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The structure of the plankton community and the cyanobacterial bloom during the rainy season in mesoeutrophic lake (Lake Juam), Korea

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Abstract

강우가 집중하고 남조류가 대발생하던 시기의 중영양호소인 주암호에서 박테리아, 식물플랑크톤, ANF, HNF, 섬모충플랑크톤, 동물플랑크톤과 환경요인들의 변화에 대해 조사하였다. 조사기간동안 우점종은 *Cyclotella meneghinana, Aulacoseira granulata, Cryptomonas tetrapyrenoidsa*로서 총현존량의 67% 이상을 차지하였다. 조사기간동안 남조류 대발생의 구성원은 현존량 및 종조성에서 크게 변화 하였다. 여름철 강우에 의한 엽록소 a, 수질 (COD, TP)의 변동이 심하였으며, 특히 *C. tetrapyrenoidsa*는 HNF, nauplii, rotifer, 섬모충의 변동에 매우 밀접한 관계를 보였다. 포식자인 rotifer는 박테리아, 피코플랑크톤이나 ANF같은 소형플랑크톤의 변동과 높은 관계를 보였다.

Key words : cyanobacterial bloom, rainfall, phytoplankton, physicochemical variables

Ⅰ. INTRODUCTION

The cyanobacterial bloom, triggered by stagnation of water body and high and/or continuous organic loadings from watersheds and tributaries, is one of the most obvious indicators of eutrophication in freshwater lakes.[1,2] The nuisance causing cyanobacterium *Microcystis* spp. decreases dissolved oxygen and light penetration, releases microcystin that threatens herbivores, planktivores and other biota, and ultimately deteriorates an aquatic ecosystem.[3,4,5,6]

Lake Juam was constructed in 1992, and since then, a bloom of *M. aeruginosa* has been occurring every summer.[7,8] A dense cyanobacterial bloom occurred at the inflow site of the lake and gradually extended towards the lake center and dam.[9] In 1993, *M. aeruginosa,* and species of the genera, *Anabaena, Coelasphaerium, Ceratium, Coelastrum, Eudorina,* and *Aulacoseira* dominated the phytoplankton community of the lake.[7] In 1994 and 1995, new genera, including *Chroococcus, Peridinium, Dictyosphaerium, Scenedesmus, Staurastrum, Fragilaria* and *Melosira,* appeared in the inflow region of the lake along with *Microcystis aeruginosa.*[8] Finally, abundance and species composition of phytoplankton community shifted from *Microcystis* and *Anabaena* to *Cryptomonas, Aulacoseira, Coelastrum* and *Peridinium.*[9,10] There are no published works that adequately discuss the mechanism of bloom formation or other aspects related to algal ecology of Lake

Juam.

The present study was carried out in Lake Juam to (i) learn the relationships between abundance and distribution of plankton and physicochemical variables, and (ii) to understand the seasonal succession patterns and predator prey relationships.

Ⅱ. METHODS AND MATERIALS

Lake Juam (lat. 3500N, long. 12715 E) impounds two upper streams of the Seomjin River, Korea. The lake has the surface area of 1,010km^2 and is surrounded by mountainous valleys 400 m at sea level). The lake is connected to another small lake, Lake Sangsa, through an underground tunnel. In Lake Juam, thermal stratification has been occurring near the dam every year, and irregularly in the central and inflow regions.

Sampling was carried out at three stations. Sta J1 was the upstream of the dam; Sta J2 was in the middle of the lake; Sta J3 was inflow site near the confluence of the two tributaries, Posung and Dongbok streams.

