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Primary Production System in the Southern Waters of the East Sea, Korea
II. The Structure of Phytoplankton Community

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한국 동해 남부해역의 일차생산계
II. 식물플랑크톤 군집구조

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A total of 190 phytoplankton taxa was identified in southern waters of the East Sea of Korea in May 1988, July 1989 and November 1991. *Leptocylindrus danicus, Nitzschia pungens* and *Bacteriastrum delicatulum* were the dominant species in spring. In summer, *Skeletonema costatum* was dominant all around the study area but *Chaetoceros socialis* and *Rhizosolenia alata* f. *gracillima* were locally dominant. On the other hand, the dominant species in autumn shifted to *Chaeotoceros socialis, Nitzschia delicatissima, Nitzschia* sp. and *Gymnodinium* sp. The average species diversities of the phytoplankton community were low in spring, summer and autumn, being 1.24, 1.69 and 2.12 respectively. The result of cluster analysis in summer suggested that the surface water of this study area could be divided into three phytohydrographic regions which consisted of the oceanic water region affected by Tsushima current, the east Korean neritic water region and the proper water region adjacent to Ulleung island. Compared with the surface phytohydrographic regions, one more region might be recognized at the 40m depth waters. It was appeared in the middle of study area and seemed to be affected by both Tsushima current and water mass of 10°C located deeper than 50 m.

동해 남부해역에서 1988년 5월과 1989년 7월 및 1991년 11월에 관찰된 식물플랑크톤 군집은 총 190종의 출현종을 기록하였고 규조류가 우점하고 있었다. 춘계에는 *Leptocylindrus danicus, Nitzschia pungens, Bacteriastrum delicatulum* 등이 우점종으로 나타났고 하계에는 *Skeletonema costatum*이 전반적인 우점현상을 보였으며 *Chaetoceros socialis, Rhizosolenia alata* f. *gracillima* 등이 수역에 따라 우점하였다. 추계에는 *Chaetoceros socialis, Nitzschia delicatissima, Nitzschia* sp., *Gymnodinium* sp. 등이 우점하였다. 종다양성 지수의 평균은 춘계에 1.24, 하계에 1.69, 추계에 2.12로 다소 낮게 측정되었다. 식물플랑크톤 군집의 집괴분석 결과 하계에는 표층에서 대마난류의 영향을 받는 외양적 특성의 수계와 동해 연안의 수계 및 울릉도 주변수등 크게 3개의 수역으로 구분할 수 있는 것으로 나타났다. 한편 하계의 40 m 수층 집괴분석 결과는 연구해역의 중앙부에서 표층 자료의 수역 구분과는 별개의 또다른 식물수문학적 수역이 인지되었는데 이곳은 표층 주변의 대마난류의 영향과 50 m 이심의 수층에 존재하는 수온 10°C 수괴의 양면적 영향을 받는 것으로 사료된다.

INTRODUCTION

The horizontal and vertical distribution of marine phytoplankton is not uniform, but presents irregularities with physico-chemical and biological factors. In a series of studies on the structure and characteristics of primary production system in the southern waters of the East Sea, a result was reported about biomass and primary productivity (Shim *et al.*, 1992). The purpose of present study is to discuss. the community structure of phytoplankton in the southern waters of the East Sea.

Nishida (1930), the first investigator of phytoplankton community in neritic water of western East Sea, observed 64 species including warm water species and cold water species. Aikawa (1934, 1936) reported Tsushima Warm Current Water species in the part of this study area. Lee (1986) studied on phytoplankton ecology in the East Sea and reported 233 phytoplankton taxa. The important factors on phytoplankton distribution patterns in this study area were temperature and salinity in spring and autumn respectively (Shim and Lee, 1987).

In the course of discussion about the relationship between primary production and front, Kim (1988) reported a total of 211 phytoplankton taxa in autumn and Shim *et al.* (1989) reported three phytohydrographic regions of the southern waters of the East Sea. This study covers widely extended area of the East Sea compared to the area investigated by the above studies.

