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ENVIRONMENTAL STUDIES OF THE JINHAE BAY 3. ECOLOGICAL SUCCESSION OF PHYTOPLANKTON POPULATIONS, 1974～1980.

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ABSTRACT

1974년 9월부터 1980년 1월까지 6년간 진해만에서 식물성플랑크톤 개체군의 생태적 천이에 관하여 조사하였다.

1974년 9월～1975년 5월에는 천이계열이 *Skeletonema costatum-Eucampia zodiacus-Chaetoceros* spp. -*Nitzschia pungens- Leptocylindrus danicus*, 1976년 7월-1978년 5월 *Skeletonema costatum-Thalassiosira hyalina-Chaetoceros* spp. -*Leptocylindrus danicus*(*Nitzschia pungens*), 1978년 7월-1980년 1월 *Chaetoceros socialis-Skeletonema costatum-Chaetoceros* spp.-*Leptocylindrus danicus-Skeletonema costatum*(*Biddulphia mobiliensis*)으로 천이계열이 바뀌어가고 있으며 이들은 계절에 따라 수온의 변화와 밀접한 관계가 있었다. 최근에는 이 해역에서 *Skeletonema costatum*이 계절에 관계없이 대량출현하여 이 종에 의해 점점 성숙한 천이계열을 형성해 가고 있다.

INTRODUCTION

One of the most important phytoplankton populations in the sea is change. Since animals are directly dependent on the plants, any change in phytoplankton populations causes change in the animal groups. Temporal changes of phytoplankton diatom populations in the coastal area are sometimes slow or sometimes rapid; some are of small scale but persistent whereas others of considerable magnitude. Perhaps as a consequence of the numerical change there have been alternations in the structure of phytoplankton populations.

There are no observations on the succession of phytoplankton populations in the coastal area of Korea. The Jinhae Bay in southern coast of Korea is a semi-closed embayment which develop-es available shellfish farms and oyster beds. Recently, the waste water of the fertilizer plant and many industrial activities cause the eutrophication in the surveyed area (Lee *et al.*, 1974: Park, 1975). Yoo and Lee (1976) carried out anual cycle of phytoplankton community with relation to diversity index in Masan Bay. Yoo and Lee (1979) reported that phytoplankton standing corps were high in May, July and November; ranged from 10^6～10^7 cells/1 during phytoplankton bloom. Park (1979) studied on field bioassay test using four species of commercially important shellfish in order to assess the effect of pollutants and determine the extent of marine environmental pollution of the Masan Bay. Park (1980) also investigated the seasonal changes of population and species composition of phytoplankton during the period from 1972 to 1979. The ecological indication by means of community dynamics was investigated in the present study area (Yoo, 1980: Yoo and Lee, 1980).

The purpose of this investigation is to study the seasonal succession of phytoplankton populations with relation to temperature that have not been studied previously in the area.

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MATERIALS AND METHODS

Observations of phytoplankton communities were carried out monthly during the periods from September 1974 to May 1975 and bimonthly from July 1976 to January 1980 at six stations in the Jinhae Bay (Yoo and Lee, 1979: 1980).

Sampling and analysis of phytoplankton were obtained by authors(Yoo and Lee, 1979).

Water temperature was determined with reversing thermometer (The Hydrolab Model 6D Surveyor) on board.

The present study area is located between 35°03′07″N and 35°11′00″N in latitude, and 128°35′02″E and 128°42′01″E in longitude.The surroundings of the investigated area is adjacent to Masan City,Jinhae City and Changwon City. Recently, the circumferences of the studied bay were constructed with many factories as a coastal composed region. Accordingly, the growth of three cities and their industrial activities caused and effected to the eutrophication.

Water mass movements and the concentrations of heavy metals in sediments in the study area have been discussed by Lee *et al.* (1974). They reported that the water movements was a reversing tidal current type and the semidiurnal tidal current was predominant. Therefore the part of the Station 1 and 2 has not good water circulations. So that the phytoplankton standing crops and the species assemblages in three stations were different from other stations.

