ABSTRACT

Correlations Between Agriculture, Harmful algal blooms, and Parkinson's Disease: How Anthropogenic Factors Are Contributing to Growth of Toxin-producing Algae

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The magnitude and duration of harmful algal blooms (HABs) is increasing, largely due to warmer climates and favorable nutrient concentrations. Cyanobacteria, one type of HAB, have the potential to release cyanotoxins dangerous to human health. This thesis reviews the reasons for the growing problem of HABs as well as what solutions are being researched to reduce the threat. Additionally, statistical analysis is used to determine whether agriculture, cyanobacterial growth, and Parkinson's Disease prevalence in the U.S. are correlated. Finally, Washington State Parkinson's related hospitalizations and microcystin data are analyzed for correlation. Results indicate that from a national perspective, agriculture, cyanobacteria density, and microcystin concentrations were positively correlated, and in Washington, data show microcystin and Parkinson's related hospitalizations to be positively correlated. Further research is needed to better understand the potential association between Parkinson's Disease and cyanobacterial HABs.

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CORRELATIONS BETWEEN AGRICULTURE, HARMFUL ALGAL BLOOMS, AND PARKINSON'S DISEASE: HOW ANTRHOPOGENIC FACTORS ARE CONTRIBUTING TO GROWTH OF TOXIN-PRODUCING ALGAE

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CHAPTER ONE

Introduction

Harmful algal blooms (HABs) have become more frequent, intense, and widespread in the past decades as favorable conditions increase (Hallegraeff et al., 2004). Algal blooms with adverse effects on the environment or human health are altogether known as harmful algal blooms, or HABs. There are three categories of harmful algal blooms; the first is composed of algae that, by themselves, are not harmful, but when the conditions are ideal, the blooms become so dense that eventually the oxygen of the water system is depleted, leading to plant and animal death in a process known as eutrophication (Anderson, et al., 2012; Hallegraeff et al., 2004). In eutrophication, high nutrient levels lead to algal bloom proliferation, and once the algae die, decomposers use much of the oxygen found in the water body (Rabotyagov et al., 2014).This results in low dissolved oxygen conditions, referred to as hypoxic or dead zones, where little aquatic life is possible (Rabotyagov et al., 2014). The second category consists of those algal species that produce toxins, such as neurotoxins, dermatoxins, hepatotoxins, and saxitoxins (Hallegraeff et al., 2004). The final category, ichthyotoxin, encompasses those species that are harmful to the gills of aquatic species such as fish and other invertebrates, but not to humans (Anderson et al., 2012; Hallegraeff et al., 2004). This paper will be focusing on the second category, the toxin-producing algae, and more specifically on cyanobacteria and whether an association with Parkinson's Disease can be determined through national and regional analyses.

Parkinson's Disease

The burden of neurological disorders is increasing in developing countries, largely due to longer life expectancies and growing populations (GBD 2016 Neurology Collaborators, 2019). As incidences increase, it is important to promote research not only in discovering cures and medicines that can help alleviate some of the symptoms experienced by victims, but also to localize causes that increase the likelihood of developing these disorders. Uncovering environmental risk factors is a large step in forming preventative solutions. The involvement of scientific investigations may provide factual information leading to modification of lifestyles and practices that benefit the protection of environmental and human health.

Neurological disorders are a major concern for public health. A global study conducted between the years of 1990-2016 shows that neurological disorders were the second leading cause of deaths worldwide and the leading cause of disability-adjusted life years, or DALYs, which calculates the years of life lost due to disability or early death (GBD 2016 Neurology Collaborators, 2019). Many countries are experiencing aging populations, and since many neurodegenerative diseases are age-related, it is understandable that incidences of such diseases are rising. The rates of most neurological disorders, with the exception of tetanus, meningitis, and encephalitis, has increased (GBD 2016 Neurology Collaborators, 2019). This will lead to more demand for facilities and care for the elderly experiencing disorders as well as research to find treatments and cures. Additionally, research is needed to find the potential causes, so that preventative measures may be taken along with treatment. With the massive number of neurological disorders seen today, my research focused on Parkinson's disease, but also considered

Alzheimer's disease and Amyotrophic Lateral Sclerosis (ALS) in the review of relevant literature.

Parkinson's Disease (PD) is a common neurodegenerative disorder causing multiple symptoms such as difficulty moving and tremors, which become worse over time (Mayo Clinic, 2020). Symptoms arise following the breakdown and ultimate death of nerve cells (neurons) in the area of the brain responsible for controlled movements (Mayo Clinic, 2020). After they die, the neurons are no longer capable of producing the neurotransmitter dopamine, which is an important messenger of information between neurons in the brain (Mayo Clinic, 2020). A decrease in dopamine levels causes trouble controlling motor movements, leading to the symptoms of PD such as tremors, stiffness, and poor balance (Mayo Clinic, 2020). While a specific cause has yet to be discovered, genes and environmental factors are thought to contribute to the manifestation of PD (Mayo Clinic, 2020). Studies have analyzed the roles of pesticides, metals, solvents, toxins, and more, but no definitive cause has been discovered (Cox et al., 2016).

There are approximately one million people living with PD in the U.S. today, around 60,000 are diagnosed per year, and by 2030, approximately 1.2 million people are expected to have PD in the U.S (Parkinson's Foundation, n.d.). Prevalence is increasing and has risen by 145% since 1990 (GBD Neurology Collaborators, 2019). This rising number is normal since, as previously discussed, the population is growing, living longer, and more people will join the older age group category. Finally, when considering an economic perspective, direct and indirect costs associated with PD costs the U.S. an estimated total of $52 billion per year (Parkinson's Foundation, n.d.).

A common aspect among many neurodegenerative diseases is that environmental factors are thought to contribute to their occurrence. However, no single environmental factor has been determined which can be certainly linked to onset of neurodegenerative diseases, and most researchers believe in an interaction between multiple environmental factors in addition to genetics and lifestyle (Mayo Clinic, 2020). There are limited studies on the prevalence and incidence of neurological disorders correlated with HABs, but those that do exist commonly report results supporting a correlation. In the remainder of this paper, an overview of the causes and concerns of HABs will be given, a correlation analysis will be conducted on national and regional data, and outlooks and solutions will be discussed.

Harmful Algal Bloom Increases

As more attention is being directed toward public health, and as technology is improving, an increasing number of studies analyzing aquatic systems and water quality are being conducted. Additionally, the public has much easier access to information, whether scientific or not, concerning the health of their immediate surroundings. This is perhaps one reason why it appears as though our water quality is so rapidly deteriorating. Sometimes new studies can lead to enhanced understanding of a problem, making the problem appear to be novel, when in reality, the problem has existed for some time just without proper documentation (Anderson et al., 2012). However, scientific data have shown that a change in algal growth patterns is occurring in response to climate change, nutrient abundance, and other anthropogenic activities being the main reasons (Brooks et al., 2018) .

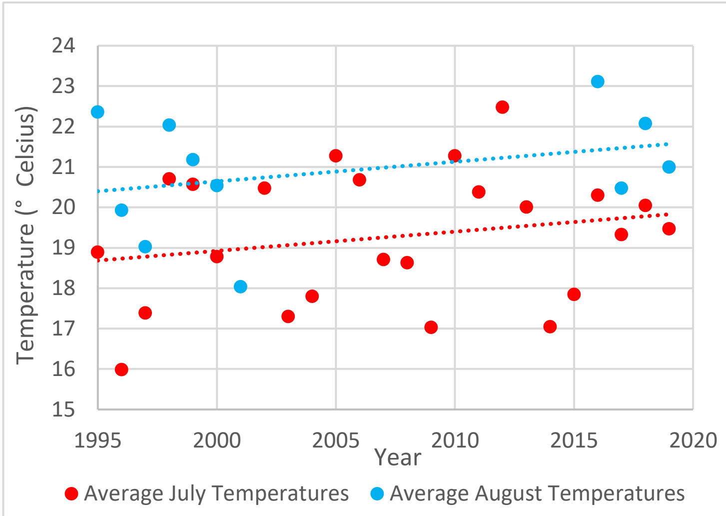

Figure 1. Average temperature of the Great Lakes in July and August from 1995 (https://coastwatch.glerl.noaa.gov/statistic/)

Climate change has led to warmer water temperatures and alterations in weather patterns that result in algal blooms lasting for longer periods of time (Paerl et al. 2016). Many water bodies are experiencing an increase in average temperatures; Figure 1 shows an average increase of about 1°C in the Great Lakes during summer months since 1995. For many cyanobacterial algal species, the temperature of optimal growth is warmer than those of other eukaryotic algal species, giving cyanobacterial species an advantage when temperatures are higher (Paerl & Paul, 2012). These species are often able to grow well past 25°C, whereas other algal species reach maximum growth and level off or begin to decline around this temperature (Paerl & Paul, 2012). In addition to warming waters, climate change also changes weather patterns such as precipitation and drought events. Longer and more intense precipitation favors growth in response to nutrient runoff from nearby land, which washes into bodies of water. These events are exacerbated by droughts, which allow nutrients to concentrate in water bodies rather than wash into larger basins (Paerl et al., 2016).

