Understanding Cyanobacteria at Marion County Lake

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Executive Summary

1. Intro

Marion County Lake is a 153 acre lake managed by Issac Hett and is located just southeast of Marion, Kansas. Marion County Lake has a regular cyanobacteria problem, and for three years now, teams of Kansas State University students in the Natural Resources and Environmental Sciences (NRES) Capstone course have sought to assist Mr. Hett in forming a lake management plan through conducting research, as well as collecting and analyzing data. This report seeks to better understand the drivers of cyanobacteria in Marion County Lake, which include weather, geese, and nutrients.

2. Weather

Determining if weather factors impact cyanobacteria blooms will help Mr. Hett determine whether or not cyanobacteria is something that can be controlled and if it is worth investing money into. Three scales were used to analyze weather: daily, weekly, and annually. Overall, there seems to be no correlation between precipitation and recorded cyanobacteria blooms at Marion County Lake. Daily, weekly and annual scales all showed different ranges of average temperature that were optimal to cyanobacteria. These ranges ultimately all fall between 40-90 degrees Fahrenheit, with cyanobacteria being more tolerant of warmer conditions and less tolerant of colder conditions.

3. Geese

To assess the effect of geese at Marion County Lake on harmful cyanobacteria algae blooms, calculations were made to estimate the nutrient input via geese fecal matter. By using data on the average number of Canada geese in the area, satellite imaging information, and biological species information the team was able to generate an estimated numerical value of phosphorus entering the water per day. Findings suggest that geese are responsible for a considerable amount of nutrient loading into the Marion County Lake system.

4. Nutrients

By utilizing data previously gathered at Marion County Lake by the Kansas Department of Health & Environment, the team was able to develop more information on the relationship between cyanobacteria and key nutrients. Specifically, the team looked at data on the cell count of cyanobacteria in water samples from the lake as well as data on the concentrations of phosphorus, orthophosphate, and total Kjeldahl nitrogen within lake water samples. Results suggest a relationship between cyanobacteria bloom success and these nutrients but also imply other factors can play a more essential role in the development of harmful algal blooms.

5. Conclusion

The goal of this NRES capstone project was to provide additional information to the Marion County Lake management team in order to aid them in their endeavor of reducing harmful algal blooms. Results from analysis of weather information indicate no correlation between cyanobacteria success and precipitation while demonstrating a relationship with temperature. Findings from the geese study show a large amount of phosphorus being added to the lake by geese daily. Nutrient cross-analysis points towards a positive correlation between key nutrient concentrations and cyanobacteria cell count. It is the hope of this NRES team that this research will help determine a lake management plan as well as provide a basis for future NRES teams.

Introduction

Marion County Lake and Park was established in 1937, several miles southeast of the town of Marion, Kansas. The park includes approximately 300 acres of land and 153 acres of water at depths up to 40 feet. Over the past several years, Marion County Lake has experienced an excess of nutrients creating eutrophic conditions, which has resulted in the periodic formation of harmful algal blooms (HABs). The formation of the HABs has severely impacted the lake's ability to provide recreational services for both the public, as well as the approximate 200 residents that live around the lake. Lake managers have been faced with the strenuous task of finding a way to mitigate and treat the HABs without compromising the recreational aspect of Marion County Lake. This NRES group decided to research some of the drivers of cyanobacteria in order to understand the impact on Marion County Lake and assist Isaac with the formation of a lake management plan.

Figure 1: Marion County Lake and Park (Google Earth, 2021).

Overview of Cyanobacteria

Cyanobacteria is a type of algae. Like all algae, cyanobacteria are dependent on nutrients to grow. To better understand cyanobacteria, it is helpful to understand the lifestyle of this organism. Essentially, cyanobacteria spends its days controlling its buoyancy in vertical columns of water. Towards the surface is where the organism typically gathers nutrients and sunlight. After these are gathered, cyanobacteria then retreat lower in the vertical column of water. This ability to regulate their own buoyancy makes cyanobacteria unique. Another characteristic that makes cyanobacteria special is its ability to produce cyanotoxins. Overall, cyanobacteria is a type of algae capable of controlling its buoyancy and producing toxins.

Cyanobacteria and other microscopic organisms such as phytoplankton make up a large majority of the NPP (net primary productivity) of a water body. As autotrophs, they are able to use basic nutrients along with sunlight to create their own food and energy sources. These organisms function at the bottom of the food pyramid, but are responsible for providing energy to the entire ecosystem. As they photosynthesize, they are consumed by larger organisms that can use the energy they had created to sustain the food pyramid. Most of this report will cover the negative impact of these microorganisms, but it is important to know how they can be incredibly beneficial as well.

Cyanobacterial blooms are often referred to as “harmful algal blooms" because of the negative impacts on vital ecosystem functions that occur as a result, including a loss of aquatic biodiversity (Visser et al., 2016). The bacterial decomposition of dying blooms can affect the populations of fish species as it may lead to hypoxia and anoxia (Paerl & Otten, 2013). It is also possible for cyanobacteria to bioaccumulate in organisms, resulting in amplification through the food chain. While cyanobacteria has been detrimental to certain aquatic species, it also has the potential to pose serious health risks to mammals as well. This includes both domestic and wild animals, as well as humans. The toxin produced by cyanobacteria can affect the digestive, endocrine, dermal, and nervous systems, resulting in liver and kidney damage, as well as reproductive toxicity (Bellamy et al., 2020). It is obvious that there is an urgent need to control water eutrophication as cyanobacterial blooms prevent full use of affected water bodies. Recurring blooms threaten the integrity of aquatic ecosystems that are depended upon for recreation, drinking water, and irrigation (Zhang et al, 2020).

Cyanobacteria need nutrients and sunlight to survive. The ability of this organism to obtain these essentials is key to how it is able to survive. Figure 2 below shows what the needs are of cyanobacteria:

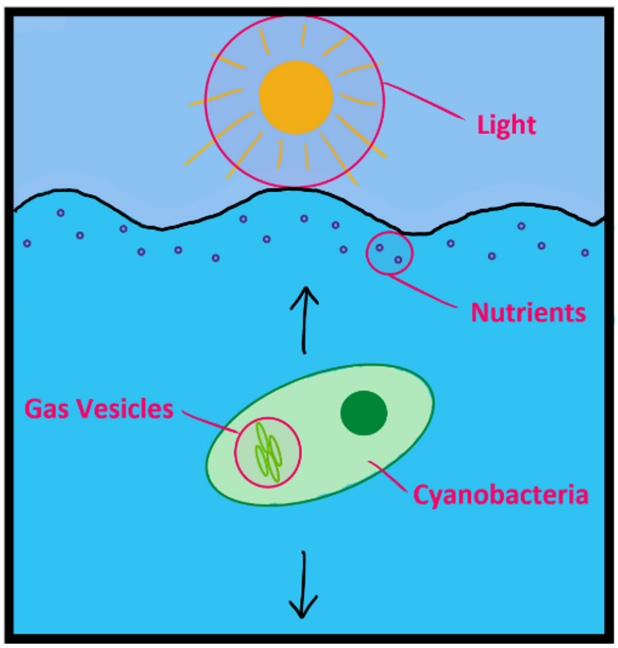


Figure 2: How Cyanobacteria Survive

- Light at the surface allows cyanobacteria to produce energy for itself using photosynthesis. This energy is necessary for cyanobacteria to survive and reproduce.
- Essential nutrients are typically found near the surface of water from runoff and animal waste. Nutrients are essential because they allow cyanobacteria to photosynthesize, develop, and reproduce.
- Gas vesicles are pockets of air in cyanobacteria. Cyanobacteria can use gas vesicles to control their buoyancy. Cyanobacteria use this buoyancy to move up and down in vertical columns of water. With this ability,

cyanobacteria can float to the top of the water, collect the light and nutrients they need, then retreat deeper into the water.

