The Journal of the Oceanological Society of Korea
Vol. 21, No. 3, p. 156−170, September 1986.

The Ecological Study of Phytoplankton in Kyeonggi Bay, Yellow Sea. III. Phytoplankton Composition, Standing Crops, Tychopelagic Plankton.

*Joong Ki Choi and Jae Hyung Shim**

Department of oceanography, Inha University, Incheon 160, Korea
*Department of oceanography, Seoul National University, Seoul 151, Korea

西海 京畿湾 植物플랑크톤에 대한 生態学的 研究
Ⅲ. 植物플랑크톤 種조성, 現存量, 일시浮游플랑크톤

崔仲基 · 沈載亨*
仁荷大 海洋学科　*서울大 海洋学科

Abstract

The phytoplankton ecology of estuarine waters was investigated in the Kyeonggi Bay from May 1981 to September 1982 on monthly basis. In this study area, a total of 228 phytoplankton species was identified. Among these taxa, the most dominant species are diatoms in this area.

Tychopelagic plankton occupies 40.4 % of total species. The percentage of tychopelagic plankton density ranged from 10.2% in September to 92.7% in March of monthly standing crops. From late autumn to early spring, the percentage values are more than 72%. They play an important role from late autumn to early spring in this estuarine plankton community.

These tychopelagic planktons are induced from benthic diatoms. Because the bottom shear stresses generated by the tides and winds are stronger than the adhesive and tractive force of benthic diatoms, most of benthic diatoms must be resuspended into tychopelagic suspensions during autumn and winter.

Paralia sulcata is the most important tychopelagic plankton as an indicator species of water mixing in the eastern coastal area of Yellow Sea. This species seems to have even broader tolerence to the environmental stress than *Skeletonema costatum*, and tends to fill the gaps in winter, when the phytoplankton is relatively unsuccessful. *Skeletonema costatum* and *Chaetoceros debilis* are dominant in other seasons.

Typical blooms of phytoplankton occur in spring and early autumn, The first bloom is started by *Skeletonema costatum* in early May, second peak is formed by various diatom population in September.

요약 : 경기만 식물플랑크톤의 조성과 분포, 생태특성에 관한 조사가 1981년 5월부터 1982년 9월까지 총 20회에 걸쳐 행하여 졌다.

채집된 식물플랑크톤은 총 228종으로 규조류가 대부분이었고 그외에 쌍편모조류, 규질편모류, 녹조류, 남조류등이 다양하게 출현하였다. 이중 92종이 저서성 규조류로 일시 부유하여 식물플랑크톤으로 나타났다. 이들 일시 부유규조류는 출현종 수에서 뿐만 아니라 식물플랑크톤 현존량에서도 늦가을부터 초봄까지 72% 이상의 높은 출현상태를 보여 식물플랑크톤 군집내에서 큰 비중을 차지하였다.

이들 일시부유플랑크톤이 겨울철에 높은 출현상태를 보인 것은 저서성 부착 규조류가 동계의 강한 북서 계절풍에 의해 형성된 전단응력에 의해 수층으로 일시적으로 부유되고 또한 동계의 강한 수괴혼합에 의하여 상층으로 유입되었기 때문이다.

이들 일시부유플랑크톤중 가장 우점하는 종은 *Paralia sulcata*로 서해 연안역의 수괴 혼합정도를 지표할 수 있는 종이다. 이종은 동계에 가장 우점하고 하계에 낮은 출현상태를 보여 수괴의 안정도와 높은 역상관관계를 보인다. 경기만내 수괴가 안정되어 환경조건이 좋은 춘하추계에는

*Skeletonema costatum*등 부유종이 많이 나타나나 환경이 나쁜 겨울에는 내성이 강한 저서종들이 많이 나타난다.

현존량의 변화는 봄과 가을에 대증식이 뚜렷이 나타나 춘계 대증식은 주로 *Skeletonema costatum*에 의해 주도되고 가을철 증가는 수괴의 안정에 의해 다양한 종들에 의해 일어난다.

INTRODUCTION

In estuarine ecosystems, numerous physico-chemical and biological factors may be responsible for phytoplankton distribution. Estuarine water circulation and mixing are most often cited as the controlling factors on distribrtion of phytoplankton (Roff *et al.*, 1980). Bv these continuous movements of water and the inputs of river discharge and polluted waste water, planktonic populations in estuaries are complicated. Estuarine phytoplanktons could be derived from three components; autochthonous populations, temporary autochthonous populations and allochthonous populations which are introduced from fresh water or the open sea (Perkins, 1974).

There are also many tychopelagic species in estuaries which live in the plankton or on the bottom with equal facility. Benthic or littoral diatoms do appear in the plankton, particularly when strong turbulence created by tidal currents puts them into suspension. These algae occasionally are resuspended by wind driven vertical mixing and winter turbulence. By these processes phytoplankton community could be diversed in winter season. Thus benthic diatoms play an important role as tychopelagic plankton assemblages. However, little is known regarding the tychopelagic mechanisms of benthic diatoms.

The physico-chemical complexities of the estuarine environment determine characteristic species composition, distribution and complex ecological patterns in the plankton community structure (Grindley, 1981). In the previous studies, to clarify the influence of environmental factors on the phytoplankton community in Kyeonggi Bay, the hydrological and light conditions were studied (Choi and Shim, 1986 *a*, *b*).

About the study of marine phytoplankton in the Kyeonggi Bay, Kurashige (1944) reported the seasonal fluctuations of the planktonic diatoms of the Kyeonggi coastal areas for the first time. After that time, there are many studies on the phytoplankton in Kyeonggi Bay (Choi, 1965; Chung *et al.*, 1969, 1971; Chung, 1969; Chung and Lee 1977; Yoo, 1982; Choi, 1982; Shim and Cho, 1984). Chung and Lee (1977) studied phytoplankton standing crops in Incheon Dock, Yoo (1982) also investigated phytoplankton and benthic algae, considering correlation with environmental factors in Incheon Dock. Shim and Cho (1984) studied benthic diatoms on the intertidal zone in the vicinity of Incheon Harbour.

As mentioned above, many studies were carried out on the distribution and abundance of phytoplankton and benthic diatoms. Most of these studies, however, are limited only to one season or artificial environment. This study lay emphasis on (1) phytoplankton composition, distribution, standing crops, (2) the role of littoral diatom as tychopelagic plankton, (3) the tychopelagic mechanism of littoral diatom, to clarify the phytoplankton ecology of Kyeonggi Bay over all season.

MATERIALS AND METHODS

Samples in this study area were collected from two surveys for each purpose. The first survey was carried out monthly during the periods from October 1981 to September 1982 at seven stations in the Incheon Bay and the second was carried out 9 times during the periods from May 1981 to April 1982 at five stations located in major tidal channels of the Kyeonggi Bay (Choi and Shim, 1986 a).

The qualitative samples of phytoplankton were collected by the vertical towing of Kitahara type plankton net with size of NXX. 25 (58μm) made of synthetic nylon. Identification of phytoplankton was followed by author's preceding method (Choi, 1982).

