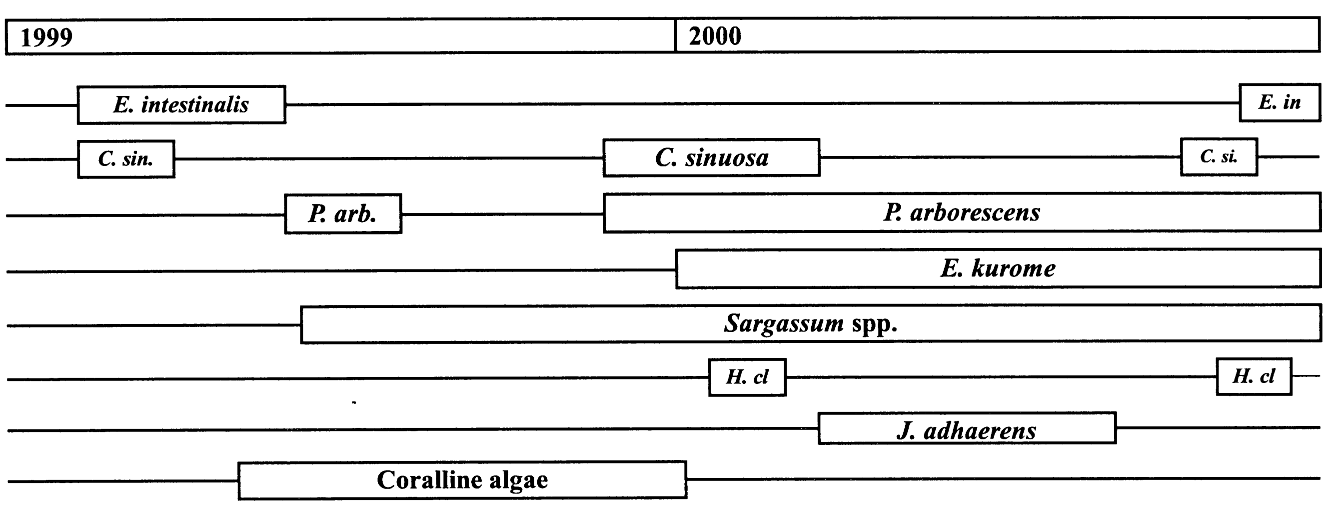

Fig. 4. Monthly dominant algal species attached on the artificial reefs.

Table 4. Monthly abundance of algae on the artificial reefs

Species	1999								2000					
	M	M	J	J	A	O	N	D	F	M	A	J	J	A
Diatom	●			●		●	●	●						
Blue-green algae				○		○								
Enteromorpha intestinalis		●	◎	◎										
E. sp.					○									
Ulva pertusa												○		
Cladophora sp.					○									
Codium fragile													○	○
Ectocarpus sp.										○				
Colpomenia sinuosa		◎	◎						◎	●	●	◎		
Hydroclathrus clathratus										○	◎	○		
Cutleria multifida										○	○			
Ecklonia kurome									○	○	○	◎	◎	◎
Dictyota linearis									○	○				
D. patens											○	○		○
Pachydictyon coriaceum									○	○	○			
Padina arborescens					○	○			○	○	○	◎	◎	◎
Spatoglossum pacificum												○		
Sargassum hemiphyllum											○	◎	◎	○
S. horneri					○	○	○	○	○	○	○	○	○	
S. macrocarpum					○	◎	◎	◎	◎	○	◎	◎	●	●
S. patens												○		
S. piluliferum												○	◎	○
S. sp.									○	○	○			
Scinaia latifrons										○				
Amphiroa zonata														◎
A. sp.									○					
Jania adhaerens												◎	●	●
J. sp.							○	◎	◎	○				
Hypnea japonica					○									
H. saidana												○		
Lomentaria catenata												○		
Ceramium kondoi					○									
C. sp.							○							
Coralline algae				◎	●	◎	●	●	●	◎				

●: Dominant (more than 40% of coverage), ◎: Subdominant (10-40% of coverage), ○: Rare (less than 10% of coverage)

spp., *E. kurome* and *P. arborescens* (Fig. 4). These results indicate that successional was impacted by season and the recruitment of spores and propagules from the mature algae around the artificial reefs.

DISCUSSION

Several kinds of algal successional patterns have already been noted on the artificial substrata. Ohno *et al*. (1990) and Watanuki and Yamamoto (1990) described *Ulva* and *Colpomenia sinuosa* colonization on the artificial concrete reefs within one month after placement. Kim (1987) reported that coccoid blue-green algae and diatoms were observed as pioneer algae settled over newly placed substrata, then filamentous green and crustose coralline algae were grown gradually, whereas diatoms decreased in abundance. Yamada *et al*. (1992) reported colonization of small annuals and crustaceous algae on the artificial concrete reefs at early stage after placed.

This experiment was most characteristic that new substrata were placed as cover on the artificial reef. *E. intestinalis* has colonized almost a homogenous community with smaller coverage of *C. sinuosa* at each plates at early stage, though this species were not appeared much on the near the shore. There is not a report that *Enteromorha* plants became a dominant on the new substrata at early stage. Many spores of such short annual algae might be drifting with suspension in the coastal waters during growing season. It is suggested from these reports that diatoms covered on the new substrata and that some annual seaweed became homogeneously dominant species on new substrata the early stage of algal succession through a year.

In this experiment, the algal coverage on each plates were measured during survey period, but the coverage among the experimental plates were not different remarkably. It is interested that the attachment of seaweeds did not be selected by the quality of the materials. Coralline algae dominated the reefs when water temperatures were higher. Coverage of *J. adhaerens* was recorded above 70% at each plate in summer season. After summer season, *Sargassum* spp., *E. kurome* and *P. arborescens* typically appeared in late successional stages. During autumn and winter, when water temperatures were lower, the coverage of brown algae was comparatively higher whilst that of the coralline algae was lower. The coverage of green algae did not become higher coverage again.

Generally, stability of substratum is very important for maintaining seaweed beds (Watanuki and Yamamoto 1990). During the investigation at our study sites, the seaweed community did not damaged on the substrata by waves, as the artificial reefs were unaffected strongly by waves. In areas where there are plenty of sea urchins and small snails, the establishment of *Sargassum* communities on artificial reefs may be delayed or hampered to some extent (Ohno 1993). In this experiment, grazers, such as sea urchins, did not colonize on the reefs as the artificial seaweed beds on cover of the iron reef which was separated from the bottom. Such artificial algal beds on the iron reef might have an effect on the barren coast where sea urchins are colonized.

Succession studies of algal communities have obviously become central to the study of community structure (Foster and Sousa 1985). A variety of research approaches, such as those on interspecific competition, the impact of grazing and the tolerance of species to physical stress, have been employed for the investigation of macroalgal succession on hard substrata (Kim *et al*. 1992). These approaches have provided useful information on community dynamics, but were only slightly considered in the present study.

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