The Journal of the Oceanological Society of Korea
Vol. 22, No. 1, p. 34-42, March 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

*Jae Hyung Shim** and *Won Ho Lee***

* Department of Oceanography, Seoul National University, Seoul 151, Korea

** Department of Marine Development, Kunsan National University, Kunsan 511, Korea

東海 西南海域 植物플랑크톤 및 환경요인의 分布 : Canonical Correlation分析

沈載亨* · 李元鎬**

*서울大 海洋学科 **群山大 海洋開発学科

Abstract

Canonical correlation analysis was applied on phytoplankton species and associated physico-chemical environmental factors of the surface mixed-layer in the southwestern waters of the East Sea (Sea of Japan), Korea. Water temperature was the most significant environmental factor for the distribution of phytoplankton species among the seven factors examined in spring, and salinity in autumn. The importance of these two environmental factors was discussed with the seasonal variations of the hydrographical regime. 'Kuroshio indicators' and two *Protoperidinium* species were positively associated with high water temperature and high salinity. Small pennate diatoms and silicoflagellates seem to prefer lower temperatures, and they might compete each other for silicate nutrient resulting in lower Ks value in silicoflagellate species than in small diatoms. A nitrogen fixing blue-green alga, *Oscillatoria erythraea*, was found to be positively associated with phosphate concentration.

요약 : 동해 西南海域의 식물플랑크톤의 분포와 환경요인의 상관관계를 연구하기 위해 Canonical Correlation分析을 실시하였다. 조사된 7가지의 환경요인 가운데서 식물플랑크톤의 분포에 가장 중요한 영향을 끼친 것은 봄철에 수온, 가을철에 염분이었다. 이 두가지 환경요인의 계절적인 변화와 연구 수역의 해양 물리학적 현상에 대하여 논하였다. 쿠로시오 指表種들과 *Protoperidinium* 속의 두종들은 높은 수온 및 높은 염분과 陽的인 연관성을 나타낸다. 소형 羽状硅藻類와 無色硅質鞭毛類들은 낮은 수온域을 選好하여, 서로 규산염에 대해 생태적인 경쟁 관계에 있는 것으로 보인다. 그 결과 無色硅質鞭毛類가 硅藻類보다 규산염농도에 대하여 더 낮은 K_s값을 보인다. 질소 고정 藍藻類의 一種인 *Oscillatoria erythraea*는 인산염 농도와 陽的인 연관성을 나타내었다.

INTRODUCTION

Several investigations have been carried out on the distribution of phytoplankton assemblages and associated environmental factors in the southwestern waters of the East Sea of Korea. Uhm and Yoo (1967) discussed the distribution of diatoms and their relation to the warm Tsushima current in the Korea Strait. Shim and Lee (1983) noted the fairly close interrelationship between the phytoplankton distribution and hydrographical structure. The standing crop, nanofraction, and primary production of phytoplankton were suggested to be highly indicative of the physical and chemical properties of the water in the study area (Shim

The present studies were supported (in part) by the Basic Science Research Institute Program, Ministry of Education, 1986.

et al., 1985). These studies, however, focussed on a search for patterns among the physical and chemical variates first, and then for related patterns among the biological variates. In other studies (Yang, 1984; Lee, 1986) phytohydrographic regions could be recognized by the Q-mode cluster analysis on the quantitative phytoplankton data sets, and such phytohydrographic regions could be interpreted in terms of the physical and chemical properties of water through the nodal analysis.

The interrelationships between two sets of measurements (biotic data set and environmental data set) made on the same subjects can be studied by canonical correlation analysis. The canonical correlation analysis selects linear functions that have maximum covariances between domains in contrast with the factor analysis that selects linear functions with maximum variances (Cooley & Lohnes, 1971). Some authors have applied this method to benthic ecology (Cassie & Michael, 1968; Cassie, 1972; McIntire, 1978; Penas & Gonzalez, 1983). Recent applications of the methods to phytoplankton ecology are done by Zurlini et al. (1983), Goodman et al. (1984), Choi (1984), and Lee (1985).

The purpose of this study is to examine the relationship between the phytoplankton species distribution and associated environmental factors statistically through canonical correlation analysis, and to learn the characteristic ecological selection of phytoplankton species by the very complex environmental hypervolume in the study area.

