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Studies on the Plankton in the Southwestern Waters of the East Sea (Sea of Japan) (II)

Phytoplankton —Standing crop, nanofraction, and primary production—

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東海 西南 海域의 플랑크톤 研究(Ⅱ)

식물플랑크톤—현존량, 미세플랑크톤 및 1차 생산—

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Abstract: A description of the "phytohydrography" in the southwestern waters of the East Sea is given from concurrent measurement of temperature, chlorophyll-a, nutrients, and phytoplankton and also from the calculated primary production during the two cruises in May and October, 1984. Past history of water mass is relatively well reflected in the distribution of phytoplankton species, but such a reflection is rarely shown in the distribution of physical and chemical parameters in general. Upper layer of the waters around Ul-gi and Gampo is typically characterized by the high chlorophyll-a, high primary production, and low nanofraction ratio due to the continuing supply of nutrients from the nutrient-rich cold water underneath. Water of Tsushima current shows poor standing crop in terms of cell numbers and chlorophyll-a concentrations, extremely high nanofraction ratio, and very low primary production. The overwhelming importance of the nanofraction is confirmed in phytoplankton cell numbers, chlorophyll-a concentration, and possibly enough in primary production. This emphasizes the exceptionally strong inflow of warm water into the study area from south among all the waters around the whole Korean peninsula.

요약: 1984년 5월과 10월, 2회에 걸쳐 동해 서남 해역에서 조사한 수온, 클로로필-a, 영양염, 식물플랑크톤 및 일차생산에 관한 자료를 토대로 하여 대상 수역의 phytohydrography를 논의하였다.

식물플랑크톤의 종별 양적분포로 부터 특성 해수의 이전 환경을 추측할 수 있었는데, 이는 해양물리·화학적인 자료만으로는 기대하기 어려운 결과였다. 울기 및 감포 부근 해역의 상층부에서는, 그 하층에 근접한 냉수로 부터 영양염을 공급받아, 높은 일차생산력, 높은 클로로필-a 및 낮은 미세플랑크톤 비율 등의 특징이 나타났다. 반면에 대마난류수에는 매우 낮은 일차생산력, 빈약한 현존량 및 극히 높은 미세플랑크톤 비율 등의 특징이 나타나 좋은 대조를 이루었다. 연구해역에서 식물플랑크톤의 세포수 뿐만 아니라 클로로필-a 및 일차생산량에서도 미세플랑크톤이 압도적으로 우세함을 확인하였다. 이는 한반도 전해역 가운데 난류수가 예외적으로 강하게 유입되는 연구해역의 생물해양학적 특성을 잘 반영해 주는 현상이다.

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INTRODUCTION

In the previous series of the phytoplankton studies in the southwestern waters of the East Sea (Shim, 1982; Shim et al., 1983; Shim et al., 1984), the overall objective was to provide information on abundance and composition of the plankton flora.

This study was done to estimate the relative importance of nanoplankton, to understand the distribution pattern of phytoplankton pigments, and to calculate the primary production adopting and modifying Bannister's model (Bannister, 1975).

Few studies are found in the literature which deals with the nanofraction, phytoplankton pigments, or primary production in the study area. Jun and Park (1969) related the spatial distribution of chlorophyll-a concentration to the change of water temperature, phosphate-P concentration and transparency of water in the southern East Sea. Shim and Bak (1983) investigated the distribution pattern of chlorophyll-a in the previous series of this study. In situ primary productivity was measured in the western channel of the Korea Strait to find the largest chlorophyll-a concentration and primary productivity in autumn, and the smallest in summer (Chin and Hong, 1985). Cho (1985) measured chlorophyll-a concentrations of microplanktion and nanoplankton, and discussed the relative importance of nanofraction in the study area.

MATERIALS AND METHODS

1. Field and laboratory works

1. 1. Sampling

Samples were taken during 2 cruises of the training ship "Hanbada" of Korea Maritime University each lasting 4 or 5 days. The sampling was done between 14 and 18 May, and between 29 October and 1 November, 1984. In every 15 to 11 stations (Figs. 1 and 2) samples were taken considering the previously accumulated data. Table 1 shows the total number of data collected in both cruises.

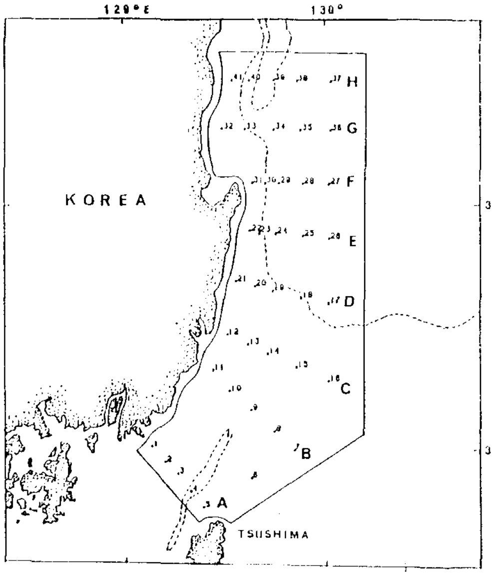

Fig. 1. Position of sampling stations visited in May, 1984. Isobaths of 200m are indicated by dotted lines.

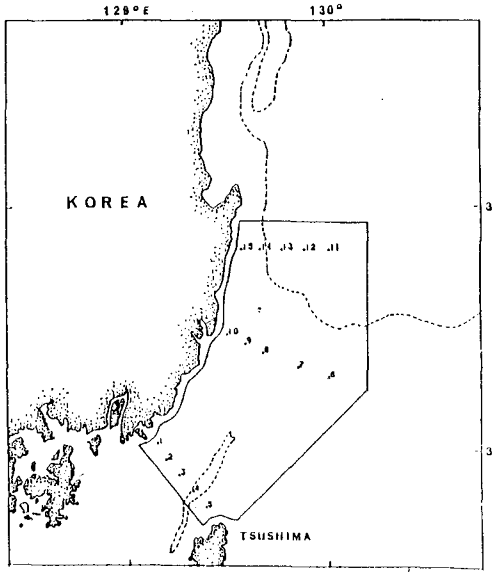

Fig. 2. Position of sampling stations visited in October, 1984. Isobaths of 200m are indicated by dotted lines.

1. 2. Phytoplankton

The quantitative samples of phytoplankton were collected using Van Dorn water samplers, stored in 500ml bottles, and fixed with modified Lugol's solution as a preservative.

Indentification and counting of phytoplankton was done with a light microscope (Nikon type 104). In many cases naked microflagellates lose their flagella and even smaller forms (less than 2 μm in cell length; Johnson and Sieburth, 1975; Waterbury et al., 1979; Murphy and Haugen, 1985) inevitably excluded from nanoplankton counting.

1. 3. Chlorophyll

Water samples for chlorophyll measurements were collected using Van Dorn water samplers, filtered through 342μm mesh nylon cloth, and transferred into 1,000ml polyethylene bottles. One ml of $MgCO_3$ suspension was added to each sample bottle, and the contents were then filtered through Whatman glass microfibre filter (GF/C). For the determination of nanofraction of chlorophyll-a another filtration through a series of 22μm Nitex screen and Whatman glass microfiber was done. Chlorophyll-a and phaeophytin concentrations were measured following the methods given by UNESCO (1966) and Lorenzen (1967).

1. 4. Physical and chemical parameters

Water temperature was measured using protected and unprotected reversing thermometers attached to Van Dorn and Nansen bottles. Water for nutrient analyses was drawn from the Van Dorn water sampler, and filtered through Whatman glass microfibre filter. Approximately 500ml of the filtrate was subsampled into the polyethylene bottle, stored at $-20°C$ during transporation and before analyses. Subsequently the concentrations of reactive nitrate, nitrite, silicate and inorganic phosphate were determined according to the respective methods in Strickland and Parsons (1972).

Table 1. Total number of data obtained in May and October.

Cruise	May	October
Temperature	167	15
NO_3-N	178	—
NO_2-N	178	—
PO_4-P	178	—
$Si(OH)_4$-Si	178	—
Chlorophyll	146	15
Phytoplankton	33	15

2. **Data processing**

2. 1. Species composition and abundance

Simpson's index for dominance was calculated as an index of dominance measure.

$$C=\sum_{i=1}^{s}[n_i/(n_i-1)]/[N(N-1)],$$

where N is the total cell number in a sample and n_i is the cell number of the ith species.