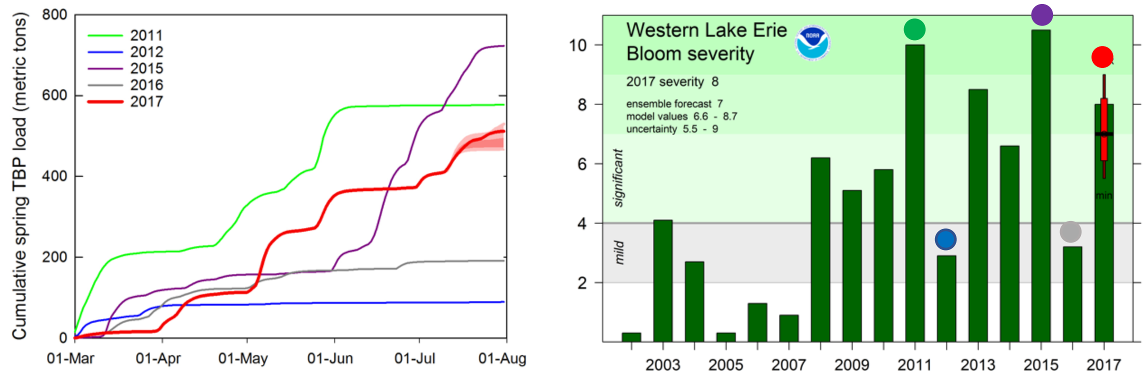

Figure 2. Relationships between phosphorus input and bloom severity A) total bioavailable phosphorus from the Maumee River (http://lakeeriealgae.com/forecast/); B) Western Lake Erie Bloom Severity (http://lakeeriealgae.com/forecast/).

Another key factor for algal growth is nutrient availability. Both phosphorus and nitrogen greatly influence the growth of cyanobacterial HABs, and anthropogenic activities, such as fertilizer usage, soil erosion, and animal waste are greatly increasing the levels of these nutrients in water systems (Paerl et al., 2016). An example of the close relationship between nutrient availability and bloom severity can be seen in Figure 2. The Maumee River, running from Indiana through Ohio and draining in Lake Eerie appears to be a key determinant in how intense the algal blooms should be any given year in Lake Eerie (Lake Erie Harmful Algal Bloom Forecast, 2015). It is the largest watershed flowing into any of the Great Lakes, and, because of its vicinity to agricultural farmland is a basin for loads of nutrient-rich fertilizers (Maumee River, 2020). Thus, the phosphorus concentration in the Maumee River from March to the end of July is largely responsible for the phosphorus levels in the western sections of Lake Eerie (Lake Eerie Harmful Algal Bloom Forecast, 2015).

Phosphorus levels were previously thought to be the limiting nutrient for primary production of cyanobacterial HABs, leading to more controlled phosphorus outputs, but research has now shown that nitrogen availability is likely just as instrumental (Paerl & Paul, 2012; Paerl et al., 2016). Some cyanobacteria species have the capability to use nitrogen gas (N_2) found in the air and convert it to useful forms of nitrogen, a process known as nitrogen fixation (Latysheva et al., 2012). This allows the organism to continue growth and production even when nutrient levels are low, which lead researchers to think that phosphorus concentrations had the greater effect on growth since nitrogen is always available. However, nitrogen fixation accounts for less than 50% of nutrient requirements for production, meaning that both excess phosphorus as well as nitrogen inputs can substantially influence growth, even when considering N_2 fixing cyanobacteria (Paerl & Paul, 2012).

Cyanobacterial HABs are mostly found in freshwater during warmer summer months but are also common in marine systems (United States Environmental Protection Agency [US EPA], 2018). The span of the bloom season varies in different locations since it is dependent on climate (US EPA, 2018). Approximately 2000 species of cyanobacteria have been discovered, many of which are able to produce toxins, known as cyanotoxins (Bláha et al., 2009; USEPA, 2018). A few of the species most commonly associated with producing freshwater cyanotoxins are *Anabaena, Cylindrospermum, Microcystis, and Planktothrix* (Bláha et al., 2009).

Table 1. Human cyanobacterial exposure health outcomes
(*Note.* Reprinted from "Climate change: Links to global expansion of harmful cyanobacteria", by Bláha, et al., 2009, *Interdisciplinary Toxicology, 2*(2)*,* p. 38.)

Year	Location (source)	Cyanobacteria	Toxin	Health outcomes
Drinking water				
1931	USA, Ohio river	*Microcystis*	?	gastroenteritis, abdominal pain, vomiting
1960–1965	Zimbabwe, Harare	*Microcystis*	?	gastroenteritis
1975	USA, Pennsylvania	*Schizotrix, Lyngbya, Phormidium*	?	gastroenteritis
1979	Australia, Palm Island	*Cylindrospermopis*	CYN	gastroenteritis, liver, kidney and intestine damage
1981	Australia, Armidale	*Microcystis*	MC	liver damage
1977–1996	China	*Microcystis*	MC	colorectal cancer, deaths
1972–1990	China	*Microcystis*	MC	primary liver cancer, deaths
1988	Brazil, Itaparica dam	*Microcystis, Anabaena*	?	gastroenteritis, diarrhoea, deaths
1994	Sweden, Malmö	*Planktothrix*	MC	gastroenteritis, fevers, abdominal and muscular pain
Recreational/occupational water contact				
1959	Canada, Saskatchewan	*Microcystis, Anabaena circinalis*	?	headache, nausea, muscular pain, vomiting, diarrhoea,
1980–1981	USA, Pennsylvania and Nevada	*Aphanizomenon, Anabaena*	?	eye and ear irritation, flu like symptoms
1989	UK, England, Stafordshire	*Microcystis*	MC	gastroenteritis, sore thorat, blistered mouth, vomiting, abdominal pain, fever, pulmonary consolidation, diarrhoea
1995	Australia	*Microcystis, Anabaena, Aphanizomenon, Nodularia*	?	gastroenteritis, flu like symptoms, blistered mouth, fever, eye and ear irritation, vomiting, diarrhoea
1996	UK	*Planktothrix*	MC	rashes, fever
1996–1998	Australia (coastal sea)	*Lyngbya*	?	contact dermatitis, eye and ear irritation, respiratory irritation
2002–2003	Finland	*Anabaena lemmermannii*	STX	fever, eye irritation, abdominal pain, rashes
Haemodialysis				
1974	USA, Washington	present	LPS	fever, myalgia, chills, vomiting
1996	Brazil, Caruaru	present	MC, CYN	visual disturbance, tinitus, nausea, vomiting, liver damage, deaths
2001	Brazil, Rio de Janeiro	*Anabaena, Microcystis*	MC	visual disturbance, tinitus, nausea, vomiting, liver damage

Abbreviations: MC - microcystin, CYN - cylindrospermopsin, STX - saxitoxin, LPS - lipopolysaccharides, "?" - toxin unknown.

Exposure to cyanotoxins can occur in a variety of ways; ingestion via contaminated water, consumption of contaminated food, contact with water from activities such as swimming, or inhalation of aerosolized toxic cells (US EPA, 2018). Both short term and long-term health effects can result from cyanotoxins, but short-term effects have been documented at a higher rate. Cyanotoxins are classified according to their target organ: hepatotoxins produce toxins affecting the liver, neurotoxins can damage nerve tissue, cytotoxins can cause cell death, and dermatotoxins result in skin damage or irritation (Bláha et al., 2009). Table 1 outlines some of the documented health outcomes that have resulted from acute, or short term, cyanotoxin exposure. The hepatotoxin microcystin is one of the most widely occurring cyanotoxins and was the cyanotoxin primarily focused on in this study.

