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Phytoplankton Community in Adjacent Waters of Ulchin Nuclear Power Plant

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Abstract - To understand the phytoplankton community in adjacent waters of Ulchin nuclear power plant (UNPP), abundance and the size fractionated chl-*a* concentrations were evaluated through seasonal interval sampling from April 2003 to February 2004. A total of 211 different phytoplankton species was observed and mean abundance of phytoplankton in each study period ranged from 244,286 to 1,221,779 cells L^{-1}. The contributions of microplankton (>20 μm) to total phytoplankton abundance ranged from 42.5 to 83.6% (average 66.1%) and those of nanoplankton (<20 μm) ranged from 16.4 to 57.5% (average 33.9%). Total chl-*a* concentrations of phytoplankton ranged from 0.52 to 2.26 μg L^{-1}. The contribution of chl-*a* concentrations of microplankton was higher than that of nano- and picoplankton through the study period with exception of July 2003. The results of abundances and chl-*a* concentrations suggest that microplankton has an important role in adjacent waters of UNPP. The diminution of abundances and chl-*a* concentrations of phytoplankton was observed after passage through the cooling water system, but it was gradually recovered by mixing with the ambient waters. Our results suggested that the influence of thermal discharges on phytoplankton should be restricted within narrow limits around outlet area of thermal effluents.

Key words : abundance, size fractionated chl-*a*, cooling water system, thermal effluents, Ulchin nuclear power plant (UNPP)

INTRODUCTION

Much electric energy has been demanded due to the improvement of living standards and the rapid industrial growth. To satisfy this electric energy demand, nuclear power plants and thermoelectric power plants have been constructed in the coastal areas. Especially, the nuclear power plants, which have been using the nuclear fuel, are technical-intensive industry and will increase more in our country where the natural resource is meager. This electric generation system using uranium as a fuel needs lower thermal efficiency and a lot of cooling waters. Because all the nuclear power plants adopt once-through cooling system which has no separated equipment (e.g. cooling tower), a lot of cooling waters of which temperature is higher than ambient sea waters enter the adjacent waters of nuclear power plant (IAEA 1974). This effluents have been called as thermal discharges, which have an influence on marine ecosystem and often limit the distribution of marine organisms (Nayor 1965; Langford 1990; Suresh *et al.* 1995). Input of artificial heat energy into marine environment is an important external pressure factor effecting the diversity of marine organisms, community structure as well as production rates (Anraku and Kozasa 1979; Langford 1990). So, the elevated temperature of thermal discharges has been one of the most important

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issues to give a serious consideration. For these reasons, many researches, which were concerned with the characteristics of plankton community (Yoo and Lee 1982; Yeo and Shim 1987; Cho 1988; Shim *et al.* 1991; Kim and Choi 1992; Lee and Lee 1995; Yoo and Kim 1997; Yi and Chin 1997; Kim *et al.* 1998; Kang and Choi 2001, 2002; Kang *et al.* 2003) and the characteristics of the distribution of benthic algae (Kim 1986; Kim and Choi 1995; Kim and Huh 1998; Kim *et al.* 1998; Yoo and Kim 2003) as well as other researches (Yi 1987; Kim *et al.* 1994; Jung *et al.* 1998) in vicinity of power plants, have been studied extensively but still stay on a fundamental phase in case of domestic studies.

Phytoplankton has an important role as a major carbon source in marine ecosystem. Because it is affected by environmental condition and has an influence on marine ecosystem, the understanding of phytoplankton community structure is a great help to understand marine environment. So, many studies concerning the influence of operation of power plant on phytoplankton community had been conducted (Hirayama and Hirano 1970; Barnett 1972; Carpenter *et al.* 1972; Eppley 1972; Briand 1973; Takesue and Tsuruta 1975; Fox and Moyer 1978; Anraku and Kozasa 1979; Dunstall 1985). Based on the size structure, phytoplankton is fractionated into three groups; microplankton ($>20\,\mu m$), nanoplankton ($2-20\,\mu m$) and picoplankton ($0.2-2\,\mu m$) (Sieburth *et al.* 1978). The size distribution of the phytoplankton community plays a fundamental role in determining the food web structure (Fenchel 1988). In addition, picoplankton is known as an important contributor to total phytoplankton biomass and is responsible for more efficient energy transfer to higher trophic levels in marine ecosystem. The researchers, thus, have been interested in distribution and biomass of small-size phytoplankton and have comprehensively studied (Johnson and Sieburth 1979; Waterbury *et al.* 1979; Malone 1980; Takahashi *et al.* 1985; Stoker and Antia 1986; Geider 1988). Until now there had been some studies conducted on the picoplankton in coastal waters of Korea (Shim *et al.* 1984; Lee *et al.* 1989; Shin *et al.* 1990; Shim *et al.* 1991; Yeo *et al.* 1996) and phytoplankton community in adjacent waters of Ulchin nuclear power plants (Cho 1988; Kang and Choi 2001, 2002; Kang *et al.* 2003). However, any studies on the biomass of picoplankton and its contributions to the phytoplankton community had not been reported yet.

The principal aims of this study were: (1) to gain information of phytoplankton community by the analysis of the abundance and biomass of phytoplankton, and (2) to evaluate the contribution of the size fractionated phytoplankton, and the effect of entrainment and thermal discharges on phytoplankton community in adjacent waters of UNPP.