The diversity index (H' in bits) which compounds richness with eveness (Peet, 1974) was calculated by Shannon-Wiener formula,

$$H'=-\sum_{i=1}^{s}p_i\cdot\mathrm{Log}_2\cdot p_i.$$

Where $p_i=n_i/N$ and is the proportion of the collection belonging to the ith species.

For the calculation of equitability the formulation,

$J=H'/H_{max}$ (Pielou, 1966),

that expresses the diversity (H') observed as a proportion of the maximum possible diversity (H_{max}) was followed.

2. 2. Calculation of the primary production

With the data of May and October primary productions per unit volume of seawater (mg C/m^3/day) and per unit surface area (mg C/m^2 /day) were calculated adopting and modifying the Bannister's model (Bannister, 1974).

To simplify theoretical analysis he chose the quantum yield of photosynthesis in weak light (Q_{max}) instead of the maximum rate in saturating light (P_{max}) as a parameter of the production equation. The following derivation shows the relation between Q_{max} and P_{max}.

The instantaneous rate of photosynthesis, assuming Smith's equation (Smith, 1936), will be

$$pdz/12(\text{moles } C/\text{m}^2/\text{day}) = (P_{\max}\cdot Idz/12)/(Ik^2+I^2)^{1/2}, \quad (2)$$

where I_k is half saturation light intensity. The quantum yield Q will be

$$Q \text{ (moles } C/\text{einstein absorbed)} = (pdz/12)/dIa = (P_{\max}/12\cdot Kc\cdot C)/(I_k^2+I^2)^{1/2}. \quad (3)$$

The quantum yiel will reach a maximum in weak light, i.e. when I becomes small compared with I_k; therefore,

$$Q_{\max}=Q(I\rightarrow 0)=P_{\max}/12\cdot Kc\cdot C\cdot I_k \quad (4)$$

or

$$P_{\max}=12\cdot Q_{\max}\cdot I_k\cdot Kc\cdot C \quad (5)$$

Substitution of equation (5) into equation (2) transforms the latter into functions of the parameter $Q_{\max}$.

$$P=Q_{\max}\cdot I_k\cdot Kc\cdot C\cdot I/(I_k^2+I^2)^{1/2} \quad (6)$$

As the Bannister's production equation (6) gives the potential photosynthestic rate which is higher than that in natural conditions (Parsons, Takahashi and Hargrave, 1982), two factors lessening the potential photosynthetic rate are additionally included. One is the hyperbolic effect of nutrient concentration on the growth of phyto plankton (equation 7), and the other is the effect of water temperature, Q_{10} (equation 8).

$$G=G_{\max}\cdot\{N/(Ks+N)\} \quad (7)$$

$$G_{\max}=0.59\ e^{0.0633\text{Temp}} \text{ (per day)} \quad (8)$$

Equations (6), (7), (8) are combined in one equation for the purposes in this model,

$$P=\{(Q_{\max}\cdot I_k\cdot Kc\cdot C\cdot I/(I_k^2+I^2)^{1/2}\}\cdot \{N/(Ks+N)\}\cdot(G_{\max}t_1/G_{\max}t_2) \quad (9)$$

where P is the production (g C/m^3/day), and Ks is the characterisastic half saturation constant of the nitrite-nitrate-N concentration (N). $G_{\max}t_1$ is the maximum growth rate at the water temperature, t_1 in conditons where neither light nor nutrients are limiting.

Bannister (1974) believed that a value of $Q_{\max}$ of 0.06 (moles C/einstein absorbed), and accepted arguments that Kc is approximately constant close to 0.016 (m^2/mg chl-a). Among input data needed those on chlorophyll-a concentration (C), nitrite-nitrate-N concentration (N), and water temperature (t_1) were from direct measurements and analyses. Finally the remaining values to be determined are ambient light intensity (I), half saturation concentration of nitrite-nitrate-N (Ks).

For integration of photosynthesis over time diurnal variation of light intensity was simulated by the following equation neglecting changes in cloud cover (Golterman, 1975),

$$I_0=0.5\ I_{\max}\cdot\{1+\text{Cos}(2\times 3.141592\cdot t/D)\},$$

where D is the day length (in hours) and t is the time of a day in hours. The abscissa is shifted so that $t=0$ at noon (thus $t=-0.5\ D$ at sunrise and $t=0.5\ D$ at sunset). $I_{\max}$ is the maximum light intensity at noon, and in this study it is replaced by the average of 30 days of average hourly rate of radiation from noon till 1 p.m. measured by Central Meteorological Office using a Eppley pyranometer. The ambient light intensity below water surface was simulated by the next equation,

$$I=(1-R)\cdot Io\cdot e^{-EZ}.$$

Here E is the extinction coefficient estimated from Secchi disc transparency (Zsd) by the relationship, $E=1.7/\text{Zsd}$ (Poole and Atkins, 1929; Idso and Gilbert, 1974), and Io is light intensity just above the surface. R is the portion of reflected light at water surface whose average value of 0.3 was adopted following the measurements of Jasper et al. (1983). The proportion of photosynthetically active radiation (PAR) was assumed to be 45% of the total solar radiation (Golterman, 1975).

To determine the value of I_k, the results of primary production measurement in the Western Channel of the Korea Strait (Chin and Hong, 1985) were used as input data solving equation (6) on I_k. For the study area Ks value of 0.25

was chosen considering the influence of oceanic waters after Eppley et al. (1969).

The photosynthetic rate were integrated numerically over time during a day length using Simpson's rule. The resulted values (g C/m^3/day) and the respective depths were used as input data into the polynomial curve fitting program (Spain, 1982). Then the polynomial equation was integrated analytically over the total sample depth (X), from surface layer down to 125m depth layer, to find the photosynthetic rate per unit area of the sea surface (g C/m^2/day).

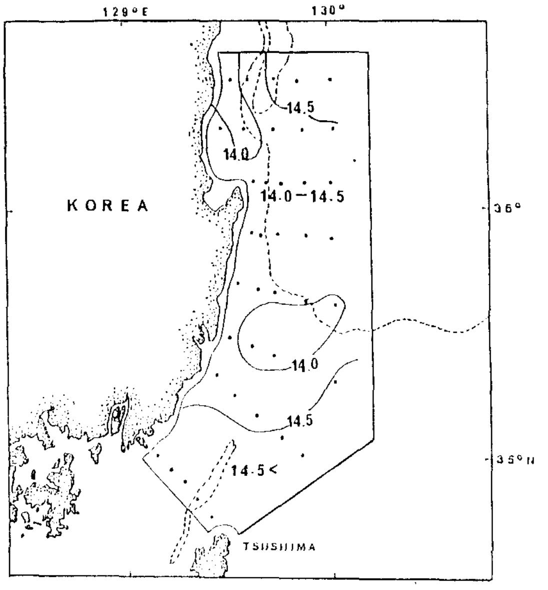

Fig. 3. Distribution of surface temperature (°C) in May, 1984.

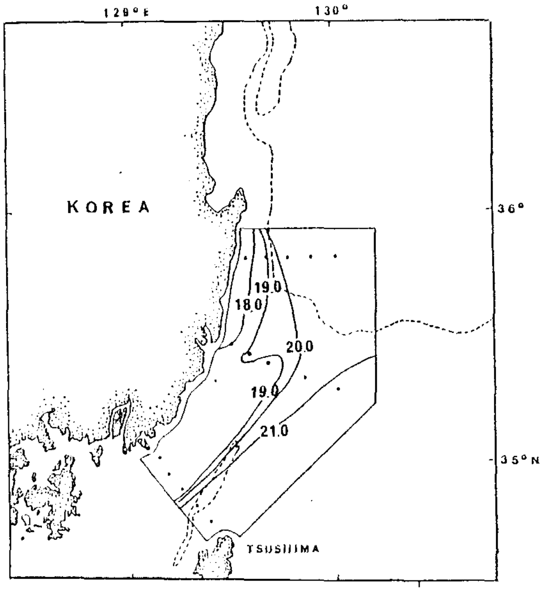

Fig. 4. Distribution of surface temperature (°C) in October, 1984.