HABs and Neurodegenerative Diseases

Several studies analyzing an association between certain neurological disorders and HABs have been conducted in recent years. Many have found that there seems to be a noticeable trend of positive correlation between HAB location and incidence of neurodegenerative diseases, specifically PD, Alzheimer's Disease, and ALS. This topic first received attention in the 1960s after the discovery that indigenous Chamorro people on the island of Guam were experiencing symptoms typical of dementia and a combination of symptoms seen in PD, Alzheimer's, and ALS (Cox et al., 2016). This became known as amyotrophic lateral sclerosis/Parkinsonism dementia complex (ALS/PDC), which Chamorro villagers were experiencing at a rate 50-100 times typical of other populations (Banack et al., 2006; Cox et al., 2016). Scientists discovered the amino acid β-methylamino-L-alanine (BMAA) in cycad seeds, which were not only used directly by the Chamorro people to make flour, but were also eaten by flying foxes, another common food in the Chamorro diet (Banack et al., 2015). Bioaccumulation of BMAA in the flying foxes was found to be 3556 μg/g while the cycad seeds themselves had only 37 μg/g (Cox et al., 2003). The neurotoxin in BMAA is produced by certain species of cyanobacteria that bioaccumulates as it moves up the food chain (Cox et al., 2003). This toxin has also been identified in the brain tissue of Canadian Alzheimer's patients and ALS patients from Florida (Torbick et al., 2014).

Another study was conducted in response to a high ALS incidence in an area in New Hampshire surrounding Lake Mascoma (Banack et al., 2015). The incidence was 10-25 times higher than expected for the population density, leading researchers to hypothesize that an environmental factor contributing to disease onset must be present (Banack et al., 2015). Scientists have shown that people living near lakes can be exposed to algal toxins either directly by contact with water or through aerosolization. Algal toxins can be introduced to the air and then inhaled via "bubble-bursting," a process which stems from the crashing of waves or other choppy water action (Caller et al., 2009). The presence of BMAA and microcystin in carp as well as in air samples supported the theory that BMAA could be found in Lake Mascoma and the air surrounding it, providing a link between ALS incidence and cyanotoxins (Banack et al., 2015). Another study also found that living near lakes of poorer water quality in New England increased the likelihood of being part of an ALS cluster (Torbick et al., 2014).

Although the main similarity between distinct neurodegenerative diseases appears to be onset with age, there are some similarities found at the physiological level, one of those being neuronal loss, mitochondrial failure, and marked proinflammatory profiles (Nunes-Costa et al., 2020). The neuroinflammatory events, which have been observed in the cerebrospinal fluid of PD, Alzheimer's, and ALS patients, is often seen alongside a decrease in neuronal mitochondrial fitness (Nunes-Costa et al., 2020). While the mechanism is still uncertain, studies have demonstrated a link between BMAA and mitochondrial health, more specifically, *in vitro* administration of BMAA to motor neurons resulting in a decrease in oxidative phosphorylation (Nunes-Costa et al., 2020). Further research on the effects of cyanotoxins on human health will need to be conducted in order to elucidate its influence.

Microcystins are one of the most widespread and well-studied cyanotoxins, and although they are classified as a hepatotoxins, research has shown that they can also cause damage to the nervous system (Hinojosa et al., 2019). It has been postulated that microcystin has the capability to cross the blood brain barrier and lead to a rise in Ca^{2+}, contributing to neuronal apoptosis, or cell death (Hinojosa et al., 2019). Apoptosis is common among many neurodegenerative diseases, including PD. Additionally, microcystin has been shown to produce a rise in oxidative stress and lipid peroxidation, alter neurotransmission (which would cause effects in the peripheral nervous system), and play a role in biochemical alterations such as Tau hyperphosphorylation which is characteristic of Alzheimer's Disease among others (Hinojosa et al., 2019). Thus, contamination of water with higher levels of cyanotoxins must be taken seriously for their potential neurodegenerative effects. In a nationwide study of the quality of U.S. lakes, the EPA detected microcystin in 39% of the sampled lakes and in at least one lake from every state, showing that it is a far-reaching problem (Marion et al., 2017). Since levels of HABs are increasing, it is a logical assumption that in the future we would expect to see increases in levels of cyanotoxins in environments where cyanobacteria can thrive.

Cyanobacteria and Drinking Water

United States drinking water is some of the safest in the world, due to regulations set forth by the EPA as sanctioned by the Safe Drinking Water Act (SDWA) (US EPA, 2015b). Currently there are over 90 contaminants regulated and individual states are allowed to apply further regulations (Allaire et al., 2018). Additionally, the SDWA requires that the EPA compose a list, the Contaminant Candidate Lists, of unregulated contaminants every five years that are not on the list but are being investigated for adverse health effects and possible regulation in the future (US EPA, 2015b). While it appears as though there are regulations ensuring safe drinking water for all, even the most regulated systems can face problems.

Microcystins, along with other cyanotoxins created by cyanobacterial blooms are not currently regulated by the EPA as part of the Safe Drinking Water Act (Jetoo et al., 2015). However, they are on the Contaminant Candidate List and advisory levels for two types of cyanotoxins have been established (Jetoo et al., 2015). The EPA recommends microcystin levels not exceed 1.6 µg/L in drinking water for people over the age of five and advise 8 µg/L in recreational water (American Water Works Association, 2016; Environmental Working Group [EWG], 2019). The other cyanotoxin for which the EPA has developed advisory levels is cylindrospermopsin. For people over the age of five, drinking water levels of cylindrospermopsin are not to exceed 3.0 µg/L. The levels are just recommended though, and the states can mandate their own regulations. Since they are part of the Contaminant Candidate List, some cyanotoxins may be more closely regulated in the future.

CHAPTER TWO

Methods and Results

Study Sites and Sample Collection

In the summers of 2007 and in 2012, the EPA conducted national lakes assessments (NLA) to survey the nation's lakes. The NLA is part of the National Aquatic Resource Surveys, which are conducted in order to assess the conditions and the changes of the nation's water systems (coastal waters, lakes and reservoirs, rivers and streams, wetlands). Sample sites are randomly selected and represent the standard state water systems in their respected ecoregion of the U.S. For the NLA, 1161 lakes from the contiguous U.S. were included in the 2007 assessment and 1038 lakes in 2012. The criteria for the 2007 survey were that lakes had to be greater than 10 acres, at least 3.3 feet deep, with a minimum of a quarter acre open water. This was slightly modified for the 2012 assessment to include lakes greater than 2.47 acres. Samples were taken from an index zone, or an area of open water, and sampled for various biological, chemical, and physical conditions as well as recreational suitability. Total nitrogen (mg/L), total phosphorus (µg/L), and trophic state (productivity, chlorophyll-*a*) were some of the chemical characteristics, while algal toxins (ppb) and cyanobacteria (cell count/cm^2) were included as indicators for recreational activity health.

In addition to the national level data, I also included a regional analysis of one single state to see how these results relate to the national level results. Washington state was chosen because it was one of 20 states that actively publish data about cyanobacteria and toxins in their lakes. Furthermore, the data were very clearly grouped according to different cyanotoxin, year, and county, unlike some of the other states. This made for a more complete analyzation of significance levels.

Washington State Department of Ecology samples and funds sampling projects for algal toxins in lakes, ponds, and streams on an annual basis. Samples are taken from counties across the state and local governments, each of which is able to report a bloom and request testing for toxins. Washington State Freshwater Algae Control Program was developed by the Department of Ecology to provide the resources for sampling and reporting results. Since 2007, more than 1000 samples for microcystin have been analyzed from over 300 different freshwater lakes with cyanobacterial blooms.

Data Analysis

Data organization and summary statistics were conducted using Microsoft Excel and RStudio. Each of the 48 states had a different number of lakes sampled, so median values were calculated for the four variables of interest (total nitrogen, total phosphorus, cyanobacteria density, and microcystin concentration). Following this, all six variables (total nitrogen, total phosphorus, percent cropland, cyanobacteria density, microcystin concentration, and Parkinson's mortality rate) were ranked from smallest value to largest value by state (1- 48), with the exception of trophic state, which was grouped into 7 values (1=oligotrophic to 7=hypereutrophic). Correlation analyses were conducted to determine statistically significant (α=0.05) associations among the aforementioned variables as well as Parkinson's mortality rates and percentage cropland.

