Climate Variability Influences Cyanobacteria **in Shallow Florida Lakes**

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Introduction

Many of Florida's nutrient-enriched lakes experience blooms of cyanobacteria nearly every summer. The blooms can lead to problems with aesthetics, with odor if they wash up on shore and die, and on occasion they can become toxic to aquatic organisms. It therefore is important to have a full understanding of what causes a wax and wane of cyanobacteria blooms that often is observed from year to year in Florida lakes, particularly when there are ongoing attempts to control them in response to federal law.

Cyanobacteria blooms generally are linked to high levels of nutrients in the lake water and the extent of nutrient enrichment of Florida lakes varies tremendously. To a large degree this is caused by a strong relationship between nutrient concentration of lake water and the natural levels of nutrients in underlying bedrock, watershed soils, and lake sediments (Bachmann et al. 2012). There also are cases where lakes have been enriched to a higher level than background by nutrients from human sources. One example is Lake Tohopekaliga, located south of Orlando. It once received high levels of nutrients from sewage treatment plants, and it had intense cyanobacteria blooms. The lake recovered after sewage diversion.

The concentration of phytoplankton in Florida lakes also varies considerably over time, across different areas of the lake, and sometimes due to the algae being concentrated along a shoreline when blown there by the wind. Rainfall and drought are factors that can cause large-scale changes in the concentration of phytoplankton and the occurrence of blooms in Florida lakes. Rainfall over the Florida peninsula is linked to distant ocean cycles, including the ENSO or El Niño Southern Oscillation (Abtew and Trimble 2010). During El Niño years, there is considerably more rainfall from late fall to early spring, whereas during La Niña years, rainfall is considerably reduced and winter droughts can occur. Hoyer et al. (2005) examined data from 84 lakes in Florida to determine how variability in rainfall affects the concentration of chlorophyll a (Chl-*a*) in the water. They found that in some lakes, there was a higher concentration of Chl-*a* in years of high rainfall, in some lakes it was higher in years of low rainfall, and in a third group of lakes there was no rainfall effect. They concluded that it is important to understand this relationship for lake management purposes, but that a careful lake-by-lake study might be needed in order to identify that relationship and its underlying causes.

General Approach

Here we present results from three large nutrient-rich lakes in Florida that have summer blooms of cyanobacteria: Lake Harris in the Ocklawaha Chain of Lakes north of Orlando, Lake George in the headwaters of the St. Johns River south of Jacksonville, and Lake Okeechobee in the center peninsular south Florida (Figure 1). All three lakes have long-term data collection programs that include monitoring water quality and cyanobacteria, as well as extensive research programs. This allowed us to (a) determine the relationship between rainfall and cyanobacteria blooms and (b) develop hypotheses about what causes year to year bloom variability.

Research Methods

Havens et al. (2016a) assembled a 15-year data set on Lake Harris including monthly measurements of rainfall, water depth, water color, flushing rate (the rate at which water in the lake is being replaced by inflow water), and the biomass of cyanobacteria determined from counts and measurements of cells. The data were obtained from the St. Johns River Water Management District and were collected following standard USEPA and other protocols.

A 15-year dataset from Lake George was assembled by Havens et al. (2016b), and included monthly measurements of water level, discharge rates at the lake's outlet (a measure of the rate at which water is flowing through the system), water color, and cyanobacteria biomass as determined for Lake Harris. This dataset is from a long-term ecological assessment program led by the Phlips laboratory, again following standard protocols for sample collection and analysis.

Lake Okeechobee data were obtained from several research projects done between 1993 and 2016 by the South Florida Water Management District, including studies in the lake's deeper central region overlying a mud sediment and a shallow region overlying sand and peat sediment where, unlike the other two lakes, a vast area of submerged plants can grow (Havens et al. 2002).

