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Seasonal Variation of Phytoplankton Community Structure in Northeastern Coastal Waters off the Korean Peninsula

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Phytoplankton community in the coastal waters off the northeastern Korean Peninsula were characterized from May 2002 to August 2003. Taxonomic composition, abundance and biomass were determined at two water depths at 10 sample sites. A total of 153 phytoplankton species including 121 diatoms, 28 dinoflagellates, 7 green algae and 7 other species were identified. The mean abundance of phytoplankton varied from 15 to 430 cells mL^{-1} in the surface layer and from 11 to 545 cells mL^{-1} in the bottom layer, respectively. Phytoplankton was more abundant in coastal stations relative to those in more open ocean. The most dominant species were marine diatoms such as *Thalassionema nitzschioides*, *Licmorphora abbreviata*, *Chaetoceros affinis* and *Chaetoceros socialis*. In addition, a few limnotic diatoms including *Fragilaria capucina* v. *rumpens*, the green alga *Scenedesmus dimorphus*, some marine dinoflagellates and *Cryptomonas* sp. appeared as dominant species. Mean concentration of total chlorophyll-*a* varied from 0.22 to 7.87 μg chl-*a* L^{-1} and from 0.45 to 6.79 μg chl-*a* L^{-1} in the surface and bottom layers, respectively. The contribution of phytoplankton each size-fractionated varied highly with season. The contribution of micro-phytoplankton to total biomass of phytoplankton in the surface and bottom layer was high in February and August 2003, and that of nano-phytoplankton was high in May 2002 in both surface and bottom layers.

Key Words: chlorophyll-*a*, Korean Peninsula, micro-phytoplankton, nano-phytoplankton

INTRODUCTION

The North Korean Cold Current (NKCC) flows southward along the east coast of Korea and it encounters the East Korean Warm Current (EKWC) in the middle zone of the East Sea (Japan Sea). The flowing of NKCC along the coast and offshore has an influence on the flowing of EKWC. The flow pattern and structure of water mass along the coast in the East Sea become very complicated due to the variations of NKCC and EKWC. In addition, the cold water flowing southward along the east coast may affect the creating the Korea Strait Bottom Cold Water (KSBCW) (Yun *et al.* 2004). Some studies concerning the oceanographic characteristics were conducted at the front zone which was formed in the encountering zone of two different currents in the East Sea, Korea (Cho *et al.* 1997; Park and Choi 1997; Moon *et al.* 1998).

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Phytoplankton is a primary producer as well as an important factor which has a pivotal role in global carbon cycle. It has also an effect on nutrient cycling in aquatic ecosystem and determining the food web structure (Fenchel 1988). The study on the characteristic of phytoplankton community is important to understand marine ecosystem. Some studies about species composition, abundance and primary production of phytoplankton along the coast and offshore in the East Sea were conducted (Shim and Lee 1983, 1987; Chin and Hong 1985; Cho 1985; Shim *et al.* 1985, 1989, 1992; Lee and Shim 1990; Park *et al.* 1991; Lee *et al.* 1998; Kang and Choi 2001, 2002; Kang *et al.* 2003; Choi *et al.* 2004a). Pigment analysis using HPLC for identifying and enumerating of phytoplankton in the East Sea and satellite remote sensing for obtaining the coastal zone color from wide area of the East Sea were used for verifying the timing of the seasonal bloom in the East Sea, recently (Park and Park 1997; Choi *et al.* 2004b; Yamada *et al.* 2004; Yoo and Kim 2004). But most studies on phytoplankton ecology exception of studies using

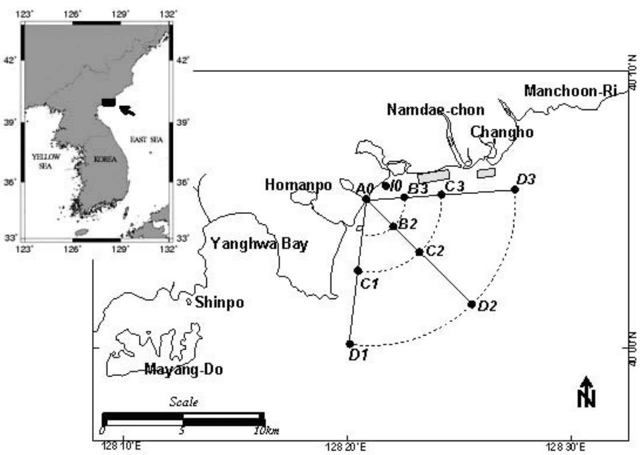

Fig. 1. Location map of study sites in the coastal waters off Shinpo district, North Korea.

