HARMFUL ALGAL BLOOMS IN THE CATSKILLS PROVIDE MORE QUESTIONS THAN ANSWERS

by

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ABSTRACT

Freshwater lakes provide many services to humans and are home to a diverse array of organisms that cannot survive elsewhere, making understanding and monitoring the quality of lake waters a critical priority in supporting these ecosystems. Harmful algal blooms, or HABs, are a recognized problem for lake ecosystems and human uses of lakes. Though many studies attempt to identify the cause of the problem, their occurrence cannot be attributed to one factor. The study site of the Catskill watershed is nearly 1,600 square miles of primarily heavily forested land. Farmland and suburban communities are dispersed around approximately 2,600 natural and manmade lakes, some of which are known to be especially prone to algal blooms. For this study, 15 years of aerial imagery of the Catskill watershed were analyzed via Google Earth Pro to determine the frequency of HABs. Several variables were considered, including year, lake surface area, lake perimeter, lake shape, temperature patterns, and precipitation patterns. HAB frequency is generally increasing between the years 2006 and 2019, apart from one year- 2009. Of the climate data, large rain events provided the clearest correlation to HAB occurrence, though no one variable was found to have a clear trend or pattern related to potential HAB frequency.

Keywords: HAB’s, lakes, cyanobacteria, aerial imagery.

INTRODUCTION

Water is an irreplaceable resource, and though Earth appears blue from afar, accessible freshwater is rare and patchily distributed. Less than one percent of all the freshwater on Earth is accessible for human use through lakes, rivers, and groundwater (Chapin et al. 2009). Freshwater is invaluable to humans not only for drinking, but it is used to irrigate farmland and grow crops, catch fish, harvest energy, and provide other provisioning, social, and cultural services (Chapin et al. 2009). Equally reliant on this resource are the thousands of macro and microorganisms who freshwater lakes are home to that cannot be found elsewhere (Hahn 2006).

Chen et al. (2010) found that microbial communities in lakes are dynamic and sensitive to many environmental variables. The success or failure of many of these populations are dependent upon several conditions, and it is difficult to pinpoint exactly which factors influence population booms. Cyanobacteria are a type of microorganism that are almost always present in lakes, but grow and form colonies that can dominate the waterbody at impressive rates. Garlapati et al. (2019) emphasize that cyanobacteria play an important role in the balance of nutrients in the environment, oxygen production, and even provide unique industrial and agricultural services for humans. However, when a lake experiences a cyanobacteria bloom, it can pose hazardous effects for the aquatic organisms below the surface, as well as the recreation above. These hazardous blooms are known as harmful algal blooms, or HAB’s. HAB’s can block out sunlight and deplete oxygen from bottom waters, which affects plant growth and can create dead zones that kill fish populations (U.S. E.P.A. 2017). HAB’s can also produce toxins that are dangerous to fish and other animals in the food web. For instance, Maerz et al. (2019) found that the introduction of a specific cyanobacteria-*Aetokthonos hydrillicola* (Ah)- releases toxins which can alter the structure and interactions between organisms in the ecosystem. Toxins produced by HAB's can also pose serious health concerns to humans if directly exposed (Stone et al. 2007). Levesque et al. (2014) found that consuming water with cyanobacteria resulted in an increase in muscle pain, gastrointestinal symptoms, skin irritation, and ear symptoms, while recreational contact with contaminated waters also resulted in increased gastrointestinal problems. Recent studies even suggest that a toxin, anatoxin-a, often produced in HABs, can even accumulate outside of the aquatic ecosystem (Sutherland et al. 2021). Sutherland et al. (2021) detected the toxin via an air sampler during a HAB occurrence, proposing the possibility of airborne exposure. As new information is provided, the threat level of HAB effects is constantly adapting.