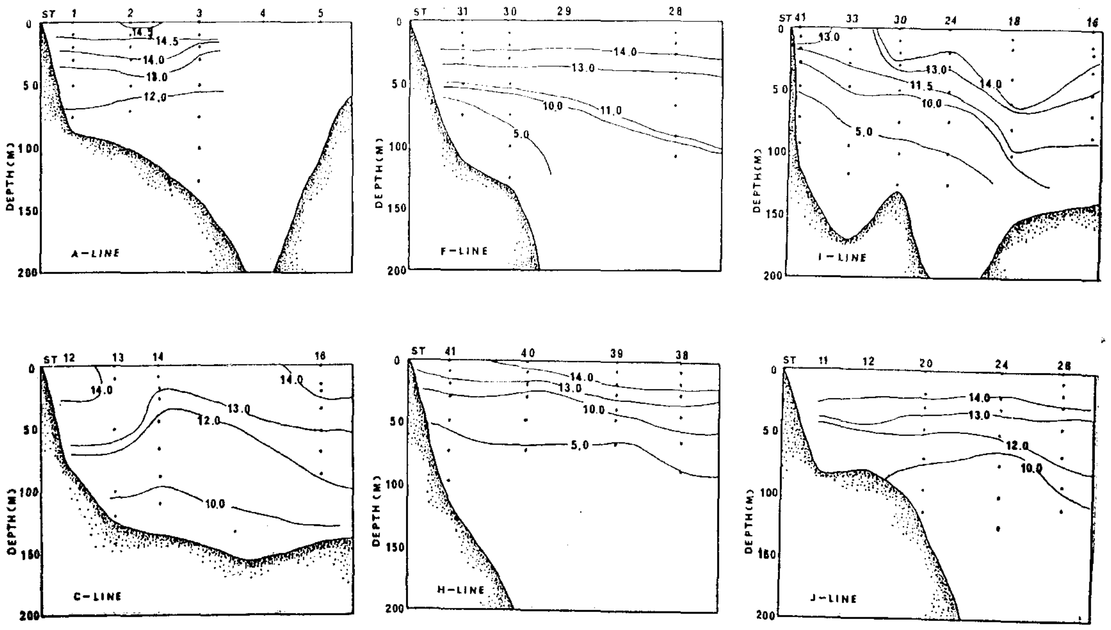

Fig. 5. Temperature (°C) profilles on each line in May, 1984 (See Fig. 1 for location of each line).

RESULTS AND DISCUSSION

1. Temperature and nutrient

1. 1. Water temperature

In October only the surface data were collected. Surface distribution of temperature in May and October are shown in Figs. 3 and 4, respectively. Rather homogeneous distribution of water temperature is seen in Fig.3 with some patches of cooler water. Northern inshore patch seems to be originated from the southward moving of cold water mass, and southern offshore patch might be formed though the upwelling of the cold water (Chung, et al., 1984)

Temperature profiles of line A,C,F,H,I, and J (Fig. 5) reveals rather mild influence of cold water in the offshore stations. Isotherms of cold water (lower than 5°C) forms a north-south slope from the 50m depth layer of H line down to the bottom of D line (125m depth). Profile of line I illustrates the northward gradual decrease in the thickness of warm water layer.

Surface distribution of water temperature (Fig. 4) in October shows rather heterogeneous pattern. Tsushima warm current water is restricted to the offshore side of the study area. Even in offshore area of the northern part lower temperature is not found.

1. 2. Temporal variation of nutrient concentrations

Concentrations of inorganic nutrients (initrate, nitrite, phosphate, and silicate) were determined on the samples of Cruise 2, 3, 4 (previous cruises), and 5 (the cruise in May for this study). The summary of the nutrients properties are shown in Tab. 2.

Among the nutrients the distribution of nitrate-N concentration is highly variable with both time and space, and this nutrient might be an important factor controlling the phytoplankton growth in the study area (Shim and Yang, 1984). The temporal variation of silicate-Si concentrations seems to reflect the general pattern of spring diatom blooms in the temperate zone.

The vertical gradients of nutrients concentrations are most evident in the samples of cruise 3, which is coincident with the trend of temperature, salinity, and dissolved oxygen distributions. On the contrary the least vertical gradient of nutrient concentrations was found in the samples of Cruise 4. This could be partly related to the influence of the nasty state of sea surface during the whole period of Cruise 4. Simple linear regression of nutrient concentrations with the sampled depths (in meters) discriminates the degree of these vertical gradients so well (Tab. 3).

Below pycnocline the nutrient concentration increases with depth except nitrite concentration. Often nitrite profile shows a maximum

Table 2. Mean, standard deviation. and the number of determinations of nutrient properties in the water column (upper lines) and in surface water (lower lines). The unit of the concentrations is (*μg-at/l*).

Cruise (M/D)	NO_3-N	NO_2-N	PO_4-P	$Si(OH)_4$-Si
2(3/29-4/1)*	2.73/2.44 (82)	0.45/0.19 (82)	0.50/0.23 (82)	8.29/3.84 (82)
	1.66/0.56 (15)	0.36/0.08 (15)	0.39/0.12 (15)	6.81/1.42 (15)
4(4/11-4/16)*	3.40/2.89(189)	0.43/0.35(189)	0.45/0.31(189)	5.01/2.07(187)
	2.74/2.47 (25)	0.43/0.28 (25)	0.29/0.08 (25)	4.38/1.59 (25)
5(5/14-5/18)	1.55/0.75(178)	0.41/0.27(178)	0.91/0.29(178)	7.18/2.72(178)
	1.02/0.26 (25)	0.29/0.13 (25)	0.71/0.69 (25)	5.99/1.74 (25)
3(10/25-10/29)*	3.69/4.25(230)	0.33/0.28(232)	0.42/0.33(235)	7.32/5.16(229)
	0.65/0.50 (35)	0.25/0.17 (35)	0.30/0.29 (35)	4.23/1.42 (35)

*Previous cruises

layer in the water column. Frequently isotherms of low temperature (2-8°C) are coincident with a dense cluster of isopleths of nitrate, phosphate, and silicate concentrations.

In surface mixed layer of the study area the pattern of nutrient distribution is the most variable, which is of consequence. Thus roughly the same patterns, however, are noticeable in the vertical profiles of temperature, nitrate, phosphate, and silicate properties with occasional slight modifications in the surface-mixed layer.

2. Phytoplankton Community

2. 1. Species composition and abundance

In Table 4 is shown the number of species and genera of the phytoplankton observed in the quantitative samples from each cruise along with the data obtained from the previous cruises. Diatoms outnumber any other groups in its number of species and genera, followed by dinoflagellates and then by silicoflagellates. Much more species occur in autumn than in spring reflecting the general successional feature of phytoplankton flora in temperate seas.

Table 3. Correlation coefficients in simple linear regression of nutrient concentrations with samled depths.

Nutrient	Cruise	Correlation coefficient
Nitrate-N	3*	0.70
	4+	0.40
Silicate-Si	3	0.64
	4	0.29

*and +; Previous cruises

Quantitatively diatom occupies 67-97 percent of total netplankton and dinoflagellates 2-31 percent during the six cruises. In the diatom community genera *Chaetoceros*, *Nitzschia* and *Thalassiosira* are dominant (Table 5). As is the chlorophyll trend of temporal variation (Table 6)

Table 4. The number of species and genera (in parentheses) of the phytoplankton observed observed in the quantitative samples from each cruise.

Cruise	1	2	3	4	5*	6+
Diatoms	33 (95)	23(50)	32 (91)	27(59)	19(34)	23(64)
Dinoflagellates	13 (27)	7(15)	9 (23)	12(27)	11(22)	7(11)
Silicoflagellates	4 (4)	3 (3)	4 (4)	3 (3)	2 (2)	1 (1)
Cryptomonads	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
Euglenoids	1 (1)	—	1 (1)	1 (1)	1 (1)	1 (1)
Blue-green algae	1 (1)	—	1 (1)	—	—	—
Rhaphidophycean	1 (1)	—	—	—	1 (1)	—
Total	54(130)	34(69)	48(121)	44(91)	35(61)	33(78)

*Cruise of May in this study +Cruise of October

Table 5. Mean percentage occupied by dominant netplankton groups in the quantitative samples from ecah cruise.

