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Community Structure and Spatial Distribution of Phytoplankton in the Southwestern Sea of Korea, in Early Summer

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초여름 韓國 西南海域 植物플랑크톤의 群集構造와 分布

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Abstract: To characterize community structure and distribution of phytoplankton, cluster analyses are performed on quantitative data of phytoplankton collected from the southwestern sea of Korea in early summer, 1980. The cluster analysis shows that the phytoplankton of the study area consists of three distinct characteristic communities, representing different water masses. The species of the first community, predominant in the southwestern coastal area of the main land, are mostly neritic and cold water diatoms. The second community consists of neritic and oceanic diatoms, a few flagellates and an euglenoid. These species are predominant in the vicinity of Jeju Island with warm and high saline waters which seems to be a branch of the Kuroshio Current. The species of the last community, consisting primarily of small-sized dinoflagellates and microflagellates, are predominant in the rest part of the study area with warm and low saline water. In addition, the vertical distributions of phytoplankton and environmental factors show that high concentration of phytoplankton cells, chlorophyll-a and dissolved oxygen are observed near the seasonal pycnocline in the off-coastal area. Fraction of nanoplankton take the above 90% of the total cell concentration in the surface mixed layer of off-coastal area where the seasonal pycnocline develops in summer

要約: 한국 서남해역에 있어서 식물플랑크톤의 군집구조와 분포를 밝히기 위하여 1980년 여름에 수평적, 수직적으로 채집한 정량 자료를 분석하였다. 연구해역은 상이한 水塊를 대표하는 상이한 3개의 특징적인 군집을 이루고 있음을 보여준다. 제 1 군집은 대부분 연안성 및 냉수성 硅藻類로 구성되어 서남해의 연안 수역을 대표하며, 제 2 군집은 외양성 및 연안성 구조류와 2-3종의 鞭毛藻類로 구성되어 黑潮의 지류로 생각되는 高鹽 暖水性인 제주 부근의 수역을 대표한다. 제 3 군집은 주로 소형인 雙鞭毛藻類와 微細藻類로 구성되고 低鹽 暖水性인 중간 수역을 대표하는 것으로 나타났다. 또한 식물플랑크톤과 환경요인의 수직분포에서 세포수, chlorophyll-a, 및 용존산소등이 특히 계절적인 pycnocline 부근의 수층에서 높은 농도를 보여준다. nanoplankton은 군집내에서 90% 이상에 이를 만큼 점유율을 보여 중요성이 높음을 나타낸다.

INTRODUCTION

The study area is located in the southwestern sea of Korea (Fig. 1), and shows average depth of 80m with the deepest ($\geq$ 120m) near the northern coast of the Jeju Island. This area has been known to be characterized by the presence of several complicted water masses which show seasonal variations in their spatial distribution, and it has important meanings in the multidisciplinary oceanographic aspects.

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Some biological surveys covering this study area, have been undertaken by Lee et al. (1967), Choe (1969), and Park (1973). Lee, et al. (1967) reported about the phytoplankton in

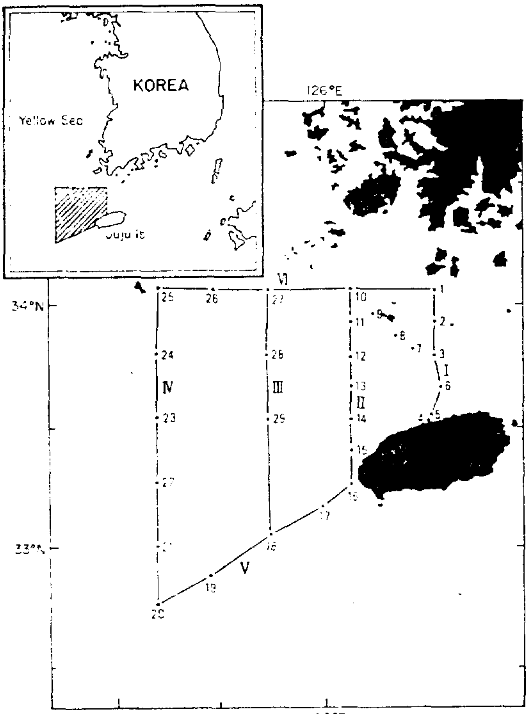


Fig. 1. The study area showing 29 sampling stations

the neighboring seas of Korea and discussed the intrusion of the Kuroshio Current into the Yellow Sea in summer using indicator species. Choe (1969) reported about the phytoplankton in the sea of Korea including this study area, and Park (1973) reported about the chaetognaths in the Korea Strait and its relation with water masses. But there has been little information on the relationship between the hydrographic conditions and the phytoplankton community changes. Recently Kim et al. (1980) reported the result of interdisciplinary oceanographic survey in this area where four different water masses exist in the southwestern sea of Korea in summer.

In this study, community structure and distribution of phytoplankton in early summer are investigated since they could reflect regional or environmental differences and give valuable informations interpreting the complicated multidisciplinary oceanographic phenomena in this area.

Multivariate methods to interprete the quantitative data used, general reviews and some examples of the application of these techniques to phytoplankton were discussed by Allen and Koonce (1973), McIntire (1973), Holland and Claflin (1975), and Estrada and Blasco (1979). Many investigators (Anderson, 1965; Ryther, 1969; McCarthy et al., 1974; Beers et al., 1975; Throndsen, 1979; Malone, 1971; 1980) have reported significance of nanoplankton in terms of primary production, productivity and food chain in marine environments. Recently, Malone (1980) reported that nanoplankton account for about 90%, 79%, and 74% of primary productivity in oceanic, coastal, and upwelling environments, respectively. Such a study in terms of standing crop is attempted to investgate the importance of nanoplankton.