Water temperature, dissolved oxygen (DO), conductivity, and turbidity were measured directly with a YSI meter (Model 610) equipped with a pH meter. A transparency was measured by Secchi disc. Water samples were collected with a 5 L Van Dorn sampler. Samples were filtered with a Whatman GF/F filter precombusted at 450°C for 3 h. Dissolved reactive phosphate phophorus was measured by the ascorbic acid method, and nitrite and nitrate by the cadmium reduction method.[11] Ammonium was determined using the salicylate hexacyanoferrate dichloroisocyanurate system.[12] Total phosphorus (TP) and total nitrogen (TN) were measured by the methods as above following persulphate digestion at 120°C for 45 min. For chlorophyll *a* (Chl *a*) measurement, 100 mL of water sample were filtered with a Nucleopore filter under gentle vacuum(<40 kPa). The amount of chl *a* was measured by high performance liquid chromatography(LC Module 1, Waters, Inc.). Other limnological variables, such as biochemical oxygen demand(BOD), chemical oxygen demand(COD), suspended solids(SS) and SiO_2, were analyzed using standard methods.[11]

For the enumeration of a pico and nanoplankton, the surface water samples were preserved with 1% glutaraldehyde solution and kept refrigerated at 4°C in the dark. Bacteria, picocyanobacteria (PC), eukaryotic picoplankton (EPP), autotrophic nanoflagellates (ANF) and heterotrophic nanoflagellates (HNF) were counted with a fluorescence microscope after being stained with DAPI and FITC.[13,14,15]

Other phytoplankton and ciliate were enumerated from samples preserved with 1% Lugol's and examined with an inverted microscope after sedimentation for 12 hrs.[16] Zooplankters were counted with a dissecting microscope, after a 5 10 L surface water sample filtered through a 40μm net and preserved with 5% sugar formalin. Carbon content of phytoplankton was estimated from the volume of live algae (1.33x fixed cells) with the following equations:

Carbon (pg $cell^{-1}$)=$0.12\times Vol^{1.051}$ (Montagenes *et al.* 1994). [17]

Plankton volume was determined from the geometric shape or gross volume of sample.

A sequential multiple regression analysis was carried out to statistically explain the various plankton component abundances (changes) with changes in all the measured physicochemical variables. The statistical significance of the series of correlation coefficients was determined

Table 1. Correlation among the planktonic components during rainy season in Lake Juam

Kinds	HNF	Copepoda	Nauplius	Cladocera	Rotifera	Ciliates
Bacteria	0.38*	0.41*	0.65***	0.41*	0.70***	0.36*
Picoplankton	0.29	0.14	0.58**	0.04	0.64***	0.54**
ANF	0.59**	0.18	-0.02	-0.10	0.71***	0.82***
Cryptomonas	0.44*	0.10	0.48*	0.03	0.74***	0.70***
Pediastrum	0.60***	0.18	0.21	-0.09	0.86***	0.86***
Anabaena	-0.12	0.10	-0.12	-0.04	-0.14	-0.01
Aphanizomenon	0.10	-0.15	0.38*	0.04	0.11	-0.10
Microcystis	-0.04	-0.01	-0.12	-0.16	0.15	0.21
Oscillatoria	-0.20	-0.22	0.74***	0.01	0.14	-0.1
Synedra	-0.10	0.09	0.10	-0.13	0.10	0.25
Aulacoseira	0.30	-0.07	-0.32	-0.13	0.09	0.30
Cyclotella	-0.31	-0.24	0.53**	0.23	-0.06	-0.2
Melosira	-0.03	0.75***	0.08	0.83***	0.17	-0.1
Nitzschia	0.68***	0.25	-0.02	-0.07	0.82***	0.92***

ANF; autotrophic nanoflagellates, HNF; heterotrophic nanoflagellates

* Phytoplankton: *Microcystis (M. aeruginosa), Aulacoseira (A. granulata), Anabaena (A. flos aquae), Peridinium (P. bipes), Cryptomonas (C. tetrapyrenoidsa), Cyclotella (C. meneghiniana), Melosira (M. varians), Staurastrum (S. floriferum), Oscillatoria (O. agardhii), Gleocystis (G. gigas), Synedra (S. acus), Nitzschia (N. pleae), Pediastrum (P. duplex), Aphnizomenon (A. sp)*

n=24, * p<0.1, ** p<0.01, *** p<0.001

by the sequential Bonferroni's procedure with the significance level at α=0.05[18]. Differences in each plankton density between bloom and non bloom periods were tested by *t*-test.

Ⅲ. RESULTS

The lake was stratified at 4~27 m depth, Sta J1 and Sta J2 from April to November. Water quality was strongly altered by rain when a typhoon occurred in August; turbidity and total phosphate(TP) suddenly increased, but gradually returned to normal levels.

