Note

Seasonal Changes in Horizontal Distribution of Algal Picoplankton in Lake Biwa with Special Reference to Water Temperature, Nutrient Levels and Heterotrophic Flagellates

Shin-ichi NAKANO, Katsumi TANAKA, Tadashi SONO, Tetsuya WAKABAYASHI, Satoshi ICHISE, Sunao YAMANAKA, Emiko KANEDA, Minoru YADA, Mikishige NAITOH, Koichi KAWABE, Kayo MAEHATA, Naoki FUJIWARA, Noriko MAEDA, Kiyoshi NOMURA and Masami NAKANISHI

Abstract

Seasonal changes in the horizontal distributions of algal picoplankton (APP) were examined in relation to those of heterotrophic flagellates and some environmental factors at 8 sampling stations covering both the northern and southern basins of Lake Biwa from June 1992 to March 1993. Water temperature and nutrient levels differed little among these stations. Horizontal distribution of APP was variable during the summer and fall. There was a consistent trend in the changing pattern of APP density at each station: cell density of APP at all stations was highest in August and low during the winter. Horizontal distributions of both flagellates and APP were changeable during the summer and fall. However, we could not find a seasonal trend in the changing pattern of flagellate density at each station.

Key words: algal picoplankton, horizontal distribution, heterotrophic flagellates, Lake Biwa

Algal picoplankton (APP) may account for a large portion of phytoplankton biomass and primary production in lake and marine ecosystems (STOCKNER and ANTIA, 1986). Previous studies have suggested that nutrient levels (SUTTLE and HARRISON, 1988; WHER, 1989) and grazing activity (NAGATA, 1988; WEISSE, 1988) greatly affect the dynamics of APP in lakes. Among grazers, heterotrophic flagellates have been considered one of the most important grazers of APP (NAGATA, 1988).

APP have been investigated in Lake Biwa, the largest lake in Japan (surface area 674 km²). Data have suggested that APP are important as a primary producer (NAGATA, 1986, 1988; ICHISE *et al.*, 1991; MAEDA *et al.*, 1992). An extremely high density of APP (maximum 4.6×10^6 cells·ml⁻¹) has been observed in this lake (ICHISE *et al.*, 1991). However, little is

known about the horizontal distribution of APP and its relation with environmental conditions such as nutrients, temperature and grazing pressure.

The purpose of this study was to examine seasonal changes in the horizontal distribution of APP, nutrients and flagellates for a better understanding of the dynamics of the microbial food web in Lake Biwa.

We staffed eight sampling stations covering both the deep North Basin (mean depth 44 m, surface area 616 km²) and the shallow South Basin (mean depth 3.5 m, surface area 58 km²) (Fig. 1). Samples were collected monthly from June 1992 to March 1993. Water samples were collected with a Van Dorn water sampler at a 0.5 m depth. Water temperature was measured with a thermistor thermometer.

A portion of water samples was filtered

through Whatman GF/F glass fiber filters. The filtrate was used for chemical analyses. Concentrations of ammonium ($\text{NH}_4\text{-N}$), nitrite ($\text{NO}_2\text{-N}$) and nitrate ($\text{NO}_3\text{-N}$) nitrogen were determined by the methods of BOWER and HOLM-HANSEN (1980), BENDSCHNEIDER and ROBINSON (1952) and WOOD *et al.* (1967), respectively. The concentration of dissolved inorganic phosphorus (DIP) was determined by the method of MURPHY and RILEY (1962).

A portion of water samples was brought to the laboratory within 3–4 hours under cool and dark conditions, and used for the enumeration of APP. Subsamples were mounted on a Sekisui microscopic plate (Sekisui Co., Ltd., Osaka), which is a commercially available slide glass with five grids covered with a cover glass. The size of each grid is 12 (L) $\times$ 10 (W) $\times$ 0.07 (D) mm, equal to 0.0084 ml volume. The number of APP in each grid was counted under an epifluorescence microscope (Nikon OPTIPHOT, G excitation EFDA2 DM 580, magnification $\times$ 400). The enumeration for one water sample was conducted within one grid until 400 cells of APP were counted. We, how-

ever, could enumerate only about 100 cells of APP from November to March, since APP numbers were very low during winter. Coefficient of variation was 14.5% for this method.

