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THE TROPHIC STATUS OF PRAIRIE CREEK RESERVOIR: IMPLICATIONS FOR RESOURCE MANAGEMENT

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ABSTRACT. This study investigated the trophic status of Prairie Creek Reservoir, located in an agricultural watershed in east-central Indiana. Currently, there are no strategies to manage water quality at the reservoir; watershed-scale practices are very limited. Two reservoir locations were monitored bi-weekly from May through September 2007 for pH, temperature, dissolved oxygen, Secchi disk transparency, chlorophyll *a*, and nutrients. Dissolved oxygen concentrations reached anoxic conditions that persisted from June through September and often reached 50% of the depth at monitored sites. Concentrations of ammonia and soluble reactive phosphorus exceeded the recommended water quality guidelines and standards. Increased concentrations of nutrients in the hypolimnion correlated with anoxic conditions. The results characterized the reservoir as a eutrophic water body based on Secchi disk transparency, total nitrogen and chlorophyll *a* concentrations, while concentrations of total phosphorus were typical of a hypereutrophic state. The results for Total Nitrogen : Total Phosphorus ratio suggested that algal growth is co-limited by both nutrients with some shifts toward nitrogen limitations in late spring and early fall. The reservoir restoration and watershed protection programs need to be employed to reduce both nitrogen and phosphorus loading and, therefore, prevent development of toxic algal blooms in the future.

Keywords: Eutrophication, agricultural watershed, nutrients, lake management, water quality

High concentrations of nutrients have been linked to eutrophication resulting in abundant plant and algal growth, depletion of dissolved oxygen, increased populations of bottom-dwelling fish, increase in pathogenic microorganisms, development of taste and odor in water supplies, and loss of recreation (Carlson 1977; Carpenter et al. 1998; Johnston & Jacoby 2003; Cooke et al. 2005). Both nitrogen (N) and phosphorus (P) were found to co-limit algal growth in majority of lakes and reservoirs (Elser et al. 1990). However, N limitation has been found to occur frequently in lakes identified as P-limited due to excessive P loading that created a shift from P- to N-limitation (Nürnberg & Peters 1984; Elser et al. 1990; Havens 1995; Havens et al. 1996; Stanley et al. 2003). Such changes in nutrient limitations affect phytoplankton communities, and green and blue-green algae dominate under nitrogen-limiting conditions (Takamura et al. 1992; Havens 1995; Havens et al. 1996).

The relationship between nutrients and algal biomass varies considerably among lakes and reservoirs, even within the same region, due to diverse and unique environments and conditions caused by, e.g., lake origin and morphology, soil quality, ecoregional differences. Therefore, each water body needs to be studied separately to characterize its own dynamics (Hatch 2003; Havens 2003). A local monitoring program was shown to be more accurate and useful for setting lake-specific conditions and management than the utilization of regional criteria (Havens 2003).

Prairie Creek Reservoir, located in an agricultural watershed of Ecoregion 55 in east-central Indiana, is used for fisheries, recreation, and drinking water supply. The Ecoregions 55, 54 and 56 have been found to have the worst water quality conditions and eutrophication problems in Indiana (IDEM 2006). Water quality investigations at Prairie Creek Reservoir commenced in 2002 on a limited basis. Popovičová (2008) found anoxic conditions and increased concentrations of orthophosphate during summer 2006. However, analyses of total nitrogen (TN) and total phosphorus (TP), the key parameters to determine the trophic status and the limiting

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nutrient that controls algal growth, were not included. Current management practices in the watershed are limited to some low- or no-till agriculture in the reservoir watershed. The use of buffer strips, livestock fencing, wetlands on the reservoir inlets or management of the reservoir itself is nonexistent. Consequently, the main objectives of this study were to (1) establish the trophic state index (TSI); (2) characterize vertical profile of temperature and dissolved oxygen to evaluate mixing regime and potential depletion of dissolved oxygen; and (3) determine the nutrient controlling eutrophication.

METHODS

Prairie Creek Reservoir, a shallow reservoir with a surface area of 507 ha, is located in a sub-watershed (44 km^2) of the White River in Delaware County, Indiana (Fig. 1). Land use in the watershed is dominated by agriculture (72.15%) that is primarily focused on corn and soybean production; two small animal feeding operations are located in the watershed as well (Popovičová 2008). Green space (18.2%) and residential properties (6.4%) comprise other larger land uses of this watershed (Popovičová 2008). The dominant soil types in the watershed, Crosby (23%) and Miamian (27%) soils, have limited drainage and the area is drained by tile drains. During the monitoring period the climate in this county was characterized by mean monthly air temperatures ranging from 61.5–75.5°C and mean monthly precipitation between 2.96 and 4.26 inches.

The reservoir was monitored only at the two deepest sites in the north (8.5 m depth) and in the center (7 m depth) (Fig. 1) because a previous investigation found no significant differences in water quality among seven monitored locations (Popovičová 2008). Field sampling and laboratory analyses were performed bi-weekly from May through September 2007. Samples for nutrient analyses were collected from the epilimnion at 0.5 m depth and from the hypolimnion at 0.2 m from the bottom using a horizontal beta sampler. Samples were transferred to high-density polyethylene Nalgene^{TM} bottles, transported on ice, stored in a refrigerator at 4°C, and analyzed within 24 h of collection (APHA 1998). Temperature, dissolved oxygen (DO), and chlorophyll *a* were measured *in-situ* at every 0.5 m of the depth using a Hydrolab Sonde DS5 (Hach, Inc.; Loveland, Colorado). A Secchi disk (SD) was used to determine water transparency (Carlson & Simpson 1996), while wind speed was measured with a Kestrel 2000 Pocket weather meter (Nielsen-Kellerman, Boothwyn, Pennsylvania). Chlorophyll *a* concentrations were calculated for the euphotic zone (1.7 times of SD) (Reynolds 1984). Samples for nitrate were analyzed by the cadmium reduction method 4500-NO3-E, and ammonia by the salicylate method (APHA 1998). The ascorbic acid method 4500-P-E was used to determine the soluble reactive phosphorus (SRP) after the sample filtration through a 0.45 µm membrane filter (U.S. EPA 1997; APHA 1998). Total nitrogen (TN) was analyzed by the persulfate digestion method, and total phosphorus (TP) was determined by the acid persulfate digestion method with ascorbic acid. Quality control procedures were employed according to the standard methods (APHA 1998).

