Lake health threats research study: An analysis of *E. coli* and blue-green algae toxins in Kosciusko County, Ind.

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Abstract:

Local water resources influence human health. The present study identifies *E. coli* and microcystin (blue-green algae toxin) as current lake-related human health threats to residents of Kosciusko County. Long-term, weekly *E. coli* sampling at seven public swimming beach sites by the Kosciusko County Health Department was confirmed to be an important endeavor to protect the public. Pike and Center Lake swimming areas were shown to have unsafe *E. coli* levels in 41% and 32% of samples collected, respectively. Monthly microcystin sampling by Kosciusko Lakes and Streams in 2010 and 2011 showed only four of 44 lakes sampled had no microcystin detected during the study; there were 14 lakes that had elevated microcystin levels. Some promising results with predictor variables such as TP were obtained, but these relationships were inconsistent among some lakes and will require further study. Both *E. coli* and microcystin levels were highest during summer months which coincide with increased recreational use of the lakes, allowing for elevated exposure threats. Public notification systems utilized in this study are critical to improving health safety related to *E. coli* and microcystin into the future.

Keywords: blue-green algae, Kosciusko County, nutrients, *E. coli*, notification systems

Introduction

Local water resources influence human health. Drinking water typically comes from either surface waters such as a river or lake or from ground water. Food in the form of fish and shellfish come from local surface waters and often accumulate toxins from the water or sediments where they live. Recreation in rivers and lakes can benefit the local populations' health by offering many diverse opportunities for exercise and inspiration. However, recreation in local surface waters can also present human health risks in the form exposure to disease-causing agents, unpredictable accidents, and negligence.

Recently, one of the most alarming human health concerns related to lakes is the presence of blue-green algae toxins (Backer et al., 2009; Funari and Testai, 2008; Manganelli et al., 2010). Funari and Testai (2008) review the state of present knowledge in the area of blue-green algae toxins as a human health threat. They describe several different classes of toxins which can be hapatotoxins (affecting liver), neurotoxins (affecting nervous system), cytotoxins (affecting specialized cells of the body), gastrointestinal toxins (affecting digestive system), and skin irritants. Research has shown that high levels of these toxins can be lethal to humans, and emerging research is indicating that chronic low-level toxin exposure can also lead to terminal health problems. Toxin exposure can come from less serious skin exposure to more serious ingestion (Funari and Testai, 2008). Research on two lakes in California has even shown that exposure can occur through inhalation of toxin aerosols near lakes with high blue-green algae populations (Backer et al., 2009). More recent research by Manganelli et al. (2010) has also demonstrated that more toxic blue-green algae can live farther below the water surface making visual detection difficult.

The present study focuses on human health threats of *E. coli* and blue-green algae toxins in the lakes of Kosciusko County. Historical data (1996-2010) from the Kosciusko County Health Department (KCHD) was analyzed for trends in *E. coli* and to formalize solutions to minimize associated human health threats. More current sampling (2010-2011) results of *E. coli* and blue-green algae toxins (microcystin) by Kosciusko Lakes and Streams (KLAS) as part of the present study are then summarized and analyzed to determine current health threats and set future research directions.

Methods

Study area

Kosciusko County contains 104 lakes greater than 5 acres in surface area (Figure 1). Most of these lakes are glacially formed and have varying lake bottom substrates (see www.water.grace.edu for individual lake details). All lakes with a surface area greater than 25 acres were selected for near shore sampling in the present study by KLAS (Table 1). The eleven all-sports lakes had two sampling sites – one near shore and one off shore. The near shore sampling sites were at representative swimming areas. The off shore, or open lake, sampling sites were at the deepest point of the lake. Syracuse Lake had two public swimming beaches sampled by the KCHD, so the present KLAS study also sampled both of these near shore sites as well as an off shore site.

Field sampling

Lake sampling was conducted at monthly intervals during August-September in 2010 and May-September in 2011. All lakes were sampled each month within a four day time period to allow comparisons between lakes at a given time.