It is imperative that we be able to identify HABs in lakes, especially when so many lakes are used by humans for recreation. Identifying lakes which are at risk for an algal bloom can help prevent human and animal exposure to toxins, and may even provide insight on how to reduce dead zone occurrence in aquatic ecosystems and prevent species loss (U.S. E.P.A. 2017). Many studies have focused on understanding the cause of HABs. In Cremona et al. (2018), hundreds of variables were considered to determine which factors provided the most influence on HABs. They determined the following six factors to have the most importance: pH, cladoceran biomass, water temperature, copepod biomass, NO_3 concentration, and rotifer abundance. Similarly, Havens et al. (2019) addresses this concept- that no singular factor can explain a bloom. However, from their analysis of seven different shallow lakes, they concluded that depth and flushing trumped other factors explored in the study. The fact that the studies did not conclude that the same variables were most influential emphasizes the complexity that HAB occurrence provides. It is difficult to understand *why* they occur, and equally difficult to predict *when* a HAB will occur (Wilkenson et al. 2018, Luo et al. 2017). Most studies on HAB's focus on larger lakes, which likely is a result of the immediate concern for human health effects if exposed to toxins in HABs. However, small lakes often make up much of the surface area of water in a watershed (Chapin et al. 2009). Perhaps the difficulty in understanding the source of a harmful algal bloom comes from studying mostly large recreational-use lakes and expecting to understand watersheds that are comprised of mostly small lakes.

New York State Department of Environmental Conservation (DEC) has worked to understand, predict, and prevent harmful algae in lakes. As a result of the HAB initiative plan implemented by Governor Andrew Cuomo, specialized teams focus on developing and implementing action plans for high risk lakes in NYS. These plans provide suggestions on how to reduce sources of pollution that may initiate HABs in 12 specific lakes. The lakes were chosen to represent a wide range of conditions and vulnerabilities as well as for their uses as drinking water and/or tourism. The lakes are ranked as higher priority, and due to the difficulty in monitoring so many lakes at once, many lakes that also would likely be identified as high-risk do not get this luxury of priority. These lakes alone cannot represent the entirety of lakes in New York state. Although these action plans have been provided, there is still more to be done to protect New York lakes. NYS DEC has referred to these as 'living documents,' meaning comments and suggestions are always encouraged. The accuracy and implementation of the plans is heavily dependent on feedback and interaction with local communities and even individual community members. To monitor every lake in New York, the DEC would have to be able to visit every lake in New York, and this is a unrealistic expectation. For this reason, NYS DEC has provided many resources for the public to access which have important information of causes, effects, identification, and concerns surrounding HAB's. They encourage anyone to report suspected HAB's found through their NYS Suspicious Algal Bloom Report Form (NYS DEC).

As a result of the health risks associated with HABs, one of the higher priority ecosystems to monitor are lakes in watersheds that produce surface drinking water supplies. The Catskills are one of these regions. The Catskill watershed covers nearly 1,600 square miles of NYS. The watershed also drains into six massive New York City Reservoirs, which are specially protected (Watershed Agricultural Council 2019). For this study approximately, 15 years of satellite imagery of the entire Catskill watershed were reviewed via Google Earth Pro to assess the lakes for the potential presence of HABs during the growing season of May to November. It is important to note that aerial interpretation only provides information on the occurrence of an algal bloom and does not give insight on whether the bloom may be harmful or not. An analysis of the frequency in bloom occurrence over time could reveal whether potential HABs are becoming more frequent over this period. In addition, several years of archived climate data provided by The National Weather Service at the Montgomery Orange County Airport, New York was retrieved to assess if average temperature, total precipitation, and size of rain events could explain any variations in potential HAB frequency. In particular, it is predicted that years which experience hotter and wetter conditions overall will exhibit the most potential for HAB's.

METHODS

Site selection. The Catskill Watershed covers approximately 1,581 square miles of New York State and overlaps with five different counties. The Catskill Watershed is also a part of NYC Water Supply System, with six reservoirs providing about 90% of the daily water requirements of NYC residents. These reservoirs are Ashokan, Cannonsville, Neversink, Pepacton, Rondout, and Schoharie Reservoirs. Due to the connection to the NYC Water Supply System, this area falls under the NYC Watershed Protection Program. These reservoirs were omitted from my analysis to avoid several concerns regarding consistency of data. Not only do these water bodies connect in a much larger network of reservoirs, they also are each so large that it is likely the conditions in one part of the lake would not be representative of the whole lake. In many instances, HABs could be observed on certain shorelines or in certain coves of the reservoir, and a more localized or specific study would be required to understand the patterns exhibited by these water bodies. Land cover in the Catskills is dominated by heavy forests, with its rural counterparts containing many small to medium sized mixed livestock, vegetable, or dairy farms. Most of these thick forests of the Catskills are privately owned. Most lakes in the Catskill watershed are smaller than 1ha and sit on private property, with several hundred larger lakes, both private and publicly owned.