Pingree et al. (1976) reported the influence of physical stability on seasonal phytoplanton blooms in the Celtic Sea, and Semina (1979) discussed the various patterns of vertical distribution of phytoplankton with the stability of the water column in the open sea. In this study, relationship between the seasonal pycnocline and the vertical distribution of phytoplankton is discussed.

MATERIALS AND METHODS

Samples were taken at 29 stations in the southwestern sea of Korea (Fig. 1) during 16–21 June, 1980. Phytoplankton samples for qualitative study were collected from surface to 30m with 10m intervals by the Clarke-Bumpus sampler at each station. Collected samples were fixed with neutralized formalin at a final concentration of 5%.

In all, 104 water samples were collected for quantitative study of phytoplankton by Van Dorn water samplers from 29 stations at nominal depths of 0m, 10m, 20m, 30m, and 50m, respectively. Sub-samples were drained into 1 liter polyethylene bottles and were fixed with neutralized formalin. The Sedgwick-Rafter counting chamber was used to determine the phytoplankton standing stock following to McAlice's treatment (1971). During the counting, phytoplankton species were identified to species level when possible, and averaged two dimensional measurements were made on all identified taxa. Length of each colonial diatom species was averaged to account for their natural configurations for the stuty of size distribution.

Samples for chlorophyll-a were determined by the spectrophotometric method (Beckman DU Spectrophotometer) outlined in Strickland and Parsons (1968). Dissolved oxygen was measured with Yellow Spring Instrument Model 57 Oxygen-temperature Meter. Measurements of pH were made with Photovolt 126A Portable pH Meter. Temperature and salinity data at each station were obtained from the hydrographic survey of which measurements have been done at the same time (Kim et al. 1980). Euphotic zone at each station was determined from the calculation of the Secchi disc measurement. To determine the relationship between the pycnocline and the vertical distribution of phytoplankton, stability of water column was calculated from the sea water density (sigma-t) at each station.

As exploratory methods, two multivariate methods were introduced to analyze the quantitative data of phytoplankton: cluster and factor analyses ran on IBM 360/370 computer. Correlation coefficient was used as a similarity measures.

RESULTS AND DISCUSSION

I. Quantitative analysis of phytoplankton with multivariate methods

I-1. Division of the study area by cluster analysis

Cluster analysis of 104 samples based on the distribution of phytoplankton shows that the study area can be divided into three major areas: the southwestern coatal area, the vicinity of the Jeju Island, and the off-costal area which occupies the largest part of the study area (Figs. 2 and 3). Hydrographic data also show general agreement with the above result (Fig. 4), and detailed hydrographic analysis should be referred to Kim et al. (1980).

In the southwestern coastal area, stations 1, 2, 26 and 27 (Fig. 1) show high vertical similarity, which could be related to the upwelling condition discussed by Kang (1971), Rho and Chung (1975), and Nakao (1977). The area in the vicinity of the Jeju Island extends with depth (Fig. 3) and the area in the offshore occupies upper layers with depth of 20~30m.

Table 1 shows a list of phytoplankton species occurred in each area with significance. In general, total cell numbers in the southwestern coastal area and in the vicinity of the Jeju Island were higher (average about 6,700~17,400 cells/liter) than in the off-coastal area. In particular, highest density about 390,000 cells/liter was observed at station 4 where eutrophication might be caused by domestic sewage and wastes from the Jeju Harbor. *Chaetoceros debilis* was the most dominant population at this station.

I-2. Grouping of phytoplankton species

Cluster analysis of phytoplankton species shows that the species can be divided into three main groups (Fig. 5).

Group A consists of mostly neritic and cold water diatoms except *Dinophysis recurva*; *Paralia sulcata*, *Navicula distans*, *Asterionella kariana*, *Amphiprora paludosa*, and *Nitzschia sigma* which are confined to/or most predominant in the southwestern coastal area with low temperature about 14°C and salinity about 33.5‰. Many species including *Paralia sulcata*, *Nitzschia closterium*, *Amphiprora paludosa*, *Diploneis bombus*, *Navicula distans*, *Nitzschia sigma*, *Synedra*

