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Factors regulating bluegreen dominance in a reservoir directly influenced by the Asian monsoon

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Abstract

Current hypotheses, based on physical and chemical theory, that account for bluegreen-blooms in lakes were evaluated in Taechung Reservoir, Korea, during May 1993–November 1994. Seasonal patterns of chlorophyll (Chl) were similar in 1993 and 1994, but the taxonomic composition and size structure of the phytoplankton communities differed between years. During August–September 1994, bluegreens comprised >80% of total cell numbers and net-Chl (fraction of Chl>35 μm) was 63% of total Chl, whereas in 1993, diatoms (*Melosira*) were the major taxa, and ultra-Chl (<11 μm) dominated. The major factor influencing bluegreen dominance in 1994 was a weak monsoon which was directly linked to strong water column stability (>25 kg μm^{-2}), high water temperature (>28°C), and reduced silica input. Low N/or N:P ratios and the concentration of monovalent cations (Na^+ and K^+) were not determining factors in this system, but light and pH seemed to act as secondary factors. Our study suggests that the magnitude and frequency of bluegreen blooms in Asian waterbodies may be reduced during an intense monsoon, but increased during a weak monsoon.

Introduction

Bluegreen algal blooms occur in certain waterbodies but not others (Smith, 1983; Vincent, 1989; Zohary & Madeira, 1990; Scheffer et al., 1997), and they occur in certain seasons or years but not others (Reynolds, 1972; Talling, 1986; Sterner, 1989; Knowlton & Jones, 1996). Variability in bluegreen-bloom formation has been linked to physical and chemical features of waterbodies and current mechanisms explaining bluegreen dominance include: 1. water column stability and algal buoyancy control (Reynolds, 1987; Paerl, 1988; Reynolds, 1994); 2. high water temperature (Tilman et al., 1986; McQueen & Lean, 1987); 3. nutrient content, particularly low N:P ratios (Schindler, 1977; Smith, 1983), high P (Trimbee & Prepas, 19871 Watson et al., 1997), or low silica (Kilham, 1971; Sterner, 1989); 4. low CO_2/high pH (Shapiro, 1990); 5. low underwater light (Robarts & Zohary, 1984; Smith, 1986; Havens et al., 1998); 6. high K^+ and Na^+ (Provasoli, 1969; Wetzel, 1983); and 7. through top down processes due to grazing by zooplankton and fish (Shapiro et al., 1982; Haney, 1987). Among these factors, the N:P ratio has most often been used as a key indicator accounting for bluegreen dominance (Shindler, 1977; Smith, 1983; McQueen & Lean, 1987; Ryding & Rast, 1989). The reason why bluegreen blooms form and why they vary with location and time, however, remain obscure and paradoxical (Paerl, 1988; Shapiro, 1990).

Eight among 15 large reservoirs in Korea have experienced massive bluegreen blooms and two reservoirs have experience freshwater red-tides (Cho et al., 1991). Data from Taechung and Soyang reservoirs suggest that the frequency of bluegreen blooms and standing crop of *Anabaena* have increased since 1986 (Choi et al., 1988; Cho et al., 1989; Cho et al., 1990). Surprisingly, these bluegreen outbreaks have occurred in nitrogen-rich environments (DIN: >0.60 mg l^{-1}) when TN:TP or NO_3–N:SRP (atomic ratio) was >150 (Cho et al., 1990). Comparable results were found in

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Iowa (Jones & Bachmann, 1978) and Canada (Trimbee & Prepas, 1987) when TN values were >0.65 mg l^{-1}. These studies indicate that low N or a low N:P ratio may not be a universal diagnostic tool for assessing bluegreen dominance. In Korea, the advent and expansion of bluegreen blooms indicate a modification in the structure of these aquatic communities, but factors regulating these blooms are little known (Cho et al., 1989, 1990).

Korean waterbodies differ from other temperate lakes because they are directly influenced by an Asian monsoon during summer. About half of total annual rainfall in Korea occurs during the summer monsoon in July–August (Watts, 1969). Rapid flushing or turbulence resulting from intense runoff during the monsoon may adversely affect formation of bluegreen blooms (Viner, 1985; Reckhow, 1988). In fact, limnological studies (Cho et al., 1990; Joo et al., 1997; Kong, 1997) show that bluegreen blooms are rare in Korea during the height of the summer monsoon. This contrasts with conditions in north-temperate lakes where summer bluegreen-blooms are expected (Shapiro, 1990).

In this study, we evaluate the six bluegreen-forming hypotheses based on physical and chemical theory using data collected from six sites in Taechung Reservoir, Korea during 1993–1994. Rainfall and flooding were above average during the 1993 monsoon, but a severe drought in 1994 provided a sharp contrast in physical and hydrological conditions. This contrast between the two monsoons provided a fortunate natural experiment and allowed us to compare limnological conditions between years. Surface chlorophyll concentrations were similar in both years, but algal composition differed. Bluegreens dominated in 1994 but not in 1993. In this study, we compare hydrological, chemical and biological conditions between the 2 years, and examine how the bluegreen community was associated with them. Our objective was to evaluate several potential reasons why bluegreen blooms varied inter-annually using current hypotheses.

Study sites

Taechung Reservoir, a warm monomictic man-made lake located in the middle of South Korea (36° 50′ N, 127° 50′ E, Figure 1), was formed in December 1980 by impounding the Keum River. This multipurpose impoundment was constructed for water supply, flood control and hydroelectric power generation. The reservoir has a surface area of 6.8×10^7 m^2 at an elevation of 80 m MSL (Mean Sea Level), and a volume of 14.3×10^8 m^3 with a mean depth of 21 m and maximum depth of 69 m. About 68% of the reservoir mean volume and 61% of the surface area lies within 14 km of the dam. The reservoir has been enriched since 1985 by nutrients (N, P) from the watershed and in-lake fish farms, and bluegreen blooms have been frequent since 1988 (Choi et al., 1988).

