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Article

Development of Benthic Community on an Artificial Reef Complex, Jeju Island, Korea

Soon Kil Yi*[1], Hyung Tack Huh[1], Jong-Geel Je[1], and Dae Gwen Kim[2]

[1]*Marine Resources Laboratory, KORDI*
Ansan P.O. Box 29, Seoul 425-600, Korea
[2]*Jeju Branch, South Sea Fisheries Res. Lab., NFRDI*
1298 Waedo-2dong, Jeju 690-192, Korea

Abstract : Development process of benthic community on experimental substrata attached on a newly installed artificial reef complex in Jeju Island was observed for 27 months from 1992 to 1994.

Among 34 species of algae and 64 species of zoobenthos obtained from the study, *Ecklonia cava* dominated with a maximum biomass of about 10 kg/m^2. It was able to smother the other animals, however it provided a new substrate for the new settlers. Opportunistic bryzoans such as *Likenopora radiata* and *Dexiospira spirillum* occurred during the early stage were substituted by poriferans, banacles and other bryzoans. Young barnacles were smothered by bryozoans, on the contrary, bryozoans were bulldozed by adult barnacles. No apparent differences have been observed between vertically and horizontally installed substrates in terms of species composition and biomass during the early stage of succession. Thereafter owing to the rapid growth of *E. cava*, the horizontal substrata carried on a higher biomass while the vertical showed a higher coverage. The benthic process on the experimental substrata can be classified into three stages: initial stage, build up stage and regulatory stage. Important mechanisms involved were canopying of *E. cava*, suffocation by bryozoans and poriferans, and bulldozing of adult barnacles.

Key words : benthic process, artificial reef, experimental substrata, *Eclonia cava.*

1. Introduction

Artificial reef is a world wide tool which is employed for the artificial enhancement of marine habitat in order to improve fisheries resources as well as fisheries itself (Ogawa 1968; Ino 1974; Huh 1987; NFRDA 1989; Grove and Sonu 1991; Nagahata 1991; McGurrin 1991; Stone 1991; Wilson 1991). It has been introduced to the shallow wasters of Korea since 1971. With the initiation of the marine ranching program in 1987, a total cost of US$370M has been invested, and artificial reefs have been installed into a total of 143,000 ha by 1999. Among about 40 countries which practicing artificial reef, presently Korea has become one of the top three nations in terms of the number of the reef.

An artificial reef complex is consisted of several hundred nodules of individual reefs and has irregular shape. Recruitment and development of a benthic community on the surface of the reef are altered not only by shapes and materials of reef itself but also by place and time of installation. In addition, currents velocity and direction, light intensity and the food availability differ from place to place even within a reef complex, and thus unable to analyse the benthic process using commonly applied competition indices (Sebens 1986; Sousa 1984; Nandakumura and Tanaka 1993).

Experimental approach using an artificial substratum is a classical method widly used for benthic process study (Wilson 1925; WHOI 1952; Haderlie 1970; Goren 1979; Southerland 1981; Kennelly 1983; Nandakumar and Tanaka 1993), and it allows a direct observation instead of a blind observation (Hedgpeth 1978). However, this method

*Corresponding author. E-mail : skyi@kordi.re.kr

has been accepted only by several authors in Korea (Song 1985; Yi 1987; Kim and Chang 1992; KORDI 1992, 1997).

The aim of the present study was to understand the development of benthic community on artificial substrata attached on a reef complex installed off coast of Jeju Island so as to provide a guideline for the artificial reef construction. Fluctuation of species composition, biomass and coverage were the major interest of the study.

2. Materials and methods

The study area is located off coast on Sinyang beach in southeastern part of Jeju Island where an edge of the Tsushima Current affects the water characteristics of the site (Fig. 1). The annual water temperature variation was about 12 °C and the monthly averages ranged between 13.9 °C and 25.1 °C. The water mass over the study area seemed to be under the oligotrophic condition. Medium sand was the main component of the bottom sediment.

The experimental substrata (ES) used in this study were concrete plates (30 × 30 × 10 cm) and had the same texture as the triangle type artificial reefs. Twenty six ES were attached vertically (VS) and horizontally (HS) on the surface of the reefs using coated wires, respectively. Then the reefs were placed as a complex body in November 1991. The water depth of the site was about 15 m.