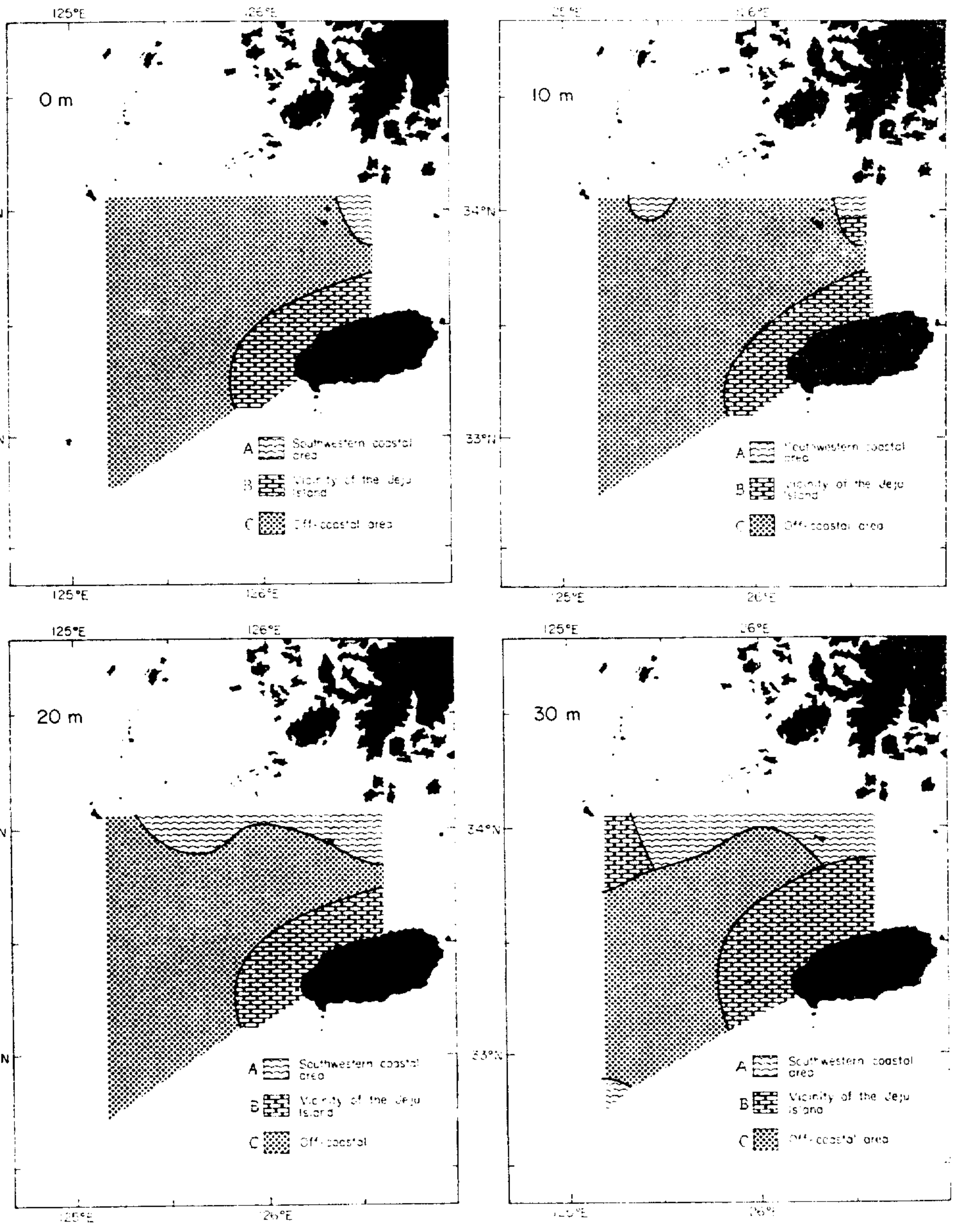


Fig. 2. Division of three areas on the horizontal plane by the cluster analysis based on the distribution of phytoplankton in June 1980 (0, 10, 20, and 30m)

sp., and *Pleurosigma angulatum* are bottom forms. Occurrence of these bottom species with relation to hydrographic condition in this local area will be discussed later.

Group B consists of neritic and oceanic warm water diatoms, three dinoflagellates (*Peridinium miniscullum*, *P. pellucidum*, and *Prorocentrum triestinum*), and an euglenoid which are predominant in the vicinity of the Jeju Island with warm (ca. 17.5°C) and high saline (ca. 34‰) water which seems to be originated from the Kuroshio Current. *Corethron criophilum*, *Eutreptiella* sp., *Prorocentrum triestinum* and *Thalassiosira rotula* are observed with high abundance.