Overall, cyanobacteria survive by using gas vesicles to regulate their buoyancy so they can float to access the essential light and nutrients at the surface of the water, or sink to exert less energy. Factors that impact the components of this lifecycle, impact cyanobacteria success. Several factors in particular have been thought to make cyanobacteria more successful, these include weather factors, the amount of geese around the lake, and available nutrients. These factors, their impact on cyanobacteria, and how to manage them are all discussed in this report.

Factors Influencing Growth of Cyanobacteria

Weather

Literature supports Marion County Lake manager, Mr. Isaac Hett's observations that weather factors play a role in determining when cyanobacteria blooms occur. For instance, one article reports that there seems to be a connection between atmospheric variables and the cyanobacteria blooms, but that connection is dependent on the type of cyanobacteria and the location (Oliver, 2020). The particular weather factors that have been most covered are water and air temperature, precipitation, wind, and light.

Before diving into these specific weather variables, it is important to explain what weather is. Weather is short term variations in atmospheric variables. In contrast to weather, climate is weather over a long period of time, usually 30 years. This is important to distinguish because one article explains that short-term changes are more important to consider in terms of whether cyanobacteria will bloom (Huber, 2012). Thus that article would allow readers to conclude that it is best to look at atmospheric variables on a weather, or short term scale rather than climate, a more long term scale.

Air temperature is one factor that has been researched for its impact on cyanobacteria blooms. Overall cyanobacteria appear to be positively impacted by warmer air temperatures. For example, one article found that warm winters promoted cyanobacteria growth (Anneville, 2015). Not only was it found that higher air temperatures enhance cyanobacteria growth, but authors of a different article believe that lower temperatures prevented cyanobacteria (Huber, 2012). Agreeing with these conclusions about a positive relationship between weather and cyanobacteria is another article that found that minimum monthly temperatures increased with cyanobacteria occurrences (Hu, 2009). Scientific literature shows that warmer air temperatures promote cyanobacteria growth.

Going a step farther, another source explains that at temperatures less than 20 degrees Celsius, few toxins are released from cyanobacteria. This same article shows that on the contrary, temperatures at and over 20 degrees C appear to release more microcystin toxins from cyanobacteria (Walls, 2018). In addition to air temperature, water temperature could be playing a factor in cyanobacteria growth. Water temperature is controlled by atmospheric variables such as air temperature and precipitation, making it another important factor to consider. One article found that the optimal water temperature range for cyanobacteria is 20-35 degrees Celsius (Dokulil, 2016). Figure 3 below shows the effect water temperature in this study had on biovolume:

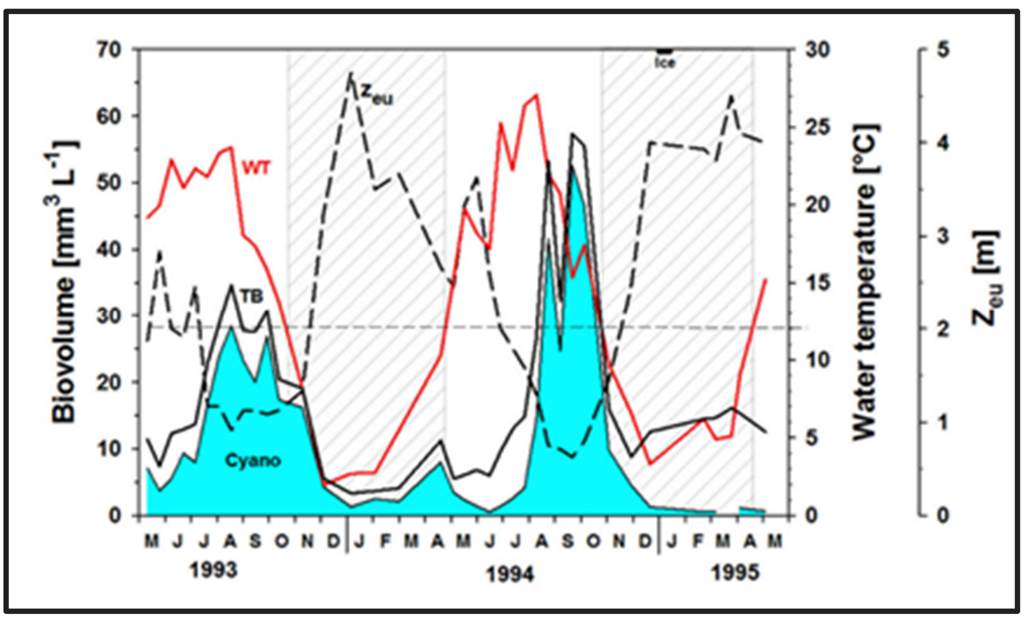


Figure 3: Water Temperature and Biovolume Over Time (Dokulil, M. T., 2016.)

Another article found that temperature increased photosynthesis through a range of temperatures, specifically between 15-35 degrees Celsius (Robarts, 1987). A third article found that most species of cyanobacteria obtain a maximum growth rate at temperatures above 20 degrees Celsius (Robarts, 1987). Overall these three articles agree with the conclusion that a fourth article came to that there seems to be a trend between higher water temperatures and increased amounts of cyanobacteria (Robarts, 1987).

Precipitation can be a source of nutrients and water turbulence. This statement is supported by an article that discusses how rainfall causes mixing of the lake and nutrient influx, both of which can impact cyanobacteria (Reichwaldt, 2012.) Precipitation can also be associated with cloudier weather, decreasing available light (see section 3.6 on light). With heavier rainfalls expected in the future, authors of one article predicted that more high intensity rainfalls would positively impact cyanobacteria and their ability to grow because high intensity rainfalls provide more nutrients than lighter rainfall events (Reichwaldt, 2012). Overall, authors found that total rainfall showed one of the strongest connections with the algae blooms, but more research is needed to determine how it impacts specific types of cyanobacteria in specific locations (Oliver, 2020).

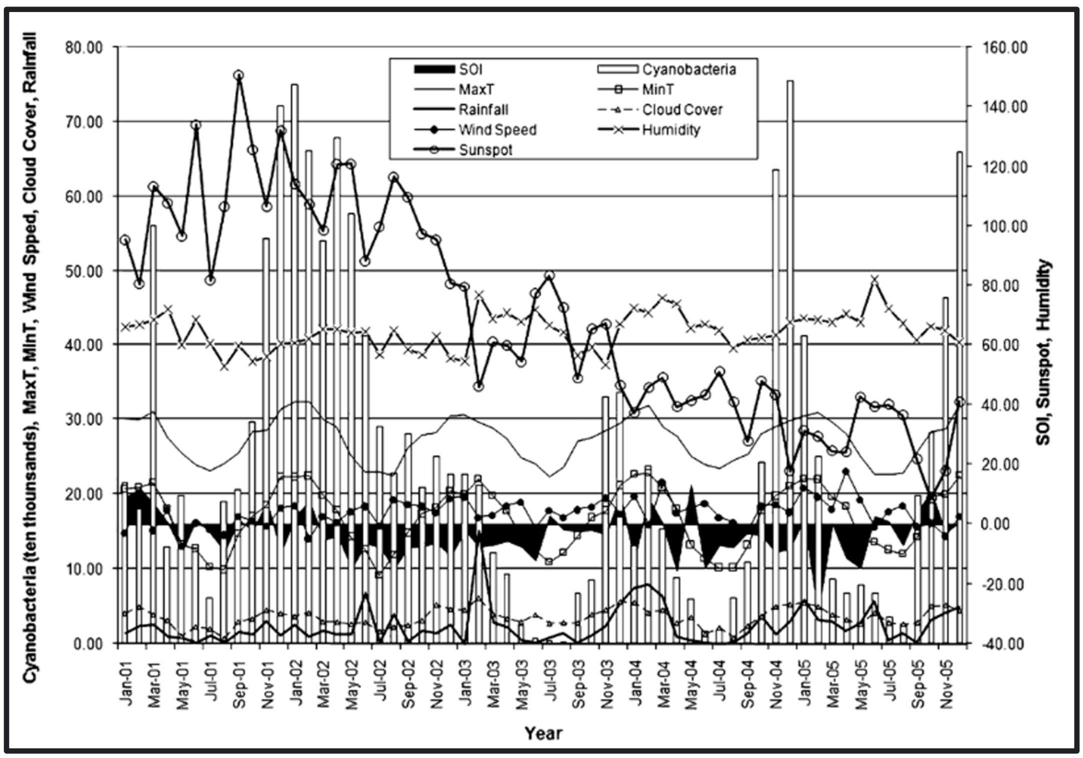
Wind can cause changes in evaporation, increased turbulence, and temperature changes in any given area. These effects of wind make it a possible factor that could impact cyanobacteria growth. Much of the researched effects of wind on cyanobacteria are lab studies rather than case studies. For example, one article modeled wind turbulence and found that wind may prevent cyanobacteria growth at night. In contrast, the same article found that wind could actually increase the amount of cyanobacteria at the surface of the water during the day (Chen, 2009).

