

Natural Climate Variability Can Influence Cyanobacteria Blooms in Florida Lakes and Reservoirs¹

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Background

Many of Florida's nutrient-enriched lakes and reservoirs experience a proliferation of phytoplankton, or microscopic algae, in their water during summer months. Most often these bloom events are caused by a certain kind of phytoplankton—cyanobacteria, also referred to as blue-green algae. Cyanobacteria are the most common kind of phytoplankton in Florida lakes and reservoirs, and their occurrence is natural. However, when they grow to high levels and bloom, they can cause problems with aesthetics, emit an odor if they wash up on shore and die, and occasionally be toxic to aquatic organisms. Before undertaking costly remediation projects, or evaluating the effectiveness of nutrient reduction strategies, it is important for resource managers to understand how natural variation in weather and climate affect cyanobacteria blooms.

Cyanobacteria blooms generally are linked to high levels of nutrients in the lake water, and in Florida those nutrient levels vary tremendously. This variance is in part because the level of nutrients in Florida rocks and soils is highly variable, resulting in variation of nutrient levels in the overlying lake water (Bachmann et al. 2012). Humans can also cause higher nutrient inputs. One example is Lake Tohopekaliga, located south of Orlando. It once received high levels of nutrients from sewage treatment plants, which caused intense algae blooms (James et al 1994). The lake recovered after sewage diversion.

The concentration of phytoplankton in the water of a Florida lake or reservoir also can vary considerably over time and even within different areas of the same water body. The changes in concentration can be due to either local differences in environmental conditions or to buoyant algae being concentrated along a shoreline when blown there by the wind. Rainfall and drought can cause large-scale changes in the concentration of phytoplankton and the occurrence of algae blooms in Florida lakes. Rainfall over the Florida peninsula is linked to distant ocean cycles, including the multi-year cycle in the Pacific known as the ENSO or El Niño Southern Oscillation (Abtew and Trimble 2010). In 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 in the water. Chlorophyll (Chl) is a major pigment in algae and can serve as a proxy for the amount of phytoplankton in the water column. Hoyer et al. (2005) found that in some lakes there was a higher concentration of Chl 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, and that a careful lake-by-lake study might be needed in order to identify that relationship, its underlying causes, and its effects.

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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 south Florida (Figure 1). All three lakes have long-term data-collection programs that include monitoring water quality and cyanobacteria, complemented by extensive research programs. The extensive data allowed us to (a) determine the relationship between rainfall and cyanobacteria blooms; and (b) develop hypotheses about what causes year-to-year bloom variability.

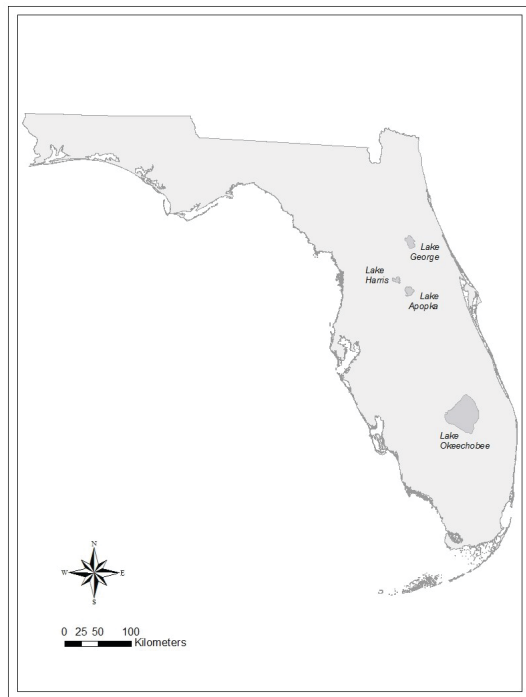


Figure 1. Map of Florida showing the location of the three study lakes. Lake Apopka also is shown as a point of reference because Lake Harris occurs in a chain of lakes that starts with flow from Apopka
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Research Methods

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, calculated from counts and measurements of algal cells. Biomass, expressed in units of micrograms per liter, is a standard measure of the mass of algae in a unit of lake water.