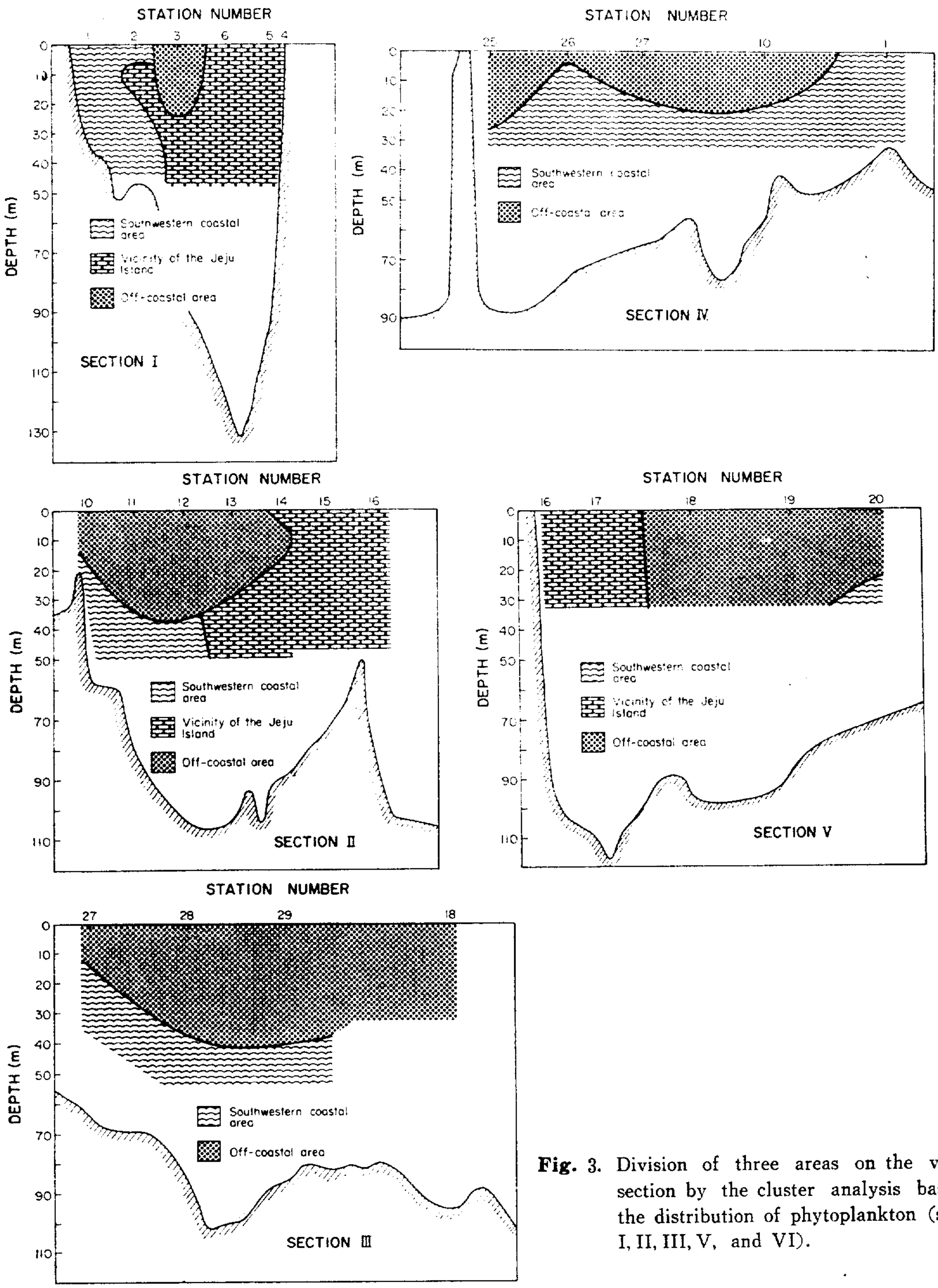


Fig. 3. Division of three areas on the vertical section by the cluster analysis based on the distribution of phytoplankton (section I, II, III, V, and VI).

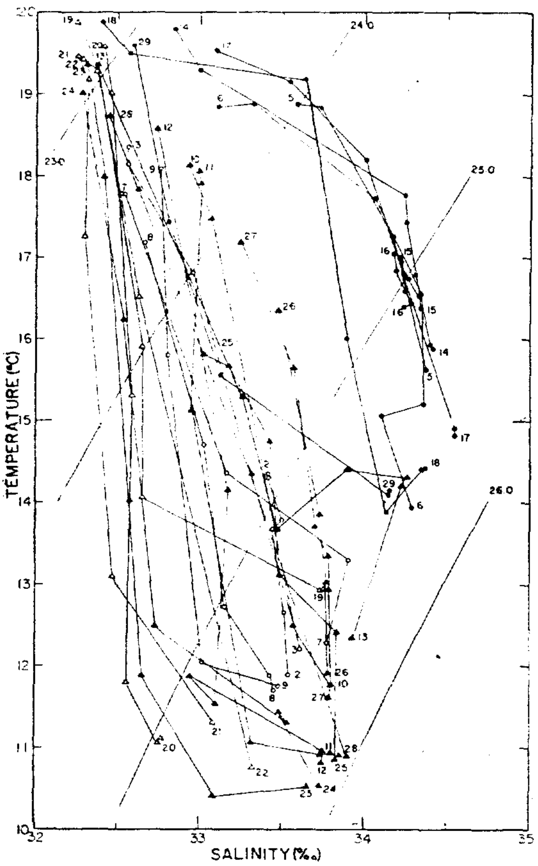


Fig. 4. T-S diagram resulted from the hydrographic observation in June 1980.

Group C consists of small-sized dinoflagellates (*Amphidinium schröderi*, *Exuviella* sp., *Gymnodinium* sp., *Gyrodinium* sp., and *Oxytoxum variable*) and microflagellates (*Chroomonas* sp.). These species are predominant in the rest part of the study area with warm (ca. 18°C) and low saline (ca. 33.0‰) water which seems to be affected by fresh water from the Yangtze River (Kim, et al., 1980).

II. Analysis of phytoplankton species

There are 123 species of phytoplankton identified in the present study from both qualitative and quantitative samples. They are 99 diatom species, 20 dinoflagellate species, 2 silicoflagellates, an euglenoid and a cryptomonad (Table 2).

The majority of species are neritic, but species repesenting oceanic and warm waters probably come from the Kuroshio Current (Choe, 1966; Lee et al., 1967; Shim, 1980).

Phytoplankton species occurred in the southwestern coastal area are mostly neritic diatoms. Phytoplankton species occurred in the vicinity of the Jeju Island include many warm oceanic species such as *Ceratium tripos*, *Chaetoceros coarctatus*, *C. convolutus*, *C. denticulatum*, *C. peruvianus*, *C, messanensis*, *Corethron criophilum*, *Rhizosolenia calca-avis*, *R. hebetata f. semispina*, *R. imbricata*, and *R. styliformis*. Above all, 21 Kuroshio indicator species based on Motoda and Marumo (1963), and Karawada (1965)

Table 1. List of dominant phytoplankton species (over 10%) occurred in each area.

Southwestern coastal area
Paralia sulcata
Asterionella kariana
Bacillaria paxillifer
Navicula distans
Nitzschia closterium
Diploneis sp.
Area in the vicinity of the Jeju Island
Chaetoceros debilis
Thalassiosira rotula
Eutreptiella sp.
Corethron criophilum
Chroomonas sp.
Paralia sulcata
Oxytoxum variable
Gymnodinium sp.
Off-coastal area
Gymnodinium sp.
Chroomonas sp.
Oxytoxum variable
Glenodinium sp.
Amphidinium schröderi
Exuviella sp.
Gyrodinium sp.

