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# Development and Succession of Marine Fouling Organisms on Artificial Substrata

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# 인조기판 위에서 해양 부착생물의 발달 및 천이

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***Abstract***

Fouling communities developing in Jinhae Harbor and Masan Bay were studied by slide and panel immersion test during the period from Dec., 1982 to Nov., 1983. The total viable count of bacteria was estimated more than $1.7\times10^4$ CFU/$cm^2$after 15 days of immersion and 46 taxa of benthic diatoms were classified in micro-community. Progressional change of fouling communities was clearly shown and dominant diatom species are *Licmophora flavellata*, *Navicula grevillei*, and *Nitzschia closterium* . Major macrofouling organisms are *Mytilus edulis*, *Balanus amphitrite amphitrite*, *Hydroides ezoensis*, and *Celleporina* sp. Wet weight production of macrofouling organisms exceeds 500 g /100 $cm^2$ after 5 months of immersion. Regional defferences in community development are clearly shown in two study areas, and mainly due to the disparities of physicochemical stability and nutritional status of ambient water. Seasonality of larvae and the growth rate are the important factors in fouling community development. Overall process of community development is as follow :

bacteria and diatoms – multicellular algae – barnacle, mussels and polychaete – sponge, anemone and ascidian.

요약 : 1982–1983년 진해항 및 마산만에서 발달하는 부착생물 군집을 슬라이드 글라스 및 浸漬基板실험에 의하여 연구하였다. 15일의 침적실험후 세균의 개체수는 $1.7\times10^4$ CFU/$cm^2$로 산출되었고, 微小生物群集에서 발달한 저생 규조류는 총 46분류군이었다. 부착생물군집의 順次的 변화과정을 명백히 볼 수 있었고, 우점 규조류종은 *Licmophora flavellata*, *Navicula grevillei*, 및 *Nitzschia closterium*으로 나타났다. 대형 생물군집의 주요 종은 *Mytilus edulis*, *Balanus amphitrite amphitrite*, *Hydroides ezoensis* 및 *Celleporina* sp.로서 5개월의 침적후에 500g /100$cm^2$이상의 생물량을 보였다. 두 조사해역에서의 군집발달양상이 큰 차이를 보이는데 이는 주로 주변수의 물리화학적 안정성 및 영양상태에 기인하는 것으로 판단된다. 부착생물 군집의 발달과정은 유생의 생성시기 및 성장률에 매우 큰 영향을 받는 것으로 밝혀졌고, 군집 발달의 전 과정은 다음과 같이 요약이 된다.

세균 및 규조류–다세포 해조류–따개비류, 홍합류 및 다모류–해면류, 말미잘류 및 해초류.

## INTRODUCTION

Biofouling is a general term used to describe all forms of biological deposits formed on the hulls of ships and other submerged marine structures. Microfouling is caused by the growth of microbes and their products on surfaces. Since bacteria are common in the marine habitats, large quantities of microbes will deposit in a few hours on various surfaces. Macrofouling may be defined as the attachment and subsequent growth of a community of usually visible plants and animals, and most commonly occurs on surfaces exposed to seawater at depth of less than eighteen hundred meters(Mitchell and Benson, 1981).

Bacteria and diatoms are two of the most significant groups found in fouling. Once attached to surfaces, they divide very rapidly and form a slime film of great importance to the fouling community development. Attachment of specific diatoms to a surface may be controlled by the presence of characteristic organic chemicals on the surface(Mitchell *et al.*, 1984). Presumably, these chemicals are produced by different bacterial populations. Also, the adhesion of bacteria, microalgae, and their products to solid surfaces–microfouling–may enhance the settlement of larvae of marine animals(Horbund and Freiberger, 1970 ; Tosteson and Corpe, 1975 ; Caron and Sieburth, 1981), and in naturally occurring environments, the primary fouling organisms normally precede the settlement of macrofouling. However, no evidence yet confirms that the microfouling is a prerequisite to subsequent settlement.

Succession is the process of change in community composition after a disturbance which provides a new habitat(Horn, 1974 ; Connell and Slatyer, 1977). In general, early–succession, or pioneer species is the only one that can tolerate the harsh conditions in a new habitat. The pioneer species then modifies habitat so that other species are able to invade, and the pioneer species are displaced (Clements, 1916 ; Odum, 1969). In recent years, other mechanisms are proposed, which include different invasion and growth rate, competitive abilities, and longevity for each species in succession(Drury and Nisbet, 1973 ; Horn, 1974 ; Connell and Slatyer, 1977).

However, in spite of many previous works, one of the most striking features of marine fouling communities is the tremendous degree of short–term change in species composition and abundances. Therefore, the major questions about the fouling community are whether succession in the classical sense occurs in such communities(Horn, 1974) and what the key factors are that influence the rate and direction of development on them.

In Jinhae Bay, only one work was performed by DePalma(1975) ; that was a part of a study of biofouling communities at selected locations throughout the world ocean by the U.S Naval Oceanographic Office, to develop fouling rate forecasting models for coastal regions. Therefore the dynamic processes in succession are not yet well known in the study area.

Using controlled field experiment(series I, II, III) on the marine fouling community, this study investigated overall process of biofouling community development which included micro–and macrofouling. In particular, we attempted to answer the following problems ;

1) rate of biofouling production
2) rate of growth
3) succession mechanism
4) local differences based on the environmental gradients

## MATERIALS AND METHODS

In Jinhae Bay, biofouling investigations were carried out by sampling test slides and panels for a year at two stations(Fig. 1).