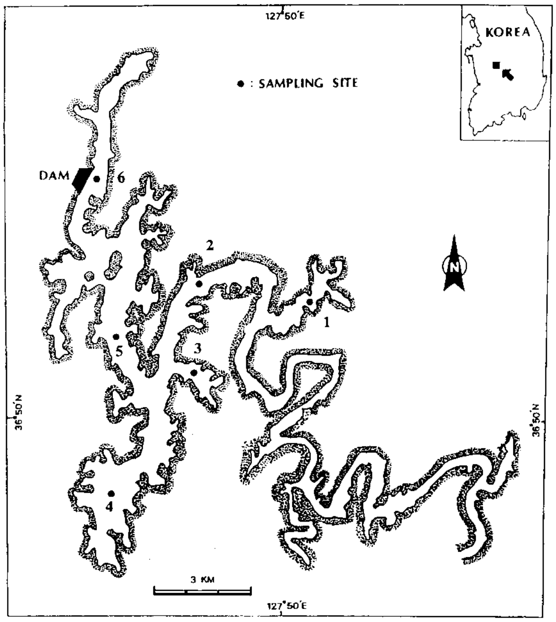

Figure 1. Map of Taechung Reservoir showing sampling sites (sites 1–6).

Materials and methods

This study was conducted at six locations (sites 1–6) in Taechung Reservoir (Figure 1) during 1993–1994 and average values from all sites were used for data presentation. Surface water samples were collected twice a month at each site, and subsurface samples at five depths were taken with a Van Dorn sampler.

Water temperature, dissolved oxygen (DO), pH and Secchi depth were measured at the time of sample collection. Total phosphorus (TP) and total dissolved phosphorus (TDP – 0.45 μm membrane filtration) were measured after Prepas & Rigler (1982). Total nitrogen (TN) and total dissolved nitrogen (TDN – same filter as TDP) were measured by the second derivative method after persulfate digestion (Crumpton et al.,

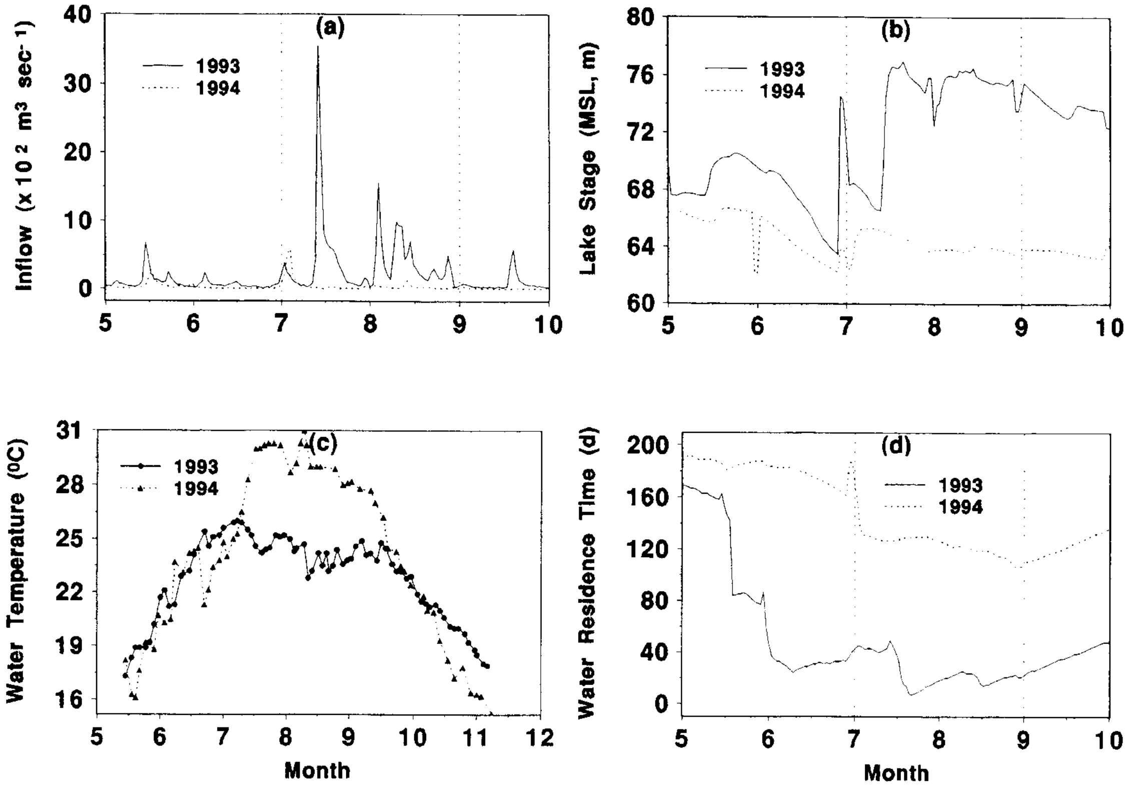

Figure 2. Hydrology and climate for 1993 and 1994; (a) inflow, (b) lake stage, (c) surface water temperature, and (d) water residence time (WRT). Maximum differences in these variables between the two years occurred during summer monsoon of July–August.

1992). Ammonia nitrogen (NH_4–N), nitrate–nitrite nitrogen (NO_3–N), silica (molibdosilicate method) and bicarbonate (sulfuric acid titration) were measured according to A.P.H.A. (1985). Sodium and potassium were determined on acid preserved samples by atomic absorption spectroscopy (A.P.H.A., 1985). Size fractions of phytoplankton were separated by use of Nitex netting. Total chlorophyll (Chl), nano-Chl (11–35 μm size fraction) and ultra-Chl (<11 μm) were measured spectrophotometrically after extraction in hot ethanol (Sartory & Grobbelaar, 1984). Herein, net-plankton Chl (>35 μm) was estimated by the difference between total Chl and nano-Chl. Also, algal taxa in acid Lugol's preserved samples were counted and identified (Jung, 1993) using a Sedgwick-Rafter counting cell (A.P.H.A., 1985). Nutrients were analyzed in triplicate and Chl in duplicate. Water residence time (WRT) was estimated after Knowlton & Jones (1990). Water column stability (S, kg m^{-2}) from temperature profiles was calculated using the formula of Viner (1984).