From February 1992, two ES were collected seasonally by scuba divers from each position group. The collected ES was put into a plastic bag to prevent the loss of organisms during sampling time and immediately fixed by 10 % neutral formalin seawater on board and transported to the laboratory. In the laboratory, the epiphytes and mobile zoobenthos were sorted and identified into species level and the biomass of each species was measured to electric balance (0.01 g interval). In case of coarsely branched and sheet-like formed algae, the total area of blades and holdfasts were determined to the nearest 0.01 cm^2. Every ES was covered with transparent section papers and the distribution patterns of sessile species were drawn to figure out the coverage. Then they were removed by shaving the surface of ES and the biomass of each species was measured.

3. Result and discussion

A total of 98 species including 34 species of algae, 45 species of sessile animals and 19 species of mobile animals were identified.

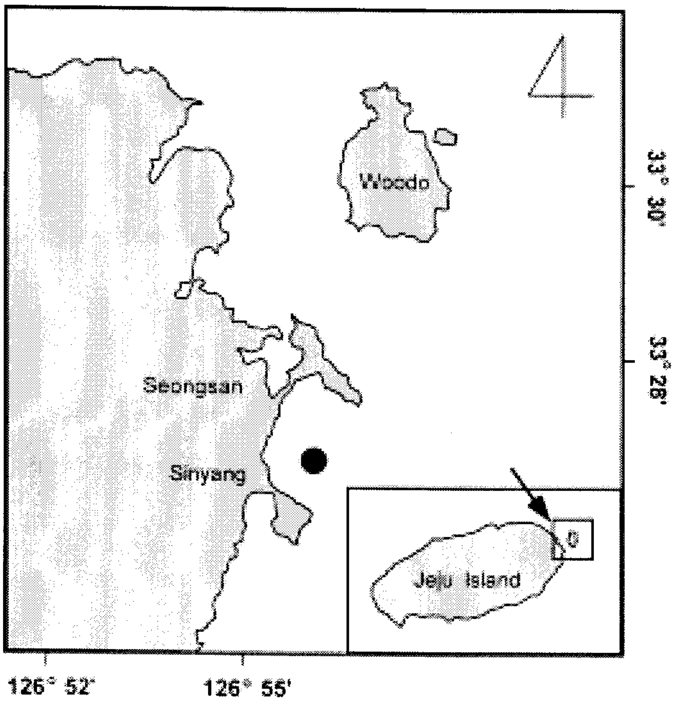

Fig. 1. Map showing sampling site on artificial reefs in sandy bottom near Sinyang beach in Jeju Island.

Table 1. Occurrence of algae on the experimental substrata attached to an artificial reef complex near Shinyang beach, Jeju Island (Feb. 1992 - Feb. 1994).

Species	Feb. '92		May '92		Aug. '92		Nov. '92		Feb. '93		May '93		Aug. '93		Nov. '93		Feb. '94	
	h	v	h	v	h	v	h	v	h	v	h	v	h	v	h	v	h	v
Chlorophyta																		
Bryopsis sp.																		+
Cladopora sp.	+		+	+		+									+	+		
Codium contractum								+		+					+	+	+	+
Derbesia marina			+		+													
Ulva japonica	+		+	+	+		+	+	+				+	+	+		+	+
Ulva pertusa			+	+														+
Phaeophyta																		
Colpomenia sinuosa	+	+	+	+	+		+		+	+					+	+		+
Dictyota dichotoma								+							+		+	
Dictyopteris latiuscula											+		+		+		+	+
Ecklonia cava	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+
Hecatonema sp.															+		+	+
Padina crassa					+			+	+	+								
Pandia arborescens	+																	
Sphacelaria variabilis							+											
Zonaria sp.													+	+	+	+		
Rhodophyta																		
Acrosorium sp.							+								+	+		+
Amphiora crassisima										+								
Amphiroa dilatata					+		+	+	+	+			+	+	+			+
Callophyllis japonica												+			+	+	+	
Ceramium fastigiramosum							+	+	+									
Clathromorphum sp.			+	+	+			+										
Corallina pilulifera			+	+	+			+	+	+	+		+		+		+	+
Erythrotrichia carnea							+		+	+					+			
Gelidium amnensii			+	+			+	+		+								+
Jania sp.			+	+											+	+		+
Laurencia pinnata			+															
Lithothamnion cystocarpiodeum								+		+	+	+					+	+
Lomentaria catenata			+	+														
Marginisporum crassissima								+						+	+	+	+	+
Peyssonnelia caulifera							+	+			+		+		+		+	
Plocamium telfairiae			+	+				+			+		+		+		+	+
Prionitis sp.									+	+								
Symphyocladia marchantioides							+	+										+
S. pennata							+											
No. of species	5		13		9		20		13		7		9		18		20	

*h: horizontal substrata, v: vertical substrata.