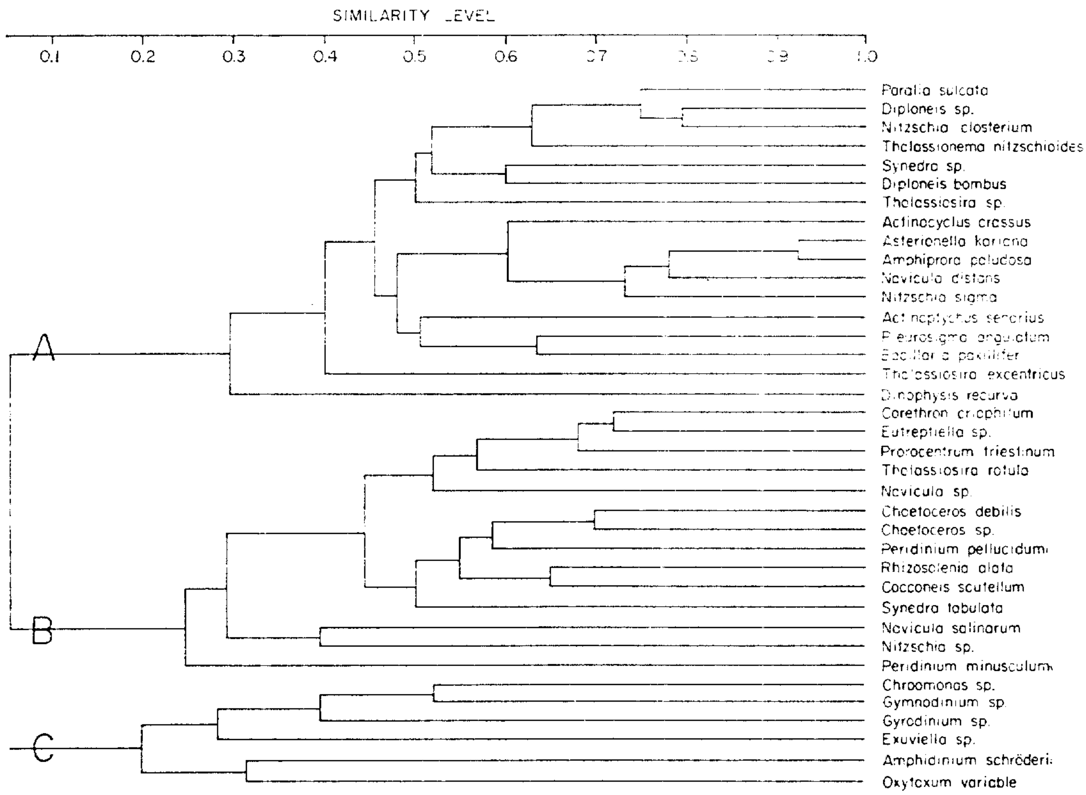


Fig. 5. Cluster analysis of phytoplankton species in the southwestern sea of Korea in June 1980.

Table 2. List of phytoplankton species occurred in this study.

	A	B	C		A	B	C
Achnanthes longipes		C	R	*Campylodiscus undulatus*	R		
Actinocyclus crassus	C			*Cerataulina bergonii*		C	
Actinoptychus senarius	C			*Ceratium furca*		R	
Arachnoidiscus ehrenbergi	R	R		*C. fusus*		R	
Amphidinium schröderi		R	C	*C. tripos*		R	R
Amphiprora gigantea v. *sulcata*	R			*Chaetoceros affinis*		R	
A. paludosa	C			**C. coarctatus*		R	
Amphora sp.	R			*C. compressus*		R	
Asterionella gracialis	R	C		*C. concavicornis*	R	R	R
A. kariana	C	R		*C. convolutus*	R	R	R
Aulacodiscus kittoni		R		**C. curvisetus*	R	C	
Bacillaria paxillifer	C	R		*C. debilis*	R	C	
Biddulphia aurita	R	C		**C. decipiens*	R	R	R
B. longicruris	R	C		**C. denticulatum*		R	R
B. mobiliensis	R	C		**C. didymus*		R	
B. pulchella	R	C		*C. didymus* v. *anglica*		R	
B. rhombus		R		**C. lorenzianus*	R	R	
B. titiana		R		**C. messanensis*		R	
B. sinensis	R	R		**C. peruvianus*		R	R

C. peruvianus f. *glacialis*		R	
**C. radicans*		R	
C. socialis		R	
C. teres	R		
Chrysanthemodiscus floreatus		R	
Climacosphenia moniligera		R	
Cocconeis scutellum	R	R	
Corethron criophilum		C	
Coscinodiscus gigas		R	
C. jonesianus	C	R	
C. oculus iridis	R	R	
C. radiatus	R		
Chroomonas sp.	R	R	C
Cymbella sp.		R	R
Dictyocha fibula		R	R
Dinophysis recurva	R		R
**D. hominculus*		R	R
Diploneis bombus	C	R	
D. sp.	R	R	
Distephanus speculum		R	
Ditylum brightwellii	R	R	
**Eucampia zodiacus*		R	
Eudictya oceanica		R	
Eutrptiella sp.	R	C	
Eunotia sp.		R	
Exuviella sp.		R	C
Glenodinium sp.			C
Gonyalax sp.		R	R
Grammatophora angulosa		R	
G. marina		R	
**Guinardia flaccida*		R	R
Gymnodinium sp.	R	R	C
Gyrodinium sp.			C
Hyalodiscus stelliger	R	R	
Ithmia enervis		R	
Leptocylindrus danicus		R	
Licmophora abbreviata		R	
Melosira moniliformis		R	R
M. nummuloides		R	R
Navicula distans	C		
N. salinarum	R	R	
N. sp.	R	R	
**Nitzschia closterium*	C	R	
**N. longssima*	R	R	
N. pungens		R	
**N. seriata*		R	
N. sigma	C		
Oxytoxum variable	R	R	C
Paralia sulcata	C	R	
Peridinium depressum	R		R
P. excentricum		R	
P. leonis		R	
P. miniscculum	R	C	R
P. pallidum		R	R
P. pellicidum		C	
Pleurosigma angulatum	C	R	
P. clevei		R	
P. normanii	R		
Prorocentrum micans	R	C	
P. triestinum		C	
Rhabdonema adriaticum		C	
Rhizosolenia alata	R	C	R
R. alata f. *gracillima*		R	
**R. calca-avis*		R	R
R. hebatata f. *semispina*	R	R	R
R. imbricata		R	R
R. robusta	R		
**R. setigera*		R	R
**R. shrubsolei*		R	
**R. stiliformis*		C	
Schroderella delicatula		R	
**Skeletonema costatum*	R	R	
Striatella unipunctata		C	R
Surirella sp.	R		
Synedra tabulata	R	C	
Tabellaria sp.		R	
Thalassiosira excentricus	C	R	
T. rotula	R	C	
Thalassiothrix frauenfeldii	R	R	
**Thalassionema nitzschioides*	R	R	
Triceratium alterans		R	
T. favus			R
T. formosum			R
T. gibbosum			R
T. shadboltianum			R