A three–series system of culture suspension exposures was used in all fouling studies. The series I experiment was designed for providing information on colonization rates of bacteria, species composition and progressive changes in the microfouling community. To acquire the initial biofouling films in natural conditions, glass slides were mounted back–to–back with wood block and rubber tube, and suspended on Dec., 13, 1982 in sea water.

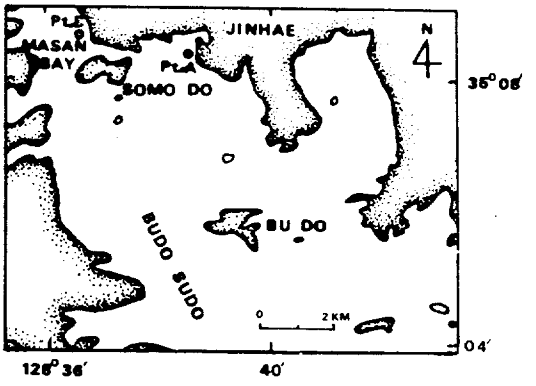

Fig. 1. A map of study area showing 2 sampling points.

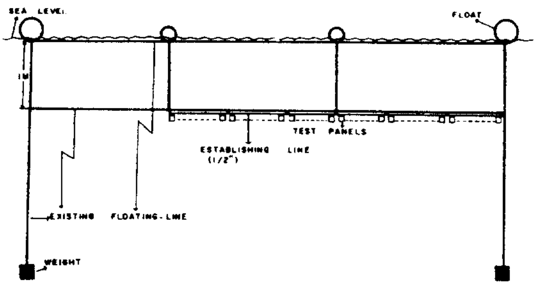

Fig. 2. Establishment of test panels in study area.

In series II system, aluminum-alloy test panels measuring 20×30×0.5 ㎤ were used. Untreated test panels were presoaked for a day in A-wash, an acidic compound to maintain bright and clean surfaces. After application of A-wash, twelve test panels were submerged on Dec., 13, 1982 at each collecting station. The detailed eastablishing methods of test panels are shown in Fig. 2. This type of exposure provides the information on the rates of biofouling production, rates of growth, successional changes in the macrofouling community.

To obtain the data on seasonal variation on the settlement of organisms, a new set of panels was installed at each season (Series III) -Feb., May, Jul., and Oct., 1983, and all sets were removed together at the same time (Nov., 1983). For the purpose of the observation, the test panels and slides were collected with time intervals shown in Table 1, and examined upon bacteria, benthic diatoms and macrofouling communities.

Table 1. Sampling dates

| | Slide | | Plate | |
|---|---|---|---|---|
| | Bacteria | Diatom | Site-A | Site-B |
| 1. Dec. 15, 1982 | * | | | |
| 2. Dec. 20, 1982 | * | * | | |
| 3. Dec. 27, 1982 | * | * | | |
| 4. Jan. 7, 1983 | | * | | |
| 5. Jan. 30, 1983 | | * | * | |
| 6. Feb. 28, 1983 | | * | * | E |
| 7. Apr. 4, 1983 | | * | * | * |
| 8. Apr. 25, 1983 | | | * | * |
| 9. May. 30, 1983 | | | * | * |
| 10. Jun. 27, 1983 | | | * | * |
| 11. Jul. 25, 1983 | | | * | * |
| 12. Aug. 29, 1983 | | | * | * |
| 13. Sep. 26, 1983 | | | * | * |
| 14. Oct. 24, 1983 | | | * | * |
| 15. Nov. 28, 1983 | | | * | * |

Remark ; E indicates the initial submerging time of test panels in Masan Bay.

For the growth studies of bacteria, the glass slides removed by the SCUBA divers were first rinsed in sterile sea water. The glass slide were then crushed in a sterile cap tube containing 100 *ml* of autoclaved sea water. This suspension was agitated with a Vortex homogenizer for one minute, and allowed to set for 30s for the glass particle to sediment, and then a portion was removed for counting purpose. Viable plate counts were made on the subsample using the Zobell's 2216 medium by techniques outlined in Standard Methods, and incubated at 25℃ for 5 days for the enumeration of the colony forming units of bacteria.

The glass slides used in the observation of benthic diatoms and multicellular microorganisms were first rinsed with sterile distilled water and immediately fixed with neutralized formalin to a final concentration

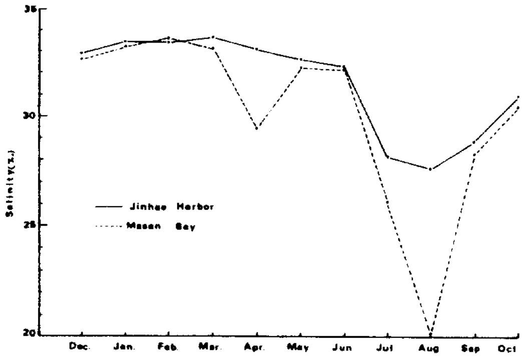

Fig. 3. Surface salinity measurements during 1982-1983.

of 4%. Quantitative counts were made with Olympus Zoom Stereo Microscope and Nikon SBR-UK Microscope up to 1000 magnifications. The coverage per unit field was adopted for comparative criteria of the abundance of each observed organism.

The aluminium test panels, fixed with 4% neutralized formalin on board were observed in order to examine the macrofouling community. The cover value was obtained by a certain percentage of the total area of a quadrat covered by a given species. Biomass measure per unit area was based on formalin wet-weight, and the thickness represented the maximum height of fouling community.

Water temperature and dissolved oxygen measured on shipboard with Monteboro-Whitney Model TC 5 C and YSI 57 DO Meter, repectively. Salinity was determined by Autosal Guildline Model 8400 in laboratory.

