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A Comparison of Phytoplankton Community Structure between Different Locations in the South Basin of Lake Biwa

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Abstract To elucidate whether or not there is local difference in phytoplankton community structure in the south basin of Lake Biwa, species diversity and similarity of phytoplankton community were examined seasonally at five stations during April 1987–May 1988. Mean annual values of diversity were not locally different and ranged from 1.99 to 2.16 bits·cell^{-1}. However, there were distinct differences in values of diversity at certain times in a year between locations. This was due to great difference in the evenness of cell number within species. Local difference in the community similarity was observed from April to July 1987 and from January to May 1988, depending on differences in dominant species belonging mainly to Bacillariophyceae and Chrysophyceae and in their relative abundance between locations. On the other hand, there was no local difference in the similarity between any station from August to December 1987 during which the community was dominated by certain species of Cyanophyceae and Bacillariophyceae.

INTRODUCTION

In Lake Biwa, three kinds of water blooms have been observed in the latest twelve years. One is an outbreak of red tide by a sudden propagation of *Uroglena americana* in spring from 1977 till now in both the north and south basins. The others are water blooms by development of *Anabaena* spp. and/or *Microcystis* spp. in late summer in 1980s in the south basin. These facts indicate that serious changes in phytoplankton abundance and community structure have occurred since the late 1970s in Lake Biwa, especially in the south basin.

In the south basin of Lake Biwa, it is known that phytoplankton abundance expressed as chlorophyll *a* shows horizontally uneven distribution with the east (high)–west (low) gradient as a typical pattern (Nakanishi, 1984; Nakanishi *et al.*, 1986). This gradient seems to be consistent nearly with the gradient of dissolved inorganic nitrogen and phosphorus concentrations. In addition, Nakanishi *et al.* (1986) observed that there were some local differences in seasonal changing pattern of chlorophyll *a* concentration especially from April to June: the pattern in the east side area was different from that in other side areas. These facts suggest the possibility that phytoplankton community

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structure or algal composition, at least at certain times of the year, differs between locations. Until now, however, there is no detailed information on the local difference in the phytoplankton community structure in the south basin of Lake Biwa.

In the present study, seasonal changes in phytoplankton composition and some related variables were surveyed at different locations in the south basin of Lake Biwa to elucidate local characteristics of phytoplankton community structure.

MATERIAL AND METHODS

Lake Biwa consists of the north and south basins. The north basin is deep (average depth, 44 m), large (surface area, 620 km^2) and mesotrophic (Tezuka, 1984). The south basin investigated is shallow (2.8 m), small (57 km^2) and eutrophic (Nakanishi *et al.*, 1986; Nakanishi *et al.*, 1988).

Surveys were conducted in principle at ten days intervals from April 1987 to May 1988 at five stations in the south basin. The stations were set in the following order: Stn. 1

