

Blue-Green Algae of Lake Thunderbird

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Fluctuations in population densities of blue-green algal species were monitored along with temperature conductivity, dissolved oxygen, pH, nitrates, phosphates, and Secchi disk readings of the water from four different sites on Lake Thunderbird, Cleveland Co., Oklahoma. Samples were collected periodically from January 1986 to January 1987. The lake was typically polymictic except for a brief three-week period of stratification in early summer. Nitrates and phosphates were generally low throughout the study, while D.O. remained near saturation and pH ranged from 7.4 to 8.2. Two species, *Lyngbya limnetica* and *L. contorta*, were the only species of the 24 identified during the study that showed strong algal blooms. All other species showed only small and isolated increases and decreases throughout the study period.

INTRODUCTION

This study of blue-green algae (cyanobacteria) was prompted by a controversy that had developed in the Norman area in August 1985. The issue concerned public health. The question was whether Norman's water supply, from Lake Thunderbird, was contaminated with blue-green algal toxin(s).

To date there have been over 200 worldwide references on toxic blue-green algae (1). Understanding and identifying the parameters that lead to a hazardous bloom of toxin-producing blue-green algae is one of the first steps in assuring a safe public water supply. Thus, we chose to study the water quality of the reservoir serving Norman.

Lake Thunderbird, approximately 16 km east of Norman, was placed in operation in 1965 providing flood control, recreation, and drinking water for the city of Norman and several other municipalities (2).

We began our lake sampling in January, 1986 in an effort to (a) document the quality and quantity of blue-green algal species; (b) note those known to be toxin producing (Table 1) and (c) relate these to selected physical and chemical parameters of the water from which they were collected.

MATERIALS AND METHODS

From January 31, 1986 to January 24, 1987 water samples were collected from Lake Thunderbird for physico-chemical and phytoplankton analysis. Samples were collected from four sites and two or three depths at those sites. The four sites (Fig. 1) were chosen to correspond with previous investigation (3, 4) of the reservoir. The maximum depths at Sites 1 through 4 were 13, 6, 6, and 10 m, respectively. Water samples were collected from depths of 1, 4 and 8 m from Sites 1 and 4 and from depths of 1 and 4 m from Sites 2 and 3, totaling ten samples for each collection date (weather permitting).

TABLE 1. List of blue-green algal species identified from Lake Thunderbird during the study period.

<i>Anabaena circinalis</i> * Rabenh.
<i>Anabaena fertilissima</i> Rao, C.B.
<i>Anabaena helocoidea</i> Bernard
<i>Anabaenopsis elenkinii</i> Miller
<i>Aphanizomenon flos-aquae</i> * (Linn.) Ralfs.
<i>Aphanocapsa pulchra</i> (Kutz.) Rabenh.
<i>Chroococcus minutus</i> (Kutz.) Nag.
<i>Coelosphaerium kuetzingianum</i> Nag.
<i>Cylindrospermum minutissimum</i> Collins
<i>Dactylococcopsis fascicularis</i> Lemm.
<i>Gleocapsa punctata</i> Nag.
<i>Gleotheca linearis</i> Nag.
<i>Gleotheca rupestris</i> (Lyngb.) Born.
<i>Gomphosphaeria aponia</i> Kutz.
<i>Gomphosphaeria lacustris</i> Chod.
<i>Lyngbya contorta</i> Lemm.
<i>Lyngbya limnetica</i> Lemm.
<i>Merismopedia minima</i> Beck
<i>Merismopedia punctata</i> Meyen
<i>Microcystis aeruginosa</i> * Kutz.
<i>Oscillatoria tenuis</i> * Ag. ex Gomont
<i>Raphidiopsis curvata</i> Fritsch et Rich
<i>Raphidiopsis mediterranea</i> Skuja
<i>Spirulina</i> sp. Turpin em. Gardner

* Indicates species known to have toxin-producing strains (26, 27)

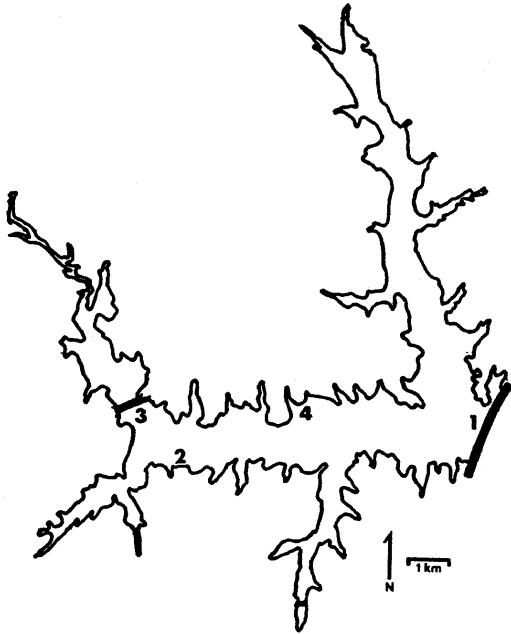


FIGURE 1. Lake Thunderbird, sample site locations.