Results

Interannual differences in monsoon, hydrology and related physical conditions

Annual precipitation at the reservoir averaged 1100 μm during 1981–1994. The major difference in rainfall between 1993 and 1994 occurred during the monsoon. Total precipitation during July–August 1993 was 660 μm which comprised 43% of the annual total, but during this period in 1994 rainfall was only 251 μm. Monsoon rainfall in 1993 was 164% of the 1981-1994 mean, whereas rainfall in 1994 was only 50% of the mean. Precipitation was similar during the remaining periods of these 2 years.

Annual total inflow volumes were 3.68×10^9 m^3 in 1993 and 0.83×10^9 m^3 in 1994 (Figure 2a). Inflows in 1993 and 1994 were 138 and 31%, respectively, of average inflow during 1981–1994. Maximum daily inflow also differed between the 2 years; 3.6×10^3 m^3 s^{-1} in July 1993 and 1.4 m^3 s^{-1} in May 1994 (Figure 2a). Interannual differences in the inflow directly influenced outflow, lake stage and water residence time.

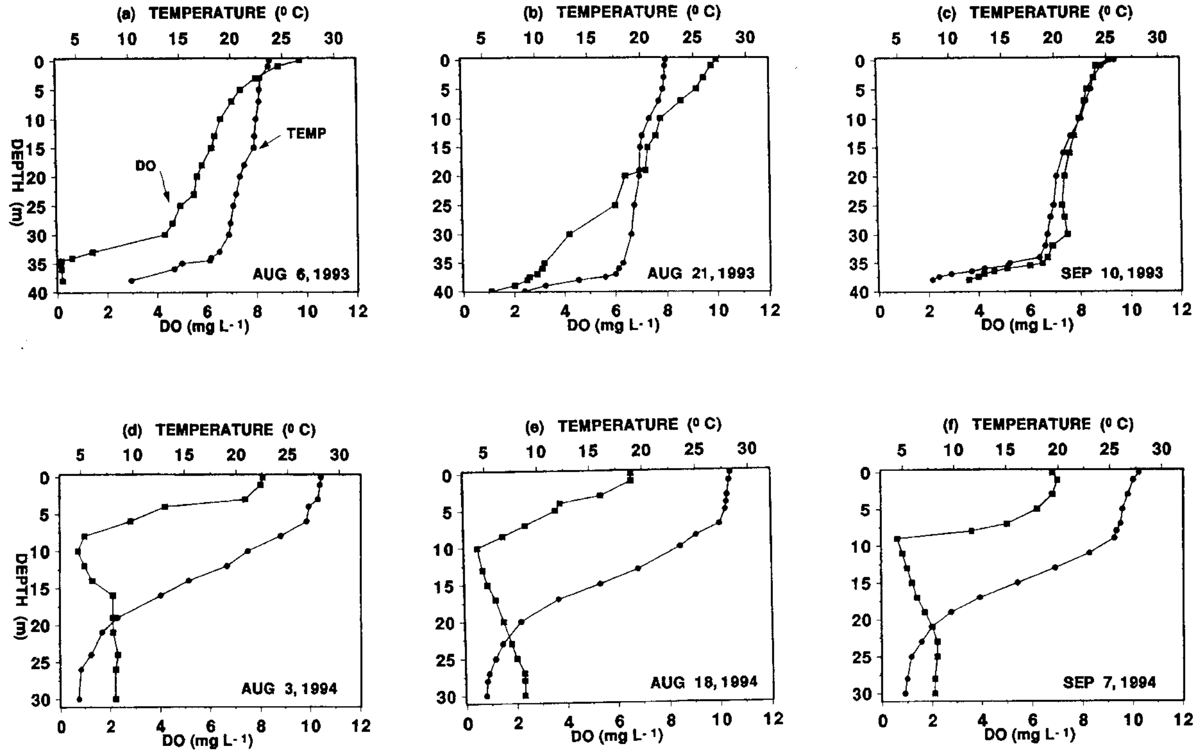

Figure 3. Water temperatures (°C, circle) and dissolved oxygen (DO, mg l^{-1}; square) distribution during August–September 1993 ('a'–'c') and 1994 ('d'–'e') at Site 2. The mixing depth in 1993 was greater than 30 m. The mixing depth in 1994 was < 5 m, and water column was strongly stratified, resulting in high water column stability. Epilimnetic temperatures were distinctly different between the 2 years.

Differences were most extreme during July–August; average outflow, lake stage (Figure 2b,c), and inflow in summer 1993 were significantly (p <0.001) greater than in the same period in 1994 while water residence time was significantly less.

Hydrological differences between years resulted in interannual differences in water temperature. Mean surface temperature during summer 1993 (range: 22.6–26.2 °C) was 5.5 °C less than in the same period in 1994 (23.6–31.3 °C, Figure 2c). Water temperature during the other seasons did not differ between years.

The pattern of vertical thermal stratification and dissolved oxygen (DO) distribution in August–September also differed between years. In 1993, the reservoir was nearly homothermal with temperatures between 22.5 and 25 °C (Figure 3a), whereas there was strong thermal stratification in 1994 (Figure 3b). Mixing depth (Z_m) was >30 m in August–September 1993 but only 5 m in 1994. The depth of anoxia (<3.0 mg l^{-1}) in 1994 extended from 6 m to the bottom (32 m), whereas in 1993 anoxia was restricted to the bottom 3 m.

Water column stability (S) averaged 7.7 kg m^{-2} during August–September 1993, compared to 29.2 kg m^{-2} during this period in 1994 (Figure 4), indicating stronger physical stability in 1994. Similarly, mean water residence time (WRT) during summer 1994 was >100 d greater than during summer 1993 (Figure 2d).