During the study period, TP influenced COD (r=0.42, p<0.001) and the concentration of Chl *a* (r=0.40, p<0.001), and COD was correlated with Chl *a* (r=0.75, p<0.0001). There were no other significant correlations among the physicochemical variables.

Bacteria and picocyanobacteria averaged $10^{5\sim6}$ and 10^4 cells/mL (Fig. 1). Ciliates were relatively low (< 10^2 cells/mL) and showed one peak in July. Rotifers gradually decreased from July, while one peak of naupli showed in September at Sta J2. During the summer, most zooplankton showed high abundance until September but thereafter showed a sudden decrease. In this lake, high abundance of planktivore predators dropped after October, however, HNF were sustained in the colder

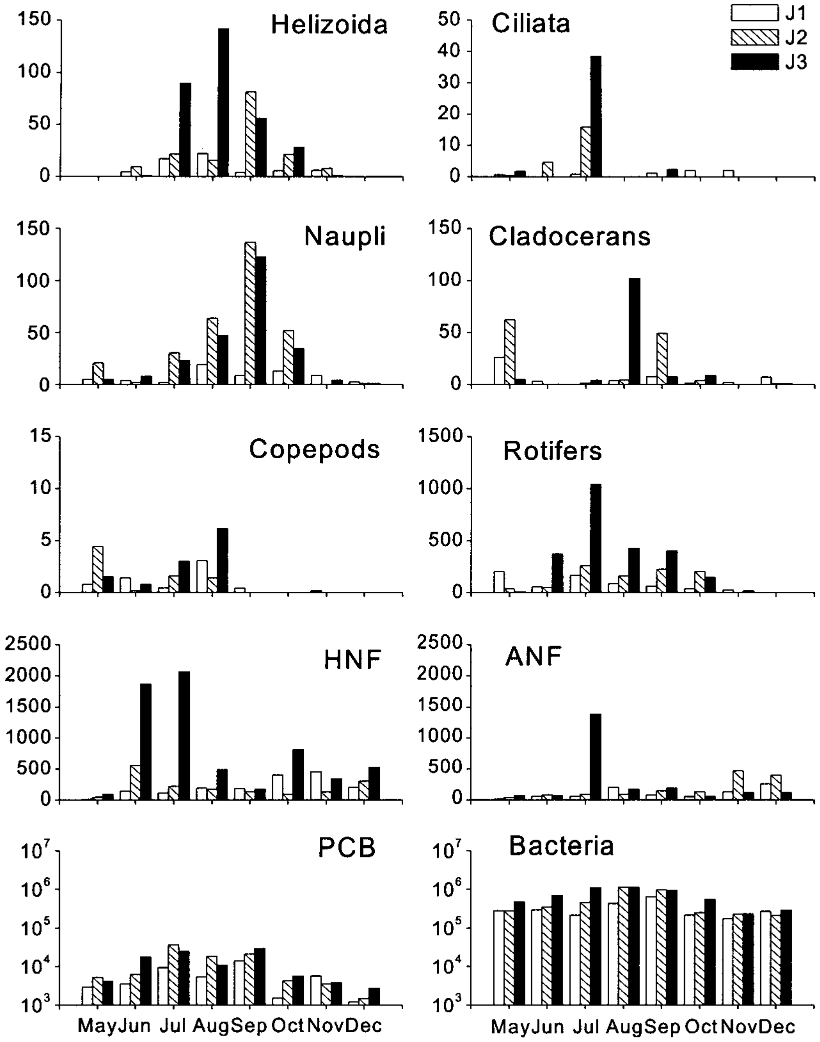

Fig. 1. Abundances of total bacteria, picocyanobacteria, ANF, and HNF in units of cells, and abundances of rotifers , copepods, cladocerans, naupli, and ciliates in individuals at three study sites of Lake Juam from May to December, 2000.