Near shore sampling occurred at all 44 lakes included in the study (Table 1), including two near shore sites at the public swimming beaches of Syracuse Lake. At each site a Secchi depth measurement was made to determine water clarity, and an *E. coli* sample was taken at approximately 0.5 m depth. Next, dissolved oxygen and water temperature was measured at the surface, 0.5 m, and 1 m depths using a YSI 550A meter. Finally, an integrated water sample from the surface to bottom was taken using a vertical Van Dorn sampler. This integrated water sample was used for the blue-green algae toxin (microcystin) sample as well as for an in-field pH measurement using an Extech Instruments ExStik2 meter.

Open lake sampling occurred at 11 all-sports lakes included in the study (Table 1). At each site a Secchi depth measurement was made to determine water clarity, and an *E. coli* sample was taken at approximately 0.5 m depth. Next, dissolved oxygen and water temperature was measured at each meter from the surface to the lake bottom. Finally, an integrated water sample from the surface to 2 m depth was taken. This integrated water sample was used for the blue-green algae toxin (microcystin) sample as well as for an in-field pH measurement.

Beginning in 2011, a multi-parameter sample was added which included suspended solids, conductivity, chloride, fluoride, sulfate, silicon dioxide, total phosphorus (TP), soluble reactive phosphorus, total nitrogen (TN), total Kjeldahl nitrogen, ammonia, nitrate, and nitrite. Samples were taken at open lake sites at a depth of 1 m below the lake surface and 1 m above the lake bottom using a vertical Van Dorn sampler. A pH measurement was also taken from the samples collected at 1 m above the bottom of the lake.

Lab analysis

Water samples obtained in the field for later lab analysis were stored in the dark near 2° C until returning to Grace College each day. Microcystin samples were immediately frozen. *E. coli* and multi-parameter samples were kept at 2° C. Microcystin samples were transported to the Center for Earth and Environmental Science at Indiana University-Purdue University at Indianapolis for analysis within 5 days of field sampling. *E. coli* samples were transported to the Kosciusko County Health Department for analysis within 24 hours of field sampling. Multi-parameter samples were transported to the National Center for Water Quality Research at Heidelberg University for analysis within 7 days of field sampling.

Data analysis

Data was collected in the field and immediately recorded electronically throughout project to aid in notification systems and avoid any loss of data. Data was always checked twice for accuracy when transferred from field log sheets to computer spreadsheets. Several microcystin samples yielded concentrations below detection limits of 0.15 ppb. To aid in data summarization and statistical analyses, these data values were recorded as 0.075 ppb.

Results and Discussion

Analysis of historical *E. coli* data record

Sampling for *E. coli* has been conducted by the KCHD since 1996 across the seven public swimming beaches of Kosciusko County (Table 1). Analysis of this data yielded important findings about overall *E. coli* trends and confirmed the importance of long-term data sets. Annual average *E. coli* concentrations remained low across the fifteen years of data for most lakes with the notable exceptions of Pike Lake and Center Lake which had annual average concentrations over the beach closure threshold of 235 cfu/100 mL for several years (Figure 2). Annual fluctuations in *E. coli* concentrations were not consistent over the different sampling sites, indicating that these lakes have unique characteristics driving *E. coli* populations in them. Monthly average *E. coli* concentrations showed the highest levels during the summer months of June, July, and August (Figure 3). Again, Pike and Center Lakes were consistently higher than other lakes. Over this period of fifteen years of weekly sampling by the KCHD, Center Lake and Pike Lake had *E. coli* concentrations above the beach closure threshold 32% and 41% of the time, respectively. The *E. coli* levels in Pike and Center lakes are concerning.

Analysis of present *E. coli* sampling

The present KLAS study sampled *E. coli* concentrations across the 56 sampling sites in 2010 and 2011. *E. coli* concentrations were on average 12 cfu/100 mL higher at the near shore sampling sites compared to the open lake sampling sites, indicating *E. coli* sources near shorelines. KLAS sampling confirmed the importance of sampling at a weekly frequency since some high *E. coli* levels were found by KCHD in between monthly KLAS sampling. The seven KCHD sampling sites were among the worst seen in the 56 KLAS sampling sites. This may indicate that KCHD is sampling some of the higher risk lakes from a human health perspective. It is important to point out, however, that several other lakes, including Big Chapman, Silver, Stanton, and Muskellunge Lakes, each had a single sample that showed *E. coli* concentrations above the beach closure threshold of 235 cfu/100 mL.