Phytoplankton dynamics and bloom characteristics

Average values and seasonal patterns of surface Chl were similar in 1993 and 1994 (Figure 5a), but the size structure and taxonomic composition of the phytoplankton communities differed (Figure 5b,d). Mean Chl was 19 mg l^{-1} in 1993 *versus* 20 mg l^{-1} in 1994. In both years, chlorophyll was <15 mg l^{-1} in both spring (March–June) and winter (December), and peaked to >30 mg l^{-1} in August–September. But, net-Chl (fraction of Chl >35 μm) and ultra-Chl (<11 μm) differed between years. Mean net-Chl during August–September 1994 (25.1 mg l^{-1}) was 2.4 times that of the same period in 1993 (Figure 5b), while ultra-Chl was significantly (p <0.001) less in 1994 (7.5 mg l^{-1}) than 1993 (18.6 mg l^{-1}, Figure 5d), indicating that

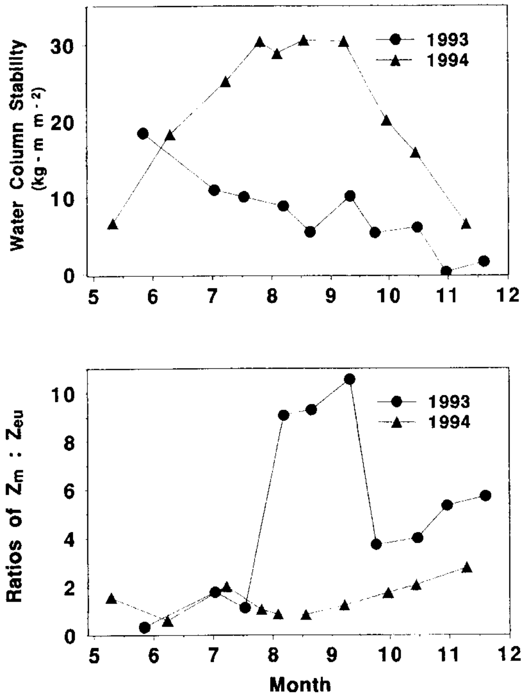

Figure 4. Seasonal changes in water column stability (kg m^{-2}) and ratios of mixed depth (Z_m) to euphotic depth (Z_{eu}). The stability was calculated by the formula of Viner (1984). Euphotic depth (Z_{eu}) indicates the depth of 1% PAR (photosynthetically active radiation) that was approximately estimated from 2.3×Secchi depth.

large phytoplankton dominated the algal community in 1994. During August–September 1994, bluegreens comprised >80% of total cell numbers (Figure 6) and the major algal taxa were *Anabaena, Microcystis* and *Oscillatoria*. During the same period in 1993, however, bluegreens were <40% of the total, and diatoms (*Melosira*) were predominant with green algae (*Pediastrum* and *Eudoria*).

During August–September 1994, Chl values >35 mg l^{-1} occurred only within the shallow mixing zone (<5 m) and >90% of total net-Chl (>25 mg l^{-1}) was in this surface layer. Below the mixing zone, Chl and net-Chl values declined by >4 fold. In contrast, in 1993 total Chl and net-Chl were nearly homogeneous within the >30 m mixed depth (range=27–33 mg l^{-1}, 9–12 mg l^{-1}, respectively). Given these values, mean total Chl per square meter in 1993 (28 mg m^{-2}) was over twice the 1994 average (13 mg m^{-2}).

Transparency

Water clarity, measured as Secchi transparency, was largely determined by algal Chl. Transparency showed a similar pattern between 2 years, being 1.5–2.2 m during summer monsoon and 2.3–3.8 m during premonsoon and postmonsoon (Figure 5c). Water clarity was inversely related to the inverse of surface Chl (Figure 5a). Minimum values, however, were the result of different factors. Shallow transparency in 1993 (1.5 m) occurred in early July when inorganic suspended solids increased (7.2–7.8 mg l^{-1}) with flow, whereas minimal transparency (<1.8 m) in 1994 occurred simultaneously with bluegreen blooms during August–September (Figure 5c). Water clarity improved (>3 m) in November 1994 when the bloom collapsed.

Phosphorus, nitrogen and N:P ratios

During the study, TP averaged 23 mg l^{-1} and varied from 9 mg l^{-1} in December 1993 to 38 mg l^{-1} in July 1993 (Figure 7a). During August–September, mean TP was 31 and 24 mg l^{-1} in 1993 and 1994, respectively. During the 1994 bloom (August–September), TP values were >20 mg l^{-1} compared to <15 mg l^{-1} during spring. Soluble reactive phosphorus (SRP) in the surface water remained under the level of detection through the study except for a period of peak inflow in July 1993 (range: 5–25 mg l^{-1}).

Total nitrogen (TN) averaged 1.48 mg l^{-1} (range: 0.94–2.03 mg l^{-1}) during the study, and the values during August–September 1993 and 1994 were >1.3 mg l^{-1} (Figure 7b). Nitrate–nitrogen (NO_3–N) was always >0.60 mg l^{-1} and accounted for some 60% of TN. In 1994, NO_3–N declined continuously from 1.20 mg l^{-1} in April to 0.65 mg l^{-1} in September (Figure 7c). Ammonia–nitrogen (NH_4–N) was <3% of TN and varied little with season or year.

Mass ratios of TN:TP and NO_3–N:TP averaged 74 and 48, respectively and always exceeded >18 (Figure 7d). Both nutrient ratios showed minima during August–September of 1993 and 1994. Values of TN:TP in 1993 declined from 69 in July to 37 in August, but rapidly increased (54–136) during October–December. In 1994, TN:TP in the spring (March–June) averaged 106, but it declined >40% during the bloom in August–September. Ratios of NO_3–N:TP in each year followed the TN:TP pattern in both years (Figure 7e).