MATERIALS AND METHODS

Study Area

The study area covers approximately 10,000 square kilometers (34°45′ – 36°30′ N, 129°05′ – 130°35′ E), and most of the area overlies continental shelf with its northern part including continental slope exceeding 1,500 meters in depth (Fig. 1). The hydrography of the study

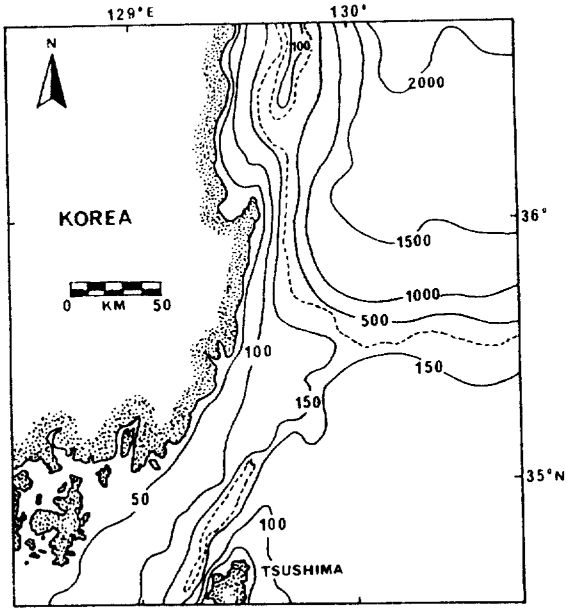

Fig. 1. Bathymetric chart of the study area. Contours in meters. Isobaths of 200 m are indicated by dotted lines. After Hahn (1979).

area can be characterized by the four major water masses. The Tsushima warm current water and the cold waters (North Korean cold water and East Sea proper water) have shown seasonal and annual fluctuations in their spatial distributions (Kim & Kim, 1983; Kim & Legekis, 1986), which in turn exerts major influences on the phytoplankton ecology (Lee, 1986) in the study area. The coastal water of low salinity mainly comes from Nagdong River, from the coastal area of Southern Sea of Korea and East China Sea (Lim & Chang, 1969; Park, 1985), and also from Yangtze estuary (Kang & Jin, 1984 b; Kim & Lee, personal communication). The effects of this less saline coastal water are more evident in summer and autumn due to the heavy riverine discharge, which results in low salinity layer at the intermediate depths of Korea Strait area (Moriyasu, 1972).

Data Collection

The data were obtained from 153 water samples (Tab. I) collected at 15 to 35 stations on three cruises in the study area (Fig. 2). In

Table I. Number of species(s) and environmental variables(t) for the canonical correlation analysis in each cruise. The table also includes sample number and period of the cruises.

Cruise	Period	Station	Sample	s	t
Cruise II-March	'82 3/29-4/1	15	37	29	7
Cruise III-October	'82 10/25-29	35	52	46	6
Cruise IV-April	'83 4/11-16	34	64	39	6

each station samples were collected in the surface mixed-layer depths, i.e., at surface, 10, and 20 m using Van Dorn water samplers. In addition to quantitative phytoplankton samples, hydrographic data on water temperature, salinity, and dissolved oxygen were obtained concurrently. Inorganic nutrients (nitrate, nitrite, silicate, and phosphate) were measured as described in Grasshoff et al. (1983) using a Technicon Autoanalyzer AA II. Phytoplankton species from 500 ml subsamples were identified and counted using a Sedgwick-Rafter counting chamber, and 187 taxa were distinguished (see Lee, 1986, for the full set of sample counts).

Data Processing

The species which occurred in less than 10% of the samples were omitted to reduce the possible noise of the original data set. Only 6 (Cruise III-October and Cruise IV-April) or 7 (Cruise II-March) abiotic factors were considered to minimize the variables-to-sample ratio (Cooley & Lohnes, 1971). The definitive number of species and environmental variables is shown in Table I. For the species data a log transformation was performed:

$$f(X) = \ln(X+1)$$

where X is a sample count. The resulting three transformed data matrices (Table I) were separately subjected to canonical correlation analyses. The same flow diagram of computer program as Cassie's (1972) was applied to the present canonical correlation analysis.