MATERIALS AND METHODS

Samplings were performed during three cruises in the southern waters of the East Sea (Fig. 1). The first, second and third cruise were done from 17 to 20 May, 1988, 8 to 14 July, 1989 and 23 November, 1991 respectively.

Qualitative and Quantitative Analysis

For qualitative anaylsis of phytoplankton, a Norpac type plankton net with 56 μm mesh opening was towed vertically. The samples were preserved with neutralized formalin at a final conce ntration of 4% and identified with a light microscope (Oympus BHS) enable to magnify upto 2500 times.

The samples for quantitative study were collected with Niskin samplers at each station. 500 m*l* sea water was subsampled into the polyethylene bottle and was fixed with modified Lugol's solution as preservative immediately after subsampling (Throndsen, 1978). These bottles were wrapped with aluminum foil to prevent from photo-oxidation of iodine. After settled and concentrated, the samples were subsampled into Sedgwick-Rafter counting chamber and Palmer-Maloney slide. Counting the phytoplankton were done with the light microscope and the data was converted into the original concentration level.

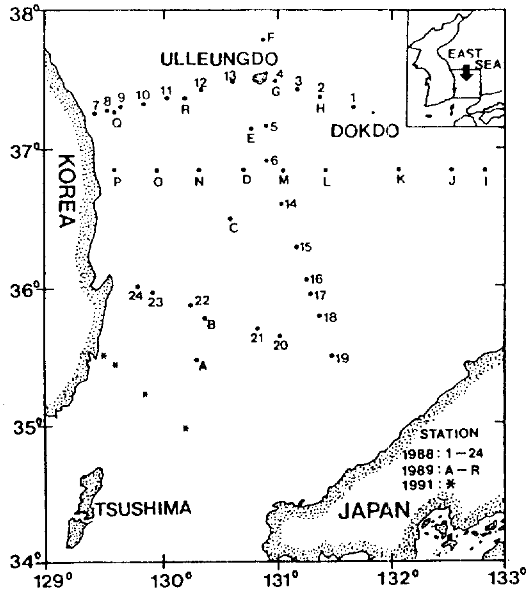

Fig. 1. A map showing sampling stations in the study area.

Data Processing

The species diversity of phytoplankton were calculated with Shannon-Wiener index. For the study on the spatial variation of phytoplankton populations, cluster anlyses were performed with quantitative data. The data was transformed logarithmically for log-normal distribution and correlation coefficient was used as similarity index (Davis, 1973).

RESULTS AND DISCUSSION

Species Composition

A total of 190 phytoplankton taxa was identified in the study area, of which phytoplankton community was composed of diatoms, dinoflagellates,

Table 1. The dominant species, their standing stock percentage and ocurrence frequency (%) within the euphotic depth.

	Species	Percentage	Freuency
1988 (May)	*Leptocylindrus danicus*	65.7	73.0
	Nitzchia pungens	18.9	73.0
	Bacteriastrum delicatulum	4.1	42.0
1989 (Jul.)	*Skeletonema costatum*	29.8	95.3
	Chaetoceros socialis	21.2	71.9
	Rhizosolenia alata f. *gracillima*	12.0	20.3
	Prorocentrum minumum	6.5	60.9
1991 (Nov.)	*Chaetoceros socialis*	26.5	85.7
	Nitzschia sp.	11.5	78.6
	Nitzschia delicatissima	7.5	85.7
	Gymnodinium sp.	6.8	78.6

silicoflagellates and euglenoids. Diatoms were made up 122 species and outnumbered any other groups in terms of species numbers. Dinoflagellates, silicoflagellates followed consisting of 62 species, 4 species respectively.