Sodium and potassium

Sodium (Na^+) varied from to 5.4 mg l^{-1} in July 1993 to 10.4 mg l^{-1} in June 1994 (Figure 7f). In 1994, mean Na^+ was 7.7 mg l^{-1}, a 24% greater than in 1993. Potassium (K^+) ranged from 1.4 to 2.9 mg

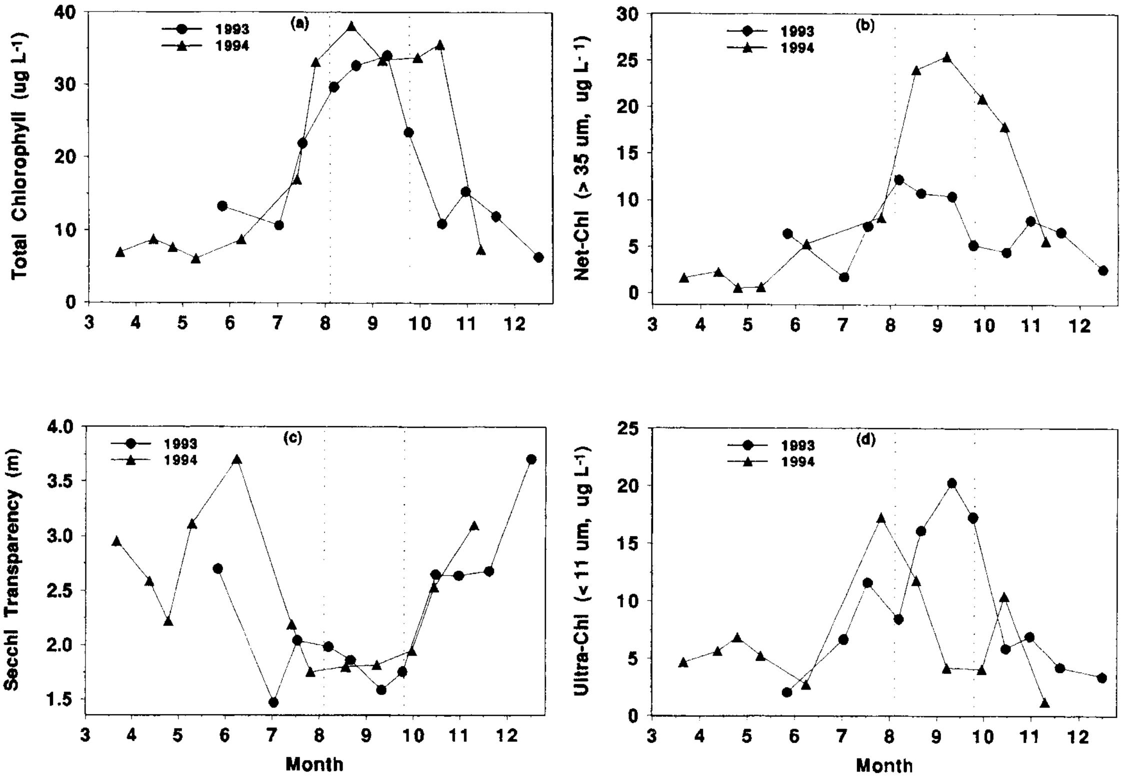

Figure 5. Temporal patterns in (a) total chlorophyll (Chl), (b) net-Chl (size compartments >35 μm), (c) Secchi transparency, and (d) ultra-Chl (<11 μm) during 1993 and 1994. Vertical dotted lines indicates the period of bluegreen dominance in 1994. Marked differences in net-Chl and ultra-Chl compartments occurred between August and September 1993 and 1994. Each data point is the average from six sites on a given sampling date.

l^{-1} throughout the study. During August–September, mean K^+ was greater in 1994 than 1993, and in 1994 there were no significant differences before, during, or after the bloom (Figure 7f).

Silica

Mean silica (SiO_2) in 1993 (3.3 mg l^{-1}) was significantly ($p<0.01$) greater than in 1994 (1.8 mg l^{-1}, Figure 8). In 1994, SiO_2 remained <0.5 mg l^{-1} during strong stratification during August to mid-September when *Microcystis, Oscillatoria* and *Anabaena* dominated and *Melosira*, *Synedra* and *Cyclotella* were rare. In contrast, SiO_2 increased to 5 mg l^{-1} by November 1994 (Figure 8) and diatom populations were predominant.

pH and bicarbonate

During the study, pH varied from 6.7 in October 1994 to 9.3 in September 1993. Peak pH in 1993 and 1994 occurred during August–September (Figure 8) and each peak coincided with a chlorophyll maximum. No significant difference in pH was found between August–September 1993 and this period in 1994. On the other hand, in 1994 mean pH in the surface water was significantly ($p<0.01$) greater during the bloom (>8.5) than before and after the bloom (<7.7). During the 1994 bloom, pH decreased exponentially from the surface (8.8) to the bottom (6.2), whereas before and after the bloom pH ranged from 7.0 to 7.5 with depth. The sharp decline of pH with depth during the bloom paralleled the vertical distribution of chlorophyll, suggesting an influence of algal photosynthesis and respiration on pH (Paerl, 1988).

Bicarbonate (HCO_3^-) varied from 20.8 to 37.6 mg l^{-1} depending upon season and year (Figure 8). Bicarbonate averaged 31.2 mg l^{-1} in 1994 and 23.5 mg l^{-1} in 1993. In 1993, bicarbonate was minimal in August–September due to dilution by monsoon rain, and this same pattern was seen in Na^+ and K^+ values (Figure 7f). In contrast, HCO_3^- in 1994 peaked in August (37.6 mg l^{-1}, Figure 8) and this value coincided with

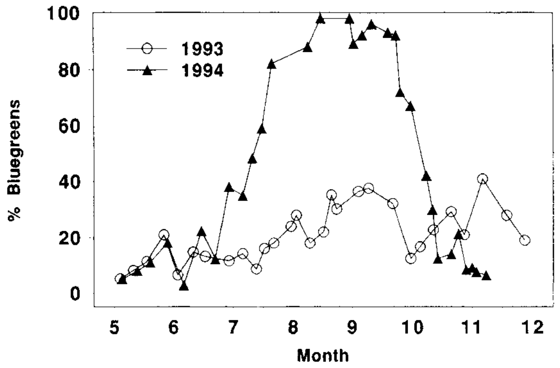

Figure 6. Relative abundance of bluegreen taxa near the dam during 1993–1994. The abundance of bluegreens was expressed as a percent of total phytoplankton biomass made up by bluegreen algae.

highest pH (9.3, Figure 8). The mean value during the 1994 bloom (35.5 mg l^{-1}) was significantly ($p < 0.05$) greater than before and after the bloom.