Results and Discussion

Lake Harris

Yearly-averaged water levels in Lake Harris are highly correlated with the amount of rain that falls over the watershed in the preceding year, which reflects the fact that rainwater must first flow off a large land area, then into other lakes in the chain and finally drain into Lake Harris. During the 15 years in which the lake was studied, there were two

Figure 1. Map of Florida showing the location of the three case study lakes. Lake Apopka also is shown as a point of reference, as Lake Harris occurs in a chain of lakes that starts with flow from Apopka.

periods of high water and two periods of low water. Cyanobacteria blooms waxed and waned with season and there was a clear pattern of summer blooms being less intense in high water years (Figure 2). How is this explained? A statistical analysis of the results indicates that summer blooms either are suppressed by something that happens when water depth is higher, or they are stimulated by something that happens when water depth is lower – or both. Havens et al. (2016a) found no evidence of a connection between nutrient inputs and blooms. However, they observed that two factors associated with water level and inflow might be at play when the lake is deep. The first is flushing rate. During times when the lake had very little water flowing through it and was nearly stagnant (flushing rate near zero in Figure 3), blooms in summer were able to develop to a very high level, presumably because of un-interrupted growth. In contrast, in deep water years, when there were periods when a large volume of the lake water was flushed out, blooms were greatly reduced, perhaps indicating interruption of growth by those disturbance events.

It also was discovered (Havens et al. 2016a) that in the high water periods, the color of the water was elevated (Figure 4). In this case, knowing that source water to the lake comes from a highly colored river, it was suggested that the increased inflow contributed to elevated color. Dissolved color absorbs a considerable amount of light, in the very same part of the spectrum that phytoplankton require to grow. Thus higher color also could have reduced blooms in the high water periods. So two factors (flushing and color) may

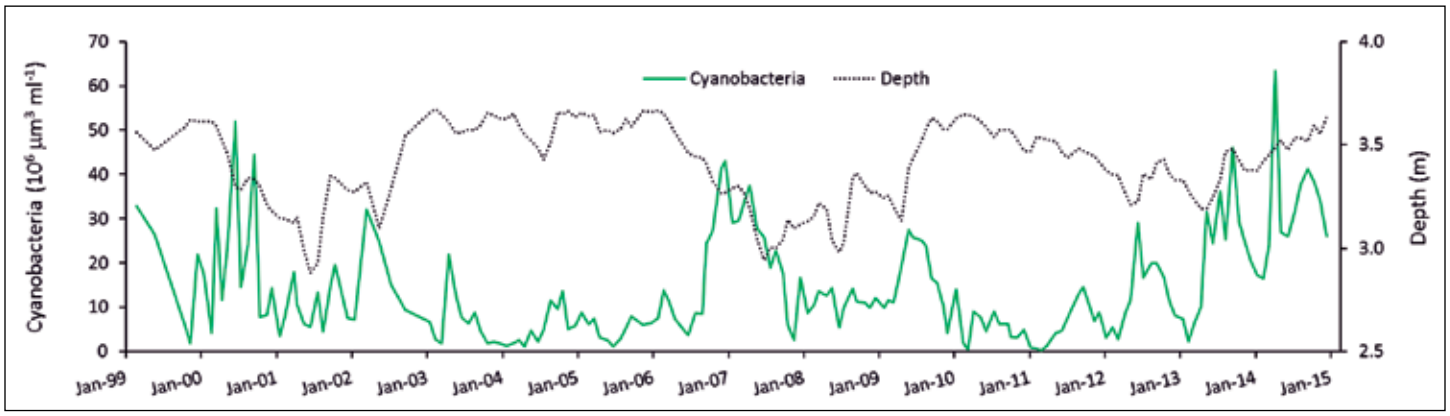

Figure 2. The biomass of cyanobacteria over a period of 15 years in Lake Harris, based on monthly sampling, superimposed on a plot of monthly water levels. Redrawn from Havens et al. 2016a.