Data collection. All lakes were identified and studied using aerial photography provided through Google Earth Pro. The boundary of the Catskill Watershed was determined via the NYS GIS dataset of watershed boundaries. The most recent photo available was used to identify the lakes, and lake estimations were made using the ruler feature set to "Circle," measuring area in hectares. Any lake which was estimated to have an area smaller than 0.1 hectare was omitted, and all lakes which were estimated to be 0.1 hectare or larger were then labelled using the following format:

[3 letter initials]_[YYYYMMDD]_[3 digit ordered sequence]

For lakes meeting the minimum size requirement, more accurate estimations of lake size were then calculated using the "draw polygon" feature. Perimeter measurements were recorded in meters and area was recorded in hectares. When drawing the polygons to measure each lake, tree overhang or any littoral zones which impedes on the accuracy of measurements must be considered carefully. In instances in which tree cover, clouds, intense shadows, or any otherwise unclear circumstance makes for a less confident estimation, photos from previous years or leaf-off photos were considered during measurement. Lakes should be measured at a close distance, though this distance may vary slightly depending on the size of the lake. Many of the lakes in the Catskill watershed were small enough to be viewed and measured clearly through the image at approximately 200-300 ft. altitude, and larger lakes required moving the zoom and view frequently to get the most accurate measure.

Sampling. After examination of the entire study area, a total of 2,558 lakes were identified and measured. The total population was sampled to remain representative of the entire watershed. I randomly selected 50% of large lakes (lakes larger than .99ha), and 33% of small lakes (lakes smaller than 1ha) using Microsoft Excel. To ensure true randomization, each lake should be assigned a random ID number via the “=randID” function and then sorted based on these numbers. Due to the large number of small lakes present in the Catskill watershed, I determined that sampling 33% of small lakes would still provide sufficient information to conduct this study. However, this luxury was not taken with the larger lakes, because there were already much fewer of them in the watershed. Separation of small vs. large lakes was only necessary to examine potential variations in trends dependent on size of the lake more closely, though is not necessary for the analysis of the climate data.

Climate Data. Local Climatological Data summaries were retrieved from the Montgomery Orange CO Airport weather station via the National Oceanic & Atmospheric Administration National Environmental Satellite, Data, and Information Services. Monthly summaries were reviewed for the following information: annual average temperature, monthly average temperature during the month each photo was taken, monthly high and low temperatures, number of rain events, and size of rain events. Of these variables, the ones examined closest in this study with respect to potential HAB frequency were annual average temperature, number of rain events annually, and number of rain events larger than 0.1 inches, herein number of large rain events.

RESULTS

The frequency of potential HAB expression for every year with available data was recorded (Fig. 1). Occurrences of potential HAB expression increased in frequency over time with a rate of approximately 2.1% per year, a trend which becomes even more significant when only considering years with a large samples, or when n>700 (Fig. 2a). When considering years where n> 700, the rate of increase of HAB frequency is approximated 5.7% per year. Apart from 2009, potential HAB events are becoming more frequent with time. Figure 2b. excludes the year 2009 to further emphasize how far this year deviates from the trend expressed by other years, and the rate of HAB frequency further increases to 8.2% increase per year.

To determine if climate changes presented a detectible signature in these data over this timeframe, potential HAB frequency was also compared to climate data. As seen in figure 3, annual average temperatures were compared to HAB occurrence, though no significant trend was found. Monthly averages, highs, and lows were also examined, but again no significant trends could be found. (Annual data provided strongest trendline and highest R^2 value)

Figures 4 and 5 both address precipitation and HAB occurrence. Number of large rain events was the biggest indicator of HAB frequency (Fig. 5), and annual precipitation patterns expressed a very similar trend but with a bit more scatter (Fig. 4).