MATERIALS AND METHODS

Since the operation of unit 1 and 2 in September 1989, the UNPP, located at Ulchin-Gun in Kyoungbuk (37° 04′00″ N 129° 23′04″ E), now has four operating nuclear units and discharges seawater from its cooling system at the rate of $50-60\,m^{-3}\,s^{-1}\,unit^{-1}$. The sampling was seasonally performed four times from April 2003 to February 2004 at the 10 stations including one comparing site within 10 km from UNPP. Also, to evaluate the effects of entrainment on phytoplankton community, one sample was taken from discharge

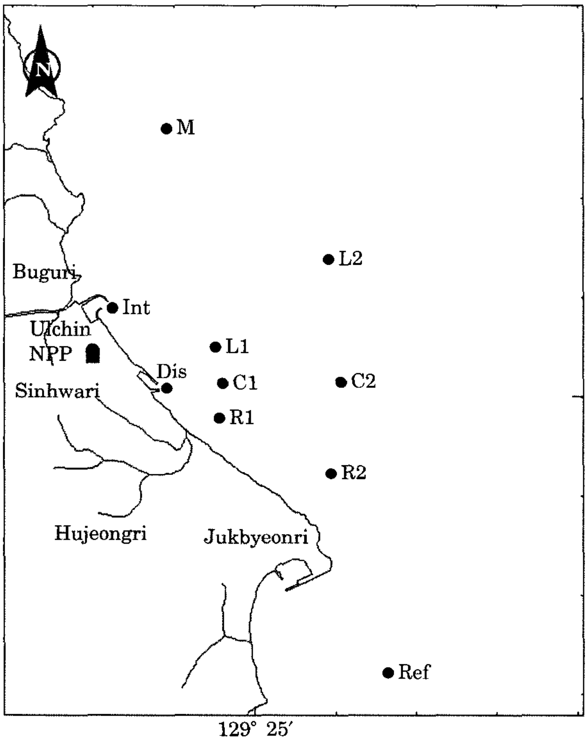

Fig. 1. Location of sampling sites around the Ulchin nuclear power plant.