On shipboard, samples for enumeration of heterotrophic flagellates were fixed with glutaraldehyde (final concentration, 1%). Flagellates were counted by the fluorescein isothiocyanate (FITC) staining method (SHERR and SHERR, 1983) with slight modifications (NAKANO *et al.*, 1993).

At all stations, water temperature increased from June (*ca.* 20°C) to September (*ca.* 27°C) and, thereafter, steadily decreased to 8.3°C during the study period (Fig. 2). A changing pattern of concentrations of dissolved inorganic

Fig. 1. Sampling stations in Lake Biwa.

Fig. 2. Seasonal changes in water temperature during the survey period at stations in Lake Biwa. Symbols indicating stations --+-- , 1; $\circ$, 2; $\bullet$, 3; $\triangle$, 4; $\blacktriangle$, 5; $\square$, 6; $\blacksquare$, 7; $\times$, 8.

Fig. 3. Seasonal changes in concentrations of dissolved inorganic nitrogen (DIN) during the survey period at stations in Lake Biwa. Symbols are the same as Fig. 2.

Fig. 4. Seasonal changes in cell densities of algal picoplankton (APP) (A) and heterotrophic flagellates (B) during the survey period at stations in Lake Biwa. Symbols are the same as in Fig. 2.

nitrogen ($\text{DIN} = \text{NO}_3\text{-N} + \text{NO}_2\text{-N} + \text{NH}_4\text{-N}$) at each station was generally the same among all stations (Fig. 3). DIN concentrations decreased down to $<50 \mu\text{g N}\cdot\text{l}^{-1}$ in July and continued low until September. Thereafter, DIN concentrations increased substantially, probably because of the vertical transport of nitrate accumulated in the hypolimnion of the North Basin (TEZUKA, 1984). Concentrations of DIP at each station was mostly below the detection limit ($<1.0 \mu\text{g P}\cdot\text{l}^{-1}$) throughout the study period (data not shown).

Seasonal changing patterns of cell densities of APP (Fig. 4A) differed little among sampling stations. At all stations, the maximum APP cell densities were observed in either August or September when water temperature was the highest. The maximum density was variable depending on stations, ranging from 3.0 to $5.7 \times 10^5 \text{ cells}\cdot\text{ml}^{-1}$. APP abundance decreased to

November, and the cell densities remained low ($<1.0 \times 10^5 \text{ cells}\cdot\text{ml}^{-1}$) in winter.

Horizontal distributions of cell densities of APP (Fig. 5) demonstrated that the distribution was seasonally variable from June to October 1992. However, in winter (November 1992 to March 1993), APP density in the South Basin (Station 1) tended to be higher than that at other stations.

Cell densities of heterotrophic flagellates were relatively high in June 1992 (4.2 to $8.5 \times 10^3 \text{ cells}\cdot\text{ml}^{-1}$) at all the stations except Station 1 (Fig. 4B). The densities decreased rapidly in July and fluctuated in the range 0.050 – $3.2 \times 10^3 \text{ cells}\cdot\text{ml}^{-1}$ thereafter. At Station 1, cell density of flagellates fluctuated from 0.40 and $4.9 \times 10^3 \text{ cells}\cdot\text{ml}^{-1}$. Horizontal distributions of cell densities of flagellates (Fig. 6) were similar to those of APP densities: flagellate density was horizontally variable every month from June to November 1992, and that at Station 1 was higher than those at other stations from December 1992.