## RESULTS AND DISCUSSION

### *Environmental Conditions*

The marine environment of the study area is characterized by a typical inner bay, and shows large fluctuation of salinity due to the seasonal variations of fresh water input (Fig. 3). In general, most fouling organisms can tolerate the salinity values of not less than 25.0‰ (DePalma, 1969). And, it is essential that biofouling studies for the practical application to ocean-going ships should be carried out in waters of full salinity (33~35‰). This, however, may not be always practicable, because most convenient sites for fouling study will lie within a harbor, or in an estuary. Therefore, the immersion site where indicator species of brackish water (e.g. *Surirella gemma*, *Nitzschia sigma*) do not exceed 2~3% of the total diatom flora is accepted to be appropriate for fouling research (Hendy, 1951). The immersion sites in the study area are suitable from this point of view, as few brackish-water species have been reported therefrom, and the stations show the salinity values more than 25‰ around the year except August, 1983 in Masan Bay.

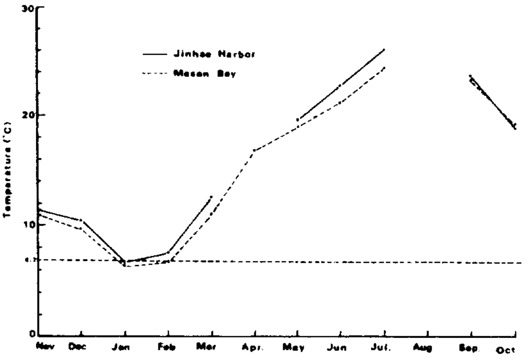

Fig. 4 3$m$-depth temperature measurements during 1982-1983. The number of days above critical temperature for settlement and growth is compared.

Water temperatures at 3 $m$ range from 6.6 to 26.2°C in Jinhae Harbor and 6.5 to 24.5°C in Masan Bay (Fig. 4). Wide fluctuations of annual temperature are the same characteristic feature of two stations, and also the annual temperature variations show similar pattern between two stations. According to Hutchins and Deevey (1944), the settlement and the growth of most foulers are limited by

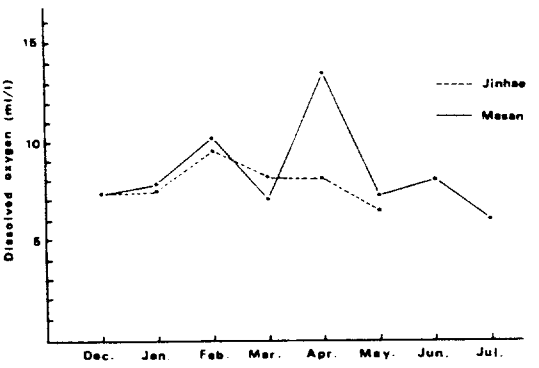

Fig. 5. 3*m*-depth dissolved oxygen measurements during 1982-1983.

temperature less than 6.7℃. Fig. 4 also shows the number of days above this critical temperature for both area. That is, Jinhae Harbor has longer growing season than Masan Bay.

Fig. 5.shows the seasonal fluctuations of dissolved oxygen contents in 3*m*-depth water. The concentrations of dissolved oxygen range from 6.5 to 9.7 *ml/l* in Jinhae Harbor, and 6.1 to 13.3 *ml/l* in Masan Bay. Dissolved oxygen contents especially fluctuate largely in Masan Bay, and with salinity records this result gives the cue that the environmental gradients of Masan Bay are more unstable and severe than those of Jinhae Harbor.

The kinetics of microfouling are closely related to sea water chemistry. Nutrient-rich waters rapidly yield thick biofilms, whereas nutrient-deficient waters yield thin biofilms (Pederson, 1982). Therefore, the nutritional status is the dominant factor in elucidating the overall process of fouling community - especially, of microfouling. In the study area, local differences are mainly distinguished in the aspects of nutritional status ; Masan Bay is much more eutrophicated than Jinhae Harbor(KORDI, 1981), and eventually, this leads the critical differences in species composition and productivity of two immersion sites(Relini and Pisano, 1977).

A direct correlation exsists between macrofouling rates and water depth. The quantity of biofouling decreases drastically with depth (Leopore and Gherardi, 1977). Initial macrofouling rates also decrease dramatically in the open ocean with the distance from land(Relini and Matricardi, 1977). In this study, the test panels were exposed at pier-side(Jinhae Harbor), and at distances of ten hundred meters from the shoreline(Masan Bay). Submerged depth of test panels was 3 *m* from sea level.

### *Microbial Biofilm Formation*

Although no evidence confirms that microfouling is a prerequisite to subsequent settlement(Horbund and Freiberger, 1970 ; Cooksey *et al*., 1984), the adhesion of bacteria and their products to solid surfaces may facilitate the attachment of diatoms and enhance the settlement of larvae of marine animals(Tosteson and Corpe, 1975 ; Caron and Sieburth, 1981). Recent studies also have shown that larvae of many fouling organisms prefer to settle on surfaces coated with a microbial film. Moreover, settlement and metamorphosis of the larvae of fouling organisms are triggered by specific bacterial films. Therefore, the formation of bacterial films is usually an essential prelude to the development of marine fouling communities. These works were also performed to elucidate the importance and the status of microfouling in the overall process of biofouling development.

