SEASONAL VARIATION IN THE PHYTOPLANKTON AND THE TROPHIC STATE OF A SOUTHERN GREAT PLAINS RESERVOIR[a]

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Nine stations were sampled from September 1980 through November 1981 from Lake Carl Blackwell, a Southern Great Plains reservoir, to measure spatial and temporal variation in algal densities, chlorophyll *a* and phosphorus and to use this data to calculate the trophic state index. Twenty-one algal taxa were observed during the study. Higher densities of algae occurred in early spring and summer and at stations in protected embayments. Generally, the more turbid stations also had the highest mean annual chlorophyll *a* content and algal biomass. The Trophic State Index (TSI) equations developed by Carlson were of limited usefulness because light attenuation from clay particles did not permit accurate predictions of chlorophyll *a* from water transparency.

INTRODUCTION

Carlson (1) developed a trophic state index (TSI) using a relationship between algal biomass (measured as chlorophyll *a*), total phosphorus, and water transparency determined with a Secchi disc (SD). Using Carlson's approach, trophic comparison among lakes is possible even if different variables are measured as long as chlorophyll *a*, phosphorus, or SD data are available. Carlson reported a correlation coefficient of 0.93 between the natural logarithm (ln) SD and chlorophyll *a* concentration for 147 lakes.

Lorenzen (2) found that water transparencies measured with a Secchi disc are affected by the attenuation of light by nonalgal substances such as seston. From 757 lakes sampled by the U. S. EPA National Eutrophication Survey (NES), the correlation between log-transformed summer SD values and chlorophyll was 0.56 (3). This suggests that attenuation of light due to nonchlorophyll suspensoids or to dissolved organic matter is more important in the lakes sampled by NES than for those sampled by Carlson.

The objectives of the present study were to determine for Lake Carl Blackwell: (a) the spatial and temporal variation in algal abundance, chlorophyll *a*, phosphorus, and water transparencies and (b) to use these data to estimate the trophic state index for this Oklahoma reservoir.

LAKE CARL BLACKWELL

Lake Carl Blackwell is located in northcentral Oklahoma, 14 km west of Stillwater on State Highway 51 in Township 19 N, Range 1W, Payne County. The lake was formed by impounding Stillwater Creek, a tributary of the Cimarron River. Construction of the dirt-filled dam was completed in 1938. The lake has a classic dendritic pattern with a long main pool oriented in an east-west axis. Several small arms result in a long shoreline (88.5 km) and a high shoreline development index (6.8) (Figure 1). The maximum depth of 15 m occurs immediately upstream from the dam, and large areas of shallow water exist in the upper reaches. Mean depth is 4.9 m. The surface area is 1250 ha and the volume is 67.1×10^6 m^3. Since 1938 lake volume has decreased 15.2% owing to sedimentation (4).

The watershed of Lake Carl Blackwell encompasses about 194 km^2. Geologically, the area is the Wellington formation, which is composed primarily of fine-grained sandstone and mudstone. The reddish-brown color of the soil is reflected in the soil and in the water itself. The watershed includes native grasslands, upland forests, and bottomland forests. Cedars have become established in over-grazed grasslands. No major housing developments or industries exist, but some drilling for oil and gas reserves occurs.

The area has long summers and short winters. Air temperature ranges from -20.8 C. to

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47.5 C. Mean annual rainfall is 83 cm and snowfall averages 17 cm (5). Most of the precipitation occurs in the spring and early summer. Long periods of drought occur and are often followed by excessively wet periods.

MATERIALS AND METHODS

Nine stations (Figure 1) were sampled monthly from late September 1980 to November 1981; samples were collected twice per month during spring and summer, 1981. Samples were collected from 0.5, 2, 5, 8, 11, and 14 m depths at Station 1 and from 0.5 m at stations 2-9. All collections were made between 0855 and 1520 h CST. Weather conditions, percent cloud cover, and wind speed and direction were also recorded.