season. During the study period, seven phytoplankton species including diatoms *Aulacoseira granulata* and *Cyclotella meneghniana*, and cryptomonads *Cryptomonas tetrapyrenoidsa* contributed significantly (67.3%) to the total phytoplankton biomass (Table 1, Fig. 2), and *M. aeruginosa* density was below about 7% of the total. A distinct shift in the cyanobacterial community was observed with the passage of time: *Anabaena flos aquae* in June August; *M. aeruginosa* in June October, *Oscillatoria agardhii* in August November; and *Aphanizomenon* sp. in August November. In spite of small quantity, *Microcystis*, *Oscillatoria* and *Aphanizomenon* were high in abundance until late summer, and *Staurastrum*, *Aphanizomenon* and *Synedra* still persisted even in December. Phytoplankton biomass was usually the highest at Sta J3

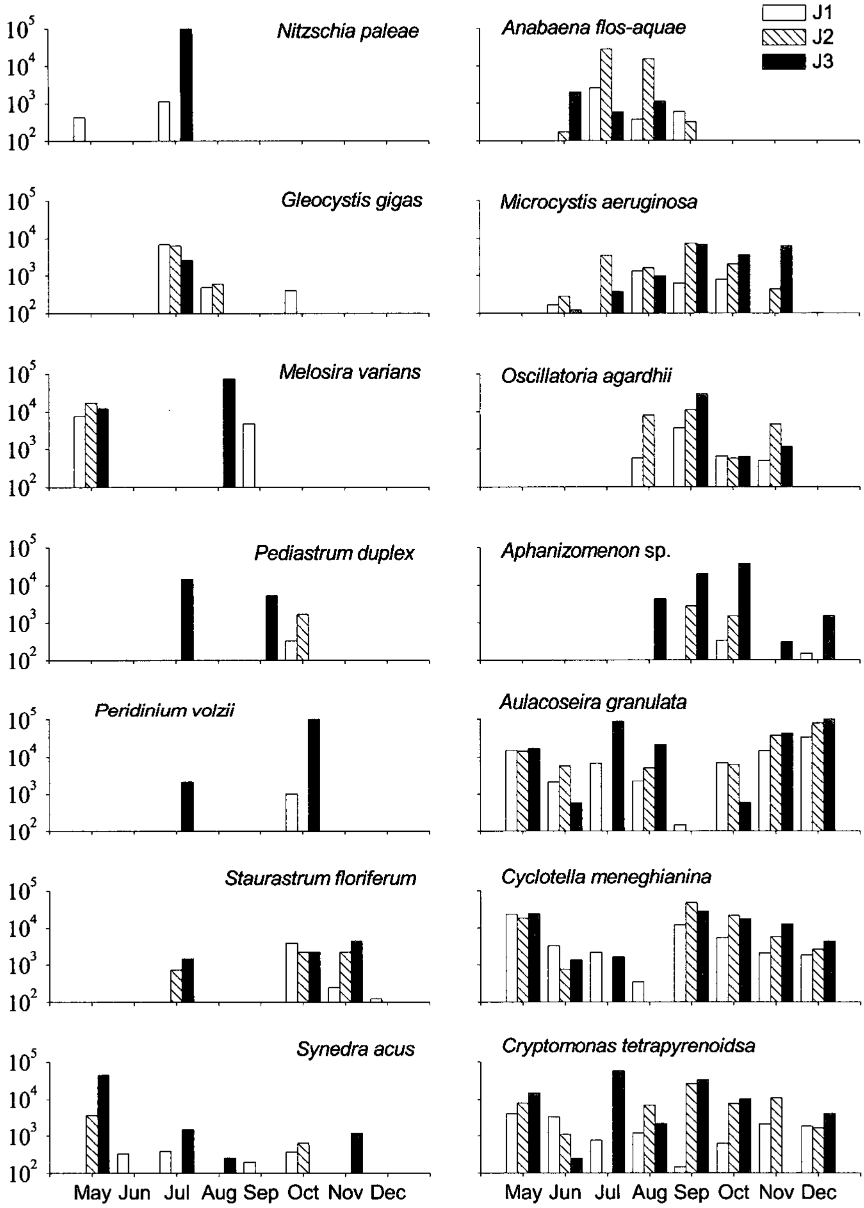

Fig. 2. Abundance (cells/mL) of major phytoplankton species at the study site of Lake Juam from May to December, 2000.

regardless of species composition, while *Anabaena flos aquae* was most abundant at Sta J2.