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, determined in the same manner as in Lake Harris.

Lake Okeechobee data were obtained from several research projects done between 1993 and 2016 that included measurements of biomass of cyanobacteria using the same methods as in the other two lakes. The data also included studies in the lake's deeper central region overlying 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).

Findings

Lake Harris

The yearly averaged water levels in Lake Harris are highly correlated with the amount of rain that falls over the watershed in the preceding year. This reflects the fact that water must first flow off a large land area, then into lakes upstream in the chain, before finally entering Lake Harris. As is the case elsewhere in the Florida peninsula, the amount of rainfall, particularly between November and May, is strongly correlated with the condition of the El Niño Southern Oscillation (Abtew and Trimble 2010).

During the 15 years in which Lake Harris was studied, there were two periods of high water and two periods of low water. Cyanobacteria blooms waxed and waned with season, and there was a pattern of summer blooms being less intense in high-water years (Figure 2).

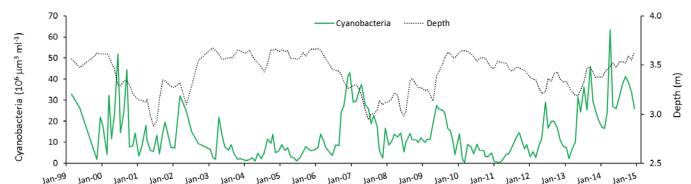


Figure 2. The biomass of cyanobacteria over a period of 15 years in Lake Harris, based on monthly sampling, superimposed on a plot of monthly water levels. Cyanobacteria biomass is lower in high-water periods.

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 compared to when it is shallower. The first factor is flushing rate. During times when the lake had 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 high level, presumably because of uninterrupted growth. In contrast, in deep-water years, when a large volume of the lake water was periodically flushed out, blooms were greatly reduced, perhaps indicating that the balance between growth and loss of algae becomes negative during those events.

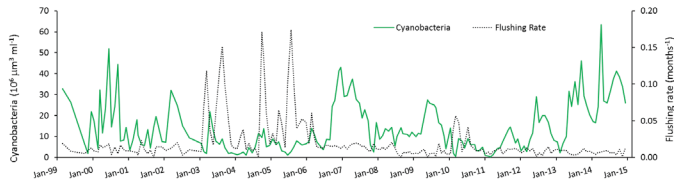


Figure 3. The biomass of cyanobacteria over a period of 15 years in Lake Harris, based on monthly sampling, superimposed on a plot of flushing rate of water through the lake (percent of lake volume). Cyanobacteria biomass is reduced during periods when there are intermittent spikes in flushing.

Havens et al. (2016a) found that during the high-water periods, the color of the water was elevated (Figure 4). Color is a measure of dissolved organic material in the water. The organic material that changes water color is sometimes formed within the lake, and sometimes comes into the lake from decomposing plants or leaches from soils in the watershed. 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. Colored dissolved organic matter absorbs a considerable amount of light, in the same part of the spectrum that algae require for growth. Thus, higher color also could have reduced blooms in the high-water periods. We conclude that two co-occurring factors (flushing and color) may have been at play in reducing blooms, especially when the lake's water column was deeper.

Lake Harris, like nearly all other Florida lakes is shallow, with a maximal depth less than 5 m. It has mud sediments at its bottom that contain high levels of nutrients that have accumulated over time, and it has a dense population of a particular kind of fish, gizzard shad, that feed on the lake bottom. Shad are known from other studies to mobilize large amounts of nutrients from the sediments into the water. These factors suggest another hypothesis, one which needs to be tested in future research, namely 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. With a lesser amount of water, the concentration of nutrients is higher, which provides more nutrient supplies for algae, and the potential for larger blooms.