Discussion

Distinct interannual differences in monsoon hydrology in Taechung Reservoir during 1993–1994 provided an opportunity to compare major theories about conditions favoring bluegreen-dominance within the algal assemblage. Current hypotheses suggest that bluegreen dominance is associated within the physical-chemical environment (Schindler, 1977; McQueen & Lean, 1987; Paerl, 1988; Reynolds, 1994), biotic factors (Shapiro et al., 1982; Haney, 1987) and varies spatially (Zohary & Madeira, 1990; Scheffer et al., 1997) and temporally (Reynolds, 1972; Sterner, 1989; Soranno, 1997). Temporal differences in the bluegreen abundance were evident in our field observations. During August–September 1994, bluegreens comprised >80% of total cell numbers and net-Chl (fraction of Chl >35 μm) was 63% of total Chl, whereas in 1993, diatoms were the major taxa, and ultra-Chl (<11 μm) dominated. We believe hydrological and chemical characteristics during summer monsoon resulted in interannual differences in the composition and size fraction of phytoplankton communities.

The first hypothesis suggests that physical stability and buoyancy determine bluegreen dominance. Rapid flushing (WRT <30 d) during monsoon 1993 completely disrupted thermal stratification and produced maximum mixed depth ($Z_m : Z_{eu} > 8$) and minimum water column stability (<10 kg m^{-2}), resulting in river-like conditions within the entire reservoir. Under these conditions, green algae and diatoms were the major taxa. Persistent turbulence in 1993 was likely unfavorable for surface bluegreen formation (Reynolds & Walsby, 1975; Reynolds, 1980; Talling, 1986; Paerl, 1988). In contrast, the weak monsoon during summer 1994 resulted in strong thermal stratification characterized by a mixing depth of <5 m, WRT >120 d, and physical stability > 25 kg m^{-2}. These conditions favored surface blooms of the buoyant taxa, *Anabaena* and *Microcystis*. During this period, total Chl in the surface water was >35 mg l^{-1} with some 70% of the total as net-Chl, suggesting that large-size bluegreens were predominant. Long retention time increased physical stability in the reservoir and likely contributed to the dominance of buoyant bluegreen populations (Walsby & McAllister, 1987; Vincent, 1989; Reckhow, 1988). The collapse of surface bluegreen-blooms during fall overturn 1994 also supports the importance of water column stability in regulating bluegreens (Reynolds & Walsby, 1975; Viner, 1985; Jensen et al., 1994; Watson et al., 1997).

Strong physical stability in 1994 resulted in significantly ($p < 0.001$) higher surface temperatures in the surface waters relative to summer 1993. Higher temperatures might have favored bluegreens in North American and European lakes (Tilman et al., 1986; McQueen & Lean, 1987; Smith, 1987). Field and laboratory studies of bluegreens (Reynolds, 1984; Tilman et al., 1986; McQueen & Lean, 1987) have demonstrated that bluegreens dominate in summer and have higher temperature optima relative to greens and diatoms. In our data, surface bluegreen colonies continued until late summer 1994 when temperature was between 20 and 25 °C, but collapsed during overturn (15 °C) in November, indicating the potential effect of temperature and mixing on the bloom (Reynolds, 1984). Surface temperatures in summer 1993, however, were >21 °C which has been identified as the critical temperature for bluegreen dominance (McQueen & Lean, 1987). Collectively, our data suggest that temperature alone can not be responsible for bluegreen dominance.

It seems low N or N:P ratio may not be a universal diagnostic tool for assessing the bluegreen dominance. When bluegreens dominated the algal assemblage, NO_3–N:TP was >26 and TN:TP was >40 in the reservoir, these values do not support the convention that bluegreen algae are favored when TN:TP is <29 (Smith, 1983) and the view that bluegreens do not dominate when NO_3–N:TP is >5 (McQueen & Lean, Indian lakes (Zafar, 1986) where bluegreen taxa, *Microsystis* and *Anabaena* were rare during the heavy monsoon, but were present immediately following blooms occurred. Our result supports the finding that year-to-year or monthly variation in bluegreen dominance can be strongly determined by regional weather patterns (Soranno, 1997).

Overall, this study suggests that the intensity of the monsoon was an important factor regulating bluegreen abundance in Taechung Reservoir during summers 1993 and 1994. Monsoon inflow was directly linked to factors such as water column stability, temperature and input of nutrients (P and silica) which are known to regulate bluegreens. Low N/or N:P ratios and high monovalent cations (Na^+ and K^+), however, may not be influential in this system, while light and pH seem to act as secondary factors. Based on these hypotheses, taxonomic composition of phytoplankton in Asian waterbodies can be influenced by the intensity of the monsoon, and the frequency and size of bluegreen blooms will be reduced by rapid flushing during extreme monsoon inflow.

In spite of this fact, since 1986 the advent and expansion of bluegreen blooms and compositional changes from green algae and diatoms to bluegreens are evident in Korean waterbodies (Cho et al., 1989; Cho et al., 1990; Joo et al., 1997), indicating an acceleration of eutrophication. Nutrient loading (P, N) to Korean reservoirs is increasing over time (Choi & Lee, 1991; Kim et al., 1997; Kong, 1997), but the monsoon may be a major determinant regulating the concentration and availability of nutrients (Jones et al., 1997) and strongly determines qualitative as well as quantitative features of algal growth. Relative to 1994, deep mixing in 1993 yielded larger areal biomass, lower volumetric biomass and dominance of non-bluegreen algae in Taechung Reservoir. In 1994, shallow stratification favored bluegreen dominance with biomass concentrated near the surface. Conditions were eutrophic during both yeras, but they were expressed differently because of the monsoon. Overall eutrophication processes in Korean reservoirs, therefore, can be modified by intensity of the monsoon.

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References

A.P.H.A., 1985. Standard Methods for the Examination of Water and Waste Water. 16th edn. New York, American Public Health Association, N.Y.: 1134 pp.

Blomqvist, P., A. Pettersson & P. Hyenstrand, 1994. Ammonnium-nitrogen: a key regulatory factors causing dominance of non-nitrogen-fixing cyanobacteria in aquatic systems. Arch. Hydrobiol. 132: 141–164.