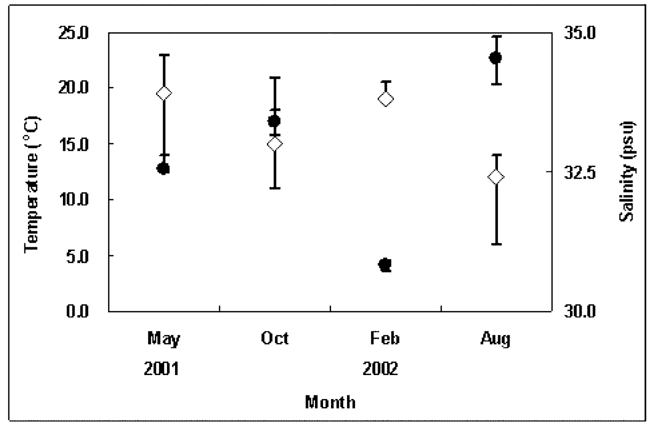

Fig. 2. The seasonal variation of sea surface temperature and sea surface salinity in the coastal waters off Shinpo district, North Korea (●: temperature, ◇: salinity).

satellite remote sensing were conducted at the middle or southwestern coastal waters off East Sea. Especially, the knowledge of phytoplankton community in the northeastern coastal waters off the Korean Peninsula was lack. The studies about the fresh water diatom flora and zooplankton were carried out only in Puckchong-Namdaechon river and three brackish lakes (Cho 2000a, 2000b, 2000c; Kim and Kang 2003), respectively. There was no information about the marine phytoplankton community in this area. The aims of this study are to introduce the distribution of phytoplankton community in the coastal waters off Shinpo district where are strong effected by the NKCC.

MATERIALS AND METHODS

The study area is located in the vicinity of Shinpo district (approximately 40°05′N, 128°20′E) where the nuclear power plant (NPP) has been constructed by Korean Peninsula Energy Development Organization (KEDO). The samples were seasonally taken four times from May 2002 to August 2003 at 10 sample sites within 10km from construction area of NPP (Fig. 1). Sea surface temperature (SST) and salinity (SSS) were measured using Horizontal Drew Monitoring System (HDMS, YSI 6000). Samples for qualitative analysis of phytoplankton were taken using Kitahara-type net (mesh opening: 60 μm) and samples for quantitative analysis of phytoplankton community were taken using water sampler in both surface and bottom layers. Samples were preserved immediately with Lugol's solution (final concentration about 4%). Identification and enumeration of phytoplankton were performed with a Sedgewick-Rafter chamber under the light microscope (Leitz Diaplan, X128~1,600) in the laboratory. Water samples for measuring chlorophyll-*a* concentration of phytoplankton were size fractionated with separate filtration by 20 μm filter. Filtered seawater was kept deep frozen and analyzed at the laboratory on Turner 10-Au fluorometer (USA).

RESULTS

Physical characteristics

The tidal variation in the study area is very small and belongs to a mixed type in which the semi-diurnal and diurnal components have similar magnitudes. The tidal range of the major semi-diurnal components is less than 10 cm throughout the all sample sites. The current speed ranged from 10.5 cm/s^{-1} in May 2002 to 32.0 cm/s^{-1} in August 2003 and the flow of current was as follow. The southward flow was predominant in February and August 2003 and the northward flow in May and October 2002 (KEPCO 2003). The mean SST and SSS for the period of survey varied from 4.1°C in February 2003 to 22.7°C in August 2003 and from 32.4 psu in August 2003 to 33.9 psu in May 2002, respectively (Fig. 2).

Species composition of phytoplankton

A total of 153 phytoplankton species including 121 diatoms, 28 dinoflagellates, 7 green algae and 7 other species was identified. During study periods, the marker of phytoplankton species appeared in on sampling time ranged from 48 in May 2002 to 76 October 2002 (Table 1). Diatoms showed most diverse species composition ranging from 32 to 54. The results showed that the

Table 1. The numbers of phytoplankton species observed in the coastal waters off Shinpo district, North Korea.

Groups	2002		2003		Total
	May	Oct.	Feb.	Aug.	
Bacillariophyceae (Diatom)	32	53	49	51	121
Dinophyceae (Dinoflagellate)	14	15	4	14	28
Chlorophyceae (Green algae)		4		4	7
Chrysophyceae		2	2	1	2
Cryptophyceae				1	1
Cyanophyceae		1			1
Euglenophyceae	2	1	1	1	2
Ciliophora				1	1
Total	48	76	56	73	153

Table 2. The total numbers of phytoplankton species observed in the different coastal waters off East Sea, Korea.