Blue-green algae toxin sampling

Results for the blue-green algae toxin, called microcystin, showed several interesting patterns and some concerning elevated levels in certain lakes. On average across the two years of sampling and the 56 sampling sites, toxin concentrations were 0.09, 0.70, 0.97, 0.30, and 0.27 ppb for May, June, July, August, and September, respectively. Similar to *E. coli* concentrations being elevated in summer months, blue-green algae toxins also seem to follow this pattern. Only four of the 44 lakes sampled had no microcystin detected during the duration of the study, including Boner, Palestine, Sechrist, and Winona Lakes. The Indiana Department of Environmental Management has set a threshold of 4 ppb of microcystin for reducing recreational contact with water for human health concerns. Lake Wawasee had a toxin concentration of 63 ppb in 2009 which prompted the present study. During 2010 and 2011, there were four lakes which exceeded this 4 ppb threshold – Big Chapman (4.5 ppb in July 2011), Dewart (5.9 ppb in June 2011), Muskellunge (12 ppb in August 2010), and Wawasee (5.1 ppb in July 2011). Several other lakes had at least one sample with over 2 ppb microcystin, including Caldwell, Carr, Crystal, Goose, Hill, Irish, Little Chapman, Sawmill, and Syracuse Lakes.

This data indicates that blue-green algae toxins are a modest concern for human health in some Kosciusko County lakes.

Microcystin concentrations were tested against several potential predictor variables with varying success. Relationships varied widely among lakes, indicating other factors influencing blue-green algae toxins that were included in the present study. For example, epilimnion total phosphorus concentration was a great predictor variable for microcystin in Oswego Lake (Figure 4), but a very poor predictor in Lake Wawasee (Figure 5). It is important to note in these plots that only four data points are used which is too few to make any definitive conclusions. Overall, total phosphorus showed the most promise as a potential predictor variable for microcystin across most lakes. This is expected since blue-green algae are largely controlled by phosphorus availability (Millie et al., 2008). Other promising variables included Secchi depth which has a predictably negative relationship with microcystin. As the algae populations increased, the Secchi depth measurements decreased. The depth of the epilimnion layer also had a negative relationship among most lakes where microcystin decreased as layer thickness increased, which is likely due to the fact that a thicker layer indicates that algae are mixed down to deeper depths with less ideal light conditions. In all of these cases as well as the other variables tested, this data would be made more useful with additional sampling.

Notification systems

Existing public notification systems were utilized and expanded upon for both the *E. coli* and blue-green algae toxin sampling as part of the present study and will continue to be used into the future. The Indiana Department of Environmental Management created the Indiana Beaches Alert system as part of the Beach Guard website (https://extranet.idem.in.gov/BeachGuard/). This system allows users to sign up for various notification options to stay informed whenever a public swimming beach in Kosciusko County is closed for high *E. coli* levels. The KCHD has committed to continue using this system as an effective method to alert the public about this human health threat. The Indiana Department of Environmental Management also created a dedicated blue-green algae website which displays recent toxin levels in lakes around Indianapolis and now Kosciusko County as well (http://www.in.gov/idem/algae/). KLAS will continue to post microcystin concentrations to this website in the future as sampling is conducted. A potential complication of these notification systems is that some questions remain as to the ability of our local Spanish-speaking community to utilize these systems.

Implications

These research results have several important implications for Kosciusko County and other midwestern U.S. counties with lakes. First, both *E. coli* and blue-green algae toxin levels were shown to be highest during the summertime. Warmer water and air temperatures encourage human recreation in the lakes during the summer months as well, which increases the exposure risk. This highlights the usefulness and necessity of the notification systems set in place as a result of the present study.

Next, this study confirms that the KCHD sampling of Kosciusko County lakes during the summer months each year is vital to human health. The public swimming beaches tested by

KCHD seem to be located in several of the lakes with the highest *E.* coli concentrations. Furthermore, this study has shown that the weekly sampling frequency is important for the KCHD to maintain to ensure high levels of *E. coli* are identified in a timely manner, and that the public can then be notified rapidly.