In another article, authors believed that stronger summer winds prevented cyanobacteria (Huber, 2012). Another article supports this, having found that daily variations in wind speed during the summer demonstrated turbulence that caused the cyanobacteria to be found lower in the water column (Moreno-ostos, 2009). When cyanobacteria are lower in the water column, it makes it more difficult to access light and have the energy to process nutrients. In contrast, a different article showed that wind speed was negatively related to cyanobacteria occurrences (Hu, 2009). The results of several weather variables, including wind, are demonstrated in the below Figure 4:

Figure 4: The Effect of Weather Variables on Cyanobacteria (Hu, W., 2009)

Regardless of the effects of wind, the impacts that wind did have were caused in mere minutes, making it quick to impact cyanobacteria (Moreno-ostos, 2009).

Light provides energy for cyanobacteria to process and survive. Despite the need



for light, cyanobacteria gas vesicles like lower-light intensities. Higher light intensities can cause increased cell turgor-pressure. Too much of this pressure can cause the cell's gas vesicles to break, preventing the cyanobacteria from controlling their buoyancy (Chen, 2009). Without the ability of the cyanobacteria to control their buoyancy, they sink and it is more difficult for the cells to obtain necessary light and nutrients.

Light intensity was associated with given depths for one study. The authors of this study found that the biovolume of cyanobacteria peaked in the latter part of both studied years. This peak corresponds with minimum transparency of water, and therefore minimum light (Dokulil, 2016). Low light offers another potential benefit as well. Low light favors non-toxic cyanobacteria more than cyanotoxin-producing bacteria (Reichwaldt, 2012). This could mean that having more intense light could help prevent cyanobacteria.

Geese

One of the potentially serious contributors to the degraded water quality at Marion County is the massive Canada and snow goose population that lives there. Lake management personnel have stated on several occasions that the goose population is simply out of control. Geese are notorious for defecating almost non-stop and have the ability to drop thousands of pounds of poop into the water annually. Geese become a factor in a cyanobacteria explosion due to the high nutrient concentration in their poop. Research has shown that dry goose poop is close to 1.5% phosphorus or phosphorus compounds. Phosphorus is identified as a limiting resource in the growth of cyanobacteria and does not normally occur naturally. In fact, research has shown that in certain areas, geese and other waterfowl are responsible for >99% of the phosphorus contributions to the water. Having too many geese creates a large, uncontrollable, external source of phosphorus that can stimulate cyanobacteria growth and ultimately be detrimental to water quality.

Nutrients

Despite efforts to reduce nutrient loading in many communities around the world, eutrophication remains one of the most serious threats to water quality (Ibelings et al., 2016). Eutrophication is a form of water pollution that refers to the over enrichment of nutrients, and occurs when there is a continuous accumulation of organic matter in the water body (Sun et al., 2018). These excess nutrients are typically a result of anthropogenic activities and may come from point pollution, such as waste water from industry and municipal sewage, as well as non-point pollution like irrigation water, and surface water runoff containing fertilizer from farmland (Zhang et al., 2020).

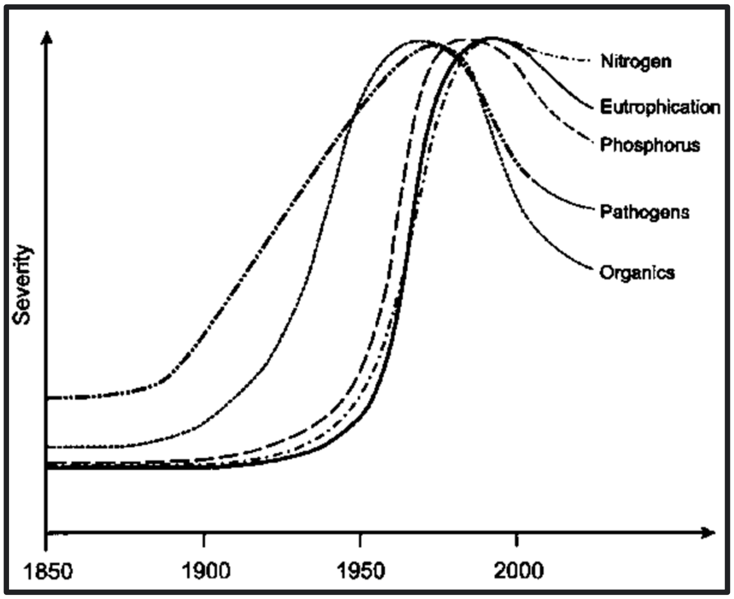


Figure 5: Schematic representation of the development of surface water pollution with pathogens, oxygen-consuming organic matter, phosphorus and cyanobacteria in north-western Europe and in North America (Chorus & Bartram, 1999).

Given the link between eutrophication and harmful algal blooms as shown in Figure 5, the team may inspect the role of key nutrients in the eutrophication process. These nutrients are nitrogen (N) and phosphorus (P). Phosphorus is typically considered to be the limiting nutrient, or the most essential nutrient, to cyanobacterial taxa and their growth (Vuorio et al, 2020). However, many cyanobacteria genera have a higher "drive" for phosphorus and nitrogen than other photosynthetic organisms, meaning that they will become more competitive when nutrients are limited (Cong, 2015). Additionally, cyanobacteria have a greater storage capacity for phosphorus than many other organisms, allowing them to produce biomass more easily when phosphorus is present (Chorus & Bartram, 1999). However, the presence of both N and P is seemingly necessary for large blooms to occur. A lower ratio of total nitrogen (TN) to total phosphorus (TP) is ideal for cyanobacteria dominance.

Phosphorus is an essential nutrient for the success of cyanobacteria. Concentrations of phosphorus of less than 0.1 mg l^{-1} may be sufficient to instigate a bloom (Chorus & Bartram, 1999).