Algal community

A total of 34 algae species were identified during this study. Among them, Rhodophyta comprising 19 species was the most abundant group followed by Phaeophyta with 8 species and Chlorophyta with 6 species (Table 1).

The succession of the benthic community on ES was relatively slow. A three-month-old ES carried only 5 species of algae, then the species number increased to 13 after another three months (Fig. 2). Summer diminutions of species number were observed both on HS and VS, but VS showed wider range of variation than HS. The maximum species number of 20 was observed 15 months after installation. However, the total number of algal species encountered during the whole study period was

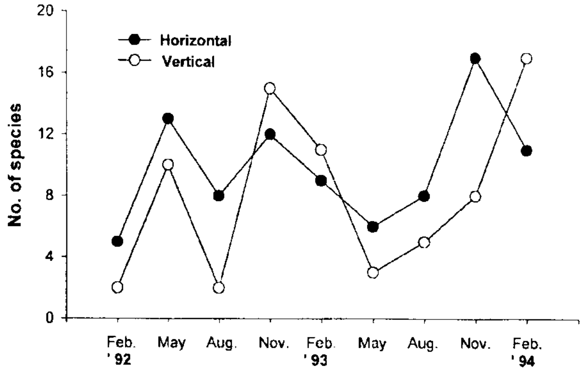

Fig. 2. Species number of benthic algae on the experimental substrata attached to an artificial reef complex near Sinyang beach, Jeju Island (Feb. 1992 - Feb. 1994).

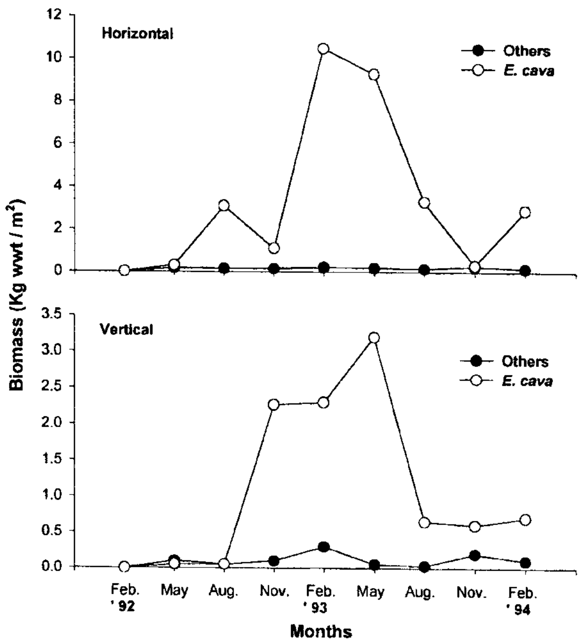

Fig. 3. Biomass of *E. cava* and remaining algae species on the experimental substrata attached to an artificial reef complex near Shinyang beach, Jeju Island (Feb. 1992 - Feb. 1994).

similar to the species number of other studies conducted in Jeju Island (Kim and Chang 1992; Kang and Sohn 1993; Koh *et al.* 1994).

The most dominant species in terms of seasonal occurrence and biomass was *Ecklonia cava*, a phaeophyte. At the early stage, it seemed to be an opportunistic species, however it quickly overwhelmed other species and became the canopy species within six months(Dayton 1975). Even though *E. cava* lost most part of the frond during summer, none was able to overtake its biomass (Fig. 3). The maximum biomass and frond areas of the species on 15 months old HS were 10.5 kg/m^2 and 13.3 kg/m^2, respectively. The average weight and frond area of individual *E. cava* were 22.9 g and 296 cm^2. The growth of *E. cava* on VS was slower than on HS and the maximum biomass of 3.2 g/m^2 was reached after 18 month of installation.

The second recruitment of *E. cava* was observed after two years after installation. Refering to the higher numbers of species, both on HS and VS, occurred coincide to the lower biomass of *E. cava*. Adult *E. cava* seemed to play an important role for the growth of other benthic algae. The relatively lower biomass of *E. cava* encountered in November of 1992 and 1993 was implied a summer death of the species. And space created by the death of *E. cava* was occupied by other algae until *E. cava* canopied them again. The numbers of young *E. cava* on VS and HS during the first nine months of the study were almost the same. The number as well as the individual biomass on HS developed faster than VS thereafter.