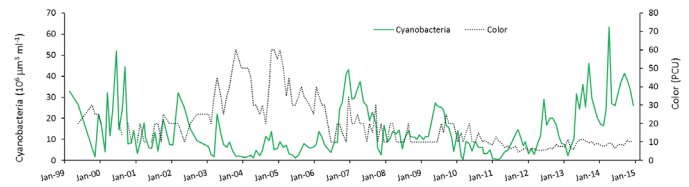


Figure 4. The biomass of cyanobacteria over a period of 15 years in Lake Harris, based on monthly sampling, superimposed on a plot of water color, which represents materials dissolved in the water that can absorb light and slow the growth of algae. Cyanobacteria biomass is reduced during periods when color is higher.

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

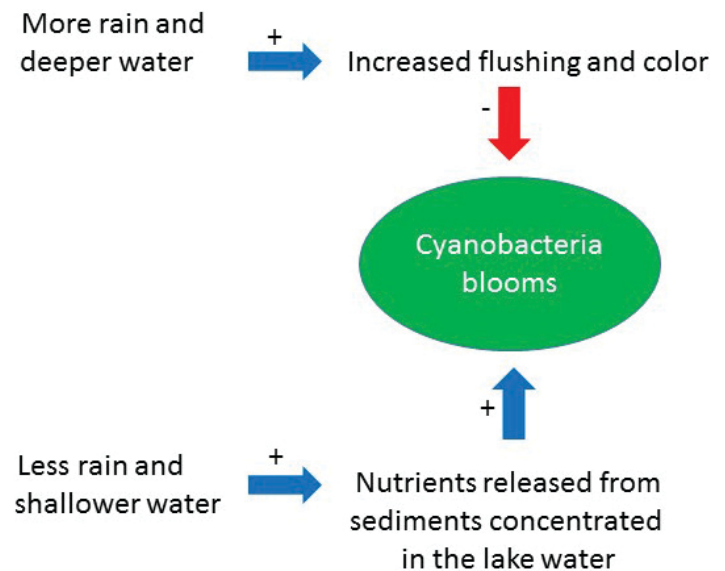


Figure 5. A conceptual diagram illustrating how experts concluded (Havens et al. 2016) that the intensity of cyanobacteria blooms in Lake Harris is controlled by variability in rainfall between wet and dry periods linked to climate cycles and variability. The blue arrows with a + indicate positive effects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

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. A statistical analysis of these data (Havens et al. 2016b) revealed a 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. Recall that colored water absorbs light and reduces phytoplankton growth potential (Sriifa et al. 2016). 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.

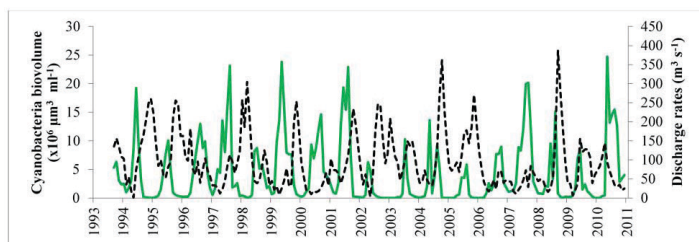


Figure 6. The biomass of cyanobacteria (green line) and discharge rate of water at the lake outflow (dashed black) over a period of 15 years in Lake George, based on monthly sampling.

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 created by wind and waves suspending the muddy bottom sediments. The suspended solids reduce light penetration (Phlips et al. 1993; Aldridge et al. 1995; Phlips et al. 1995). However, there are occasional intense summer cyanobacteria blooms. Havens et al. (1998) examined physical, chemical and biological data from the open-water region and by using multi-variate statistics, found that blooms are not necessarily stimulated by elevated levels of nutrients, but rather, by periods of time when there is a combination of 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. The process starts with dormant cyanobacteria near the lake sediments. The most recent lake-wide bloom was in summer 2005. In that case, there was a perfect storm where large rain and wind events introduced high levels of nutrients into the water and then a hot, calm period provided favorable conditions for cyanobacteria blooms to occur. This response is not unlike that observed in Lakes 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 hurricanes ends Okeechobee's cyanobacteria blooms. Hurricane Irene in autumn 2005, for instance, 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 (Scheffer et al. 1993). When the lake is deep, insufficient light gets to the bottom to support growth of plants. Phytoplankton is the dominant form of primary producers and blooms can occur. When the lake is shallow and depth is less than one meter in the shoreline area, light reaches the bottom and there is dense growth of submerged plants that compete with the phytoplankton for nutrients (Hwang et al. 1998), keeping 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 monitoring and research.