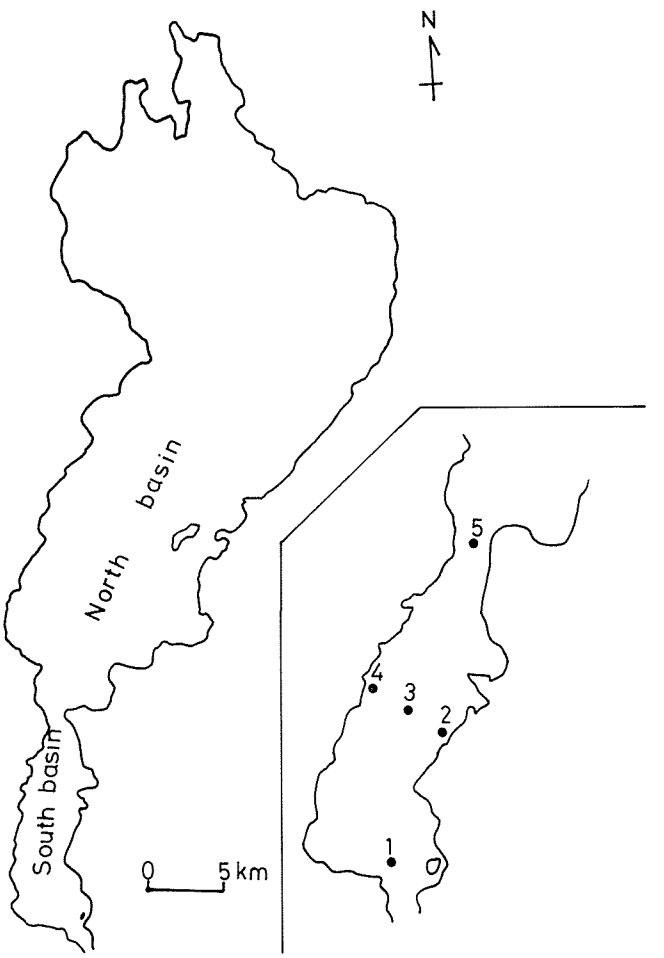

Fig. 1. Maps showing Lake Biwa and sampling stations in the south basin.

(around 4.5 m deep) located in the south, Stn. 2 (2 m) in the east, Stn. 3 (4 m) in the center, Stn. 4 (5 m) in the west and Stn. 5 (8 m) in the north, adjacent to the north basin (Fig. 1). Thermal stratification was observed only at Stn. 5 in summer.

Water samples were collected with a 3 l Van Dorn water sampler from 0.5 m layer below the surface at each station. At the same time, water temperature and transparency were measured with a thermistor thermometer (Tohodentan, RB–2) and Secchi disc, respectively.

Samples for determination of chlorophyll *a* (Chl–*a*) and phaeopigments (Phaeo) were obtained by filtration through Whatman GF/C glass fiber filters. The amounts of Chl–*a* and Phaeo on the filter were determined by the method of Lorenzen (1967). The filtrate through the glass fiber filter was put to determinations of dissolved inorganic nitrogen (DIN, $NO_3^- - N + NO_2^- - N + NH_4^+ - N$) and dissolved inorganic phosphorus (DIP) (see Nakanishi *et al.*, 1986). The pH was measured by the colorimetric method. A 200 ml water sample collected at each station was immediately preserved in acid Lugol's solution (Saraceni and Ruggiu, 1969) for identification and counting of planktonic algae. Each sample was concentrated to 0.2–0.4 ml by natural precipitation. The algal cell numbers in 0.9 μl of the concentrated sample were counted four times at 400–600 magnification. A haematocytometer was used as counting chamber.

Species diversity of phytoplankton was calculated by the Shannon–Weaver's function (cf. Ogawa and Ichimura, 1984 a),

$$H' = -\Sigma \frac{ni}{N} \log_2 \frac{ni}{N}$$

where H' is the diversity expressed as bits$\cdot$cell$^{-1}\cdot$ml^{-1}, and ni and N are cell number of the i–th species and total cell number of planktonic algae in the sample, respectively.

Similarity index (C_λ) of phytoplankton community was calculated by the Morisita's (1959) formula derived from the Simpson's measure of diversity (λ),

$$\lambda = \frac{\Sigma\, ni\,(ni-1)}{N(N-1)}$$

where N and ni are total cell number in sample and cell number of each species, respectively.

$$C_\lambda = \frac{2 \sum_{i=1}^{m} n_1 i \cdot n_2 i}{(\lambda_1 + \lambda_2) N_1 N_2}$$

where λ_1 and λ_2, N_1 and N_2 are λ and N of the community I and II, and $n_1 i$ and $n_2 i$ are cell number of the i–th species found in the community I and II, respectively.

