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Distribution of Phytoplankton Standing Crop and the Associated T-S Properties in the Southwestern East Sea (Sea of Japan)

WON HO LEE AND JAE HYUNG SHIM*
Dept. of Oceanography, Kunsan National University, Kunsan 573-360, Korea
**Dept. of Oceanography, Seoul National University, Seoul 151-742, Korea*

東海 西南海域 植物플랑크톤의 現存量 分布와 水温-鹽分 特性

李元鎬 · 沈載亨*
群山大學 海洋學科 · 서울大學校 海洋學科*

Seawater temperature, salinity, inorganic nutrients and the standing crop of phytoplankton species of the 841 water samples from the upper 125 m at 15-40 stations on the 6 semiannual cruises in the southwestern waters of the East Sea (Korea) were studied during the period from September, 1981 to October, 1984. Among the 235 taxa identified two pennate diatoms, *Cylindrotheca closterium* and *Nitzschia delicatissima*, were the most common and dominant species. The multiple regression analyses between net phytoplankton abundance (dependent variable) and associated environmental factors (independent variables) were applied to the samples from the surface mixed-layer. In spring the coefficients for the seawater temperature was 1.6 to 4.2 times greater than those for salinity, while the coefficients for the salinity was 2.1 to 3.4 times greater than those for seawater temperature in autumn. Distribution pattern of phytoplankton standing crops on the T-S diagram was sensitive to the slight change of seawater temperature in spring, and salinity in autumn. Schematically the zone of high standing crops moved about on the T-S diagram in a cyclic manner. The distribution of phytoplankton standing crop was quite closely associated with the hydrographic conditions among various kinds of environmental factors studied.

동해 서남해역의 상부 125미터 수층을 대상으로 1981년 9월부터 1984년 10월에 걸쳐 6회의 현장조사를 실시하여 841개의 해수시료를 구하였고, 이들의 수온, 염분, 무기영양염류 및 식물플랑크톤 종별 현존량에 대하여 연구하였다. 도합 235종류의 식물플랑크톤을 동정하였으며, 이 가운데 *Cylindrotheca closterium* 과 *Nitzschia delicatissima* 등의 두 종이 최고의 공통종인 동시에 우점종으로 나타났다. 연구해역 상부혼합층 시료 중의 식물플랑크톤 현존량과 수온, 염분 및 무기영양염류 등의 환경요인과의 관계를 다중회귀 분석한 결과 봄에는 수온의 회귀상수가 염분에 비해 1.6-4.2배 컸으며, 반대로 가을에는 염분의 회귀상수가 수온에 비해 2.1-3.4배 크게 나타났다. T-S diagram 위에서 식물플랑크톤 현존량 분포가 봄에는 수온 변화에 민감하였으며 가을에는 염분 변화에 민감하였고, 도식적으로 T-S diagram 상에 표시한 높은 현존량 구역은 계절적으로 순환하는 양상을 나타내었다. 이는 연구해역의 식물플랑크톤 현존량 분포가 여타의 환경요인보다 특별히 해양물리학적 특성과 긴밀한 관계가 있음을 의미한다.

INTRODUCTION

Phytoplankton community in the sea is subjected to the synthetic influences of various physical and biological processes. In each case, however, the relative importance of each processes for the phytoplankton community are entirely different from that of the other cases. Comparing the average ranges of adhesive and tractive forces for the benthic pennate diatoms with the bottom shear stresses induced by the northwest wind during autumn and winter, Choi (1984) concluded that most of the benthic diatoms must be resuspended by the bottom shear stresses in Gyeonggi Bay, Korea, and that the seasonal variation of the surface wind might be one of the most important factors affecting the successional pattern of phytoplankton community in the bay. The large-scale horizontal pattern of biological properties (primary production and standing stock of phytoplankton and macrozooplankton) could be used to infer horizontal variations in the physical processes which affect the rate of nutrient supply to the euphotic zone in the central North Pacific Ocean (Hayward and McGown, 1985).

A series of oceanographic survey on the southwestern waters of the East Sea (Sea of Japan) has been being carried out semiannually since September, 1981. This present paper deals with the data from the first half of the above period, viz. 1981-1984 (RIBS, 1982, 1983, 1984, 1985). In the southwestern waters of the East Sea the gradient of water temperature was estimated most significant for the distribution of phytoplankton species among the seven environmental factors examined in spring, and the gradient of salinity in autumn through canonical correlation analysis (Shim and Lee, 1987) on the same data used in the present study. Multiple regression analysis between phytoplankton standing crop and the associated environmental factors and also the plotting of phytoplankton standing crops on the plane of T-S axis were done for the understanding of the more detailed processes engaged with.