Cruise (M/D)	2 3/29-4/1	4 4/11-16	5* 5/14-18	1 9/21-24	3 10/25-29	6+ 10/29-11/1
Diatoms	90	86	78	67	96	97
Chaetoceros	15	9	1	17	46	35
Nitzschia	35	26	55	13	21	24
Thalassiosira	—	43	—	—	—	—
Dinoflagellates	6	12	21	31	2	2
Gymnodiniales	4	7	14	26	1.7	1

*Cruise of May in this study +Cruise of October

Table 6. Summary of chlorophyll-a concentrations. Data are compiled to show mean, standard deviation, the number of determinations (upperlines), and the maximum value (lower lines). The unit of concentrations is (mg chl/m^3).

Cruise	Total sample	Surface sample
4(4/11-4/16)*	1.36/0.75(168)	1.65/0.44(27)
	4.52	2.55
5(5/14-5/18)	0.75/0.49(146)	0.87/0.49(25)
	2.18	2.18
3(10/25-10/29)*	0.44/0.44(219)	0.62/0.50(31)
	2.54	2.19
6(10/29-11/1)	—	0.89/0.32(15)
	—	1.35

*Previous cruises

mean phytoplankton abundance shows two maxima in its temporal variation (Table 7), one in spring and the other in autumn. Maximum cell concentration reaches up to 3,040 cells/ml including nanoplankton, and that of netplankton reaches 369 cells/ml.

Information measures of diversity (Shannon-Wiener index, Simpson's index, and equitability index) are calculated for every sample, and the statistics of the measures are given in Table 8. While lower specific diversity is found around summer season higher dominance index is seen at that time. Equitability index, however, shows seemignly random values in each cruise. Vertically equitability index is almost uniform throughout the whole water column surveyed.

2.1.1. May

Only the surface plankton was studied in May and October. Among a total of 61 species obser-

Table 7. Statistics on the temporal variations of phytoplankton standing crop in surface water. Data are compiled to show mean, standard deviation (upper lines), and ranges (lower lines). The unit of standing crop is cells/ml.

Cruise (M/D)	2* 3/29-4/1	4* 4/11-16	5 5/14-18	1* 9/21-24	3* 10/25-29	6 10/29-11/1
Netplankton	66/46	78/61	70/48	25/23	41/49	176/120
	7-181	14-270	6-179	2.9-94	0.9-169	35-369
Nanoplankton	—	798/282	783/622	—	226/150	720/275
	—	366-1434	151-2992	—	84-910	341-1187

*Previous cruises

Table 8. Summary of specific diversity(H'), dominance(C), and equitability(J') of phytoplankton in the water column (upper lines) and in surface water (lower lines). Data are compiled to show the mean, standard deviation, and the number of determinations.

Cruise (M/D)	H'	C	J'
2(3/29-4/1)*	3.28/0.68 (81)	0.15/0.11 (81)	0.85/0.08 (81)
	3.61/0.38 (15)	0.12/0.03 (15)	0.845/0.07 (15)
4(4/11-4/16)*	2.29/0.60(194)	0.31/0.13(195)	0.68/0.15(194)
	2.55/0.54 (33)	0.28/0.12 (33)	0.63/0.14 (33)
5(5/14-5/18)	—	—	—
	2.47/0.48 (33)	0.30/0.10 (33)	0.67/0.10 (33)
1(9/21-9/24)*	2.43/0.77(242)	0.27/0.13(252)	0.85/0.09(243)
	2.59/0.75 (38)	0.24/0.12 (38)	0.84/0.10 (38)
3(10/25-10/29)*	2.40/0.86(245)	0.30/0.16(248)	0.76/0.13(243)
	2.67/0.82 (34)	0.26/0.16 (34)	0.75/0.14 (34)
6(10/29-11/1)	—	—	—
	3.92/0.61 (15)	0.10/1.05 (15)	0.82/0.04 (15)

*Previous cruises

Table 9. Fifteen common species in May. Frequency is the number of occurrences among the total 33 samples. Percent dominance is in parentheses.

Species name	frequency
Asterionella glacialis	18
Cylindrotheca closterium	27 (5%)
Eucampia zodiacus	15
Leptocylindrus danicus	17
Nitzschia delicatissima	22 (7%)
Nitzschia seriata	31(47%)
Rhizosolenia pungens	22
Thalassiosira sp.	15
Ceratium kofoidii	14
Gymnodinium sp.	32
Gyrodinium sp.	32 (6%)
Prorocentrum dentatum	15
Protoperidinium bipes	15
Protoperidinium hirobis	17
Scrippsiella trochoideum	15

Table 10. Thirteen common species in October. Frequency is the number of occurrences among the total 15 samples. Percent dominance is in parentheses.

Species name	frequency
Bacteriastrum delicatulum	13
Chaetoceros compressus	12 (7%)
Chaetoceros curvisetus	14
Chaetoceros lorenzianus	12 (5%)
Cylindrotheca closterium	15(12%)
Hemiaulus haukii	12
Nitzschia delicatissima	15(17%)
Nitzschia seriata	14 (6%)
Rhizosolenia calcar avis	12
Rhizosolenia fragilissima	12
Rhizosolenia indica	12
Gymnodinium sp.	12
Gyrodinium sp.	13

ved in May fifteen species appeared in more than 40% of the totcl 33 samples (Tab. 9). ***Nitzschia seriata***, one of the most dominant species in the whole cruises, occupied 47% of the total netplankton in the surface layer of the study area, followed by ***Nitzschia delicatissima*** (7%), ***Gyrodinium*** sp. (6%), and ***Cylindrotheca closterium*** (5%).

In comparison with the diversity measures in Cruise 4 equitability index and dominance index in May are higher, but species diversity index is lower than those in Cruise 4. Such differences in diversity measures are from the exclusive predominance (47%) of only one species in May, which is different from the great dominance of the two rather equivalent species in Cruise 4 (Tab. 9).

2. 1. 2. October

Cell concentrations of netplankton in October is at least two times as high as in any other cruises (Tab. 7). However surface chlorophyll concentration is far lower than that in Cruise 1, and nearly the same as that in May (Tab. 10). Chlorophyll concentration per cell is a matter of consequence: ***Thalassiosira pacifica***, a centric diatom, predominates in cruise 4, but in October the two most dominant species are all pennate diatoms with less chlorophyll contents.

Among a total of 78 taxa observed 14 taxa appeared in more than 12 bottles (80%). The 5 most dominant species (Tab. 10) are all diatoms, and they occupy 47% of cells in surface water. No one speciess of dinoflagellates makes up 5% of all cells, and this means the general decrease of seawater temperature at that time. The greatest species diversity and rather high equitatability reflects the somewhat even distributions of species abundances in each sample.

2. 2. Spatial distribution

Quantitative data on each species in a space could be a quite powerful tool for the disclosure of some hidden facts in the sea even when its structure is so complex as is the study area. In this section spatial distribution of phytoplankton is considered in association with physical and chemical parameters and also with chlorophyll concentrations.

2. 2. 1. May

Chlorophyll distribution has close relation to

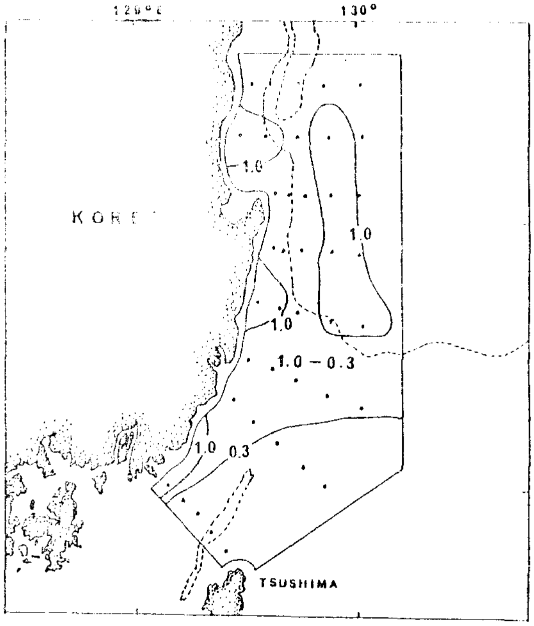

Fig. 6. Distribution of surface chlorophyll (mg chl-a/m^3) in May, 1984.