Sites	Number of species	Periods	References
Southeastern sea of Korea	185	Sep. 1981	Shim and Lee 1983
Gori	230	1986-1987	Cho 1988 (in Korean)
Wolseong	222	1986-1987	
Southwestern water of East Sea	235	1981-1984	Lee and Shim 1990
Gori	160	1987-1989	Yeo and Shim 1990
Southeastern coastal waters of East Sea	133	Sep. 1994	Lee *et al.* 1998 (in Korean)
Gori	333	1992-1996	Kang and Choi 2001 (in Korean)
Wolseong	364	1992-1996	
Uljin	364	1992-1996	
Ullundo	136	1999	Jung *et al.* 2001 (in Korean)
Tokdo Islands	87	1999	
Uljin	211	2003-2004	Choi *et al.* 2004
Chuksan	363	2000-2002	Kang *et al.* 2005 (in Korean)
Shinpo	153	2002-2003	This study

number of species in the study area was similar or lower than that at coastal waters in the East Sea (Table 2).

Abundance and dominant species of phytoplankon

The mean abundances of phytoplankton are shown in the Fig. 3. The mean abundances of phytoplankton varied from 15 to 430 cells mL^{-1} in the surface layer and from 11 to 545 cells mL^{-1} at the bottom layer. The abundances at the surface layer were higher than in the bottom layer with the exception that in February 2003. In May 2002 when the lowest mean value was recorded during the study period, the abundances ranged from 7 to 39 cells mL^{-1} in the surface layer and from 6 to 18 cells mL^{-1} in the bottom layer. Abundances were high at the station I0 and A0 where were near to the NPP site. The abundances varied from 11 to 147 cells mL^{-1} in the surface layer and 9 to 21 cells mL^{-1} in the bottom layer in October 2002. The highest abundance also observed at the I0 in case of surface layer but there were not shown the clear regional variations in the bottom layer. The abundances varied from 82 to 617 cells mL^{-1} in the surface layer and 137 to 1,309 cells mL^{-1} in the bottom layer in February 2003 when the highest mean value recorded. There were shown the clear variations among the stations. Phytoplankton was more abundant in coastal stations relative to those in more open ocean. In addition, in this time, the abundances in the bottom layer were higher than those in the surface layer. The abundances in August 2003 varied from 43 to 1,651 cells mL^{-1} in the surface layer and 11 to 27 cells mL^{-1} in the bottom layer. The abundances in the surface layer were higher than those at the bottom layer contrary to results of winter season, but the standing crops were higher at the near coastal area. The highest value at the surface layer was especially detected at the station C3 in August 2003. This result may be the influence of freshwater input from Namdaechon river.

Most of dominant species were marine diatoms. In

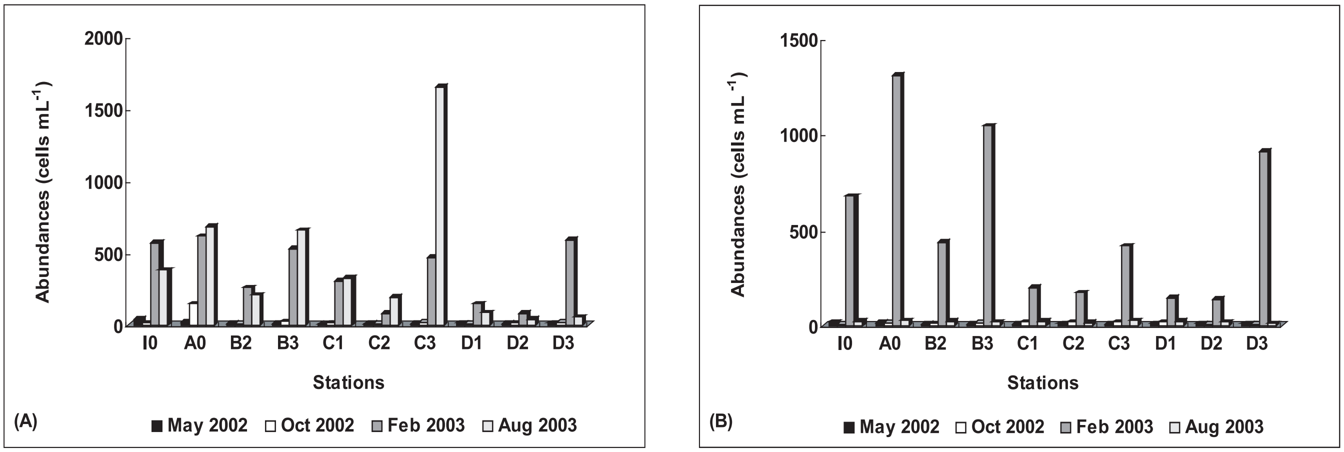

Fig. 3. The seasonal variation of abundance of phytoplankton at the surface (A) and bottom layer (B) in the coastal waters off Shinpo district, North Korea.