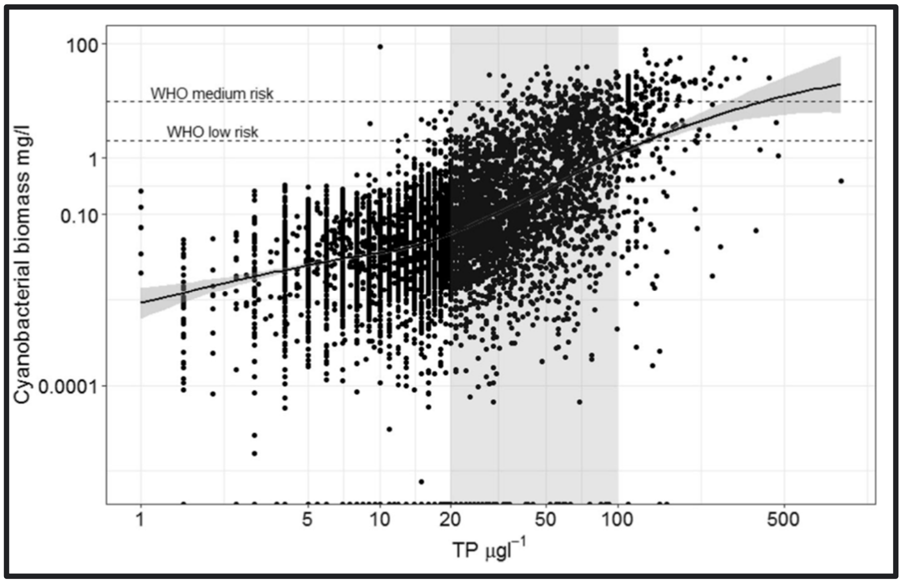


Figure 6: Log-log scatterplot and smoothed regression line of total cyanobacteria biomass and total phosphorus (TP). Vertical gray area represents 20 and 100 µg l^{-1} TP range for linear increase in cyanobacterial biomass. The horizontal dotted lines indicate the low health risk threshold (2 mg l^{-1}) and medium health risk threshold (10 mg l^{-1}) (WHO, 2003).

As shown in Figure 6, there is a positive correlation between TP and cyanobacterial biomass. This is because excess amounts of phosphorus allows cyanobacteria to fixate nitrogen in the environment. However, phosphorus-driven eutrophication can lead to N_2-fixing or non-N_2 fixing HABs (Paerl, 2008). Phosphorus is essential in the sense that it provides the mechanism for storing energy in the form ATP. That energy is then used to activate functions such as nitrogen fixation. N-fixation is processed by heterocysts, specialized cells that lack photosynthetic membranes and have thicker cell walls compared to normal cells (Cong, 2015). The purpose of these cells is to reduce nitrogen molecular into ammonia, aiding in the generation of glutamine, a metabolite important for the biosynthesis of nitrogen-containing compounds. N_2-fixation also turns N_2 into NH_4 and allows for bacterial growth. It follows then that large quantities of phosphorus in waters causes rapid algal bloom development.

The presence of nitrogen is certainly required for algal blooms. However, cyanobacteria can still utilize atmospheric nitrogen (N_2) in cases where nitrogen is limited (as discussed above). As a result, the lack of nitrate of ammonia will favor the dominance of cyanobacteria over other planktonic algae (Chorus & Bartram, 1999).

Methods of Analysis

Weather

In order to understand if what literature suggests in regards to weather applies to Marion County Lake, it is important to analyze data. To perform this analysis, assumptions had to be made and data was collected and analyzed.

Cyanobacteria cell count dates are only recorded when there are extreme blooms that warrant the Kansas Department of Health and Environment (KDHE) taking action. This means not all cyanobacteria bloom dates are accounted for. For this study, a significant cyanobacteria bloom is deemed to be a bloom that KDHE must respond to and take a cell count of. For this reason, only the dates with significant cyanobacteria blooms are considered representative of cyanobacteria blooms within this analysis.

With the nearest National Oceanic and Atmospheric Administration (NOAA) weather station at Marion County Reservoir, a second assumption had to be made. This assumption is that the weather station at Marion County Reservoir, six miles away, is close enough for the data there to be representative of the weather at Marion County Lake.

To properly assess whether or not weather plays a role in causing cyanobacteria blooms, it is important to have data representing when cyanobacteria blooms occur and what the daily weather is at Marion County Lake. The data demonstrating when cyanobacteria blooms occur was collected from the Kansas Department of Health and Environment website for Marion County Lake specifically. It is important to remember that these blooms only represent the most severe blooms, and that cyanobacteria data is not regularly collected unless it becomes a safety hazard. Daily weather data was then collected from NOAA. This weather data is representative of the weather station at Marion County Reservoir, approximately six miles away from Marion County Lake. This was thought to be a negligible distance when considering weather and was used to represent the weather at Marion County Lake.

Unfortunately, wind, light, and water temperature data were not recorded for Marion County Lake, and therefore it is impossible at this time to analyze the role these may play in cyanobacteria success at Marion County Lake. In the future it would be a good idea to monitor and record data for these factors to determine if they do play a part in producing or preventing cyanobacteria blooms.

The analysis determining if weather impacts cyanobacteria at Marion County Lake is broken down into three different scales. These scales of analysis are annually, weekly (or rather, week-prior, including day-of), and daily scales of analysis. The reason for the variety of scales is to gauge long and short term effects of weather on cyanobacteria blooms. In this way, annually will be representative of longer-term impacts of weather, while weekly and daily analysis will be representative of short term impacts of weather. Ultimately graphs of temperature, precipitation and cell count over time will be utilized to determine if there is a noticeable relationship between weather factors and cyanobacteria.

Geese

In order to successfully diagnose the geese at Marion County as a serious issue, the team had to know exactly how they function and their contributions. They first received an average observed number of Canada geese in the whole of Marion County over the last 5 years (3257). By assessing land and water cover using satellite imaging, I assumed about 800 of those geese to be Marion County Lake residents. An individual goose can put out about two pounds of fecal matter per day. About 75% of that is water, so that gives us 25% (one half pound) of dry fecal weight per day. If roughly 1.5% of that is phosphorus or phosphorus compound, it can be estimated one goose puts out about 1.7 g of phosphorus daily. Not all of the geese are at the lake, so the team assumed 400 at a time. So, to finalize the assumption, around 680 grams of phosphorus go into the water at Marion County Lake every day, provided the geese are present.

Most of the data used were assumptions, but population counts were retrieved from the National Audubon Society website and their annual Christmas Bird Counts from the last few years. The team also used measurements of the lake itself from the Marion County Lake website to get values for perimeter, surface area, and average depth to achieve an estimated volume. By using this estimated volume and assumed values from the goose populations, the team was able to develop a simple tool in excel that gives a running total of the phosphorus concentration contributions from the geese (in μg/L).

The analysis gives fewer answers and more of a tool to get more answers. By leaving this basic document full of assumptions with the lakefront management personnel, a rough running total of phosphorus concentration can be had. Since phosphorus very rarely occurs naturally in standing water, the geese are assumed to be the lead contributor (alongside residential fertilizer). This tool shows their contributions and can be used to further assess exactly how much of a threat these geese really are to the water quality at Marion County Lake.

Nutrients

Information from two different datasets was used for the analysis of the role of nutrients in excessive algal bloom formations. It must be assumed that the water samples that were captured for both data sets were collected close enough in time and space to draw meaningful information from a cross-analysis.

Two different data sets from the Kansas Department of Health & Environment (KDHE) were cross-analyzed. One set has data on nutrient densities within Marion County Lake and the other set consists of algae monitoring data. These data sets are long term data sets with one beginning in 1980 and the other in 1993. However, water sampling and testing only took place every three to four years. Since both sets were compiled by KDHE, many of the collection dates line up, allowing for a cross-analysis to measure the relationship between the nutrient composition and cyanobacteria cell count.

