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Water-quality Effects on Phytoplankton Species and Density and Trophic State Indices at Big Base and Little Base Lakes, Little Rock Air Force Base, Arkansas, June through August, 2015

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Running title: Nutrients, Phytoplankton, and Trophic State Index in Small Lakes on Little Rock Air Force Base

Abstract

Big Base and Little Base Lakes are located on Little Rock Air Force Base, Arkansas, and their close proximity to a dense residential population and an active military/aircraft installation make the lakes vulnerable to water-quality degradation. The U.S. Geological Survey (USGS) conducted a study from June through August 2015 to investigate the effects of water quality on phytoplankton species and density and trophic state in Big Base and Little Base Lakes, with particular regard to nutrient concentrations. Nutrient concentrations, trophic-state indices, and the large part of the phytoplankton biovolume composed of cyanobacteria, indicate eutrophic conditions were prevalent for Big Base and Little Base Lakes, particularly in August 2015. Cyanobacteria densities and biovolumes measured in this study likely pose a low to moderate risk of adverse algal toxicity, and the high proportion of filamentous cyanobacteria in the lakes, in relation to other algal groups, is important from a fisheries standpoint because these algae are a poor food source for many aquatic taxa. In both lakes, total nitrogen to total phosphorus (N:P) ratios declined over the sampling period as total phosphorus concentrations increased relative to nitrogen concentrations. The N:P ratios in the August samples (20:1 and 15:1 in Big Base and Little Base Lakes, respectively) and other indications of eutrophic conditions are of concern and suggest that exposure of the two lakes to additional nutrients could cause unfavorable dissolved-oxygen conditions and increase the risk of cyanobacteria blooms and associated cyanotoxin issues.

Introduction

Eutrophication, the process by which primary production in aquatic ecosystems is increased by nutrients, poses a widespread threat to water quality in both freshwater and marine ecosystems (Smith et al. 1999). The potential consequences of eutrophication include excessive plant/algal growth, harmful algal blooms (HABs), dissolved-oxygen (DO) depletion (anoxia), fish kills, alteration of food webs, and loss of ecosystem services such as fish consumption and recreational amenities (Smith et al. 1999, Carpenter 2005). Cyanobacterial harmful algal blooms (cyanoHABs) can result in low and unstable DO concentrations, possible toxic conditions for humans and animals, and negative effects on fish biomass and density (Lee et al. 1991).

Primary production (i.e. phytoplankton stimulus), which is often limited by nitrogen, phosphorus, or light, is a key determinant of fish density and diversity in streams and lakes (Downing and Plante 1993). Because phytoplankton are the base of freshwater food webs, the growth, survival, and biomass of fish in lakes are often correlated with phytoplankton density (Oglesby 1977, Downing et al. 1990, Diana et al. 1991). Thus, fish production generally increases as lakes become more eutrophic (Bachmann et al. 1996).

Big Base and Little Base Lakes, located on the Little Rock Air Force Base (LRAFB, Fig. 1) in Arkansas, are used for recreational fishing and other recreational activities (e.g. kayaking). In addition, these lakes provide forage (fish) for a federally endangered Interior Least Tern (*Sterna antillarum athalassos*) population that nests annually on the LRAFB. Close proximity to a residential population and an active military aircraft installation make Big Base and Little Base Lakes vulnerable to water-quality degradation. Assisting Federal resource managers is an important part of the USGS mission, and previous studies conducted by the USGS have indicated that both lakes are susceptible to eutrophication (Justus 2005). Periodic assessments of biological and chemical conditions are necessary to monitor changes in water quality and to support future decisions and management efforts in both lakes.

The purpose of this study was to investigate water quality, phytoplankton, and trophic-state in Big Base and Little Base Lakes to assess their relations with eutrophication, cyanoHABS, and potential risks to humans and wildlife. Information provided in this article will provide a baseline to which LRAFB personnel can compare future water-quality conditions, thereby enabling them to make informed decisions for managing nutrients and fish and wildlife resources in the two lakes.