Table 2 shows the bacterial colony counts on each test slide at two sampling stations. Total viable count per square centimeter was $8.0 \times 10^2$ CFU/㎠ and $2.5 \times 10^3$ CFU/㎠ after 3 days in Jinhae Harbor and Masan Bay, respectively. With longer period of submergence, more than $1.7 \times 10^4$ CFU/㎠ were estimated at the end of 15 days, and this result well confirmed the earlier work(Zobell, 1943)

Table 2. Bacterial colony counts on each test slides during initial stages (CFU/㎠)

| After | 3 days | 7 days | 14 days |
|---|---|---|---|
| Point A | $8.0\times10^2$ | $2.8\times10^3$ | $1.7\times10^4$ |
| Point B | $2.5\times10^3$ | $6.3\times10^3$ | $2.2\times10^4$ |

The rate of attachment and growth was different in two sampling stations, and was probably related to the nutrient levels of the waters and to the bacterial concentration in the ambient water (Bott *et al*., 1983 ; KORDI, 1981 ; Kwon, 1983) ; Slides submerged in Masan Bay developed films of bacteria quite rapidly as compared with those in Jinhae Harbor.

### *Fouling of Benthic Diatoms*

Total 46 taxa of fouling organism were classified from the test slide collected from two submerging points. There were 26 diatom species, 6 blue-green algae species, 3 green algae, 3 brown algae, 6 protozoans and two kinds of larval form of benthic invertebrate.

Seasonal progressions of dominant fouling organisms are summarized in Table 3. Conspicuous development of initial fouling community is found during the second week of immersion. The most abundant benthic diatom species were *Navicula grevillei*, *N. mutica*, and *N. ramosissima* commonly in both sampling stations. *Licmophora flavellata*, *Nitzschia closterium* and *Synedra gaillonii*, however, were the major components exclusively in Masan Bay. From the Table 5, it can be also recognized that benthic diatom communities were more diverse and dense in Jinhae Harbor than Masan Bay. Another remarkable features are species compositions. In Masan Bay, solitary form diatom (e.g. *Nitzschia closterium* ) occurred abundantly, whereas rarely in Jinhae Harbor. As Mook(1980) pointed out, it may be due to that the stenotopic colonial species tend to dominate the fouling community at a stable environment, whereas, at unstable and eutrophicated conditions, dominant species are, in general, eurytopic solitary forms.

Multicellular microscopic algae and protozoans were found after two months. *Cladophora* sp., *Ectocarpus* sp. and *Myrionema* sp. were predominant in Jinhae Harbor, and *Stromatella* sp. and *Ectocarpus* sp. in Masan

Table 3. Time-course variations in percent coverage of the dominant groups of microscopic fouling organism in Jinhae Harbor(J) and Masan Bay(M).

| | | Dec. 1982 | | Jan. 1983 | | Feb. | Apr. |
|---|---|---|---|---|---|---|---|
| | | 20 | 27 | 7 | 30 | 28 | 5 |
| *Amphora coffeaeformis* | J | | | | | + | |
| | M | | + | + | | | 10 |
| *Cocconeis sublittoralis* | J | | | 10 | | | |
| | M | | + | 5 | + | | |
| *Licmophora flavellata* | J | | | + | + | + | 5 |
| | M | | 10 | 5 | 15 | 35 | 25 |
| *Navicula mutica* | J | | | | | + | 30 |
| | M | | + | 25 | | | |
| *Navicula grevillei* | J | | 20 | 25 | + | 10 | |
| | M | | + | 15 | 40 | 10 | |
| | | | 20 | | | | |
| | | | | 10 | | | |
| *Nitzschia closterium* | J | | | | | + | |
| | M | | + | | 15 | + | 20 |
| *Synedra gaillonii* | J | | + | + | | | |
| | M | | 25 | 5 | | | |
| *Oscillatoria* SP. | J | | | | 25 | | |
| | M | | | | | | |
| *Calothrix scopulorum* | J | | | | | 25 | |
| | M | | | | | | |
| *Cladophora* SP. | J | | | | | 45 | 10 |
| | M | | | | | | |
| *Stromatella papillosa* | J | | | | | | |
| | M | | | | | 15 | |
| *Ectocarpus* SP. | J | | | | | 35 | 15 |
| | M | | | | | | 20 |
| *Myrionema strangulans* | J | | | | | | 30 |
| | M | | | | | | |
| *Acineta turberosa* | J | | | + | 60 | | |
| | M | | | | 10 | | + |
| *Vorticella oceanica* | J | | | | | + | |
| | M | | | | | 30 | |

Bay. After 2 months, while the abundance of algal populations was very poor in Masan Bay, Jinhae Harbor showed comparatively diverse and abundant community structure.

Successional change of fouling communities was clearly shown, especially in Jinhae Harbor. The most abundant species in a month were *Navicula grevillei* and *N. ramosissima*. Thereafter, protozoans (*Acineta* sp.), blue-green algae(*Oscillatoria* sp., *Callothrix* sp.), green(*Cladophora* sp.) and brown algae(*Ectocarpus* sp.) were gradually co-dominant with diatom species.

### *Macrofouling Communities*

**Development of Community Structure** : For the purpose of the structural analysis, macrofouling community was divided into two parts. The first was algal community containing protozoans, and the second was animal community.