The Washington analysis was similarly conducted using Microsoft Excel correlations, however only two variables (Parkinson's Hospitalization rates per county and microcystin presence in lakes) were analyzed. Data for 29 out of the 39 counties in

Washington were gathered. Parkinson's hospitalization data were retrieved from the Washington State Department of Health. Data from six of the counties (Asotin, Clark, Cowlitz, Island, Pacific, San Juan) were considered to be unreliable because residents of these counties sometimes travel out-of-state to receive care. Thus, these numbers are an underrepresentation, but they were still added to the analysis. For microcystin data, a percentage was assigned to each county, which was calculated by taking the number of lakes with a sampled concentration over the recommended recreational guideline of 8 μg/L divided by the total number of lakes sampled in that county. These microcystin and Parkinson's data were then grouped into five categories, with 1 being the lowest and 5 being the highest. Finally, correlation analyses were conducted using Microsoft Excel.

Microsoft Excel correlation analyses resulted in the correlation coefficient, r. The correlation coefficient provides a measure of the strength of a relationship between two variables. The result is a value between -1 and 1, with 1 demonstrating a perfectly positive relationship and -1 a perfectly negative relationship. A value around 0 indicates no relationship, and the closer the number is to 1, the stronger the relationship.

Results

National Trends

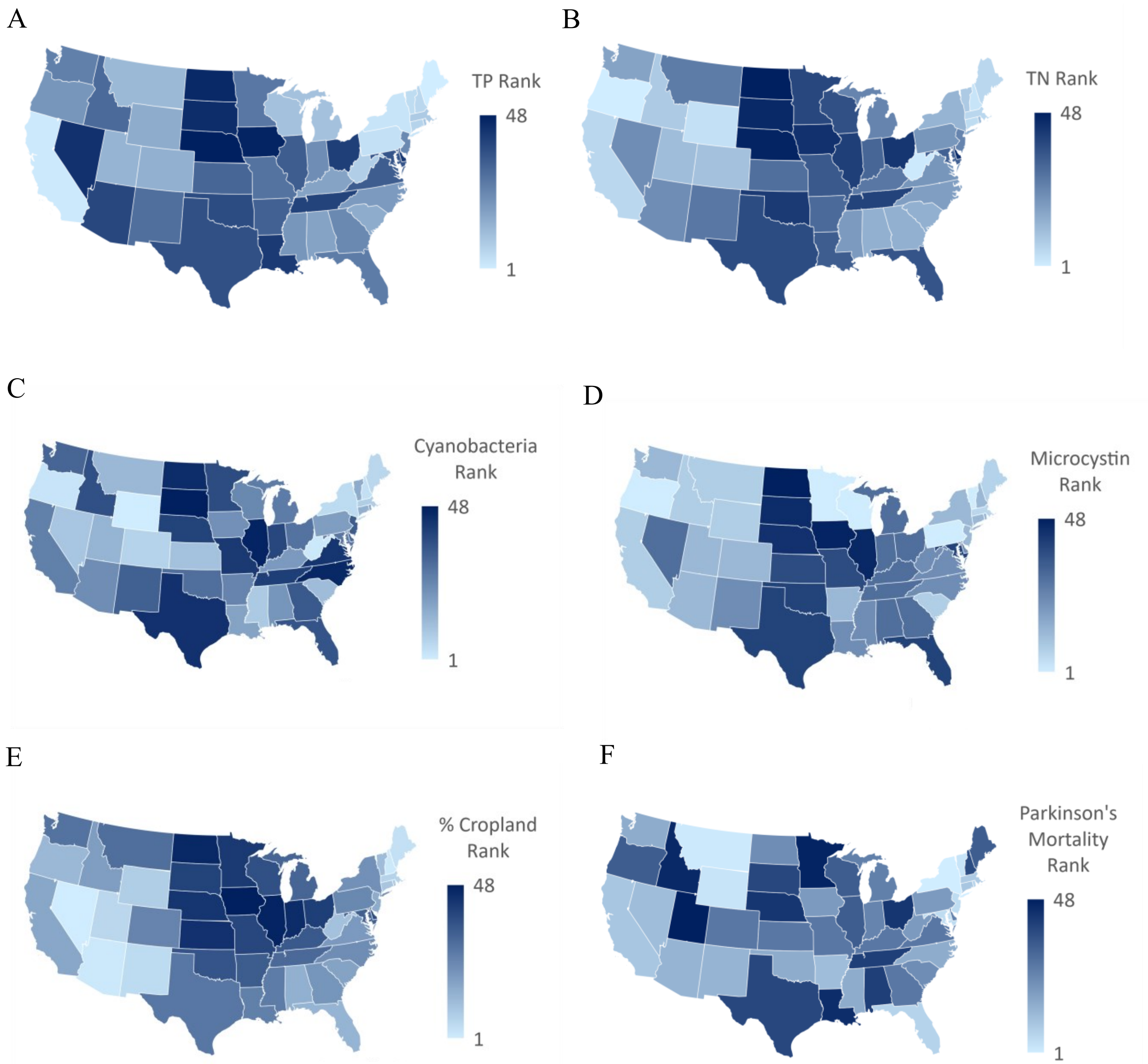

Figure 3. U.S. maps showing rank of A total phosphorus, B total nitrogen, C cyanobacteria density, D microcystin concentration in U.S. lakes from the 2012 or 2007 NLA, E percent cropland, F Parkinson's mortality in 2018.

The results show a positive correlation trend in the Midwest region for states with the highest total nitrogen, total phosphorus, percent cropland, cyanobacteria density, and microcystin concentration (Figure 3A,B,C,D,E). There does not, however, appear to be a regional cluster where Parkinson's mortality is highest or lowest.

Table 2. Microsoft Excel correlation p values (statistically significant results α<0.05).

Variable	TN Rank	TP Rank	Cyanobacteria Density Rank	Microcystin Concentration Rank	Parkinson's Disease Mortality Rank
% Cropland Rank	3.9313E-11	0.00025228	8.9315E-05	7.4365E-05	0.0462987
TN Rank		1.3483E-10	1.6021E-07	1.5668E-07	0.07410651
TP Rank			1.7528E-05	1.2035E-07	0.03609078
Cyanobacteria Density Rank				0.00011095	0.0569561
Microcystin Concentration Rank					0.22877434