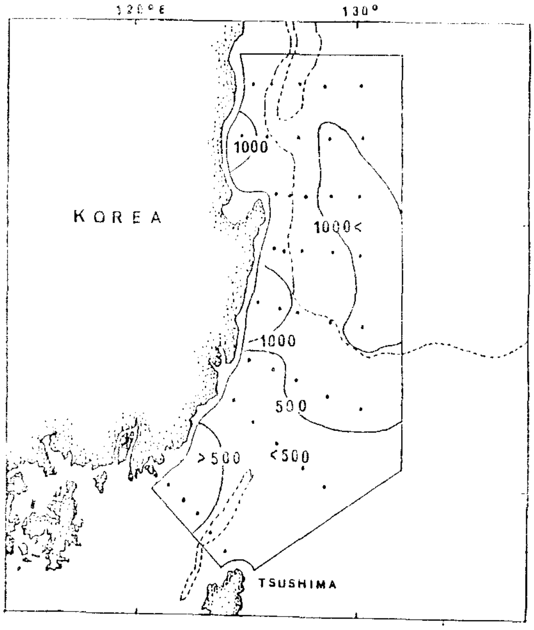

Fig. 7. Distribution of nanophytoplankton concentrations (cells/ml) in the surface layer in May, 1984.

the distribution of nanoplankton rather than to that of netplankton (Fig. 6, 7, and 8). This demonstrates the absolute importance of nanoplankton in the study on phytoplankton here.

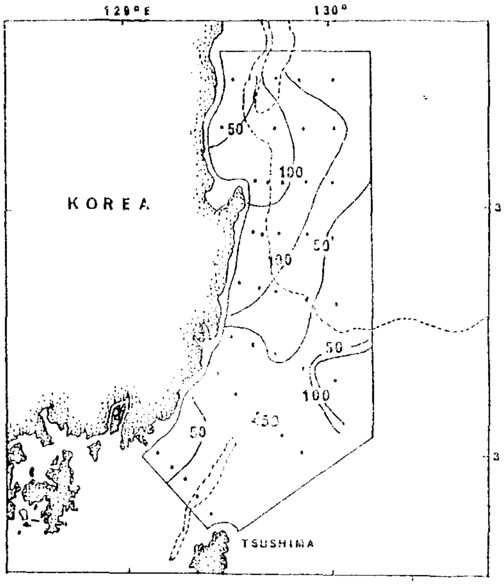

Fig. 8. Distribution of netplankton plankton concentrations (cells/ml) in the surface layer in May, 1984.

Nevertheless high standing crop is seen in the areas near Nagdong Estuary and off Gampo in the distribution of netphytoplankton as well as in that of nanoplankton. In addition rather a long patch of high standing crop is found in the northern area with its south-to-north orientation. Only in the netplankton distribution is shown a high standing corp in station 16. The lowest concentrations are distributed in the offshore area of the southern part.

Area of high standing crop of netplankton

In the area of high standing crop near Nagdong Estuary a tongue-like extension is formed in the chlorophyll profile on Line A. On line *D* is seen an offshore patch of high standing crop in addition to the tongue-like extension in the coastal side. This offshore patch seems to be only a part of a very long patch that is developed from the upper layer off Chugsan to that off Busan (Fig. 9). In Table 11 are shown the specific composition and abundance in the inshore patch and offshore patch. As in other cruises more diatoms and benthic species appear in the

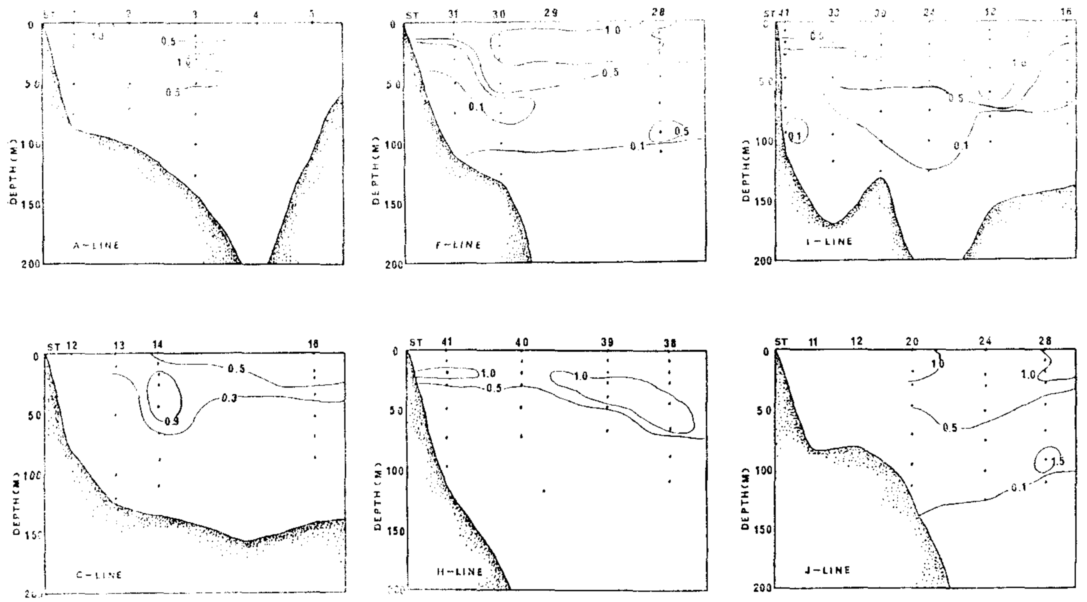

Fig. 9. Profiles of chlorphyll-a concentration (mg chl-a/m^3) on each line in May, 1984 (See Fig. 1 for location of each line).

Table 11. Mean percent dominance represented by dominant groups in the samples from the area of high netplakton concentrations in May.

Patches	inshore	offshore
Dominant group(percent dominance)		
Diatoms	78	54
Dinonlagelltes	20	44
(Gymnodiniales)	15	11
Nitzschia seriata	54	27
Cylindrotheca closterium	2	11

inshore patch.

Off shore stations with low standing crops

Surprisingly special dominance of *Nitzschia seriata* is not observed only in those stations which are located in the eastern end of each line (that is, stations 5, 6, 7, 17, and 26; Fig. 9) with low standing crop of netplankton (Tab. 12). These stations aie quite different from other stations in that *Nitzschia seriata* is not a dominant species and in that dinoflagellates occupies the majority of the total cells there. In station 5, however, dinoflagellates make up only 18% of the cells, and *Leptocylindrus danicus* predominates (43%), which might be from the "island effect"

Hydrographic conditions and plankton flora

Rather homogeneous distribution of water temperature give little information on the prehistory of the water masses. On the contrary three zones

Table 12. Mean percent dominance represented by dominant groups in the samples collected from the offshore stations with low standing crops in May.

Station	5	6	7	17	26
Dominant group(percent dominance)					
Diatoms	81	22	22	13	37
Dinofllagelltes	18	77	77	86	60
Nitzschia seriata	8	0	6	5	0
Cylindrotheca closterium	5	7	0	5	23

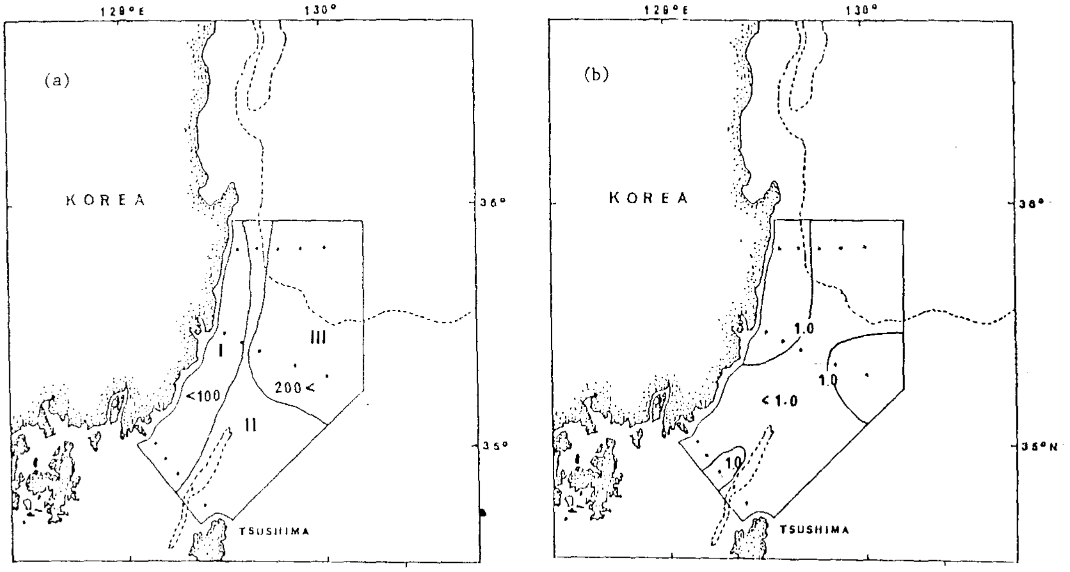

Fig. 10. Distribution of surface concentrations: (a) netplankton (cells/ml); (b) chlorophyll-a (mg chl-a/m^3).

of distinctive waters are distinguished through the comparisons of specific composition and abundance. Prehistory of the charcteristic water is "recorded" in the flora living in the water.