RESULTS

Some limnological variables at study sites

Figure 2 shows seasonal variations of water temperature, pH value and Secchi disc reading (transparency) at the investigated stations. As a whole, there was no significant difference in seasonal variation of water temperature between stations. However, water temperature tended to be lower from March to June at Stn. 5 than at other stations and to be higher from October to February. This tendency seems to have occurred due to inflow

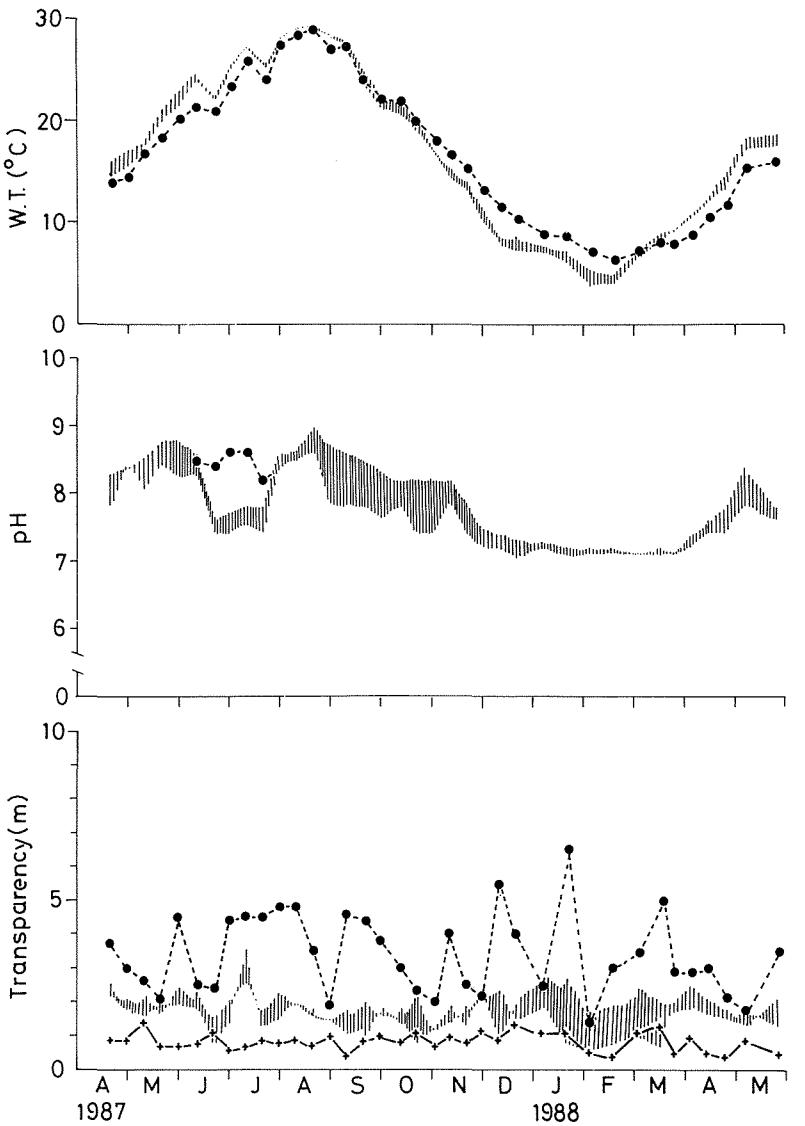

Fig. 2. Seasonal changes in water temperature (W.T.), pH and Secchi disc transparency at the sampling stations. Shaded area shows the ranges of water temperature at four stations except for Stn. 5 (solid circles), pH at all stations except for June and July (solid circles: Stn. 5) and transparency at three stations other than Stn. 2 (crosses) and Stn. 5 (solid circles).

of the water mass from the deep north basin into Stn. 5.

It was noted that the pH value sharply dropped at Stns. 1–4 in rainy season (June and July), whereas such drop was not observed at Stn. 5. This fact also suggests that the water around Stn. 5 was strongly influenced by inflowing water from the large and deep north basin, which is less influenced by precipitation. The other characteristic is that the pH value fluctuated irregularly with a fairly wide range from September to mid-November at all stations.