MATERIALS AND METHODS

During the 6 cruises of the training ship "Hanbada" of the Korea Maritime University for the four years (1981-1984), a large number of phytoplankton samples were collected along with simultaneous measurements of seawater temperature and salinity (Table 1) in the study area. The study area is approximated to be 10,000 square kilometers, and most of the basin is continental shelf except the northern continental slope exceeding 1,500 meter in depth (Fig. 1). Four major water masses are known in the study area, i.e., Tsushima warm current water, North Korean cold water, East Sea deep proper water (Kim and Kim, 1983), and the less saline coastal water. The coastal water is more influential in summer and autumn due to the heavy riverine discharges from the neighboring lands (Moriyasu, 1972).

Water temperature was measured using protected and unprotected reversing thermometer attached to Van Dorn bottles. The analyses of

Table 1. Number of stations and phytoplankton samples in each cruise

Cruise	Period	Station	Sample
I	'81. 9/21-24	40	257
II	'82. 3/29-4/1	15	82
III	'82. 10/25-29	35	253
IV	'83. 4/11-16	34	201
V	'84. 5/14-18	41	33
VI	'84. 10/29-11/1	15	15

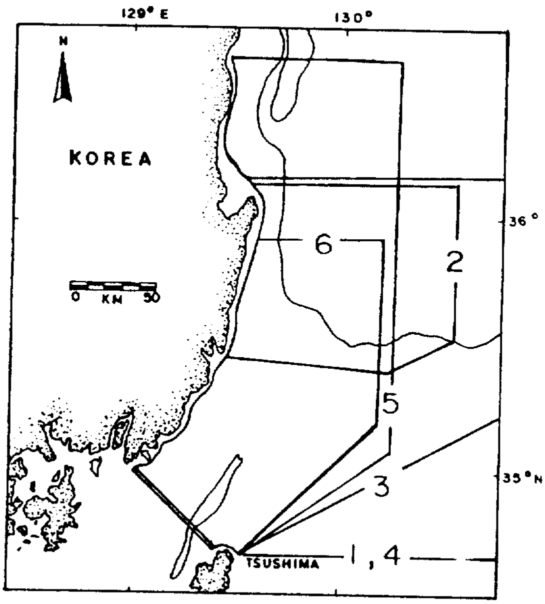

Fig. 1. A map showing the study area (1: Cruise 1, 2: Cruise 2, 3: Cruise 3, 4: Cruise 4, 5: Cruise 5, 6: Cruise 6). The isobath of 200 meter water depth is indicated by solid line.

Table 2. Summary of water temperature, salinity, and netphytoplankton standing crop in each cruise. Data are compiled to show mean, standard deviation(S.D.), and number of determinations(no.d.).

Cruise		2	4	5	1	3	6
Mon./Dat.		3/29-4/1	4/11-16	5/14-18	9/21-24	10/25-29	10/29-11/1
Temp.(°C)	(all samples)						
Mean		12.34	12.19	11.68	19.32	17	
S.D. (no.d.)		2.03(82)	2.18(253)	3.54(167)	6.29(244)	4.42(267)	
	(surface samples)						
Mean		13.21	13.38	14.2	23.64	20.33	19.66
S.D. (no.d.)		0.84(15)	0.93(34)	0.44(25)	1.26(38)	0.97(35)	1.35(15)
Salinity (‰)	(all samples)						
Mean		34.52	34.42		33.69	33.70	
S.D. (no. d.)		0.10(82)	0.17(237)		0.66(248)	0.52(195)	
	(surface samples)						
Mean		34.57	34.48		33.06	33.29	
S.D. (no.d.)		0.03(15)	0.12(33)		0.82(36)	0.26(26)	
Netphytoplankton standing crop (cells/m*l*) (surface samples)							
Mean		66	78	70	25	41	76
S.D. (no.d.)		46(15)	61(34)	48(33)	23(38)	49(35)	120(15)

salinity on the seawater subsamples from the Van Dorn bottles were done with a digital salinometer, Autosal Guildline Model 8400. Inorganic nutrients (nitrate, nitrite, silicate and phosphate) were measured using Technicon Autoanalyzer AA II. Seawater subsamples for the quantitative study of phytoplankton were stored in 500 m*l* polyethylene bottles, and fixed with modified Lugol's solution as a preservative. Phytoplankters were observed under a microscope (Nikon type 104), and Sedgwick-Rafter slides were used for the cell counting.