2.2.2. October

High standing crop in the right half of the northern part (area III) is found in the chlorophyll distribution as well as in the netplankton distribution. The lowest concentration of netplankton is seen in the area near the coastline (area I). Between the two area intermediate concentrations (area II) are distributed (Fig. 10-a). Each of these three zones is distinguished by its floristic composition and abundance (Tab. 13). Area III is represented by the lowest percentages of naked dinoflagellaes and by the highest relative abundances of diatoms and *Chaetoceros.* On the contrary lowest percentages of diatoms and *Chaetoceros* are found in area I. Moreover in area III small-sized naked dinoflagellates show thel owest relative abundance. This means that the water in area I has been originated from the more oligotrophic and warm Tsushima current water than the water in area III.

Table 13. Mean percent dominance represented by dominant groups in the samples from the three characteristic area in October.

Area	I	II	III
Dominant group			
Diatoms	90	97	98.5
Dinofllagelltes	8.5	2	0.6
(Gymnodiniales)	8	2	0.5
Chaetoceros	26	29	38
Nitzschia	23	25	23

Table 14. Maximum value of calculated production (Max. Production) and mean/standard deviation of integrated primary production (Production/Area). The number in the parentheses is the number of determinations

Cruise	Max. Production (mg c/m^3/day)	Pioduction/Area (mg c/m^2/day)
4(4/11~4/16)*	92(137)	637/145(14) 883
5(5/14~5/18)	116(125)	607/251(14) 1090
3(10/25~1(/29)*	80(183)	2(4/157(25) 583
6(10/29~11/1)	52 (15)	— —

*Previous cruises.

3. Chlorophyll-a and primary production

Concentrations of chlorohyll-a were determined on the samples of May and October, and using these data primary production per unit volume of seawater (mg C/m^3/day) and per unit surface area (mg C/m^2/day) were calculated. The results are summarized in Table 6 and 14.

3. 1. May

Fig. 6 shows the surface distribution of chlorophyll-a concentration with three patches of high chlorophyll concentration. The first one is around the Nakdong Estuary, the second in the landward stations on line G, and the last one in the north-south direction parallel with the 200 m contour line. Three zones of low silicate concentration are coincident with th high chlorophyll patches (Fig. 11).

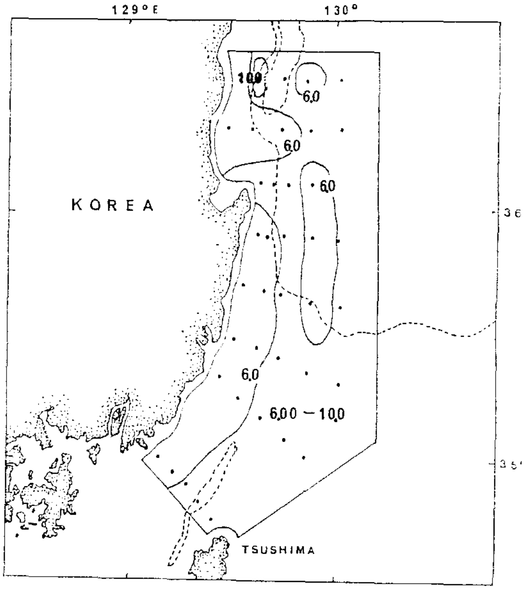

Fig. 11. Surface distribution of Si(OH)$_4$-Si concentrations (μg-at/l) in May, 1984.

No particular influence of the nutrient-rich cold water is seen in the oblique band of high chlorophyll cencentration in the upper layer of stations 1, 2, and 3 on line A (Fig. 9). However the chlorophyll maximum layers on the other lines than line A are associated with the cold water underneath.

Primary production profiles (Fig. 12) show high values in the upper layer near the 200m contour line, and results in high values of depth integrated primary production (Fig. 13) there. The cores of highest value in the area near

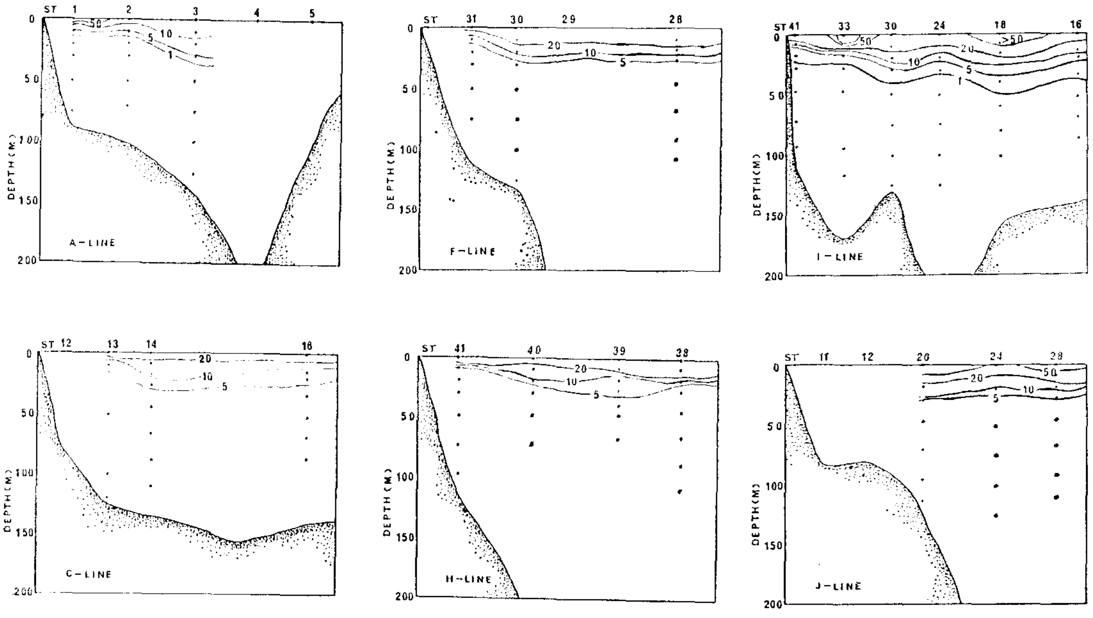

Fig. 12. Profiles of gross primary production (mg C/m^3/day) on each line in May, 1984. (See Fig. 1 for location of each line).