Table 4. Local abundance of biofouling organ-(algae and protozoa) on test panels in Jinhae Harbor and Masan Bay, during 1982-1983.

| Organism | Local abundance | |
|---|---|---|
| | Jinhae Harbor | Masan Bay |
| Cyanophyta | | |
| *Oscillatoria* sp. | ×× | × |
| *Phormidium* sp. | ×× | ×× |
| Chlorophyta | | |
| *Cladophora* sp. | ×× | ×× |
| *Enteromorpha* sp. | × | ××× |
| *Stromatella papillosa* sp. | ×× | ×× |
| *Ulothrix* sp. | ×× | × |
| Phaeophyta | | |
| *Actinetospora* sp. | | × |
| *Ectocarpus* sp. | ×× | ×× |
| *Giffordia* sp. | ×× | ×× |
| *Myrionema* sp. | ×× | ×× |
| *Pilayella* sp. | | × |
| Protozoa | | |
| *Acineta tuberosa* sp. | ×× | |
| *Favella* sp. | × | |
| *Helocostomella* sp. | ×× | |
| *Tintinnopsis kofoidii* sp. | × | |
| *Vorticella oceanica* sp. | × | ×× |
| *Codonellopsis* sp. | × | |

× × × ; 40% or greater coverage on panels.
× × ; less than 40% coverage but occurs frequently.
× ; never exceeds 1% coverage or occurs only rarely.

In algal community, fouling organisms were 17 species in all. They were 2 species of blue-green algae, 4 species of chlorophyta, 5 species of phaeophyta and 6 species of protozoans(Table 4). The most dominant species was *Enteromorpha* sp. especially in Masan Bay, and the others showed even distribution through the initial community development.

Table 5 shows the local occurrence and abundance of biofouling animals. Abundant species were *Hydroides ezoensis*, *Balanus amphitrite amphitrite*, *Balanus pacificus*, *Mytilus*

Table 5. Local abundance of biofouling organisms (animals) on test panels in Jinhae Harbor and Masan Bay, during 1982-1983.

| Organism | Local Anundance | |
|---|---|---|
| | Jinhae Harbor | Masan Bay |
| Porifera | | |
| *Mycale* sp. | × | |
| Coelenterata | | |
| *Obelia geniculata* | ×× | × |
| *Actinia equina* | | × |
| *Haliplanella* sp. | | × |
| Bryozoa | | |
| *Bugula subglobosa* | × | ×× |
| *Bugula* sp. | ×× | × |
| *Celleporina* sp. | ×× | |
| Platyhelminthes | | |
| *Pseudoceros* sp. | × | ×× |
| Annelida | | |
| *Hydroides ezoensis* | ××× | ×× |
| Arthropoda | | |
| *Balanus amphitrite amphitrite* | ××× | × |
| *Balanus pacificus* | ××× | ××× |
| Mollusca | | |
| *Mytilus edulis* | ××× | ××× |
| *Saxostria echinata* | × | ××× |
| Chordata | | |
| *Styella clava var. symmetrica* | × | |
| *Styella clava* | ×× | |
| *Botryllus primigenus* | × | |
| *Cnemidocarpa* sp. | | ×× |
| *Ascidia* sp. | ××× | × |

× × × ; 40% or greater coverage on panels
× × ; less than 40% coverage but occurs frequently
× ; never exceeds 1% coverage or occurs only rarely

*edulis* and *Ascidia* sp. in Jinhae Harbor, and *Balanus pacificus*, *Mytilus edulis* and *Saxostrea echinata* in Masan Bay.

Settlement times and percent cover of major fouling organisms are illustrated in Fig. 6. In general, pioneering algae such as the cosmopolitan genera *Enteromorpha* and *Ectocarpus* can remain as the dominant organisms of unstable structures, such as ship's hull (Evans and Christie, 1970 ; Baker and Evans, 1973), but they also play a large facilitating role in the colonization of fully immersed stable structure, often being succeeded by a climax community of animals (Withers and Thorp, 1977).

Foster (1975) examined that successional changes were generally the results of differences in growth of ephemeral and perennial species, but he noted that ephemeral algae were more abundant than perennials during the early stages of colonizations. Furthermore, colonization of ephemerals was less in established communities than at the same time on newly immersed blocks. Apparently, established communities inhibited colonization of ephemerals, which then could not persist in the succession.

In this study, these patterns of algal community development were also recognized. That is, the species colonized the initial fouling community were almost ephemeral forms (Table 4), and the settlement time and continuity of settlement were restricted only in the initial stage of community development (Fig. 7). After 3 months of immersion, considerable algal community development never be investigated until at the end of experiments, and it was completely replaced by the animal groups. It would be thought that this result was mainly due to the species composition of algae in ambient waters and the different colonization rate of each species. Although vegetative fragmentation can play a role in the dispersal processes of algae, the great majority of plants reach new substrata using quite specialized reproductive spore bodies formed in sporangia. Especially, asexual spores are primarily involved in substrate colonization. Therefore, the initial attachment and recolonization rate of asexual spore

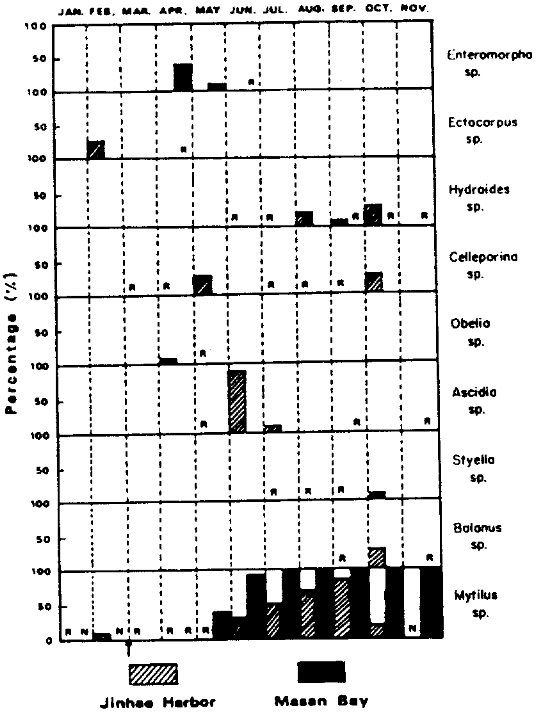

Fig. 6. Settlement times and average percent cover of the most common (at least 10% coverage) fouling organisms. Arrow indicates the initial submerging time in Masan Bay. R ; less than 10% cover. N ; not sampled.