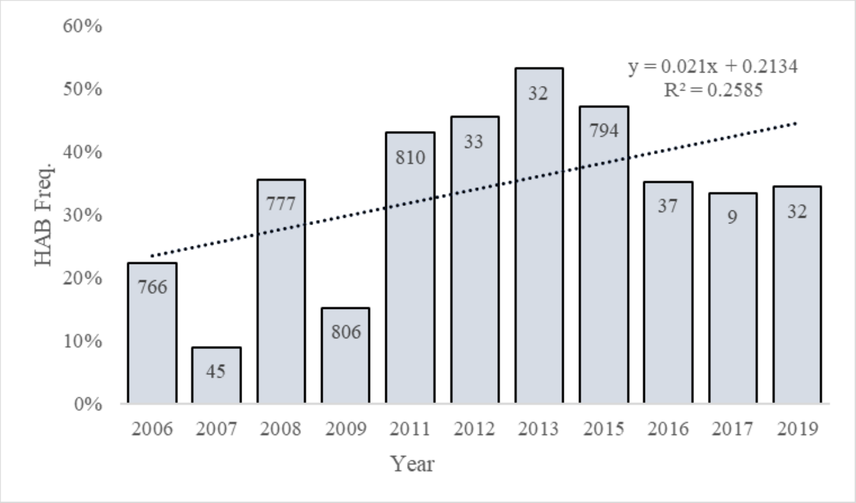

Figure 1. HAB frequency over time. Data labels represent sample size (n), or number of clear photographs available for each year.

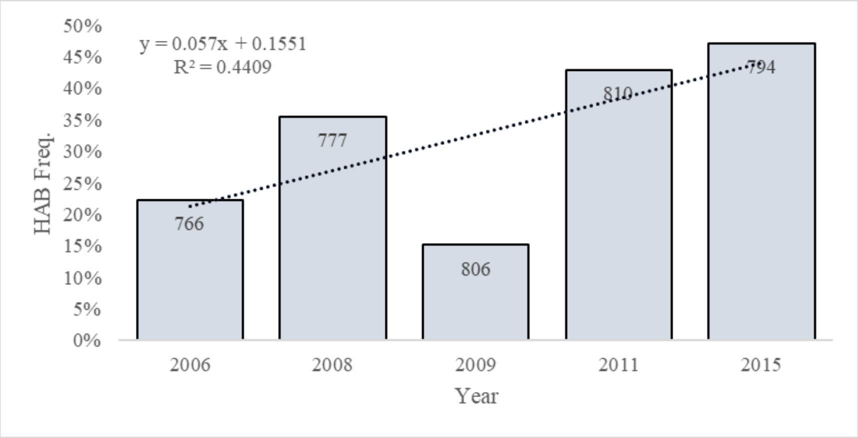

Figure 2a. HAB frequency over time. Excludes sample sizes smaller than 700 lakes. Data labels represent sample size (n) for each year.

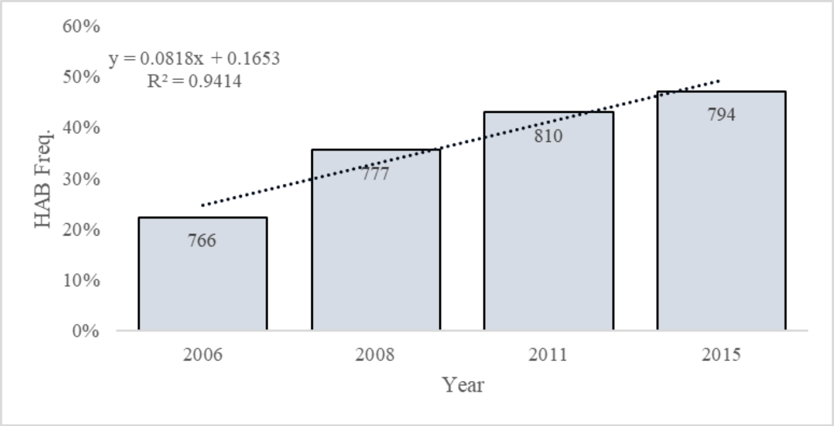

Figure 2b. HAB frequency over time. Excludes 2009. Excludes sample sizes smaller than 700 lakes. Data labels represent sample size (n) for each year.