Materials and Methods

Study area

Located northeast of Little Rock, Arkansas (Fig. 1), LRAFB sits along the fall line between the Ozark Highlands and the Mississippi Alluvial Plain. The LRAFB covers approximately 24.3 km^2 and accommodates more than 11,000 military and civilian personnel, several thousand of which live on base (United States Air Force 2016). Big Base and Little Base Lakes are located near the western boundary of LRAFB and are connected by a culvert beneath Arnold Drive (Fig. 1; Table 1). Under normal lake conditions, the surface areas of Big Base Lake and Little Base Lake are approximately 16 hectare and 0.5 hectare, respectively (Justus 2005). The land surrounding the lakes comprises suburban development (residential and commercial), aircraft installations, and small forested tracts.

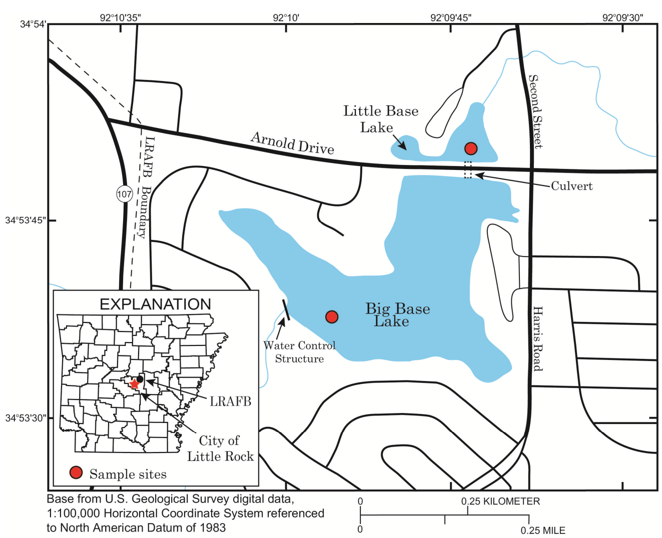

Figure 1. Map of sample site locations in Big Base and Little Base Lake, Little Rock Air Force Base, Arkansas, 2015.

Table 1. Site information for two lake sites sampled at Little Rock Air Force Base, Arkansas, 2015. Latitude and longitude coordinates are relative to the North American Datum of 1927 (NAD 27). [USGS, U.S. Geological Survey]

Site name	USGS station number	Latitude	Longitude
Big Base Lake	07263924	34° 53' 38"	92° 09' 57"
Little Base Lake	07263922	34° 53' 50"	92° 09' 43"

Field Collections

The USGS collected water-quality and phytoplankton samples from Big Base and Little Base Lakes three times each during the summer of 2015 (June 4, July 9, and August 20). The Big Base Lake sample site was located at the deepest part of the lake (depth approximately 6 m) east of the water-control structure (Fig. 1). The Little Base Lake sample site was located near the center of the lake where the depth was approximately 1 m. Vertical-depth profiles of DO, pH, specific conductance, turbidity, and water temperature were measured at 0.3-m depth intervals with a calibrated multiparameter water-quality monitor in both lakes on each sampling date. Transparency (optical clarity) was measured with a Secchi disk.

Water-quality samples were collected and processed according to USGS protocols (Wilde et al. 1999, Green et al. 2015). Water samples for nutrient concentrations, phytoplankton composition, and chlorophyll *a* were collected by pumping water to the lake surface using a peristaltic pump and weighted

hose. In Big Base Lake, water was pumped from a depth approximately midway (1.0-1.5 m) through the epilimnion (the uppermost thermal stratification layer), whereas water from Little Base Lake was pumped from a depth midway through the water column (approximately 0.6 m). In addition, field observations were recorded for lake appearance and weather characteristics.

Laboratory Processing and Analysis

Water-quality constituents were selected for sampling and analysis based on their potential relation and impact on phytoplankton density and lake trophic status (Wetzel 2001). Nutrient constituents included total nitrogen, dissolved ammonia, dissolved nitrite plus nitrate, organic nitrogen, dissolved orthophosphate, and total phosphorus. Total nitrogen represents combined forms of organic and inorganic