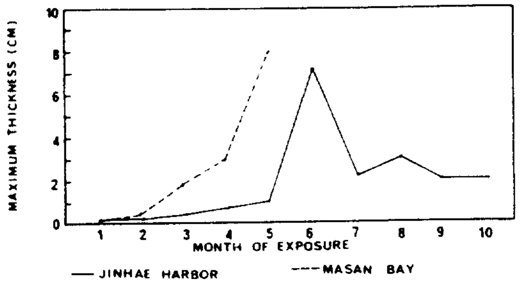

Fig. 7. Wet weight production of biofouling organisms on test panels exposed in Jinhae Harbor and Masan Bay, during Jan. -Nov., 1983.

in surrounding water are the key factors of algal community development. And also, it appears that once a fouling community is well developed, further settlement of some species is inhibited and those species tend eventually to disappear from the community.

**Local Differences** : Local abundance and species composition of biofouling organisms have specific feature in this study. In Jinhae Harbor, total 30 species were recorded, and various species were co-dominant at the end of experiments(*Hydroides ezoensis*, *Cellepor-ina* sp., *Balanus amphitrite amphitrite*, *Mytilus edulis*). In Masan Bay, however, 25 species were identified, and after 4 months of immersion, *Mytilus* sp. occupied the space predominantly(80~100%) through the whole remaining periods(Table 4 and 5, Fig. 6). From this it can be deduced that constitution of community in Jinhae Bay is more diverse and stable than that of Masan Bay.

And, it is mainly attributed to the fact that the physicochemical environments(e.g. dissolved oxygen, salinity) in Masan Bay were critically unstable(Fig. 3 and 5), and heavily eutrophicated. These phenomena were also confirmed by another result of animal community development. In the previous studies, many workers(Goodbody, 1961 ; Sugimoto and Nakavchi, 1974 ; Young and Young, 1978) investigated that ascidians and bryozoans had relatively short planktonic stages, and lower probability of settling because of the low dispersal capabilities. Therefore, their parent stocks are generally restricted to more physically stable areas, and this can support the characteristic feature of local differences in this study.

From both stations, free living animals such as gammarids and carprellids were commonly present among the developed fouling communities. The branching organisms, such as the bryzoan *Bugula* sp. and the hydroid *Obelia* sp. act as substratum for tubiculous amphipod(*Corophium* sp.) and carprellid amphipod(*Carprella acanthogaster*). Local differences are also observed in these adventitious organisms ; carprellid amphipod was completely predominant in Masan Bay, but in contrast tubiculous amphipod in Jinhae Harbor.

**Biomass Production** : Fig. 7 shows the progressional wet-weight production of biofouling organisms. In Jinhae Harbor, biofouling production gradually increased to 40 g/100 $cm^2$ until 5 months of immersion. After 6 months, biomass production showed abrupt increase up to 400 g/100 $cm^2$, and fluctuated from 80 g /100 $cm^2$ to 220 g /100 $cm^2$ during the remaining period. Sudden increase of biomass in June, 1983 was due to the dense growth of *Ascidia* sp., and as described in previous section, this reflected the result that the larvae of *Ascidia* sp. had a short planktonic stage and high seasonality of settlement.

Gradual decrease in biomass after 8 months was mainly attributable to the progressional changes in community structure. On August, fouling community was dominantly composed of double layered *Mytilus* population, which was the most important species in biomass increase. But after this period, *Mytilus edulis* was gradually replaced by *Hydroides ezoensis* and *Balanus amphitrite amphitrite*, which were not to be treated seriously in fouling production. Therefore, although the community structures became more diverse and stable than the former stages, total biomass of fouling community decreased with increasing exposure time.

In Masan Bay, however, there were another features in biomass production. In this area, increasing rates of biofouling production were found to be larger than those in Jinhae Harbor, and showed logarithmic pattern. Only after 5 months of immersion, wet weight production per unit area exceeded 500 g /100 ㎠, but after this period biomass measures could not be obtained because of detachment of fouling organisms, possibly due both to heavy weight of organisms and to mechanical force. This detachment phenomenon was mainly due to the unusual species composition of study area. In opposition to Jinhae Harbor, single species (*Mytilus edulis*) occupied the full surface of exposed panel only after 4 month (Fig. 6). According to the growth of *Mytilus edulis*, byssus threads anchoring its body to the substratum could not support the weight loaded by biomass increase. In general, the mussels, like most fouling organisms, attach to stationary objects ; rocks, floats, buoys and ships moored in harbors. And also, their attachment withstands currents and wave action although only a few have strong attachment enough to maintain their community on the hull of an active, cruising ship. In this study, there was unusual decrease in attachment force of *Mytilus edulis*. This was mainly attributable to the weakness of physiological conditions of *Mytilus edulis*, which might be under influence of physicochemical unstability and red tide in the study area.

In two sampling stations, *Mytilus edulis* is the most important species in biofouling production. Therefore, the differences in biofouling production rate of each area are closely related to the growth rate of *Mytilus edulis*. Fig. 8 shows the size distribution of *Mytilus edulis* appeared in arbitrary 5×5 ㎝ quadrat. In Jinhae Harbor, there were more than 1000 inds/25 ㎠ after 3 months of immersion, and their average body size was 1 ㎜. After 4 months, individual numbers were decreased to 600 inds/25 ㎠, but average size was increased to 6 ㎜.