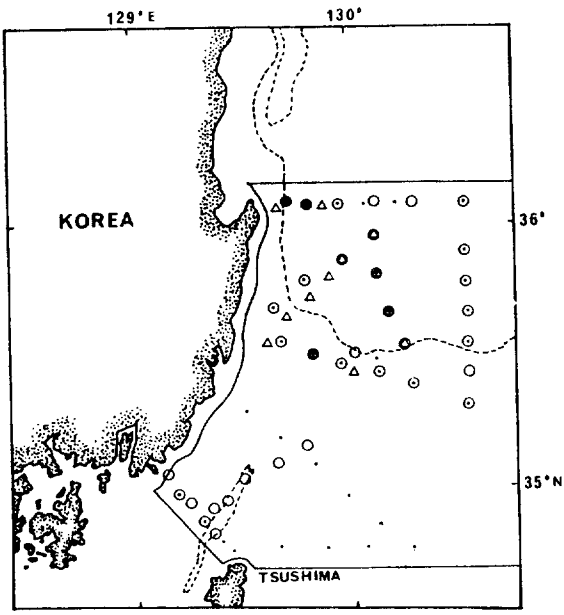

Fig. 2. Position of sampling stations visited in Cruise II-March (Δ), Cruise III-October (O), and Cruise IV-April (•). Isobaths of 200 m are indicated by dotted lines.

RESULTS

According to Bartlett's method, significance of canonical correlations were tested. Table II shows the result of the test on the canonical correlations for the first six pairs of canonical variates extracted. While the first three pairs are significant enough in Cruise II-March and

Table II. Canonical correlations (CCor) for the six pairs of canonical variates (CV), and Bartlett's test of significance in each cruise.

Cruise	CV	CCor	χ^2	df	Significance
Cruise II-March	1	0.9995	122.1	35	P<0.001
	2	0.9975	92.6	33	P<0.001
	3	0.9798	56.3	31	P<0.005
	4	0.9714	50.3	29	P>0.005
	5	0.9466	39.6	27	P>0.005
	6	0.8020	18.0	25	P>0.5
Cruise III-October	1	0.9999	303.8	51	P<0.001
	2	0.9998	204.9	49	P<0.001
	3	0.9977	132.0	47	P<0.001
	4	0.9872	90.0	45	P<0.001
	5	0.9697	69.1	43	P>0.005
	6	0.9590	61.8	41	P>0.01
Cruise IV-April	1	0.9712	114.7	44	P<0.001
	2	0.9189	74.4	42	P<0.005
	3	0.8494	51.1	40	P>0.1
	4	0.8003	40.9	38	P>0.1
	5	0.7672	35.5	36	P>0.1
	6	0.6559	22.5	34	P>0.1

Cruise III-October, only the first two pairs are significant in Cruise IV-April. Therefore, the analyses reduced the dimensionality of the original variables into two or three orthogonal dimensions. The corresponding canonical correlation coefficients for canonical variates selected (CV1, CV2, and CV3) were greater than 0.91 (Tab. II), and were significantly different from zero ($P<0.005$).

In Cruise II-March CV1 was more correlated with silicate concentration and it seems that this variate represents the gradient of silicate concentration (Tab. III). CV2 is essentially a contrast of dissolved oxygen against nitrite. Finally CV3 can be taken as an expression of offshore slope water with low temperatures. All in all the correlations of original environmental variables with canonical variates imply that the phytoplankton distribution examined above are more closely related to the dissolved oxygen, silicate concentration, and water temperature than to salinity and phosphate concentration. Although the nominal value of the correlation (Tab. III) is not so large, the trend of the correlation along the original variables well indicates the interrelationships between the two

Table III. Correlation matrix between the original variables and the first three canonical variates in Cruise II-March.