In general diatoms were the most dominant group in the whole of the study area. Among the total taxa observed in quantitative samples, only three diatom species occupied 88.7% of the total phytoplankton standing stocks within the upper 60 m layer of the study area in May, 1988. *Leptocylindrus danicus*, the most dominant species in the whole stations, occupied 65.7% of the total phytoplankton standing stocks, followed by *Nitzschis pungens* (18.9%), *Bacteria delicatulum* (4.1%) (Table 1). All the groups mostly consisted of neritic and cold water species. This suggests that the study area would be affected by the North Korean Cold Water and the environmental conditions could be favorable for the blooming of neritic species. Among the 3 dominant species in May 1988, *Leptocylindrus danicus* and *Nitzschia pungens* were dominated also at the upwelling region of Kuroshio Current in Japan where *Nitzschia pungens* predominated (Furuya *et al.*, 1986). This means that these species have a liking for fluctuating conditions. Accordingly, occurrence of these species indicates that this environmental conditions are unstable.

In July 1989, *Skeletonema costatum* (29.8%) was the 1st dominant species in the whole of the study area and followed by *Chaetoceros socialis* (21.2%), *Rhizosolenia alata* f. *gracillima* (12.0%). *Rhizosolenia alata* f. *gracillima* appeared, however, at small parts of total quantitative samples showing lower occurrence frequency level (20.3%) than any other dominant species.

Kim (1988) reported *Chaetoceros* sp. as the first dominant species and *Thalassiothrix frauenfeldii* as the highest frequent species in Autumn in this study area. However, the result of present study showed that *Chaetoceros socialis*. an unidentified pennate diatom species, *Nitzschia delicatissima* and *Gymnodinium* sp. were dominant in Autumn, 1991. The difference between the present result and Kim's (1988) might be caused by different annual conditions, sampling month and area; Kim (1988) investigated comparatively wide area in October, 1986, but autumn investigation of this study was performed at only a small portion of the East Sea (Fig. 1) and 5 years after his study.

A total of 62 species dinoflagellates observed in this study and included 14 species of genus *Protoperidinium*, 13 species of genus *Ceratium* and 7 species of genus *Prorocentrum*. The species numbers of these three genera occupied 54.8% of total species number of dinoflagellates. In May 1988, 46 species of dinoflagellates were observed and occupied 29.7% of total phytoplankton species. Although dinoflagellates accounted for relatively high fraction in qualitative result, their quantities (standing stocks) were very low (0.6%) at most of the samples (Table 2). But, at 120 m water depth dinoflagellates amounted to 17.6% of total phytoplankton standing stocks. This suggested that they should have fairly high moving ability by flagella.

32 species of dinoflagellates were recorded in

Table 2. The quantitative percentages of the various taxonomic groups in each depth in May, 1988

Taxon/Depth	0 m	20 m	40 m	60 m	120 m	all
Diatoms Centrales	88.6	79.3	68.3	57.1	60.3	78.2
Pennales	10.5	20.1	30.9	41.9	21.4	21.1
Dinoflagellates	0.7	0.5	0.6	0.9	17.6	0.6
Silicoflagellates	-	-	0.1	0.1	0.7	0.1
Euglenoids	0.1	-	-			-

Table 3. Seceis diversity indices measured in this study

Year(month)	Range	Average	(S.D.)	Sample Number
1988(May)	0.36-2.34	1.24	0.49	81
1989(Jul.)	0.26-2.36	1.69	0.35	64
1991(Nov.)	1.33-2.68	2.12	0.35	14

(S.D.: Standard deviation)

summer 1989, being relatively less abundant compared with that of spring data. However, standing stock of dinoflagellate in summer was larger than in spring. *Prorocentrum minimum* and *Prorocentrum triestinum* showed a little high standing stocks at several stations and especially, in northwestern region of the study area *prorocentrum minimum* occurred more than 20 cells/m*l*.

Silicoflagellates including 4 species were rare but showed wide distribution. *Eutreptiella marina* and an unidentified *Euglena* sp. belonging to Euglenophyta were rare too.