RESULTS AND DISCUSSION

Phytoplankton community

A total of 235 taxa were identified; 1 blue-green, 1 cryptomonoid, 1 rhaphidophycean, 4 silicoflagellates, 72 dinoflagellates, and 155 diatoms. Quantitatively diatom occupied 67-97% of total netplankton standing crop (cells/m*l*), and dinoflagellates 2-31% during the entire 6 cruises. Maximum cell concentration of netphytoplanton reached 368 cells/m*l*. Mean netphytoplankton abundance seemed to show a bimodal pattern in its temporal variation while unimodal pattern was found in the temporal fluctuations of mean surface water temperature and salinity (Table 2). Two peaks of netphytoplankton abundance might possibly be found at the time of medial level of seawater temperature and salinity.

Two pennate diatoms, *Cylindrotheca closterium* and *Nitzschia delicatissima,* were the most common and dominant phytoplankton species in the present study (Table 3). Dinoflagellates were frequent from April (Cruise 4) to September (Cruise 1), and they were also dominant from May to September. The most dominant species seems to be switched off unpredictably viz. opportunistically: the most dominant species not only occupied great portion of total standing crop at an one instance, but also were replaced by another species soon (Table 3).

Multiple regression analyses between phytoplankton abundance and the associated environmental factors

The multiple regression analyses between netphytoplankton abundance (dependent

Table 3. Mean percent dominance represented by the dominant species that occupied more than 5% of the total standing crop of netphytoplankton in each cruise.

Cruise	2	4	5	1	3	6
Period (M/D)	3/29 -4/1	4/11 -16	5/14 -18	9/21 -24	10/25 -29	10/29 -11/1
Chaetoceros compressus	5					7
Rhiz. setigera v. pungens	11					
Nitzschia pungens	8					
Nitzschia seriata	13		47			6
Thalassiosira pacifica		42				
Nitzschia delicatissima		24	7	8	15	17
Cylindrotheca closterium			5	14	5	12
Gyrodinium sp.			6	8		
Gymnodinium sp.				16		
Chaetoceros tortissimus					26	
Chaetoceros lorenzianus						5

Table 4. Number of samples (n), multiple correlation (R), number of independent variables (m), and coefficients of the independent variables for the netphytoplankton abundance (dependent variable). All the variables were standardized for the multiple regression analyses. Phytoplankton abundance (cells/m*l*) were log-normally transformed before the standardization. Samples from the upper-35-meter layer were chosen for the multiple regression analyses.

Cruise	CR2-March	CR4-April	CR1-September	CR3-October
n	38	86	137	64
m	7	6	3	7
R	0.785	0.637	0.582	0.319
coefficients				
T	0.328	0.517	-0.237	0.093
S	-0.287	-0.125	-0.446	0.142
nitrate	-0.249	-0.174		-0.054
nitrate	0.133	-0.114		0.027
phosphate	-0.168	-0.295		0.202
silicate	-0.382	0.148		0.131
disvd. oxygen	0.182		0.056	0.073

Table 5. Multiple regression analysis between netphytoplankton abundance (cells/m*l*) and the two environmental factors i.e., water temperature and salinity (n; number of samples, R; multiple correlation). All the variables were standardized for the multiple regression analyses. Phytoplankton abundance (cells/m*l*) were log-normally transformed before the standardization. Samples from the upper-35-meter layer were chosen for the multiple regression analyses.

Cruise	CR2-March	CR4-April	CR1-September	CR3-October
n	38	86	137	64
R	0.462	0.560	0.580	0.216
coefficients				
T	0.527	0.618	-0.229	0.054
S	-0.318	-0.146	-0.480	0.181

variable) and the associated environmental factors (independent variables) clearly showed the relative importances of water temperature and salinity to the phytoplankton communities (Table 4 and 5). In spring (Cruise 2 and 4) water temperature had higher coefficients (Table 4): water temperature had the second highest coefficient (0.328) next to silicate concentration (0.382) in Cruise 2, and the highest (0.517) in Cruise 4. Salinity showed higher coefficients in autumn (Table 4): salinity had the highest coefficient (0.446) in Cruise 1, and the second highest (0.142) next to phosphate concentration (0.202) in Cruise 3. The relative importance of water temperature and salinity for the phytoplankton distribution is well demonstrated in the result of