Phytoplankton samples for standing stock determinations were collected with Van-Dorn water sampler. 1*l*-polyetylene bottles were used for the sampler and samples were preserved with Lugol's solution. Following McAlice's treatment (1971), Sedgwick-Rafter chamber was used to determine phytoplankton standing crops.

RESULTS AND DISCUSSION

1. Phytoplankton composition and distribution

1.1 Composition

A total of 228 phytoplankters was identified in this study. Taxa included 178 species and 3 varieties of diatoms, 4 species and one variety of silicoflagellates, 29 species and 2 varieties of dinoflagellates, and 11 blue green algae and green algae.

Among these taxa, 31 diatoms, 13 dinoflagellates, 1 silicoflagellate, and 1 green alga are reported for the first time from this area. Among them, 7 diatoms, 3 dinoflagellates and 1 species of silicoflagellate are new records for the Korean coastal waters.

These newly recorded species are *Craspedodiscus moelleri, Cocconeis sublittoralis, Didymosphenia geminata, Navicula pusilla, Pinnularia ambigua, Tropidoneis vanheurckii, Surirella armoricana, Dinobryon sertularia, Protoperidinium pyriforme, Diplosalopsis orbicularis, Gonyaulax catennela.*

Total numbers of taxa were relatively larger than that reported by Chung *et al.* (1971) and Yoo(1982).The reason is that their studies were carried out during only one season or limited in artificial dock. By this time, total phytoplankters collected in Kyeonggi Bay, excluding Incheon Dock, were 293 taxa.

These phytoplankton could be divided into 7 groups with habitat characteristics by many references (Hustedt, 1927-1966; Hendey, 1964; Kokubo, 1955; Shim, 1977); 113 neritic species, 18 brackish species, 12 fresh-brackish species, 17 fresh species, 21 neritic-brackish species, 16 oceanic species and 31 oceanic-neritic species. Oceanic and oceanic-neritic species showed relatively high occurrences. This means that, although this study area is an estuary, the circulations with offshore waters are more frequently.

The low occurrence of brackish species indicates that most of proper brackish species could not be adapted in the large environmental fluctuations. Freshwater species occurred at all stations. However, most of them occurred mainly in the upper part of the bay. Freshwater species are relatively frequent at stations A, B, 6, 5 and 3 (Fig. 1). This means that freshwater discharges from Han River distinctively influence on the distribution of water masses to station B area. From station B area toward the outer bay, the number of freshwater species markedly reduce, while the

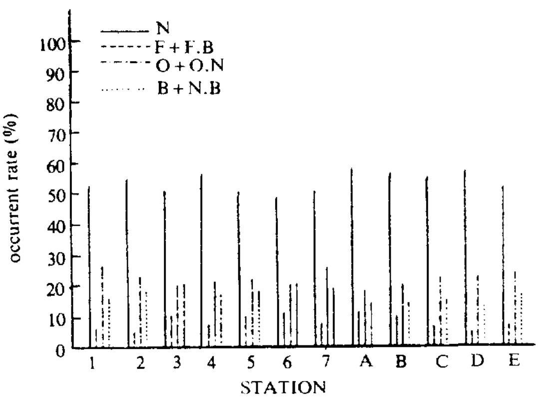

Fig. 1. The percentage variation of the composition of 4 main forms.
N: neritic, O: oceanic, O.N: oceanic and neritic, B: brackish, N.B: neritic and brackish, F: fresh, F.B: fresh and brackish.

oceanic and oceanic-neritic species increase toward the mouth of bay.

Brackish species show relatively homogeneous distribution excepting at station 4. The low occurrence of brackish species at station 4 seems to the fact that water masses at station 4 are extremely polluted (Choi and Shim, 1986 *a*). The number of neritic species decrease toward the outer part of the bay.

The monthly distribution of these groups are distinctively varied with seasons (Fig. 2). The percentages of oceanic and oceanic-neritic species varied greatly with seasons. In winter, oceanic species decrease considerably, however, from July, these groups increase to a maximum in September. During summer and autumn, high occurrence of these oceanic species may be due to the incursion of oceanic species from offshore water.

Most of these invading oceanic species are indicator species of Kuroshio Current (Motoda and Marumo, 1963). This indicates that a branch of Kuroshio Current runs northward in outside of the bay(Lee, *et al.*,1967; Choi, 1983), and that a part of this tributary could introduce into the bay in summer. The oceanic species which were observed in this study area mainly are *Chaetoceros borealis, Ch. convolutus, Ch. decipiens, Ch. decipiens* form. *singularis, Rhizosolenia styliformis, Thalassiosira punctigera, Protoperidinium brochii, P. depressum. Ceratium kofoidii,*

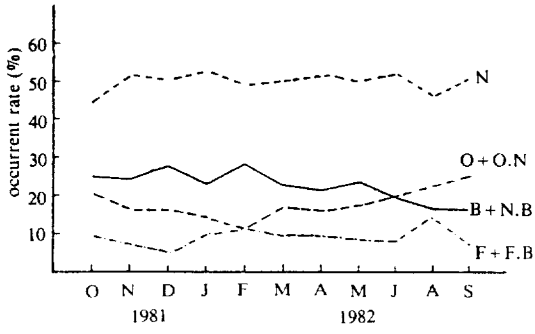

Fig. 2. Monthly variations of 4 main habitat forms. N: neritic, O: oceanic, O.N: oceanic and neritic, B: brackish, N.B: neritic and brackish, F: fresh, F.B: fresh and brackish.

Ceratium macroceros var. gallicum.

The number of freshwater species also varied with seasons. In winter, the occurrence of freshwater species are rare, being due to the small river discharge. However, after heavy rainy periods, these species increased rapidly to a maximum in August. Thus the distribution of invading species, both from freshwater and from offshore water show distinctive seasonal vairations. However, neritic species and brackish species occurred irregularly or showed less variations. Some organisms have become adapted to the environmental fluctuations in estuaries and represent a comparatively stable biotope, but this group does not contain a large variety of species (Caspers, 1967).

In estuaries, because of the periodic change in current direction, the plankton remains in the same water mass for a long period enough to develop populations of various species (Schulz, 1960). These assemblages consist not only of brackish water species but many other species able to resist the unstable conditions. Some of them develops and passes its whole life history in the estuary and is referred to as autochthonous organisms or native species (Riley, 1967; Perkins, 1974; Smayda, 1980; Grindley, 1981). Permanent or temporary autochthonous populations of marine diatoms play an important role particularly in the lower reaches of estuaries (Grindley, 1981). In this study area, autochthonous species occurred at all stations around the year are listed in Table 1.

1.2 Distribution

The number of total species occurred at each station ranged from 141 species to 167 species, with a mean of 152 species.

Average numbers of occurring species at each station in the second survey area are slightly more than that in the first survey area. In the first survey area, average numbers of species occurred at each sample are 39 species, being low distribution in compared with another coastal area. This means that first

Table 1. Autochthonous species occurred at all stations through the year in this study area.