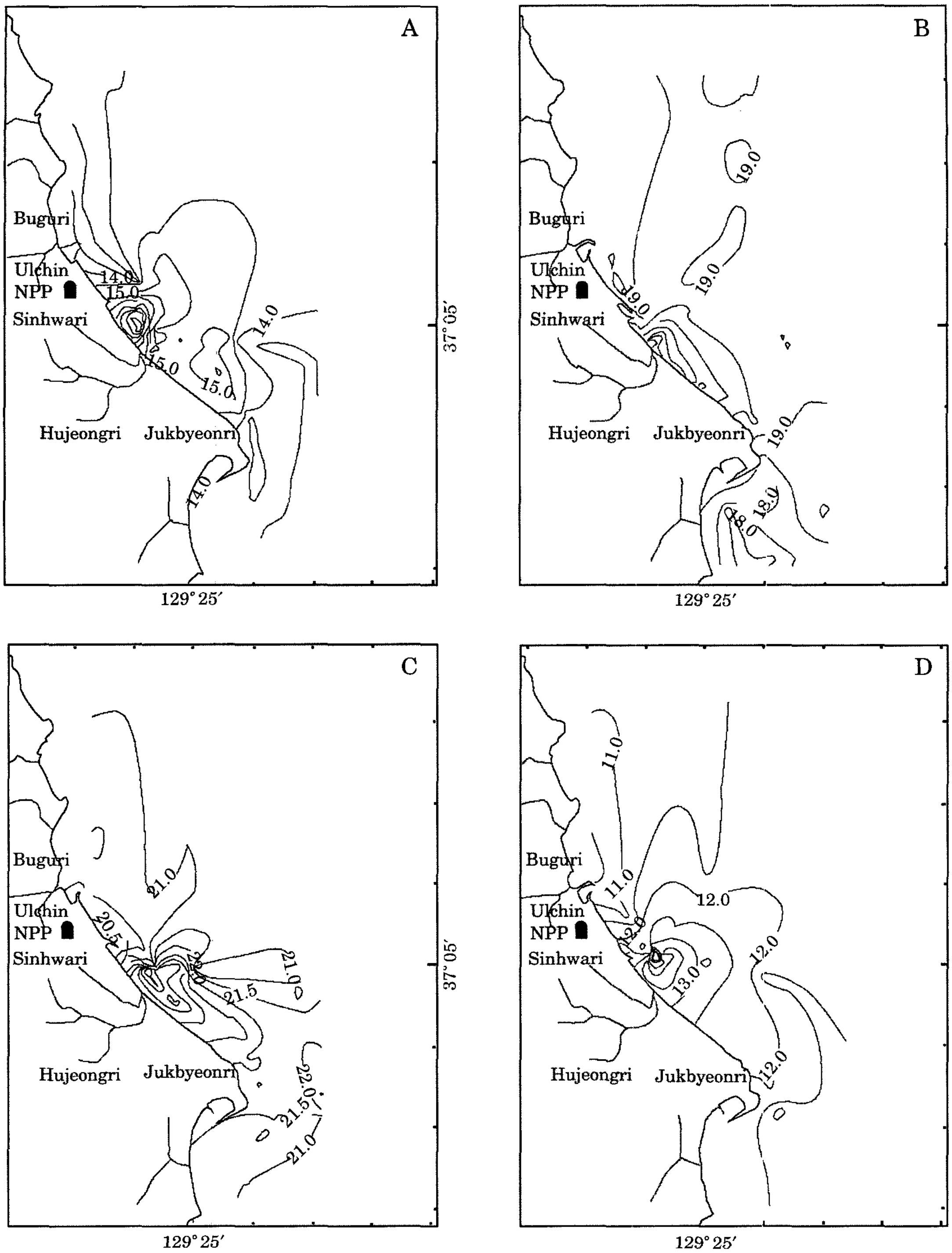

Fig. 2. Horizontal distributions of surface water temperature around the Ulchin nuclear power plant (A: April, 2003, B: July, 2003, C: Oct., 2003, D: Feb., 2004).

mouth (Fig. 1).

Samples taken by Kitahara-type net (mesh opening: 40 μm) for the species composition and by water sampler for abundance of phytoplankton, respectively at the surface seawater were preserved immediately with Lugol's solution (final concentration of ca. 4%) and were identified and counted under the light microscope (Nikon HFX-IIA) in the laboratory. Water samples for measuring chl-*a* concentration were size fractionated with separate filtration according to Fenchel (1988):

0.2–2 μm (picoplankton), 2–20 μm (nanoplankton), >20 μm (microplankton). Filtered seawater was kept deep frozen and analyzed at the laboratory on Turner 10-Au fluorometer (USA).

RESULTS

1. Distribution of surface seawater temperature (SST)

The SST was measured using Horizontal Drew Monitoring System (HDMS, YSI 6000). The annual variation of SST was 11.5–21.0°C in adjacent waters of UNPP. The highest SST was observed in October 2003 and the lowest was observed in February 2004 (KEPCO 2004). The SST of the vicinity of discharge area was about 6.3–7.8°C warmer than ambient seawater and the diffusion area of thermal effluents covered over approximately 2.0–3.0 km (Fig. 2).

2. Species composition and abundance

A total of 211 different phytoplankton species including 154 diatoms, 50 dinoflagellates and 7 other species was identified in adjacent waters of UNPP (Fig. 3). The number of species of phytoplankton through the season ranged from 70 to 99 and most of them were diatoms (Fig. 4).

The seasonal mean abundances of phytoplankton ranged from 59,581 to 1,586,938 cells L^{-1}, with the highest abundance in April 2003 when phytoplankton bloom occurred (Fig. 5A). In April 2003, the abundances of phytoplankton were very high at all stations and *Leptocylindrus danicus* became the key species occupying 71.3% of the total phytoplankton abundance. Dinoflagellates, *Gymnodinium* sp. and *Prorocentrum triestinum* became dominant in the summer season (Table 1). There were small differences in phytoplankton abundance among the stations but outlet area of ther-

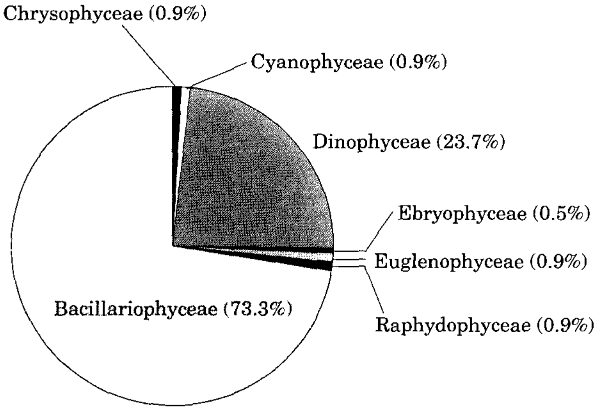

Fig. 3. Species composition of phytoplankton around the Ulchin nuclear power plant.

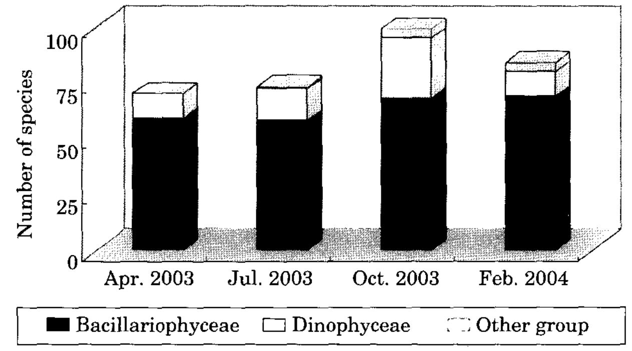

Fig. 4. Species number of the each group of phytoplankton around the Ulchin nuclear power plant.