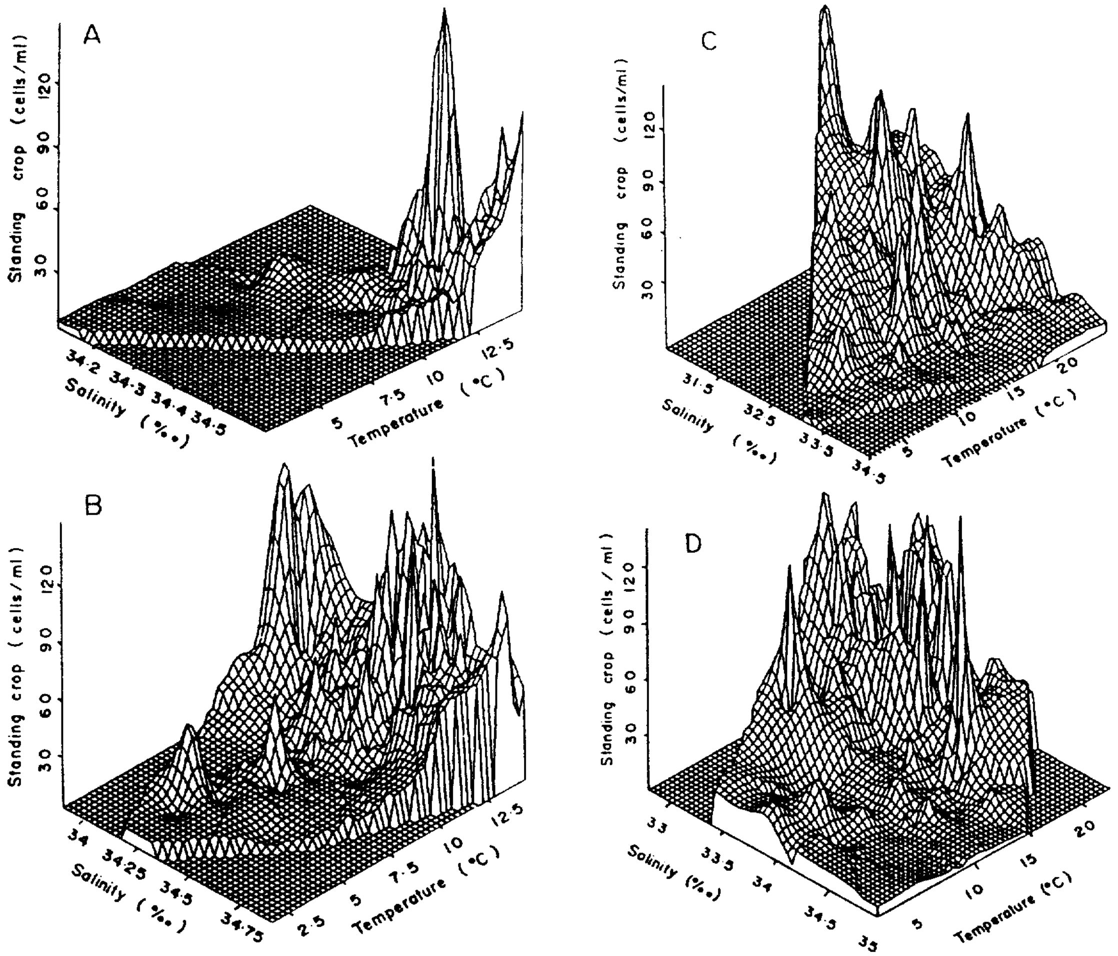

Fig. 2. Distribution of netphytoplankton standing crops on the T-S plane (A: Cruise 2-March, B: Cruise 4-April, C: Cruise 1-September, D: Cruise 3-October).

the multiple regression analyses between netphytoplankton abundance and the two environmental factors (Table 5): water temperature showed 1.6-4.2 times higher coefficients than salinity in spring, and salinity had 2.1-3.4 times higher coefficients than water temperature is autumn.