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nitrogen (i.e. nitrite plus nitrate and ammonia nitrogen). Organic nitrogen was calculated as total nitrogen minus the total concentrations of nitrite plus nitrate and ammonia. If either nitrite plus nitrate or ammonia concentrations were below laboratory detection levels, the range of organic nitrogen concentrations was reported as total nitrogen minus the lowest (i.e. zero) and highest (i.e. detection level) concentrations of each constituent. Water-quality samples for chemical analyses were shipped overnight on ice (on the date of collection) to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, and analyzed following USGS procedures (Fishman 1993). Phytoplankton were identified and counted in a laboratory at the University of Arkansas at Little Rock by USGS personnel (Dr. Reed Green) using the inverted-microscope method described by Britton and Greeson (1989). Calculations of cell/colony biovolume (mm^3/L) for each algal taxa followed formulas in Kellar et al. (1980). Water-quality and depth profile data used in support of this article are available from the USGS National Water Information System (U.S Geological Survey 2016).

Concentrations of total phosphorus and chlorophyll *a* and Secchi depth measurements are often related to algal density. Because algal density increases in response to increased productivity, Carlson's trophic state index (TSI) values calculated using phosphorus, chlorophyll *a*, and Secchi depth measurements are often used to determine trophic status (oligotrophic <40; mesotrophic 40-49; eutrophic 50-69; hypereutrophic ≥70 (Wetzel 2001)). Carlson's TSI values were calculated from total phosphorus and chlorophyll *a* concentrations, and Secchi depth measurements using the following equations:

$$\text{TSI (TP)} = 14.42 \ln(\text{TP}*1000) + 4.15 \quad (1)$$

$$\text{TSI (CHL)} = 9.81 \ln(\text{CHL}) + 30.6 \quad (2)$$

$$\text{TSI (SD)} = 60 - 14.41 \ln(\text{SD}) \quad (3)$$

where TP is total phosphorus concentration (milligrams per liter), CHL is chlorophyll *a* pigment concentrations (micrograms per liter), SD is Secchi depth measurement (meters, m) (Carlson 1977), and ln is the natural logarithm. The TSI can be used to assess lake productivity along a continuum of trophic states assuming that lakes age in progression from oligotrophic (i.e. low nutrient input, low productivity) to eutrophic (i.e. high nutrient input, high productivity; Wetzel 2001).

Results

Vertical water-temperature profile measurements indicate that Big Base Lake was thermally stratified on all three sampling dates during the summer of 2015. Maximum surface temperatures ranged from 24.4 to 27.9 °C, whereas minimum bottom temperatures ranged from 11.6 to 13.6 °C. Changes in water temperature near the thermocline in Big Base Lake were more gradual on August 20 compared to the two prior sampling events (less than 1 C° change over a depth of almost 1 m, compared to more than 1 C° over 0.6 and 0.3 m for June and July, respectively). DO concentrations ranged from 0.1 to 9.4 mg/L across all depths, with concentrations generally less than 3.0 mg/L below the 2-m depth in each monthly sample. Values of pH varied little across depth and ranged from 6.4 to 7.5 in the epilimnion. Median pH over the sampling period was 6.2 across all depths. Turbidity