Sites were typically collected monthly during the winter, biweekly during the spring and fall and weekly during the summer months.

Parameters measured at the time of collection included water temperature, dissolved oxygen (DO), conductivity, and Secchi disk readings. Water samples were collected by using a three-liter horizontal Van Dorn water sampler. Water temperature and specific conductance were measured with a Yellow Springs Instrument Model 33. Dissolved oxygen was measured with a YSI Model 51B oxygen meter. Water from the sampler was collected in 1-L polyethylene bottles and placed in an insulated chest for return to the laboratory. Water analyses were performed immediately upon return to the laboratory. The pH of each sample was measured at room temperature, with a Model 501 Orion Research digital ionalyzer equipped with a combination pH electrode.

Assays were performed for nitrate-nitrogen, orthophosphate-phosphorus, and total phosphate-phosphorus. Nitrate-nitrogen was determined by employing a cadmium reduction procedure using Hach chemicals (5). The samples were read against standard concentration of sodium nitrate with a Beckman DB-G grating spectrophotometer at 380 nm. The orthophosphate-phosphorus was determined by a method described by Murphy and Riley (6) and read against standard concentrations of potassium dihydrogen phosphate at 710 nm. Total phosphate-phosphorus was similarly assayed after the organic material was first oxidized as described in the Hach Manual (5).

Algae were concentrated by centrifugation at 2,400 g for 10 min. The pellet was resuspended in a 50-50 mixture of Transeau's solution (6 parts water: 3 parts 95% ethanol: 1 part formalin) and water, which yielded a 10-fold concentration of the original water sample. These concentrated samples have been stored in the phycological laboratory at the University of Oklahoma.

An aliquot of the algal samples was placed on a slide and species identifications were made using an oil immersion lens. Blue-green algal species counts were made with a Sedgwick-Rafter counting cell and a Nikon binocular microscope equipped with a Whipple grid. Strip counts were made, averaged, and corrected for strip volume and sample concentration so that the algal species counts were reported as the number of trichomes or colonies of a particular species per milliliter of original, unconcentrated lake water (7).

RESULTS

Over the course of the study (January 1986-January 1987), 247 water samples were collected and analyzed.

Lake water temperature showed a steady increase from January 1986 until the end of June. From July to the end of September, the temperature remained fairly constant, after which there was a steady decline until the last sample date, January 1987 (Fig. 2).

Dissolved oxygen decreased as water temperature increased. However, DO remained near saturation for the water temperature in most instances (Fig. 2).

Secchi disk readings averaged 0.67 m for all sites and sample dates, with a maximum reading of 1.4 m (Fig. 2).

The pH ranged from 7.4 to 8.2, with most readings in the 7.9 to 8.0 range (Fig. 2).

Specific conductance of the lake water,

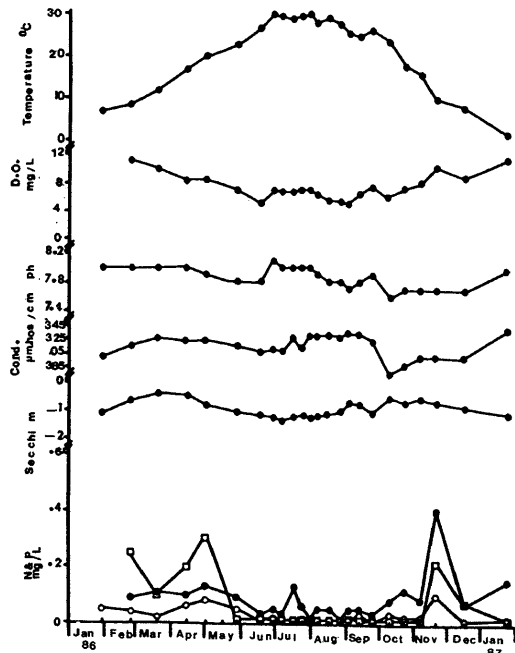


FIGURE 2. Physical and chemical parameters of Lake Thunderbird during the study period. Nitrate-nitrogen $\square-\square$, orthophosphate phosphorus $\circ-\circ$, total phosphate phosphorus $\bullet-\bullet$.

corrected to 18 °C (8), showed most samples to be near 320 $\mu\text{mhos/cm}$ (Fig. 2).

Nitrate-nitrogen, orthophosphate-phosphorus, and total phosphate-phosphorus were all relatively low throughout the study, especially during the summer and early fall months, when most readings were near zero (Fig. 2).

Twenty-four species of blue-green algae in seventeen genera were identified and quantified from the water samples (Table 1). Identification was made by using Desikachary (9) and Prescott (10).