RESULTS AND DISCUSSIONS

1. Water temperature

Mean surface water temperature during the investigations was 15°C in the site area. The highest water temperature occurred in July 1978, 29.6°C and that of the lowest in January 1977, 1.3°C at surface layer. It showed change range of 28.3°C throughout all sampling stations.

Mean bottom water temperature during the observations period was 15°C in the study area. The highest water temperature occurred in July 1978, 27.2°C and that of the lowest in January 1977, 1.2°C at bottom layer. Bottom water temperature change was 26°C. Between surface and bottom, water temperature shows difference of 2.3°C. As a whole, vertical temperature profiles showed nearly homogeneous structure, but station 1 and 2 were well stratified. Thus, annual changes of water temperature throughtout the entire study area would imply more different vertical temperature profile than horizontal temperature profiles.

2. Occurrence of phytoplankton diatom species

During this study 106 taxa of phytoplankton diatoms, were identified which were composed of 37 genera, 102 species, 2 forma and 2 varieties (Table 1). Of these taxa, the number of species in surface was 36 genera, 91 species, 2 forma and 2 varieties, and in bottom 32 genera, 88 species, 2 forma and 2 varieties. Yoo and Lee (1976) observed 25 genera, 63 species in Masan Bay(Station 1, 2, 3 in this study area), and the total 84 taxa were found in the Jinhae Bay(Yoo and Lee, 1979). The number of taxa identified in this study was higher than the previous studies and it was suggested that the long-term investigations may be conducted in details.

The most significant species of this study were *Chaetoceros compressus, C. costatus, C. curvisetus,*

Table 1. Seasonal occurrence of phytoplankton diatom species in 1974~1980

Season / Species	spring	summer	autumn	winter	Season / Species	spring	summer	autumn	winter
Actinoptychus seranius	+ −	+ −	+ −	+ −	*C. lineatus*	−	+	+ −	+ −
Amphiprora gigantea var. *sulcata*	−		+ −		*C. marginatus*	+			
Amphora ovalis			−		*C. nitidus*	+ −	+	+	−
Asterionella gracialis	+ −	+ −	+ −	+ −	*C. perforatus*	+	+		
Asteromphalus heptactis	+ −	+ −	+ −	−	*C. radiatus*	+ −	+ −	+ −	+ −
Bacteriastrum delicatulum		+	+ −		*C. stellaris*			−	
B. hyalinum			+ −		*C. wailesii*	−			−
Bacillaria paxillifer	+	+ −	+ −	+ −	*Cylindrotheca closterium*	+ −	+ −	+ −	+ −
Biddulphia mobiliensis			+ −	−	*Ditylum brightwellii*	+ −	+ −	+ −	+ −
B. sinensis		+	+ −	+	*D. sol*	−		+ −	
Cerataulina bergonii			+ −		*Eucampia zodiacus*	+ −	+ −	+ −	+ −
Chaetoceros affinis	+ −	+ −	+ −	+ −	*Grammatophora angulosa*		−		
C. anastomosans			+		*Guinardia flaccida*	+ −	+ −	+ −	+ −
C. atlanticus	−	+ −	+ −	+ −	*Hemiaulus sinensis*	+ −	+ −	+ −	+ −
C. brevis		+	+		*Lauderia borealis*	+ −		+ −	+ −
C. compressus	+ −	+	+ −	+ −	*Leptocylindrus danicus*	+ −	+ −	+ −	+ −
C. constrictus	+ −	+ −	+ −	+ −	*Licmophora abbreviata*	+ −		−	−
C. costatus	+ −	+ −	+ −	+ −	*Melosira granulata*			+	
C. curvisetus	+ −	+ −	+ −	+ −	*Navicula distans*	+ −	+ −	+ −	+ −
C. danicus			+		*N. membranacea*	−		+	
C. debilis	+ −	+ −	+ −	+ −	*Nitzschia delicatissima*	+ −		+	+
C. decipiens	+ −	+ −	+ −	+ −	*N. longissima*	+ −		+ −	+ −
C. didymus	+ −	+ −	+ −	+ −	*N. pacifica*	+ −		+ −	+ −
C. difficialis		+			*N. pungens*	+ −	+ −	+ −	+ −
C. diversus			+		*N. seriata*	+ −	+ −	+ −	+ −
C. eibenii	−			+ −	*Paralia sulcata*	+ −	−	+ −	+ −
C. gracilis	+ −	+ −	+ −		*Pleurosigma elongatum*	+ −	+ −	+ −	+ −
C. laciniosus	+ −	+ −	+ −	−	*P. normanii*	+ −	+ −	+ −	+ −
C. lauderi	+				*Rhizosolonia alata*	+ −	+	+ −	+ −
C. lorenzianus	+ −		+ −	+ −	*R. alata* f. *indica*		−	+ −	
C. pelagicus	+ −		+ −	+	*R. calcar-avis*	+ −	−	+ −	
C. pendulus	+		+ −	+ −	*R. castracanei*				−
C. perpusillus		+			*R. cylindrus*	−			
C. peruvianus			+	+	*R. delicatula*	+ −	+ −	+ −	+ −
C. radicans	+ −		+	+	*R. fragilissima*	+ −	+ −	+ −	+ −
C. socialis	+ −	+ −	+ −	+ −	*R. hebetata* f. *semispina*	+ −	+ −	+ −	+ −
C. teres			−		*R. imbricata*	+ −	+ −	+ −	−
C. tortissimus			+		*R. robusta*	+ −	−	+ −	−
C. vanheurckii	+				*R. setigera*	+ −	+ −	+ −	+ −
Climacosphenia moniligera		−			*R. stolterfothii*	+ −	+ −	+ −	+ −
Corethron criophilum			+ −		*R. styliformis*	+ −	−	−	+ −
Coscinodiscus asteromphalus				+	*Schroederella delicatula*		+ −	+ −	−
C. centralis var. *pacifica*	+ −	+ −	+ −	+ −	*Skeletonema costatum*	+ −	+ −	+ −	+ −
C. concinnus	+ −	+ −	+ −	+ −	*Stephanopyxis palmeriana*	−		+ −	−
C. curvatulus			−		*S. turris*	+ −	−	+ −	
C. granii		+	+ −	−	*Streptotheca tamesis*			+ −	