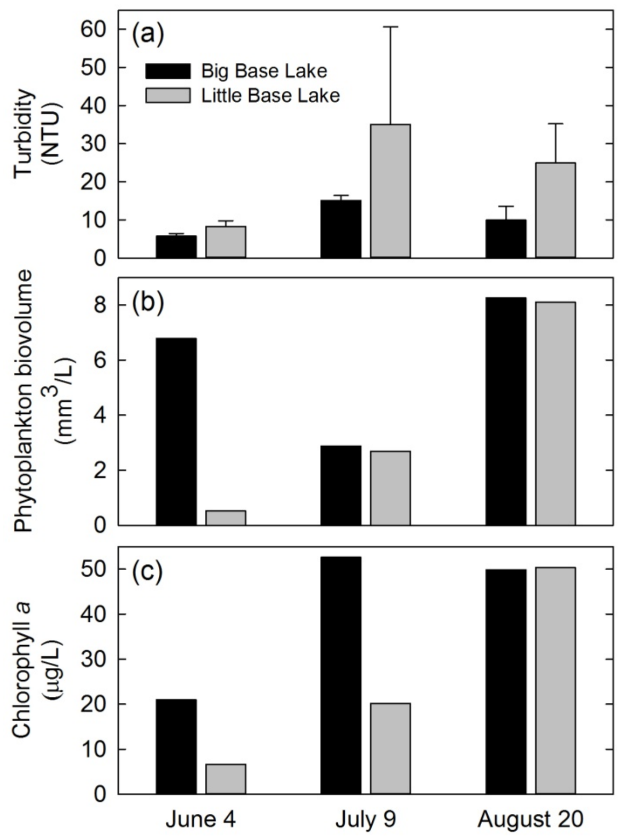

Figure 2. Bar graphs indicating mean (±SD) water column turbidity, total phytoplankton biovolume, chlorophyll *a* and for samples collected from June through August, 2015 in Big Base and Little Base Lakes, Little Rock Air Force Base, Arkansas. [NTU, nephelometric turbidity units; mm^3/L, millimeters cubed per liter; µg/L, micrograms per liter]

Table 2. Laboratory results for selected nutrients from water samples collected from Big Base and Little Base Lakes, Little Rock Air Force Base, Arkansas, June through August, 2015. [<, censored values at or below laboratory minimum detection limit; mg/L, milligrams per liter; N, nitrogen; P, phosphorus]

	Sample date	Organic nitrogen[1] (mg/L)	Ammonia, dissolved (mg/L as N)	Nitrite plus nitrate, dissolved (mg/L as N)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Ortho-phosphate, dissolved (mg/L as P)
Big Base Lake	June 4	0.29-0.34	<0.01	<0.04	0.34	0.006	<0.004
	July 9	0.30-0.35	<0.01	<0.04	0.35	0.008	<0.004
	Aug. 20	1.0-1.1	0.13	<0.04	1.2	0.06	<0.004
Little Base Lake	June 4	0.33-0.38	<0.01	<0.04	0.38	0.014	0.006
	July 9	0.37-0.42	0.02	<0.04	0.42	0.017	<0.004
	Aug. 20	1.1	0.11	<0.04	1.2	0.084	<0.004

[1]Organic nitrogen was calculated as total nitrogen minus the total concentrations of ammonia plus nitrite and nitrate. If either ammonia or nitrite plus nitrate concentrations were below laboratory detection levels, the range of organic nitrogen concentrations was reported as total nitrogen minus the lowest (i.e. zero) and highest (i.e. detection level) concentration of each constituent.

differed between the three monthly samples (Fig. 2a), but turbidity in Big Base Lake was fairly uniform throughout the water column profile on June 4 (mean = 5.7 ± 0.7 nephelometric turbidity units (NTU)) and July 9 (15.1 ± 1.3 NTU). In contrast, turbidity was stratified on August 20 and averaged 13.5 NTU in the epilimnion compared to 6.7 NTU in the hypolimnion (depths below 2.4 m), with an overall mean of 9.9 ± 3.6 NTU. Secchi depth measurements decreased from 1.09 m on June 4, to 0.96 m on July 9, to 0.48 m on August 20.

Little Base Lake was shallow (~0.7-1.4 m) and was not thermally stratified during the three sampling events. Water-quality constituents in Little Base Lake were generally similar to surface readings from Big Base Lake: mean values for temperature and DO were 24.3 °C and 5.3 mg/L, respectively, and median pH was 6.2. Turbidity and Secchi depth were also similar to values from Big Base Lake in that the highest mean turbidity measurement (20.3 NTU) was recorded in the July sample (Fig. 2a) and the shallowest Secchi depth measurement (0.46 m) was recorded in the August sample.

Total nitrogen and total phosphorus concentrations generally increased over the sampling period—the highest concentrations from both lakes were measured on August 20 (Table 2; Fig. 3). Organic nitrogen comprised the majority of the total nitrogen concentration as dissolved ammonia was detected only in the August sample from Big Base Lake and in the July and August samples from Little Base Lake, and nitrite plus nitrate was not detected in any of the three samples from either lake (Table 2). Orthophosphate was detected once on June 4 in Little Base Lake. Total nitrogen to total phosphorus (N:P) concentration ratios declined over time between the June and August samples in both lakes, but the decline was more pronounced in Big Base Lake (Fig. 3). Carlson's TSIs