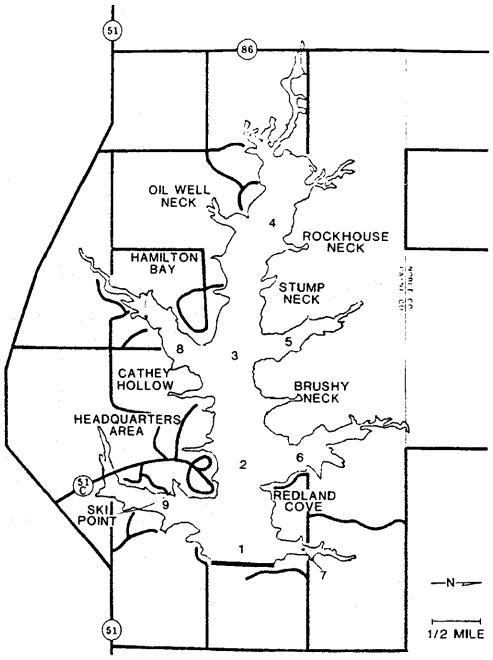

FIGURE 1. Sampling sites on Lake Carl Blackwell.

Water temperature, pH, and dissolved oxygen (DO) concentrations were measured with a Hydrolab model 4041 water quality monitoring system. Water transparencies were measured with a Secchi disc at each station in duplicate as described by Wetzel (6). Water samples were collected by using an acrylic plastic 8.3-*l* capacity Van Dorn water sampler. Samples were stored on ice and transported to the laboratory for measurement of turbidity, suspended solids, and phosphorus. Samples for determining numerical abundance and biomass of algae were collected with a 28-μm-mesh, 11.5-cm-diameter Wisconsin plankton net drawn from the bottom to the top of the water column.

A Hach Model 16800 nephelometer was used to measure water turbidity in NTU. Excessively turbid samples were first diluted with distilled water and corrections made to account for dilution. Suspended solids were determined by a modification of procedures outlined in Standard Methods (7). A 250-m*l* sample was filtered through a pre-weighed 0.22-m-pore-size, 47-mm-diameter membrane filter, which was then weighed on a Mettler balance to the nearest 0.1 mg. The filter was then oven-dried at 60 C for at least 3 h, allowed to cool, and reweighed.

Total and soluble reactive phosphorus (SRP) concentrations were determined by the molybdate blue procedure (8), analyses being performed by Dr. Dale Toetz's staff in conjunction with the Lake Carl Blackwell Clean Lakes program.

Water samples were collected in the field and transported to the laboratory for immediate analysis for chlorophyll α in the manner described by Weber (9) and Slack et al. (10). Chlorophyll α concentrations of the prepared sample were determined as described by the EPA (1973) and algal numbers by the filtration method described by Slack et al. (10). Cell volumes were determined according to Wetzel (6) or were estimated by measuring 20 representative individuals of the major species or genus. Biomass was determined by multiplying average volume (μm^3) by the number of organisms per milliliter.

The slides were examined using a 100 × (oil immersion) objective lens with 10 × ocular. All cells appearing within 20 random grids on the filter were enumerated. Empty diatom frustules were not counted.

Data comparison was accomplished using the Statistical Analysis Systems program (11). Since the data were not of a balance design and lacked replication, a one-way analysis of variance (ANOVA) was performed for each parameter using the general linear models procedure. Sources of variation included sampling date, station, and depth from which to sample was collected. When significant differences existed at the 95% confidence level, a Duncan's multiple range test was used to delineate the source of variation. As a measure of laboratory precision, replicate samples were analyzed from at least one station during each sampling period.

RESULTS

Water temperature in Lake Carl Blackwell varied significantly with time, but not with station or depth. Temperature ranged from 2.9 to 29.2 C. The lake was thermally stratified from 8 June to 30 August 1981 with the thermocline forming between 8 and 11 m. Surface temperatures at Station 1 were slightly higher than those at greater depths. Physicochemical conditions were described in detail by Howick and Wilhm (4).