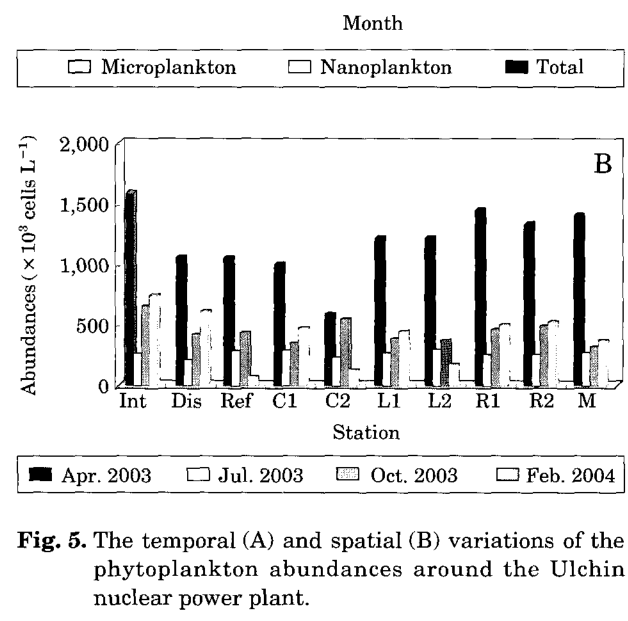

Fig. 5. The temporal (A) and spatial (B) variations of the phytoplankton abundances around the Ulchin nuclear power plant.

Table 1. The contributions of dominant species to total abundance of phytoplankton community in the study area (unit: %)

Dominant Species	2003			2004
	Apr.	Jul.	Oct.	Feb.
Chaetoceros debilis			5.8	
Chaetoceros socialis			4.8	
Chaetoceros spp.				9.0
Eucampia zodiacus	3.5			
Leptocylindrus danicus	71.3		6.7	
Pseudo-nitzschia seriata	20.2		34.7	
Pseudo-nitzschia pungens v. *atlantica*			8.9	
Skeletonema costatum		8.7		48.3
Thalassiosira sp. (10 μm)				9.9
Gymnodinium sp.		45.8	5.5	
Prorocentrum triestinum		22.1		

mal effluents nearby at discharge mouth displayed lower values than other stations located at the coastal area (Fig. 5B).

The abundances of the microplankton (>20 μm) out of the total abundances of phytoplankton ranged from 104,811 to 966,154 cells L^{-1}. The highest abundance was recorded in April 2003 and the lowest in July 2003. The mean contribution of microplankton was 66.1% ranging from 42.5% to 83.6%, and the highest contribution was recorded in April 2003 when the bloom of microplankton occurred (Fig. 6A). This results imply that the microplankton was the main contributor of phytoplankton community in adjacent waters of UNPP. In case of nanoplankton (<20 μm), the abundances ranged from 47,869 to 255,625 cells L^{-1}, and the highest abundance was recorded in April 2003 and the lowest in February 2004. The fraction of nanoplankton averaged 33.9% ranging from 16.4% to 57.5% (Fig. 6B). The contribution of nanoplankton to the total phytoplankton community was the highest in July 2003 and the higher contribution was shown when the SST was relatively high.

3. Chl-*a* concentration

The seasonal mean chl-*a* concentrations of phytoplankton ranged from 0.52 to 2.26 μg L^{-1} in the study area. The highest concentration occurred in April 2003 when the bloom of phytoplankton was observed and the lowest concentration occurred in October 2003 (Fig. 7A).

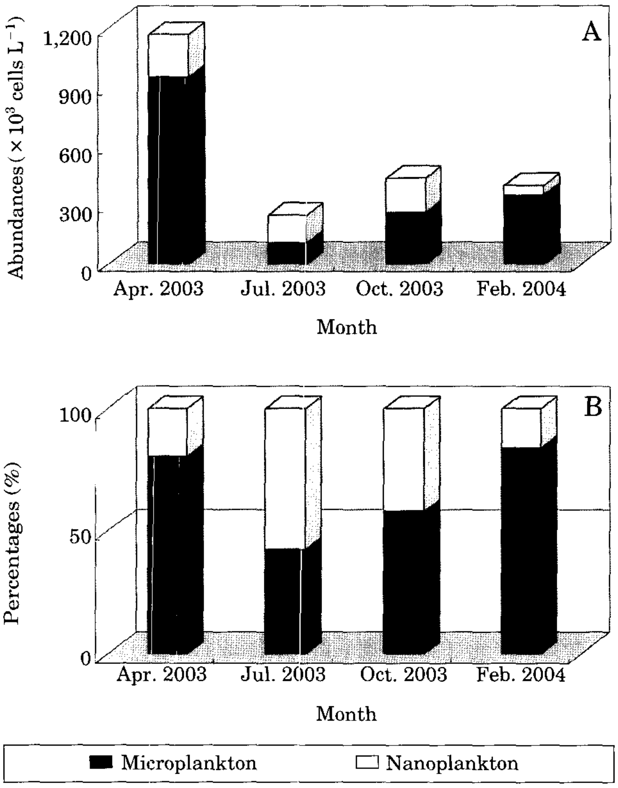

Fig. 6. The temporal variation of the mean abundances (A) and relative percentages (B) of nanoplankton and microplankton around the Ulchin nuclear power plant.