R ; rare

C ; common

A ; The southwestern coastal area

B ; The vicinity of the Jeju Island

C ; The off-coastal area

* ; The Kuroshio indicator species based on Motoda and Marumo(1963), and Karawada(1965).

are recorded in the present study (Table 2), and all of them occur in the vicinity of the Jeju Island. From this, it is suggested that the branch of the Kuroshio Current seems to mostly turn around the Jeju Island in early summer. The off-coastal area is characterized by scarcity of diatom species and abundance of small-sized dinoflagellates.

Many bottom living or benthic forms are occurring frequently through the water column near the western end of Jeju Island (sts. 15 and 16) and in the southwestern coastal area (sts. 1, 2, 26 and 27). This indicates that there could be a vertical mixing in these local areas. A rare colonial bottom diatom species, *Chrysanthemodiscus floreatus* of which structure is very simple form of centric diatom occurs at stations 15 and 16, and its taxonomical consideration with detailed morphology has been discussed by Round (1978).

III. Vertical distribution of phytoplankton in relation to environmental factors.

Relationship between the vertical distribution of phytoplankton and vertical stability of sea water in the ocean has been investigated by many authors and it is well known that phytoplanktons tend to concentrate in the discontinuity layers (Semina, 1979). In the off-coastal area, the seasonal pycnocline developed at the average depth of 20~30m, and its density gradient approximates 0.1~0.19 sigma-t units/m in June 1980. Maximum cell concentration appears in and above the seasonal pycnocline (Fig. 6). Large density gradient of pycnocline may be act as a density barrier which prevents phytoplankton from singking below the pycnocline. Semina (1979) inferred that high concentration of the cells observed in the pycnocline are formed partly by the reproduction of cells at this depth and partly by their singking from upper layers, under favorable light condition. Maximum chlorophyll-a layers are related with the high concentration of cells near the pycnocline. As the lower limit of the euphotic zone extends below the pycnocline, it seems that the oxygen evolved from active photosynthesis accounts for high dissolved oxygen value and supersaturated condition in and above the seasonal pycnocline. Supersaturation of dissolved oxygen near the pycnocline, measured by the differences between the saturation values computed from T,S and the observed contents, seems to be not due to physical diffusion from other water masses, but due to active photosynthesis by highly concentrated phytoplankton cells in and above the pycnocline. In some cases, slight pH increase is observed near the pycnocline, and it can be explained as the active consumption of dissolved CO_2 by photosynthetic activity of phytoplankton, which in turn results in pH increase. Shabica et al. (1977) have already discussed about the dissolved oxygen and pH increases by primary production in the surface water of Athur Harbor, Antarctica.

As shown in Figure 6, it is evident that the larger the density gradient of pycnocline is, the higher concentration of phytoplankton cells is observed.

Small-sized dinoflagellates and microflagellates are predominant above the pycnocline, while diatom cells increase below it in the off-coastal area. As only the cells which contain chloroplasts were counted, occurrence of the cells far below the euphotic zone is rather difficult to interprete. But a closer examination of phytoplankton species reveals that the species composition above the pycnocline is quite different from that of deeper layers. This indicates that the occurrence of the cells below the euphotic zone is not due to sinking from upper layers. On the while, as some species in the deeper layers of the off-coastal area and occasionally in the southwestern coastal area are the major components which are distributed uniformly