Dissolved oxygen (DO) concentrations varied significantly with date and depth. Surface DO concentrations ranged from 6.2 to 15.1 mg/*l*. DO averaged 13.1 mg/*l* in winter and 5.4 mg/*l* in summer. During thermal stratification in summer, the hypolimnion became anoxic at 11 - 14 m. The volume of the hypolimnion is only about 4% of total lake volume (4).

The pH in the lake varied with date and depth. Mean seasonal surface values ranged from 7.6 in fall to 8.4 in summer. Values of pH were significantly lower in the fall than in other seasons. In summer, values between 0 and 5 m were significantly higher than those at 8 or 11 m; values at 8 and 11 m were higher than those at 14 m.

Water transparency, turbidity (NTU), and suspended solids were used to provide estimates of water clarity. Secchi disc values ranged from 23 to 130 cm. Secchi disc values were higher in winter than in summer (Figure 2). The upstream stations (4, 5, and 8) had lower Secchi disc values than the other stations.

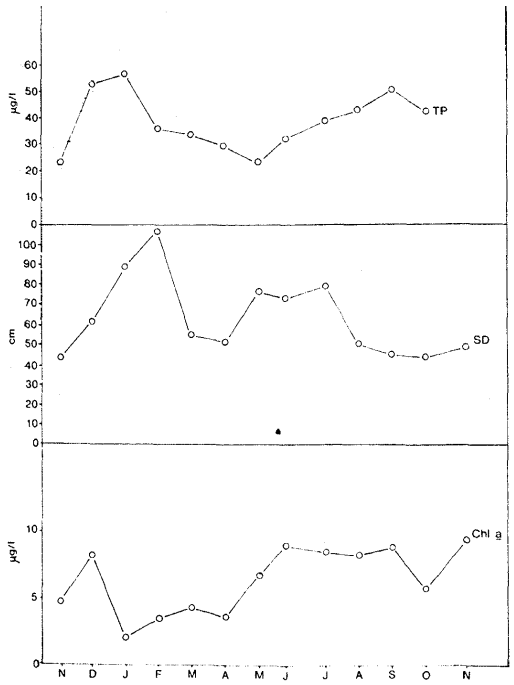

FIGURE 2. Temporal variation in total phosphorus, Secchi disc, and chlorophyll *a*, in Lake Carl Blackwell. Points represent the mean of two samples in spring and summer and one sample in fall and winter.

Turbidity and suspended solids were inversely related to water transparency. Surface turbidity values ranged from 7 to 81 NTU and did not differ significantly among stations. Turbidity varied seasonally, with a mean of 18 NTU in winter and 62 in summer. Turbidity was higher at 11 and 14 m than at other depths.

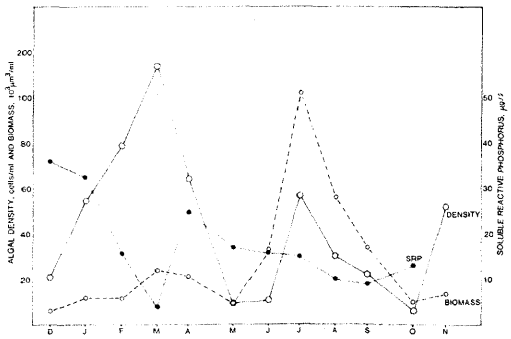

FIGURE 3. Temporal variation in algal density, biomass, and soluble reactive phosphorus in Lake Carl Blackwell. Points represent the mean of two samples in spring and summer and one sample in fall and winter.

Suspended solids ranged from 3.2 to 42.2 mg/*l* for all samples. Values for summer, fall, and spring were lower than those observed in winter. The mean concentration of suspended solids was 12.7 mg/*l* in winter. Concentration at 14 m were higher than those at 5, 2, or 0.5 m.

Mean surface conductivity values ranged seasonally from 406 to 615 μmhos/cm. Mean surface readings varied temporally but not spatially. Means ranged from 419 μmhos/cm in winter to 505 μmhos in winter. Little variation in conductivity existed among depths.