Table 3. The dominant species of phytoplankton observed in the coastal waters off Shinpo district, North Korea (Sur: surface layer, Bot: Bottom layer).

Year		Dominant species	Standing crops (cells/mL)	Dominance rates (%)
May 2002	Sur.	*Fragilaria capucina* v. *rumpens*	1.0	6.5
		Symbiodinium microadriaticum	0.9	6.3
		Thalassionema nitzschioides	0.9	6.1
		Gymnodinium fungiforme	0.8	5.2
		Licmorphora abbreviata	0.8	5.6
	Bot.	*Thalassionema nitzschioides*	1.4	12.7
		Nitzschia longissima	0.8	7.3
		Dactyliosolen fragillisima	0.8	6.8
		Licmorphora abbreviata	0.6	5.6
Oct. 2002	Sur.	*Scenedesmus dimorphus*	10.5	34.8
		Chaetoceros compressus	3.3	10.9
		Thalassionema nitzschioides	2.9	9.5
	Bot.	*Thalassionema nitzschioides*	4.2	28.2
		Chaetoceros affinis	1.3	9.0
		Cymbella leptoceros	1.3	8.5
Feb. 2003	Sur.	*Chaetoceros socialis*	118.1	32.2
		Chaetoceros radicans	65.5	17.9
		Chaetoceros compressus	41.8	11.4
		Chaetoceros debilis	39.0	10.2
		Chaetoceros sp.	0.0	9.2
	Bot.	*Chaetoceros debilis*	132.1	24.2
		Chaetoceros socialis	82.1	15.0
		Chaetoceros radicans	77.4	14.2
		Chaetoceros compressus	73.8	13.5
		Chaetoceros sp.	53.4	9.8
Aug. 2003	Sur.	*Cryptomonas* sp.	388.1	90.3
	Bot.	*Cryptomonas* sp.	8.5	40.0
		Prorocentrum minimum	1.7	7.9
		Chaetoceros sp.	1.5	6.8
		Nitzschia longissima	1.1	5.3
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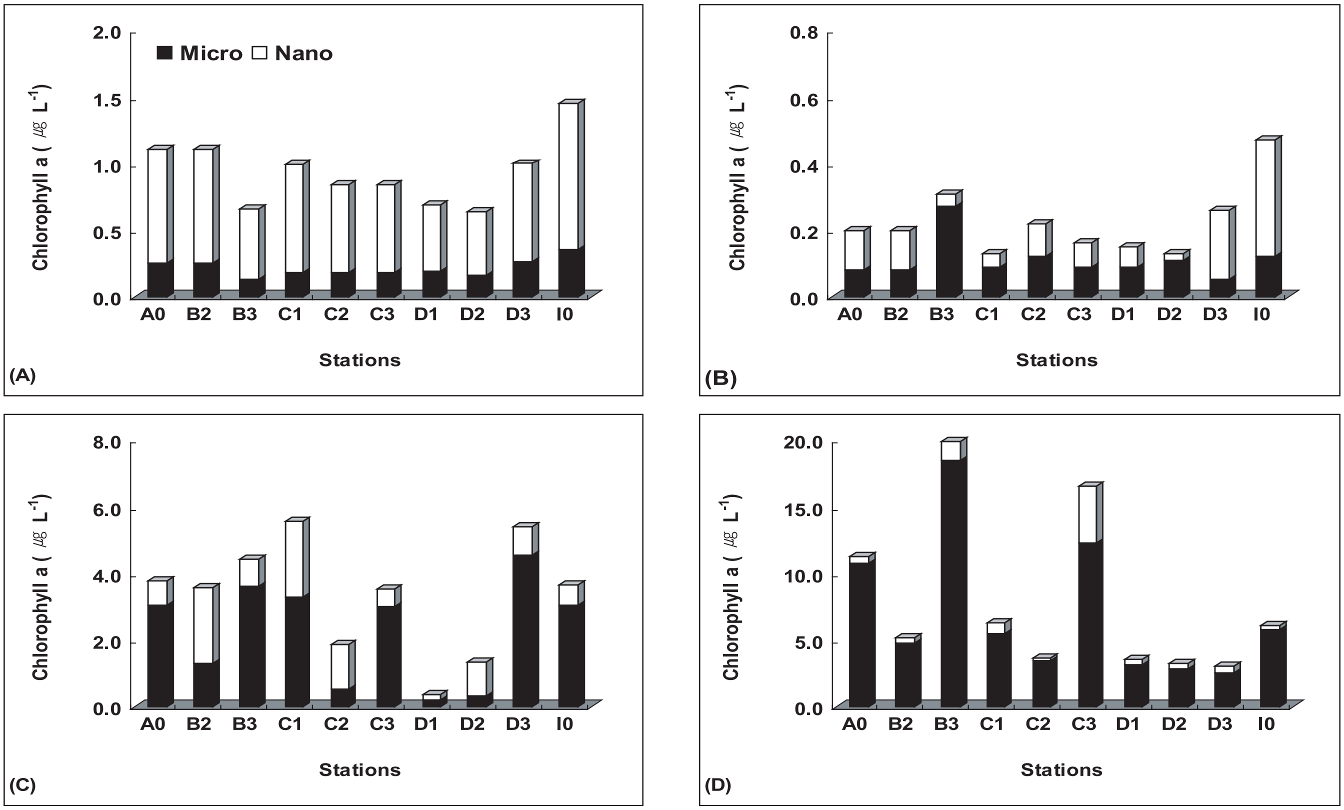