Distribution pattern of standing crop on the plane of T-S axes

Distribution pattern of phytoplankton standing crop on the plane of T-S axes were examined into to understand the subtle trend. Samples were scattered widest over the T-S diagram in September (Cruise 1), and in late March (Cruise 2) they were concentrated in a narrow band (Fig. 4A– 4D). The distribution of high standing crop was restricted in an upper right corner of the T-S diagram in March (Fig. 2A), and then it expanded to the whole upper part of the diagram in mide-April (Fig. 2B). In September the zone of high standing crop covered the left two thirds of the T-S diagram leaving only the right one third with low standing crop (Fig. 2C). In late October (Fig. 2D) the zone of high standing crop in the T-S diagram assumed the form of reversed "L" which is the mixed type of

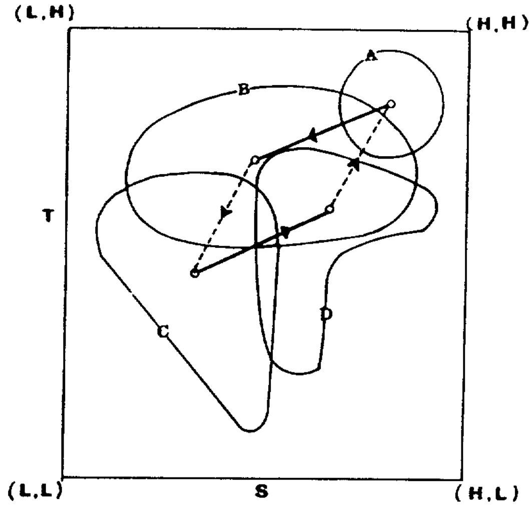

Fig. 3. A schematic diagram illustrating the relative positions of the zones of high standing crop on the T-S plane. Closed circles in each zones indicate the relative positions of highest standing crop (A: March, B: April, C: September, D: October).

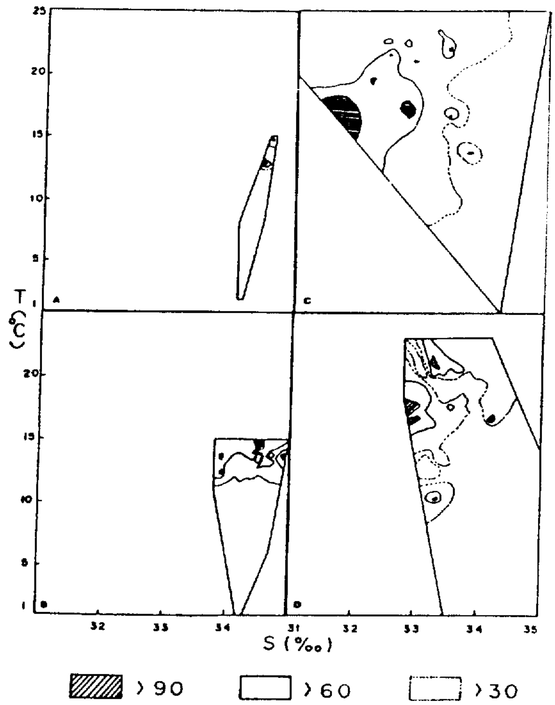

Fig. 4. Contour lines of the netphytoplankton standing crops (cells/m*l*) on the T-S plane in each cruise (A: March, B: April, C: September, D: October).

horizontal and vertical rod (Fig. 2B and 2C).

Schematically the zone of high standing crop moved about on T-S diagram in some cyclic manner (Fig. 3). In March (A in Fig. 3) high standing crop was possible where the water temperature was highest even though salinity was high. At that time less saline and nutrient-rich coastal water was much colder than offshore saline water (Fig. 4A). As the less-saline coastal water gets warmer along time, high standing crop is also possible where the salinity is rather low (B in Fig. 3). It is possible because the less saline and nutrient-rich coastal water is not quite colder than offshore water now (Fig. 4B). In spring, therefore, slight increase in seawater temperature is much more important for the phytoplankton community than the salinity difference (Shim and Lee, 1987). Contrary to the situation in spring the zone of high standing crop seems to be much more sensitive to salinity than water temperature in September (C in Fig. 3) and October (D in Fig. 3). In September standing crop greater than 100 cells/m*l* were restricted within the zone where the salinity was less than 33‰, and the zone of high standing crop was rather vertical in its rod-shape (Fig. 4C).