In Masan Bay, however, 400 inds/25 ㎠ were observed after 3 months, which had average size more than 3 ㎜. After 4 months, individual numbers were changed to 350 inds/25 ㎠, and average size to 11 ㎜ and maximum size to 25 ㎜. From this result, Jinhae Harbor was characterized by dense population and small body size, which resulted in low growth rate. Therefore, the disparity in production rate of two sampling stations may be come about from the intraspecific competition of *Mytilus edulis* and larval recruitment rate in initial stage which is influenced by the physico-chemical properties of the ambient water. Rapid increases of biofouling production in Masan Bay can be explained in these respects of population growth.

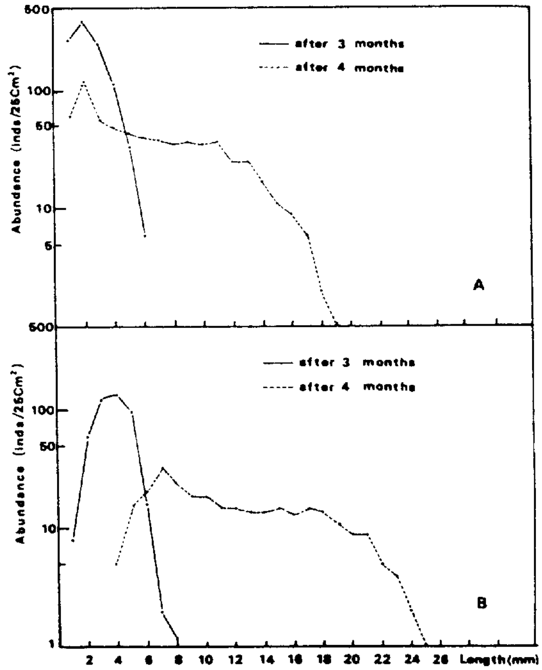

Fig. 8. Size distribution of *Mytilus edulis* on the test panel in Jinhae Harbor (A) and Masan Bay (B).

Fig. 9 shows the maximum thickness of fouling communities. Monthly variations of maximum thickness were well coincided with those of wet weight production, and this was also resulted from the same

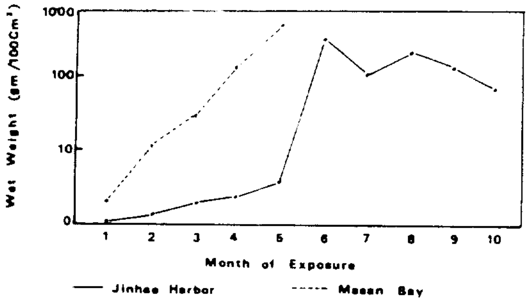

Fig. 9. Maximum thickness of fouling organism on test panels in two sampling stations.

changes in fouling community as described in wet weight production.

According to traditional hypothesis of community stablility, the older fouling community is more stable than the younger one in terms of physical structure and statistical properties, and the former sustains larger standing crop than the latter. But in this study, there were some implications in the respects of those conventional hypotheses. In Jinhae Harbor, species numbers gradually increased and became more diverse with increasing exposure time, but the biomass of foulers decreased. In Masan Bay, however, another features were investigated ; decreased species number and stability, and increased biomass. That is, this result reveals a lack of consistent support for traditional concepts. It might be due to that the monthly variation of community development and fouling production was closely related to the seasonality and different growth rate of fouling organisms. Therefore, it can be concluded that environmental stress, together with ecological strategies are more important in determining community resistance stability and biomass than statistical properties such as diversity and richness.

**Seasonal Effects in Community Development :** Many sessile animals and marine algae release into the sea large numbers of free-swimming propagules which, after dispersal, settle on rocks and floating objects. Although some species reproduced year-round, many are limited to a particular season for the production of larvae. Even among the former species, many exhibit a concentration of reproductive output, during a definitive portion of the year. Therefore, the seasonality of larvae is the most important factor in fouling community development, particularly in temperate region. In this study, the importance of seasonality was also documented in fouling community (Table 6).

In Jinhae Harbor, test panels exposed in

Table 6. Occurrence of fouling organism (at least more than 5% coverage) on panels at different initial exposure time, but with same peiod during 1982-1983.

| | Marine Exposure Period (Months) | | | |
|---|---|---|---|---|
| | 1 | 4 | 6 | 9 |
| Jinhae Harbor | Oct. 1983–<br>Nov. 1983 | Jul. 1983–<br>Nov. 1983 | May 1983–<br>Nov. 1983 | Feb. 1983–<br>Nov. 1983 |
| | | *Balanus*<br>*Mytilus*<br>*Bugula* | *Balanus*<br>*Mytilus*<br>*Bugula*<br>*Hydroides* | *Hydroides*<br>*Balanus*<br>*Mytilus*<br>*Mycale*<br>*Styella*<br>*Celleporina* |
| | Dec. 1982–<br>Jan. 1983 | Dec. 1982–<br>Apr. 1983 | Dec. 1982–<br>Jun. 1983 | Dec. 1982–<br>Sep. 1983 |
| | | *Obelia*<br>*Mytilus* | *Ascidia*<br>*Mytilus*<br>*Hydroides* | *Hydroides*<br>*Mytilus*<br>*Balanus*<br>*Bugula*<br>*Celleporina*<br>*Styella* |
| Masan Bay | Oct. 1983–<br>Nov. 1983 | Jul. 1983–<br>Nov. 1983 | May 1983–<br>Nov. 1983 | Feb. 1983–<br>Nov. 1983 |
| | *Enteromorpha*<br>*Mytilus* | *Mytilus*<br>*Saxostrea*<br>*Balanus* | *Balanus*<br>*Mytilus*<br>*Saxostrea*<br>*Hydroides*<br>*Cnemidocarpa*<br>*Pseudoceros* | *N.D.* |
| | Feb. 1983–<br>May 1983 | Feb. 1983–<br>Jun. 1983 | Feb. 1983–<br>Aug. 1983 | Feb. 1983–<br>Nov. 1983 |
| | *Phormidium* | *Mytilus*<br>*Enteromorpha* | *Mytilus* | *Mytilus* |