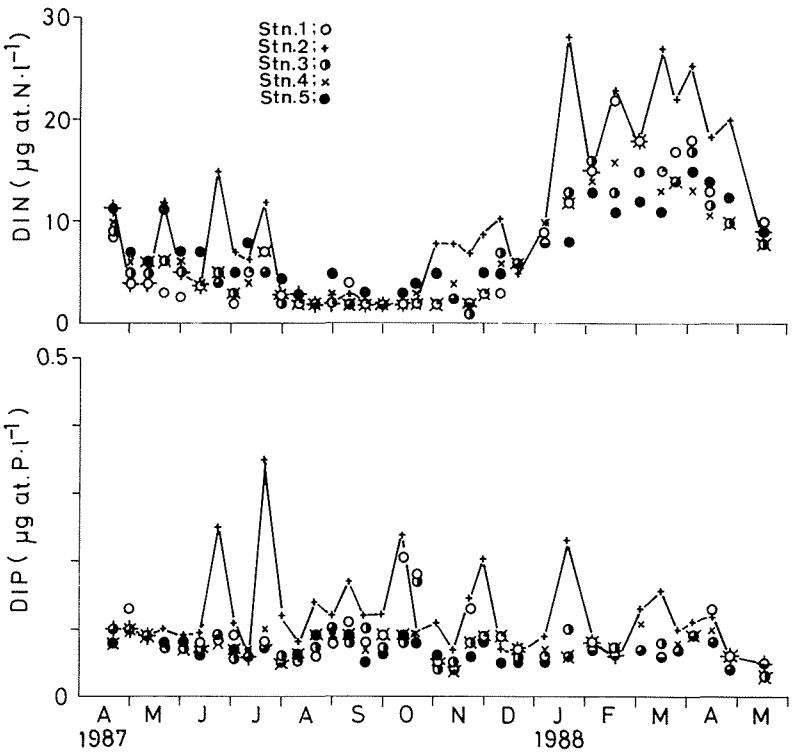

Fig. 3. Seasonal changes in DIN and DIP concentrations at the sampling stations.

Secchi disc reading was highest at Stn. 5 throughout the study period, though it fluctuated largely from 1.4 to 6.5 m. On the other hand, it was lowest at Stn. 2, ranging from 0.2 to 1.4 m. The readings at Stns. 1, 3 and 4 were mostly intermediate between those at Stns. 2 and 5. Around Stn. 2, dredging to obtain sand is being done on a large scale. Thus, it is considered that admixture of suspended detrital and/or mineral matter due to the dredging operations disturbed strongly light penetration into water at Stn. 2. Admixture of large amounts of mineral matter means that optical properties at Stn. 2 differ from those at other stations.

DIN and DIP concentrations are compared between stations (Fig. 3) . DIN and DIP concentrations were not different between Stns. 1, 3, 4 and 5, but they tended to be slightly higher at Stn. 2 with many pulses. Mean annual concentration of DIN was 6.6 ± 5.7 (SD), 9.6 ± 7.8, 6.3 ± 4.8, 6.7 ± 4.8 and 7.0 ± 4.0 μg at. N·l^{-1} at Stns. 1, 2, 3, 4 and 5, respectively. The mean annual concentration with great standard deviation indicates that DIN concentration fluctuated largely at any station during the study period. In the months except DIN depletion period of August–October, DIN concentration at Stn. 2 fluctuated with many pulses and tended to be higher than that at other stations. DIP concentration was not as seasonally changeable as DIN at the stations other than Stn. 2 with many pulses. Mean annual concentration of DIP was 0.085 ± 0.034 (SD), 0.123 ± 0.061, 0.069 ± 0.015, 0.076 ± 0.023 and 0.078 ± 0.015 μg at. P·l^{-1} at Stns. 1, 2, 3, 4 and 5, respectively.