Variables	CV1	CV2	CV3
Environment			
Nitrate	0.054	−0.055	−0.415
Nitrite	0.232	−0.543	0.105
Phosphate	0.186	0.005	−0.370
Silicate	0.399	0.213	−0.118
D.O.	−0.153	0.452	0.477
Temperature	0.306	0.095	−0.517
Salinity	0.041	−0.011	−0.383
Species			
Chaetoceros affinis Lauder	−0.003	0.120	0.036
Chaetoceros compressus Lauder	0.156	0.279	−0.222
Chaetoceros curvisetus Cleve	−0.178	−0.065	0.053
Chaetoceros danicus Cleve	0.131	0.107	−0.114
Chaetoceros decipiens Cleve	0.125	−0.104	0.206
Chaetoceros didymus Ehrenberg	−0.164	0.196	0.160
Coscinodiscus sp.	−0.105	−0.171	0.046
Cryptomonas sp.	−0.247	0.014	−0.075
Cylindrotheca closterium Reiman & Lewin	0.314	−0.193	0.270
Distephanus speculum (Ehrenberg) Haekel	−0.246	−0.095	0.337
Ditylum brightwellii (West) Grunow	−0.045	−0.002	0.231
Eucampia zodiacus Ehrenberg	−0.036	−0.162	0.178
Guinardia flaccida (Castracane) Peragallo	−0.099	−0.350	−0.043
Gymnodinium gelbum Kofoid	0.019	0.104	−0.234
Gymnodinium sp.	−0.007	0.309	0.209
Gyrodinium sp.	0.044	0.022	0.176
Lauderia annulata Cleve	−0.097	−0.071	0.292
Leptocylindrus danicus Cleve	−0.021	0.010	0.110
Navicula sp.	−0.013	0.043	0.053
Nitzschia delicatissima Cleve	0.318	−0.185	−0.229
Nitzschia pungens Grunow	0.083	−0.091	0.244
Nitzschia seriata Cleve	0.032	0.095	0.181
Prorocentrum bipes (Paulsen) Balech	−0.074	0.180	−0.282
Prorocentrum triestinum Schiller	0.214	0.172	−0.273
Prorocentrum sp.	0.091	0.152	−0.227
Rhizosolenia hebetata f. *semispina* (Hansen) Gran	−0.051	−0.339	0.122
Rhizosolenia setigera Brightwell	−0.036	−0.106	0.007
Thalassiosira sp.	0.170	−0.196	−0.165
Thalassiothrix frauenfeldii Grunow	−0.052	−0.091	−0.067

sets of original variables. Correlation between species and canonical variates reveals a few groups of phytoplankton species among the environmental gradients: Two pennate diatoms, *Cylindrotheca closterium* and *Nitzschia delicatissima* are associated with higher silicate concentrations, but *Distephanus speculum* and *Cryptomonas* sp. are common in lower silicate concentrations. While *Lauderia annulata, Cylindrotheca closterium, Nitzschia pungens*, and *Distephanus speculum* prefer lower temperatures, dinoflagellate species such as *Gymnodinium gelbum, Protoperidinium bipes*, and *Protoperidinium triestinum* are common in warmer water.

CV1 had higher correlations with phosphate concentrations, CV2 exhibited highly negative correlations with salinity ($r = -0.760$) and water temperature in Cruise III-October (Tab. IV). Thus species with highly positive correlation with CV2 are heavily influenced by coastal water of low salinity. CV3 is positively correlated with the nutrient-rich and cooler water.

In Cruise IV-April CV1 had highly positive correlation with water temperature ($r = 0.833$), and CV2 showed highly negative correlation with nitrate concentration (Tab. IV). The remarkable increase in the nominal value of correlations in Cruise IV-April (Tab. III and Tab. IV) reflects the distinct difference of warm water influences between late March (Cruise II) and mid April (Cruise IV) in the study area. Table V shows the species groups noted from the correlations between species and canonical variates (Table III for example) in all the above three cruises.

Table IV. Correlation between the environmental variables and the significant canonical variates in Cruise III-October and Cruise IV-April.

Environmental Variables	Cruise III-October			Cruise IV-April	
	CV1	CV2	CV3	CV1	CV2
Nitrate	0.313	−0.039	0.381	0.077	−0.756
Nitrite	0.177	0.144	0.377	−0.274	0.254
Phosphate	0.510	−0.081	0.295	0.050	0.108
Silicate	0.132	0.297	0.294	0.144	−0.094
Temperature	0.354	−0.462	−0.376	0.883	−0.106
Salinity	0.129	−0.760	−0.060	0.290	−0.313

Table V. Species groups identified by canonical correlation analysis. The ii, iii, and iv designate the species that were identified as corresponding group members in cruise II (March), III (October), and IV (April), respectively.