The mean chl-*a* concentrations of microplankton (>20 μm) ranged from 0.37 to 1.69 μg L^{-1} and its contribution to the total chl-*a* ranged from 25.5% to 74.8%. The fraction of microplankton out of the total chl-*a* concentration was higher than that of others through the seasons with exception of the summer. These results were similar to the contribution of microplankton to total abundance of phytoplankton and showed that the microplankton was the main contributor of phytoplankton biomass in adjacent waters of UNPP. The mean chl-*a* concentrations of nano- (2-20 μm) and picoplankton (0.2-2 μm) ranged from 0.06 to 0.33 and from 0.11 to 1.17 μg L^{-1}, and the contribution of nano- and picoplankton ranged from 10.1% to 16.6% and from 15.1% to 58.0%, respectively (Fig. 8). The contribution of nanoplankton was the lowest among the size-fractionated planktons through the seasons and that of picoplankton showed the highest in July 2003. In July 2003, the abundances of phytoplankton were low but the chl-*a* concentrations were relatively high, because of the chl-

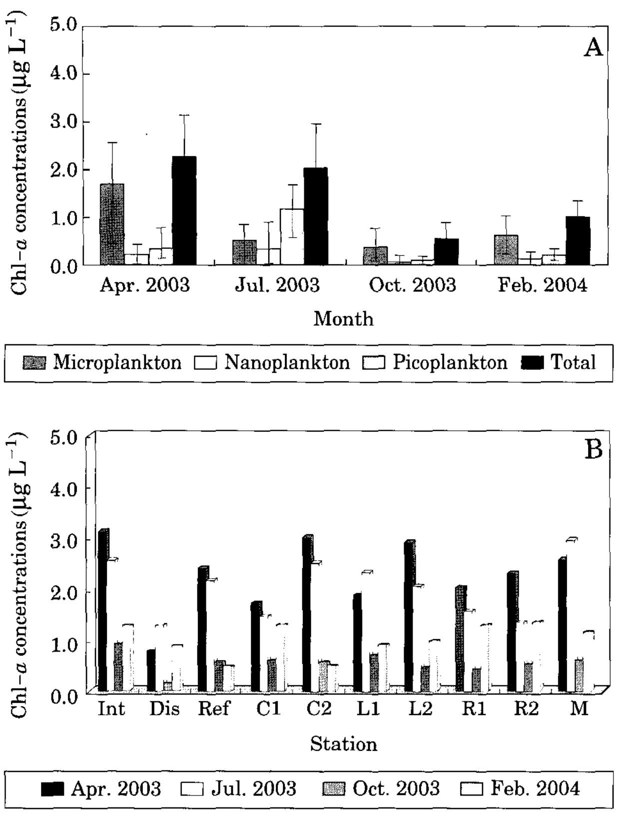

Fig. 7. The temporal variation of the size-fractionated chl-a concentrations (A) and spatial variation of total concentrations (B) around the Ulchin nuclear power plant.

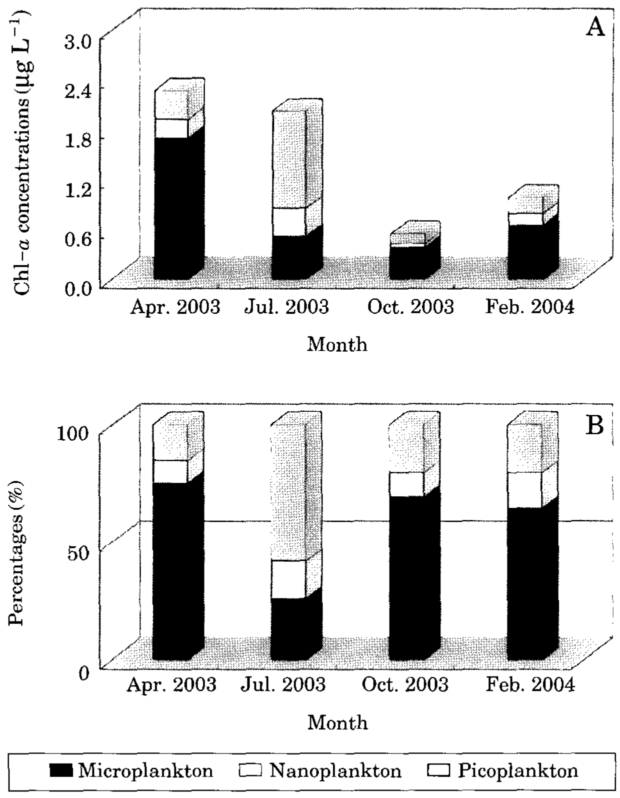

Fig. 8. The variation of concentrations (A) and relative percentages (B) of the size-fractionated chl-a around the Ulchin nuclear power plant.

a concentrations of picoplankton. The small differences of the chl-a concentrations of the size-fractionated phytoplankton were shown among the stations and the chl-a concentrations of phytoplankton in discharge area were lower than those in other stations (Fig. 7B).

4. Effects of entrainment

The abundance and biomass of phytoplankton were generally reduced when they underwent changes passing through the cooling system.

The total abundances of phytoplankton ranged from 252,390 to 1,586,938 cells L^{-1} in the station of seawater intake for the cooling system, but they were slightly reduced ranging from 244,390 to 1,221,779 cells L^{-1} after passage through the cooling system. The mean decrease of total abundance of phytoplankton was 18.7% and seasonal variation of it was from 10.2% to 52.6% (Fig. 9). The highest decrease of total abundance occurred in April 2003 and the lowest one was observed in July 2003. The abundances of microplankton out of the total abundance of phytoplankton fluctuated before and after passage through the cooling system. They varied from 84,976-1,416,938 cells L^{-1} to 104,811-966,154 cells L^{-1}, and the mean decrease was 25.3%, ranging from −18.4% to 64.3%. The highest decrease occurred in April 2003 when the bloom of microplankton was observed but in July 2003, the abundance of microplankton before taking into the cooling system was higher than that of microplankton after taking into the cooling system. In case of nanoplankton, the abundances varied from 167,412-247,093 cells L^{-1} to 104,811-966,154 cells L^{-1}, and the mean decrease was 21.8% ranging from −45.6% to 82.8%. The highest decrease occurred in February 2004 and the abundances of nanoplankton increased after than before passage through the cooling system in April 2003.