Generally speaking, the number of algal species on HS were greater than VS except in winter. As *E. cava* is an erectile flora and has to compete for light the only, individuals on the upper part of HS are able to survive for a certain period. It means that lower part of VS is available to other species and thus able to keep more species than HS. Species recruited during this time were *Bryopsis* sp., *Ulva pertusa*, *Dictyota dichotoma*, *Amphiora crassisima*, *Peyssonnelia caulifera* and *Symphyocladia marchantiodes*. Species such as *U. japonica*, *Codium*, *Corallina pilulifera*, *Amphiora dilatata*, *Gelidium ammensii* and *Plocamium telfairia* seemed to be the year round. *Colpomenia sinuosa*, *Derbesia marina*, *Padia crassa*, *Clathromorphum* sp. and *Lomentaria catenata* occurred during the first half of the study. On the other hand, *D. dichotoma*, *Dictyopteris latiuscula*, *Zonaria* sp., *Lithothammnion cystocarpiodeum* and *Marginisporum crassissima* occurred during the second half. However, it does not necessarily mean that the former was replaced by the latter.

The occurrence of erect Corallinaceae such as *A. dilatata* and *C. pilulifera* seemed to be related to the abundance of *E. cava*, while the occurrence of epiphytic Corallinaceae such as *Clathromorphum* sp. and *L. cystocarpiodeum* seemed to relate to the suffocation of bryozoans and tunicates. The maximum coverage of *Clathromorphum* sp. and *L. cystocarpiodeum* reached up to 21.8 % and 5.2 %, respectively. However they were diminished with propagations of bryozoans and barnacles. Species belonging to the genus *Sargassum,* known to be widely distributed along the coast of Jeju Island (Kim and Chang 1992; Kang *et al.* 1994; Kang *et al.* 1993; Koh *et al.* 1994), were not found in this study. Kim and Chang (1992) have found that *Sargassum horneri* could be the second dominant species and overcame *E. cava* in terms of biomass when *S. horneri* was planted by artificial seedling.

Dayton (1975) identified intertidal algae into three categories; canopy species, obligatory understory species and fugitive species. The present study did not include a removal experiment of any species, thus the obligatory

Table 2. Occurrence of zoobenthos on the experimental substrata attached to an artificial reef complex near Shinyang beach, Jeju Island (Feb. 1992 - Feb. 1994).

Species	Feb. '92		May '92		Aug. '92		Nov. '92		Feb. '93		May '93		Aug. '93		Nov. '93		Feb. '94	
	h	v	h	v	h	v	h	v	h	v	h	v	h	v	h	v	h	v
Porifera																		
Haliclona permollis																		
Halichondria japonica						+	+	+	+	+	+		+	+	+	+	+	
Halichondria sp.									+	+	+		+	+				
Sycon ? sp.			+															
Porifera unid.																		
															+		+	+
Hydrozoa																		
Dynamena crisioides																		
Sertularella giganta							+	+	+	+			+	+				
Sertularia sp.							+	+						+				
									+				+					
Anthozoa																		
Anthopleura sp.																		
Anthozoa unid.											+		+	+	+	+		+
											+	+						
Bryozoa																		
Amastigia rudis																		
Bowerbankia impricatus								+	+	+				+	+			
Celleporina sp.							+	+										
Crisia sp.											+	+	+	+	+	+	+	
Escharoides sauroglossa													+	+	+	+	+	+
Likenopora radiata	+	+	+	+	+	+	+	+		+			+	+		+		
Scrupocellaria sp.					+	+	+	+										
Watersipora platypora	+	+	+	+	+	+	+	+			+	+				+		
Bryozoa unid.													+	+	+	+	+	+
													+	+	+	+	+	
Polychaeta							+	+										
Amphitrite cirrta											+	+						
Chone teres							+				+	+						
Dexiospira spirillum	+		+	+	+	+	+	+										
Eunice tibiana	+				+		+			+								
Hydroides ezoensis	+		+	+	+	+	+	+	+	+	+	+	+	+			+	
Neanthes sp.													+	+	+	+	+	+
Nepthys ciliata			+															
Perineris brevicirris	+	+															+	
Periserrula leucophryna																		
Platynerisbicanaliculata																	+	+
Spirobis sp.																+	+	+

*h: horizontal substrata, v: vertical substrata.