Factors	Positive Group	Negative group
Water temperature		
	Chaetoceros compressus iv	*Cylindrotheca closterium* ii
	Chaetoceros debilis iv	*Lauderia annulata* ii
	Chaetocers didymus iv	*Nitzschia pungens* ii
	Gymnodinium gelbum ii	*Dictyocha fibula* iv
	Prorocentrum triestinum ii	*Distephanus speculum* ii, iv
	Protoperidinium bipes ii, iv	*Tropidoneis antarctica* v. *polylasta* iv
Salinity		
	Chaetoceros curvisetus iii	*Scrippsiella trochoideum* iv
	Hemiaulus haukii iii	
	Leptocylindrus danicus iii	
	Nitzschia pacifica iii	
	Stauroneis membranacea iii	
Nitrate concentration		
		Leptocylindrus danicus iv
		Rhizosolenia. hebetata f. *semispina* iv
		Prorocentrum bipes iv
		Prorocentrum triestinum iv
Silicate concentration		
	Cylindrotheca closterium ii	*Distephanus speculum* ii
	Nitzschia delicatissima ii	*Cryptomonas* sp. ii
Phosphate concentration		
	Oscillatoria erythraea iii	

DISCUSSION

Spring (late March and mid April) and autumn (late October) were quite different with respect to the environmental conditions which favor corresponding phytoplankton species. Silicate concentration and water temperature were found to be the major factors regulating species distribution in spring (Tab. III and IV), and salinity was the most influential factor in autumn. Naturally the gradients of water temperature and salinity in the present study are accompanied by the concurrent variations of the other environmental factors which in turn affect the distribution of the phytoplankton community. That is, each of the two environmental factors well reflects the synthetic mechanisms which regulate the biological processes of the phytoplankton community in the study area.

Annually heat advection into the study area by the Tsushima current results in higher mean SST (Sea Surface Temperature) and smaller variation of SST (Kang & Jin, 1984 a) than in any other seas surrounding Korean Peninsula. Thus the temperature difference between land and sea surface is maximal in early spring and minimal in early autumn (Kang, 1985). This feature of temperature gradient was found to be a major environmental factor for the phytolankton community in spring (Fig. 3 and 4); Clustering of samples along the canonical variates in Cruise IV-April (Fig. 3) corresponds well with the sample clusters in the temperature zonation (Fig. 4). While temperature gradient is weak in autumn, less saline surface water extends far north across the study area in early autumn (Miyazaki & Abe, 1960). Nishimura (1969) noted a remarkable propagation of neritic animal populations even in the central offshore region of the East Sea in midsummer. In Cruise III-October sample clusters on the plane of the canonical variates (Fig. 5) are also

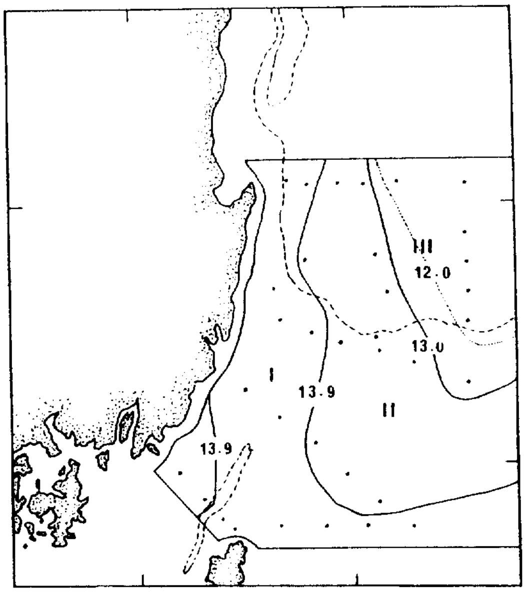

Fig. 4. Distribution of surface temperature (°C) in Cruise IV-April.

correspondent with the clustering in the salinity zonation (Fig. 6). The degree of the correspondence, however, is lower in autumn (Fig. 5) than in spring (Fig. 3). The northward extension of less saline surface water, however,

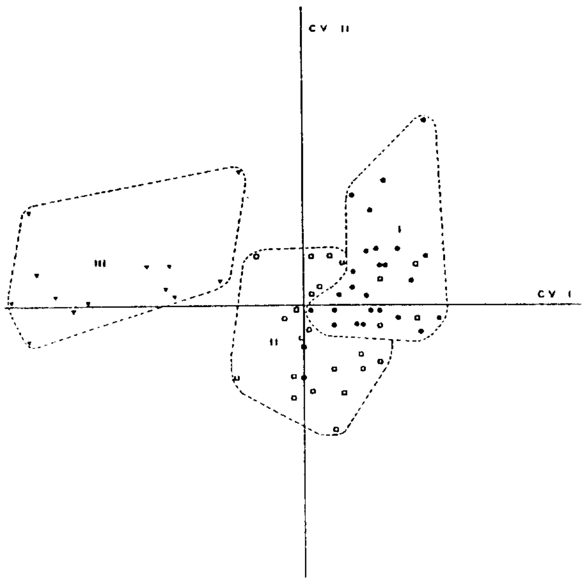

Fig. 3. Distribution of samples in Cruise Iv-April along the first two canonical variates. ●, ☐, and ▼ designates samples from the zone I, II, III in Fig. 4, respectively.