Remarks

1. Species names are omitted.
2. Species are more dominant upward in sequence.
3. N.D. ; Not determined.

spring and summer seasons were occupied predominantly by *Balanus* sp., Whereas *Ascidia* sp. and *Obelia* sp. on December. After 9 months of immersion, species composition showed more or less similar patterns regardless of different initial exposure time. More species were co-dominant with increasing exposure time commonly irrespective of initial submerging time. In Masan Bay, *Saxostrea* sp. and *Balanus* sp. appeared considerably on test panels exposed in spring and summer. But, in winter, *Mytilus* sp. was the only species occupied the space through the whole experiment periods. In the pervious work(Kim, 1984), it was investigated that the larvae of several invertebrates were most abundant especially in spring and summer ; barnacles in spring and summer, polychaetes in summer, mussels in summer but predominant year-round.

From these three results, it is generally concluded that settlement patterns and different growth rates are important factors for producing successions in marine fouling communities. That is, a consequence of settlement of each species is that the pattern of succession will vary depending on the time when a bare surface becomes available for colonization. Only those species which are settling at the time when, for example, a new plate is immersed, can colonize it. The species which are not settling at that time will be absent from the succession, or at least from part of it. These phenomena were more critical in Masan Bay than in Jinhae Harbor. In winter, *Mytilus* larvae occupied the large portions of total invertebrate larvae. Therefore, the initial animal fouling community was mainly composed of young *Mytilus* sp., and also this species showed the rapid growth rate as decribed in previous section. Furthermore, *Mytilus edulis* deposits a mud composed of feces and pseudofeces, and this mud-depositing organism decreases at the available bottom substratum for settlement of other foulers(Field, 1982). Consequently, the test panels exposed on winter were appeared as single population structure regardless of immersion period. These results demonstrate that organisms already presented in the community can inhibit the settlement of other organisms.

Connell and Slatyer(1977) proposed a series of three models in succession. Among them, facilitation model was generally adopted as the proper one in fouling community. In this study, it is suggested that the structure of the secondary foulers is dependent on the settlement time and the growth rate of primary fouling assemblage, and that the succession in the fouling community appears partly to follow Conell and Slatyer's inhibition (Connell and Slatyer, 1977) model although there is no single generalized mechanism of succession.

## CONCLUSION

Marine biofouling is the result of the attachment of larvae of invertebrate organisms, and the spore of marine algae settling and growing on submerged surfaces. The fouling organisms vary from place to place and with different seasons. The sequence of fouling organisms that colonize a surface introduced into seawater usually follows a pattern which is predictable and directional. Each successional stage can be identified by a particular organism or group of organisms that dominates both spatially and temporally. It has been shown that fouling is controlled not only by the organisms that are most abundant in the water, but also by wide range of environmental conditions, and this is more critical in Masan Bay. The overall sequence of fouling populations developed on a surface is shown in Table. 7, which is typical especially in Jinhae Harbor.

Table 7. Development of the fouling community.

| | |
|---|---|
| A. Slime Forming organisms | Bacteria |
| | Diatoms |
| | *Navicula grevillei* |
| | *Amphora costata* |
| | *Navicula mutica* |
| | *Synedra gaillonii* |
| | *Licmophora flavellata* |
| | Protozoa |
| | *Acineta turberosa* |
| | *Vorticella oceanica* |
| B. Preliminary fouling organisms | Epiphytic algae |
| | *Cladophora* sp. |
| | *Enteromorpha* sp. |
| | *Ectocarpus* sp. |
| | Hydroides |
| | *Obelia geniculata* |
| C. Primary fouling organisms | Banacles |
| | *Balanus amphitrite amphitrite* |
| | *Balanus pacificus* |
| | Bryozoa |
| | *Bugula* sp. |
| | *Celleporina* sp. |
| | Mussels |
| | *Mytilus edulis* |
| | *Saxostrea echinata* |
| | Polychaete (attached) |
| | *Hydroides ezoensis* |
| D. Secondary fouling organisms | Sponges |
| | *Mycale* sp. |
| | Anemones |
| | *Actinia equina* |
| | *Haliplanella* sp. |
| | Chordata |
| | *Ascidia* sp. |
| | *Styella clava* |
| E. Adventitious organisms | Polychaete |
| | Platyhelminthes |
| | *Pseudoceros* sp. |
| | Amphipod and other small crustaceans |

Climax community is accompanied by an increase in diversity, decreased dominance, and a more equal distribution of species within the assemblage. However, this is not true in the polluted areas. Because of the apparent absence of a climax community in Masan Bay, the following description of succession is proposed. Succession is a progressive changes in species composition brought about by physical change caused by organisms within the assemblage, and, this change is mainly attributable to the seasonal variation and the growth rate of fouling organisms, which is resulted from the life strategies of specific organism in partcular environmental conditions.

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