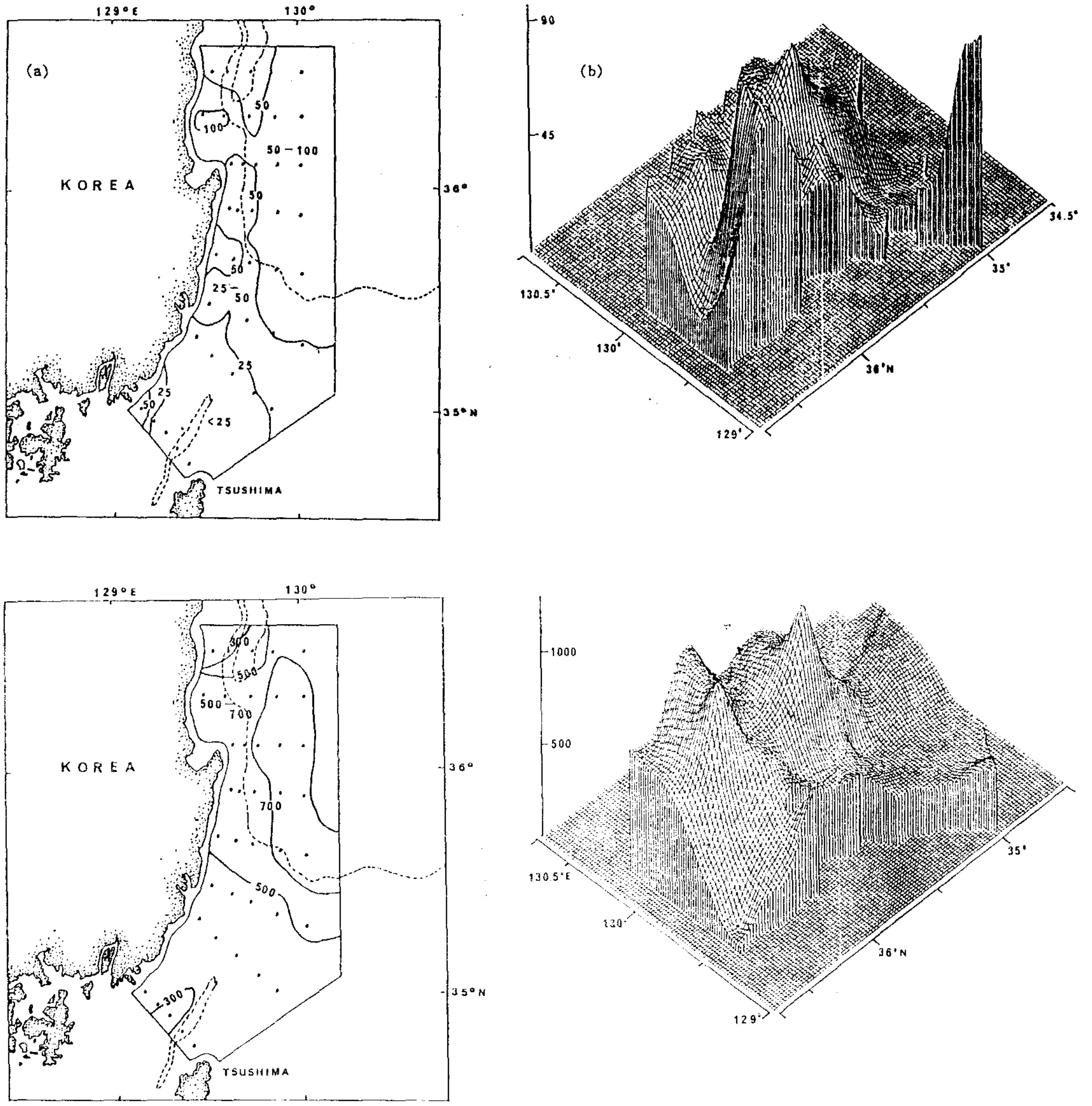

Fig. 13. Distribution of gross primary production in May, 1984: (a) surface production (mg $C/m^3/day$); (b) a three-dimensional plotting of (a); (c) depth-integrated production (mg $C/m^2/day$); (d) a three-dimensional plotting of (c).

Chugsan and Nagdong Estuary that are seen in the surface distribution of primary production no more survive in the distribution of depth integrated production. The productive surface layers formed there seem to be very thin in their vertical thickness.

3.3. October

High chlorophyll-a concentration is distributed in the surface area near Ul-gi and in the lower right of the northern area (Fig. 10). The same trend is seen again in the distribution of surface production even though somewhat difference is clearly shown in the distribution patterns of the two properties (Fig. 14).

Lack of data imposes restrictions on the deep insight into the distribution pattern.

4. Nanoplankton

In most cases nanoplankton usually defined as the size fraction passing the smallest fractionation (20 μm), dominates the biomass and produc-

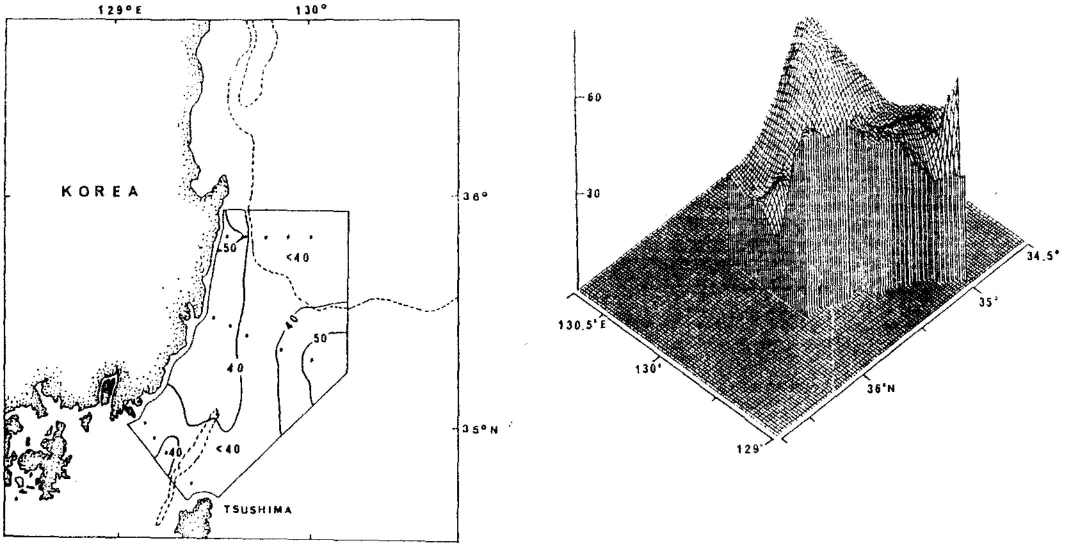

Fig. 14. Distribution of gross primary production in surface layer (mgC/m^3/day) during the cruise of October, 1984: (a) a two-dimensional plotting; (b) a three-dimenstonal plotting.

tivity. Especially in oligotrophic water and warmer water it predominates.

Abundance of nanoplankton was estimated through the chlorophyll-a measurements and through the cell countings. Table 15 and 16 show the summarized results. Greater superiority of nanoplankton is evident in spring than in autumn, which is coincidently seen in the distribution of both cell concentration and the chlorophyll concentration. It seems that in the less "conditioned" water of spring season more superior and opportunistic "competitor," nanoplankton, grows far better than the netplankton.

Although nanoplankton per netplankton ratio increase as the season is near summer, the absolute quantity of nanoplankton decrease then. Hence the nanoplankton standing crop varies in the same pattern as the netplankton standing crop. Vertically in the lower layers nanoplankton is less limited than netplankton in its growth. As a result nanoplankton per netplankton ratio increase with depth (Tab. 16), which also proves the broader ecological niche possessed by the nanoplankton.

4.1. May

Table 15. Summary of nanofraction measurements on the surface samples from each cruise. Data are complied to show mean nanofraction, netfraction, and the nanofraction per netfraction ratio (in parentheses).

Cruise	Cell concentration (cells/*l*)	Chlorophyll concentration (mg chl/m^3)
4(4/11~4/16)*	798/78(10.2)	—
5(5/14~5/18)	783/70(11.2)	0.78/0.09(8.7)
3(10/25~10/29)*	226/41 (5.1)	—
6(10/29~11/1)	720/176(4.1)	0.54/0.36(1.5)

*Previous cruises

Table 16. Summary of mean nanofraction per netfraction ratios in each cruise. Each fraction was estimated from the phytoplankton concentrations (cells/ml).

Cruise	Surface	Total column
4(4/11~4/16)*	10.2	11.3
5(5/14~5/18)	11.2	—
3(10/25~10/29)*	5.1	6.5
6(10/29~11/1)	4.1	—

*Previous cruises

The nanofraction in chlorophyll-a concentration is averaged 89% which is the overwhelming majority of standing crop(Tab. 17). In spring this trend seems to be general (Tab. 15), and

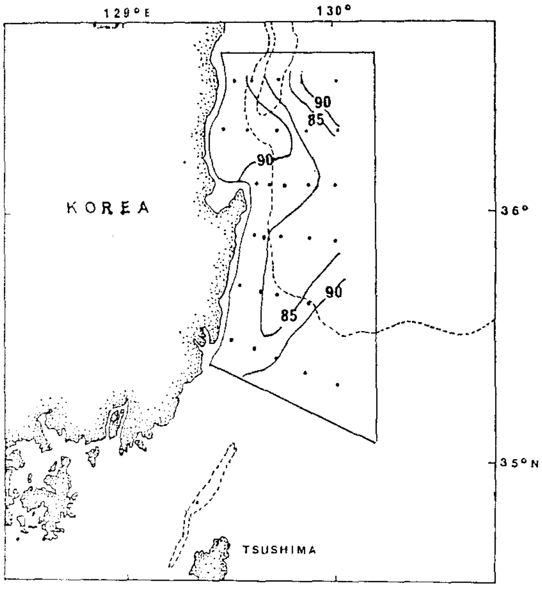

Fig. 15. Surface distribution of nanofraction percentages to total cell counts (cells/ml) in May, 1984.