All data were log-transformed due to the lack of normality and/or homogeneity of variances to reduce the standard error. Significant differences among sampling sites, months, and depths were determined using a 3-way ANOVA, and temporal differences for different depth were determined by Tukey's pairwise comparisons (significance set at $P < 0.05$) (SPSS Inc., Chicago Illinois). Spearman's rho correlation analysis was used to determine relationships between variables ($P < 0.05$). The trophic state index (TSI) of the reservoir based on SD, chlorophyll *a,* and TP data was calculated using Carlson's equations (Carlson 1977):

$$\text{Total phosphorus TSI} = 14.42 * [\ln(\text{TP})] + 4.15 \tag{1}$$

$$\text{Chlorophyll-}a\text{ TSI} = 9.81 * [\ln(\text{Chlorophyll-}a)] + 30.6 \tag{2}$$

$$\text{Secchi disk TSI} = 60 - (14.41 * [\ln(\text{Secchidisk})]) \tag{3}$$

The TSI based on TN data was calculated using Kratzer and Brezonik's equation (1981):

$$\text{TSI} = 54.45 + 14.43 \ln(\text{TN}) \tag{4}$$

RESULTS

The results for all studied parameters showed no significant differences ($P > 0.05$) between

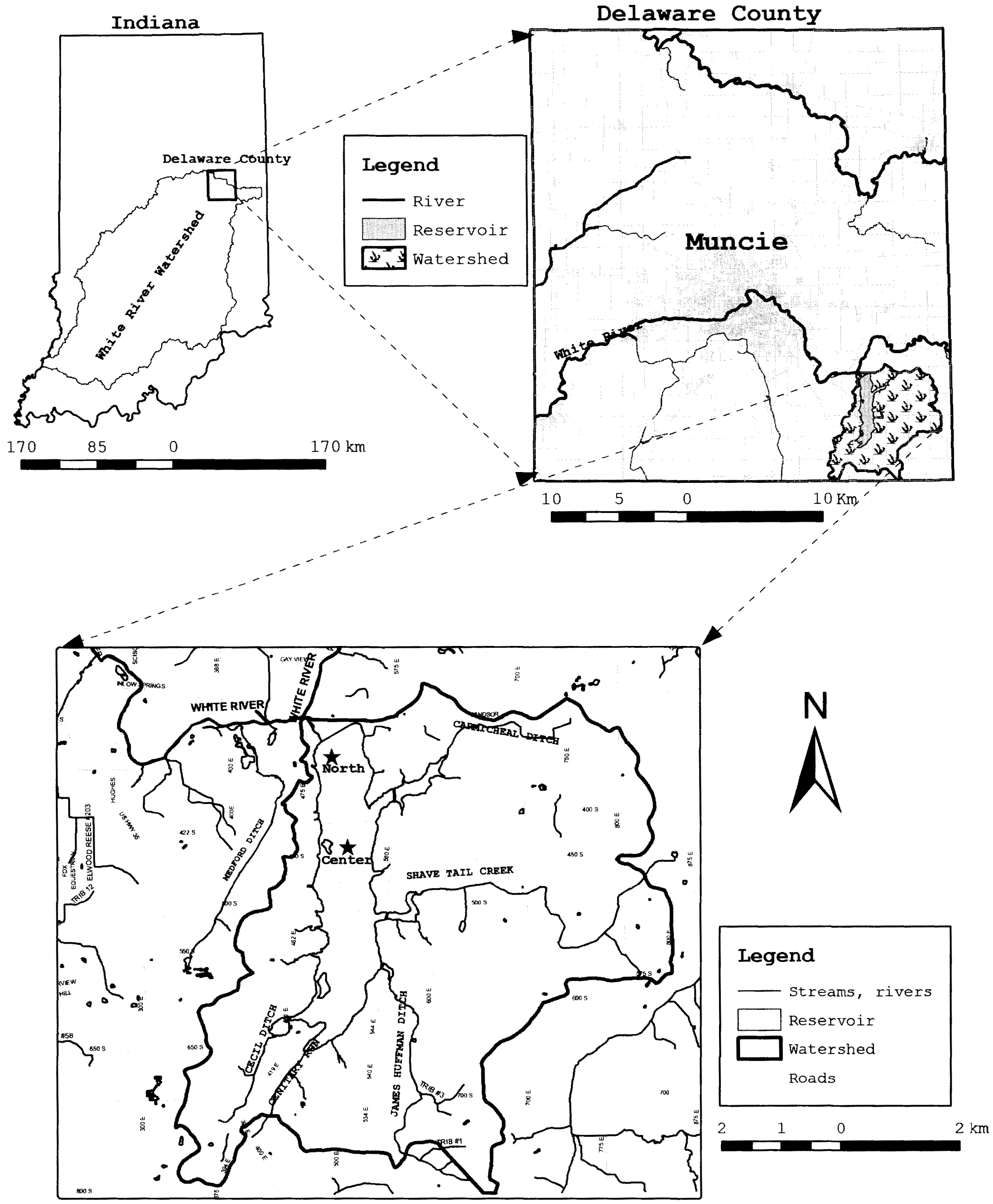

Figure 1.—Location of the Prairie Creek Reservoir near Muncie, Indiana and the sampling sites.

the north and center locations (Table 1). Therefore, all the results reported in this section are discussed as means for the reservoir and not for individual sites.