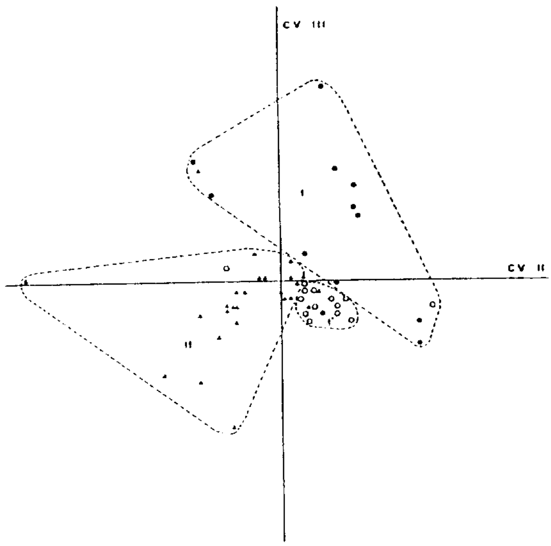

Fig. 5. Distribution of samples in Cruise III-October along the second and the third canonical variates. ●, O, and ▲ designates samples from the zone I, I', and II in Fig. 6, respectively.

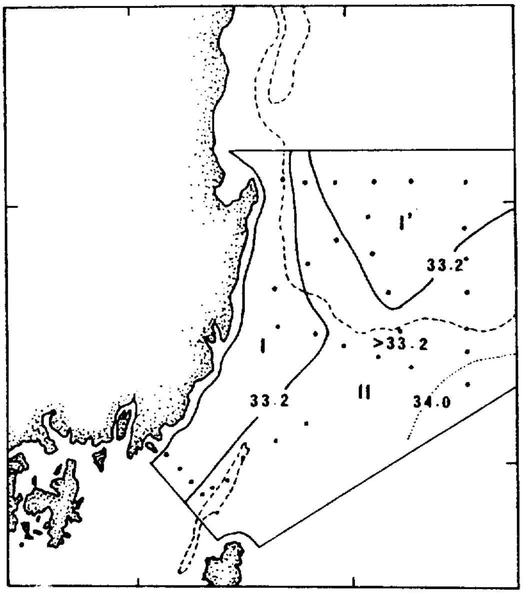

Fig. 6. Distribution of surface salinity (°/oo) in Cruise III-October.

does not always mean the horizontal salinity gradient in surface water which exerted heavy influence on the early autumn phytoplankton community (Tab. IV). This situation implies some special hydrographic structures that ensure heterogeneous distribution of the less saline water in the offshore regions. Isolated parcels of less saline water might be one of such special hydrographic structures. The "isolated parcels" will be discussed separately elsewhere.