Figure 4 shows seasonal variation of [Chl-*a* + Phaeo] concentration and dominant planktonic algae in the east–west (Stns. 2, 3 and 4) and in the south–north (Stns. 1, 3 and 5)

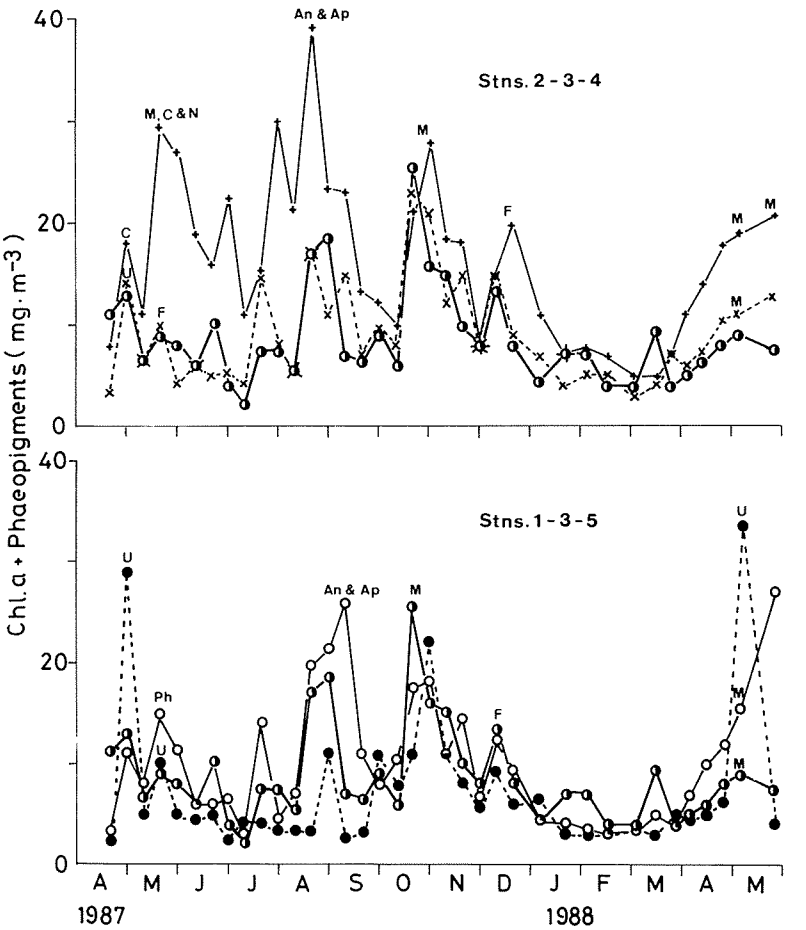

Fig. 4. Seasonal change in [Chl-*a* + Phaeo] concentration at the sampling stations. Symbols are the same as in Fig. 3. Literal symbols show dominant species at peaks.
C: *Cyclotella glomerata* and *C. stelligera*, U: *Uroglena americana*, M: *Melosira granulata*, N: *Nitzschia holsatica*, F: *Fragilaria crotonensis*, Ph: *Phormidium tenue*, An: *Anabaena affinis* and *A. macrospora*, Ap: *Aphanocapsa elachista*.

directions. There are some differences in the changing patterns from station to station in May and/or June. One was the formation of big peaks at Stn. 2 through May into June 1987. These peaks were mainly due to development of *Melosira granulata–Cyclotella glomerata–C. stelligera–Nitzschia holsatica* community different from other stations. The other was a sharp peak at Stn. 5 in early May of 1987 and 1988 due to propagation of *Uroglena americana*. Except for the above mentioned peaks, [Chl-*a* + Phaeo] concentration fluctuated seasonally with similar pattern showing mainly three peaks at any station , though there were differences in the concentration and a time lag for peak formation between stations. The first common peak observed in August–September was brought about by development of *Anabaena affinis–A. macrospora–Aphanocapsa elachista* community. The second peak in October–November and the third one in December were due to propagation of *M. granulata* and *Fragilaria crotonensis*,