Species Diversity of Phytoplankton Community

The diversity of a plankton community might be expressed using data on the number of species present, the distribution of biomass, the pigment composition or a number of other parameters related to plankton properties which could be easily measured (Pielou, 1975). The commonly used diversity index which comprises richness and evenness (Peets, 1974) is Shannon-Wiener index. An index of species diversity is valuable both in characterizing the flora of different regions and in examining species succession (Raymont, 1980).

The diversity values measured in this study are summarized at Table 3. The averaged value is 1.24 in May, 1988 and this is quite lower than that of previous study (Lee, 1986) in which the value is 2.47 in May, 1984.

Margalef (1958) pointed out that while the mixing of two water masses might result in a passive increase in density, more generally the meeting of water masses caused stress, though there was an enhancement of production. Frequently better nutrient balance in the mixed layer led to active growth of the population, but this was accompanied by a lowering of diversity; only some species react immediately to the improved conditions by rapid growth. Thus, in this study area where the biomass was increased, such active contacts of water masses would partly play a role of lowering of the species diversity in May, 1988.

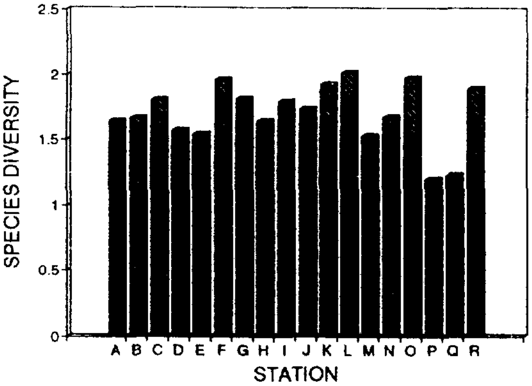

Fig. 2. Species diversity indices measured in each station July, 1989.

The diversity indices in summer 1989 were ranged from 0.26 to 2.36 and averaged to be 1.69. This was slightly high in comparison with the average value (1.24) in spring 1988, but this was lower than in May, 1984 (Lee, 1986). These relatively low diversities were observed in the most of study area and caused by only a few dominant species. This implied that phytoplankton community structure was unstable.

The means of diversity indices in water column were ranged from 1.21 to 2.02 and specially quite

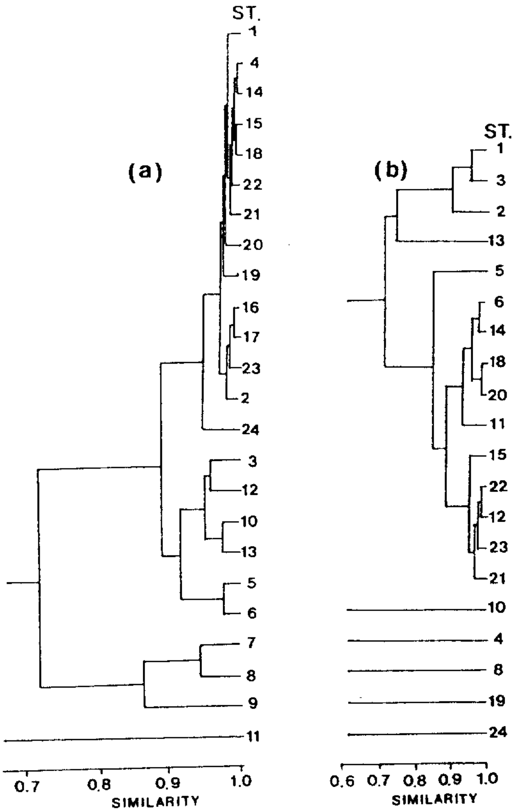

Fig. 3. Dendrogram showing clusters from samples in surface(a) and chlorophyll maximum layer(b) in May, 1988

low values were due to monospecific dominance with *Skeletonema costatum* which were measured in neritic region, station P and Q (Fig. 2). Lower diversities in neritic water than in oceanic water are general pattern. This pattern had already been reported by Kim (1988) in this study area. The average diversity index in November 1991 was 2.12 which was higher than that of spring and summer data. But, it is not certain that the community structure in autumn was more stable than that in spring or summer because autumn data was obtained from only 4 stations.