Results and Discussion

Weather

Temperature and precipitation were the two weather factors investigated in this analysis. These factors were analyzed on an annual, weekly, and daily scale. Each of these scales showed similar temperatures that promote cyanobacteria blooms. Meanwhile, none of these scales showed any direct relationship between precipitation and cyanobacteria. The detailed results of the annual, weekly, and daily analyses are discussed in the below sections.

Annual Basis

The results of analyzing precipitation and cyanobacteria on an annual basis do not appear to show any pattern or correlation. This can be noticed in Figure 7 below. While the year with the highest average cell count did correspond to the year with the highest amount of precipitation, this correlation does not hold beyond this point. In all, precipitation alone does not seem to be a direct driver of cyanobacteria blooms.

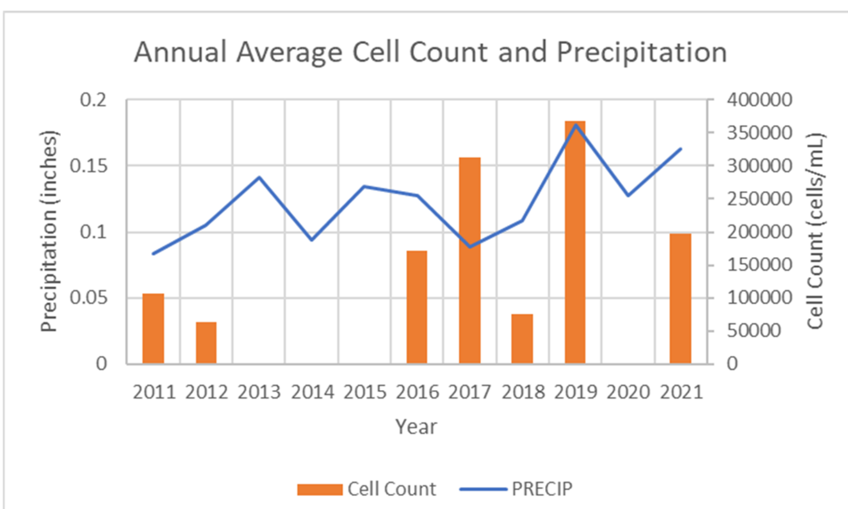


Figure 7: Annual Average Cell Count and Precipitation

While precipitation does not appear to have a correlation with cyanobacteria blooms at Marion County Lake, temperature might. On an annual basis, the years with higher cell counts had a temperature at or near 60 degrees Fahrenheit, as shown in Figure 8. Figure 8 also shows the minimum yearly temperature does not seem to have much of a correlation. It makes sense that there is no relationship here because cyanobacteria blooms primarily occur in the summer, while temperature minimums typically occur during wintertime. While there is no clear relationship between cyanobacteria blooms and maximum yearly temperature, the warmer temperatures do not seem to hinder the cyanobacteria growth, suggesting that cyanobacteria may be tolerant of warmer temperatures.

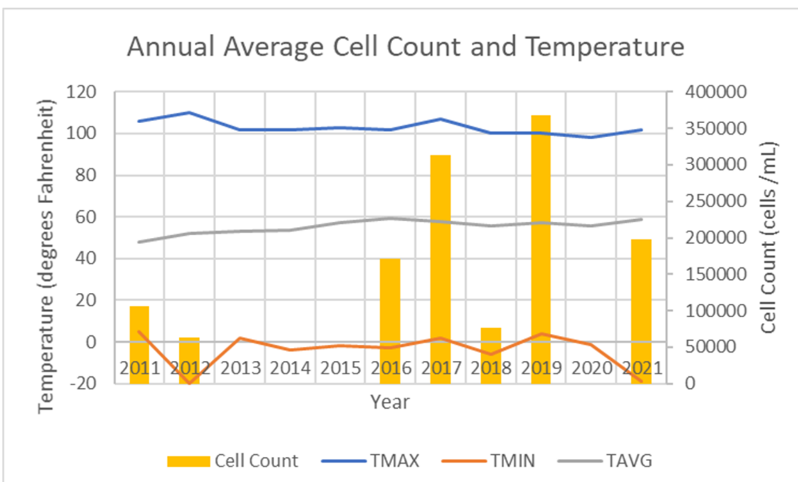


Figure 8: Annual Average Cell Count and Temperature.

Weekly Basis

The below Figure 9 shows a graph with weekly precipitation and cell count over time. Like Figure 7, Figure 9 shows no direct relationship between precipitation and cell count. There is a consistent increase in cell count during a few weeks in 2017 in Figure 7. These increases seem to have had some precipitation prior, but a similar occurrence in the leftmost grouping of blue week-prior precipitation points does not lead to similar increases in cyanobacteria. Overall, this does not lead to a conclusive relationship between cyanobacteria blooms and precipitation.

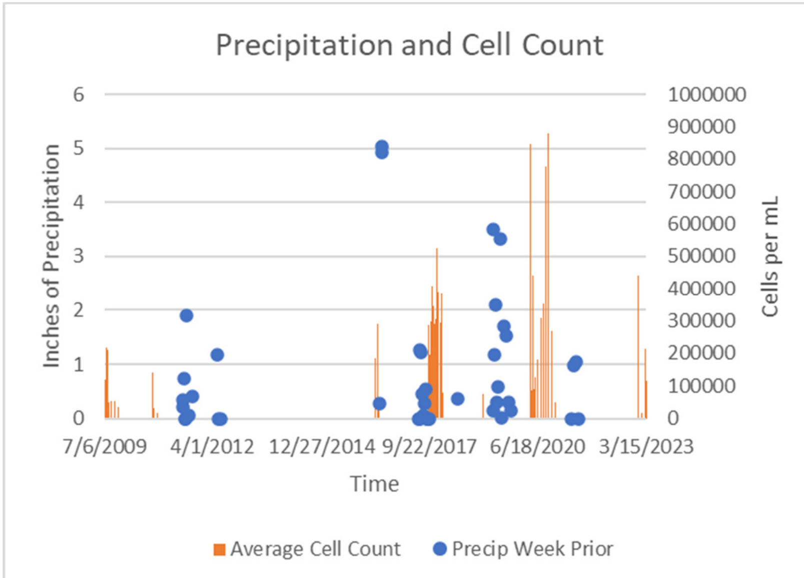


Figure 9: Weekly Average Precipitation and Cell Count

In Figure 10 below, it should be noted that all temperature points here are associated with cyanobacteria blooms, yet because the bloom is a specific day, and the temperature is for the week, some points may appear to be slightly off-alignment of the cell counts they are associated with.