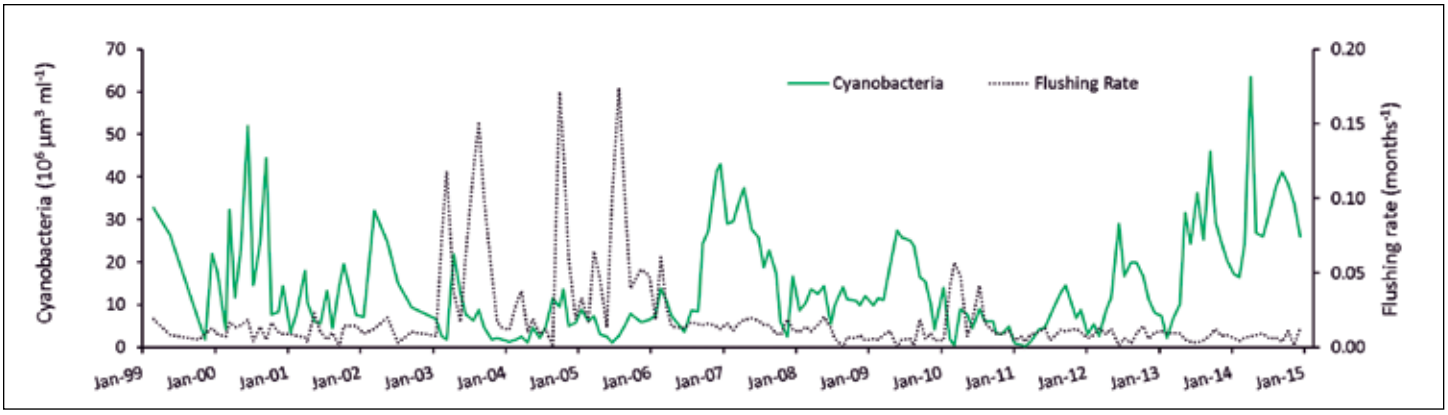

Figure 3. The biomass of cyanobacteria over a period of 15 years in Lake Harris, based on monthly sampling, superimposed on a plot of flushing rate of water through the lake (percent of lake volume). Redrawn from Havens et al. 2016a.

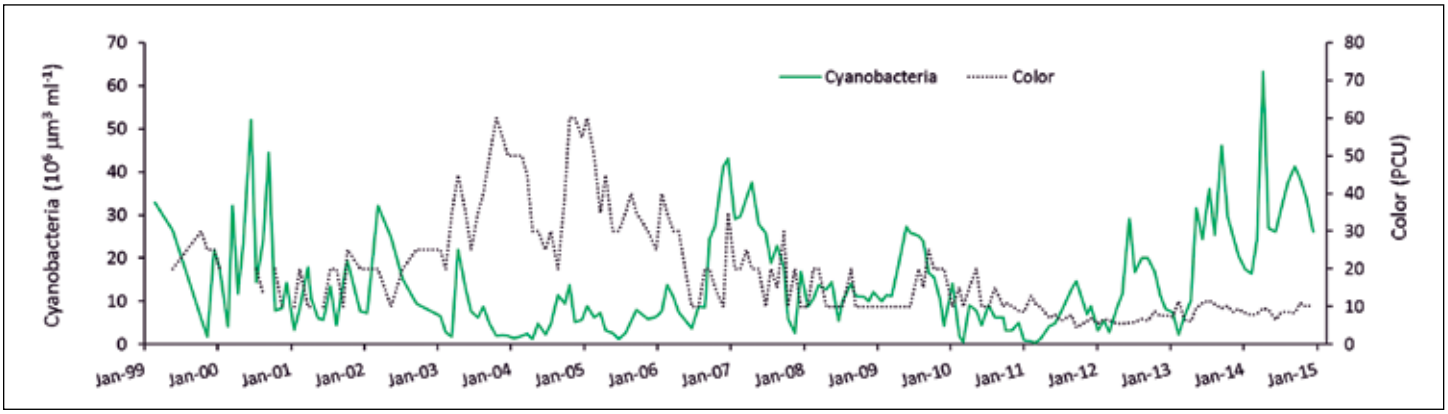

Figure 4. The biomass of cyanobacteria over a period of 15 years in Lake Harris, based on monthly sampling, superimposed on a plot of water color, which represents materials dissolved in the water than can absorb light and negatively affect growth of algae. Redrawn from Havens et al. 2016a.

have been at play in reducing blooms when the lake was deeper.