Distribution of standing crop and hydrographic conditions

The great horizontal gradient of SST (sea surface temperature) in early spring (Kang and Jin, 1984a; Kang, 1985) in the study area can explain why the zone of high standing crop on T-S diagram is restricted within small upper right corner (Fig. 2A and Fig. 3). In early autumn light condition and water temperature can't be considered as possible limiting factors for phytoplankton growth in the study area, but inorganic and organic nutrients can be: as the seasonal thermocline depth is minimal in warm season, nutrient cycling is severely restricted. Moreover, such nutrient depletion is very severe in the warm Tsushima Current water (Shim *et al.*, 1989; Lee, 1986). In this case there are two possible sources of nutrient supplies into the study area. One of the sources is the less saline and nutrient-rich coastal water from Nagdong River, the coastal area of Southern Sea of Korea and East China Sea (Lim and Chang, 1969; Park, 1985), and also from Yangtze Estuary (Kang and Jin, 1984b). The other minor source of nutrient supply is the local nutrient flux upwards from the extensions of the North Korean cold water (Lim, 1983; Lee, 1986) near Gampo and Ul-gi area. Of the above two possible sources of nutrient supplies the less saline coastal water is much more important than the local upward flux of inorganic nutrients. This is the reason why the zone of high standing crop is sensitive to salinity than water temperature in autum in the study area (Fig. 2C, D and Fig. 3). The striking contrast of influences of the gradients of water temperature and salinty on the phytoplankton community between early spring and autumn is well illustrated in a synthetic diagram under absolute T-S scale (Fig. 4).

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REFERENCES

Choi, J.K., 1984. The ecological study of phytoplankton in Gyeonggi Bay, Korea. Ph.D. thesis, SNU, p. 320.

Hayward, T.L. and J.A. McGown, 1985. Spatial patterns of chlorophyll, primary production, macrozooplankton biomass, and physical structure in the central North Pacific Ocean. *J. Plankton Res.*, 7(2): 147-167.

Kang, Y.Q., 1985. Influences of the Asian monsoon and the Kuroshio on the surface temperature in the Yellow, the Japan and the East China Seas. *J. Oceanol. Soc. Korea,* **20**(1): 1-9.

Kang, Y.Q. and M.S. Jin, 1984a. Seasonal variation of surface temperatures in the neighbouring seas of Korea. *J. Oceanol. Soc. Korea,* **19**(1): 31-35.

Kang, Y.Q. and M.S. Jin, 1984b. Annual variation of salinity in the neighbouring seas of Korea. *J. Oceanol. Soc. Korea,* **19**(2): 105-110.

Kim, C.H. and K. Kim, 1983. Characteristics and origin of the cold water mass along the east coast of Korea. *J. Oceanol. Soc. Korea,* **18**(1): 73-83 (in Korean).

Lee, W.H., 1986. An ecological study of phytoplankton in the southwestern waters of the East Sea (Sea of Japan), Korea. Ph. D. thesis, SNU, p. 225.

Lim, K.S., 1983. The characteristics and the origin of the cold water mass in the southeastern sea of Korea. M.S. thesis, SNU, p. 40.

Lim, D.B. and S. Chang, 1969. On the cold water mass in the Korea Strait. *J. Oceanol. Soc. Korea,* **4**(2): 71-82.

Moriyasu, S., 1972. The Tsushima Current. In: Kuroshio (Stommel, H. and K. Yoshida eds.). Univ. Washington Press, pp. 353-369.

Park, Y.H., 1985. Some important summer oceanographic phenomena in the East China Sea. *J. Oceanol. Soc. Korea,* **20**(1): 12-21.

RIBS (Research Institute for Basic Sciences), 1982. Oceanographic studies on the south eastern sea of Korea. Seoul National University, p. 147.

RIBS, 1983. Oceanographic studies on the southern waters of Korean eastern sea. Seoul National University, p. 215.

RIBS, 1984. Oceanographic characteristics in the south eastern area of the East Sea. Seoul National University, p. 125.

RIBS, 1985. Oceanographical processes in the boundary region of the various water masses on the southern waters of the East Sea (Japan Sea). Seoul National University, p. 172.

Shim, J.H. and W.H. Lee, 1987. Distribution of phytoplankton species and associated environmental factors in the southwestern waters of the East Sea (Sea of Japan), Korea: A canonical correlation analysis. *J. Oceanol. Soc. Korea,* **22**(1): 34-42.

Shim, J.H., S.R. Yang and W.H. Lee, 1989. Phytohydrography and the vertical patterns of nitracline in southern waters of the Korean East Sea in early spring. *J. Oceanol. Soc. Korea,* **24**(1): 15-29.

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