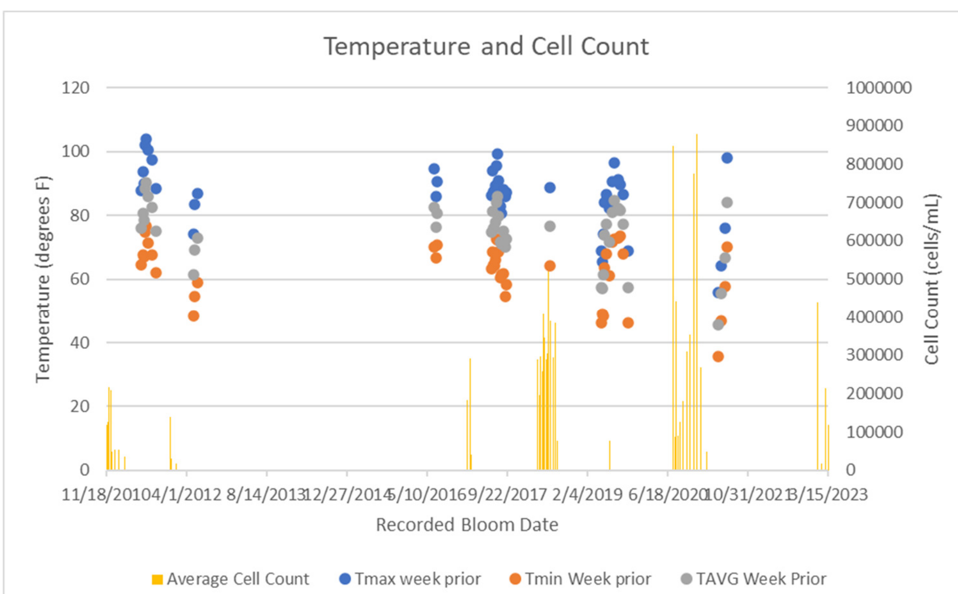


Figure 10: Weekly Temperature and Cell Count over Time

As seen in Figure 10, above, average temperatures of approximately 45-90 degrees Fahrenheit appear to be the prime temperature range for cyanobacteria blooms to occur. This can be seen by the range of the average temperature for the week prior on Figure 10. No significant cyanobacteria blooms occurred below 35 degrees Fahrenheit, so temperatures below this can be concluded to prevent cyanobacteria blooms. On the other hand, cyanobacteria appear to be tolerant to higher temperatures, with some blooms tolerating high temperatures of over 100 degrees Fahrenheit. This shows that cyanobacteria can survive naturally high temperatures at Marion County Lake. To summarize, on a weekly basis precipitation shows no direct relationship with cyanobacteria blooms, cyanobacteria are tolerant to higher temperatures, inhibited by temperatures below 35 degrees Fahrenheit, and the optimal temperature range for cyanobacteria is 45-90 degrees Fahrenheit.

Daily Basis

Similar to both the annual and weekly basis, precipitation and cyanobacteria blooms do not seem to have a distinct relationship on their own. Although the day with the highest precipitation was soon followed by the day with the second highest cell count, the day with the second highest amount of precipitation was followed by no recorded cell count. According to the assumptions of this analysis, no recorded cell count means that no significant cyanobacteria bloom was present. The other points on this chart also offer mixed results, so the relationship between cyanobacteria and precipitation remains inconclusive. The team recommends that Marion County Lake management record weather and cyanobacteria observations so that more data can be observed outside of the cell counts recorded by the Kansas Department of Health and Environment.

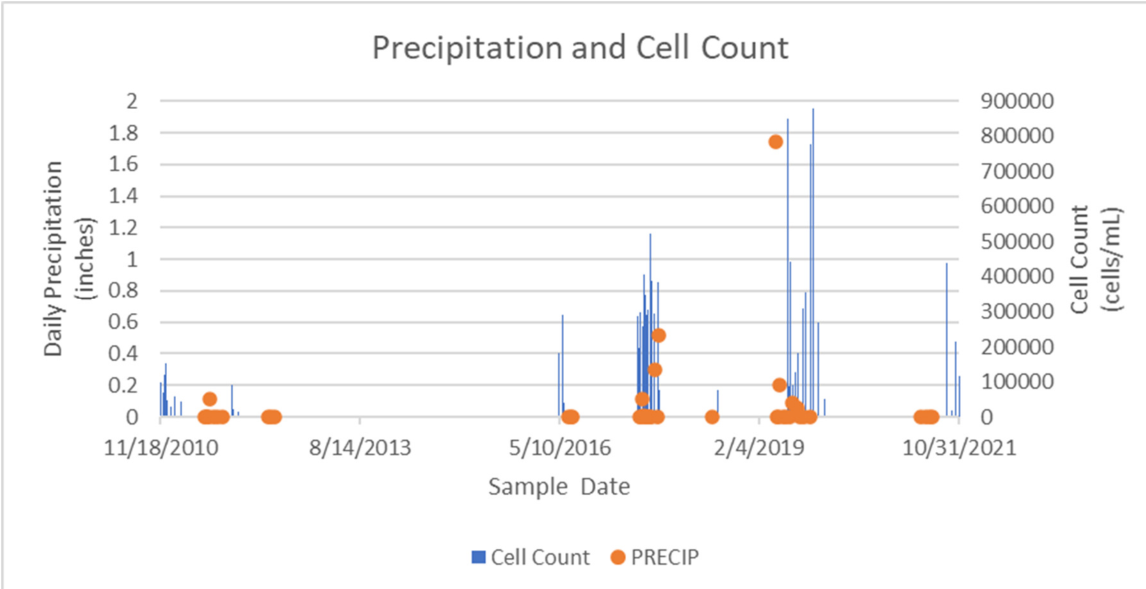


Figure 11: Daily Precipitation and Cell Count

Figure 12, below, shows that daily temperature results are very similar to the weekly results. On a daily scale, there are no significant cyanobacteria blooms below 40 degrees Fahrenheit. Additionally, a temperature range best defines when cyanobacteria blooms occur. The entirety of the daily temperature range for days with significant cyanobacteria blooms is 40-108 degrees Fahrenheit. With temperatures reaching past 100 degrees Fahrenheit on day with bloom occurrences, it is clear that cyanobacteria have some tolerance to warmer temperatures. The average daily temperature range, also shown in Figure 12, is between 55 and 90 degrees Fahrenheit. Overall, this contributes further to the evidence that a range of temperature promotes cyanobacteria growth.

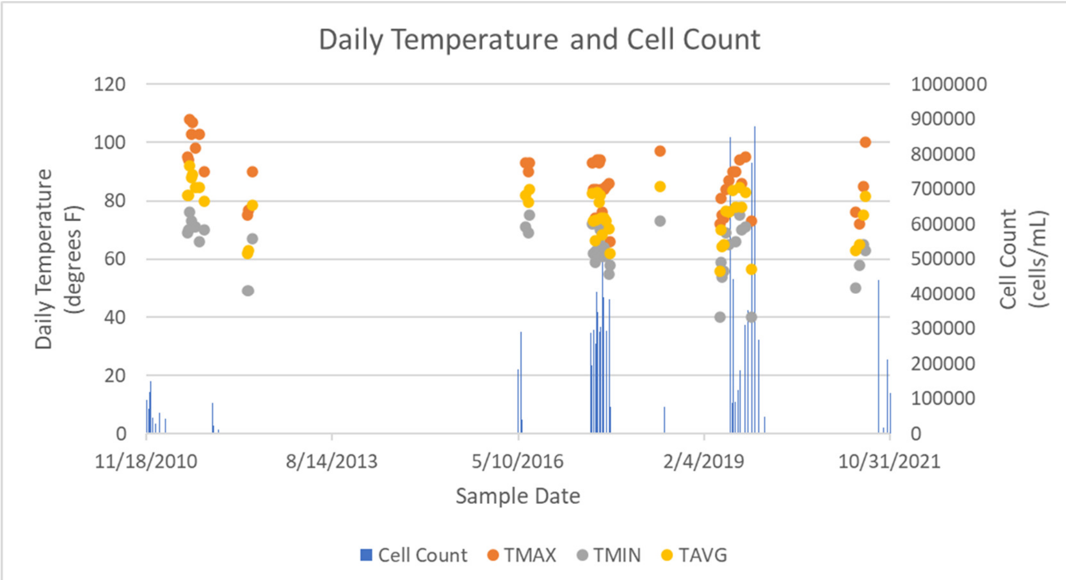


Figure 12: Daily Temperature and Cell Count.