Fig. 4. The distribution of chlorophyll-*a* concentration of phytoplankton at the surface layer in the coastal waters off Shinpo district, North Korea (A: May 2002, B: Oct. 2002, C: Feb. 2003, D: Aug. 2003).

addition, a limnotic diatom such as *Fragilaria capucina* v. *rumpens*, some dinoflagellates, green alga *Scenedesmus dimorphus* and cryptomonad *Cryptomonas* sp. appeared as dominant species. In May 2002, marine diatom *Thalassionema nitzschioides*, *Licmorphora abbreviata* and limnotic diatom *Fragilaria capucina* v. *rumpens* were the most dominant species. Green alga *Scenedesmus dimorphus* was the dominant species in the surface layer in October 2002. But the high dominant rate of this species was shown only at the A0 where was influenced by the input of freshwater. *Thalassionema nitzschioides* and *Chaetoceros affinis* were the most dominant species in the bottom layer in this time. In February 2003, marine diatoms *Chaetoceros socialis* and *Chaetoceros debilis* were the most dominant species in both surface and bottom layers. Cryptomonad *Cryptomonas* sp. was the dominant species in both layers in August 2003 (Table 3).

Chlorophyll-*a* concentration of phytoplankton

Mean concentration of total chlorophyll-*a* varied from 0.22 to 7.87 μg L^{-1} in the surface layer and from 0.45 to 6.79 μg L^{-1} in the bottom layer. The highest mean value was recorded in August 2003 in the surface layer and February 2003 in the bottom layer, respectively (Fig. 4 and 5). The distribution of chlorophyll-*a* of phytoplankton was very similar to that of abundances. The chlorophyll-*a* concentration at the stations located near the coastal area was high relative to those in more open ocean. The mean chlorophyll-*a* concentration of micro-phytoplankton (> 20 μm) ranged from 0.11 to 6.97 μg chl-*a* L^{-1} in the surface layer and from 0.12 to 5.83 μg chl-*a* L^{-1} in the bottom layer. The mean contribution of micro-sized chlorophyll-a to total chlorophyll-*a* ranged from 22.8 to 88.6% in the surface layer and from 22.2 to 85.8% in the bottom layer. The contribution of micro-phytoplankton to total phytoplankton was low in May and October 2002. On the contrary, it was high in February and August 2003. In case of nano-phytoplankton (<20 μm), the mean chlorophyll-*a* concentration varied from 0.11 to 1.07 μg chl-*a* L^{-1} in the surface layer and from 0.34 to 0.97 μg chl-*a* L^{-1} in the bottom layer. The contribution of nano-sized chlorophyll-*a* to total chlorophyll-*a* ranged from 11.4 to 77.2% in the surface layer and from 14.2 to 77.8% in the bottom layer. The contribution of nano-phytoplankton was high in May and October 2002, and was low in February and August 2003.