Physico-chemical water quality parameters.—During the entire monitoring period, Indiana and Ohio water quality standards for water pH (range 6–9) were met (Table 1) (Ohio EPA 1999; IAC 2007). *In situ* pH in the epilimnion ranged from 7.3 to 8.5 and was significantly higher ($P <$ 0.001) than hypolimnetic pH that ranged from 6.5 to 7.6. The water temperature did not exceed the maximum allowable limit of 26.7°C (May) and 32.2°C (June to September) (IAC 2007).

Table 1.—Water quality parameters measured at the Prairie Creek Reservoir from May to September 2007. Abbreviations: TN = total nitrogen; SRP = soluble reactive phosphorus; TP = total phosphorus.

Parameters	Depth	*n*	Min.	Max.	Mean	SD.
pH	Epilimnion	22	7.3	8.5	8.1	0.3
	Hypolimnion	22	6.5	7.6	6.9	0.2
Dissolved oxygen (mg/L)	Epilimnion	22	4.67	18.62	9.74	3.20
	Hypolimnion	22	0.25	5.89	1.14	1.38
Temperature (°C)	Epilimnion	22	18.1	27.8	24.3	2.8
	Hypolimnion	22	14.1	25.0	20.9	3.2
Nitrate - N (mg/L)	Epilimnion	22	0.10	0.50	0.27	0.11
	Hypolimnion	22	0.10	2.30	0.58	0.52
Ammonia - N (mg/L)	Epilimnion	22	<0.01	0.66	0.13	0.16
	Hypolimnion	22	0.03	3.80	0.66	0.88
TN (mg/L)	Epilimnion	22	0.3	1.6	1.0	0.4
	Hypolimnion	22	0.6	4.6	1.7	1.2
SRP (mg/L)	Epilimnion	22	<0.01	0.07	0.03	0.02
	Hypolimnion	22	<0.01	0.14	0.05	0.04
TP (mg/L)	Epilimnion	22	0.07	0.16	0.12	0.02
	Hypolimnion	22	0.11	0.71	0.27	0.20
Secchi disk (m)	-	22	0.70	0.95	0.85	0.06
Chlorophyll *a* (μg/L)	Euphotic zone	22	10.74	31.03	17.70	6.48

Dissolved oxygen concentrations showed significantly higher means ($P < 0.001$) in the epilimnion (9.7 mg/L) than hypolimnion (1.14 mg/L) (Table 1), although no significant differences were found over time. Concentrations of DO measured in May and September in the hypolimnion (2.3 and 1.8 mg/L, respectively) indicated the beginning and end of anoxic conditions (DO concentration < 1 mg/L). These months were also characterized by increasing (May) and decreasing (September) concentrations of nutrients in the reservoir (Figs. 2, 6, 7). The Indiana water quality standard of 5 mg/L for DO concentration was not met in 95% of the hypolimnion samples and in 5% of epilimnion samples (IAC 2007). Concentrations of DO in the hypolimnion were lower than 1 mg/L in June, July and August. This indicated anoxic conditions for the summer (Figs. 3, 4), which also correlated with the higher concentrations of nutrients in the reservoir (Figs. 2, 6, 7). On several occasions, anoxic conditions reached 50% of the monitored depth (Figs. 3, 4). However, some oxygen replenishment was also observed in late July, early August, and early to mid-September as a result of vertical mixing of water (Figs. 3, 4) that can be attributed to the lack of thermal stratification, wave action and mixing caused by wind and motorboats (Kelton & Chow-Fraser 2005).

Although statistical differences in DO concentrations were not found between the monitored locations, higher hypolimnetic DO concentrations at the center location could be the result of depth and wind action that control vertical mixing (Scheffer 2004), and can be also affected by temperature and temperature gradients. The mean water temperatures were significantly different ($P < 0.001$) between the sampled depths and also among monitored months. However, water in the center location had higher hypolimnetic temperatures and lower temperature gradients ($0.01°C/m \leq \Delta T \leq 0.89°C/m$) than the north location ($0.03°C/m \leq \Delta T \leq 0.94°C/m$). Furthermore, the center location was characterized by stronger winds, with a mean speed of 8.85 km/h for the monitoring period and shallower depths ($\approx$7 m), making it more susceptible to water mixing and thus reoxygenation of the hypolimnion. In contrast, the north location was deeper ($\approx$8.5 m) and more shielded from the wind (the measured average wind speed was 8.05 km/h), which could reduce vertical mixing and, consequently, oxygen flux from the upper to lower layers.

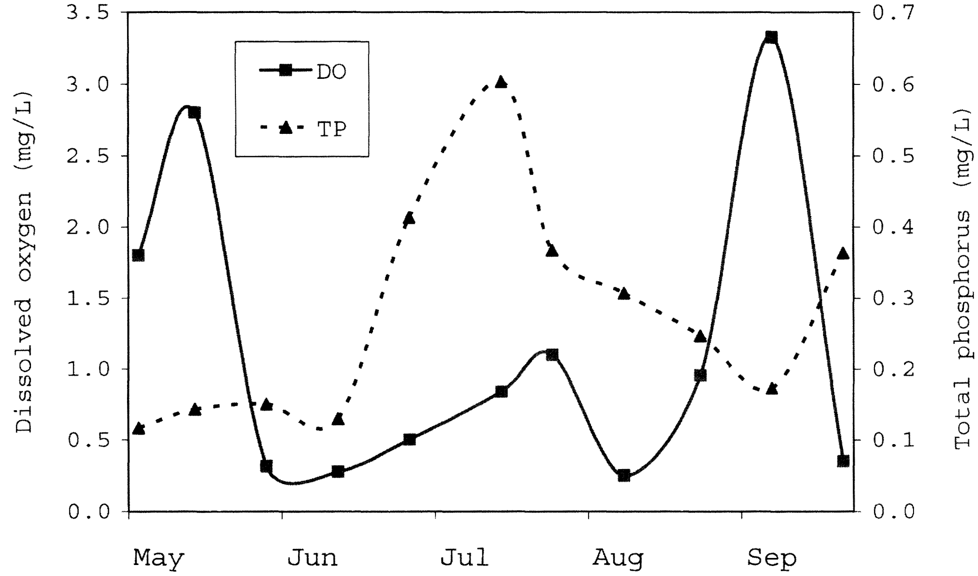

Figure 2.—Relationship between concentrations of dissolved oxygen and total phosphorus in the hypolimnion at the Prairie Creek Reservoir.