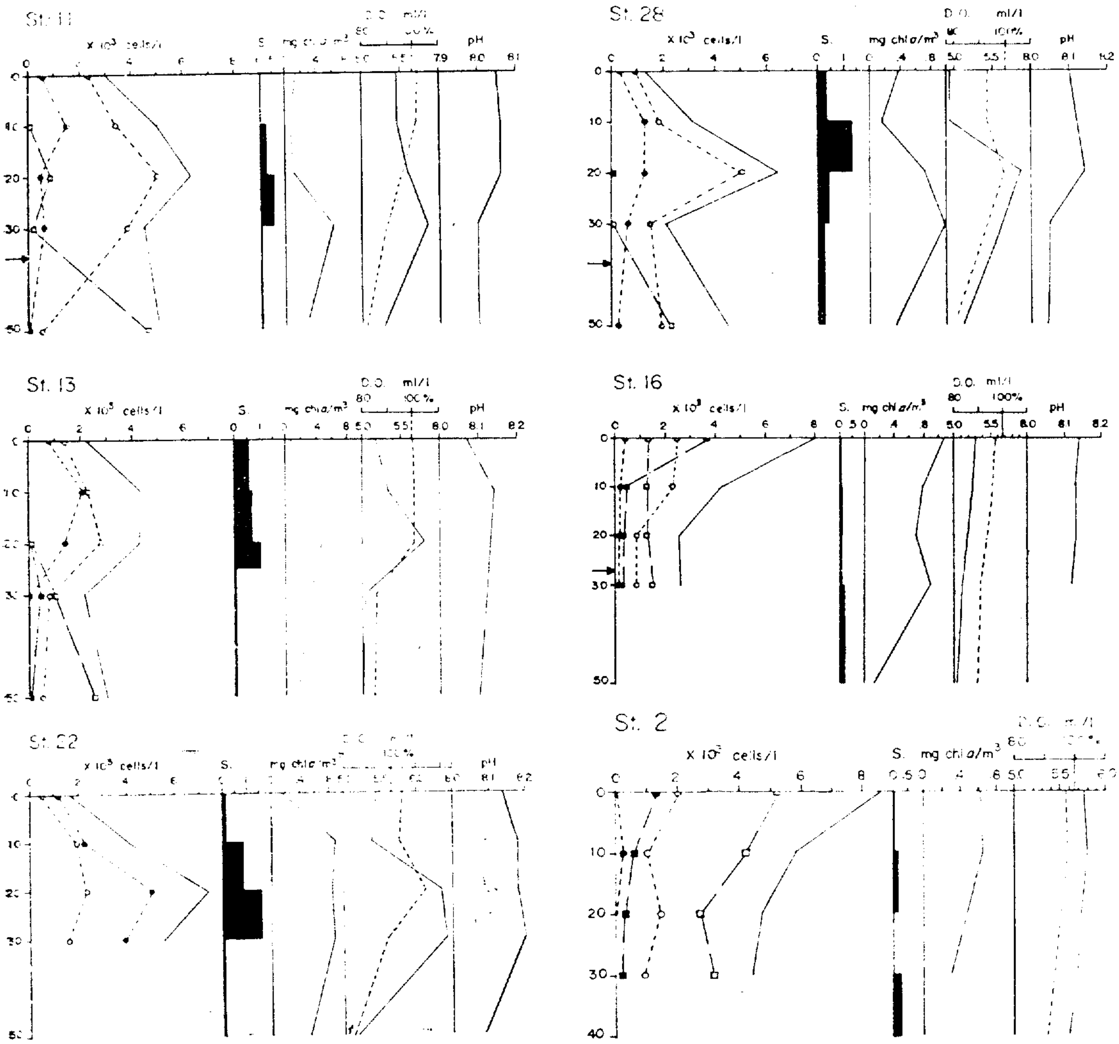


Fig. 6. Vertical distribution of phytoplankton with environmental factors in the off-coastal area. S is arbitrary unit of stability.
——Total cell count open square: Diatom species
open circle: Dinoflagellatees closed square: Euglenoid closed circle: Microflagellates

from surface to bottom in the vicinity of the Jeju Island, it seems more reasonable to suggest that they are transported as allochthonous species by the extension of the Kuroshio Current beneath the overlying light-density surface water. From this, there can be a possible speculation that part of the water from the Kuroshio Current might have been depressed to the deeper layer due to light-density surface water and mixed with the bottom cold waters of southwestern coastal area and the Yellow Sea.

Meanwhile, maximum concentration of cells and chlorophyll-a is observed at the surface in the southwestern coastal area and at the western end of the Jeju Island (Fig. 6). As mentioned earlier, neritic and cold water diatoms took the majority of the phytoplankton cells, and bottom species occurred at a constant ratio ($\geq$ 50 %) from surface to bottom in the southwestern coastal area and at the western end of the Jeju Island where the vertical stability of sea water was low. In general, it is well known that relatively uniform distribution of the phytoplankton is due to intensive mixing of water in early spring before stratification sets in (Smina, 1979). However, where the mixed condition continues, maximum cell counts may be appear at the surface, because the light condition would be much favorable to surface with nutrient-enriched water from the bottom. The above suggestion implies that mixing or upwelling condition might be prevalent in the southwestern coastal area and at the western end of the Jeju Island.