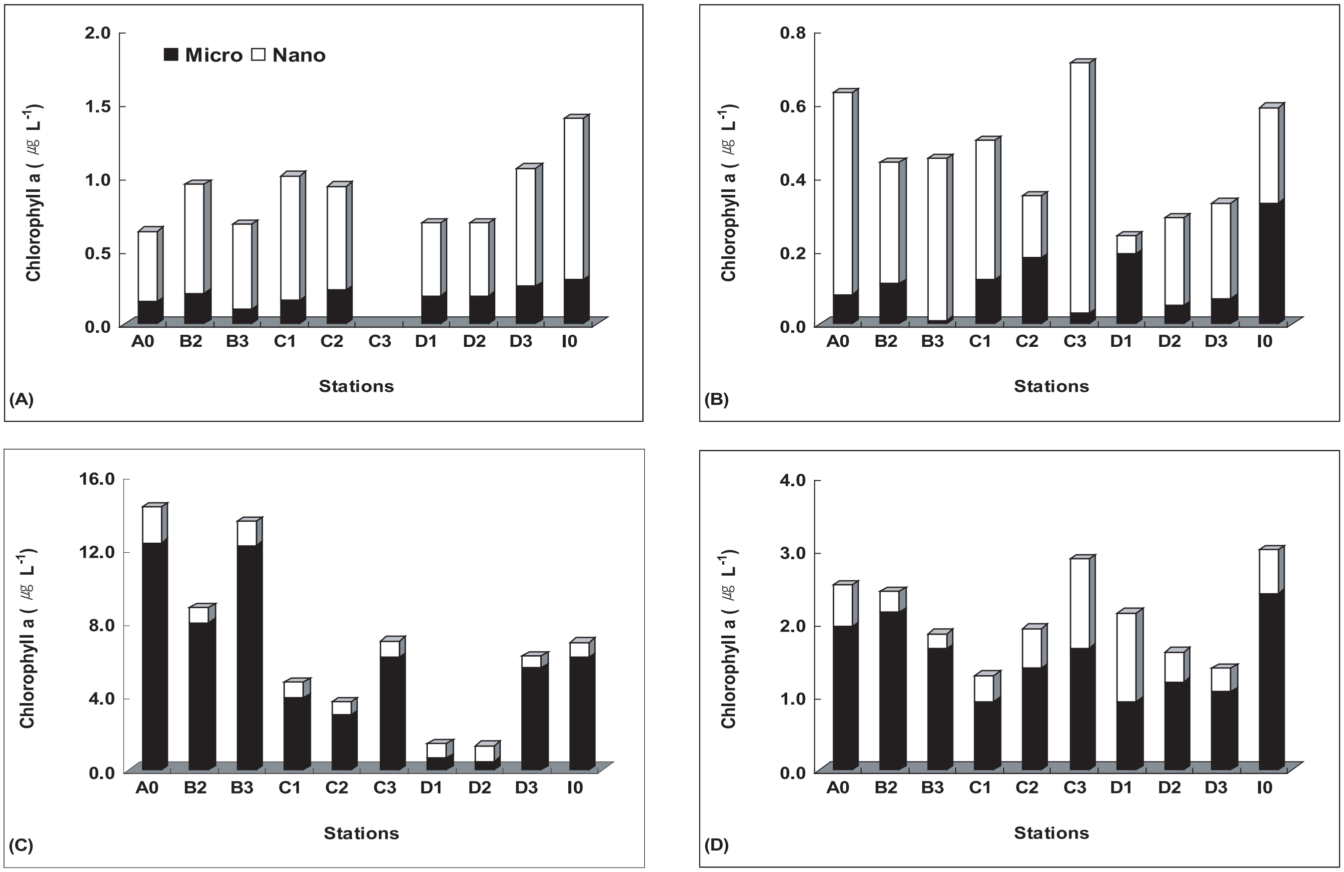

Fig. 5. The distribution of chlorophyll-*a* concentration of phytoplankton at the bottom layer in the coastal waters off Shinpo district, North Korea (A: May 2002, B: Oct. 2002, C: Feb. 2003, D: Aug. 2003)

DISCUSSION

A total of 144 phytoplankton species including 121 diatoms, 28 dinoflagellates, 7 green algae and 7 other species was identified in the northeastern coastal waters off the Korean Peninsula. During the study periods, the occurrence of phytoplankton species seasonally varied from 48 to 76. That was similar or lower than the results of previous studies about the phytoplankton in the different coastal area of East Sea, Korea (Table 1). The mean abundances of phytoplankton varied from 15 to 430 cells mL^{-1} and from 11 to 545 cells mL^{-1} in the surface and bottom layer, respectively. Phytoplankton blooms in spring and fall were not detected in this study. But the mean abundances of phytoplankton were high in winter and summer season. It showed that our reseults were different from general pattern in spring and fall bloom. The timing and magnitude of spring or fall blooms of phytoplankton in East Sea were different among the areas, and there were differences in the timing and magnitude of phytoplankton blooms year by year (Yamada *et al.* 2004). So the spring or fall bloom of phytoplankton not detected in this study might be due to such accounts. Kim *et al.* (2000) showed from sporadic Coastal Zone Color Scanner (CZCS) data that the spring bloom in the East Sea began in the southern area in April and moved to the northern area in May and the fall bloom which appeared in November and December appeared first in the southwest region then in the southeast and northeast regions, finally appearing in the northwest region in the East Sea. In this study, the abundances showed clear regional variations. Phytoplankton was more abundant in coastal stations relative to those in more open ocean. The stations recording the high abundances of phytoplankton such as at the I0, A0 and C3 were strongly influenced by the input of freshwater. These results showed that the phytoplankton community in this area was very strong influenced by the input of terrestrial materials leaching from the river into coastal area. Most of the dominant species were marine diatoms. In addition, some dinoflagellates as well as limnotic diatoms were occasionally detected as dominant species in May 2002.