Trophic parameters.—The concentrations of nitrate (NO_3–N) met the Indiana water quality standard of 1.6 mg N/L for aquatic life with exception of one sample ($n = 44$) (IAC 2007). Hypolimnetic concetrations ranged from 0.10 to 2.30 mg N/L and were significantly higher ($P < 0.05$) than in the epilimnion (Table 1). The highest mean concentration of NO_3–N in the epilimnion was observed in July (0.5 mg N/L), and in September (2.3 mg N/L) for the hypolimnion. Additionally, hypolimnetic concentrations varied significantly among the monitored months ($P < 0.01$), while epilimnetic concentrations did not show any temporal variation.

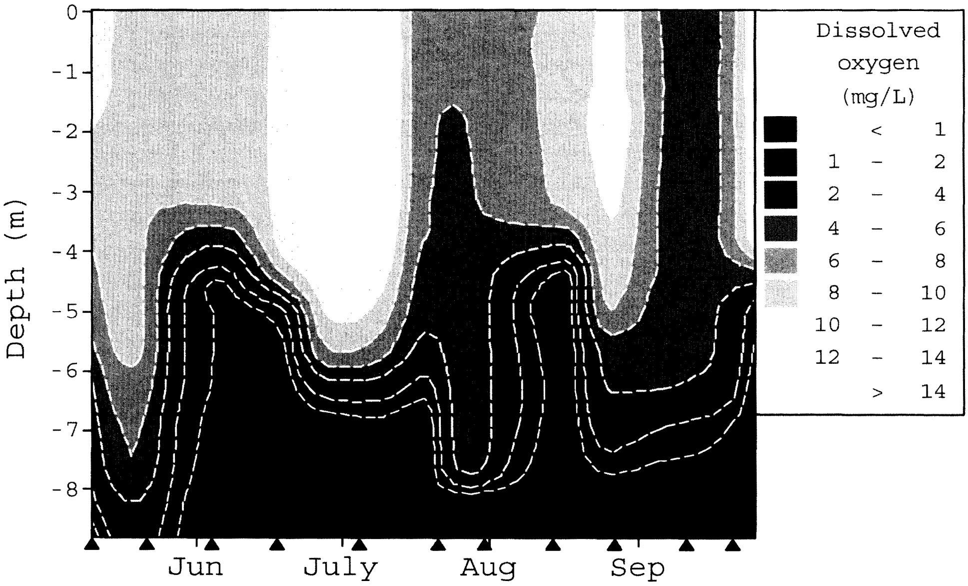

Figure 3.—Vertical and seasonal profiles of dissolved oxygen concentrations at the north location of the reservoir in 2007. The marker "▲" denotes sampling day.

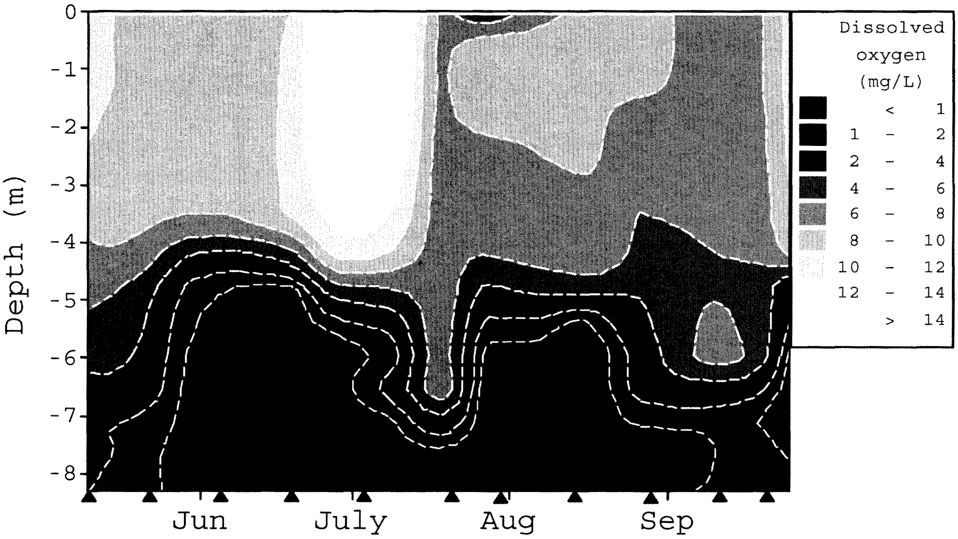

Figure 4.—Vertical and seasonal profiles of dissolved oxygen concentrations at the central location in the reservoir in 2007. The marker "▲" denotes sampling day.