This lake health threat study also demonstrates that each lake needs to be studied and managed separately. Data collected to date on Kosciusko County lakes show wide variation in *E. coli* and microcystin levels that do not always correlate well with the predictor variables that were tested. Solutions to human health problems in one lake may not be valid for another adjacent lake, and it is not enough to just study one lake in the county to get a general synopsis of Kosciusko County lakes overall.

Finally, the present study implies that further work needs to be done with Kosciusko County lakes in order to protect human health. Many preliminary patterns with blue-green algae toxins could be confirmed or disproven through further sampling efforts and more complete data analysis.

Future work

Sampling as part of the present KLAS study as well as historical sampling by the KCHD has identified the public swimming beaches of Pike and Center Lakes as concerning human health threats due to consistently high *E. coli* levels. Conversations have already begun with the KCHD about actions to be taken to minimize these health concerns. Solutions to high *E. coli* levels at these two beaches will likely include exploration of stagnant water trapped by swimming piers, high waterfowl populations, and direct sanitary sewer discharge to the lakes.

Unlike the *E. coli* part of the present study, blue-green algae toxins in Kosciusko County lakes are not understood well enough yet to propose certain actions to minimize human health threats. More work still needs to be done to characterize the microcystin concentrations across time and across the different lakes. Some promising predictor variables have been identified, but these relationships need to be confirmed. More factors influencing blue-green algae in Kosciusko County lakes also need to be considered in order to identify specific actions to protect human health in the future. Further research will also serve to continue to monitor this human health threat as better understanding of blue-green algae in Kosciusko County is achieved.

Conclusion

The present study identifies *E. coli* and microcystin (blue-green algae toxin) as current lake-related human health threats to residents of Kosciusko County. Long-term, weekly *E. coli* sampling at seven public swimming beach sites by the KCHD was confirmed to be an important endeavor to protect the public. Pike and Center Lake swimming areas were shown to have unsafe *E. coli* levels in 41% and 32% of samples collected by the KCHD, respectively. Monthly microcystin sampling by KLAS in 2010 and 2011 showed only four of 44 lakes sampled had no microcystin detected during the study; there were 14 lakes that had elevated microcystin levels. Some promising results with predictor variables such as TP were obtained, but these relationships were inconsistent among some lakes and will require further study. Both *E. coli* and microcystin levels were highest during summer months which coincide with increased recreational use of the lakes, allowing for elevated exposure threats. Public notifications systems utilized in this study are critical to improving health safety related to *E. coli* and microcystin into the future.

Acknowledgements

We are grateful to the following people for their insight related to this work: Lenore Tedesco, Nicolas Clercin, Mike Stouder, and Bill Jones. We also wish to thank the following boat owners who took us out sampling throughout the course of the study: Steve Anderson, Ken Brehob, Chuck Brinkman, Diana Castell, Buster Courtney, Lyn Crighton, Tom Dunn, Len Draving, Bill Gordon, Becky Hartman, Bill Magurany, Don and Dawn Meyer, and Chris Rankin. Many lake-front property owners also allowed us to gain access to the lakes for near shore samples. Kosciusko Lakes and Streams was established in 2007 with the vision and support of Dr. Ron Manahan, President of Grace College, and Suzie Light, Executive Director of the Kosciusko County Community Foundation. This research was funded by the K21 Health Foundation, Grace College, and private donations.

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Tables

Table 1. Lake sampling sites included in present study.