Table 2. continued.

Species	Feb. '92		May '92		Aug. '92		Nov. '92		Feb. '93		May '93		Aug. '93		Nov. '93		Feb. '94	
	h	v	h	v	h	v	h	v	h	v	h	v	h	v	h	v	h	v
Polyplacopoda																		
Achantochitonna delilippi																		–
Ischnochiton sp.	–		–															
Lepidozona coreanea																		–
Liolophura sp.										–	–	–						
Placiphorella japonica							–											
Gastropoda																		
Discodoris sp.																	–	–
Haliotis discus											–							
Notoacemea schrenkii			–				–	–			–	–	–	–				–
Notria shirikishinaiensis																		–
Pleurobranchaea sp.																		
Serpulorbis imbricatus							–	–										–
Gastropoda unid.															–			
Bivalves																		
Anomia chienesis							–	–	–		–	–						
Chama fragum													–	–				–
Chlamis farrei farrei													–		–		–	
Claudiconcha japonica													–	–				
Glycydonta marina													–	–				
Mitylus edulis									–									
Musculus senhousia							–	–	–	–			–				–	–
Ostrea denselamellosa							–	–										
Porterius dalli									–									
Crustacea																		
Balanus trigonus							–	–	–	–	–	–	–	–	–	–	–	–
Caprella califoniansis			–	–														
Cirolana sp.											–	–						
Erictonius brasiliensis	–	–		–														
Ibacus ciliatus						–											–	
Leptodius extratus											–	–					–	–
Paradexamine sp.							–	–										
Solenocera sp.							–	–										
Others																		
Amaroucium pliciterum																–		
Halocynthia sp.	–								–									
Molgula sp.		–														–		
Tunicate unid.											–						–	
Hermicentrotus pulcherrimus																		
No. of species	10		10		8		22		15		17		21		17		25	

*h: horizontal substrata, v: vertical substrata.

understory species were not identified. However, a higher number of algal species was observed with lower biomass of *E. cava* (Nov. 1992 and 1993). Vandermeulen and Dewreede (1986) found that the removal of a dominant overstory species had no effect upon the seasonal abundance of *Colpomenia peregrina*. This species may be defined as an opportunistic species in the sense of Littler and Littler (1980), or a fugitive species in the sense of

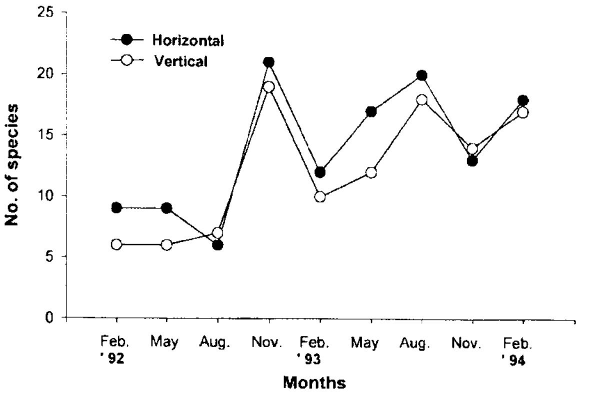

Fig. 4. Species number of benthic animal on the experimental substrata attached to an artificial reef complex near Shinyang beach, Jeju Island (Feb. 1992 -Feb. 1994).

Dayton (1975). *C. sinuosa* and *Padina crassa* observed in this study had a similar ecology to *C. peregrina*. However, they occurred only for the first half of the study.

Zoobenthic community

A total of 64 species were encountered during the study. Among them, 46 species were sessile or less mobile zoobenthos (Table 2).

The development of zoobenthic community on ES was very slow. The three month old ES had only a few sessile species and eight to ten species were encountered after nine months of installation (Fig. 4). Then the species number, especially for sessile form, increased rapidly up to 21 species and became more or less stable. Refered to a slower development of zoobenthic community than those of other studies (Song 1985; Yi 1987), a relatively long lag phase seemed to exist. It was not clear that the lag phase was caused by seasonal variation of recruitments or harmful effects of concrete.