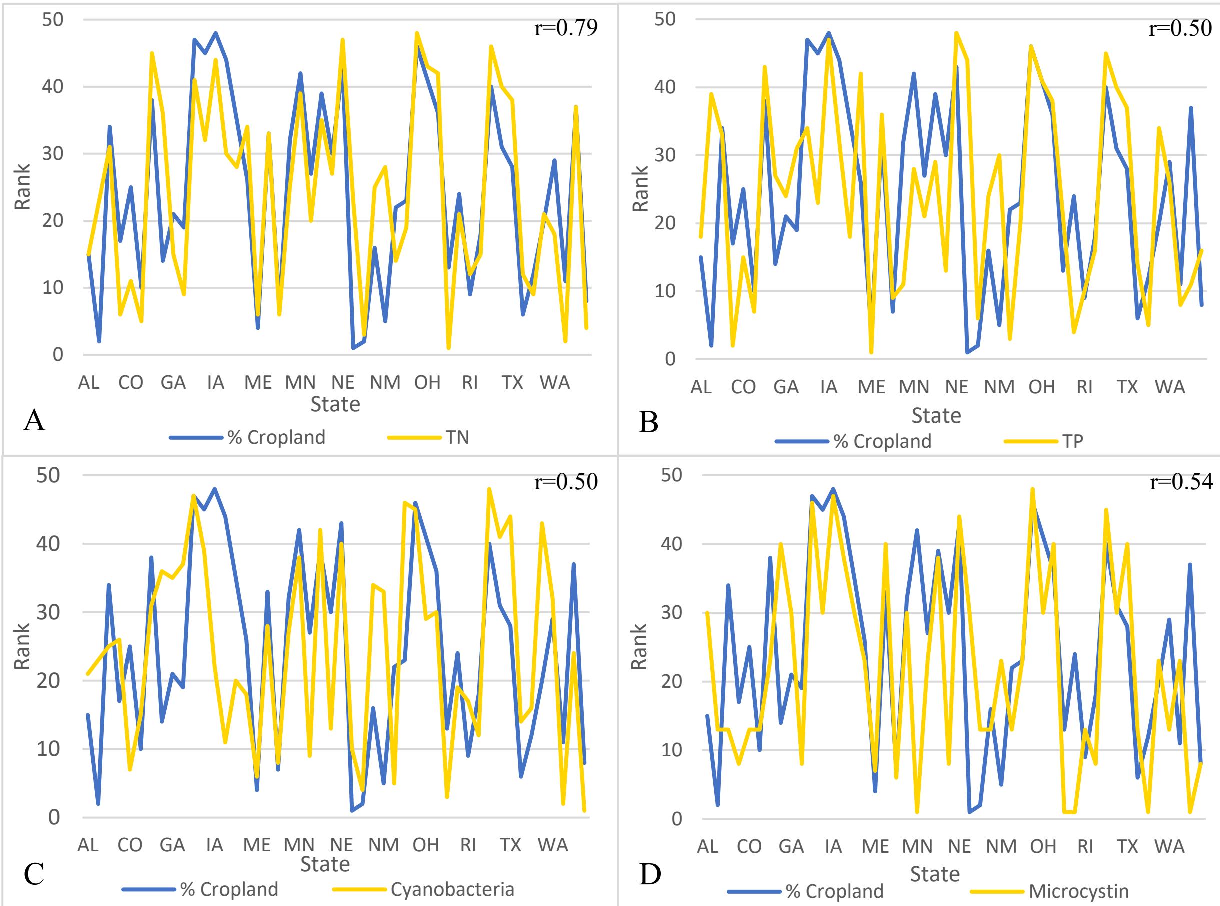

Figure 4. Correlation between percent cropland and A total nitrogen (r=0.79), B total phosphorus (r=0.50), C cyanobacteria density (r=0.54), and D microcystin concentration (r=0.54).

The correlation analyses indicated a statistically significant relationship between many of the variables. The percentage of cropland per state correlated most strongly with total nitrogen, but also showed moderate correlation with total phosphorus, microcystin concentration, and cyanobacteria density (Figure 4).

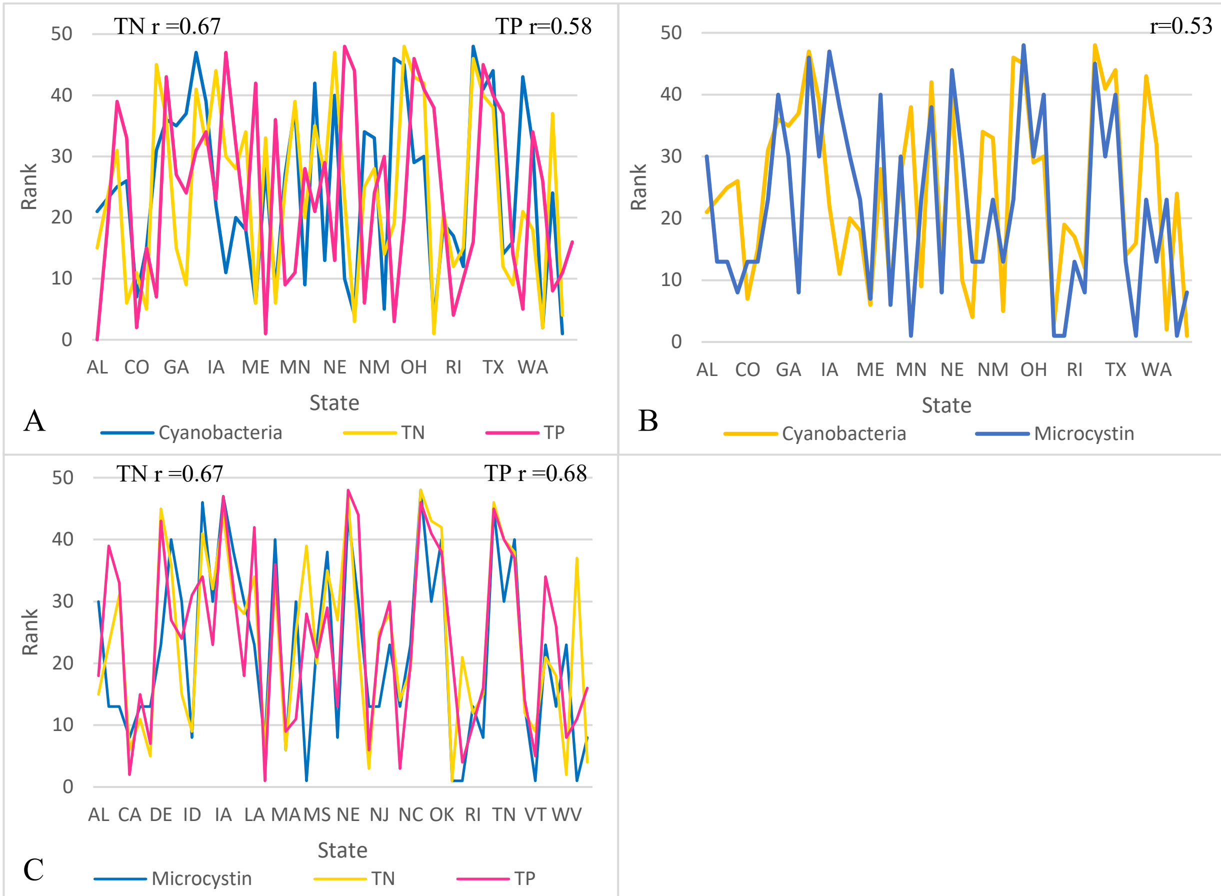

Figure 5. Cyanobacteria correlation with A total nitrogen (r=0.67), and total phosphorus (r=0.58), and B microcystin (r=0.53); C microcystin correlation with total nitrogen (r=0.67) and total phosphorus (r=0.68).

Cyanobacteria correlated most strongly with total nitrogen, but also moderately with total phosphorus and microcystin. Microcystin correlated strongly with total nitrogen and total phosphorus, which also correlated strongly with each other (Figure 5).