Concentrations of ammonia (NH_4^+–N) found in hypolimnion (0.03 to 3.80 mg N/L) and epilimnion (< 0.01 to 0.66 mg N/L) were significantly different ($P < 0.001$) (Table 1). Significant temporal differences in NH_4^+-N concentrations were identified only in the hypolimnion ($P < 0.01$) where the maximum (3.80 mg N/L) was reached in August. Ammonia concentrations violated the Indiana standard in 23% of the epilimnion samples and 86% of the hypolimnion samples (IAC 2007); the maximum allowable concentration of ammonia depends on water pH and temperature, and ranged from 0.0299 to 0.2137 mg N/L for the collected data. The TN concentrations in the hypolimnion followed the temporal trend of NO_3–N and NH_4^+–N (Fig. 6). TN concentrations found in the epilimnion (mean value 0.99 mg N/L) and the hypolimnion (mean value 1.73 mg N/L) were significantly different ($P < 0.05$) (Table 1).

Contrary to the distribution of nitrogenous compounds, concentrations of SRP were not statistically different between sampling depths and among the monitored months. The mean SRP concentration for the monitoring period was 0.03 mg/L in the epilimnion and 0.05 mg/L in the hypolimnion (Table 1). The 63.6% of SRP samples from the hypolimnion and 59.1% of the epilimnion samples did not meet the U.S. EPA national water quality criterion of 0.025 mg/L set to prevent eutrophication in lakes and reservoirs (U.S. EPA 1986). The mean concentrations of TP in the hypolimnion (0.27 mg/L) were significantly higher than in the epilimnion (0.12 mg/L; $P < 0.001$) (Table 1, Fig. 7). The hypolimnetic TP concentrations showed temporal differences ($P < 0.05$), while epilimnion concentrations remained almost constant during the summer (Table 1, Fig. 7).

Algal biomass, as measured by chlorophyll *a* concentration, increased during the monitoring period and mean monthly concentrations reached their maximum in September (23.25 µg/L) and minimum in June (11.75 µg/L; Fig. 8). Water transparency was inversely correlated with chlorophyll *a* concentrations ($n = 22$; -0.63; $P < 0.01$). The maximum water transparency was measured in June (0. 93 m) and the minimum was recorded in August (0.80 m) (Fig. 8). However, no significant temporal differences were found.

DISCUSSION

The results for water quality parameters measured between May and October 2007 at Prairie Creek reservoir showed oxygen depletion in the hypolimnion, low water transparency, high nutrient concentrations, especially phosphorus, and increased concentrations of chlorophyll *a*. The assessment of trophic parameters indicate an eutrophic status of this water body based on the results for water transparency (TSI = 62), concentration of TN (TSI = 56) and chlorophyll *a* (TSI = 58) (Carlson 1977; Kratzer

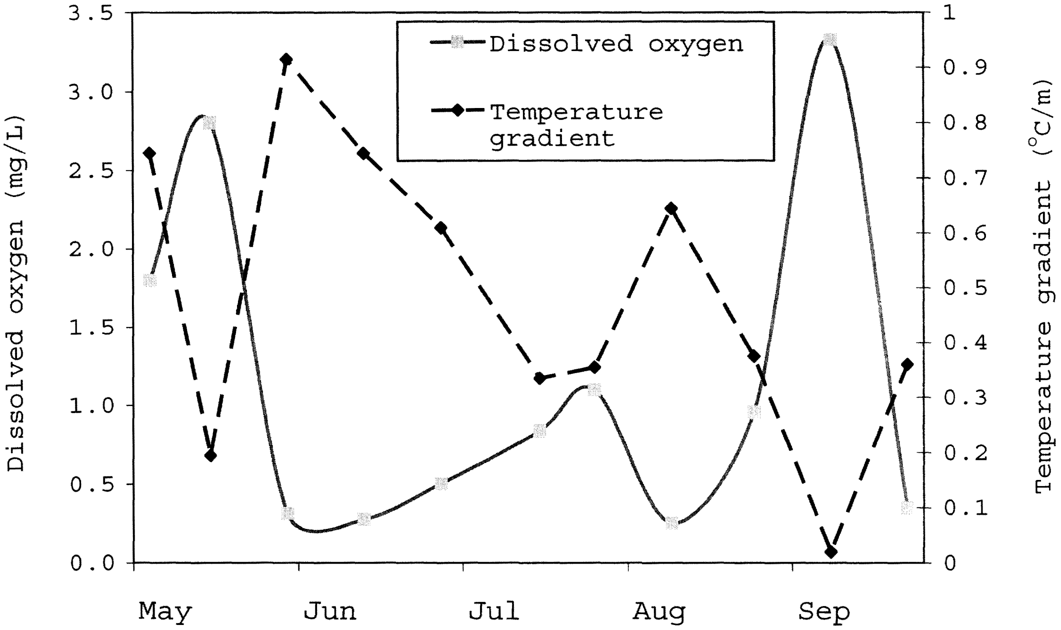

Figure 5.—Relationship between hypolimnetic concentrations of dissolved oxygen and the temperature gradient at the Prairie Creek Reservoir.