Lake Name	Latitude/Longitude (degrees)	Site Type	Lake Size (acres)	Health Department Site
Backwater Lake	41.31615, 85.67004	Near shore	189	
Beaver Dam Lake	41.09133, 85.97198	Near shore	146	
Beaver Dam Lake	41.09157, 85.97524	Open lake	146	
Big Barbee Lake	41.28802, 85.70242	Near shore	304	
Big Barbee Lake	41.28647, 85.70634	Open lake	304	
Big Chapman Lake	41.28750, 85.77840	Near shore	414	
Big Chapman Lake	41.28149, 85.79365	Open lake	414	
Boner Lake	41.43108, 85.72089	Near shore	40	
Caldwell Lake	41.12424, 85.90229	Near shore	45	
Camelot Lake	41.41694, 85.79337	Near shore	30	
Carr Lake	41.15819, 85.86029	Near shore	79	
Center Lake	41.24310, 85.85549	Near shore	120	x
Crystal Lake	41.23516, 85.98844	Near shore	68	
Dewart Lake	41.37385, 85.78273	Near shore	551	
Dewart Lake	41.37209, 85.77593	Open lake	551	
Diamond Lake	41.10541, 85.93382	Near shore	79	
Goose Lake	41.18977, 85.88303	Near shore	28	
Hill Lake	41.10752, 85.90884	Near shore	70	
Hoffman Lake	41.27538, 85.99001	Near shore	180	
Irish Lake	41.29276, 85.73309	Near shore	182	
James Lake	41.31745, 85.72312	Near shore	282	
James Lake	41.32078, 85.72589	Open lake	182	
Kuhn Lake	41.28099, 85.69418	Near shore	137	
Lake Tippecanoe	41.32446, 85.74200	Near shore	768	
Lake Tippecanoe	41.33408, 85.76875	Open lake	768	
Lake Wawasee	41.38576, 85.68483	Near shore	3410	
Lake Wawasee	41.40449, 85.70878	Open lake	3410	
Little Barbee Lake	41.28867, 85.72048	Near shore	74	
Little Chapman Lake	41.27188, 85.78696	Near shore	121	
Loon Lake	41.08316, 85.96662	Near shore	40	
McClure's Lake	41.08123, 85.95111	Near shore	34	

Lake Name	Latitude/Longitude (degrees)	Site Type	Lake Size (acres)	Health Department Site
Muskellunge Lake	41.17076, 85.85298	Near shore	32	
Oswego Lake	41.32990, 85.78367	Near shore	83	
Oswego Lake	41.32506, 85.78555	Open lake	83	
Palestine Lake	41.16908, 85.93968	Near shore	290	
Papakeechie Lake	41.37160, 85.66665	Near shore	189	
Pike Lake	41.24788, 85.84209	Near shore	230	x
Ridinger Lake	41.26077, 85.66436	Near shore	141	
Rock Lake	41.04129, 85.97614	Near shore	56	
Sawmill Lake	41.30028, 85.72938	Near shore	56	
Sechrist Lake	41.29752, 85.71688	Near shore	105	
Sellers Lake	41.15295, 85.74738	Near shore	32	
Shock Lake	41.35548, 85.69279	Near shore	32	
Shoe Lake	41.30650, 85.74950	Near shore	43	
Silver Lake	41.07897, 85.89878	Near shore	102	
Spear Lake	41.35709, 85.66479	Near shore	40	
Stanton Lake	41.32293, 85.76988	Near shore	30	
Syracuse Lake	41.42664, 85.74702	Near shore	414	x
Syracuse Lake	41.43001, 85.74925	Near shore	414	x
Syracuse Lake	41.42848, 85.73789	Open lake	414	
Waubee Lake	41.39492, 85.83566	Near shore	187	x
Webster Lake	41.32259, 85.69317	Near shore	585	x
Webster Lake	41.32858, 85.69328	Open lake	585	
Winona Lake	41.22225, 85.82243	Near shore	562	x
Winona Lake	41.22232, 85.83064	Open lake	562	
Yellow Creek Lake	41.10729, 85.95212	Near shore	150	