Actinoptychus senarius	*Nitzschia spectabilis*
A. splendens	*Odontella mobiliensis*
Bacillaria paxillifer	*O. sinensis*
Campylosira cymbelliformis	*Paralia sulcata*
Chaetoceros affinis	*Pleurosigma angulatum*
Coscinodiscus asteromphalus	*P. elongatum*
C. kutzingii	*Rhaphoneis surirella*
C. radiatus	*Rhizosolenia setigera*
Cyclotella striata	*Skeletonema costatum*
Ditylum brightwellii	*Streptotheca thamesis*
Hyalodiscus stelliger	*Thalassiosira eccentrica*
Navicula salinarum	*Thalassiothrix frauenfeldii*
Nitzschia longissima	*Triceratium favus*
N. seriata	*Ceratium fusus*
N. sigma	*Dictyocha fibula*

survey area is stressed by environmental pollution.

In both survey areas, the monthly occurrence are high in summer to early autumn, and are low in late autumn to early spring, through winter. Such high occurrences in summer and early autumn may be due to the invasion of oceanic and freshwater species, and low occurrence in winter and early spring may be induced by the extreme fluctuation of environmental factors.

In the second survey area, the year round occurred forms are 32 species, ranging 28-43% of total phytoplankton. This means that relatively many species succeed with times and that seasonal fluctuations of species are relatively high.

The variations of diatom species ranged from 75.2% in August to 89.7% in March. Dinoflagellates variations ranged from 6.6% in February to 19.1% in July. Green algae, blue green algae and silicoflagellates show maximum occurrence in August. The percentage of diatom occurrence are high in winter and low in summer and early autumn. Dinoflagellates, blue green algae, green algae and silicoflagellates show high occurrence in summer and early autumn.

2. *Tychopelagic plankton.*

2.1 Distribution.

There are many extensive mud flats composed of mud or fine sands in this study area. Various benthic diatoms live on these mud flats (Shim and Cho, 1984). These benthic or littoral diatoms are mainly source of tychopelagic plankton.

In this study area, the occurring species can be divided into planktonic forms and tychopelagic forms. Tychopelagic forms identified are 92 species, 40.4% of total species, playing an important role in this ecosystem. Shim and Cho (1984) reported 99 benthic diatoms on the intertidal zone of Yeongjong island and Incheon Bridge area. At each station, tychopelagic plankton occurred are in the range of 55-61 species in the second survey area. The occurrences of tychopelagic plankton at the upper part of the bay are relatively more than that at the lower part. This may be due to the strong tidal current and the shallowness at the upper. In the first survey area, the occurrences of tychopelagic plankton are relatively less than that in the second area. This result may be due to the reduction of littoral species affected by water pollution as well as that at station B.

In the first survey area, the occurrence of tychopelagic plankton shows distinctive seasonal variation. The species occurred at each month varied from 26 species in April to 48 species in January. In general, the frequency of occurrence are low during spring and summer, and are high in winter.

The occurrence of tychopelagic species plays an important role from late autumn to late winter in this estuarine phytoplankton communities. However, annual variations in the composition of tychopelagic plankton are not great. This means that the compositions of benthic diatoms in this study area are relatively uniform. This result concurred well with that by Shim and Cho (1984).

The percentage of the density of tychopelagic plankton to total standing stocks are

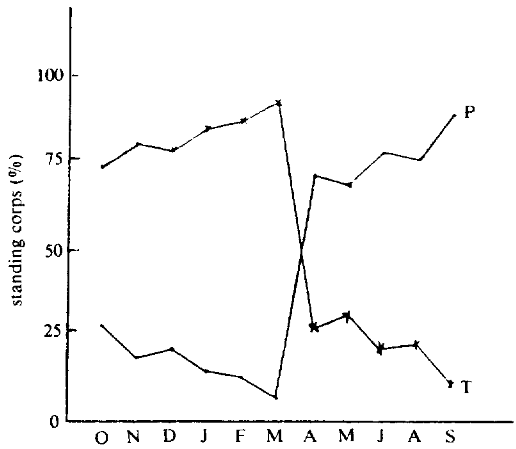

Fig. 3 Monthyl variations of percentage of tychopelagic plankton and planktonic standing crops.
P: planktonic form, T: tychopelagic form

shown in Fig. 3. In the first survey area, the density of tychopelagic plankton ranged from 6,930 cells/l at station 1 in September to 542,682 cells/l at station 1 in March (Table 2).

The percentages of tychopelagic plankton density show the distinctive seasonal variation (Fig. 3). In the first survey area, the percentage of tychopelagic plankton density ranged from 10.2% in September to 92.7% in March. From late autumn to early spring, the percentage values are more than 72%. From April, the percentage decreases rapidly to minimum in September. From spring to early autumn, the percentage values are less than 31%.

As a whole, the density of tychopelagic plankton are high from late autumn to early spring, and are low from spring to early autumn.

The horizontal distributions of tychopelagic plankton density are relatively homogeneous. However, densities at stations 4 and 6, which are shallow and have strong tidal currents, are relatively higher than those at another stations. In the vertical distribution of tychopelagic plankton, the densities increase toward the bottom (Table 3).

In this study area, the common tychopelagic species are as followings; *Actinocyclus ehrenbergii, Actinoptychus senarius, A. splendens, Amphora ovalis, Bacillaria paxillifer, Odontella aurita, O. sinensis, Cocconeis placentula, Coscinodiscus radiatus, Cyclotella striata, Diploneis interrupta, Gyrosigma spencerii, Hyalodiscus stelliger, Navicula distans, N. pusilla, N. salinarum, Nitzschia sigma, Paralia sulcata, Pleurosigma angulatum, Surirella ovata, Thalassiosira eccentrica, Triceratium favus.* Among these, *Paralia sulcata* is the most dominant species.

Thus the pelagic system in the Yellow Sea is characterized by many bottom living or benthic diatoms. In Chung *et al.*'s study (1971), benthic diatoms occurred in their study on the phytoplankton in Kyeonggi Bay are 32% of total species. In the phytoplankton community of Incheon Dock, the benthic forms occupy only 14% of total number of species (Chung and Lee, 1977). In Cheonsu Bay, 37 benthic species, 26% of total speices, are occurred (Shim and Lee, 1979). Kurashige (1943) reported that the densities of *Paralia sp.* were

Table 2. The distribution of tychopelagic plankton densities in the first survey area (cells/*l*)

	1981			1982							
Station	oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jul.	Aug.	Sep.
St. 1	48,180	209,920	146,250	299,460	309,056	542,682	36,143	167,240	39,480	53,613	6,930
St. 2	38,200	107,916	165,315	139,320	263,568	144,088	263,250	89,984	67,620	43,707	27,417
St. 3	83,763	95,062	47,600	239,010	117,120	130,314	188,811	196,882	21,168	40,404	26,190
St. 4	58,308	38,610	21,600	66,566	79,254	61,360	259,548	154,830	25,480	26,920	13,380
St. 5	123,280	166,056	93,240	199,584	320,814	111,948	417,162	157,366	16,372	18,690	14,721
St. 6	112,746	117,612	132,240	274,971	266,742	141,330	464,820	78,122	36,765	18,700	45,126
St. 7	90,152	155,411	178,100	282,370	158,456	161,020	243,006	108,800	42,016	12,257	11,010