At the same time, Lake Harris, like nearly all other Florida lakes (a) is very shallow, with a maximal depth less than 5 m; (b) has mud sediments at its bottom that contain high levels of nutrients that have accumulated over time; and (c) has a dense population of gizzard shad that feed on the lake bottom and are known from other studies to mobilize large amounts of nutrients from the sediments into the water. Therefore, another hypothesis, that needs to be tested in future research, is that during low water periods, the normal array of chemical and biological processes (including fish) are at work releasing nutrients from the sediments into the water, and with a lesser amount of water, the concentration of nutrients is higher … providing more nutrients for algae, and larger blooms.

We can summarize these effects using a simple conceptual diagram (Figure 5) of hypothetical controlling factors. To

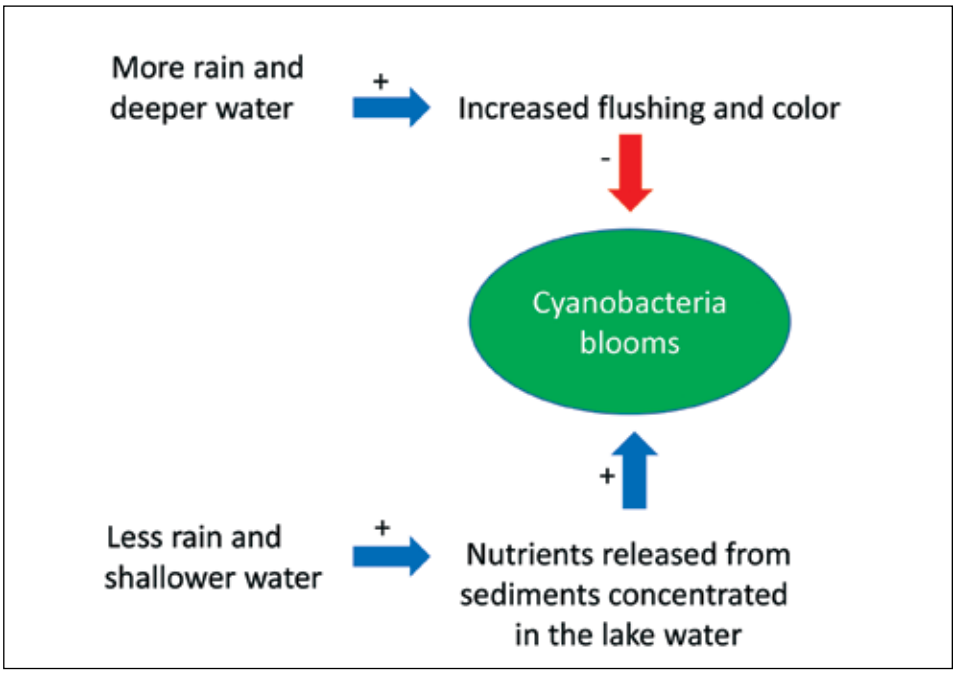

Figure 5. A conceptual diagram illustrating how recent research identified (Havens et al. 2016) that the intensity of cyanobacteria blooms in Lake Harris is controlled by variability in rainfall between wet and dry periods linked to a natural climate cycle. The blue arrows (+) indicate positive effects and the red arrow (-) indicates inhibitory effects.

resolve the relative importance of the various processes requires a focused research project. At this point we only can say that normal variations in water depth that are linked with a climate cycle can have a major impact on the intensity of potentially-toxic cyanobacteria blooms, and there are several explanations that suggest it is more than a coincidental occurrence.

Lake George

In this lake, there also is a 15-year monthly record of the biomass of phytoplankton (Figure 6) and it can be observed that the maximal summer biomass is lower in some years than in others (Srifa et al. 2016). A statistical analysis of these data (Havens et al. 2016b) revealed a very similar result to what was found in Lake Harris. In years of below-average rainfall and lower water levels, the most intense summer blooms of cyanobacteria occurred. Blooms were reduced in years of high rainfall and higher water, which coincided with more water flowing through the lake into the St. Johns River and with much higher color, which again, absorbs light and reduces phytoplankton growth potential. It also may be the case that the stimulatory processes identified in Figure 4 were at play in lower water years and favored blooms of cyanobacteria, along with them having more time to grow and take up nutrients in the more stagnant water.