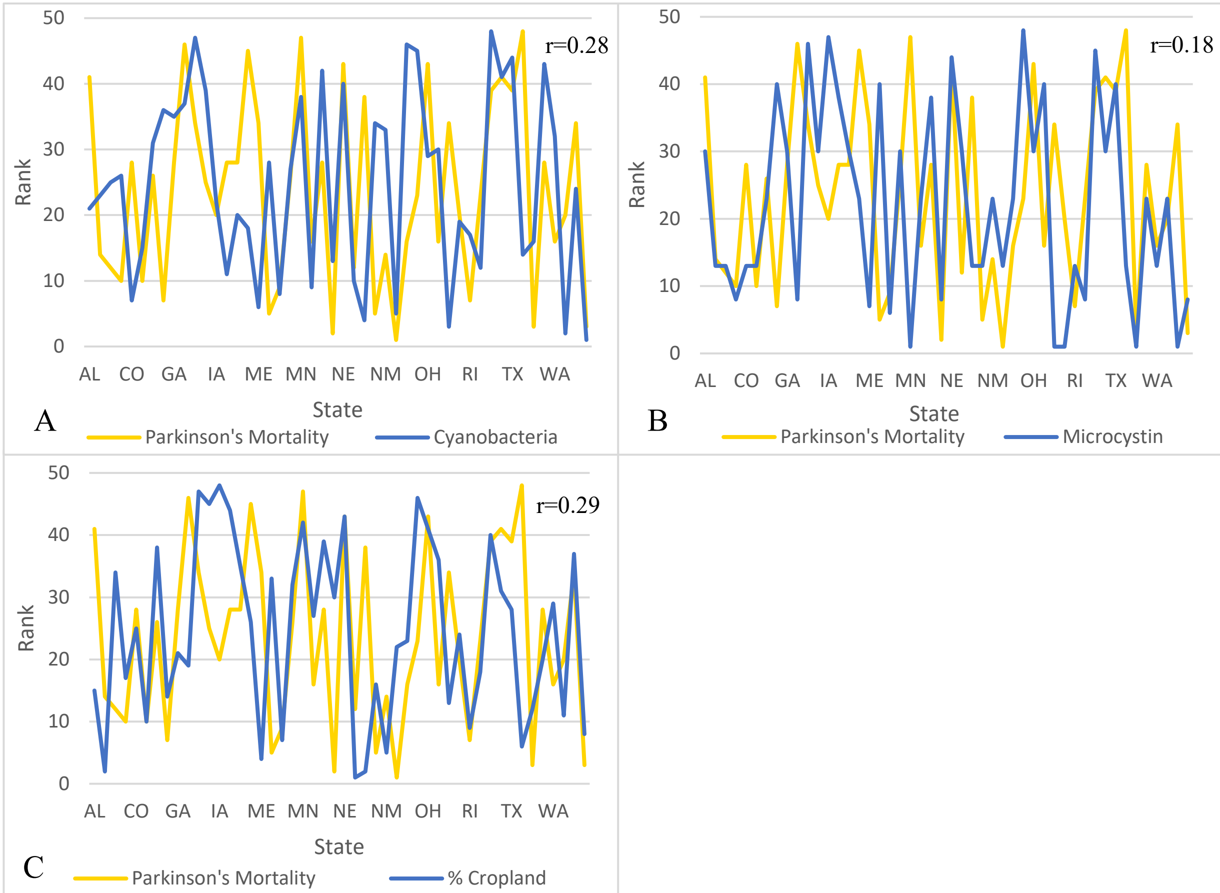

Figure 6. Correlation between Parkinson's mortality and A cyanobacteria (r=0.28), B microcystin (r=0.18), and C and percent cropland (r=0.29).

Parkinson's Disease mortality correlated weakly with cyanobacteria and microcystin but did not show statistically significant results. However, weak correlation with percent cropland proved to be statistically significant (Figure 6). Additionally, there was also a statistically significant but weak positive correlation with total phosphorus (r=0.30).

Washington Analysis

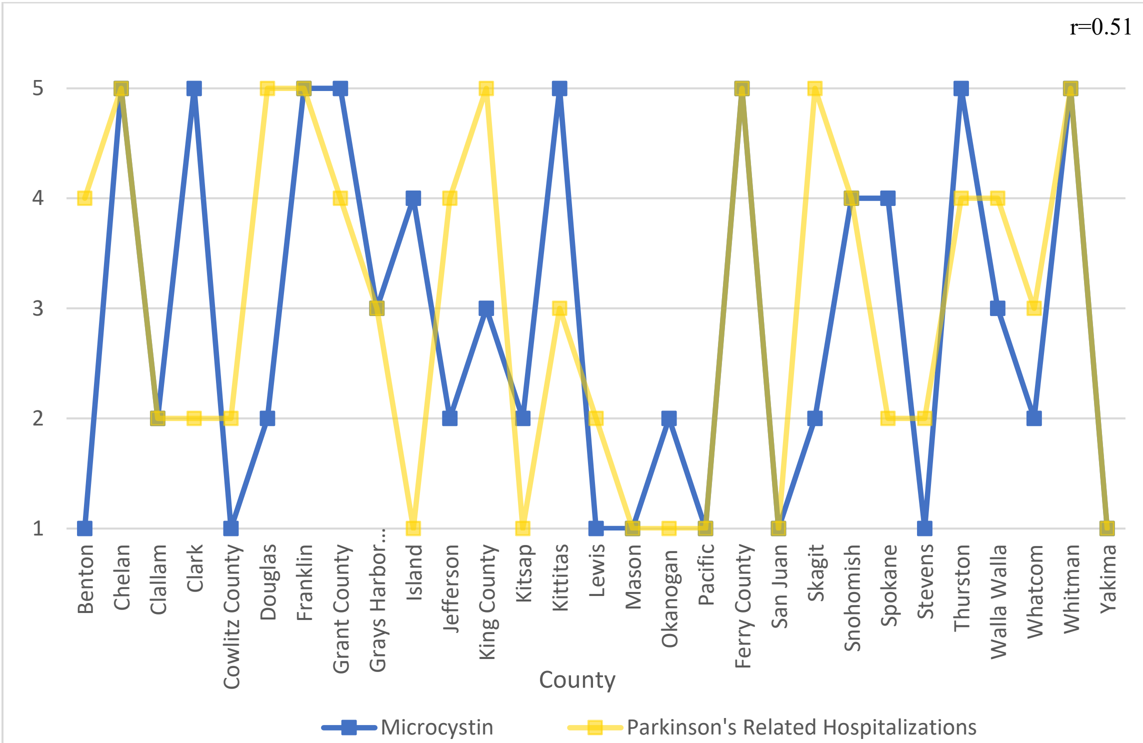

Figure 7. Correlation between microcystin in Washington lakes and Parkinson's Related hospitalizations in 2018 ($r=0.51$, p value=0.000218 with $\alpha<0.05$).

In Washington state, the results show a statistically significant moderate correlation between microcystin and Parkinson's related hospitalizations (Figure 7). Parkinson's hospitalization rates ranged from 22.73 to 83.44 per 100,000. Table 3 shows how values of 1-5 were reached. Microcystin were present in varying amounts; some counties had a high percent of sampled lakes testing positive for excess microcystin and others very low. These data were likewise grouped into five categories, shown in Table 4.

Table 3. Parkinson's related hospitalization rates in 2018.

Assigned Value	Parkinson's hospitalization rate
1	22.73 - < 38.38
2	38.38 - < 49.52
3	49.52 - < 51.89
4	51.89 - < 62.82
5	62.82 - 83.44

Table 4. Sampled lakes with microcystin above the recommended level

Assigned Value	Microcystin rate
1	0% - < 18%
2	18% - < 33%
3	33% - < 37.5%
4	37.5% - < 42.85%
5	42.85% – 100%

CHAPTER THREE

Discussion

Agriculture and HABs

Nutrient concentrations did in fact correlate with percent cropland as suspected. States with higher percentage of cropland require more nutrient rich fertilizer for crop production, especially nitrogen and phosphorus. This is easily seen in North Dakota, South Dakota, Nebraska, Iowa, and Ohio, all of which are in the Midwest region, known for its agriculture. The nitrogen and phosphorus concentrations in these states are in the top eight highest, and so is the percent cropland. This leads to the conclusion that states with higher agricultural land usage had higher levels of total nitrogen and total phosphorus in their lake systems, likely due to fertilizer runoff. Furthermore, nutrient concentrations affect trophic state, which is the biological condition of lakes determined by biological production. Figure 8 demonstrates that the aforementioned states also have poor lake water quality, falling either within the eutrophic or hypereutrophic category.

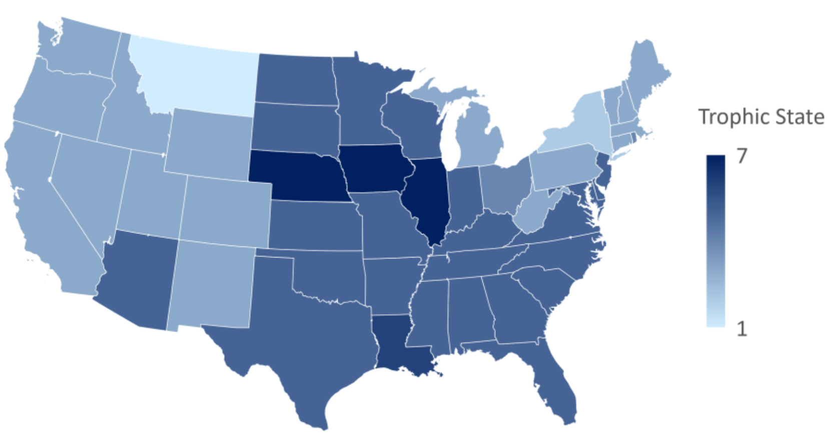

Figure 8. Trophic state in U.S. lakes from the 2012 NLA.

Eutrophic and hypereutrophic conditions refer to lakes with an excess amount of nutrients and decreased oxygen concentrations. This situation can cause dead zones to form where conditions are nearly impossible for survival of most aquatic organisms. The poorest quality water (hypereutrophic lakes) is found in Iowa, Illinois, and Nebraska, which rank 48th, 47th , and 43rd (Figure 3C) respectively for percent cropland. Montana and New York are at the other end of the scale, with most lakes in the oligotrophic state. Compared to eutrophic systems, oligotrophic lakes express low nutrient levels, which results in relatively low abundance of aquatic life. The percent cropland rank of Montana is quite high (30th) and New York was 22nd.