Table 3. The vertical distribution of total standing crops of tychopelagic plankton in the second survey area during the sampling period

Unit: Cells and Percentage

Type	Station A			Station B			Station C		
	Surface	Middle	Bottom	Surface	Middle	Bottom	Surface	Middle	Bottom
Tychopelagic	1,241,539	1,068,580	1,737,583	1,316,141	2,223,905	1,851,959	690,721	1,983,097	2,087,127
(%)	(50.2)	(54.6)	(72.1)	(51.2)	(67.0)	(63.3)	(42.0)	(49.9)	(68.3)
Planktonic	1,230,311	888,673	673,637	1,255,147	1,093,064	1,072,505	952,784	1,989,589	968,975
(%)	(49.8)	(45.4)	(27.9)	(48.8)	(33.8)	(36.7)	(58.0)	(60.1)	(31.7)

Type	Station D			Station E		
	Surface	Middle	Bottom	Surface	Middle	Bottom
Tychopelagic	1,191,979	1,896,568	2,112,426	2,760,778	2,350,156	2,658,586
(%)	(44.3)	(65.7)	(78.4)	(85.3)	(67.2)	(82.4)
Planktonic	1,498,718	991,723	581,407	474,596	1,147,710	566,816
(%)	(55.7)	(34.3)	(21.6)	(14.7)	(32.8)	(17.6)

11-85% of total standing crops in Taeya island of the Yellow Sea. He (1944) also reported that the densities of *Paralia sp.* were 13-47% of total standing stocks in Incheon Harbor and 17-36% in Daedong River mouth. In Garolim Bay, the densities of benthic diatoms were 16-97% of total standing crops (KORDI, 1980). Thus, the composition and abundance of benthic species contribute greatly to the phytoplankton assemblages in the Yellow Sea.

2.2 Tychopelagic mechanism of benthic diatoms.

As mentined above, benthic diatoms are mainly source of tychopelagic plankton. These algae occasionally resuspended by wind or tide induced turbulence in shallow waters. Such turbulence is responsible for raising tychopelagic species into planktonic suspension (Perkins, 1974). Gallagher (1975) found that the surace film of water flooding is rich in pennate diatoms which is becoming tychopelagic plankton from benthic diatoms.

Harper and Harper (1967) carried out measurements of diatom adhesion and their relationship with movement. They found that resistance to shear stress in laminar flow through a capillary tube is particularly high in a large episamic species, e.g., *Amphora ovalis* and is related to strong adhesion.

Table 4 indicates that stationary diatoms often have higher values of adhesion than moving ones. Average ranges of adhesive and tractive forces for diatoms on a horizontal surface varied from 0.08 to 410 millidynes with maximum of 2,900 millidynes in *Diploneis ovalis*, an episamic species (Table 4).

In the middle of the Yellow Sea basin, the bottom shear stress induced from northwest wind during autumn and winter seasons, calculated by Kang and Choi (1984), are in the range of 0.1 to 1.0 dyne/cm^2. If we follow Harper's measurement on adhhsive and tractive force of benthic diatoms, most of benthic diatoms must be resuspended by the bottom shear stresses in the Yellow Sea basin.

The high correlation ($R = 0.793$) between tychopelagic plankton abundance and S.S. concentrations suggests that these two substances are resuspended simultaneously by the bottom shear stresses (Fig. 4). The bottom shear stresses by strong northwest winds in winter are enough to resuspend benthic diatoms into tychopelagic forms in the Kyeonggi Bay.

The low denstiy of tychopelagic plankton in summer and early autumn attribute to the two possible reasons. Such a sink in summer may be due to the decrease of the standing

Table 4. Ranges of adhesive and tractive forces for diatoms on a horizontal surface. Mean and standard deviation (S.D.) not given if number of readings (N) less than 7 (In Harpr and Harper, 1967)

		ADHESION (mdynes)					TRACTION (mdynes)				
Species	state	N	Max.	mean	Min.	S.D.	N	Max.	mean	Min.	S.D.
Diploneis ovalis	stationary	2	2900		1000		2	48			
Amphora ovalis	moving	3	480		230					48	
	stationary	11	630	410	140	170	4	7.3			
Surirella ovalis	moving									2.1	
	stationary	7	14	4.6	1.0	4.0	8	21			
Nitzschia	moving	16	6.6	1.9	0.36	2.0			1.1	0.05	0.94
linearis	stationary	12	12	4.3	0.1	3.4	24	0.57			
Navicula	moving	25	4.2	0.83	0.02	1.1			0.25	0.01	0.14
oblonga	stationary	21	6.8	2.0	0.24	1.7	2	2.2			
Cymatopleura	moving	2	4.8		0.23					0.25	
solea	stationary	9	4.5	0.91	0.02	1.4	20	1.9			
Nitzschia sigma	moving	24	9.3	1.3	0.02	2.0			0.08	0.01	0.08
	stationary	23	14	1.7	0.05	3.1					

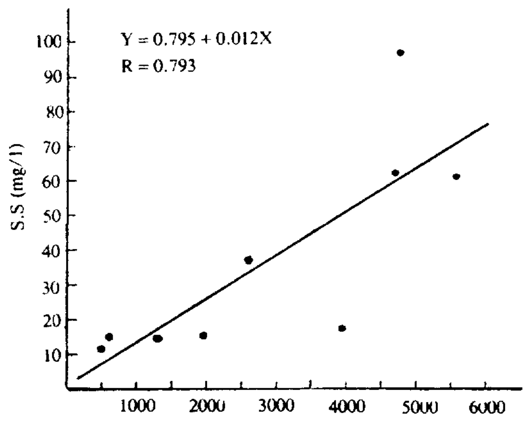

Fig. 4. Relation between the tychopelagic abundance and the concentration of S.S in the second survey area.

stocks of benthic diatoms during the summer (Shim and Cho, 1984). However, their results do not completely agree with the distribution of tychopelagic plankton densities. The standing stocks of benthic diatoms are minimum in June. But, the densities of tychopelagic plankton are minimum in August and September. Therefore another reason must be considered.

Their low densities may be due to the stability of water mass to prevent the resuspension of benthic diatoms. The resuspension of benthic diatoms from late autumn to early spring are maintained in phytoplankton community by the convectional mixing. However, in the advancing spring, the turbulence of water column decreases and light intensity increases. As a result, tychopelagic forms again sediment, and planktonic forms increase rapidly. In summer, weak stratified layers are formed vertically in the bay (Choi and Shim, 1986 a). Such a stratified layer prevents the resuspension of tychopelagic plankton.

3. Standing crops and dominant species

3.1 Standing crops.

Except Kurashige (1944) and Choi's (1982), little is known about the phytoplankton standing crops in Kyeonggi Bay. They reported that phytoplankton standing crops ranged from 1,860 cells/l to 25,780 cells/l, and from 93,690 cells/l to 588,676 cells/l, respectively.