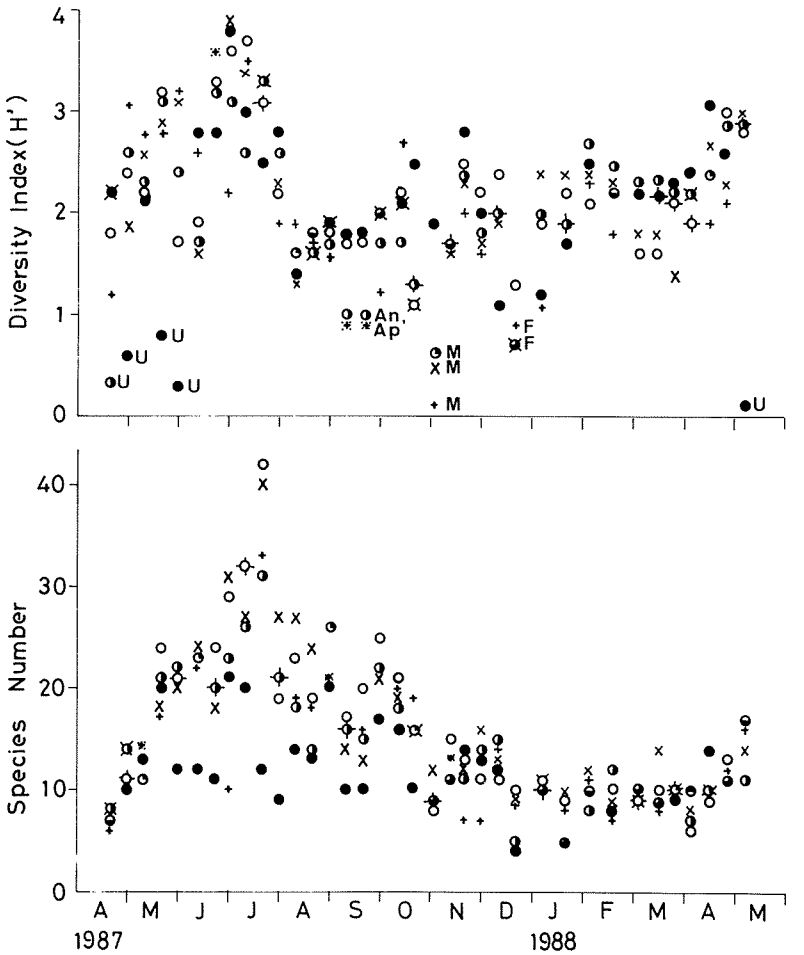

Fig. 5. Seasonal changes in species diversity and species richness of phytoplankton. Symbols are the same as in Fig. 3. U, An, Ap, M and F in the Figure are the same as in Fig. 4.

respectively.

Species diversity and community similarity

To compare the phytoplankton community structure between the stations, species diversity and community similarity were examined using cell number (ml^{-1}) of each species identified. Seasonal changes in the values of the diversity index and in species richness are shown in Fig. 5. The diversity index varied seasonally with a wide range at all stations, showing a tendency to become high from late-June to July with relatively high species number. Seasonal ranges of the index values at Stns. 1, 2, 3, 4 and 5 were 0.63–3.68 (2.16 on the average), 0.12–3.61 (2.03), 0.33–3.29 (2.13), 0.51–3.95 (2.11) and 0.13–3.80 (1.99) bits·$cell^{-1}$, respectively. Extremely low diversity below 1 was observed sometimes at some stations where the following species were predominant: *Uroglena americana in* April–June at Stns. 3 and 5, *Anabaena affinis, A. macrospora* and *Aphanocapsa elachista* in September at Stns. 2–4, *Melosira granulata* in November at Stns. 1–4, and *Fragilaria*

Table 1. Typical patterns of similarity matrix observed in the south basin of Lake Biwa during April 1987–May 1988.