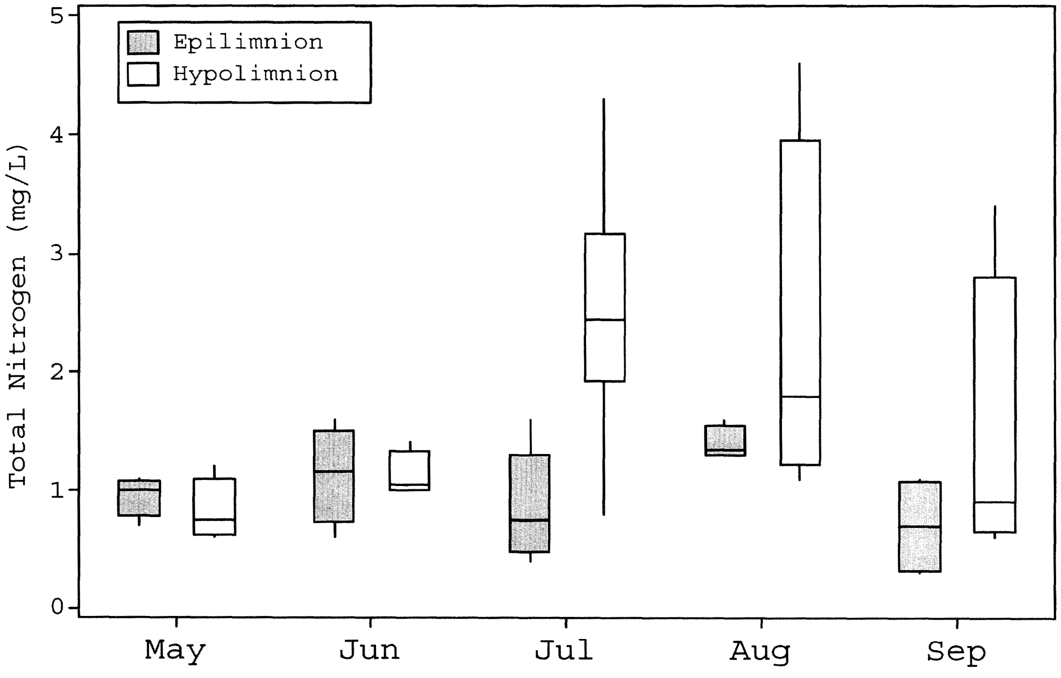

Figure 6.—Seasonal and vertical variations in total nitrogen concentrations at the Prairie Creek Reservoir in 2007. The upper and lower whiskers on the graph represent the maximum and minimum data points, respectively. The bottom line of the box indicates the first quartile, the middle line shows median value, and the top line the third quartile.

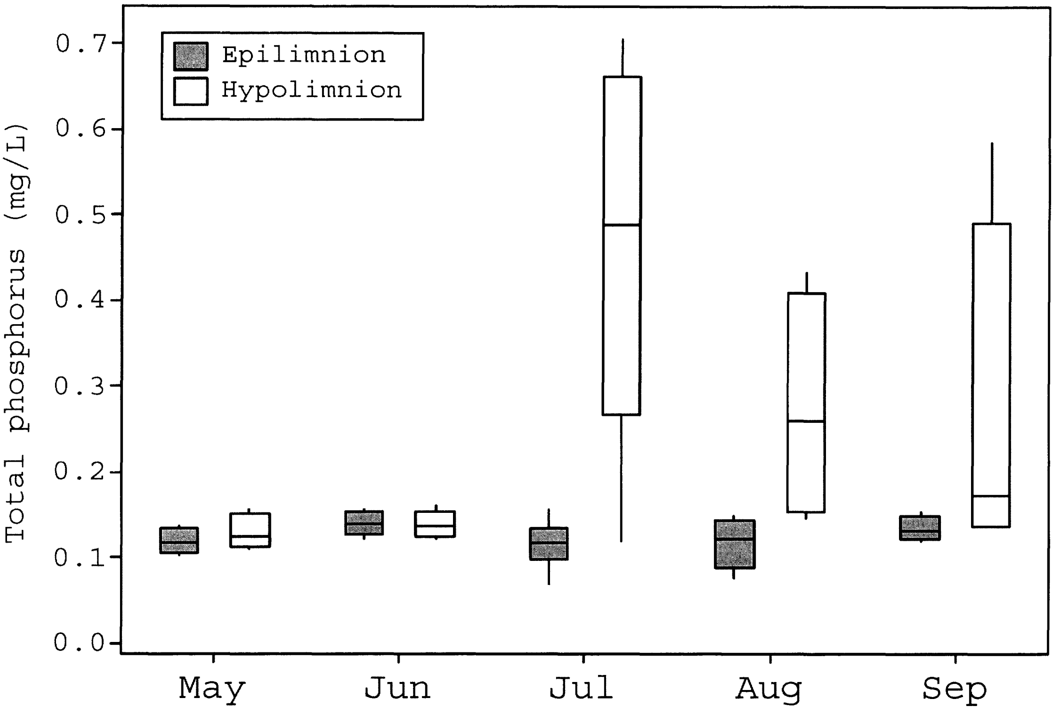

Figure 7.—Seasonal and vertical variations of total phosphorus concentrations in the Prairie Creek Reservoir in 2007. The upper and lower whiskers on the graph represent the maximum and minimum data points, respectively. The bottom line of the box indicates the first quartile, the middle line shows median value, and the top line the third quartile.

& Brezonik 1981). However, high concentrations of TP found at the reservoir characterized this waterbody as slightly hypereutrophic (TSI = 73) (Carlson 1977).

The results for pH and DO also suggest an eutrophic status. The higher epiliminetic pH (Table 1) is a result of increased CO_2 consumption due to photosynthetic activity by algae in the water column, which causes the removal of carbonic acid from the aquatic system (Horne & Goldman 1994). Conversely, the lower pH in the hypolimnion (Table 1) can be attributed to decomposition of organic matter that releases CO_2 and, ultimately, acidifies the water (Horne & Goldman 1994; Cooke et al. 2005; Jørgensen et al. 2005).

Anoxic conditions (DO < 1 mg/L) found at the reservoir between June and August are also characteristic of eutrophic conditions (Nürnberg & Peters 1984; Nürnberg 1988; Horne & Goldman 1994). Aside from negative effects on aquatic life and taste and odor of water, anoxia exacerbates algal growth due to the release of nutrients from sediment into the water column that become available for phytoplankton growth in epilimnion (Nürnberg 1988; Horne & Goldman 1994; Kelton & Chow-Fraser 2005).