Figures

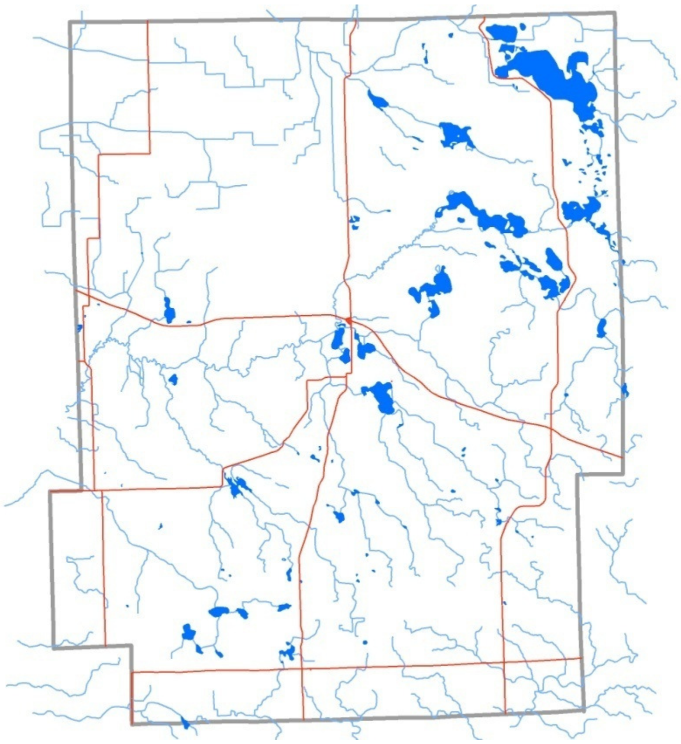

Figure 1. Map of Kosciusko County showing locations of lakes.

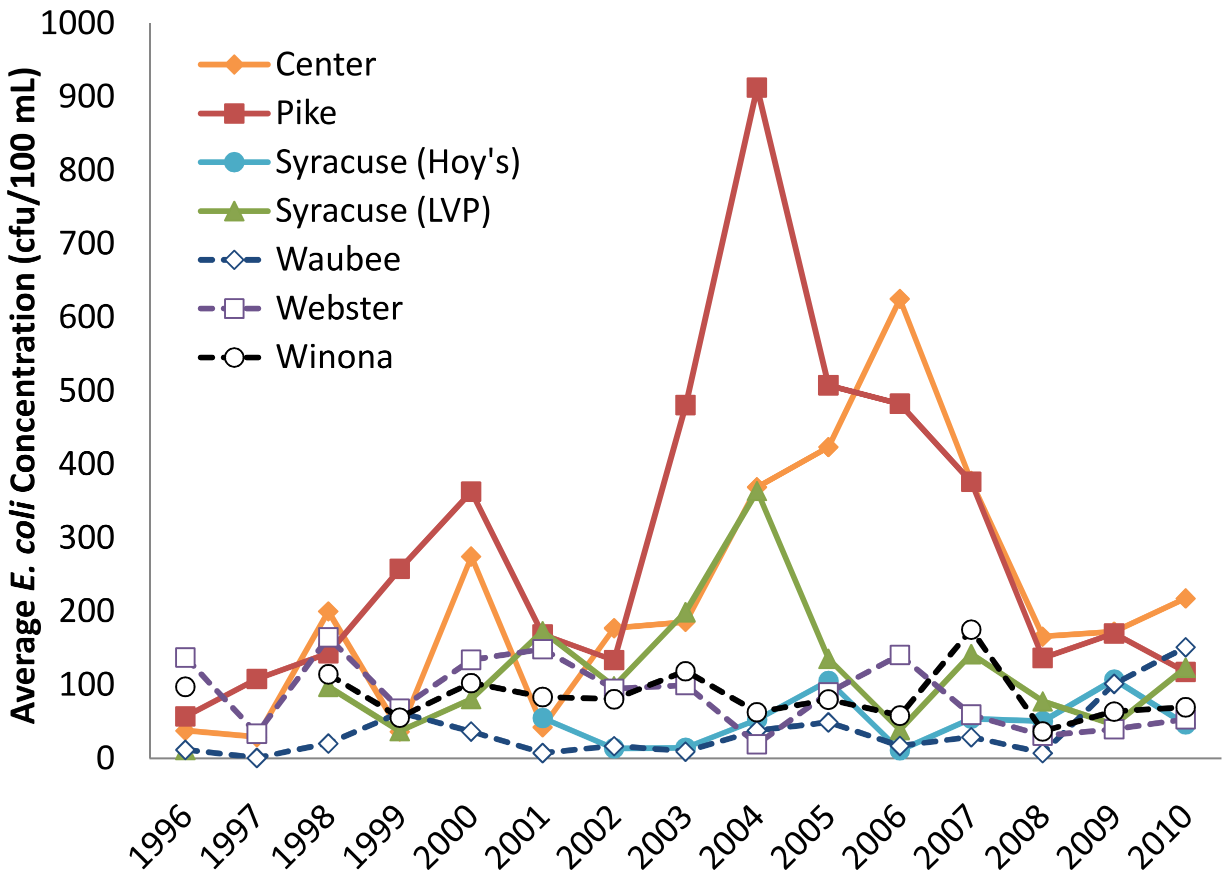

Figure 2. Average annual *E. coli* concentrations for seven public swimming beaches sampled by the Kosciusko County Health Department. Syracuse Lake has two public swimming beaches, Hoy's Landing and Lakeview Park.

