Relationships between the Dominant Phytoplankton and DIN:DIP Ratios in Inland Waters

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The relationships between the dominant phytoplankton and the factors of water quality were investigated at 28 stations in inland waters.

In large and deep lakes and dams between mountains, total nitrogen (TN), total phosphorus (TP), and TN:TP were low while TN:TP and dissolved inorganic nitrogen (DIN): dissolved inorganic phosphorus (DIP) ratios were high. However, in small and shallow ponds the former water quality factors were high while the latter factors were low.

Uroglena americana, *Fragilaria crotonensis*, and *Asterionella formosa* occurred dominantly in waters with low water temperature (WT), TN $\times$ TP, DIP, and TN:DIN ratios and with high DIN, TN:TP, DIN:DIP, and TP:DIP ratios. On the other hand, the blue-green algae *Microcystis aeruginosa*, *Microcystis wesenbergii*, and *Lyngbya contorta* occurred in waters with high WT, TN $\times$ TP, TN:DIN, and TP:DIP ratios and with low TN:TP and DIN:DIP ratios.

These results suggest that DIN:DIP, TN:DIN, and TP:DIP ratios were closely related with the other factors of water quality, and these factors also restricted the waters where the specific phytoplankton occurred dominantly.

Key words: inland water, dominant phytoplankton, DIN:DIP ratio, TN:DIN ratio, TP:DIP ratio

Recently, the total nitrogen (TN): total phosphorus (TP) ratio in inland waters has increased due to the removal of phosphorus from sewage through treatment and by the prohibition of the use of detergents containing phosphorus. As a result, the high TN:TP ratio in water may have an effect on aquatic microorganisms. Much is now known about the relationships between the dominant phytoplankton and TN:TP ratio^{1–12)} or dissolved inorganic nitrogen (DIN):TP ratios,^{4,9)} especially concerning the blue-green algae occurring in waters with low ratios of these factors.

In a previous study,¹²⁾ the interrelationships among the dominant phytoplankton and concentrations of DIN, dissolved inorganic phosphorus (DIP), and DIN:DIP ratios in inland waters were investigated and it was found that *Uroglena americana* occurred in waters with comparatively high DIN and DIN:DIP ratios and with low DIP.

In the present study, the interrelationships between the dominant phytoplankton and the factors of water quality such as TN:TP and DIN:DIP ratios and newly added factors TN $\times$ TP (eutrophic degree), TN:DIN, and TP:DIP ratios (utilization intensity of nutrient salts) were evaluated in inland waters.

Methods

Surface water samples were collected in May and September in 1991 and 1992, respectively, at 28 stations set up at Lake Biwa (4 points), 7 lakes, 5 dams, and 12 ponds (Fig. 1). Water temperature (WT) was also measured.

Chemical analyses were performed using the following

methods; TP and TN were determined using a Technicon Autoanalyzer II after persulfate digestion.^{13,14)} Dissolved inorganic phosphorus (DIP), ammonium nitrogen (NH₄-N), nitrite nitrogen (NO₂-N), and nitrate nitrogen (NO₃-N) were also quantified using a Technicon Autoanalyzer II. DIN was determined by summing the concentrations of NH₄-N, NO₂-N, and NO₃-N.

The phytoplankton was fixed with 0.5 ml of an acetic acid-lugol solution (I: 10 g, KI: 20 g, acetic acid: 100 ml, and distilled water: 200 ml) per 100 ml of water sample. Then, the phytoplankton which appeared with the highest and the second highest cell number in each sample were treated as the dominant phytoplankton.

For each of 13 species of dominant phytoplankton which occurred at levels 4 times or more that in the inland waters, the average value of each factor affecting water quality in the waters where each species occurred dominantly were calculated. These values were then compared and the interrelationships between the phytoplankton and the factors were examined.

In addition, *U. americana* which is a harmful phytoplankton that causes "red water bloom",¹⁵⁾ occurred dominantly only 3 times in the present study. *U. americana* samples shown previously (Table 11.1)¹²⁾ were therefore added to the present study as one of the dominant phytoplankton samples.

Results

Relationships between Inland Waters and Water Quality Factors

Fig. 1. Approximate locations of the lake and pond stations.

Scale bars: 30 km.