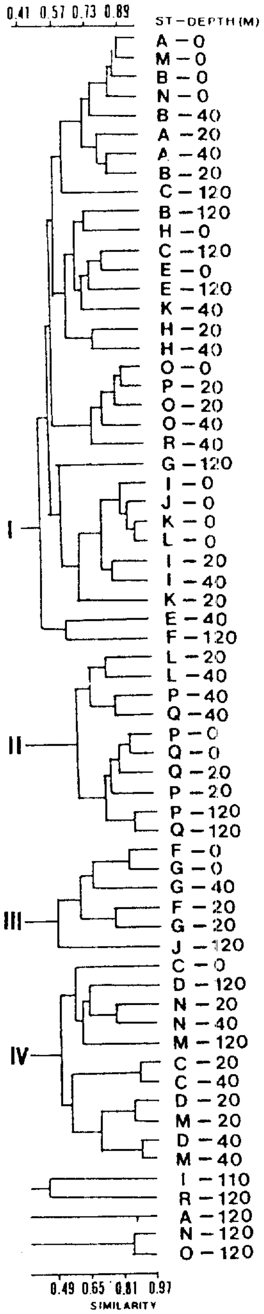

Fig. 4. Dendrogram showing clusters from samples in July, 1989.

Phytohydrographic Regions

A single cluster of 62 samples out of 81 samples from all stations in May 1988 was found with similarity larger than 0.7. This indicates that whole stations were not variable horizontally and vertically in distribution of phytoplankton species. It was verified by the cluster analysis at each depth level. At surface, all samples were grouped into

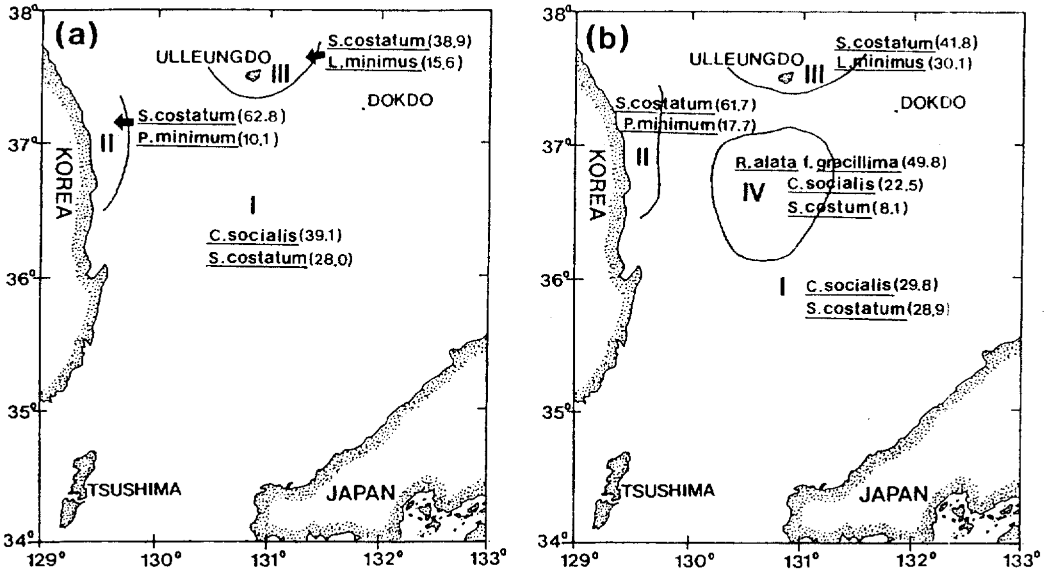

Fig. 5. Phytohydrographic region in this study area(surface(a) and 40 m depth(b)). Numbers in parentheses are percentages of standing stocks