Lake Okeechobee

In the open-water region of Lake Okeechobee blooms of cyanobacteria generally are suppressed by a high amount of inorganic solids in the water (Phlips et al. 1993). This is created by suspension of the mud bottom sediments by wind and waves, which reduces light penetration and creates light-limited conditions for phytoplankton (Aldridge et al. 1995; Phlips et al. 1995). However, there are occasional intense summer blooms. Examination of physical, chemical, and biological data from the open-water region with multi-variate statistics indicates that blooms are not stimulated by elevated levels of nutrients, but rather, by periods of time when there is unusually low rainfall, hot and calm conditions, and a water column that is stable for many days (Figure 7). These conditions allow cyanobacteria to grow, float to the water surface, and form intense blooms. It is important to note that the process starts with dormant cyanobacteria near the lake sediments where they have an ample supply of phosphorus. The most recent lake-wide bloom was in summer 2005. In this case, elevated levels of biologically available nutrients, introduced into the water column by two hurricanes in the prior year, may have set the stage, but the proximal cause seems to fit the model of hot calm conditions. This response is not unlike that observed in Harris and George – i.e., cyanobacteria have a preference for periods of tranquil water and hot mid-summer conditions. Intense rainfall and mixing of the water by wind during Hurricane Irene in late 2005 immediately disrupted the cyanobacteria bloom in Okeechobee.

Lake Okeechobee is unique among the three lakes in also having a vast area along the west and south shore that can support submerged plants – up to 50,000 acres (Havens et al. 2002). In this particular lake region, water level has the opposite effect from what was described for Lake Harris, Lake George, and the open-water region of Lake Okeechobee. The response is akin to what is observed in shallow lakes in The Netherlands. When the lake is deep, insufficient light gets to the bottom to support growth of plants. Phytoplankton are the dominant form of primary producers and blooms can occur. When the lake is very shallow, and there is just one or two feet of water in the shoreline area, light reaches the bottom and there is dense growth of submerged plants that compete with the phytoplankton for nutrients and keep blooms in check. There no doubt are other lakes in Florida that behave in this manner, but to our knowledge, none with such a comprehensive history of research.

Management Implications

The results presented here illustrate how variation in rainfall, which results in wet and dry periods with high and low lake levels, respectively, can have profound effects on blooms of cyanobacteria in Florida lakes. Large-scale changes in the maximal summer level of cyanobacteria have been observed in three large Florida lakes – Harris, George, and also the open-water region of Okeechobee. In all three cases, years of increased bloom intensity can be explained by physical and chemical factors related to variation in weather and climate. In the Winter 2015 issue of *LakeLine*, the featured topic was "managing lakes in droughts." In the examples provided, there were massive cyanobacteria blooms in Diamond Valley Lake, California, and Rampart Reservoir,