Species \ Season	spring	summer	autumn	winter	Species \ Season	spring	summer	autumn	winter
Surirella fastuosa	−				*T. hyalina*	+ −	+ −	+ −	+ −
Thalassinema nitzschioides	+ −	+ −	+ −	+ −	*T. nordenskioeldii*			+	+ −
Thalassiosira aestivalis	+ −			−	*T. polychorda*	+ −	+	+ −	+ −
T. angstii	−		+ −	+	*T. rotula*	−	−	+ −	+ −
T. decipiens	+ −	+ −	+ −	+ −	*T. substilis*	+ −		+	+
T. exentrica	+ −	+	+	+ −	*Thalassiothrix frauenfeldii*	+ −	+ −	+ −	+ −
T. gravida	−	+			*Tropidoneis lepidoptera*			−	

*+; surface present, −; bottom present, blank is absent

C. debilis, *C. didymus*, *C. socialis*, *Eucampia zodiacus*, *Leptocylindrus danicus*, *Nitzschia pungens*, *N. seriata*, *Skeletonema costatum* and *Thalassiosira hyalina*.

The phytoplankton diatom species may be grouped into four associations based on seasonal distribution pattern (Table 2). Of the associations in Table 2, constant species which appeared through four seasons were, 19 genera, 33 species 1 forma and 1 varieties. These taxa may be thought as a representative species with relation to the abundance and/or dominance in this study area. Other divisions was thought of non-significant species in seasonal occurrence.

3. Variations of dominant species

Monthly variations; The principal diatoms which were responsible for the abundance and/or dominance on diatom communities are shown in Table 3. Of these diatom populations *Skeletonema costatum* appeared annually from July (except 1978) to the end of the year. At the same time, this population was delayed in occurrence till January 1978 and 1980. The major species which comes after *Skeletonema costatum* was *Thalassiosira hyalina* in January 1977 and March 1978.