Only two species, *Hydroides ezoensis* (Polychaeta) and *Watersipora platypora* (Bryozoa, except in February 1993) occurred throughout the whole study period. A bryozoan, *Likenopora radiata* and a polychaete, *Dexiospira spirillum* settled at the beginning of the experiment. However, they failed to survive more than a year as *Balanus trigonus* (barnacle), *Haliclona permollis* (poriferan), *Anthopleura* sp. (sea anemone), and other bryozoans such as *Celleporina* sp., and *Crisia* sp. started to propagate on ES. Thereafter the latter group governed the ES in terms of biomass and coverage. Bivalves such as *Amomia chinensis, Musculus senhousia*, *Cama fragum*, and *Chlamis farrei farrei* occurred from the mid-stage, however they seemed to be an occasional settlers.

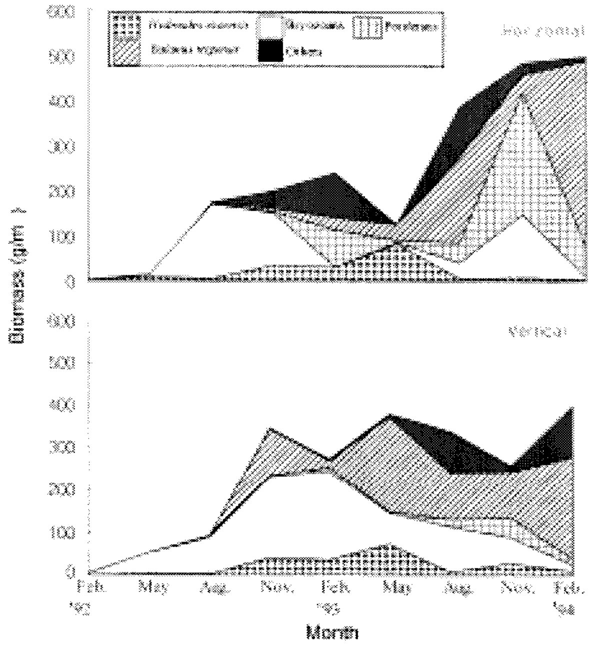

Fig. 5. Biomass of zoobenthos on the experimental substrata attached to an artificial reef complex near Shinyang beach, Jeju Island (Feb. 1992 - Feb. 1994).

Development process of the zoobenthic community on ES can be classified into three stages, initial stages, build up stage and regulatory stage. The initial stage was characterized by a large individual number of smaller species such as *H. ezoensis*, *D. spirillum*, and *L. radiata*. The biomass and percent coverage on VS increased faster than HS caused by a rapid growth of bryozoans (Figs. 5, 6). The initial stage lasted for six month after installation. The build up stage was identified by a rapid increase of the biomass and coverage. The build up stage on HS can be further subdivided into two substages. The first substage was characterized by a rapid fill up of empty space by bryozoans, poriferans and barnacle. However no severe interspecific competition for space occurred. This stage lasted for six months. During the first substage, the biomass and coverage increased to about 200 g/m^2 and 20 %, respectively. The second substage started with the propagation of poriferans and barnacles. The biomass and coverage of bryozoans decreased because of suffocation by rapidly growing poriferans and bulldozing of barnacles. During the second substage, the biomass increment was more or less stagnated while the coverage increased continuously. On the other hand, the build up stage on the VS started a little bit later than the HS. However the build

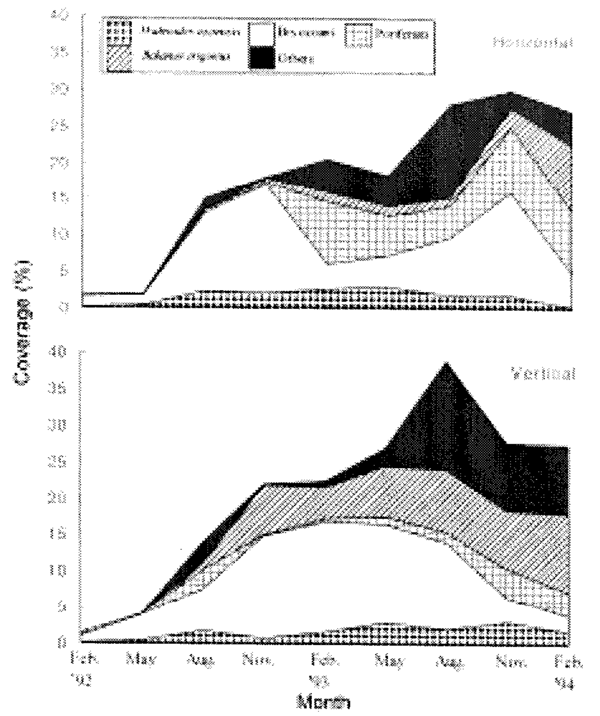

Fig. 6. Percent coverage of zoobenthos on the experimental substrata attached to an artificial reef complex near Shinyang beach, Jeju Island (Feb. 1992 - Feb. 1994).