In this study area, the standing crops of phytoplankton ranged from 16,234 cells/l at station E to 1,753,458 cells/l at station 4. The fluctuations of standing crops varied greatly with seasons and stations (Fig. 5). Typical two peaks of phytoplankton standing crops are occurred in spring and early autumn at stations

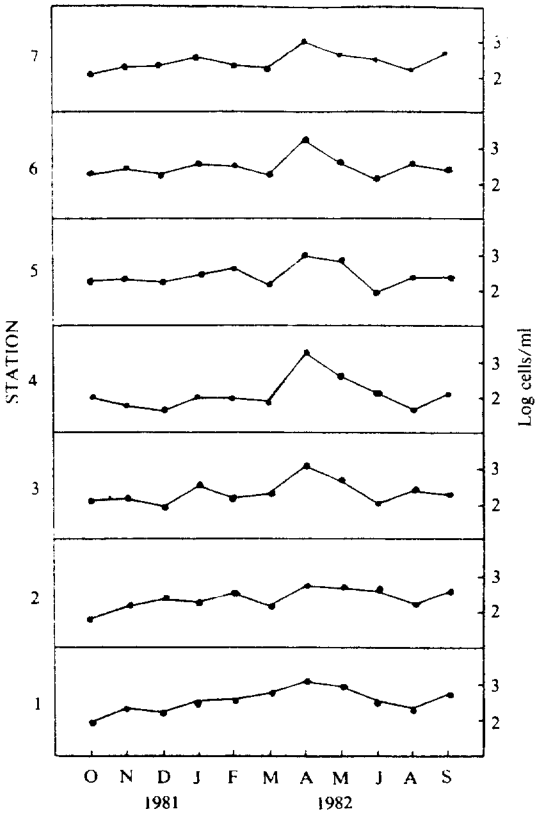

Fig. 5. Monthly variations of total standing crops in the first survey area.

1, 2 and 7, respectively. The general pattern of the annual cycle of the phytoplankton shows first increase in the standing crops in April and decrease in May, and then a second peak in early autumn. The autumn peak was lower than that of spring. From late autumn to early winter, phytoplankton standing crops are minimum. During the winter and early spring, the low standing crops are maintained. Such a low densities of phytoplankton may be due to the decrease of planktonic forms by unfavorable light condition. During winter season, though relatively low densities, considerable standing crops were maintained, ranging from 120,620 cells/1 to 457,000 cells/1. Such a winter population mainly consists of benthic diatoms which were resuspended by winter mixing into tychopelagic planktons. Tychopelagic plankton can photosynthesize at extremely low light intensities (Colijn and Van Buurt, 1975). Since October, tychopelagic populations begin to increase through winter to a maximum of 92.7% in March. From spring, however, tychopelagic populations decrease gradually to minimum with 10.2% in September. The seasonal variations of planktonic populations are inverse relationship with tychopelagic populations (Fig. 3).

In the vertical distribution of standing crops, from spring to early autumn, the surface population are more abundant than the bottom populations. However, from late autumn to early spring, bottom population are by far more abundant than the surface population. This may be due to the resuspension of benthic diatoms from bottom. Among neritic, oceanic, brackish water and freshwater forms, neritic forms are dominant, exceeding 80% at all stations. The percentage of oceanic forms ranged from 3.8% to 6.3%, brackish water forms are 3.2-8.3%, and the percentage of freshwater forms ranged from 0.21% to 2.5%

Seasonal variations of neritic and oceanic forms are distinct (Fig. 6). Neritic populations decrease from summer to early winter and increase from winter to spring. Oceanic population increase from August to a maximum of 12.6% in October and decrease gradually to 5.2% in February. The high percentage of oceanic populations in late Summer and

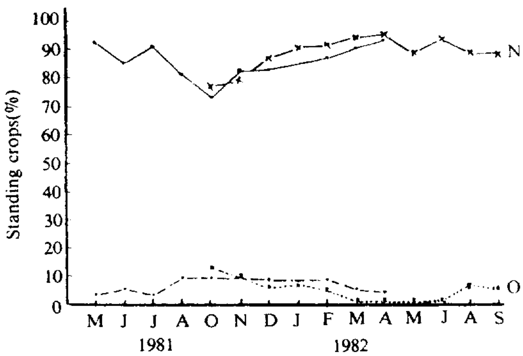

Fig. 6. Monthly variations of the percentage of neritic form (N) and oceanic form (O).

autumn may be brought by the incursion of offshore water from the outer bay.

3.2 Blooming and Red tide.

The phytoplankton community is characterized by two diatom blooms. The first bloom occurs in late April and early May. Especially, at station 4 which is receiving more environmental stress from industrial complex, the standing crops occurred in tremendous quantities, over one million cells. This means that these spring blooms are positively correlated with nutrients or another pollution materials.

Among many species, *Skeletonema costatum* is the predominant species by number. During bloom period, *Skeletonema costatum* densities ranged from 549,180 cells/l to 1339,596 cells/l. *Paralia sulcata* also attained large populations, ranging from 135,344 cells/l to 477,012 cells/l. Although their densities are less than 10% of total populations, three other species, *Chaetoceros debilis, Nitzschia acicularis, Thalassiosira* sp. also attained considerable populations. In spring bloom, a few common species lead to the dominance.

Autumn blooms occurred in 1982 were correlated with nutrient concentration and the stability of water mass. After summer rainy period, estuarine water masses were relatively fertilized by the input of nutrients from land (Choi and Shim, 1986*a*). And favourable physical conditions with optimum light intensity were formed by thermal stability (Choi and Shim, 1986*b*). Therefore, autumn blooms are characterized by the occurrence of various planktonic species, being due to the physical and chemical favourable conditions. Dominant species consist of *Chaetoceros debilis, Ch. compressus, Ch. decipiens, Ch. danicus, Asterionella glacialis, Ditylum brightwellii, Nitzschia seriata, Skeletonema costatum., Rhizosolenia stolterfothii* and *Thalassiosira rotula.*

In autumn blooms, *Paralia sulcata* was shown low densities. This may be due to the thermal stability preventing from the resuspension of *Paralia sulcata.*

The supplementary sampling was performed in July 1984 and red tide was observed for the first time in the study area. Not only are red tide organisms liable to cause widespread discoloration of the sea but they may produce notable secondary effects. In this study area, yellowish discoloration by *Skeletonema costatum* has been occurred in spring occasionally. However, reddish waters were firstly observed at this time. This red tide was produced by the dinoflagellate *Noctiluca scintillans* after summer diatom bloom in July.

The discoloration was due to extremely high concentrations of the *Noctiluca scintillans,* ranging from 120,000 cells/l to 250,000 cells/l, closely packed together in a dense layer only a several centimeters thick on the surface of the water. Their length extended several hundred meters and widths were in 20-30 meters. This red tide was limited from Yeongheung Island to Incheon harbor, more densities in Banwol area, Wolmi area and station 4 area. This red tide happened rapidly during the neap tide, in 24 July 1984, and disappeared in spring tide. This may be due to the high concentrations of nutrients and rapid decrease in salinity after heavy precipitations, and exceptional high transparency with a mean of 4.5 meters, induced by water stabilities during neap tide.