The total chl-a concentrations of phytoplankton also decreased after passage through the cooling system. The total chl-a concentrations of phytoplankton ranged

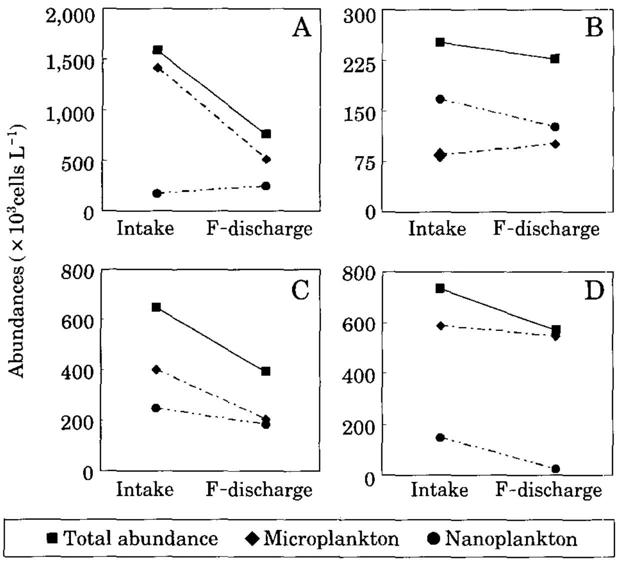

Fig. 9. Variations of phytoplankton abundances after passage through the cooling water system (A: Apr. 2003, B: Jul. 2003, C: Oct. 2003, D: Feb. 2004).

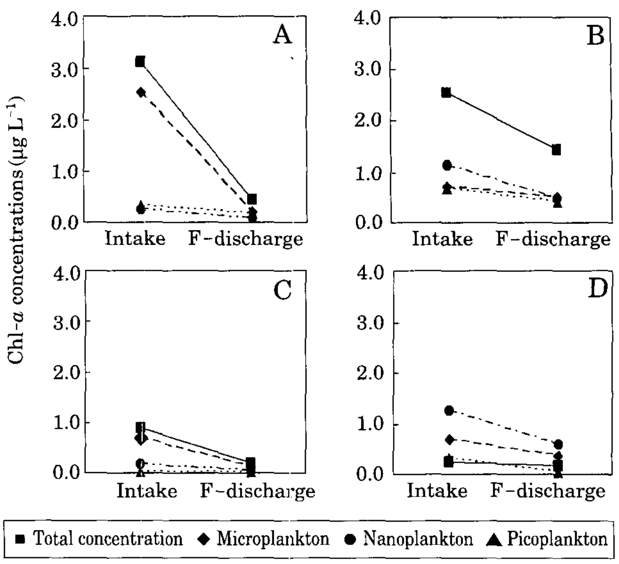

Fig. 10. Variations of the size-fractionated chl-*a* concentrations after passage through the cooling water system (A: Apr. 2003, B: Jul. 2003, C: Oct. 2003, D: Feb. 2004).

from 0.53 to 2.26 μg L^{-1} before passage through the cooling system but they were reduced greatly ranging from 0.20 to 1.42 μg L^{-1} after passage through the cooling system. The mean diminution of the total chl-*a* concentrations of phytoplankton was 65.1% and changed seasonally from 44.0% to 85.8% (Fig. 10). The diminution of the total chl-*a* concentrations of phytoplankton was similar to that of the total abundances of phytoplankton. The highest diminution of the total abundances was observed in April 2003 and the lowest one was observed in July 2003. The chl-*a* concentrations of microplankton varied from 0.69-2.54 μg L^{-1} to 0.12-0.51 μg L^{-1} and the mean diminution was 61.8% ranging from 27.8% to 91.8% after passage through the cooling system. The highest diminution of microplankton was observed in April 2003 and the lowest one was observed in July 2003. The chl-*a* concentrations of nanoplankton also decreased and varied from 0.04-0.33 μg L^{-1} to 0.02-0.42 μg L^{-1} after passage through the cooling system. The mean diminution was 41.6%, ranging from 34.0% to 47.9%, and the highest and the lowest one occurred in April 2003 and February 2004, respectively. In case of picoplankton, the chl-*a* concentrations were varied from 0.16-1.14 μg L^{-1} to 0.05-0.50 μg L^{-1}, and the mean diminution was 69.5%, ranging from 56.5% to 83.6%, which was the highest value among the size-fractionated phytoplankton. The highest diminution of picoplankton occurred in February 2004, and the lowest one occurred in July 2003 when the contribution of picoplankton to the total phytoplankton was very high.