The thermal regime of a lake can also affect the availability of nutrients in the epilimnion. In thermally stratified lakes nutrient concentrations in the water column tend to decrease because thermocline acts as a barrier to water column mixing and prevents transport of nutrients into the euphotic zone (Welch & Cooke 1995). However, the low temperature gradients ($\Delta T \leq 1°C/m$) measured at both monitored locations indicated a lack of thermal stratification at the reservoir in 2007. These conditions can facilitate vertical mixing of water column and replenishment of DO in the hypolimnion, as observed at the reservoir, and lead to increased concentrations of nutrients within the water column. Non-stratified shallow lakes are prone to mixing, and can efficiently cycle phosphorus and convert it to phytoplankton biomass (Welch & Cooke 1995). The lack of thermal stratification documented at this reservoir in 2007 resulted in vertical

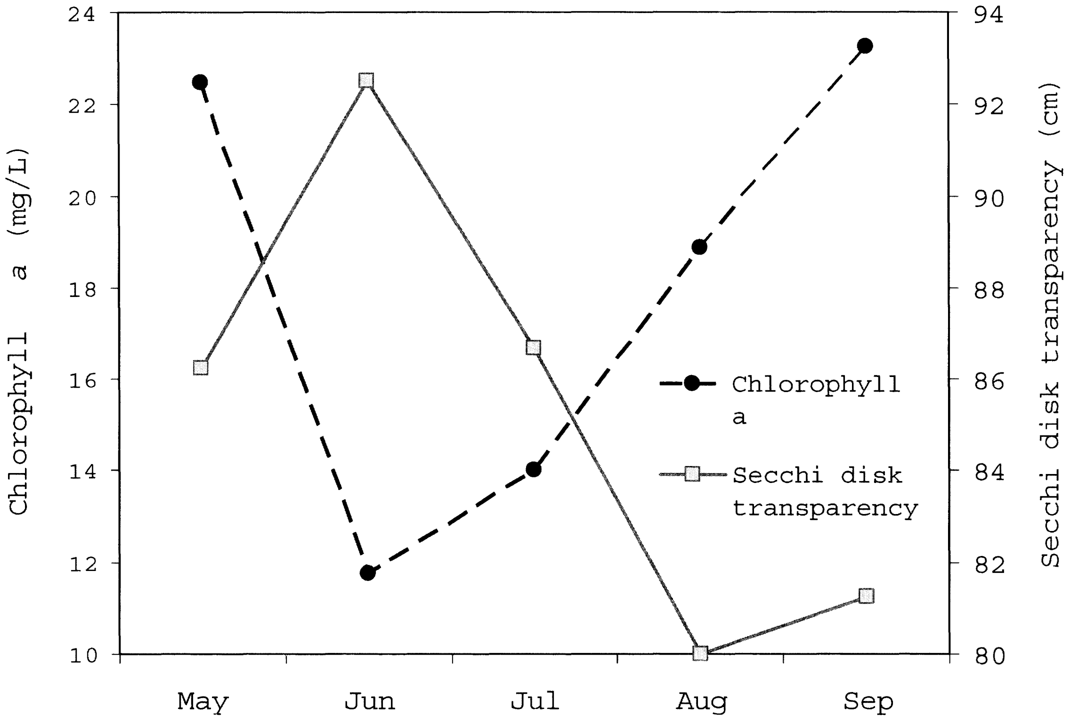

Figure 8.—Seasonal variations of chlorophyll *a* concentration and Secchi disk transparency at the Prairie Creek Reservoir.

mixing and distribution of nutrients, especially SRP, throughout the water column.

The vertical and temporal variations of NO_3–N, NH_4^+–N, TN and TP found by this study can also be attributed to decomposition and mineralization of organic matter in the benthos that increases as summer advances due to higher water temperatures and higher flux of settling algae. The contribution of inorganic nitrogen in the hypolimnion reached almost 100% of TN in August and September; epilimnetic concentrations increased as well, although this change was not significant. The increased mass of decaying algae during summer and the release of ammonia from the sediment to the water column can both contribute to higher ammonia concentrations in the hypolimnion (Scheffer 2004; Jørgensen et al. 2005). High levels of ammonia found in this reservoir can be detrimental to aquatic life due to its toxicity (Thurston et al. 1981; Follett & Delgado 2002), but it can also produce undesirable taste and odor in drinking water and stimulate excessive primary productivity (Horne & Goldman 1994; Follett & Delgado 2002).

Concentrations of nitrate did not reach high levels but they were found to increase in the hypolimnion as summer progressed. Microbial conversion of ammonia to nitrate via nitrification can occur in the presence of any available oxygen and it takes place primarily close to the sediment where higher concentrations of ammonia are available when oxygen is present (Scheffer 2004). Other studies showed that the leakage of oxygen from macrophyte roots can cause local aeration of anaerobic sediments and encourage nitrification (Van Donk et al. 1993; Scheffer 2004). Additionally, temperature fluctuations at night can induce vertical mixing of the water column and, consequently, oxygen replenishment (Herb & Stefan 2004). While the effect of macrophytes and diurnal variations in DO was not studied, nitrification of ammonia could have occurred due to the lack of thermal stratification at this reservoir in 2007, demonstrated intermittent vertical mixing and consequent oxygen replenishment (Figs. 3, 4).

Observed vertical and temporal variations in TP concentrations indicate the influence of biomass accumulation and anoxia. Intensive primary productivity generates excessive quantities of biomass that eventually settles in the bottom of the reservoir and becomes an important source of P that will be released to the water column (Nürnberg & Peters 1984; Nürnberg 1988; Horne & Goldman 1994; Kelton & Chow-Fraser 2005). Additionally, the extent and duration of anoxia determine the amount of released nutrients and, if anaerobic conditions persist over a long period of time, the release of nutrients intensifies (Nürnberg 1988). Prolonged duration of anoxia in summer can augment the concentrations of SRP in the hypolimnion (Herb & Stefan 2004; Horne & Goldman 1994; Nürnberg & Peters 1984; Nürnberg 1988; Nürnberg 1994; Scheffer 2004; Jørgensen et al. 2005). The SRP concentrations at the reservoir increased from May to September 2007, which corresponded with the period of anoxic conditions. However, the SRP concentrations in the epilimnion and hypolimnion at the Prairie Creek reservoir were not significantly different suggesting that the rate of SRP release from the sediment was reduced due to the influence of intermittent vertical mixing that leads to reoxygenation of the hypolimnion (Horne & Goldman 1994; Welch & Cooke 1995).