The alga found on most sample dates was *Aphanizomenon flos-aquae*, recorded on 23 of the 25 sample dates, and absent from the counts only on May 30 and October 11. The species with the most colonies or trichomes was *Lyngbya limnetica*, which on August 28 reached a concentration of 3689 trichomes per milliliter of lake water at Site 1, depth 1 m. The greatest number of species and individuals were seen between June 30 and September 25 (Fig. 3). Only two species, *L. limnetica* and *L. contorta*, occurred in quantities that could be considered strong algal blooms (Fig. 4). Other species showing somewhat limited blooms were *Raphidiopsis mediterranea*, *Gomphosphaeria lacustris*, *Anabaena circinalis*, *A. fertilissima*, and *Aphanizomenon flos-aquae*. All other species showed only small and isolated increases and decreases throughout the study period (11).

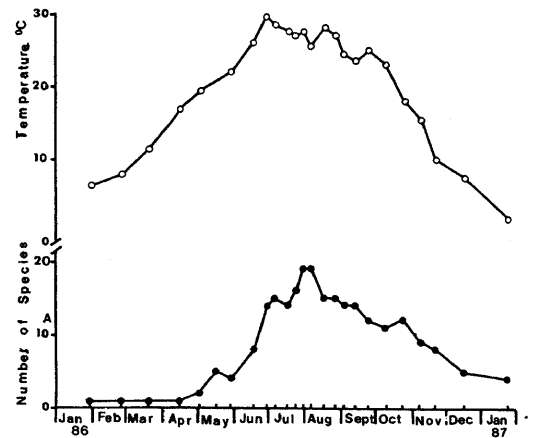


FIGURE 3. Temperature (Site 1, depth 4 m) and number of species (all samples).

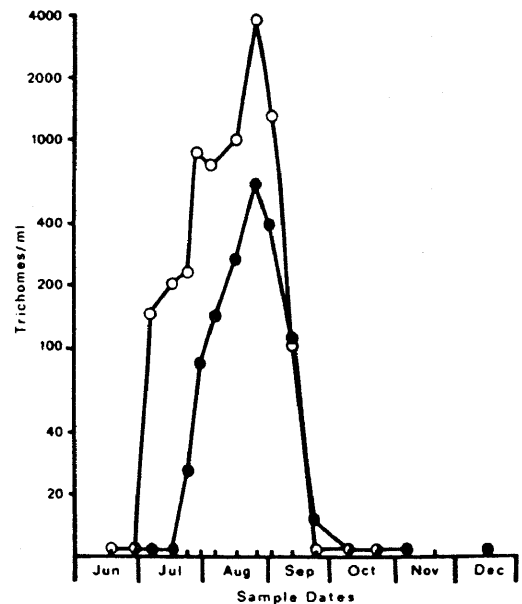


FIGURE 4. Algal blooms of *Lyngbya* species at Site 1, depth 4 m. *L. limnetica* $\circ-\circ$, *L. contorta* $\bullet-\bullet$.

DISCUSSION

Nutrients in water have long been known

to affect algal growth. As early as 1922, W. H. Pearsall reported that the composition of nutrients affects the distribution of free-floating vegetation (12).

Climatological data can also provide valuable information in attempting to interpret an ecological study. Weather data from the National Oceanic and Atmospheric Administration (13) and local unpublished data were used and indicate the period of the study to be fairly normal as to air temperature, wind, and sunshine, but above normal for precipitation in the spring and fall months. Though many of the blue-green algae appeared to be on a decline prior to the October 11 sampling date (Fig. 3), the heavy fall rainfall and subsequent increase in lake volume appeared to have a real effect in diluting the reservoir water and diminishing the algal counts (11).

One visible change in a physical parameter occurred at Site 1, Lake Thunderbird Dam, where clay, brought in with the runoff, decreased the Secchi disk transparency reading from 1.10 m to 0.55 m between September 25 and October 11. An increase in soluble phosphate-phosphorus from a reported zero mg/L at all sites and depths on September 25 to reading of 0.03 to 0.09 mg/L for all sites and depths on October 11 (Fig. 2) may have been a result of the addition of rain runoff (11).

Temperatures recorded at the end of June at most sites and depths were equal to or within a few degrees of the highest temperatures recorded at those respective sites and depths. The temperature remained fairly constant from the end of June until the end of September (Fig. 2).

Blue-green algae as a group are generally much more tolerant of higher temperatures than other algae. Many blue-greens require a temperature higher than 15 °C for incipient photosynthesis. In fact, many blue-greens have higher temperature optima than eukaryotic algae of the same water (14), with temperature optima for some of the bloom-forming species probably in the 25-35 °C range (15). Most of the blue-green biomass production occurred between June 30 and September 25 (Fig. 3), during a time when the water temperature remained above 23 °C for all sites and depths (11).