Left: Kansai Area, A, Pond Shoubutani; B, P. Osawa; C, P. Hirotsawa; D, P. Midoroga; E, P. Takaraga; F, Imazu in Lake Biwa; G, P. Komatsu in L. Biwa; H, Omimaiko in L. Biwa; I, Sakamoto in L. Biwa; J, Hamaotsu in L. Biwa; K, Dam Odo; L, D. Yasugawa; M, D. Hino; N, D. Eigenji; O, D. Usogawa; P, P. Obuti; Q, P. Saki; R, P. Konabe; S, P. Sarusawa; T, P. Kono.

Right: Kanto Area, U, P. Suge; V, L. Yuno; W, L. Chuzenji; X, L. Motosu; Y, L. Shoji; Z, L. Sai; AA, L. Kawaguchi; AB, L. Yamanaka.

Fig. 2. Relationships between inland waters and TN, TP, and $TN \times TP$ parameters of water quality (abbreviations as in Fig. 1).

□, deep lake and dam; ■, shallow pond and lake (depth, ca. 3–5 m).

Fig. 3. Relationships between inland waters and $TN:TP$ or $DIN:DIP$ ratios (abbreviations as in Fig. 1).

□, deep lake and dam; ■, shallow pond and lake (depth, ca. 3–5 m).

The relationships between inland waters and water quality factors were examined by comparing the average values of each factor at each station.

As shown in Fig. 2, TN, TP, and $TN \times TP$ were higher in small and shallow ponds with depths of ca. 3–5 m, while they were lower in large and deep lakes and dams between mountains. Among the water quality factors, $TN \times TP$ was the highest in Saki Pond and the lowest in Lake Motosu. $TN:TP$ and $DIN:DIP$ ratios tended to be higher in deep lakes and dams, but lower in shallow ponds (Fig. 3). Furthermore, in the waters where $TN:TP$ ratios were high, $DIN:DIP$ ratios tended to be higher than $TN:TP$ ratios. In those waters where $TN:TP$ ratios were lower, the converse was true.

Relationships between Dominant Phytoplankton and Water Quality Factors

The relationships between the dominant phytoplankton and water quality factors were examined for the following 13 species of phytoplankton: 3 species found mostly in deep lakes and dams, *U. americana* (code in Figs: Ua), *Asterionella formosa* (Af), and *Dinobryon* sp. (Ds), 6 species found mostly in shallow ponds, *Microcystis wesenbergii* (Mw), *Microcystis aeruginosa* (Ma), *Lyngbya contorta* (Lc), *Nitzschia acicularis* (Na), *Melosira granulata* (Mg), and *Chlamydomonas conferta* (Cc), and 4 species found both in deep and shallow waters, *Fragilaria crotonensis* (Fc), *Cryptomonas* sp. (Cs), *Ceratium hirundinella* (Ch), and *Aphanocapsa elachista* (Ae).

The relationships between the dominant phytoplankton and the concentrations of DIN or DIP are shown in Fig. 4A. *U. americana*, *A. formosa*, and *F. crotonensis* (abbreviation: *U. americana* group) occurred in waters with comparatively high DIN and low DIP, *L. contorta*, and *N. acicularis* were observed in waters with low DIN and DIP, and *M. wesenbergii* were dominant in waters with low DIN and high DIP. With regard to TN, TP, and $TN \times TP$, the *U. americana* group occurred in waters with compara-

Fig. 4. Relationships between the dominant phytoplankton and DIN or DIP (A), or the plankton and TN or TP (B), (abbreviations as in the text).

tively low values of these factors, while the blue-green algae *M. aeruginosa*, *M. wesenbergii*, and *L. contorta* (abbreviation: *M. aeruginosa* group) were dominant in waters with high values of these factors (Fig. 4B).

The relationships between the dominant phytoplankton and TN:TP, or DIN:DIP ratios are shown in Fig. 5A. The *U. americana* group occurred in waters with comparatively high ratios of TN:TP or DIN:DIP while the *M. aeruginosa* group was dominant in waters with low ratios of both factors. With regard to TN:DIN and TP:DIP ratios, the *U. americana* group occurred in waters with comparatively low ratios of both factors, while the former ratio was lower than the latter. In contrast, the *M. aeruginosa* group was observed in waters with high ratios of both factors while the former was higher than the latter (Fig. 5B).