Pattern	Type I				Type II				Type III				Type IV				Type V			
Date	20 Apr., 1987				21 May, 1987				12 June, 1987				21 July, 1987				1 Sep., 1987			
Stn.	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
1	0.02	0.01	0.97	0.88	0.52	0.48	0.44	0.01	0.54	0.99	0.99	0.68	0.93	0.85	0.88	0.30	1.00	1.00	0.99	0.99
2		0.00	0.11	0.01		0.55	0.47	0.54		0.52	0.51	0.49		0.86	0.78	0.12		0.99	0.98	0.97
3			0.01	0.01			0.88	0.04			1.00	0.70			0.93	0.29			0.99	0.99
4				0.95				0.04				0.65				0.33				0.99

crotonensis in December at Stns. 2–5. As a whole, it was noted that the species diversity of phytoplankton differed fairly between stations at certain times of the year.

Table 1 shows typical patterns of similarity matrix during the study period. Phytoplankton similarity between stations tended to change complicatedly from April to July 1987. Thereafter until December, with a few exceptions, phytoplankton community structure was stable at all stations with high C_λ values. And it became unstable again from January to May 1988. The first and/or second ranked species were the same at all stations during the stable period, but not during the unstable one. Five types of the similarity matrix were observed throughout the study period.

Type I in the matrix, being characterized by high C_λ values between Stns. 1, 4 and 5, was observed in April 1987. The first and second ranked species were as follows: *Dinobryon bavaricum–Asterionella formosa* at Stns. 1, 4 and 5, *Cyclotella glomerata* and *C. stelligera–Nitzschia holsatica* at Stn. 2 and *Uroglena americana* at Stn. 3. Type II, showing high C_λ value between Stns. 3 and 4, was observed in May 1987. The first and second species were *Phormidium tenue–Melosira granulata* at Stn. 1, *M. granulata–Cyclotella stelligera* at Stn. 2, *Fragilaria crotonensis–Ankistrodesmus falcatus* at Stns. 3 and 4, *U. americana–F. crotonensis* at Stn. 5. Type III, showing high C_λ values between Stns. 1, 3 and 4, became representative in June with *P. tenue–M. granulata* at Stns. 1, 3 and 4, *C. stelligera–M. granulata* at Stn. 2, and *P. tenue–Stephanodiscus carconensis* at Stn. 5. Type IV, showing very high C_λ values between Stns. 1, 2, 3 and 4, occurred mainly in July. The communities were composed mainly of *M. granulata* and *Pediastrum biwae* at Stns. 1, 2, 3 and 4, and *Planktospheria gelatinosa–Staurastrum dorsidentiferum* at Stn. 5.

During the stable period (August–December) with Type V, showing high C_λ values between any station, the first and second ranked species were not so different at all stations: *Aphanocapsa* elachista–*M. granulata* or *Anabaena affinis* in August, *Microcystis aeruginosa–A. elachista* in September, *A. elachista–M. granulata* or *M. aeruginosa* in October, *M. granulata–S. dorsidentiferum* or *F. crotonensis* in November and *F. crotonensis–A. formosa* in December.

From January to April 1988, phytoplankton community structure became unstable again and was characterized by more typical Type III in the similarity matrix. The first and second ranked species were shifted from *D. bavaricum–F. crotonensis* to *A. formosa* or *D. bavaricum–M. granulata* through *A. formosa–C. glomerata* and *C. stelligera* at Stns. 1, 3 and 4. On the other hand, the species were shifted from *C. glomerata–C. stelligera* to *C. glomerata–Synedra acus* through *A. formosa–C. glomerata and C. stelligera* at Stn. 2, and

from *F. crotonensis–S. carconensis* through *Melosira solida–A. formosa* at Stn. 5.

DISCUSSION

The diversity index of phytoplankton by Shannon–Weaver's function is significantly correlated with relative abundance rather than species richness (Sager and Hasler, 1969). This was nearly true of the results in the present study, with the exception of late June to July with relatively high species richness when the diversity tended to be high (Fig. 5).