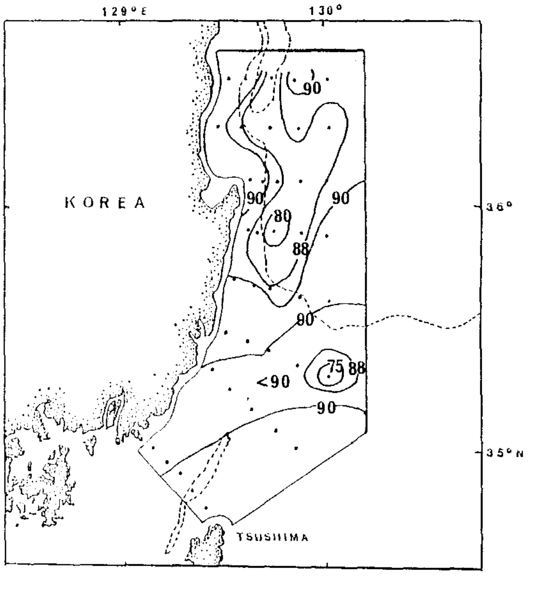

Fig. 16. Surface distribution of nanofraction percentages to total chlorophyll-a concentrations (mg chl-a/m^3) in May, 1984.

the relative importance of nanoplankton is in absolute level in the study area especially in spring. Highest concentration of netplankton in the area off Gampo never fails to be distinguished by its low percentages of nanofraction (in chlorophyll distribution as well as in plankton distribution) and by its high chlorophyll

Table 17. Summary of surface chlorophyll concentrations. Data are compiled to show mean, standard deviation, the number of determinations (upper lines), and range (lower lines). The unit of chlorophyll-a concentrations is (mg chl-a/m^3).

Cruise	Total fraction	Nanofraction	Nano/Total (%)
May	0. 87/0. 49(25)	0. 78/0. 50(22)	89. 2/7. 8(22)
	0. 21-2. 18	0. 21-2. 14	67-99
October	0. 89/0. 32(15)	0. 54/0. 31(15)	62. 2/27. 4(15)
	0. 31-1. 35	0. 20-1. 10	16-97

Predominant (more than 60%) *Nitzschia* and *Cylindrotheca* are all pennate diatoms with only little chlorophyll contents, and it brings about the very low correlation ($r=0.40$) between the percentages of nanoplankton in cell concentrations and in chlorophyll concentrations. Hence surface distributions of nanofraction ratio seem to be apparently disturbing.

The complexity of phytoplankton distribution is clearly demonstrated in the distributions of nanoplankton percentages on the three line *A*, *D*, and *G* (Fig. 16). In the study area environmental gradient is exceptionally great horizontally and vertically in terms of physical and chemical parameters. Such great gradient builds a very complex make-up of plankton distribution.

4. 2. October

Mean nanofraction ratio in chlorophyll-a concentration is 60% which is still the majority of standing crop. However it is far lower than that in May. Generally in autumn then anofraction ratio seems to be lower than that in spring (Tab. 16 and 17). Through the whole cruises nanoplankton exceeded netplnkton in its standing crop, and clearly established is the greater importance of nanoplankton over netplankton in the cell concentrations as well as in the chlorophyll concentrations.

In October chlorophyll concentrations of nanofraction decrease with distance from the coast-

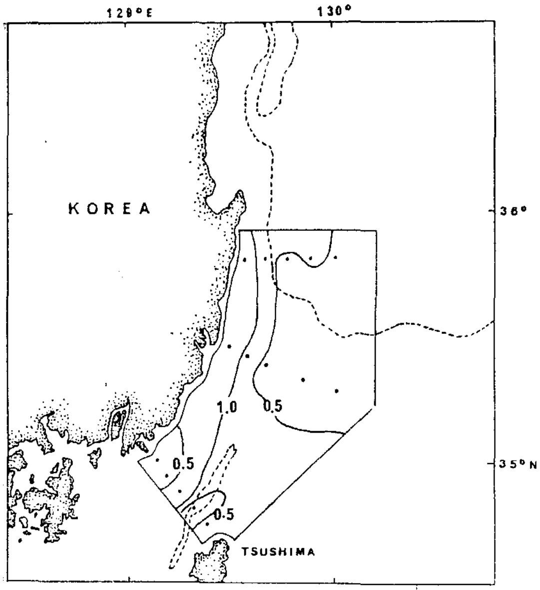

Fig. 17. Surface distribution of chlorophyll-a concentrations (mg chl-a/m^3) in the nanophytoplankters in October, 1984.

line. The lowest concentration is noted surprisingly in the area of highest total chlorophyll concentration. On the contrary the highest chlorophyll concentration of nanofraction occupies a narrow north-south zone where net plankton concentration is the lowest (Fig. 17). As a matter of course nanofraction ratio decrease very rapidly with the distance from the coastline in chlorophyll distribution and in the distribution of plankton concentration (Fig. 18). This implies that the water nearest to the coastline is the poorest in its conditions for the netplanktion growth that the water in the right half of the northern part has enough capability to nourish the great concentration (reaching 358 cells/ml) of netplankton. Although the water temperature in the north-south zone nearest to the coastline is the lowest the water in the zone might have been originated from the oligotrophic and warm Tsushima current water. In other words physical parameters could be better identifiers of sea state when they are examined in harmony with phytoplankton parameters in many areas with complex hydrographic structure.

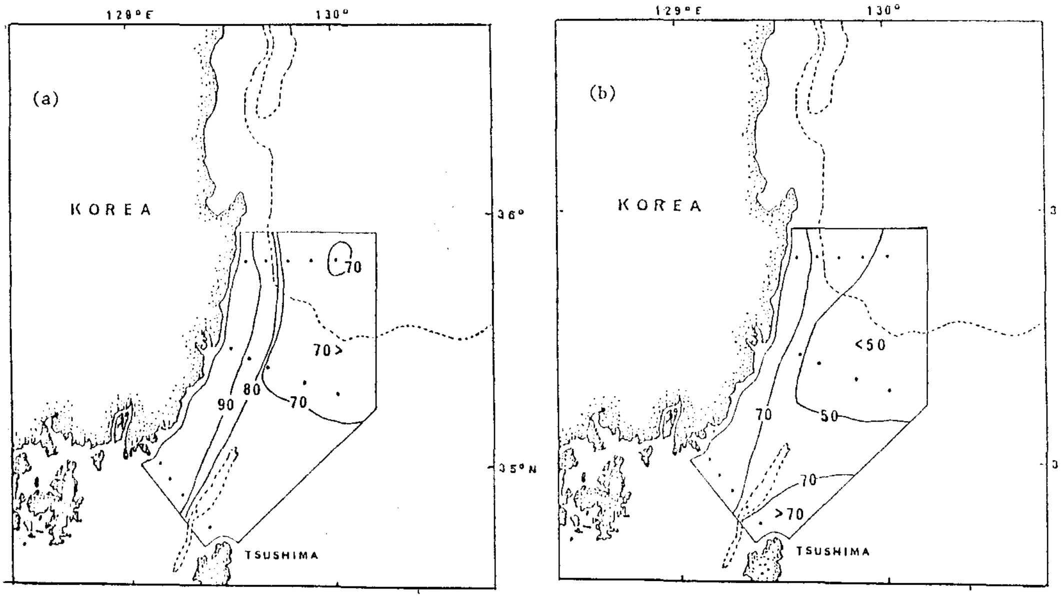

Fig. 18. Distribution of nanofraction ratio(%) in October, 1984: (a) phytoplankton concentration; (b) chlorophyll-a concentration.

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