All predators were closely related to bacteria ($p<0.1$). Of these, ciliates, rotifers and nauplius showed a highly positive relation with picoplankton ($p<0.01$). For the cyanobacterial members, such as *A. flos aquae, Aphnizomenon* sp., *O. agardhi* and *Synedra acus*, most of the predators did not show any relationship; only naupli showed a relationship with *Aphanizomenon* ($p<0.1$) and *Oscillatoria* ($p<0.001$) (Table 1). For all the phytoplankton, no predator showed a specific relation with the abundance of its prey.

Ⅳ. DISCUSSION

Although the high abundance of the epilithic diatom *C. meneghiniana* at the dam station was not expected, cyanobacterial components of the bloom remarkably changed in biomass and species composition. The filamentous cyanobacterium *Aphanizomenon* sp. was newly introduced with *Cryptomonas* to Lake Juam. In particular, the former was mainly concentrated in the inflowing region of the lake during the study period, and occurred in small number in the center of the lake. It has been commonly known that the seasonal changes of species composition and/or succession in the phytoplankton community are triggered by shift in nutrient ratios such as C:P[19] N:P[20,21,22) and Si:P[22,23] Also, low N:P ratio (~5) and/or falling nitrogen in phosphorus rich lakes usually induces the proliferation of nitrogen fixing cyanobacteria such as *Anabaena* spp. and *Aphanizomenon* spp.[24,25] while high nitrate and ammonia promote green algae belonging to Chloroococcales.[26]

In general, silicate limitation is followed by a decline in diatom biomass.[27] Although the high abundance of *Cyclotella* at the dam site cannot be explained with the available data, changes in cyanobacterial population observed in the present study are contrary to the previous studies. The N:P ratio of Lake Juam has been increasing year after year, while the relative abundance of cyanobacteria was decreased in phytoplankton community. The silicate level, increased by the heavy rains during the study period, remained relatively high throughout the lake. However, lack of data for the past does not permit us to relate increase in abundance of six diatoms, regardless of sampling sites, to rise in silicate concentration. Therefore, the species succession and/or changes of phytoplankton community in Lake Juam may be attributed to the nutrient gradient influenced by summer heavy rain, and there is the change of relative abundance of each species, rather than species composition in the phytoplankton community.

It is not surprising that most plankton communities flourished in the inflowing region of the lake, due to the high and/or continuous input of organic loadings from its watershed and tributaries. In the last two decades, the changes of dominant phytoplankton species are not rare in a majority of Korean lakes.[28,29] High abundance of predators such as rotifers, cladocera, ciliates, copepods and HNF was particularly evident in the lake. However, due to lack of adequate data for the present as well as the past it cannot be fully understood whether it was induced by the flourishing summer phytoplankton, such as, *A. granulata*, *C. meneghiniana* and *C. tetrapyrenoidsa*. However, according to several indirect evidence, for instance, positive and negative correlations among the prey and predators, it may be suggested that the dominant pico and nanoplankton are mainly fed on by copepod naupli, while rotifer zooplankton and copepod naupli fed on phytoplankton.

Ⅴ. ABSTRACT

The rainy season and a cyanobacterial bloom, abundance and distribution of bacteria, picocyanobacteria(PC), autotrophic nanoflagellates (ANF), heterotrophic nanoflagellates (HNF), ciliates, and zooplankton were examined in relation to physicochemical variables in mesotrophic Lake Juam, Korea. Three species dominated the phytoplankton community even in the cold season; *Cyclotella meneghinana* and *Aulacoseira granulata* (Bacillariophyceae), and

Cryptomonas tetrapyrenoidsa (Cryptophyceae) contributed over 67% to the total phytoplankton biomass. The cyanobacterial component of the algal bloom changed remarkably in biomass and species composition. The phytoplankton abundance (Chl *a*) and water quality (COD and TP), were markedly influenced by heavy rain during the summer. The abundance of *Cryptomonas* was closely related to that of HNF, nauplii, rotifers and ciliates. The abundance of rotifers was highly correlated to that of bacteria, PC and ANF.

Ⅵ. ACKNOWLEDGMENTS

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