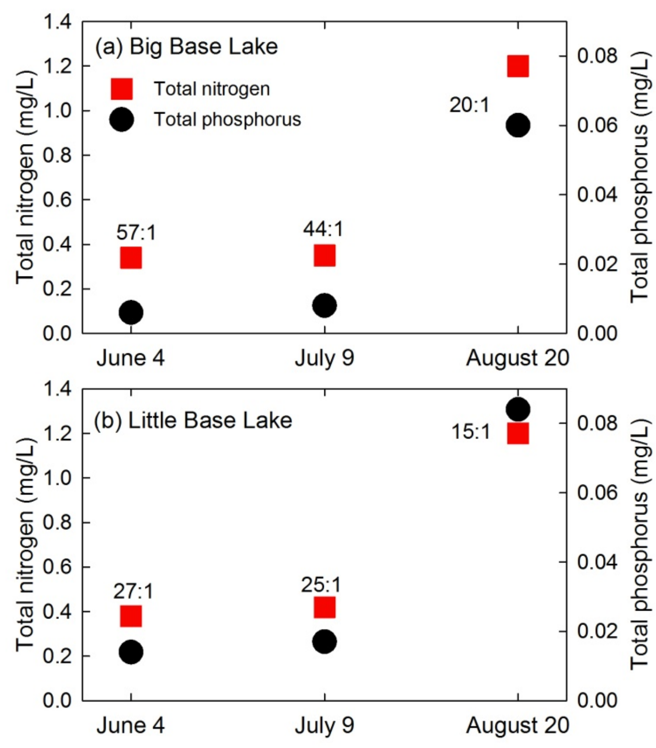

Figure 3. Total nitrogen (N) and total phosphorus (P) for samples collected in June, July, and August for Big Base and Little Base Lakes, Little Rock Air Force Base, Arkansas, 2015. Inset values are N:P ratios. [mg/L, milligrams per liter]

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Table 3. Carlson's trophic-state indices of total phosphorus, chlorophyll *a*, and Secchi depth measurements for Big Base and Little Base Lakes, Little Rock Air Force Base, Arkansas, June through August, 2015. Values ≥ 50 (in bold) indicate eutrophic conditions (Carlson 1977).

		Carlson's trophic-state index	
Index	Sample Date	Big Base Lake	Little Base Lake
Phosphorus	June 4	30	42
	July 9	35	45
	Aug. 20	**63**	**68**
Chlorophyll *a*	June 4	**60**	49
	July 9	**69**	**60**
	Aug. 20	**69**	**69**
Secchi transparency	June 4	**59**	**63**
	July 9	**61**	**65**
	Aug. 20	**70**	**71**

for total phosphorus, chlorophyll *a*, and Secchi depth measurements varied from 30 to 70 at Big Base Lake and 42 to 71 at Little Base Lake (Table 3).

In Big Base Lake, total phytoplankton biovolume was highest in the August sample and was second highest in the June sample; however, chlorophyll *a* concentration was lowest on June 4 and highest on July 9 (Fig. 2b-c). The phytoplankton community in Big Base Lake was largely dominated by cyanobacteria over the sampling period (Fig. 4), and taxa within genus *Anabaena* were particularly abundant (Table 4).

In Little Base Lake, total phytoplankton biovolume and chlorophyll *a* concentrations increased over the three sampling events (Fig. 2b-c). However, low total phytoplankton biovolume in the June sample may be underestimated due to a sample-processing error in which the algae sample was poorly preserved. Phytoplankton communities in the June and August samples were predominately cyanobacteria (*Anabaena* spp; Fig. 4; Table 4). In the July sample, cyanobacteria biovolume was relatively low and the overall phytoplankton biovolume was evenly distributed across the four algal groups compared to the biovolume measured in the June and August samples (Fig. 4). The most prominent taxon on July 9 was a colonial diatom, *Tabellaria*; however, a cyanobacterium, *Chroococcus prescotti*, had only slightly less biovolume (Table 4).