DISCUSSION

A total of 211 different phytoplankton species was observed in adjacent waters of UNPP from April 2003 to February 2004. In comparison with published data from coastal waters of East Sea and other nuclear power plants (KEPCO 2003), it was similar to the results of previous studies (Table 2). The seasonal mean abundance and chl-*a* concentrations of phytoplankton ranged from 59,581 to 1,586,938 cells L^{-1} and from 0.52 to 2.26 μg L^{-1}, respectively. The mean contribution of microplankton to total abundances of phytoplankton was 66.1%, ranging from 42.4% to 83.8%, and that of nanoplankton was 33.9%, ranging from 16.4% to 57.5%. These results showed that the microplankton was an important group in the phytoplankton community. Especially, the contribution of nanoplankton was high when the SST was relatively high. The contribution of microp-

Table 2. The comparisons of the total numbers of phytoplankton species in various regions of East Sea, Korea

Study sites	Sp. number	Study period	References
Kori coastal area	110	1977-1978	Yoo and Lee (1982)
Southeastern sea of Korea	185	Sep. 1981	Shim and Lee (1983)
Kori coastal area	230	1986-1987	Cho (1988)
Wolsong coastal area	222	1986-1987	Cho (1988)
Southwestern waters of East Sea	235	1981-1984	Lee and Shim (1990)
Kori coastal area	160	1987-1989	Yeo and Shim (1992)
Kori coastal area	333	1992-1996	Kang and Choi (2001)
Wolsong coastal area	364	1992-1996	Kang and Choi (2001)
Ulchin coastal area	364	1992-1996	Kang and Choi (2001)
Ulchin coastal area	211	2003-2004	This study

Table 3. The comparisons of the chl-*a* concentrations of phytoplankton in surface waters off various power plants (KR; Kori, WS: Wolsong, YG: Yonggwang, UC: Ulchin)

Power plant	Season	Type	Range ($\mu g\ L^{-1}$)	Mean ($\mu g\ L^{-1}$)	Percents (%)	Period	Reference
KR	Spr.	Total	1.08-3.50	2.06	100	May (1986)	Cho (1988)
		Nano	0.84-2.60	1.54	75.8		
	Sur.	Total	1.33-3.76	2.49	100	Aug. (1986)	
		Nano	0.90-1.90	1.39	55.8		
	Aut.	Total	1.30-3.02	2.18	100	Nov. (1986)	
		Nano	0.92-2.41	1.64	75.2		
WS	Sur.	Total	1.92-7.55	5.13	100	Aug. (1986)	Cho (1988)
		Nano	1.18-3.00	2.48	48.3		
	Aut.	Total	1.90-2.68	2.35	100	Nov. (1986)	
		Nano	1.57-2.55	2.13	90.6		
YG	Spr.	Total	1.48-3.15	2.29	100	Jun. (1986)	Cho (1988)
		Nano	1.24-2.54	1.96	85.6		
	Sur.	Total	1.22-4.00	2.64	100	Aug. (1986)	
		Nano	0.93-2.64	2.01	76.1		
	Aut.	Total	1.36-2.61	2.16	100	Nov. (1986)	
KR	Win	Total	1.89-12.68	6.21	100	Nov. (1988) -Feb. (1989)	Yeo (1992)
		Micro	0.01-4.37	1.17	18.8		
		Nano	0.21-5.16	2.47	39.8		
		Pico	0.46-5.64	2.57	41.4		
UC	Spr.	Total	0.77-3.12	2.26	100	Apr. (2003)	This study
		Micro	0.46-2.54	1.69	74.8		
		Nano	0.01-0.37	0.23	10.1		
		Pico	0.13-0.77	0.34	15.1		
	Sum.	Total	1.28-2.54	2.01	100	Jul. (2003)	
		Micro	0.03-0.82	0.51	25.5		
		Nano	0.02-0.86	0.33	16.6		
		Pico	0.54-1.66	1.17	58.0		
	Aut.	Total	0.15-0.90	0.53	100	Oct. (2003)	
		Micro	0.08-0.70	0.37	69.0		
		Nano	0.02-0.17	0.06	10.5		
		Pico	0.05-0.16	0.11	20.5		
	Win.	Total	0.47-1.33	0.99	100	Feb. (2004)	
		Micro	0.17-1.03	0.64	64.6		
		Nano	0.03-0.25	0.15	14.8		
		Pico	0.10-0.32	0.20	20.6		