up speed was faster and the biomass reached to about 350 g/m^2 within a year after installation. There was no clear interjunction between substages on VS seemed to be caused by a poorer vegetation of *E. cava* and poriferans.

One and a half year since installation, the process entered into the regulatory stage. The biomass and coverage increased continuously and reached about 500 g/m^2 and 30 % on HS and about 400 g/m^2 and 27 % on VS, respectively. The highest coverage of 39 % observed on VS in August 1993 was the result of a high occurrence of bivalves. Bryozoans overgrew and suffocated small zoobenthos including young *B. trigonus*. On the other hand, bryozoans was bulldozed by adult *B. trigonus*. Finally, *B. trigonus* and poriferans overtook bryozoans.

Two exceptional cases of monopolizing the space were observed from extra substrates. The first case was a rapid colonizing of *D. spirillum* over an empty space created in consequence of the summer death of *E. cava* on a 21 month old HS. *D. spirillum* settled inclusively with a density of about 1.4 × 10^4 inds./m^2. The *D. spirillum* in some patches exceeded 5 × 10^4 inds./m^2 and mostly consisted by adult individuals. In ordinary case, *D. spirillum* settled at the early stage and was eliminated by other species as the build up stage began. However, in this case, it occupied all over the substrate and smothered other species. This phenomenon imposed that the opportunistic species were able to keep up their population size against challenging species when the circumstance allowed. The web like roots of *E. cava* provided an excellent shelter for smaller zoobenthos and kept the whole benthic community from exclusion.

Another case was space monopolized by *B. trigonus* on a 27 month old VS, except small area where the species was overtaken by a polifera, *H. permolis*. The density of living *B. trigonus* was 9 × 10^3 inds./m^2 and most of them were adults. There were almost the same number of dead shells of the species. Although the VS showed a higher density of *B. trigonus* compared to the HS in most cases, the maximum density of the species in ordinary samples was less than 7.3 × 10^3 inds./m^2 and it was mainly consisted of young individuals. Then the density decreased to 1.8 × 10^3 inds./m^2 within six months. It seemed that barnacles had settled in the previous year had propagated well and died after excluding other neighboring species in any way, just before the next spat. Then, new breed of cyprid settled on it and propagated without a severe challenge of others.

In general, as time went, the artificial habitat became more and more complicated. The most important mechanisms involved, at least in this study, seemed to be the canopy effect of *E. cava*, and direct overgrowth of bryozoans and poriferans over others and bulldozing of adult barnacles as pointed out by Sebens (1986) and Nandakumar and Tanaka (1993). It seemed the benthic process on ES has not reached the equilibrium stage yet, but the biomass became more or less similar to nearby natural habitat.

4. Conclusion

A 27 month lasting study on the development of benthic communities on experimental substrata resulted 98 species which including 34 species of benthic algae, 45 species of sessile zoobenthos and 19 species of mobile zoobenthos. In general, horizontal substrata were able to carry more species than vertical substrata except in winter. There was a lag phase existing on the initial develop-ment stage. However, it was not clear that the lag phase was caused by seasonal variation of the recruitment or by the harmful effects of the experimental substrata which were made of concrete.

The most dominant algal species was *E. cava*, a phaeophyte. It was considered to be a canopy species. *E. cava* was able to suffocate other species, however its holdfast and frond provided a new substratum for the late settlers.

Development of the zoobenthic community on ES can be classified into the initial stage, build up stage and regulatory stage. The initial stage was characterized by a larger individual number of smaller species. The build up stage was identified by a rapid increase of biomass and coverage. No severe interspecific competition for space occurred in this stage. The regulatory stage was characterized by a higher and more stable biomass and coverage. However, the degree of competition seemed to be keener and keener.

It seemed that the benthic process on the experimental substrata had not reached the ecological equilibrium yet. But the benthic community on the experimental substrata, at least in terms of biomass, had became similar to the natural habitat within 27 months after installation.

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