In August 2003, *Cryptomonas* sp. was the dominant species taking 90.3% of total abundance in the surface layer. Especially, the diatom *Chaetoceros socialis* and *Chaetoceros debilis* which were well known as very important plankton in the northern cold region or cooler waters showed the regional characteristics influenced by NKCC (Tomas 1997). Mean value of total chlorophyll-*a* concentration of phytoplankton varied from 0.22 to 7.87 μg chl-*a* L^{-1} and from 0.45 to 6.79 μg chl-*a* L^{-1} in the surface and bottom layers, respectively. The contribution of micro-phytoplankton to total phytoplankton was high in February and October 2003 and that of nano-phytoplankton was high in May and October 2002. Some studies about contribution of phytoplankton in each sizefraction were conducted in the coastal area of East Sea. Shim *et al.* (1991) reported that the contribution of pico-phytoplankton (< 2 μm) to total phytoplankton was higher than that of other groups to the total phytoplankton in the Korea Strait. Choi *et al.* (2004a) suggested that small cell including the prokaryotic algae as well as pico-phytoplanktonic eukaryotic algae were extremely great contributor of the biomass of phytoplankton. The contribution of phytoplankton in each size-fractionated varied highly with seasons in this study. The contribution of large cell was high in winter and summer, while that of small cell was high in spring and autumn.

REFERENCES

Chin P. and Hong S.Y. 1985. The primary production of phytoplankton in the western channel of the Korea Strait. *Bull. Korean Fish. Soc.* **18:** 74-83. (in Korean)

Cho C.H. 1985. Chlorophyll-*a* concentrations of microplankton and nannoplankton in the coastal seas of Korea in fall. *Bull. Korean Fish. Soc.* **18:** 63-66. (in Korean)

Cho K.J. 2000a. Epilithic Diatom Flora of the Pukchong-Namdaechon River of North Korea. *Algae* **15:** 209-231.

Cho K.J. 2000b. Epipsammic Diatom Flora of the Pukchong-Namdaechon River of North Korea. *Algae* **15:** 233-254.

Cho K. J. 2000c. Epiphytic Diatom Flora of the Pukchong-Namdaechon River of North Korea. *Algae* **15:** 255-286.

Cho H., Moon C., Yang H., Kang W. and Lee K. 1997. Regeneration processes of nutrients in the polar front area of the East Sea. III. Distribution patterns of water masses and nutrients in the Middle-Northern East Sea of Korea in October, 1995. *J. Korean Fish. Soc.* **30:** 393-407. (in Korean)

Choi H.C., Kang Y.S. and Jeon I.S. 2004a. Phytoplankton community in adjacent waters of Ulchin nuclear power plant. *J. Environ. Biol.* **22:** 426-437.

Choi H.C., Kang Y.S., Choi J.K., Song T.Y. and Yoo M.H. 2004b. Analysis on the pigment composition of phytoplankton assemblages using HPLC (High Performance Liquid Chromatography) in the adjacent waters of nuclear power plants in Spring. *J. Oceanogr. Soc. Korea.* **39:** 234-242.

Fenchel T. 1988. Marine plankton food chains. *Annu. Rev. Ecol. Syst.* **19:** 19-38.