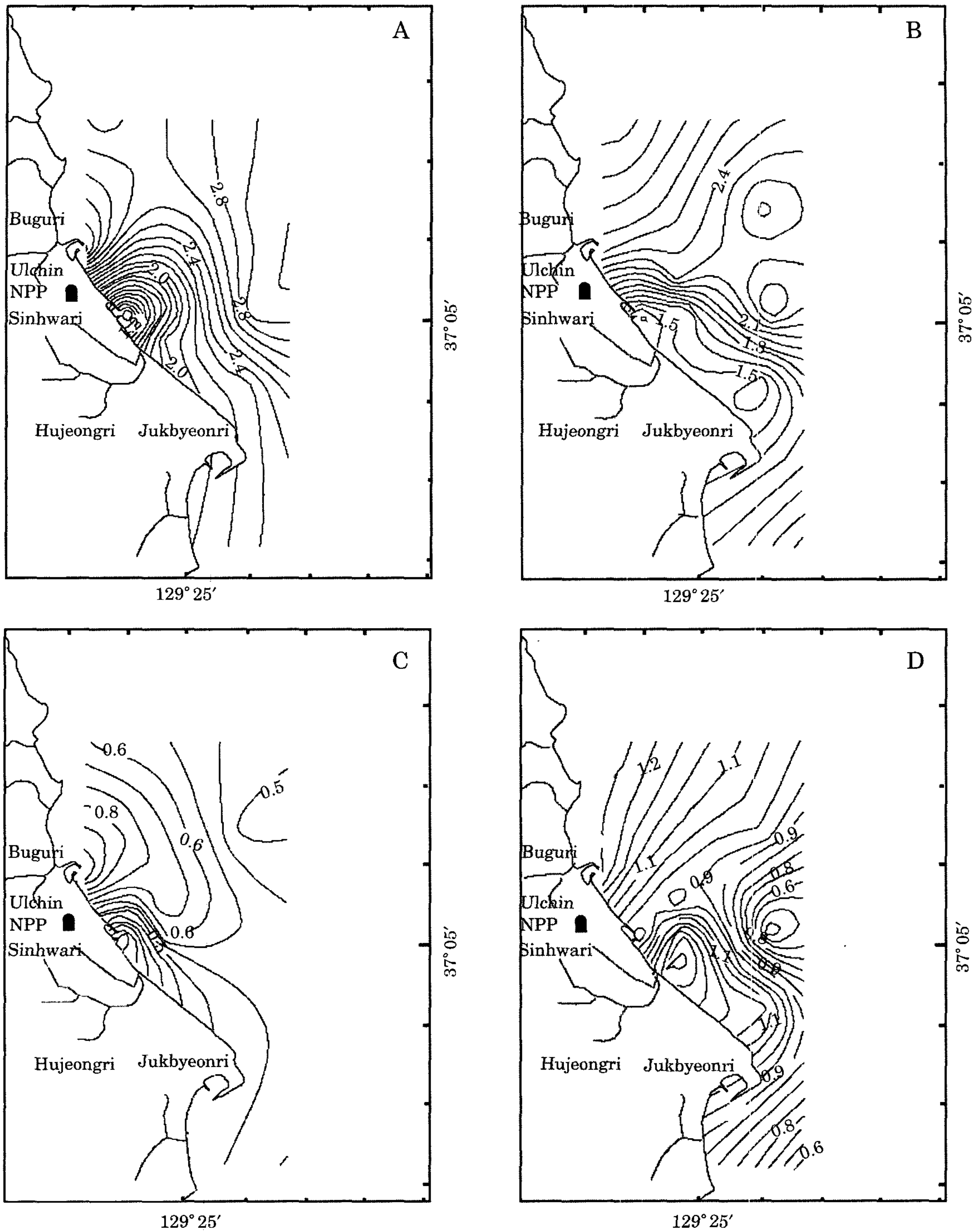

Fig. 11. Horizontal distribution of chl-*a* concentrations of surface waters around the Ulchin nuclear power plant (A: Apr. 2003, B: Jul. 2003, C: Oct., 2003, D: Feb., 2004).

lankton to total chl-*a* concentrations was the higher than other groups and it ranged from 25.5% to 74.8%. The contributions of nano- and picoplankton ranged from 10.2% to 16.6% and from 15.1% to 58.0%, respectively. In case of picoplankton, its contribution was over 50% in July 2003. These results showed that the microplankton had an important role in offshore area of UNPP during the study period. In July 2003, the chl-*a* concentrations were relatively high but nevertheless the abundances were low. It suggested that extremely small cells, including the prokaryotic algae as well as picoplanktonic eukaryotic algae, were abundant in July 2003. Some studies concerning the contribution of small cells to total biomass of phytoplnakton had been conducted (Table 3). Shim *et al.* (1991) reported that the contribution of picoplankton to total biomass of phytoplankton was very higher than other groups in adjacent waters of Kori nuclear power plant (KNPP) in winter season. Yang and Choi (2003) reported that small cells (< 20 μm) were dominant with exception of period when the bloom of phytoplankton occurred in Kyeonggi Bay.

Phytoplnakton community was affected by some factors such as elevated temperature, chlorination or dechlorination and mechanical effects (Langford 1990). Briand (1975) suggested that the losses of cells of phytoplankton were result of high temeratures during entrainment. In this study, the abundance and biomass of phytoplankton were reduced by the influence of entrainment. The mean diminution of total abundances of phytoplankton was 18.7%, ranging from 10.2% to 52.5% and that of total chl-*a* concentrations of phytoplankton was 65.1%, ranging from 44.0% to 85.8% (Fig. 9 and 10). The diminution of the abundances and chl-*a* concentrations of phytoplankton differed according to the sampling time and season but the results of this study were similar to those of some previous studies (Cho 1988; Yeo 1992). Cho *et al.* (1989) suggested that the scope of the effect of thermal discharges be within 1 km from power plants. The diffusion area of thermal discharge covered over approximately 2.0-3.0 km in this study, and the abundances and biomass of phytoplankton were lower in outlet area nearby discharge mouth than other stations located at the coastal area. But, those were gradually recovered by mixing with the ambient waters (Fig. 11). Our results suggested that the influence of thermal discharges on phytoplankton community should be restricted within narrow limits around outlet area of thermal effluents.

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