Table 2. The flora grouped into four associations based on seasonal distribution pattern (Sep. 1974~Jan. 1980)

Division and month	Occurrence species
Constant (Jan.-Dec.)	*Actinoptychus seranius*, *Asterionella gracialis*, *Asteromphalus heptactis*, *Chaetoceros affinis*, *C. constrictus*, *C. costatus*, *C. curvisetus*, *C. debilis*, *C. decipiens*, *C. didymus*, *C. socialis*, *Coscinodiscus centralis* var. *pacifica*, *C. concinnus*, *C. radiatus*, *Cylindrotheca closterium*, *Ditylum brightwellii*, *Eucampia zodiacus*, *Guinardia flaccida*, *Hemiaulus sinensis*, *Leptocylindrus danicus*, *Navicula distans*, *Nitzschia pungens*, *N. seriata*,, *Pleurosigma elongatum*, *P. normanii*, *Rhizosolenia delicatula*, *R. fragilissima*, *R. hebetata* f. *semispina*, *R.setigera*, *R.stolterfothii*, *Skeletonema costatum*, *Thalassionma nitzschioides*, *Thalassiosira decipiens*, *T. hyalina*, *Thalassiothrix frauenfeldii*
Spring (Mar.-May)	*Chaetoceros lauderi*, *Coscinodiscus*, *marginatus* *Rhizosolenia cylindrus*, *Surirella fastuosa*
Summer (June-Aug.)	*Chaetoceros difficialis*, *C. perpusillus*, *C. vanheurckii*, *Climacosphenia moniligera*, *Grammatophora angulosa*
Autumn (Sept.-Nov.)	*Amphora ovalis*, *Chaetoceros anastomosans*, *C. danicus*, *C. diversus*, *C. teres*, *C. tortissimus*, *Corethron criophilum*, *Coscinodiscus curvatulus*, *Melosira granulata*, *Streptotheca tamesis*, *Tropidoneis lepidoptera*, *Bacteriastrum hyalinum*, *Cerataulina bergonii*
Winter (Dec.-Feb.)	*Coscinodiscus asteromphalus*, *C. stellaris*, *Rhizosolenia castracanei*

But *Eucampia zodiacus* and *Chaetoceros debilis* in January 1975 and 1979 were respectively predominant. In spring season *Leptocylindrus danicus, Nitzschia pungens, N. seriata, Chaetoceros compressus, C. costatus, C. curvisetus* appeared and comprised predominant part of total occurrence. Yoo and Lee (1979) indicated that the occurrence of *Skeletonema costatum* was dominant and *Leptocylindrus danicus* (Yoo and Lee,1976: Yoo and Lee, 1979) was recorded as predominant diatom in the study area. Park (1980) reported that dominant phytoplakton species were *Skeletonema costatum, Chaetoceros curvisetus, C. affinis, Nitzschia seriata, Leptocylindrus danicus, Eucampia zodiacus, C. compressus* etc..

Seasonal variations; The seasonal variations of phytoplankton diatoms were nearly observed similar to the number of occurrence species except autumn. But seasonal distribution of dominant species differed from the other seasons.

Spring (March 1975-May 1980)

73 species, 1 forma and 2 varieties representing 26 genera were taken in the present survey. There was a tendency of an increase of the populations; *Nitzschia pungens, Leptocylindrus danicus, Chaetoceros costatus, C. curvisetus, Thalassiosira hyalina.* Among these species, the optimal temperature range of *Thalassiosira hyalina* was from 1.2 to 8.1 °C, when it was observed in January and March.

Smayda (1958) discussed the biogeographical distribution of phytoplankon, particularly diatoms, that *Thalassiosira hialina* is stenothermal; although it shows a temprature range from -1.35° C to 9.0ₒC, it apparently does not grow actively at temperatures exceeding 5°C.

In April and May 1975, *Leptocylindrus danicus* comprised 73.73%~90.05% of phytoplankton standing crops and its optimal temperature range was 14.9°C(bottom) ~17.4°C(surface). Brunel (1962) reported that *Leptocylindrus danicus* was neritic species, meroplankton, monoacmic and eurythemal; optimal temperature was 8.2°C. Yoo and Lee(1976) commented this species with relation to salinity and standing crops.