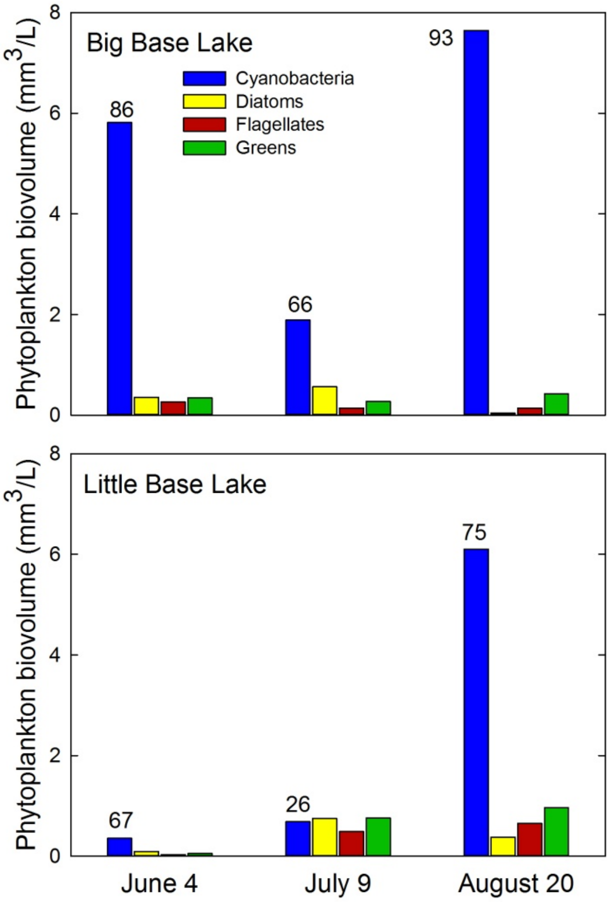

Figure 4. Total biovolume for four groups of phytoplankton in Big Base and Little Base Lakes, Little Rock Air Force Base, Arkansas, June through August, 2015. Inset values are the relative percentages of cyanobacteria. [mm^3/L, millimeters cubed per liter]

Discussion

Nutrient concentrations (including N:P ratios), Carlson’s TSI indices, and the large percentage of phytoplankton biomass composed of cyanobacteria indicate eutrophic conditions were prevalent during the three summer sampling events, particularly for the August sample. In general, nutrient-related conditions in Big Base and Little Base Lakes were similar to those observed in the summer conditions in 2003-04 (Justus 2005).

Small temperate lakes and ponds in populated areas are susceptible to pulses of nutrient inputs and eutrophication due to runoff from the landscape, and it is common for lakes to have high, as well as, temporally variable nutrient loads (Dodds and Whiles

Table 4. Synopsis of the three most dominant algae taxa by biovolume collected from Big Base and Little Base Lake, Little Rock Air Force Base, Arkansas, June through August 2015. [mm^3/L, millimeters cubed per liter; %, percent]

Lake	Sample date	Group	Taxon	Biovolume (mm^3/L)	Biovolume (%)
Big Base Lake	June 4	Cyanobacteria	*Anabaena affinis*	4.14	61
		Cyanobacteria	*Anabaena* sp.	1.39	20
		Cyanobacteria	*Anabaena planktonica*	0.24	3
	July 9	Cyanobacteria	*Anabaena planktonica*	1.32	46
		Cyanobacteria	*Gomphosphaeria lacustris*	0.56	19
		Diatom	*Asterionella formosa*	0.55	19
	Aug. 20	Cyanobacteria	*Anabaena planktonica*	5.76	70
		Cyanobacteria	*Anabaena affinis*	1.19	14
		Cyanobacteria	*Anabaena* sp.	0.55	7
Little Base Lake	June 4	Cyanobacteria	*Anabaena affinis*	0.32	61
		Diatom	*Aulacoseria*	0.08	16
		Green	*Pediastrum duplex*	0.04	7
	July 9	Diatom	*Tabellaria*	0.47	17
		Cyanobacteria	*Chroococcus prescotti*	0.4	15
		Green	*Sphaerocystis* sp.	0.3	11
	Aug. 20	Cyanobacteria	*Anabaena planktonica*	4.96	61
		Cyanobacteria	*Anabaena* sp.	0.51	6
		Cyanobacteria	*Anabaena affinis*	0.41	5