Each species group identified by canonical correlations (Tab. V) reveals delicate ecological niches of the corresponding group members in the study area. Species groups that are positively associated with water temperature or salinity include two "useful indicator species of Kuroshio water" in Motoda and Marumo (1963) and five diatom species of "Kuroshio indicators" in Kawarada (1965). Two *Protoperidinium* species, *Protoperidinium triestinum* and *Protoperidinium bipes*, are positive members for water temperature, and at the same time they are negative members against nitrate concentration. Thus the two species possibly indicate warm and nitrogen depleted (Yang, 1984; Lee, 1985) Tsushima current water in this area. Small-sized pennate diatoms are found in the negative members against water temperature (*Cylindrotheca closterium* and *Nitzschia pungens*) and in the positive members for silicate concentrations (*Cylindrotheca closterium* and *Nitzschia delicatissima*). Small-sized diatoms grow first in the seasonal succession at temperate coastal waters (Margalef, 1958) with low temperature and high nutrient concentrations in early spring. Silicoflagellates are among the negative members against water temperature (*Dictyocha fibula, Distephanus speculum,* and *Tropidoneis antarctic* v. *polyplasta*), and *Distephanus speculum* is in the negative group against silicate concentration. *Dictyocha fibula* was cultured to find that its optimum temperature was 10°C (Valkenburg & Norris, 1970). Huang (1979) also reported high cell counts of silicoflagellate species in winter and spring along the northern coast of Taiwan. *Distephanus speculum* in the present area might compete with small diatoms for silicate nutrient, and result in an evolution of species with lower Ks values (Dugdale, 1967) than small diatoms in early spring. *Oscillatoria erythraea*, a nitrogen fixing species (Humm & Wicks, 1980; Dugdale et al., 1964), is positively associated with phosphate concentrations (Tab. IV). Among many factors contributing to the development and maintenance of blue-green algal bloom (in only a single genus, *Oscillatora*, in the open ocean), low salinity and high phosphorus content are of importance (McCarthy & Carpenter, 1983). The stimulation of nitrogen fixation by the addition of phosphorus nutrient would have a profound impact on the marine nitrogen cycle. The result of the canonical correlation analysis that *Oscillatoria erythraea* is positively associated with phosphate concentration well reflects the importance of phosphorus nutrient as a limiting factor for the active growth of the species in the study area.

Canonical correlation analyses in this paper led us to recognize the most influential environmental factors on the phytoplankton community and to search for characteristic ecological adaptations of phytoplankton species to the seemingly very complex physico-chemical structures of the hydrographic regime. Applications of canonical analysis to phytoplankton are found to be promising even in such complex environmental structures as in the present study area.

ACKNOWLEDGEMENTS

This work is part of the Basic Science Research Institute Program of Seoul National University supported by Ministry of Education, 1986. We would like to thank Drs. C.H. Koh, J.K. Choi, and Y.C. Park for critically reading earlier drafts. The authors extend their appreciation to the captain and crew of the Training Ship 'Hanbada' and to all those individuals who helped in the collection of samples.

REFERENCES

Cassie, R.M., 1972. A Computer programme for multivariate statistical analysis of ecological data. *J. Exp. Mar. Biol. Ecol.*, Vol. **10**, pp. 207-241.

Cassie, R.M. & A.D. Michael, 1968. Fauna and sediments of an intertidal mud flat: a multivariate analysis. *J. Exp. Mar. Biol. Ecol.*, Vol. **2**, pp. 1-23.

Choi, J.K., 1984. *The ecological study of phytoplankton in Gyeonggi Bay, Korea*, Ph.D. thesis, Department of Oceanography, Seoul National University, Seoul, 320 pp.

Cooleey, W.W. & P.R. Lohnes, 1971. *Multivariate data analysis.* John Wiley & Sons, New York, 364 pp.

Dugdale, R.C., 1967. Nutrient limitation in the sea: dynamics, identification and significance. *Limnol. Oceanogr.*, Vol. **9**, pp. 507-510.

Dugdale, R.C., J.J. Goering & J.H. Ryther, 1964. High nitrogen fixation rates in the Sargasso Sea and the Arabian Sea. *Limnol. Oceanogr.*, Vol. **9**, pp. 507-510.

Goodman, D., R.W. Eppley & F.M. Reid, 1984. Summer phytoplankton assemblages and their environmental correlates in the Southern California Bight. *J. Mar. Res.*, Vol. **42**, pp. 1019-1049.

Grasshoff, K., M. Ehrhardt & K. Kremling (editors), 1983. *Methods of seawater analysis.* Verlag Chemie, 419 pp.

Huang, R., 1979. A study on the silicoflagellates along the northern waters of Taiwan. *Acta Oceanogr. Taiwan*, Vol. **9**, pp. 119-125.

Humm, H.J. & S.R. Wicks, 1980. *Introduction and guide to the marine bluegreen algae.* John Wiley & Sons, New York, 194 pp.

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.*, Vol. **20**, pp. 1-9.

Kang, Y.Q. & M.S. Jin, 1984a, Seasonal variation of surface temperatures in the neighbouring Seas of Korea. *J. Oceanol. Soc. Kor.*, Vol. **19**, pp. 31-35.

Kang, Y.Q. & M.S. Jin, 1984b, Annual variation of salinity in the neighbourng seas of Korea. *J. Oceanol. Soc. Kor.*, Vol. **19**, pp. 105-110.