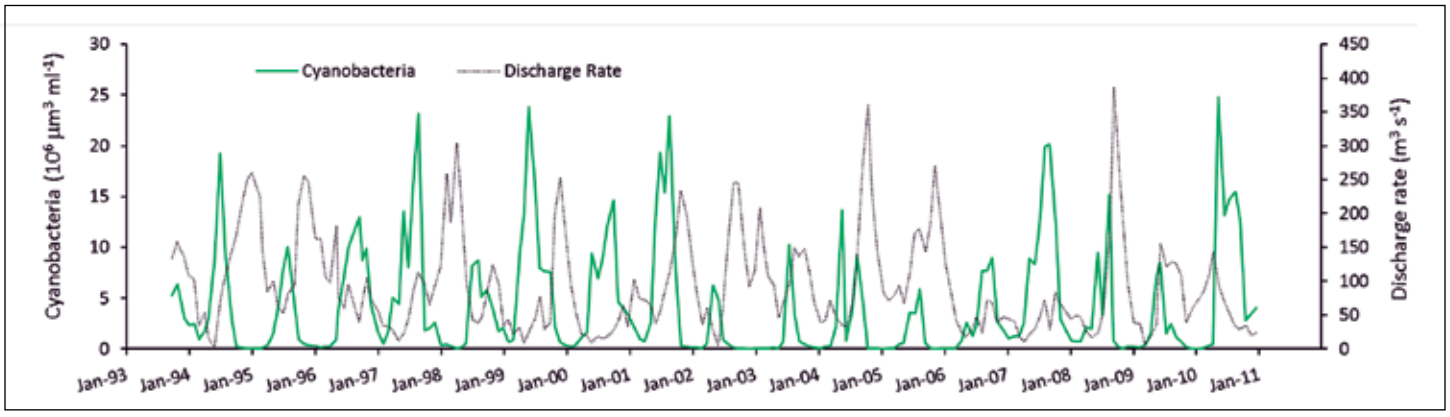

Figure 6. The biomass of cyanobacteria (blue-green algae) and other phytoplankton over a period of 15 years in Lake George, based on monthly sampling. Redrawn from Havens et al. 2016b.

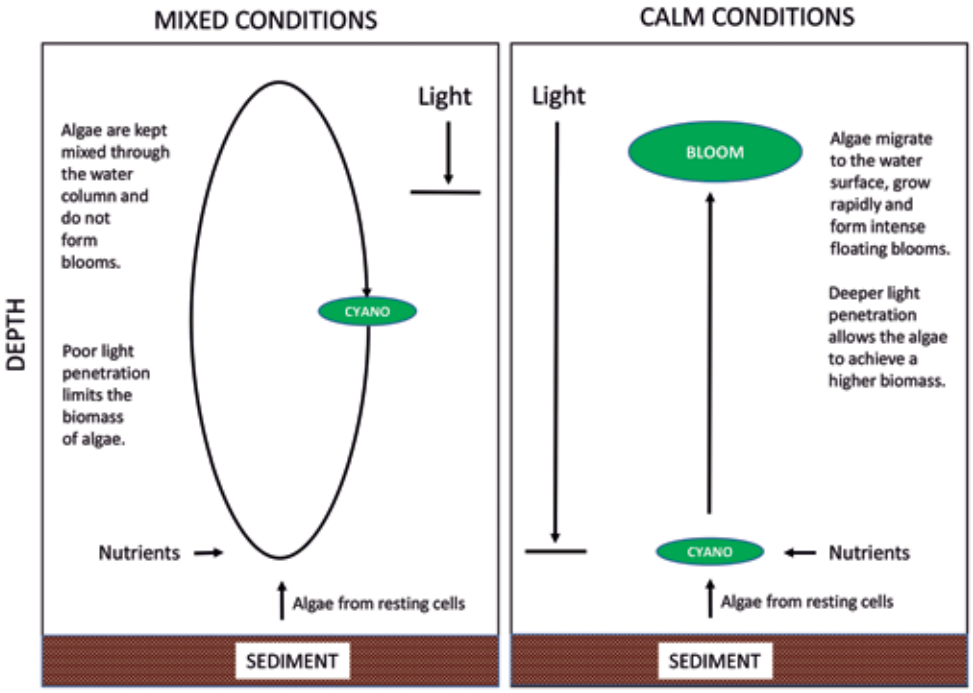

Figure 7. Conceptual diagram of cyanobacteria bloom dynamics in Lake Okeechobee under mixed conditions, which occur when wind blows across the lake with sufficient intensity to stir up the water and sediments, and under calm conditions that occur sometimes in dry summer periods. Under mixed conditions, cyanobacteria biomass is lower and distributed through the water column. Under calm conditions, surface blooms occur. Redrawn from Havens et al. 1998.

Colorado, during drought years. The first record of microcystin in Lake Mead was during a drought that resulted in *Microcystis* blooms. These observations are consistent with what we report here for Florida lakes.

In order to protect lakes from over-enrichment by nutrients (i.e., eutrophication), the Environmental Protection Agency requires the states establish nutrient concentration and input thresholds. In Florida, it already has been established that this standard setting must be done in the context of natural background variation caused by differences in bedrock and soils.