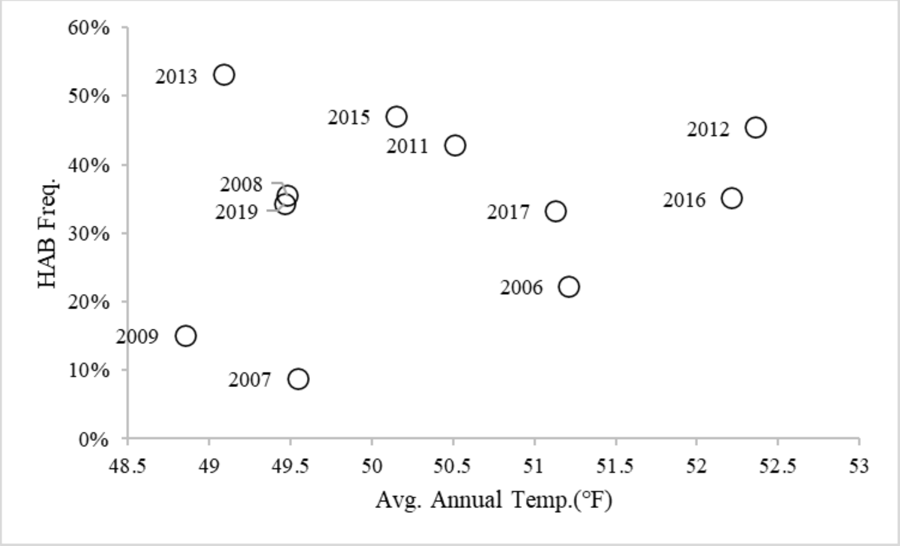

Figure 3. HAB frequency compared to average annual temperature.

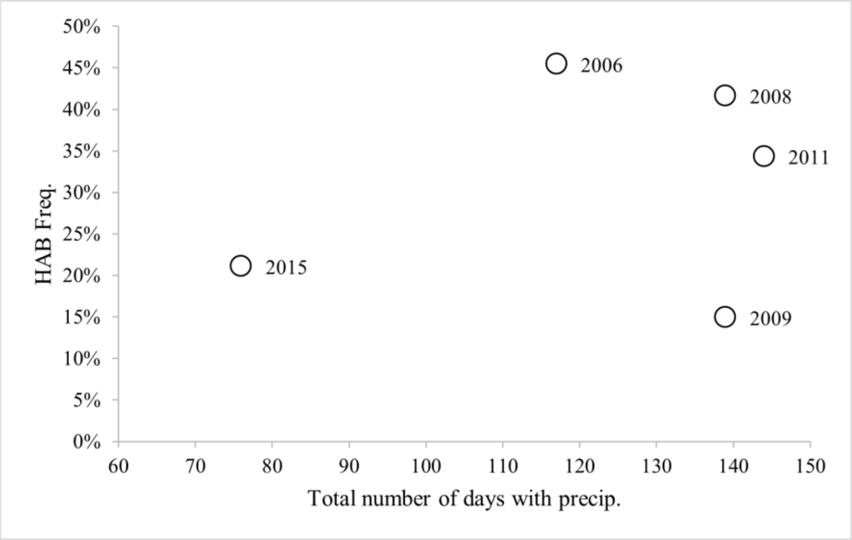

Figure 4. HAB frequency compared to total annual precipitation.