Combined Results

Determining if weather factors impact cyanobacteria blooms will help Mr. Hett determine whether or not cyanobacteria is something that can be controlled and if it is worth investing money into. Three scales were used to analyze weather: daily, weekly, and annually. On a daily basis, precipitation does not seem to be correlated with cell counts. Daily temperature on cyanobacteria days ranges from 40-108 degrees Fahrenheit, with the average falling between 55 and 90 degrees Fahrenheit. On a weekly scale, precipitation does not appear to be correlated with cyanobacteria blooms. Additionally, average temperatures between 45-90 degrees Fahrenheit seem to be the optimal temperature range for cyanobacteria, with cyanobacteria being more tolerant to higher temperatures and less tolerant to temperatures below 35 degrees Fahrenheit.

Annually, there is no clear relationship between cell count and precipitation. Annual temperature seems to show that an average temperature around 60 degrees Fahrenheit is optimal for cyanobacteria. Along with this, the years where the low annual temperature was highest were some of the years with larger cyanobacteria cell counts. Overall, there seems to be no correlation between precipitation and recorded cyanobacteria blooms at Marion County Lake. Meanwhile, a range of temperatures appears to be optimal for cyanobacteria blooms. This range changed on daily, weekly, and annual scales, but all ranges were between 45 and 90 degrees Fahrenheit. Ultimately, temperature showed some correlation to cyanobacteria blooms, but precipitation did not.

Geese

The impact specifically of the geese at Marion County is hard to gauge. On one hand, there are first-hand accounts of geese and their poop covering the surface of the water. It seems that there are adequate grounds to assume geese are the culprit. But upon visiting the lake, there were no geese in sight aside from a dozen or so. The water quality tests were very normal and did not give us anything more than minimal phosphorus amounts. Compounding the low goose numbers observed and the fairly low orthophosphate levels, it is fair to wonder what exactly the impact of these geese really is on the water. It must be taken into account that the observations and measurements were made in the migration season, meaning it is possible for the goose populations to have an effect on the water that is simply not observable during the winter. By using a worksheet created by one of the team members, the lake managers at Marion County lake should be able to provide a rough estimate to the actual effect the geese have on the water in order to determine if they really are a culprit.

Nutrients

Results from the cell count and nutrient KDHE data sets cross-analysis indicate a relationship between harmful algal blooms and key nutrients. While detailed statistical analysis was not conducted, figures were created to illustrate the manner in which these nutrients appear to be correlated to cyanobacteria success as a variable throughout time. However, there are still uncertainties in the extent with which nutrients affect the harmful algal blooms at Marion County Lake.

Phosphorus

Phosphorus is typically considered to be the limiting nutrient, or the most essential nutrient, to cyanobacterial taxa and their growth (Vuorio et al., 2020).

However, many cyanobacteria genera have a higher “drive” for phosphorus (and nitrogen) than other photosynthetic organisms, meaning that they will become more competitive when these nutrients are limited (Cong, 2015). Additionally, cyanobacteria have a greater storage capacity for phosphorus than many other organisms, allowing them to produce biomass more easily when phosphorus is present (Chorus & Bartram, 1999).

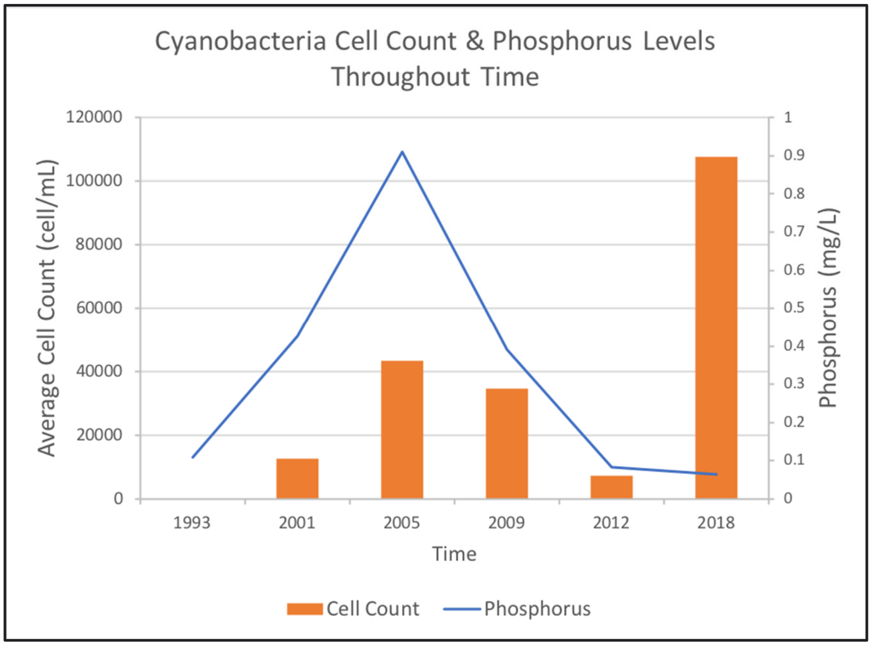


Figure 13: Cyanobacteria Cell Count & Phosphorus Levels Through Time

As seen in Figure 13, the team compared the average phosphorus levels to the average cyanobacteria cell count from 1993 to 2018. It appears that there is a correlation between the two variables initially. From 1993 to 2005, both variables increased together. From 2005 to 2012, both variables decreased alongside one another. However, in 2018, an anomaly occurs - an extremely high cyanobacteria cell count is measured but decade-low phosphorus levels are recorded. Perhaps this is a fluke in the data or perhaps there were other, more impactful, factors promoting algal bloom development in 2018.

Orthophosphate

Orthophosphate is a salt of phosphoric acid. When a lake system has a high concentration of orthophosphates, it is commonly as a result of an anthropogenic source. Typical sources include sewage water interaction, agricultural runoff, and lawn fertilizing around the lakefront.

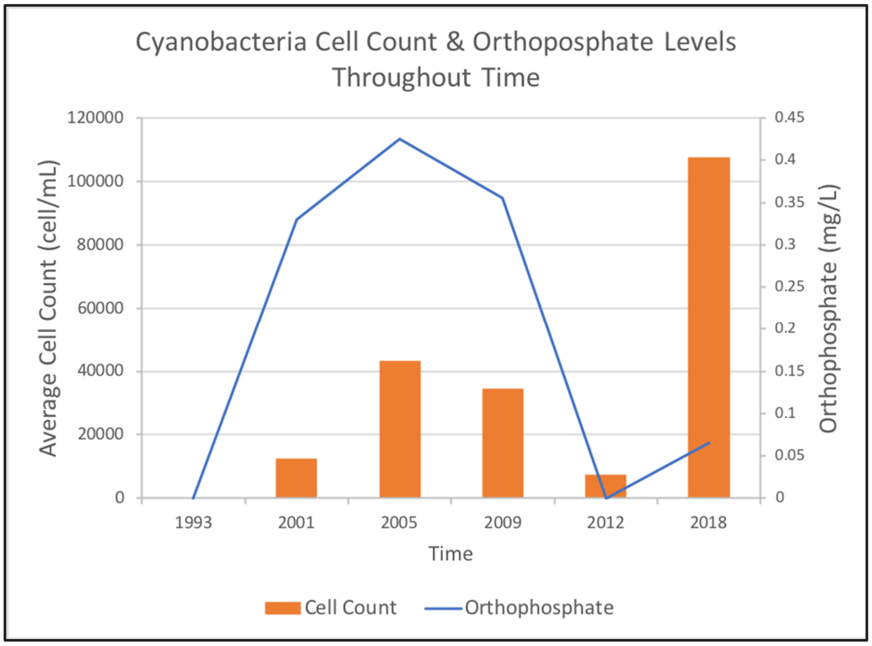


Figure 14: Cyanobacteria Cell Count & Orthophosphate Levels Throughout Time

Figure 14 depicts orthophosphate concentrations as they relate to cyanobacteria cell count over time. Orthophosphate levels follow a similar trend as phosphate levels shown in Figure 13. However, the team observed an increase in concentrations in 2018. Perhaps the additional orthophosphates available relative to 2012 contributed to the massive bloomings recorded in 2018.