The results of our case studies also demonstrate that nutrient standards need to consider how lakes respond to variation in weather and climate. Further, if there is a projected long-term change in climatic conditions, such as duration of droughts or intensified rainfall, this needs to be taken into consideration when setting nutrient standards. At the present time, there are consistent projections among climate models that the future will be warmer, with a greater loss of water from lakes by evapotranspiration. However, there is not agreement among climate models regarding future trends in rainfall. As new research emerges, managers need to consider whether climate change will be a substantive issue for lake rehabilitation planning.

There is another reason why, from a lake management standpoint, it is critical to understand natural variation in cyanobacteria blooms: because without being aware of natural environmental controls, wrong conclusions could be reached and wrong actions taken. For example, if an agency is monitoring a lake where nutrient inputs have been reduced, and this coincides with the onset of a multi-year drought, there might be intensified cyanobacteria blooms simply due to the lower water. Without knowing this, it might be concluded that nutrient reduction strategies were not sufficiently aggressive and additional unnecessary projects might be planned, possibly wasting tax dollars. Or, an agency might implement a nutrient-reduction program at a time when a lake transitions from a drought to a wet period and observe a large suppression of cyanobacteria as happened in Lake Harris and George. It might wrongly be attributed to the nutrient reduction program and could termination of rehabilitation efforts, when in fact they might still be needed.

The bottom line is that periods of extremes in rainfall (wet and dry) can significantly impact cyanobacteria blooms along with the nutrients discharged during these events. These naturally occurring events need to be considered by the agencies charged with setting water quality standards and monitoring and enforcing compliance with those standards. If either water quality standards or compliance are determined and evaluated in only periods of extremes, invalid conclusions can be made. This is why several authors have suggested the need for multiple years of data ranging from 6 to 20 years to evaluate true trends in lake water chemistry and responses to nutrient reduction strategies.

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Affiliate News

"How We Celebrated Lakes Appreciation Month"

Indiana Lakes Management Society (ILMS)

ILMS hosted "Love Your Lakes" Day at the Indiana State Fair Fishing Pond – super- rainy day at the fair but we had fun fishing with youth and parents! Photos are here: https://www.facebook.com/indianalakes/photos/pcb.941827969295746/941827562629120/?type=3.

We also co-hosted the Great Aquatic Invasive Species Workshop with the Indiana Clean Lakes Program at Lake Lemon – photos are here: https://www.facebook.com/IndianaCLP/posts/1169061046500304

Submitted by: Sara Peel

Pennsylvania Lake Management Society (PALMS)

Once again in Pennsylvania July was proclaimed Lake Awareness Month by Governor Tom Wolf. The PA Lake Management Society (PALMS) conducted outreach to lake associations around the state to conduct lake awareness events, promote the Secchi Dip In, as well as encourage citizens to enjoy the lakes and reservoirs in Pennsylvania. Of note was a new event at Harveys Lake, in Luzerne County. The event included an initiative to educate lake users on the danger of aquatic invasive species, especially hydrilla, which was recently found at the lake. Other outreach events included displays and materials at the Linesville State Fish Hatchery as well as others around the Commonwealth.

Submitted by: Brian S. Pilarcik.

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Karl Havens is director of the Florida Sea Grant College Program and a professor in the fisheries and aquatic sciences program of the University of Florida IFAS School of Forest Resources and Conservation. His research deals with responses of lake ecosystems to perturbations, and he is a past recipient of the Edward Deevy Jr. award.

Mark Hoyer is director of Florida LAKEWATCH, a volunteer water quality-monitoring program at the University of Florida IFAS. Mark has been active in Florida Lake Management Society (FLMS) and the Mothership NALMS since the early 1990s, including a turn as NALMS president from 2009 to 2011.

Edward Phlips is a professor in the fisheries and aquatic sciences program of the School of Forest Resources and Conservation at University of Florida IFAS. His research focuses on the ecology of algal blooms in freshwater and marine ecosystems.

Akaepot Srifa is an assistant professor of biology at Mahasarakham University, Thailand. His research focuses on the dynamics of freshwater plankton.