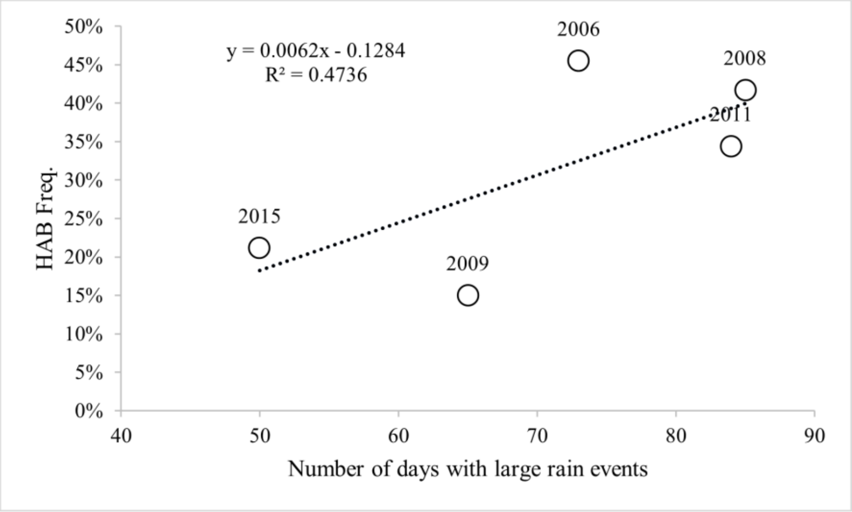

Figure 5. HAB frequency compared to annual number of large rain events.

DISCUSSION

These results suggest potential HAB expression is increasing in frequency as time goes on in the Catskill watershed. This data exhibits the strongest trends with extremely large sample sizes, or when n.700, and even stronger trends can be seen when considering 2009 as a particularly unusual circumstance. Though HAB occurrence has been increasing within the Catskill basin over this period, temperature provided little to no insight on algal bloom occurrence. There was a lot of scatter within the dataset, and no powerful trend was observed. This was also the case when considering the monthly average temperature, monthly highs, lows, and year-to-date data instead of the calendar year. However, no matter the time scale presented, no observable pattern could be found for these variables. Of all potential combinations, annual data provided the least scatter, but still no strong correlation could be observed for temperature and HAB frequency.

In addition, while it is not possible to accurately predict HAB's off total number of days of precipitation, number of large rain events provided a clearer indication of when to expect a bloom. The trend expressed from large rain events was much stronger than the one expressed from total number of days with precipitation. This data suggests that with more large rain events comes more algal blooms, though it is still a very weak trend.

Data from 2009 contradicted all observable patterns seen through other years, however. For instance, the R^2 nearly doubles when data from 2009 was omitted in figure 2b, and this emphasizes that 2009's conditions stray greatly from the expected, though neither provided significant regressions. There were also fewer observed potential HAB occurrences in 2009 than implied from the trend seen in number of large rain events. For the number of large rain events that occurred in 2009, it would be expected to see nearly double the potential HAB occurrence than actually expressed. The weak patterns observed for the temperature data as well as for the total number of rain events had too much variation to make this same conclusion, however. In future studies of the Catskill watershed, I would suggest considering data from 2009 very closely, or perhaps entirely separate from other years, as it is clear that 2009 deviates greatly from the observable trend.

This data further emphasizes the complexity of HABs which Havens et al. (2019), Cremona et al. (2018) and many others attempt to address; none of the variables considered in any of these studies could singlehandedly explain the patterns seen in HAB frequency. Instead, it would be most useful to consider a select number of variables in conjunction with one another, as all experiments found interesting patterns taking very different approaches and looking at very different variables. There is no algorithm or equation for predicting harmful algal blooms, though we continue to try and find one with hopes to mitigate the harmful effects that can result from these blooms. As we learn more about the occurrence and frequency of HABs, we will continue to reduce human health concerns related to toxins in cyanobacteria, promote the continued use of freshwater lakes for recreation, and support and protect our aquatic ecosystem.

CONCLUSION

The Catskill watershed frequently experiences HABs and should continue to expect more in years to come based on these findings. There is a gradual increase in frequency of potential HABs, and this pattern might express a correlation to the number of large rain events that occur annually, though more information is needed. Study of climate data will help reach the goal of understanding which factors to monitor closest when looking for a bloom, as there is no one variable which correlates to their occurrence. Reviewing aerial imagery for potential HAB occurrence can be an efficient way to conduct studies on a large number of lakes at once. Though this approach faces difficulty in revealing what causes blooms, it provides useful information about patterns over time and can be helpful in monitoring lakes of any priority.