Dissolved oxygen in the reservoir is the result of interaction between atmospheric oxygen, photosynthetic activity of plants, and biochemical oxidation of organisms (14). Generally, dissolved oxygen was near saturation level for most dates at the different sites and depths.

Lake Thunderbird would be classified as polymictic, as the entire water column was continually mixed. The only exception to this was the brief three-week period in early summer, at which time there was distinct temperature and oxygen stratification at the greater depths of Sites 1 and 4. This can be seen by the uniformity in the physical and chemical parameters recorded and the phytoplankton counts at various depths at different sites. By the July 18 sampling date, the lake again appears to have been well mixed as there was a temperature difference of only 0.5 °C between all samples and the lowest dissolved oxygen reading was 5 mg/L (11).

Algal counts showed little indication of species stratification. Individual blue-green species were fairly well mixed throughout the water column (11).

The mean Secchi disk transparency of Lake Thunderbird for all samples dates and sites through the study period was less than 1 m (11), indicating that light penetration was less than 2 m; this implies that algal cells suspended below 2-m depths would not be carrying on photosynthetic activity.

The pH of the reservoir during the study period generally ranged from pH 7.7 to 8.1 (Fig. 2), a range favorable to the growth of blue-green algae (16).

Specific conductance of water is closely proportional to the concentration of major ions in the reservoir (14). Such conductance remained fairly constant throughout the study period (Fig. 2). We assumed that the major-ionic composition of the water remained constant also.

The nitrate-nitrogen in Lake Thunderbird was low (Fig. 2) for most of the study period, corresponding to Hillerman's (17) data. The low levels of nitrate-nitrogen would not likely limit the growth of blue-green species anyway since many species have the ability to fix atmospheric nitrogen to ammonia. In fact, the

low level of dissolved nitrate-nitrogen could be competitively advantageous to the nitrogen-fixing blue-green algae because it would limit the growth of other algae (18).

The level of dissolved orthophosphate-phosphorus in Lake Thunderbird during the study period, like that of nitrate-nitrogen, was comparatively low (Fig. 2). Phosphate uptake kinetics are known to favor blue-green algae over green algae, so when the phosphate level is critical, blue-green algae are favored. In a variety of blue-greens, the maximal phosphate uptake occurs between pH 7.5 and 8.5 and declines sharply below neutrality (20). The pH optimum for phosphate uptake corresponds well with the pH values found in Lake Thunderbird samples during the study period (Fig. 2).

For algae, internal nutrient concentration seems to be more important than external concentration in evaluating nutrients and growth rates (20). Blue-green algae frequently become the dominant algae in lakes at about the same time that concentrations of dissolved nitrogen and phosphorus reach their seasonal minima (15, 21, 22). Although phosphate or nitrogen was low (Fig. 2) during the study period in Lake Thunderbird, it may not have been a limiting factor for the growth rate of the blue-green species present. Smith (23) reported that the ratio of total nitrogen to total phosphorus has a strong effect on blue-green algal growth. That is, blue-green algae tend to dominate in lakes with a low N:P ratio and to be rare when the ratio exceeds 29:1 (N:P) by weight.

Two paradoxes were observed in Lake Thunderbird during the study period. The first paradox is the suggested eutrophic classification (3) when nutrients appear low to absent (Fig. 2), and the second is that blue-green algae thrive (Fig. 3) in nutrient-rich lakes at times when nutrients appear depleted. These are both misleading, because although the phosphorus may appear depleted from the water, we must not neglect the phosphorus within the algal cells (21).

Our understanding of planktonic blue-green algal growth requirements is relatively poor (24), and the precise environmental conditions for rapid growth are known for only a small number of algal species (25). However, Lake Thunderbird apparently provides the physical and chemical parameters for growth of many blue-green algal species with what might be considered optimal growth for a few species during short periods of the year, especially in the summer to early fall.

Whether any of the blue-green algal species identified from Lake Thunderbird during the study period were producing toxins (endo- or exo-) remains unknown. Of the genera identified, five are from genera known to do so. Four of the 24 species identified (Table 1), *Anabaena circinalis*, *Aphanizomenon flos-aquae*, *Microcystis aeruginosa*, and *Oscillatoria tenuis*, are known to have strains that, under certain conditions, will produce toxins (26, 27) and according to W. W. Carmichael (pers. comm.) the *Microcystis* strain present in Lake Thunderbird did produce toxins in 1985.

The conditions during the study period never led to an obvious visible surface bloom as described by Reynolds and Walsby (15) on any of the sample dates. Moreover, there appeared to be no widespread concern over the safety of drinking water in Norman during the study period such as there had been in previous years. This latter may be due to the fact that blue-green algal blooms were not nearly as great as in 1985, when a large segment of the population experienced gastrointestinal problems.

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