2010). Marked increases in total nitrogen and total phosphorus concentrations in the August samples from both lakes could have been partially influenced by precipitation through two different mechanisms. First, heavy rain just prior to the August sampling event likely contributed to an increase in nutrient concentrations in both lakes due to overbank runoff from the surrounding suburban landscape. Second, cool water temperatures near the thermocline on August 20, which is typically hotter than June and July, suggest that precipitation resulted in cooler lake temperatures and subtle mixing of the epilimnion and hypolimnion. This mixing could have exposed the epilimnion to nutrients that had accumulated in the hypolimnion of Big Base Lake over summer. Vertical mixing of the hyplimnion and epilimnion in stratified lakes can release nutrients (e.g. ammonia) from hypoxic sediments (internal load) and alter nutrient concentrations within the water column (Paerl et al. 2001, Wetzel 2001).

Carlson's TSI values for chlorophyll *a* and Secchi depth measurements indicate conditions in both lakes were consistently eutrophic across samples in each month, but phosphorus TSI values indicate that both lakes were mesotrophic during the collection of June 4 and July 9 samples. The highest TSI values as well as increased total phytoplankton biovolume and chlorophyll *a* concentrations on August 20 indicate that these variables generally responded positively to increased nutrients. Carlson's TSI values may vary seasonally as nutrient and phytoplankton dynamics change with differing lake conditions (i.e. temperature, DO, turbidity). Carlson (1977) suggested that chlorophyll *a* be given priority for interpreting trophic status during summer months because the relation between phytoplankton growth and chlorophyll *a* is

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perhaps more straightforward than the relation between phytoplankton growth and phosphorus.

Phytoplankton communities in both lakes were dominated by cyanobacteria, which composed generally between 66 and 93% of the total phytoplankton biovolume (except for the July 9 sample from Little Base Lake when cyanobacteria biovolume was only 26%; see Fig. 4). Taxa within the genus *Anabaena* were the dominant algae and these species are capable of producing HABs that result in toxins such as microcystin and anatoxin that are harmful to humans and animals (Paerl et al. 2001). Cyanobacteria biovolumes in Big Base and Little Base Lake ranged between 0.24 and 7.5 mm^3/L and represent a low (<2.5 mm^3/L) to moderate risk (2.5-12.5 mm^3/L) to human health based on criteria set by the World Health Organization (WHO) for recreational, non-consumptive waters (Falconer et al. 1999). Biovolumes of *Anabaena* taxa in the current study were generally similar to values reported by Justus (2005); however, the relative proportions of cyanobacteria were considerably higher in the current 2015 study.

The abundance and impacts of cyanobacteria are known to vary with the relative availability of nitrogen and phosphorus in the environment, in which cyanoHABs have often been associated with nutrient enrichment, particularly phosphorus, and lower N:P ratios (Smith 1983, Downing et al. 2001, Paerl et al. 2001, Anderson et al. 2002). Cyanobacteria taxa are able to fix atmospheric nitrogen and may out compete other algae in nitrogen-limited conditions (i.e. low N:P ratios; Smith 1983, Paerl et al. 2001). High biovolumes/proportions of cyanobacteria in the August samples corresponded with increased nutrient concentrations and decreased N:P ratios in both lakes and indicate that both lakes may be vulnerable to periodic cyanoHABs.

Conclusions

Nutrient concentrations and cyanobacteria densities throughout the sample period in Big Base and Little Base Lakes suggest that exposure to additional nutrients, particularly total phosphorus, could result in unfavorable water-quality conditions (i.e. low DO) and increase the risk of toxicity issues associated with eutrophication and cyanoHABs. Based on criteria set by the World Health Organization (WHO) for recreational, non-consumptive waters, densities of cyanobacteria measured during the study pose a low to moderate risk of adverse algal toxicity, and, as such, are a water-quality concern. The occurrence of high proportions of filamentous cyanobacteria in these lakes is an important consideration from a fisheries standpoint, because they are generally considered a poor food source for many aquatic taxa (Paerl et al. 2001). If a large portion of the basal food web is not utilized, increases in nutrient concentrations could further increase the risk of cyanoHABs rather than the more desired effect of increasing fish production, and could decrease the value of these lakes as a recreational resource and as a foraging resource for endangered Interior Least Tern.

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