Canfield, D. J., J. E. Philips & C. M. Duarte, 1989. Factors influencing the abundance of bluegreen algae in Florida lakes. Can. J. Fish. aquat. Sci. 46: 1232–1237.

Cho, K. S., B. C. Kim, W. P. Heo. & S. J. Cho, 1989. The succession of phytoplankton in Lake Soyang. Kor. J. Lim. 22: 179–189.

Cho, K. S., B. C. Kim & W. P. Heo, 1990. The succession of phytoplankton in Lake Soyang. Physiol. Ecol. Japan 27: 81–92.

Cho, K. S., B. C. Kim, W. M. Heo & D. S. Kim, 1991. Eutrophication of the major reservoirs in Korea. Rep. Suwa Hydrobiol. 7: 21–29.

Choi, S-S., H. Kang, Y-W. Kim, S-M. Bhu, M-Y. Song, H-M. Oho, Y-H. Lee, H-S. Lee, H-Y. Lee, C-K. Choi & U-H. Hong, 1988. The studies for water quality conservation at Taechung Reservoir in Korea. Taejon Environmental Protection Agency: 304 pp.

Choi, S. S. & Y. H. Lee. 1991, Water quality management of lakes by reduction of nutrient loading. Korean Environmental Science Council: 9–13.

Crumpton, W. G., T. M. Isenhart & P. D. Mitchell, 1992. Nitrate and organic N analyses with second-derivative spectroscopy. Limnol. Oceanogr. 37: 907–913.

Ganf, G. G. & R. L. Oliver, 1982. Vertical separation of light and available nutrients as factor causing replacement of green algae by blue-green algae in the plankton of a stratified lake. J. Ecol. 70: 829–844.

Haney, J. F., 1987. Field studies on zooplankton-cyanobacteria interactions. New Zealand J. mar. Freshwat. Res. 21: 467–475.

Ha, K., H-W Kim & G-J Joo, 1998. The phytoplankton succession in the lower part of hypertrophic Nakdong River (Mulgum), South Korea. Hydrobiologia 369/370 (Dev. Hydrobiol. 129): 217–227.

Happey, C. M., 1970. The estimation of cell numbers of flagellate and coccoid Chlorophyta in natural populations. Br. Phycol. J. 5: 71–78.

Havens, K. E., E. J. Phlips & M. F. Cichra. 1998. Light availability as a possible regulator of cyanobacteria species composition in a shallow subtropical lake. Freshwat. Biol. 39: 547–562.

Ingle, R. K. & B. Colman, 1975. Carbonic anhydrase levels in bluegreen algae. Can. J. Bot. 53: 2385–2387.

Jensen, J. P., E. Jeppensen, K. Olrik & P. Kristensen, 1994. Impact of nutrients and physical factors on the shift from cyanobacterial to chlorophyte dominance in shallow Danish lakes. Can. J. Fish. aquat. Sci. 51: 1692–1699.

Jones, J. R., K. F. Mattew & K-G. An, 1997. Developing a paradigm to study and model the eutrophication process in Korean reservoirs. Korean J. of Limnol. Supplement 30: 463–471.

Jones, J. R. & R. W. Bachmann, 1978. Trophic status of Iowa lakes in relation to origin and glacial geology. Hydrobiologia 57: 267–273.

Joo, G. J., H. W. Kim, K. Ha & J. K. Kim, 1997. Long-term trends of the eutrophication of the lower Nakdong River. Korean J. of Limnol. Supplement 30: 472–480.

Jorgensen, E. G., 1957. Diatom periodicity and silicon assimilation. Dansk. Bot. Arkiv. 18: 54 pp.

Jung, J., 1993. Illustration of the freshwater algae of Korea. Academy Publishing Company: 420 pp.

Kilham, S. S., 1971. A hypothesis concerning silica and the freshwater plankton diatoms. Limnol. Oceanogr. 16: 10–18.

Kim, B. C., J. H. Park, K. S. Choi & G. S. Hwang, 1997. Eutrophication of large freshwater ecosystems in Korea. In: International symposium on eutrophication and water resources management and the 30th annual meeting of the KSL. The Korean Society of Limnology: 63–68.

Knowlton, M. F. & J. R. Jones, 1996. Nutrient addition experiments in a nitrogen-limited high plains reservoir where nitrogen-fixing algae seldom bloom. J. Freshwat. Ecol. 11: 123–130.

Knowlton, M. F. & J. R. Jones, 1990. Occurrence and prediction of algal blooms in Lake Taneycomo. Lake Reserv. Manage. 6: 143–152.

Kong, D. S., 1997. Limnological and ecological characteristics of a river-reservoir (Paldang), Korea. Korean J. Limnol. Supplement 30: 524–535.

Kratz, W. A. & J. Myers, 1955. Nutrition and growth of several blue-green algae. Am. J. Bot. 42: 282-287.

Lucas, W. J. & J.A. Berry, 1985. Inorganic carbon uptake by aquatic photosynthetic organisms. Amers. Soc. Plant Physiologists. Waverly Press, Baltimore: 120 pp.

Lund, J. W. G., 1950. Studies on *Asterionella formosa* Hass. II. Nutrient depletion and the spring maximum. J. Ecol. 38: 1–35.

McQueen, D. J. & D. R. S. Lean, 1987. Influence of water temperature and nitrogen–phosphorus ratios on the dominant bluegreen algae in Lake St. George, Ontario. Can. J. Fish. aquat. Sci. 44: 598–604.

Mur, L. R., H. J. Gons & L. VanLiere, 1978. Competition of the green alga *Scenedesmus* and the blue-green alga *Oscillatoria*. Mitt. int. Ver. Limnol. 21: 473–479.

Oh, H-M. & D-H. Kim, 1995. Short-term prediction of the blue-green algal bloom in Daechung Reservoir. Korean J. Limnol. 28: 127–135.

Paerl, H. W., 1988. Nuisance phytoplankton blooms in coastal, estuarine and inland waters. Limnol. Oceanogr. 33: 823–847.