As discussed in Chapter 1, nutrients are one of the most important contributors to increased HAB prevalence, so it can be predicted that states with higher nutrient concentrations (eutrophic lakes) will express greater cyanobacteria density. The results in this paper support this. Nitrogen was the best predictor of cyanobacteria blooms followed by phosphorus (Figure 5A). Although older studies reported that phosphorus was the limiting nutrient, currently there is inconclusive evidence as to which nutrient has the greater impact on HAB growth (Paerl et al., 2016). What can be repeated is that high levels of total nitrogen and total phosphorus will result in greater cyanobacterial density. This relationship is supported in Figure 3, specifically with North Dakota, South Dakota, and Nebraska. Additionally, cyanobacteria and microcystin correlated positively with percent cropland (Figure 4). These results are supported by one study in which researchers found that the proportion of land area used to grow crops was the greatest predictor for elevated cyanobacteria density (Marion et al., 2017).

Cyanobacteria density and microcystin concentration both appeared to be influenced by nutrient concentrations and appeared to be correlated with each other. This may be due to increased microcystin production where cyanobacteria density is greater. Examples from the data can be used to support this statement. North Dakota had the highest microcystin concentration (0.62 ppb) and the fourth highest cyanobacteria density (25,407 cells/ cm^2). The state with the highest cyanobacteria density was South Dakota (60,120 cells/cm^2), which had the fourth highest microcystin concentration (0.18 ppb). Oregon tied for the lowest microcystin concentration (0 ppb) and had the third lowest cyanobacteria density (483 cells/cm^2). These examples validate a relationship between cyanobacteria density and microcystin concentration, especially at the extremes, as well as a link between agricultural land use, cyanobacteria, and cyanotoxins in lakes. This is consistent with other studies, which found that the greatest concentration of microcystin was found in lakes of the Northern Plains ecoregion where nitrogen and phosphorus levels were greatest (Beaver et al., 2018; Marion et al., 2017).

HABs and Parkinson's Disease

Neither cyanobacteria nor microcystin had a strong association with Parkinson's mortality at the national level. Cyanobacteria showed a slightly higher correlation coefficient of 0.28 than microcystin (0.18), but nonetheless remained only weakly correlated (Figure 6A and 6B). Likewise, incidence of Parkinson's weakly correlated with percent cropland (Figure 6C). However, the Washington analysis showed a moderate correlation between microcystin and Parkinson's related hospitalizations. Out of the 10 counties with the lowest Parkinson's-related hospitalizations rates, five of them detected no microcystin levels that exceeded the guideline in sampled lakes. Conversely, out of the 10 counties with the highest Parkinson's-related hospitalizations, over half of the counties reported greater than 48% of lakes with excess microcystin while not one had 0%. Although the national analysis provided only very weak evidence of association, the Washington example demonstrates that upon closer examination, an association is present. Support for this result is provided in one study, in which an increase in Parkinson's incidence was found in populations living closer to large agricultural fields (Yitshak et al., 2018).

Confounding Variables

A couple of confounding variables could have affected the results of this study. First, the data-reporting date of the cyanobacteria density was different from the other variables. While data for the other variables were gathered from the 2012 NLA, cyanobacteria cell count was only provided in the 2007 NLA. The 2012 NLA provided the risk calculated from cell count to allow comparison over the years, but not the actual cell count. Since comparison of the two NLAs resulted in similar risk location, it was assumed that the density according to location remained similar for the purpose of this study. A second confounding variable was the uncertainty of total years people lived in a certain area. Thus, length of exposure prior to disease onset could not be determined. Finally, the type of exposure to contaminated water (drinking water, recreational activity, inhalation) and level of exposure was not addressed.

Conclusion

Cyanobacteria blooms are increasing, largely due to warming climates and increasing nutrient concentrations. This can be demonstrated by the results, showing that nutrient concentration was a predictor for cyanobacteria density. There also appears to be a relationship between exposure to the cyanotoxin microcystin from lake water and incidence of Parkinson's Disease. The greatest evidence for this was provided by the Washington data, showing increases in Parkinson's related hospitalizations in counties with a greater percentage of lakes above the microcystin guideline level. More research is needed, however, to uncover the mechanism with which microcystin can potentially lead to Parkinson's Disease as well as development of mechanisms for environmental remediation. There have been many research attempts to discover ways to control HABs, such as sorption methods to remove nutrients directly from water or applying better agricultural practices to maximize nutrient efficiency while decreasing runoff (Good & Beatty, 2011; Longanathan et al., 2014). Future research may also focus on microcystin association with other neurodegenerative diseases, such as Alzheimer's Disease and ALS, for which some studies have also determined a relationship (Banack et al, 2015). Clean water is a necessary resource for human wellbeing, so controlling HABs in water systems is becoming an important mission to ensure the health of current as well as future generations.

CHAPTER FOUR

Outlook and Solutions

The science behind increases in algal blooms is very important as are the consequences that these can have on public and environmental health. However, it is not enough to consider the causes and effects that algal blooms have, but also to consider ways to improve the situation. The science must provide the evidence and the policy makers and public must desire to make a change in order to remedy a situation such as this. The remainder of this paper will look into how the problem of HABs can be faced from a policy as well as from an individual behavioral standpoint, and possible solutions and preventions currently researched are identified.

Facing Problems and Policy Making

There are two possible routes to take when considering how to combat a problem such as that of HABs. The first involves taking preventative measures, while the second aims to remedy the situation, but not take steps to prevent its occurrence. The former is often overlooked; humans frequently fail to give preventative measures much consideration until a problem poses a serious threat and preventative measures become unavoidable. The latter is much easier, because it does not require complete reform to common practices, just minor modifications. Scientific terminology for these approaches is called backward and forward reasoning, as is referenced in behavioral studies, AI problem solving, and primary or secondary prevention in medicine (Amidu et al., 2019; Kisling & Das, 2020; Sharma et al., 2012).

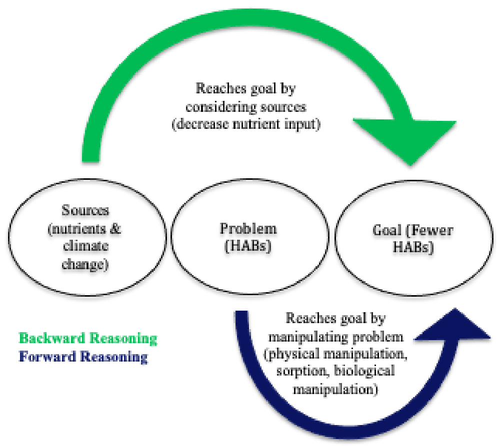

Figure 9. Backward and Forward reasoning with HABs.

Backward reasoning is similar to taking the preventative perspective. The aim of such an approach is to designate a goal or localize a problem, such as that of HABs, and then develop solutions that prevent the onset of the problem (Amidu et al., 2019; Kisling & Das, 2020). Taking a forward approach, secondary prevention, or solution perspective involves questioning how the *effects* of a problem may be reduced after onset of a problem by altering existing variables until the desired goal is achieved (Amidu et al., 2019; Kisling & Das, 2020). When it comes to HABs, the causes for increasing intensity and duration are well understood, meaning preventative measures should be identifiable and available. However, because the sources of HABs increase are a result of daily anthropogenic actions, it becomes difficult to propose a plan effective at combating HABs that would not pose major modifications to certain lifestyles, such as agricultural workers who rely on synthetic fertilizers to make a living. Finding the correct balance is difficult, and this leads to the discussion of the 3-legged stool model of sustainability, as pictured in Figure 10.

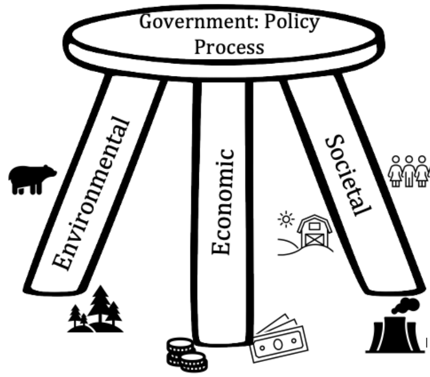

Figure 10. Three-legged stool model of sustainability.