Total Kjeldahl Nitrogen

The term total Kjeldahl nitrogen is defined as the total concentration of organic nitrogen and ammonia. Nitrogen-fixation is processed by heterocysts, specialized cells in cyanobacteria that lack photosynthetic membranes and have thicker cell walls compared to normal cells (Cong, 2015). The purpose of these cells is to reduce nitrogen molecular into ammonia, aiding in the generation of glutamine, a metabolite important for the biosynthesis of nitrogen-containing compounds. N_2-fixation also turns N_2 into NH_4 and allows for bacterial growth. The presence of nitrogen is certainly required for algal blooms. However, cyanobacteria can still utilize atmospheric nitrogen (N_2) in cases where nitrogen is limited. As a result, the lack of nitrate or ammonia will favor the dominance of cyanobacteria over other planktonic algae (Chorus & Bartram, 1999).

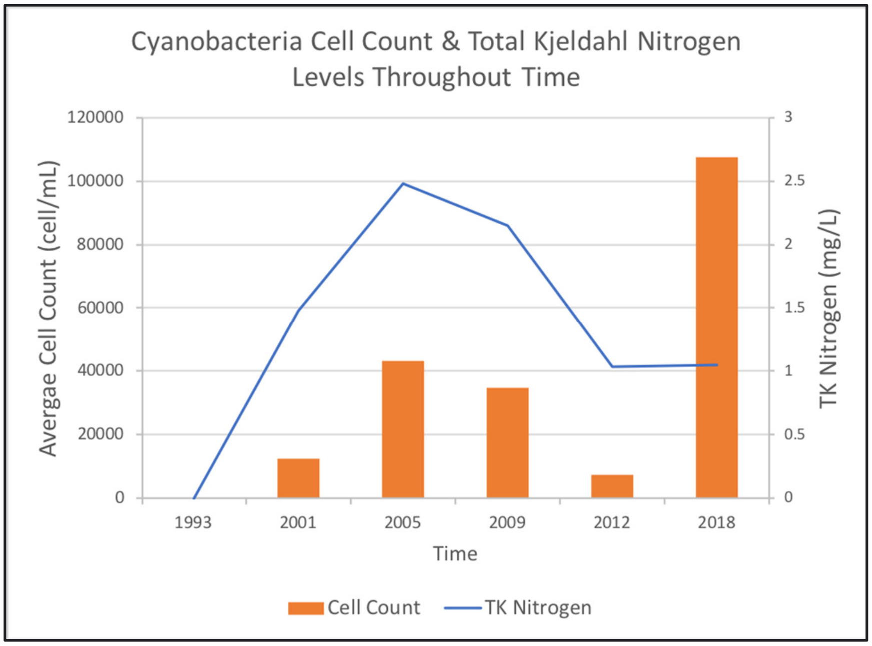


Figure 15: Cyanobacteria Cell Count & Total Kjeldahl Nitrogen Levels Throughout Time

A similar story can be seen between cell count and TK nitrogen in Figure 15. Something noteworthy here is that levels essentially remained constant from 2012 sampling to 2018 sampling while cell count reached an all-time high. This is counter-intuitive and also suggests that another factor or driver of algal blooms is at play.

Treatment Methods

It would be beneficial for lake managers to conduct a lake assessment strategy in order to determine the priority management targets and implement control measures based on lake composition. This can be done by utilizing a eutrophication model that combines theoretical analysis with experimental research in order to determine which types of preventive and control measures would yield optimal results. The type of measure selected can be based on specific goals that need to be met, as well as the available budget and time frame (Stroom & Kardinaal, 2016). Preventive measures are defined as those which aim at achieving long-term improvement of a water body's ecosystem, while control measures are used to directly reduce cyanobacterial blooms. Both preventive and control measures can be explored and implemented together to determine which are most suitable in terms of efficacy and feasibility. Figure 16 shows a comparison of treatment methods and techniques, as well as the advantages and disadvantages associated with each one.

Methods	Techniques	Advantages	Limitations	References
Chemical methods	Metals (aluminum, iron, copper, calcium)	-Low cost -High residence time	-Toxicity against non-target species -Accumulation in the environment	(Magdaleno et al., 2014)
	Photosensitizers (hydrogen peroxide, phthalocyanines, titanium dioxide)	-Low cost -Degradability	-Risky manipulation -Coloration	(Pohl et al., 2015)
	Herbicides (diuron, endothall, atrazine, simazine)	-Low cost -High residence time	-Toxicity -Release of toxins	(Nagai et al., 2016)
Physical methods	Ultrasound techniques	-Low impact on ecosystems -Contamination free	-To be confirmed at up-scaled levels	(Park et al., 2017)
	UV irradiation	-Eco-friendly -Contamination free	-High energy requirement -To be confirmed at up-scaled levels	(Alam et al., 2001)
	Membrane filtration technology	-Well-established technology -High stability	-High cost	(Zhao et al., 2017)
	Adsorption	-Eco-friendly -Contamination free	-High cost -To be confirmed at up-scaled levels	(Marzbali et al., 2017)
Biology methods	Aquatic plants	-Technically simple reactor	-Affect biodiversity -Deteriorate eutrophication	(Zuo et al., 2014)
	Aquatic animals	-User-friendly -Environmentally sound	-It will not work in oxygen-poor conditions -Affect biodiversity -Poor efficiency	(Montemezzani et al., 2017)
Combined technologies	Microorganisms	-High specificity -High efficiency	-High cost -To be confirmed at up-scaled levels	(Sun et al., 2016).
	Ultrasonic radiation and jet circulation to flushing	-High efficiency	-High cost -To be confirmed at up-scaled levels	(Nakano et al., 2001)
	Combination of uniform design with artificial neural network coupling genetic algorithm	-High efficiency -Low cost	-To be confirmed at up-scaled levels	(Cai et al., 2014)

Figure 16: Comparison of methods for HAB control (Sun et al., 2018).

Conclusion

For the past several years, groups of NRES students have conducted research, as well as collected and analyzed data pertaining to cyanobacteria at Marion County Lake. In order to better understand how cyanobacteria function at Marion County Lake, this NRES group decided to research how certain factors influence cyanobacterial growth, including weather, geese, and nutrients. This was done in order to provide more information to the Marion County Lake and Park manager, Isaac Hett, and ultimately to assist with the writing of a lake management plan.

One factor that cannot be managed by Mr. Hett is weather. While precipitation does not have a standalone relationship with cyanobacteria blooms, temperature does. Cyanobacteria are more tolerant of warmer weather and less tolerant of colder temperatures, particularly temperatures below 35 degrees Fahrenheit. An optimal range for cyanobacteria is approximately 45 to 90 degrees Fahrenheit, which agrees closely with peer-reviewed literature. Unfortunately there was no conclusive evidence to determine whether or not geese are directly responsible for a nutrient influx that promotes cyanobacteria growth. The one thing that lake management can attempt to control is the nutrient loadings. Nutrients, particularly phosphate, orthophosphate, and total Kjeldahl nitrogen, were found to have a direct relationship to cyanobacteria blooms.

With this new research, it is the hope of the NRES student team that a lake management plan can be determined. Both preventive and control measures can be chosen and implemented as part of this plan in order to mitigate cyanobacterial blooms at Marion County Lake. The type of measure(s) selected should be based on the goals determined in the lake management plan, as well as whichever measures are most suitable for bloom mitigation based on feasibility and efficiency.

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