Prepas, E. E. & F. A. Rigler, 1982. Improvements in qualifying the phosphorus concentration in lake water. Can. J. Fish. aquat. Sci. 39: 822–829.

Provasoli, L., 1969. Algal nutrition and eutrophication. In: eutrophication: causes, consequences, correctives. National Academy of Sciences, Washington, D.C.: 574–593.

Reckhow, K. H., 1988. Empirical models for trophic state in southeastern U.S. lakes and reservoirs. Wat. Res. Bull. 24: 723–734.

Reynolds, C. S., 1972. Growth, gas-vacuolation and buoyancy in a natural population of a blue-green alga. Freshwat. Biol. 2: 87–106.

Reynolds, C. S., 1980. Phytoplankton assemblages and their periodicity in stratifying lake systems. Holarct. Ecol. 3: 141–159.

Reynolds, C. S., 1984. The Ecology of Freshwater Phytoplankton. Cambridge Univ. Press, New York: 384 pp.

Reynolds, C. S., 1987. Cyanobacterial water-blooms. Adv. Bot. Res. 13: 67–143.

Reynolds, C. S., 1994. The long, the short and the stalled: on the attributes of phytoplankton selected by physical mixing in lakes and rivers. Hydrobiologia 289: 9–21.

Reynolds, C. S. & A. E. Walsby, 1975. Water blooms. Biol. Rev. 50: 437–481.

Robarts, R. D. & T. Zohary, 1984. *Microcystis aeruginosa* and underwater light attenuation in a hypertrophic lake (Hartbeespoort dam, South Africa). J. Ecol. 72: 1001–1017.

Ryding, S. O. & W. Rast, 1989. The control of eutrophication of lakes and reservoirs. Man and The Biosphere Series. Vol. I, UNESCO and The Parthenon Publishing Group: 54–58.

Sartory, D. P. & J. U. Grobbelaar, 1984. Extraction of chlorophyll-a from freshwater phytoplankton for spectrophotometric analysis. Hydrobiologia. 114: 177–187.

Scheffer, M., S. Rinaldi, A. Gragnani, L. R. Mur & E. H. Van Nes, 1997. On the dominance of filamentous cyanobacteria in shallow, turbid lakes. Ecology 78: 272–282.

Schindler, D. W., 1977. Evolution of phosphorus limitation in lakes. Science 195: 260–262.

Shapiro, J. B., B. Forsberg, V. Lamarra, G. Lindmark, M. Lynch, E. Smeltzer & G. Zoto, 1982. Experiments and experiences in biomanipulation: Studies of biological ways to reduce algal abundance and eliminate blue-greens. U.S. EPA 600/3-82-096: p 251.

Shapiro, J., 1990. Current beliefs regarding dominance by blue-greens: The case for the importance of CO_2 and pH. Verh. int. Ver. Limnol. 24: 38–54.

Smith, V. H., 1983. Low nitrogen to phosphorus ratios favor dominance by bluegreen algae in lake phytoplankton. Science 221: 669–671.

Smith, V. H., 1986. Predicting the proportion of bluegreen algae in lake phytoplankton. Can. J. Fish. aquat. Sci. 43: 148–153.

Smith, V. H., 1987. Predicting the summer peak biomass of four species of blue-green algae (Cyanophyta/Cyanobacteria) in Swedish Lakes. Wat. Res. Bull. 23: 397–402.

Soranno, P. A., 1997. Factors affecting the time of surface scums and epilimnetic blooms of blue-green algae in a eutrophic lake. Can. J. Fish. aquat. Sci. 54: 1965–1975.

Sterner, R. W., 1989. Resource competition during seasonal succession toward dominance by cyanobacteria. Ecology 70: 229–245.

Talling, J. F., 1976. The depletion of carbon dioxide from lake water by phytoplankton. J. Ecol. 64: 79–121.

Talling, J. F., 1986. The seasonality of phytoplankton in African lakes. Hydrobiologia 138: 139–160.

Tilman, D., R. Kiesling, R. Sterner, S. Kilham & F. A. Johnson, 1986. Green, blue-green and diatom algae – taxonomic differences in competitive ability for phosphorus, silica and nitrogen. Arch. Hydrobiol. 106: 473–485.

Trimbee, A. M. & E. E. Prepas, 1987. Evaluation of total phosphorus as a predictor of the relative biomass of blue-green algae with emphasis on Alberta lakes. Can. J. Fish. aquatic. Sci. 44: 1337–1342.

Vincent, W. F., 1989. Cyanobacterial growth and dominance in two eutrophic lakes: review and synthesis. Arch. Hydrobiol. Beih. 32: 239–254.

Viner, A. B., 1985. Thermal stability and phytoplankton distribution. Hydrobiologia 125: 47–69.

Viner, A. B., 1984. Resistance to mixing in New Zealand lakes. New Zealand J. mar. Freshwat. Res. 18: 73–82.

Walsby, A. E. & G. K. MacAllister, 1987. Buoyancy regulation by *Microcystis* in Lake Okaro. New Zealand J. mar. Freshwat. Res. 21: 521–524.

Watson, S. B., E. McCauley & J. A. Downing, 1997. Patterns in phytoplankton taxonomic composition across temperate lakes of differing nutrient status. Limnol. Oceanogr. 42: 487–495.

Watts, I. E. M., 1969. Climates of China and Korea. In: Arakawa, H. (ed.), Climates of Northern and Eastern Asia. Elsevier, Amsterdam: 24.

Wetzel, R. G., 1983. Limnology. W. B. Saunders Co., Philadelphia, PA: 767 pp.

Zafar, A. R., 1986. Seasonality of phytoplankton in some South Indian lakes. Hydrobiologia 138: 177–187.

Willen, E., 1991. Planktonic diatoms – an ecological review. Archiv. Fur Hydrobiologie. Supplement-Band 89: 69–106.

Zohary, T. & A. M. P. Madeira, 1990. Structural, physical and chemical characteristics of *Microcystis aeruginosa* hyperscums from a hypertrophic lake. Freshwat. Biol. 23: 339–352.