Summer (June 1976-August 1979)

In summer samples, 65 taxa of diatoms belonging to 27 genera, 62 species, 2 forma and 1 variety were observed. There was an obvious dominant species, *Skeletonema costatum* and in July 1978 *Chaetoceros socialis* appeared as a dominant species instead of *Skeletonema costatum. Skeletonema costatum* was also dominant species of this season, and then its occurrence percentage ranged from 29.20%(July 1977) to 91.54%(July 1976). Yoo (1974) observed that *Chaetoceros socialis* and *Skeletonema costatum, Chaetoceros* spp. constituted about 80-90% of the total phytoplankton standing crops.

Autumn (September 1974-November 1979)

A total of 89 taxa,representing 34 genera, 85 species, 2 forma and 2 varieties of phytoplankton diatoms were identified in this season. Throughout the periods studied, this value was richer than any other season. Among 89 taxa, *Skeletonema costatum* was overwhemingly the principal species; ranging from 22.14% (November 1974) to 95.89%(September 1978) of total diatom standing crops. According to Choe(1969), *Skeletonema costatum* occupied a great portion of 80.5% in September 1966 in the Suyung Bay of Busan.

One of the interesting things was the appearance of *Streptotheca tamesis* which was distributed in the south-west coastal waters of Korea. This taxa was known to be occurred in the Kwang Yang Bay(Choe, 1970:Yoo *et al*,, 1974), the Masan Bay (Yoo and Lee, 1979) and also in the Kema-Ri of west coastal water (Yoo and Lee, unpublished data).

Surprisingly an unexpected appearance of *Biddulphia mobiliensis* was observed as a dominant species (surface:56.17%, bottom:62.87%) of total standing crops in November 1979. There is a species which forms resting spores and these sink into the deeper waters or to the bottom where they remain until suitable conditions return and so ensure the „re-seeding" (meroplankton diatom species) (Bougis, 1976).

Winter (December 1974-January 1980)

73 taxa of phytoplankton diatoms belonging to 26 genera, 71 species, 1 forma and 1 variety were observed in this season. In winter samples, ***Skeletonema costatum*** was still the most abundant species except January, February 1975 and January 1979. ***Eucampia zodiacus*** was once a dominant species more than 85% of occurrence in January 1975. The occurrence of ***Skeletonema costatum*** was delayed to winter and substituted for ***Thalassiosira hyalina*** in January 1977 and March 1978; ranging from 31.90% to 50.67% of phytoplankton standing crops. In January 1980, ***Skeletonema costatum*** was ranged from 372,220 cells/1 (St. 4) to 7,166,234 cells/1 (St. 1) in surface samples. Smayda (1973) and Hitchcock and Smayda (1977) investigated the growth of ***Skeletonema costatum*** during the winter-spring bloom in Narragansett Bay. In this season, ***Chaetoceros compressus*** and ***C. debilis*** were composed of the following major species.

4. Succession of phytoplankton diatom populations

Odum (1969) viewed that ecological succession may be defined by three parameters. One of three parameters, succession is an orderly process of community development that is seasonally directional and, therefore, predictable. To give consideration to this view, the phytoplankton of the present study area was composed of series of dominant species which succeed one after another during the seasons. The order of this succession (chiefly ***Skeletonema costatum-Eucampia zodiacus-Thalas-***

Table 3. Seasonal occurrence of dominant species in the Jinhae Bay (S: surface, B: bottom).