The relationships among the TN:TP, TN:DIN, and TP:DIP ratios in waters where the dominant phytoplankton occurred are shown in Fig. 6A. TN:DIN and TP:DIP ratios tended to be lower with increased TN:TP ratio, and this was more remarkable for TN:DIN ratios than TP:DIP ratios. TN:TP and DIN:DIP ratios tended to be lower with increased WT, and this tendency was more remarkable for DIN:DIP ratios than TN:TP ratios (Fig. 6B). Furthermore, the *U. americana* group occurred in waters where WT was comparatively low, while the *M. aeruginosa* group was observed in waters with high WT.

The relationships among the $TN \times TP$, TN:TP and DIN:DIP ratios are shown in Fig. 7A. TN:TP and DIN:DIP ratios tended to be lower with increased $TN \times TP$, and this observation was more remarkable for DIN:DIP ratios than TN:TP ratios. TN:DIN and TP:DIP ratios tended to be higher with increased $TN \times TP$, and

Fig. 5. Relationships between the dominant phytoplankton and TN:TP or DIN:DIP ratios (A), or the plankton and TN:DIN or TP:DIP ratios (B), (abbreviations as in the text).

Fig. 6. Interrelationships among TN:TP, TN:DIN, and TP:DIP ratios (A), or WT, TN:TP, and DIN:DIP ratios (B), (abbreviations as in the text).

A: □, TN:DIN ratio; ■, TP:DIP ratio.
B: □, TN:TP ratio; ■, DIN:DIP ratio.

this tendency was more remarkable for TN:DIN ratios than TP:DIP ratios (Fig. 7B). Moreover, the *U. americana* group occurred in waters with comparatively low

Fig. 7. Interrelationships among $TN \times TP$, $TN:TP$ and $DIN:DIP$ ratios (A), or $TN \times TP$, $TN:DIN$, and $TP:DIP$ ratios (B), (abbreviations as in the text).

A: □, $TN:TP$ ratio; ■, $DIN:DIP$ ratio.
 B: □, $TN:DIN$ ratio; ■, $TP:DIP$ ratio.

$TN \times TP$, while the *M. aeruginosa* group was present in waters with high $TN \times TP$.

Discussion

It has generally been accepted that in inland waters influenced by sewage, concentrations of TN and TP are increased but $TN:TP$ ratios are decreased to approximately the ratios of sewage (atomic ratios; ca 6–10),¹⁶⁾ and the TN, TP, chlorophyll contents, and production rates of phytoplankton tend to be higher with increasing water depth.¹⁷⁾

In the present study, it was similarly found that TN, TP, and $TN \times TP$ tended to be lower and $TN:TP$ and $DIN:DIP$ ratios were higher in deep lakes and dams between mountains, while the former were higher and the latter lower in small and shallow ponds in plains.

The relationships between the dominant phytoplankton and water quality factors were variable and complex. However, by comparing the two groups of dominant phytoplankton, the *U. americana* group which is usually found in deep lakes and dams tended to occur in waters with high $TN:TP$, $DIN:DIP$, and $TP:DIP$ ratios and with low WT, DIP, and $TN:DIN$ ratios, while the *M. aeruginosa* group which usually occurs in small and shallow ponds was observed in waters with low DIN, $DIN:DIP$, and $TN:TP$ ratios and with high WT, $TN:DIN$, and $TP:DIP$ ratios.

In waters with high $TN:TP$ ratios, $DIN:DIP$ ratios tended to be higher than $TN:TP$ ratios, while $DIN:DIP$ ratios were lower than $TN:TP$ ratios in waters with low $TN:TP$ ratios. These results suggest that in waters with

high $TN:TP$ ratios, the utilization rate of DIP is high in waters relatively depleted of DIP, while the converse occurs in waters with low $TN:TP$ ratios.

Furthermore, $TN:DIN$ and $TP:DIP$ ratios tended to be higher with increased $TN \times TP$ and WT, and the tendency was more remarkable in $TN:DIN$ ratios than $TP:DIP$ ratios. These results suggest that the uptake and liberation rates of nutrient salts by microorganisms such as bacteria and plankton as a whole in the waters^{18,19)} were intensely affected by $TN \times TP$ and WT.

From the above results, it is suggested that $DIN:DIP$, $TN:DIN$, and $TP:DIP$ ratios are closely related with other factors of water quality, and these factors also restrict the waters where the dominant phytoplankton occurred.

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