Moss (1973) and Ogawa and Ichimura (1984a) pointed out that diversity of phytoplankton varies depending on trophic status of waters. Mean annual values of diversity index, ranging from 1.99 to 2.16 bits·cell^{-1}, were almost the same between the investigated locations. This fact indicates that, on the annual average, trophic status is not so different between locations in the south basin of Lake Biwa. However, it should be noted that there were distinct differences in the diversity index between the stations at certain times during the study period (*cf.* Fig. 5). Relatively high diversity tended to occur at stations with no numerically dominant species and with relatively low Chl–*a* concentration. On the other hand, low diversity was obtained at stations with high relative abundance of dominant species and with relatively high Chl–*a* concentration. After Ogawa and Ichimura (1984 a and b), eutrophic and hypereutrophic waters are characterized by large propagation of small number of species that can achieve high growth rates in nutrient rich waters. As a result, the diversity becomes low. In the present study, *Uroglena americana, Anabaena affinis, A. macrospora, Melosira granulata* and *Fragilaria crotonensis* are characterized as the species which can grow rapidly at certain times in the south basin of Lake Biwa. Local and/or seasonal variations of the phytoplankton diversity seems to have been governed more or less by the rise and fall of populations of these species.

Similarity index (C_i) between two phytoplankton communities is strongly influenced by relative abundance of common species.

When we compare the values of similarity index between the respective two stations, local difference in phytoplankton community structure was observed often during periods of April–July 1987 and January–May 1988. This difference was mainly due to a great difference in relative abundance of common species between stations. Dominant and/or common species belonged mainly to Chrysophyceae *(Uroglena americana* and *Dinobryon bavaricum)* and Bacillariophyceae *(Cyclotella glomerata, C. stelligera, Melosira granulata, Asterionella formosa* and *Fragilaria crotonensis)*. At present, it is unknown why *U. americana* occurred only at the restricted stations and the other species which were distributed at all stations differed greatly in their relative abundance between stations. On the other hand, during August–December 1987, no local difference in phytoplankton community structure was observed. Dominant species were *Anabaena affinis, A. macrospora, Aphanocapsa elachista* and *Microcystis aeruginosa* (Cyanophyceae) and *F. crotonensis* and *M. granulata* (Bacillariophyceae). These species grew synchronously and became dominant at all stations during this period. Thus, relative abundance of these dominant and common species contributed to the high similarity index.

One of the characteristics in similarity matrix during unstable periods, April–June 1987 and January–April 1988, is that phytoplankton community structure at Stn. 2 in the east side area was often different from that at other stations (see Type I–III in Table 1).

This was mainly due to difference in dominant species between Stn. 2 and other stations: *Cyclotella glomerata* and *C. stelligera* community was typical in most cases at Stn. 2 but not at other stations. Holland and Clafin (1975) pointed out that large numbers of *C. stelligera* were maintained at the sites with high level of total phosphorus in Green Bay of Lake Michigan. In the present study, concentration of DIP plus particulate phosphorus (PP, unpublished data) at Stn. 2 was higher than those at other stations. The higher [DIP + PP] concentration may have been partly correlated with abundance of *Cyclotella* community at Stn. 2. Taking dredging operations around Stn. 2 into consideration, release of micronutrients from sediments might be related also delicately to development of the phytoplankton community (Vanni, 1987). Study on micronutrients including silica may be one of the important subjects in the south basin. Effect of difference in optical properties on alteration of algal community is unkown. The other characteristic during the unstable periods was that phytoplankton community structure was different between Stn. 5 and other stations (see Type II–IV in Table 1). This was also brought about by the difference in dominant species between Stn. 5 and other stations. This phenomenon can be explained by the fact that phytoplankton at Stn. 5 were mainly composed of the species originated in the north basin, being different from those in the south basin (Ichise and Wakabayashi, 1985).

In the present study, it was difficult to explain local and seasonal differences in species diversity and community similarity in connection with some related variables. Structure of phytoplankton community may be influenced delicately not only by water temperature, light conditions, pH and nutrient concentrations and ratios but also by concentrations of electrolytes and dissolved organic matter. Further, it is also influenced by zooplankton grazing. Analytical studies on factors regulating phytoplankton community structure are required as a next step.

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