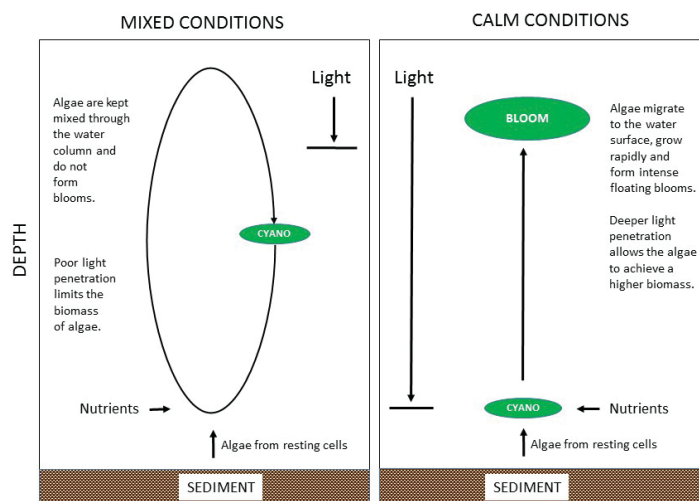


Figure 7. Conceptual diagram of cyanobacteria bloom dynamics in Lake Okeechobee under mixed conditions that occur when wind blows across the lake with sufficient intensity to stir up the water and sediments, and under calm conditions that occur sometimes in dry summer periods. Under mixed conditions,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

Practical Implications for Lake Management

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 and reservoirs. Large-scale changes in the maximal summer level of cyanobacteria were 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 nearshore region of Lake Okeechobee, which can support submerged plants, there is a different relationship, and blooms are suppressed in low-water years.

In order to protect lakes and reservoirs from over-enrichment by nutrients (eutrophication), the Environmental Protection Agency requires the states establish nutrient concentration and input thresholds. In Florida, this must be done in the context of natural background variation caused by differences in bedrock and soils. The results presented here demonstrate that nutrient standards also need to consider how lakes and reservoirs respond to natural variation in weather, including variation that is related to climate cycles such as the El Niño / La Niña. In the future, effects of climate change on our weather may also need to be considered. At the present time, climate models consistently project that the future will be warmer, with a greater loss of water from lakes and reservoirs by evapotranspiration. However, the climate models do not agree about future trends in rainfall (Obeysekera et al. 2015). As new research emerges, managers will need to consider whether or not climate change is 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, we could reach wrong conclusions and take wrong actions. For example, if an agency is monitoring a lake or reservoir 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. If the agency doesn't understand the relationship between lower water levels and cyanobacteria blooms, it might conclude that nutrient-reduction strategies were not sufficiently aggressive, and additional, unnecessary projects might be planned, possibly wasting tax dollars. Alternatively, an agency might implement a nutrient-reduction program at a time when a lake or reservoir transitions from a drought to a wet period and observe a large suppression of cyanobacteria as happened in Lake Harris and George. The agency might wrongfully attribute the suppression to its nutrient-reduction program and decide to terminate 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. Agencies charged with setting water quality standards and monitoring and enforcing compliance with those standards must consider these naturally occurring events. If either water-quality standards or compliance are determined and evaluated in only periods of extremes, invalid conclusions will almost necessarily 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 (Knowlton and Jones 2006) and responses to nutrient-reduction strategies.

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