Concentrations of TP in this reservoir correlated positively with anoxic conditions ($n = 44$; 0.56; $P < 0.01$). Similarly, Kelton & Chow-Fraser (2005) reported increased concentrations of P in the water column to be positively correlated with duration of anaerobic conditions. These results suggest that the phosphorus load at the reservoir was intensified by both biomass accumulation and anoxia (Nürnberg & Peters 1984; Nürnberg 1994; Scheffer 2004; Kelton & Chow-Fraser 2005).

As a result of high nutrient concentrations, increased levels of chlorophyll *a*, typical of an eutrophic water body, were observed in this reservoir. High concentrations of chlorophyll *a* measured in May decreased through June and then peaked in September. The measured June decline could be attributed to the clear-water phase that often occurs at the end of spring due to depletion of available nutrients caused by the spring algal bloom of diatoms (Vyhnálek 1989; Carpenter et al. 1993; Scheffer 2004). This is followed by consequent heavy zooplankton grazing that peaks after the spring algal bloom (Reynolds 1984; Vyhnálek 1989; Carpenter et al. 1993) and subsequent growth of green and blue-green algae in summer (Reynolds 1984; Scheffer 2004).

Growth of algae can be limited by light, N, P or co-limited by both nutrients (Guildfrod & Hecky 2000; Dzialowski et al. 2005). Although high TP concentrations classify this reservoir as slightly hypereutrophic, these conditions did not result in excessive algal scum as would be expected (Horne & Goldman 1994). The results showed N and P co-limitation of algal growth in summer and the nutrient loading shifts toward low TN:TP ratio in spring and fall. The molar TN:TP ratio showed seasonal variability as it decreased from co-limiting (TN:TP between 18 and 46) to N-limiting conditions (TN:TP < 18) in late spring/early summer, increased toward co-limitation as the growing season progressed from July to August, and moved toward N-limitation again in September (Guildfrod & Hecky 2000; Dzialowski et al. 2005). Seasonal changes in nutrient limitations and chlorophyll *a* concentrations can be the result of various factors such as unstable thermal conditions, water temperature, hydrodynamic conditions, as well as interactions within the food web, especially the influence of zooplankton grazers (Elser 1999; Sterner 1994). Sterner (1994) found seasonal as well as temporal changes in nutrient limitation and Elser (1999) stated that unstable thermal conditions, such as those found in the studied reservoir in 2007, may not trigger noxious algal blooms due to increased competition from other algal taxa. Furthermore, increased growth of zooplankton biomass may change the nutrient ratio due to increased nitrogen input affecting TN:TP ratio and growth of cyanobacteria (Elser 1999; Hall et al. 2005).

A shift from P- to N-limiting conditions may be also caused by an overload of P and anoxic conditions that result in the release of sediment-bound P (Nürnberg & Peters 1984; Elser et al. 1990; Havens 1995; Stanley et al. 2003). Nitrogen limitation has been found to occur frequently in lakes with excessive availability of natural and/or anthropogenic P (Havens et al. 1996; Nürnberg & Peters 1984; Stanley et al. 2003), in water bodies with abundant macrophyte growth (Ozimek et al. 1990; Van Donk et al. 1993; Sheffer 2004), and where conditions are adequate for denitrification processes (Vitousek & Howarth 1991; Van Donk et al. 1993; Scheffer 2004).

Nitrogen limiting conditions may lead to growth of noxious cyanobacterial bloom. Therefore, a complete shift of TN:TP ratio toward low values is of great consequence for management of the studied reservoir since such conditions induce changes in phytoplankton communities (Takamura et al. 1992; Elser 1999) with domination of green and blue-green algae (Havens 1995; Havens et al. 1996; Sterner 1994) that can produce a nuisance environment to humans and animals due to algal toxicity, formation of surface scums, and production of obnoxious taste and odor compounds (Johnston & Jacoby 2003). While this study has not investigated the composition of phytoplankton community, the presence of cyanobacteria at this reservoir has been shown previously by Jones and Medrano (2006) supporting the existence of N-limiting conditions at the reservoir. The authors found that blue-green algae constituted 41% of the plankton in 2002 monitoring season and *Cylindrospermopsis reciborskii* was found at the level of 84,247 cells/mL (Jones and Sauter 2005). Consequently, the nitrogen limitation is a concern at this reservoir and future research should investigate the effects of trophic interactions, seasons, and thermal stratification on nutrient cycling and phytoplankton composition to clearly determine the factors affecting the shifts of TN:TP ratio from co-limitation to N-limiting conditions.

Implementation of management strategies to prevent growth of blue-green algae in the future is also necessary. Such management efforts should focus on reduction of both N and P because decreasing input of N from the watershed might not prevent growth of cyanobacteria due to their ability to fix atmospheric nitrogen (Scheffer 2004; Dzialowski et al. 2005). The management of anoxic conditions (e.g., using hypolimnetic water withdrawal or chemical precipitation) could also be considered to reduce and control the release of P from anoxic sediment.

In conclusion, this study characterized Prairie Creek reservoir as an eutrophic water body in which nutrients release from the sediment was intensified by hypolimnetic anoxia during summer. The results suggest N and P co-limitation of algal growth marked by seasonal shifts toward N-limiting conditions. Future research should investigate factors affecting these TN:TP shifts.

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