Kawarada, Y., 1965. Diatoms in the Kuroshio waters neighbouring Japan. *Inform. Bull. Planktol. Japan.*, Vol. **12**, pp. 8-15.

Kim, K. & C. H. Kim, 1983. Characteristics and origin of the cold water mass along the east coast of Korea. *J. Oceanol. Soc. Kor.*, Vol. **18**, pp. 73-83.

Kim, K. & R. Legekis, 1986. Branching of the Tsushima Current in 1981-1983. *Deep-Sea Res.* (submitted).

Lee, W.H., 1986. *An ecological study of phytoplankton in the southwestern waters of the East Sea (Sea of Japan), Korea*, Ph.D. thesis, Department of Oceanography, Seoul National University, Seoul, 225 pp.

Lim, D.B. & S. Chang, 1969. On the cold water mass in the Korea Strait. *J. Oceanol. Soc. Kor.*, Vol. **4**, pp. 71-82.

Margalef, R., 1958. Temporal succession and spatial heterogeneity in phytoplankton. In, *Perspectives in marine biology*, edited by Buzzati-Traverso, University of California Press, Berkeley & Los Angelis, pp. 323-349.

McCarthy, J.J. & E.J. Carenter, 1983. Nitrogen cycling in near-surface waters of open ocean. In, *Nitrogen in the marine environment*, edited by E.J. Carpenter & D.G. Capone, Academic Press, New York, pp. 487-512.

McIntire, C.D., 1978. The distribution of estuarine diatoms along environmental gradients: a canonical correlation. *Estuarine Coastal Mar. Sci.*, Vol. **6**, pp. 447-457.

Miyazaki, M. & S. Abe, 1960. On the water masses in the Tsushima current area. *J. Oceanogr. Soc. Japan*, Vol. **16**, 19-28.

Moriyasu, S., 1972. The Tsushima current. In, *Kuroshio*, edited by H. Stommel & K. Yoshida, University of Tokyo Press, Tokyo, pp. 353-369.

Motoda, S. & R. Marumo, 1963. Plankton of the Kuroshio water. In, *Proceedings of Symposium on Kuroshio*, 1963, pp. 40-61.

Nishimura, S., 1969. the zoogeographical aspects of the Japan Sea. Part V. *Publ. Seto. Mar. Biol. Lab.*, Vol. **27**, 67-142.

Park, Y.H., 1985. Some important summer oceanographic phenomena in the East China Sea. *J. Oceanol. Soc. Kor.*, Vol. **20**, pp. 12-21.

Penas, E. & G. Gonzalez, 1983. Relationships between benthic infauna and environmental factors in three beaches of the Ria de Arosa embayment (Spain) using canonical correlation analysis. *J. Exp. Mar. Biol. Ecol.*, Vol. **68**, pp. 245-256.

Shim, J.H. & W.H. Lee, 1983. Plankton study in the southeastern sea of Korea (I) — Phytoplankton distribution in September, 1981 — *J. Oceanol. Soc. Kor.*, Vol. **18**, pp. 91-103.

Shim, J.H., W.H. Lee & S.Y. Bak, 1985. Studies on the plankton in the southwestern waters of the East Sea (Sea of Japan) (II). Phytoplankton — standing crop, nanofraction, and primary production — *J. Oceanol. Soc. Kor.*, Vol. **20**, pp. 37-54.

Uhm, K.B. & K.I. Yoo, 1967. Diatoms in Korea Strait. *Reports from the Institute of Marine Biology, Seoul National University*. Vol. **1**, pp. 1-6.

Valkenburg, S. Van & R.E. Norris, 1970. The growth and morphology of the silicoflagellate *Dictyocha fibula* Ehrenberg in culture. *J. Physol.*, Vol. **6**, pp. 48-54.

Yang, S.R., 1984. *Phytohydrography and nutrient distribution in the southwestern area of the East Sea in early spring*, M.S. thesis, Department of oceanography, Seoul National University, Seoul, 61 pp.

Zurlini, G., A. Zattera & A. Bruschi, 1983. Structural analysis of phytoplankton communities variation in the Archipelago of La Maddalena (North Sardinian Coast): a canonical correlation approach. *J. Exp. Mar. Biol. Ecol.*, Vol. **70**, pp. 227-248.

Received February 12, 1987
Accepted March 18, 1987