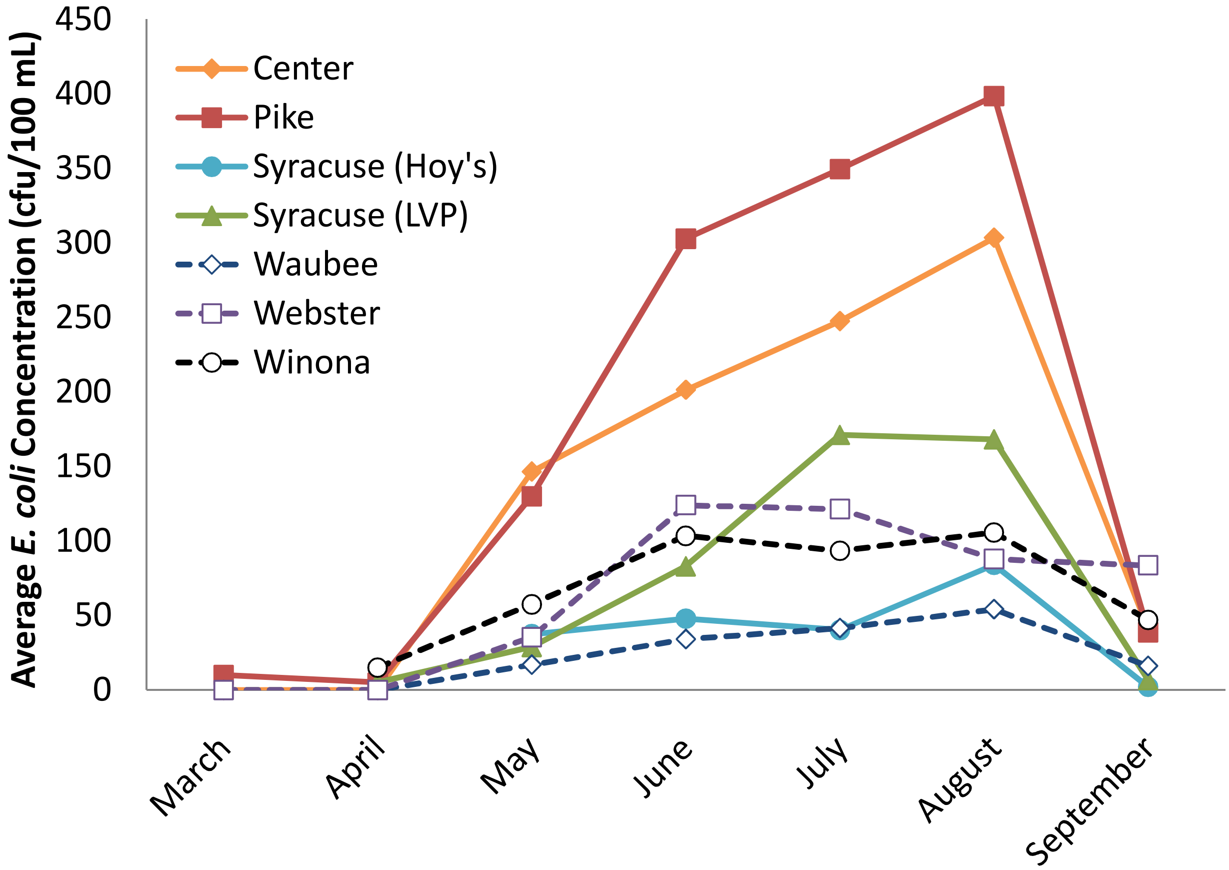

Figure 3. Average monthly *E. coli* concentrations for seven public swimming beaches sampled by the Kosciusko County Health Department over 1996-2010. Syracuse Lake has two public swimming beaches, Hoy's Landing and Lakeview Park.