Mean total phosphorus (TP) concentrations of surface samples ranged from 3.8 to 59 μg/*l*. Seasonally concentrations ranged from an average 32.2 μg/*l* in fall to 44.3 μg/*l* in winter (Figure 2). Values from 0.5 to 5 m were similar, while those at 8, 11, and 14 m

were higher. Mean soluble reactive phosphorus (SRP) concentrations for 0.5 m ranged from nondetectable to 36 $\mu g/l$. Mean SRP concentrations were highest at Station 7 and lowest at Station 4. SRP concentrations were generally higher in early winter and lower in later summer and spring (Figure 3).

Chlorophyll α concentrations at 0.5 m ranged from 0.9 to 20.2 $\mu g/l$. Stations 4, 5, and 8 were higher in chlorophyll α content than other stations. Higher concentrations occurred during the summer and fall than during winter or spring (Figure 2). Chlorophyll averaged 3.8 $\mu g/l$ in winter and 5.2 $\mu g/l$ in summer.

Twenty-one dominant algal taxa were observed in 187 samples collected during the study (Table 1). All 21 taxa occurred in the summer, while 20 were collected in fall, 19 in spring, and 16 in winter. Two blue-green algae (*Aphanizomenon* and *Anabaena*) and one diatom (*Melosira*) comprised 99.6% of the total numbers of phytoplankton in the winter, 97% in the spring, 86% in summer, and 97.8% in the fall. *Aphanizomenon* was the dominant taxon in all seasons. *Anabaena* was the second most abundant genus in the winter and summer, while *Melosira* was the second most abundant genus in spring and fall.

Phytoplankton abundance varied with time and station. Higher cell numbers occurred in early spring and summer, while lower densities existed in late spring and fall (Figure 3). Mean algal densities ranged from 25 cells/ml at Station 1 to 52 cells/ml at Station 9. Higher densities were found at stations in protected arms of the lake, while lower densities were found in the open water stations.

Biomass estimates of all samples ranged from a mean of 5.8 to $10^5 \times 10^4$ $\mu m^3/ml$. Biomass remained relatively low from December through May, but then increased abruptly reaching a maximum value on 7 July 1981 (Figure 3). Minimum biomass occurred at Station 1 and maximum biomass at Station 4. Generally, stations in the arms had greater algal biomass than stations in the main pool.

DISCUSSION

Although comparisons are influenced by variation in counting methods used by different authors, the number of dominant algal genera in Lake Carl Blackwell appears to be decreasing. Eight genera of algae were common in 1940-41 (12), four in 1949-50 (12), four in 1971-72 (13), and only three genera in the present investigation. Dominance by blue-green algal species has increased, suggesting continued eutrophication. Seasonal variation was also reported in the various studies. Leonard (12) reported maximum algal abundance in November and April of 1940-41 and in February 1949-50. Maximum algal biomass occurred in June and September of 1971 and in May of 1972 (13). In the present study, algal abundance was greatest in March, with smaller peaks in July and November (Figure 3).

Between 1972 and 1975, 815 lakes were sampled as part of EPA's National Eutrophication Survey (3). *Aphanizomenon* was the most abundant in the fall, while *Anabaena* was dominant in the summer and *Melosira* in the spring. In the present investigation, *Aphanizomenon* was the most common in all seasons.

TABLE 1. *Dominant algae collected in Lake Carl Blackwell*[a]

CHLOROPHYTA	EUGLENOPHYTA	PYRROPHYTA	BACILLARIOPHYTA	CYANOPHYTA
		Melosira	*Anabaena*	
Eudorina	*Euglena*	*Glenodinium*	*Fragilaria*	Aphanizomenon
Pandorina		*Ceratium*	*Synedra*	Microcystis
Oocystis			*Gyrosigma*	
Botryococcus			*Navicula*	
Pediastrum			*Cosinodiscus*	
Closterium				
Staurastrum				
Ankistrodesmus				
Kirchnerella				