From their seasonal study in 1990, ICHISE *et al.* (1991) have reported that APP abundance at 11 sampling stations in Lake Biwa started to increase simultaneously and attained maximum cell density in the summer. A similar seasonal pattern was observed in the present study. Summer maxima of APP abundance have been reported in other lakes (CARON *et al.*, 1985; SØNDERGAARD, 1991; NAGATA *et al.*, 1994). These studies have suggested that the seasonal dynamics of APP are controlled by several factors including temperature, light and nutrients. Besides these physical and chemical factors, we suspect that grazing pressure is another factor which greatly affects the seasonal changes of APP in Lake Biwa. In the present study, we observed that the rapid increases in cell densities of APP in August coincided with the rapid decreases in densities of flagellates (Figs. 4A and 4B). The low numbers of flagellates would probably indicate low grazing pressure of flagellates on APP, which might explain the rapid increases in APP abundance in August.

Although water temperature and nutrient

Fig. 5. Horizontal distribution of algal picoplankton (APP) during the survey period.

Fig. 6. Horizontal distribution of heterotrophic flagellates during the survey period.

levels were almost the same among stations (Figs. 2 and 3), the horizontal distribution of APP was variable during the summer and fall (Fig. 5). We compared the horizontal distribution of APP with that of flagellates (Fig. 6), but we could not find a consistent trend between them. As for the mortality of APP in lakes, not only the grazing of flagellates but also that of ciliates (WEISSE, 1988) and rotifers (CARON *et al.*, 1985) as well as infection by viruses (MAEDA, 1995) may be also important. During warm weather, such biological activity could be high. The abundance and activity of these organisms should be determined in future studies.

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摘 要

琵琶湖における超微細藻類の水平分布の 季節変化：とくに水温、栄養塩類、 従属栄養鞭毛虫との関連

1992年6月から1993年3月までの、琵琶湖8定点における超微細藻類(algal picoplankton, 以下APP)の現存量の水平分布の季節変化と、従属栄養鞭毛虫およびいくつかの環境要因のそれらとを対応させ、琵琶湖のAPPの消長について考察した。水温および栄養塩類のレベルには、定点間の差はほとんど見られなかった。APPの細胞密度の水平分布は、夏期および秋期には明瞭なパターンは見いだされなかった。しかし、各定点におけるAPPの細胞密度は、ほぼ同一のパターンを示した：APPは全ての定点において8月に最大の細胞密度に達し、冬期は細胞密度は低かった。夏期と秋期における従属栄養鞭毛虫の細胞密度の水平分布には、APPと同様に明瞭なパターンは見られなかった。さらに、各定点における鞭毛虫の細胞密度の季節変化にも、明瞭な傾向は得られな

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- (著者: 中野伸一, 滋賀県琵琶湖研究所, 〒520 大津市打出浜 1-10; 田中勝美, 園 正, 若林徹哉, 一瀬諭, 山中 直, 金田恵美子, 矢田 稔, 内藤幹滋, 川部浩市, 前畑佳代, 藤原直樹, 前田典子, 野村 潔, 滋賀県立衛生環境センター, 〒520 大津市御殿浜 13-45; 中西正己, 京大大学生態学研究センター, 〒520 大津市下坂本 4 丁目 1-23; Shin-ichi NAKANO, Lake Biwa Research Institute, 1-10 Uchidehama, Otsu 520; Katsumi TANAKA, Tadashi SONO, Tetsuya WAKABAYASHI, Satoshi ICHISE, Sunao YAMANAKA, Emiko KANEDA, Minoru YADA, Mikishige NAITOH, Koichi KAWABE, Kayo MAEHATA, Naoki FUJIWARA, Noriko MAEDA, and Kiyoshi NOMURA, The Shiga Prefectural Institute of Public Health and Environmental Science, 13-45 Midonohama, Otsu 520; Masami NAKANISHI, Center for Ecological Research, Kyoto University, 4-1-23 Shimosakamimoto, Otsu 520)

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