Month	Layer	Species	Occurrence (%)
Sep. 1974	S	*Skeletonema costatum*	35.91
	B	*Skeletonema costatum*	64.03
Oct.	S	*Skeletonema costatum*	56.47
	B	*Skeletonema costatum*	55.36
Nov.	S	*Skeletonema costatum*	24.49
	B	*Skeletonema costatum*	22.14
Dec.	S	*Skeletonema costatum*	33.59
	B	*Skeletonema costatum*	39.16
Jan. 1975	S	*Eucampia zodiacus*	86.27
	B	*Eucampia zodiacus*	88.25
Feb.	S	*Chaetoceros compressus*	30.69
	B	*Chaetoceros debilis*	28.06
Mar.	S	*Nitzschia pungens*	77.04
	B	*Nitzschia pungens*	67.52
Apr.	S	*Leptocylindrus danicus*	73.72
	B	*Leptocylindrus denicus*	82.16
May	S	*Leptocylindrus danicus*	90.05
	B	*Leptocylindrus danicus*	85.91
July 1976	S	*Skeletonema costatum*	91.54
	B	*Skeletonema costatum*	89.67
Sep.	S	*Skeletonema costatum*	64.79
	B	*Skeletonema costatum*	86.51
Nov.	S	*Skeletonema costatum*	35.75
	B	*Skeletonema costatum*	45.15
Jan. 1977	S	*Thalassiosira hyalina*	50.67
	B	*Thalassiosira hyalina*	36.19
Mar.	S	*Chaetoceros curvisetus*	22.50
	B	*Chaetoceros costatus*	52.04
May	S	*Leptocylindrus danicus*	88.68
	B	*Leptocylindrus danicus*	58.10
July	S	*Skeletonema costatum*	29.20
	B	*Skeletonema costatum*	32.22
Sep.	S	*Skeletonema costatum*	53.82
	B	*Skeletonema costatum*	50.19
Nov.	S	*Skeletonema costatum*	53.73
	B	*Skeletonema costatum*	57.94
Jan. 1978	S	*Skeletonema costatum*	25.04
	B	*Skeletonema costatum*	53.19
Mar.	S	*Thalassiosira hyalina*	41.92
	B	*Thalassiosira hyalina*	31.90
May	S	*Nitzschia pungens*	34.42
	B	*Nitzschia seriata*	22.64
July	S	*Chaetoceros socialis*	84.00
	B	*Chaetoceros socialis*	71.60
Sep.	S	*Skeletonema costatum*	95.89

Month	Layer	Species	Occurence (%)
	B	*Skeletonema costatum*	87.66
Nov.	S	*Skeletonema costatum*	70.79
	B	*Skeletonema costatum*	67.06
Jan. 1979	S	*Chaetoceros debilis*	35.76
	B	*Chaetoceros debilis*	20.10
Mar.	S	*Chaetoceros compressus*	48.68
	B	*Chaetoceros compressus*	40.77
May	S	*Chaetoceros didymus*	38.61
	B	*Leptocylindrus danicus*	20.03
July	S	*Skeletonema costatum*	54.01
	B	*Skeletonema costatum*	46.89
Sep.	S	*Cylindrotheca closterium*	51.20
	B	*Skeletonema costatum*	63.00
Nov.	S	*Biddulphia mobiliensis*	56.19
	B	*Biddulphia mobiliensis*	62.87
Jan. 1980	S	*Skeletonema costatum*	82.37
	B	*Skeletonema costatum*	77.78

siosira hyalina-Chaetoceros debilis-Nitzschia pungens-N. seriata-Leptocylindrus danicus-Chaetoceros debilis-Skeletonema costatum-Biddulphia mobiliensis)was gradually changing in the investigated period (Table 3). Hulburt(1964) reported that a succession of dominant diatom species coincided with changes in hydrography. In recent years, the succession of phytoplankton diatoms has been approached from a point of view of nutrient salts. Stockner *et al.* (1967) stated that the succession of diatom assemblages in the recent sediments changed in proportion in accordance with their ascribed trophic behavior.

Phosphate limitation is implied as a chief factor limiting primary production with relation to phytoplakton succession (Stockner *et al.*, 1975). Butler *et al.* (1979) also pointed out that regulation of phytoplankton productivity and succession in the sea was due to the dissolved organic nitrogen. Succession of species is related not only to interaction between a plant cell and its environment, but to interactions between species (Raymont, 1980). Yoo and Lee(1980) reported that environmental factor influencing on the phytoplankton standing crops was PO_4-P, chlorophyll-a, temperature, transparency as the significant factors. Judging from the succession of the standing crops and the dominant species of the phytoplankton diatom populations, ecological succession of the Jinhae Bay seems to be caused by various nutrient salts and complex physico-chemical factors as eutrophication progresses.

The dominant species dynamics was dependant upon water temperature and season, but ***Skeletonema costatum*** which was superior to other phytoplankton populations was gradually succeeding to the whole months without the influence of water temperature.

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