4. Indicator species and Dominant species.

4.1 Indicator species

Since water pollution is in many instances a biological phenomenon, it would appear logical that it ought to be measured biologically. Biological indicators show the degree of ecological unbalance that has been caused, and chemical methods measure the concentration of pollutant responsible (James, 1979). It is important to see these not as alternative but as complementary methods of assessment. Algae as indicators of water quality have been studied by many investigators (Palmer, 1977; Maestrini *et al.*, 1984).

In this study area, only a few species were limited to more eutrophicated area; at station 3,4 and 6. These species included *Lingbya contorta, Gyrosigma fasciola, Melosira islandica, Oscillatoria tenuis, Scenedesmus dimorphus.* Among these species, *Lingbya contorta* mainly occurred at Station 4. According to Palmer (1977), *Scenedesmus dimorphus* is a sewage alga. Therefore, in this study area, two species, *Lingbya contorta* and *Scenedesmus dimorphus,* may be identified as indicator species of water quality.

Plankton species are useful for indicators of particular water masses and of their movements. In this study area, the occurrence of oceanic species started from July, reached a maximum in September and October and disappeared at the end of winter.

The incursions of oceanic waters were suggested by Kuroshio indicator species (Lee et al., 1967) and oceanic species as mentioned previously. Among these, *Chaetoceros convolutus, Rhizosolenia styliformis, Ceratium kofoidii, C. macroceros, var. gallicum* can be characterized as oceanic indicator species. *Rhizosolenia styliformis* is stenohaline and tolerate high salinity (Perkins, 1974). Their main habitat is doubtless the oceanic waters, but they occur also in coastal waters, apparently in connection with a recent introduction from offshore (Braarud, 1962). *Rhizosolenia styliformis* may be true oceanic species in North Sea (Robinson and Waller, 1966). *Chaetoceros convolutus* are also oceanic species (Kokubo, 1955; Hendey, 1964). *Ceratium kofoidii* is warm species and Kuroshio indicator species (Yamaji, 1980). *Ceratium macroceros var. gallicum* is oceanic cold water species (Ohwada and Asaoka, 1963).

As mentioned previously, tychopelagic planktons are useful as an indicator of water mixing. Because benthic diatoms are resuspended by tide and wind induced water mixing into tychopelagic plankton, the amounts of tychopelagic plankton point the degree of water mixing. In this study area, there are many tychopelagic species. Among these, *Actinoptychus senarius, A. splendens, Cyclotella striata, Hyalodiscus stelliger, Navicula pusilla, Paralia sulcata, Pleurosigma angulatum, Surirella ovata* and *Triceratium favus* are dominant in winter mixing and poor in summer stability. Especially, *Paralia sulcata* is predominant species from late autumn to early spring in all eastern coastal area of Yellow Sea (Kurashige, 1943, 1944, KORDI, 1980). *Paralia sulcata* is common benthic species on the surface of bottom sediment all the year around (Shim and Cho, 1984). Dominance as tychopelagic plankton in winter means that *Paralia sulcata* is liable to be resuspended by winter mixing. Therefore, *Paralia sulcata* is the most important species as an indicator of water mixing in the Yellow Sea.

4.2 Dominant species.

Over the whole year, many species appear in estuaries but most of them are in small numbers. Very few species are always common. Any criterion of dominance that is chosen will be somewhat arbitrary; the present one merely indicates that the species are well enough suited to the environment to be significant in normal patterns of seasonal succession, rather than stays which achieve some degree of success on rare occassions (Riley, 1967).

In this study area, the author defined dominant species as one consisting more than 5% of the population during particular month, for at least 10% of total samples. As a result, the list will be reduced to 10 species, which are shown in Fig. 7. The small vertical lines below the base line indicate the number of stations

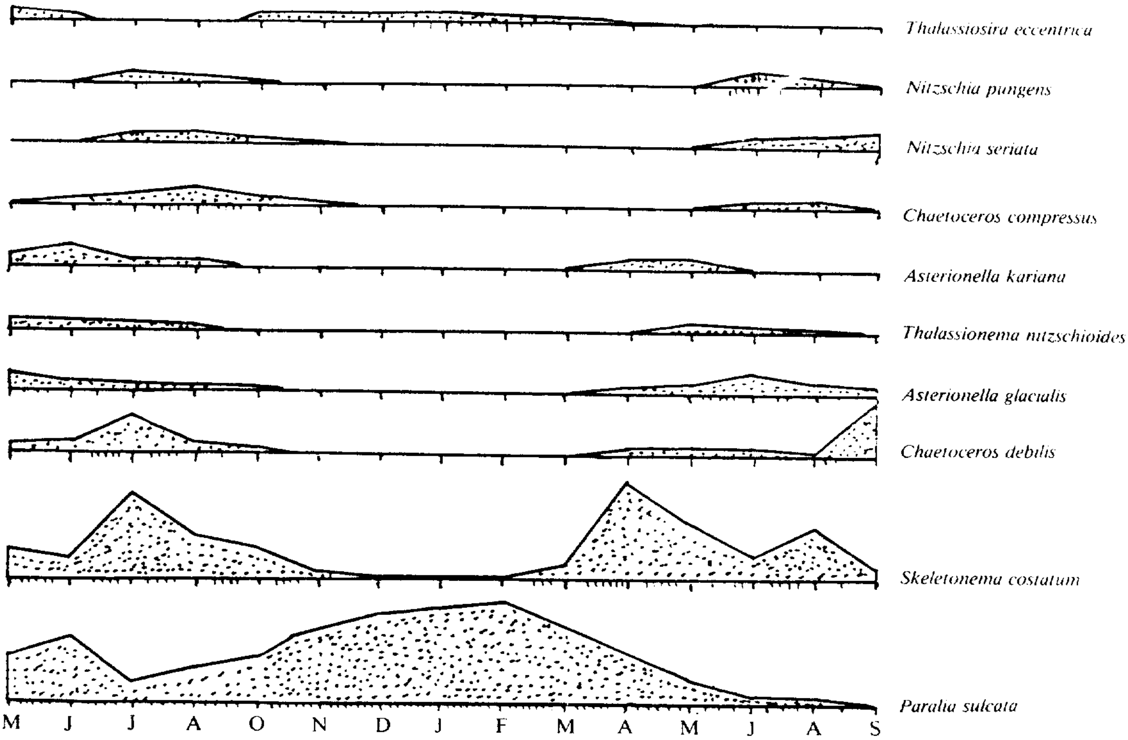

Fig. 7. Seasonal occurrence and degree of dominance of the dominant species.

that the relative concentration exceed five percent during any given month.

Among dominant species, *Paralia sulcata* is predominant from October to March, with average values of 67.1% of total populations. The densities of *Paralia sulcata* ranged from 3,345 cells/l in September at Station 4 to 541,620 cells/l in March at Station 1, the average dominant values ranged from 3.9% in September to 79.6% in January. In winter season, their cell concentrations did not increase makedly, but the percentages rose because other species declined. *Paralia sulcata* as a benthic diatom tolerates at low light intensity, low temperature, low salinity, high hydrogen ion concentration and shows no distinctive seasonal variations except an increase in April and May (Shim and Cho, 1984). However, in this study area, *Paralia sulcata* as a tychopelagic plankton showed a distinctive seasonal variations; low densities in summer and high densities in winter. This could be closely related to the water mixing induced by winds and tidal action discussed before.