[a] >28 μm plankton net, bottom to surface tow

Phosphorus (TP) is frequently cited as a factor limiting algal productivity in lakes (14, 15, 16). However phosphorus may not be the primary factor limiting algal biomass in Lake Carl Blackwell because concentrations of SRP remained available for algal uptake. A strong relationship between total phosphorus and chlorophyll α has been described (1, 17, 18, 19). Carlson's equation is as follows:

ln Chl α = 11.06 + 1.45 ln TP (n = 43, r = 0.85)

A regression developed for Lake Carl Blackwell resulted in:

ln Chl α = 1.83 - .031 ln TP (n = 12, r = 0.14)

The positive slope of Carlson's regression indicates that increases in chlorophyll α occur faster than increases in TP concentrations. The equation for Lake Carl Blackwell indicates that TP is not as important in limiting chlorophyll concentrations.

The relationship between light and chlorophyll α was also examined for Lake Carl Blackwell. Toetz et al. (20) reported chlorophyll α concentrations were maximal in July and again in mid-September. Similar temporal trends were noted during the present study (Figure 3). Chlorophyll α content was found to be greater at 0.5 m than at other depths. Generally, the stations showing more turbidity also had the highest mean annual chlorophyll α content and algal biomass, perhaps as a phytoplankton adaptation to turbid conditions. Chlorophyll α per cell does increase in certain species at lower light intensities (21, 22, 23).

The relationship between Secchi disc measurements and chlorophyll α concentration has been investigated (1, 15, 16). Carlson's equation relating Secchi disc measurements (cm) and chlorophyll α (μg/l) is as follows:

ln (Secchi disc) = 2.04 - 0.68 ln (Chl α) (n = 147, r = 0.93)

A similar relationship for Lake Carl Blackwell is:

ln (Secchi disc) = 10.06 - 0.29 ln (Chl α) (n = 187, r = 0.41)

Correlation between these parameters for Lake Carl Blackwell is low compared to Carlson's possibly because light attenuation in Lake Carl Blackwell is mostly due to clay particles. Low correlations between chlorophyll α and Secchi disc measurements due to these particles have been noted by others (2, 24).

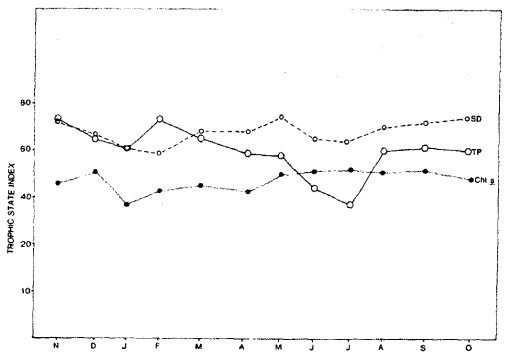

FIGURE 4. Temporal variation in Carlson's TSI in Lake Carl Blackwell. Points represent the mean of two samples in spring and summer and one sample in fall and winter.

The tropic state index (TSI) based on the relationship among phosphorus, chlorophyll α, and Secchi disc can be computed from any of the three parameters and should be approximately the same regardless of the parameter chosen (1). Carlson generated a single number to fit into a numerical scale ranging from 0 to 100, with major tropic divisions at 10 unit increments. Mean annual TSI values computed for Lake Carl Blackwell were 68 based on water transparency, 49 based on concentration for chlorophyll α, and 56 based on concentration of total phosphorus. Seasonal TSI values calculated for Lake Carl Blackwell are shown in Figure 4. Values generated from the different methods of calculation were all significantly different from each other ($p > .05$). Carlson conducted his work on natural lakes where relationships among Secchi disc measurements, chlorophyll α, and total phosphorus relate well because turbidity was chiefly due to algae. These relationships do not hold for reservoirs (24) such as Lake Carl Blackwell where transparency depth is limited largely by interference from non-algal particles and phosphorus is probably not the major limiting factor. The Secchi disc value more nearly equaled the derived value for TP. Lambou et al. (25) also found that Secchi disc measurements were more useful as a predictor of lake total phosphorus concentration than of chlorophyll.

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