single cluster with similarity over 0.72, except station 11 (Fig. 3 (a)). In chlorophyll maximum layer (about 40 m water depth) some different trend was seen. There existed much more heterogeneous samples than surface layer and correlation coefficients between some stations were much lower. However, its variation was not so great, which could be known from the large single cluster of 15 stations out of 20 stations with similarity larger than 0.72 (Fig. 3(b)). This implied that the phytoplankton species assemblages would be nearly same in all station and depth but would be more similar in surface layer than in the chlorophyll maximum layer.

The dendrogram from cluster analysis between stations in July 1989 is shown in Fig. 4 and phytohydrographic regions according to cluster analysis are shown in Fig. 5. This study area could be divided into four phytohydrographic water masses (Fig. 4) but into only three water masses (Region I, II, III) at surface (Fig. 5(a)). Region I reflected offshore large water mass affected by Tsushima Current and region II was characterized by inshore neritic water mass. Monospecific dominance of *Skeletonema costatum* (62.8%) and high standing stocks of *Prorocentrum minimum* (10.1%) was shown in surface water of region II. Region III represented productive area having comparatively large biomass and high primary productivity (Shim *et al.*, 1992) affected by Ulleung Island. The dominant species were *Skeletonema costatum* (38.9%) and *Leptocylindrus minimus* (15.6%) in the region III and species diversity was recorded slightly higher than in the other regions.

On the other hand, the result of cluster analysis at 40 m water depth (Fig. 5(b)) was characterized by the other water mass, region IV. The region had different phytoplankton community structure from the other regions. That could be distinguished by the phenomenon of dominance of *Rhizosolenia alata* f. *gracillima* (49.8%) and *Chaetoceros socialis* (22.5%). *Chaetoceros socialis* distributed in broad area including region I and IV, but *Rhizosolenia alata* f. *gracillima*, a warm water species, occurred only in region IV. The existence of region IV was distinctive feature at 40 m water depth and was not shown at surface. Kim (1990) reported that convex lens shaped water mass was formed between 50 m to 350 m water depth in the area of region IV at the time of inveatigation of this study, having very homogeneous physical characteristics. The temperature and salinity were 10°C and 34.3‰ respectively. So it seemed that the 10°C water mass located below the region IV might affect the formation of phytohydrographic region IV at 40 m water depth. Though the mechanism of formation of 10°C water mass was not interpreted completely, the water mass should affect the distribution of phytoplankton. That is, large cell sized phytoplankton, *Rhizosolenia alata* f. *gracillima*, might be sinked from surface and concentrated at 40 m water depth over the 10°C homogeneous water mass.

SUMMARY

For the study of phytoplankton community structure in the southern waters of the East Sea, three times investigations were performed in May 1988, July 1989 and November 1991. A total of 190 phytoplankton taxa was observed in this study and diatoms predominated over the entire study area. In spring, *Leptocylindrus danicus, Nitzschia pungens* and *Bacteriastrum delicatulum* were dominant species. In summer, *Skeletonema costatum* was the 1st dominant species in the whole of the study area and followed by *Chaetoceros socialis*. On the other hand, *Chaetoceros socialis, Nitzschia delicatissima, Nitzschia* sp. and *Gymnodinium* sp. were dominant species in autumn. Phytoplankton diversity indices measured were 1.24 in spring, 1.69 in summer and 2.12 in autumn, respectively and these values were slightly lower than those values in previous studies. While phytohydrographic regions represented by the result of cluster analysis were not distinct in May, there were three phytohydrographic regions at surface waters and four regions at 40 m water depth in July 1989. The fourth phytohydrographic region at 40 m depth in July was located on the 10°C water mass formed between 50 m to 350 m in the middle of this study area.

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