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LITERATURE CITED

Chapin, S., G. Kofinas, and C. Folke. Principles of Ecosystem Stewardship: Resilience Based Natural Resource Management in a Changing World. 2009

Coffer, M. M.., B. A. Schaeffer, J. A. Darling, E. A. Urquhart, and W. B. Salls. 2020. Quantifying National and Regional Cyanobacterial Occurrence in US Lakes Using Satellite Remote Sensing. Ecological Indicators 111

Cremona, F., L. Tuvikene, J. Haberman, P. Nõges, and T. Nõges. (2018). Factors controlling the three-decade long rise in cyanobacteria biomass in a eutrophic shallow lake. Science of the Total Environment. 621: 352–359.

Garlapati, D., M. Chandrasekaran, A. Devanesan, T. Mathimani, and A. Pugazhendhi. (2019) Role of Cyanobacteria in Agricultural and Industrial Sectors: An Outlook on Economically Important Byproducts. Applied Microbiology & Biotechnology 103(12): 4709–21.

Hahn, Martin W. 2006. The Microbial Diversity of Inland Waters. Current Opinion in Biotechnology. 17 (3): 256–61.

Havens, K. E., G. Ji, J.R. Beaver, R.S. Fulton, & C.E. Teacher. (2019) Dynamics of cyanobacteria blooms are linked to the hydrology of shallow Florida lakes and provide insight into possible impacts of climate change. Hydrobiologia. 829(1): 43–59.

Lévesque, B, M. Gervais, P. Chevalier, D. Gauvin, E. Anassour-Laouan-Sidi, S. Gingras, N. Fortin, G. Brisson, C. Greer, and D. Bird. 2014. Prospective Study of Acute Health Effects in Relation to Exposure to Cyanobacteria. Science of the Total Environment 466–467: 397–403.

Luo, Y., K. Yang, Z. Yu, J. Chen, Y. Xu, X. Zhou, and Y. Yang. (2017). Dynamic monitoring and prediction of Dianchi Lake cyanobacteria outbreaks in the context of rapid urbanization. Environmental Science & Pollution Research. 24(6): 5335–5348.

Maerz, J. C., S. B. Wilde, V. K. Terrell, B. Haram, R. C. Trimmer, C. Nunez, E. Cork, A. Pessier, S. Lannoo, M. Lannoo, and S. Diamond. 2019. Seasonal and Plant Specific Vulnerability of

Amphibian Tadpoles to the Invasion of a Novel Cyanobacteria. Biological Invasions 21 (3): 821–31.

Meijun, C., F. Chen, B. Zhao, Q. L. Wu, and F. Kong. 2010. Seasonal Variation of Microbial Eukaryotic Community Composition in the Large, Shallow, Subtropical Taihu Lake, China. Aquatic Ecology. 44 (1): 1–12.

New York State Department of Environmental Conservation. Water Quality Monitoring and Assessment. Harmful Algal Blooms (HABs).

Stone, D. and W. Bress. 2007. Addressing Public Health Risks for Cyanobacteria in Recreational Freshwaters: The Oregon and Vermont Framework. Integrated Environmental Assessment & Management 3 (1): 137–43.

Sutherland, J.W., R.J. Turcotte, E. Molden, V. Moriarty, M. Kelly, M. Aubel, A. Foss. 2021. The detection of airborne anatoxin-a (ATX) on glass fiber filters during a harmful algal bloom. Lake & Reservoir Management.

United States Environmental Protection Agency. (2017) Nutrient Pollution. The Effects: Dead Zones and Harmful Algal Blooms

Watershed Agricultural Council. 2019. Croton & Catskill/Delaware Watersheds

Wilkinson, G. M., S.R. Carpenter, J.J. Cole, M.L. Pace, R.D. Batt, C.D. Buelo, and J.T. Kurtzweil. (2018) Early Warning Signals Precede Cyanobacterial Blooms in Multiple Whole-lake Experiments. Ecological Monographs. 88(2): 188-203.