As mentioned above, *Paralia sulcata* is dominant species in all eastern coastal area of Yellow Sea during winter and early spring. *Paralia sulcata* seem to have even broader tolerence to changing physical conditions than *Skeletonema costatum* (Riley, 1967), and tended to fill the gaps when the planktonic forms were relatively unsuccessful.

Skeletonema costatum was predominant from April to October contrasting with *Paralia sulcata*. This species prompts to grow rapidly from April and reaches the first bloom in late April, with a maximum of 1,339 , 596 cells/l at station 4, 80.5% of total population. Since the first bloom, the densities declined gradually to about 10,000 cells/l in June, but again increased to form small second blooms in July or maintained relatively high density till October, and disappeared in the beginning of winter mixings. As a rule, during the stability of water mass, *Skeletonema costatum* shows dominance in contrast with *Paralia sulcata. Skeletonema costatum* is one of the best adapted and most successful diatcm in estuaries in many parts of the world.

The density distribution of *Chaetoceros debilis* is similar to *Skeletonema costatum* in this study area. *Chaetoceros debilis* reached its greatest abundance at the same time as did *Skeletonema* (Braarud and Nygaard, 1980). Its maximum is reached somewhat later than that of the *Thalassiosira* species. According to Braarud (1962), at the end of the spring development in coastal waters it forms resting spores and the same take place when it occurrs in abundance during autumn.

Asterionella glacialis also was dominant in spring and summer. This species occured in maximum abundance of 87,420 cells/1, 24% of total standing crops in July 1982. *Asterionella glacialis* is allochthonous species (Perkins, 1974). This species can bloom in the interval from winter to late spring and/or during the autumn as in Narragansett Bay (Smayda, 1980). *Thalassionema nitzschioides* seems to have broader tolerence to changing physical conditions than *Skeletonema costatum* (Riley, 1967). However, in this study area, this species was dominant only in spring and relatively poor in other seasons. The maximum percentage in May is 11.3%, corresponding to 19,990 cells/s.

Asterionella kariana was also dominant only in the spring season. This species occurs mainly from May to June.

Nitzschia pungens was dominant in summer. Especially, in July this species was predominant, the percentages of standing crops reached 58.3% of total populations. According to Marshall and Cohn (1983), in northeastern coastal waters of the United States, *Nitzschia pungens* is dominant during spring and summer.

Chaetoceros compressus and *Nitzschia seriata* were widely distributed in small concentrations, but occurred as dominant species in summer and early autumn. These species were often dominant in summer in Narragansett Bay (Smayda, 1980).

Thalassiosira eccentrica was dominant in winter season as well as *Paralia sulcata*. In compared with *Paralia sulcata*, the concentrations are less, but the distributions are similar. This may be due to the attachment of *Thalassiosira eccentrica. Thalassiosira eccentrica* exist singly of as aggreates having attached mineral grains (Cloern *et al.*, 1983).

In addition, although they distributed in the range of less than 5% of total densities, there were common species occurred with some densities in many samples. The common species included *Cylindrotheca closterium, Nitzschia acicularis, N. longissima, Rhizosolenia delicatula, R. setigera, Bacillaria paxillifer, Campylosira cymbelliformis, Odontella sinensis, Ditylum brightwelli, Cosinodiscus asteromphalus, Actinoptychus senarius, A. splendens, Thalassiosira hyalina, Navicula salinarum, Prorocentrum triestinam* and two silicoflagellates, *Dictyocha fibula* and *Distephanus speculum.*

CONCLUSION

A total of 228 phytoplankton species was identified in this study area. Among these taxa, most species are diatoms. The percentage of diatom occurrence are high in winter, while in summer, because of the decrease of diatom percentage, dinoflagellates and green algae increase only a little. As a rule, neritic diatom species are dominent throughout the year in the study area, but, in summer and autumn some oceanic species such as Kuroshio indicator species and freshwater species invade into this bay. The composition of species within the bay consists of about 30 autochthonous species, 17-20 freshwater species, 20-30 oceanic species, 20-30 brackish species and 93 tychopelagic species.

Tychopelagic plankton occupies 40.4% of total species. They play an important role from late autumn to early spring in this estuarine plankton assemblages. Their origins are benthic or littoral diatoms.

Following Harper's measurement on adhesive and tractive force of benthic diatoms, most of benthic diatoms must be resuspended by the bottom shear stress during autumn and winter. In late spring, the water mass become stable, tychopelagic plankton sedimented and planktonic species again increase rapidly. The seasonal variations of planktonic standing crops show inverse relationship with tychopelagic plankton. In summer and early autumn, the densities of tychopelagic plankton show a minimum due to the stability of water mass.

Typical peaks of phytoplankton occur in spring and early autumn, respectively. The first bloom is started by *Skeletonema costatum* and *Paralia sulcata* in early May, second peak is formed by various diatom populations in September. Seasonal varibility of the water column was the primary factor controlling the phytoplankton blooms. Summer diatom blooms were followed by red tide of *Noctiluca scintillans* in July 1984. This red tide happened rapidly during the neap tide and disappeared in spring tide. Exceptional high transparency during the neap tide and low salinity may be important factors for the occurrence of red tide.

In this study area, there may be three types of indicator species associated with the properties of water mass. *Lyngbya contorta* and *Scnedesmus dimorphus* could be identified as an indicator species of polluted water. *Chaetoceros convolutus, Rizosolenia styliformis, Ceratium kofoidii* and *Ceratium macroceros var. gallicum* could be extracted as an indicator species of the input of oceanic water masses. Tychopelagic planktons could be considered as an indicator species of the mixing of water masses. *Paralia sulcata* is the most important tychopelagic plankton as an indicator species of water mixing in the eastern coastal area of Yellow Sea.

Paralia sulcata is predominant from October to March, with average values of 67.17% of total populations. This species seems to have even broader tolerance to change of physical conditions than *Skeletonema costatum,* and tends to fill the gaps when the phytoplankton is relatively unsuccessful, while *Skeletonema costatum* and *Chaetoceros debilis* were dominant in other seasons.

REFERENCES

Braarud, T., 1962. Species distribution in marine phytoplankton. J. Oceano. Soc. Japan. **20:** 528-649.

Braarud, T. and I. Nygaard, 1980. Phytoplankton observations in offshore Norwegian coastal waters between 62°N and 69°N. Sarsia **65(2):** 93-114.

Caspers, H., 1967. Estuaries: Analysis of definitions and Biological consideration. In: Estuaries (Lauff ed.) pp 6-8.

Choi, J.K., 1982. On the phytoplanktonic community structure of the Kyeonggi Bay, Yellow Sea, in Autumn. Bull. Inst. Basic Sci. Inha Univ., **3:** 169-176.

Choi, J.K., 1983. Newly recorded phytoplankton for Korea, from the Yellow Sea. Bull. Inst. Basic Sci. Inha Univ. **4:** 111-117.