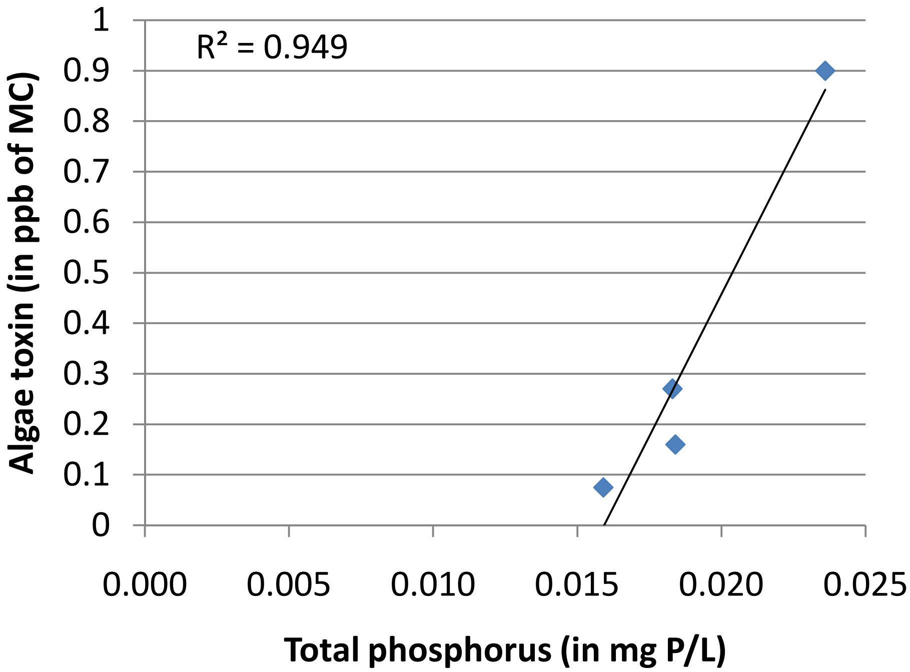

Figure 4. Relationship between epilimnion total phosphorus concentration and microcystin concentration in Oswego Lake during 2011.

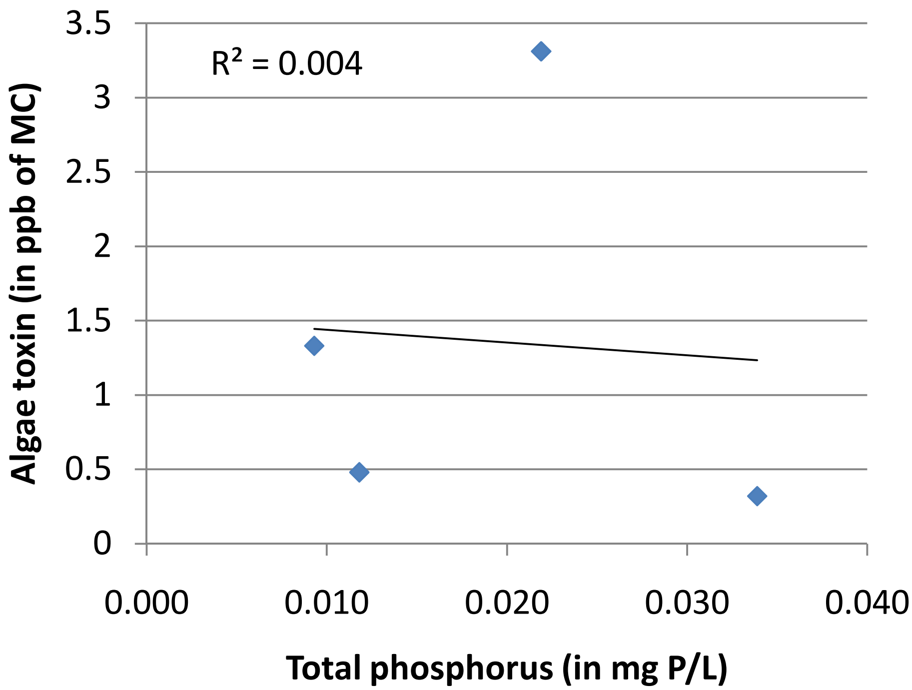

Figure 5. Relationship between epilimnion total phosphorus concentration and microcystin concentration in Lake Wawasee during 2011.