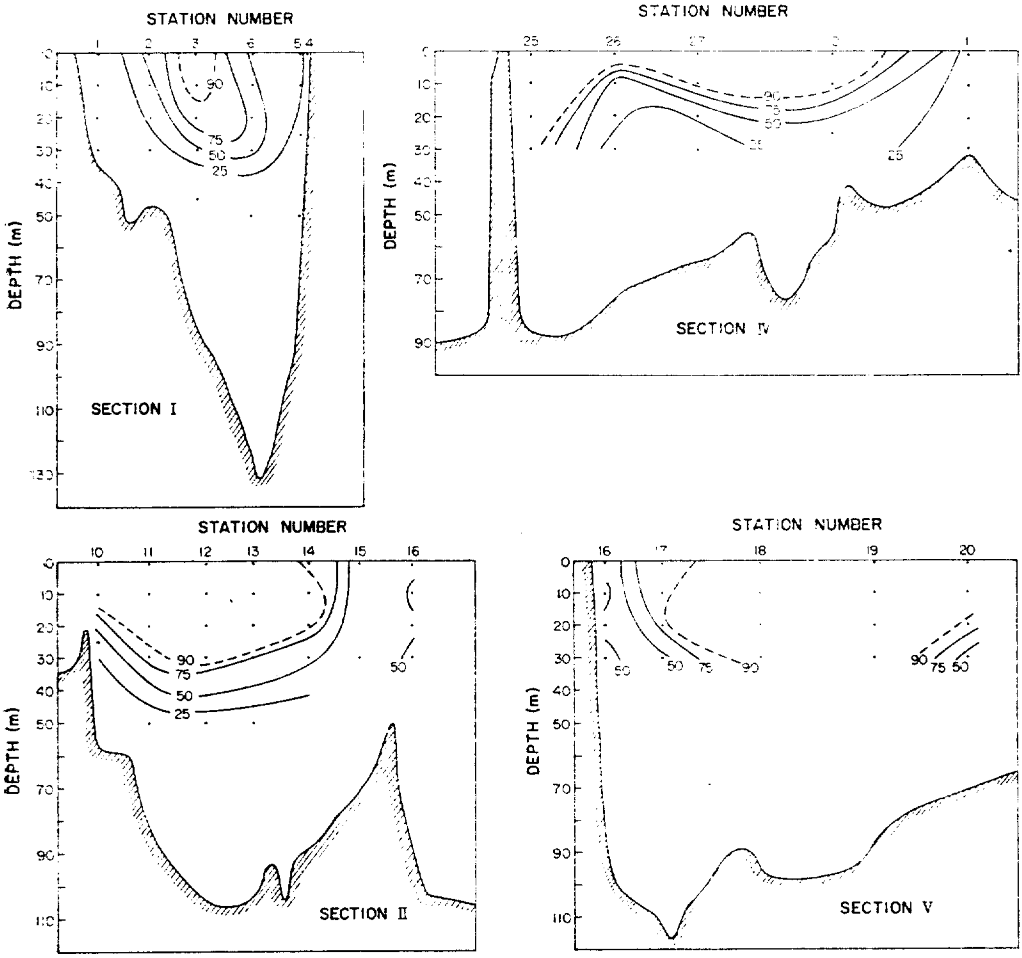
According to the qualitative net samples, many bottom or bentic diatom species including *Achnanthes longipes, Biddulphia aurita, B. pulchella, Campylodiscus undulatus, Chrysanthemodiscus floreatus, Grammatophora angulosa, G. marina, Ithmia enervis, Licmophora abbreviata, Paralia sulcata, Rhabdonema adriaticum, Striatella unipunctata and Triceratium alterans* distribute particularly at the western end of the Jeju Island (sts. 15 and 16).

IV. Size fractionation of phytoplankton

To study size distribution of phytoplankton in each community, equivalent sphere diameter of each species was calculated and all the phytoplankton species occurred in the study area can be seperated into two groups; nanoplankton refering to the smaller organisms (2-20 μm) and netpalnkton refering specifically to the larger organisms (20-200 μm) (Parsons *et al.*, 1977; Beers *et al.*, 1975). Figure 7 shows spatial distribution of nanoplankton in terms of fraction of total cells at each sampling points. Nanoplankton fraction of the total concentration exceeds 90% (sometimes near 100%) in the surface mixed layer above pycnocline in the off-coastal area, but decreases below the pycnocline and near the coastal area where the vertical stability of sea water is low and water coumn is hardly stratified as mentioned earlier. It is most likely that nanoplankton tend to dominate in the off-coastal area where the stratification is well developed, while netplankton tend to dominate in the mixing and upwelling waters in the coastal area.

Relationship between the cell size and environmental factors has been discussed by Hecky and Kilham (1974), and Parsons *et al.*, (1977). Similary, Taguchi (1976) observed that the small cell which has a high ratio of surface area to volume shows high rate of photosynthesis at light saturation under experimental condition, and it coincides with the result of Eppley *et al.* (1969) that the half-saturation constant for nitrate and ammonia uptake of small sized oceanic species is lower than that of larger neritic species. From these, it is evident that the smaller cells would be more advantageous to oligotrophic conditions. Malone (1980) has reported that high netplankton primary productivity tends to be associated with mixing and upwelling events espeicially in coastal environments. Beers *et al.* (1975) also has reported that the direct enumeration of the total population of cells shows the preponderance of small cells in oligotrophic water community from field observations. Consequently, it seems reasonable to deduce that the coastal waters with low stability where netplankton populations tend to dominate (Fig. 7) are more nutrient-enriched environments than the well stratified off-coastal area where the nanoplankton populations tend to dominate in this study area.

The ranking dominant species of nanoplankton in the study area are *Gymnodinium* sp., *Chroomonas* sp., *Oxytoxum variable*, *Glenodinium* sp., *Amphidinium schröderi* and *Exuviella* sp., and less dominant species are *Peridinium minisculum*,



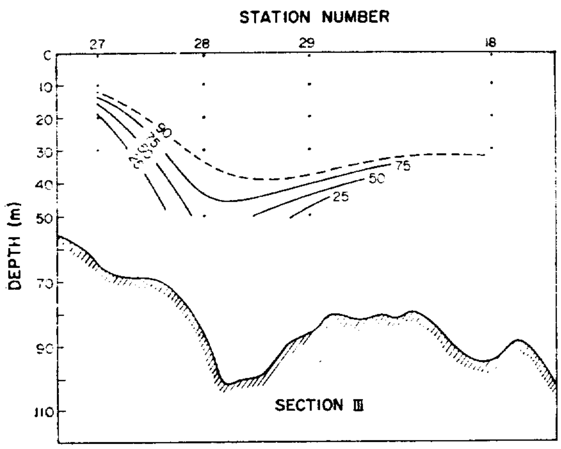


Fig. 7. Spatial distribution of nanoplankton fraction (%) of total cell concentration.

Prorocentrum triestinum and a few diatom species including *Diploneis* sp., *Navicula* sp.. But it must be considered that some nanoplankton cells which were too small (<4 μm) to identify under the light microscope might have been inevitably excluded from counting in this study.

From the above results, it is evident that the contribution of the nanoplankton to the total phytoplankton standing crop is highly significant in this study area.

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