Choi, J.K. and J.H. Shim, 1986 a. The ecological study of phytoplankton in Kyeonggi Bay, Yellow Sea. I. Environmental characteristics. The J. Oceano. Soc. Korea, **21(1):** 56-71.

Choi, J.K. and J.H. Shim, 1986 b. The ecological study of phytoplankton in Kyeonggi Bay, Yellow Sea. II. Light intensity, Transparency, Suspended substances. The Journ. Oceano. Soc. Korea, **21(2):** 101-109.

Choi, K.C., 1965. Ecological studies on early stages of the bialve, *Tapes philippinarum.* College. Educat. Review, **7(1):** 160-234.

Chung, Y.H., 1959. A study on the microflora of the Han River (III). The environmental conditions and phytoplankton of Han River Estuary. National Academy Bull. **8:** 59-132.

Chung, Y.H., J.H. Shim and M.J. Lee, 1969. Studies on the water pollution and productivity in Kyeonggi Bay in summer season (3). Classification of the phytoplankton (1). Report for the IBP. Kor. Nat. Acad. **3:** 3-16.

Chung, Y.H., J.H. Shim and M.J. Lee, 1971. Studies on the water pollution and productivity in Kyeonggi Bay in summer season. (3). Korea Botany Soc. **14(3):**

47-59.

hung, Y.H. and K. Lee, 1977. Seasonal fluctuations of phytoplankton in Incheon Dock-Autumn. Korea Journ. Botany. **20(3)**: 135-140.

loern, J.E., A.E. Alpine, B.E. Cole and M.D. Ball, 1983. River discharge controls phytoplankton dynamics in the Northern San Francisco Bay Estuary. Estuarine, coastal and shelf science **16**: 45-429.

olijn, F. and G. Van Buurt, 1975. Influence of light and temperature on the photosynthetic rate of marine benthic diatoms. Mar. Biol. **31**: 209-214.

iallagher, J.L., 1975. The significance of the surface film in salt marsh plankton metabolism. Limnol. Oceano. **20**: 120-127.

irindley, J.R., 1981. Estuarine Plankton. In: Estuarine Ecology (Day ed.) 117-146.

larper, M.A. and J.F. Harper, 1967. Measurements of diatom adhesion and their relationship movement. Br. phycol. Bull. **3(2)**: 195-207.

lendey, N.I., 1964. An Introductory Account of the Samller Algae of British Coastal waters, Pt. V. Fishery Invest. Ser. IV. London; 317.

lustedt, F., 1927-1966. Die Kieselagen Deutschlands, Oesterreich and der Schweig. In Kabonhorst Krytogamenflora. Akademische Verlagsgesellshaft, M.B.H., Leipzig. **7**(1): 1920. 1927-1930 **7**(2): 845, 1931-1959 **7**(3): 816, 1961-1966.

ames, A., 1979. The value of biological indicators in relation to other parameters of water quality. In Biological indicators of water quality, James and Evison (ed.) Wiley; 1-15.

ang, S.W. and J.K. Choi, 1984. Surface waves and Bottom Shear Streams in the Yellow Sea. J. Oceanol. Soc. Korea. **19(2)**: 118-124.

okubo, K. 1955. Planktonic diatioms. Shinkokai, Tokyo: pp. 330

ORDI, 1980. Studies on the useful fisheries resources in Garolm Bay. BSPE 00030-55-3: pp. 81.

urashige, H. 1943. Quantitative and qualitative characteristics of the marine diatom in the coastal water of Taiyato at the Yellow Sea side of Tyosen, in comparison with that of Tataho Bay at the southern coast of the peninsula. Bull. Fish. Exp. Stat. **8**: 1-114.

urashige, H. 1944. Quantitative and qualitative characters of the marine diatom in the coastal water at the Yellow Sea in comparison that at the southern coast of the peninsula. Jour. Oceanogr. Soc. Japan. **3(4)**: 254-275.

ee. M.J., J.H. Shim and C.K. Kim., 1967. Studies on the plankton of the neighboring seas of Korea. Part 1: On the marine conditions and phytoplankton of the Yellow Sea in summer. Reports. The Inst. Mar. Biol. S.N.U.I. **6**: 1-14.

Maestrini, S.Y., D.J. Bonin and M.R. Droog, 1984. Phytoplankton as indicators of sea water quality; bioassay approach and protocols. In Algae as ecological indicators. (L.E. Shubert ed.). Academic press; 71-132.

Marshall, H.B. and M.S. Cohn., 1983. Distribution and composition of phytoplankton in Northeastern coastal waters of the United States. Estuarine, coastal and shelf science **17**: 119-131.

McAlice, B.J., 1971. Phytoplankton sampling with the Sedgwickrafter cell. Limno. Oceanogr. **16(1)**: 19-28.

Motoda, S. and R. Marumo., 1963. Plankton of the Kuroshio water. Proceedings of symposium on the Kuroshio; 40-61.

Ohwada, M. and O. Asaoka 1963. A microplankton survey as a contribution to the hydrography of the North Pacific and adjacent seas. The Oceanogr. Magazine. **14(2)**: 73-85.

Palmer, C.M., 1977. Algae and water pollution. EPA-60019-77-036; 124.

Perkins, E.J., 1974. The biology of estuaries and coastal waetrs. Academic. Press. London; pp. 678.

Riley, G.A., 1967. The plankton of estuaries. In estuaries (Lauff ed.): 316-328.

Robinson, G.A. and D.R. Waller, 1966. The distribution of *Rhizosolenia styliformis* Brightwell and its varieties. Some contemporary studies in marine science: 645-553.

Roff, J.C., R.J. Pett, G.F. Rogers and W.R. Budgell, 1980. A study of plankton Ecology in Chesterfield Inlet, Northwest Territories, An Arctic Estuary. Estuarine perspectives Ed. V.S. Kennedy, Academic Press, 185-198.

Schulz, H., 1960. Qualitative and quantitative plankton unter suchungen in Elbe-Aestuar. Arch. Hydro. Biol. Suppl. **26**: 5-105.

Shim, J.H., 1977. A taxonomic study of marine planktonic diatoms of vancouver island and coastal waters. Proc. Coll. Nature Sci. S.N.U. **2(2)**: 79-184.

Shim, J.H. and W.H. Lee 1979. On phytoplankton of the Cheonsu Bay. West coast. J. Ocean. Soc. Korea **14(1)**: 6-14.

Shim, J.H. and B.C. Cho, 1984. The intertidal benthic diatom community in the vicinity of Incheon. Korea. Proc. Coll. Nature Sci. S.N.U. **9(1)**: 135-150.

Smayda, T.J., 1980. Phytoplankton species succession. In the physiological ecology of phytoplankton (Morris ed.): 493-570.

Yamaji, I., 1980. Illustrations of the marine plankton of Japan. Hoikusha Pub. pp. 537.

Yoo. S.A., 1982. An ecological study on marine algae of Incheon Dock. Thesis for Ph. D., SUN. pp. 170.

Received August 11, 1986
Accepted September 1, 1986