Kang Y.S. and Choi J.K. 2001. Ecological characteristics of phytoplankton communities in the coastal waters of Gori, Wulseong, Uljin and Youngkwang. I. Species composition and distribution (1992-1996). *Algae* **16:** 85-111. (in Korean)

Kang Y.S. and Choi J.K. 2002. Ecological characteristics of phytoplankton communities in the coastal waters of Gori, Wulseong, Uljin and Youngkwang. II. Distributions of standing crop and environmental variables (1992-1996). *J. Oceanogr. Soc. Korea.* **7:** 108-128. (in Korean)

Kang Y.S., Choi J.K. and Eum H.M. 2003. Ecological characteristics of phytoplankton communities in the coastal waters of Gori, Wulseong, Uljin and Youngkwang. III. Distribution of dominant species and environmental variables. *Algae* **16:** 85-111. (in Korean)

Kang Y.S., Choi H.C., Lim J.H., Jeon I.S. and Seo J.H. 2005. Dynamics of the Phytoplankton community in the Coastal Waters of Chuksan Harbor, East Sea. *Algae* **20:** 345-352. (in Korean)

Kim S. and Kang Y. 2003. Brackish lakes in Shinpo district, North Korea. I. Zooplankton. *Korean J. Limnol.* **13:** 17-22.

Kim S.W., Saitoh S., Ishizaka J., Isoda Y. and Kishino M. 2000. Temporal and spatial variability of phytoplankton pigment concentration in the Japan Sea derived from CZCS images. *J. Oceanogr.* **56:** 527-538.

Lee J., Han M. and Yang H. 1998. The ecosystem of the southern coastal waters of the East Sea, Korea. I. Phytoplankton community structure and primary productivity in September, 1994. *J. Korean Fish. Soc.* **31:** 45-55. (in Korean)

Lee W.H. and Shim J.H. 1990. Distribution of phytoplankton standing crop and the associated T-S properties in the southwestern East Sea (Sea of Japan). *J. Oceanogr. Soc. Korea.* **25:** 1-7.

Moon C., Yang S., Yang H., Cho H., Lee S. and Kim S. 1998. Regeneration processes of nutrients in the polar front area of the East Sea. IV. Chlorophyll a distribution, new production and the vertical diffusion of nitrate. *J. Korean Fish. Soc.* **31:** 259-266. (in Korean)

Park C. and Choi J.K. 1997. Zooplankton community in the front zone of the East Sea of Korea (the Sea of Japan): 1. Species list, distribution of dominant taxa, and species association. *J. Korean Fish. Soc.* **30:** 225-238. (in Korean)

Park J.S., Kang C.K. and An K.H. 1991. Community structure and spatial distribution of phytoplankton in the polar front region off the East Coast of Korea in summer. *Bull. Korean Fish. Soc.* **24:** 237-247.

Park, M.O. and Park J.S. 1997. HPLC method for analysis of chlorophylls and carotenoids from marine phytoplankton. *J. Korean Soc. Oceanogr.* **32:** 46-55.

Shim J.H. and Lee W.H. 1983. Plankton study in the southeastern sea of Korea (I) Phytoplankton distribution in September, 1981. *J. Oceanogr. Soc. Korea.* **18:** 91-103.

Shim J.H. and Lee W.H. 1987. Distribution of phytoplankton species and associated environmental factors in the Southwestern Waters of the East Sea (Sea of Japan), Korea. *J. Oceanogr. Soc. Korea*. **22:** 34-42.

Shim J.H., Lee W.H. and Bak S.Y. 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. Oceanogr. Soc. Korea*. **20:** 37-54.

Shim J.H., Yang S.R. and Lee W.H. 1989. Phytohydrography and the vertical pattern of nitracline in the southern waters of the Korean East Sea in early spring. *J. Oceanogr. Soc. Korea*. **24:** 15-28.

Shim J.H., Yeo H.G. and Park J.G. 1992. Primary production system in the southern waters of the East Sea, Korea. I. Biomass and productivity. *J. Oceanogr. Soc. Korea*. **27:** 91-100.

Shim J.H., Yeo H.G. and Shin Y.K. 1991. Ecological effect of thermal effluent in the Korean coastal waters I. Significance of autotrophic nano and picoplankton in adjacent waters of Kori nuclear power plant. *J. Oceanogr. Soc. Korea*. **26:** 77-82. (in Korean)

Tomas C.R. 1997. Identifying marine phytoplankton. Academic Press. 858pp.

Yamada K., Ishizaka J., Yoo S., Kim H. and Chiba S. 2004. Seasonal and interannual variability of sea surface chlorophyll a concentration in the Japan/East Sea (JES). *Prog. Oceanogr*. **61:** 193-211.

Yoo J. and Kim H. 2004. Suppression and enhancement of the spring bloom in the southwestern East Sea/Japan Sea. *Deep-Sea Res*. II. **51:** 1093-1111.

Yun J., Magaard L., Kim K., Shin C., Kim C. and Byun S. 2004. Spatial and temporal variability of the North Korean Cold Water leading to the near-bottom cold water intrusion in Korea Strait. *Prog. Oceanogr*. **60:** 99-131.

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