When considering possible preventative measures, it is difficult and time-consuming to find feasible proposals, because there are a couple of components that play a symbiotic role in developing viable policies. These components form what is known as the “3-legged stool model of sustainability,” with environment, economy, and society coming together to encourage long-term sustainability (Young, 1997). Each has a different goal and is an equally important component of the whole; but without one, sustainability cannot thrive. The goal of environmental sustainability is using natural resources at a rate which promotes the welfare of the present generation but also ensures the future generation the same resources (Basiago, 1998; Goodland, 2002). Economic sustainability seeks to ensure a steady capital by focusing on responsible money management and maintenance (Basiago, 1998; Goodland, 2002). Lastly, social sustainability prioritizes the wellbeing of a society (Basiago, 1998; Goodland, 2002). At the apex of sustainability is the process of forming policy, which creates the seat of the stool. Finding the right balance, which includes benefitting the ecosystem, reflecting the general attitude of the society, and not directly harming the economy, is crucial to the success of sustainable policies. In order to achieve this, conversation between scientists and policy makers must occur so that the result is a stable stool, wherein all factors have been equally considered (Young, 1997).

The word sustainable refers to something that can be continued at a certain rate over a period of time (Di Fabio, 2017). Subsequently, the primary goal for sustainable policies is to determine how humans can have a healthy and productive life using natural resources without degrading them so that future generations have the same access to the environment and resources as the present one (Di Fabio, 2017; Young, 1997). In order for a society to truly move towards sustainability, both policymakers as well as individuals must feel compelled to live more sustainably. Policies are based on public opinion, but public opinion influences policy makers, making it challenging to discern which comes first: individual action or policy driven action (Manning, 2009). An important topic emerging from these types of discussions is the psychology of sustainability, which investigates methods that normalize sustainable actions within societies by focusing on individual psychological perceptions of sustainability (Manning, 2009).

Psychology of Sustainability and Environmental Ethics

In early human populations, living in groups provided the best survival chances, so humans have evolved as social creatures with a desire to "fit in" (Manning, 2009). Consequently, people's actions today are largely driven by what is seen as acceptable and normal in their society (Cialdini & Goldstein, 2004; Manning, 2009). This has led to the development of unspoken standards of behavior, or social norms, which govern our everyday lives (Manning, 2016). When it comes to sustainability, many people see the need for change in order to protect the environment, but they nevertheless continue to pursue unsustainable behaviors because of existing social norms that make unsustainable actions the standard (Manning, 2009; Gagnon Thompson & Barton, 1994). However, social norms are not static; they change over time, meaning that in order to promote sustainability, sustainable behavior must be made desirable by becoming socially acceptable (Manning, 2009).

Social standards are not the only factor responsible for unsustainable behaviors, especially in people who see a need for sustainability. Psychologists distinguish between two decision making processes, one of which is primarily a conscious process and rational, while the second is unconscious and instinct-driven (Ham & van den Bos, 2010; Manning, 2009). The processes implemented most often remain unknown, but the unconscious process is typically comprised of decisions that must be made quickly, because quick actions follow patterns from previous experiences (Ham & van den Bos, 2010; Manning, 2009). Since non-sustainable actions, such as using plastic bottles rather than reusable ones or eating meat with every meal, become habitual, they occur unconsciously and are difficult to change. Thus, either the unconscious process must be trained to make sustainable behaviors instinctive, or the conscious process must overpower the unconscious in sustainable matters (Manning, 2009). The other evolutionary trait commonly observed is acting in a manner of self-interest for short-term gain, explored in the 1968 paper “The Tragedy of the Commons” by Garrett Hardin, meaning that the unconscious process in many people will continue destructive habits unless forced otherwise, which is why policies are important for furthering environmental protection (Good & Beatty, 2011; Manning, 2009; Rolston, 2003).

Human behavior is also studied in the philosophical field of environmental ethics, which examines the interaction between humans and the environment (Verma, 2019). There are a couple types of "lenses" through which environmental ethics can be studied based on the ways different people perceive the world. These lenses are used to describe the way our moral values govern our actions, with the two most common ones being anthropocentrism and ecocentrism (Gagnon Thompson & Barton, 1994; Verma, 2019). Individuals viewing environmental ethics through either of these lenses desire positive environmental action, but their reasons for these actions differ (Gagnon Thompson & Barton, 1994). Anthropocentric, or human-centered ethics view humans as the most important species and the master over nature, while nature's principal purpose is to benefit humans (Verma, 2019). These individuals support environmental protection so that humans can reap the maximum benefits from the environment (Gagnon Thompson & Barton, 1994). The other view, the ecocentric view, sees Earth as housing a plethora of species with limited resources, leading to the understanding that each species should only use what is necessary for survival without degrading additional resources or harming other species (Verma, 2019). This view focuses on humans as being part of the natural world and not a dominating force, as it is in anthropocentrism.

On the topic of HABs, both types of lenses would want the threat to be taken seriously. Anthropocentricists would be concerned with drinking water quality and recreational activities in response to the presence of HABs and cyanotoxins. Ecocentrists would be concerned with the health of all life within the affected ecosystem due to the presence of HABs (Brooks et al., 2018; Gagnon Thompson & Barton, 1994). While both lenses could lead to better environmental practices, promoting ecocentric behavior should result in the greater benefit for sustainable practices.

The role of the individual in improving environmental problems is important and some recommendations will be provided further on in the paper when discussing solutions. Aside from individual behavior, policy is necessary for widespread change. The behavior of an individual accomplishes little if the larger society does not have the same values. This is where policy is useful, because it can help protect human health and the environment by mandating certain actions for everyone. In the United States, this is the responsibility of the U.S. Environmental Protection Agency.

Regulations

The U.S. Environmental Protection Agency (EPA) has designated nutrient pollution to be one of the most challenging environmental issues in the U.S and has developed programs such as providing monetary support and information to the states to help combat the issue (US EPA, 2013). Under the Clean Water Act of 1972, the EPA is able to regulate pollutants that are easily traceable, or so-called point source pollutants (US EPA, 2014b). Industrial wastewater treatment facilities, factories, and septic systems are all considered to be point sources and must abide by regulations set forth by the EPA. The regulations are part of a program called the National Pollutant Discharge Elimination System (NPDES), which mandates that in order for a facility to discharge pollutants, it must first acquire a permit (US EPA, 2014b).

The EPA does not regulate nonpoint source pollution or groundwater discharge. Nonpoint source pollution is difficult to regulate because it is typically the result of runoff from precipitation events that carry pollutants from many different sources (US

EPA, 2015a). These can include excess nutrients and pesticides from agricultural lands, chemicals and toxic materials from urban communities, and bacteria from livestock, waste, or non-functioning septic systems (US EPA, 2015a). Of main concern for HAB development is nutrient runoff, to which both point, and nonpoint sources contribute significantly, including agriculture, stormwater, wastewater, hydromodification, and urban activities (US EPA, 2013). Figure 11 shows the effects excess nutrients have on water systems.

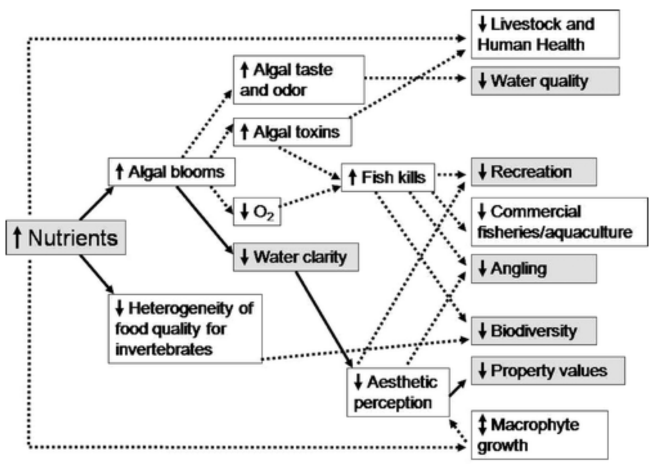

Figure 11. Consequences of nutrient surpluses.
(Note. Reprinted from "Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages", by Dodds et al., 2009, *Environmental Science & Technology, 43*(1), p.12.)

Nutrients in Water Systems

Agriculture is the largest source of nutrient nonpoint source pollution and consequently is not regulated by the EPA (US EPA, 2013). Agricultural practices have drastically changed since the Green Revolution beginning in the 1950s, with synthetic fertilization doubling from 1960 to 2000 in order to produce enough crops to feed the growing population (Keiser, 2020; Lasaletta et al., 2014). Some agricultural modifications during this time period included widespread use of pesticides, synthetic fertilizers, and improved technology (Keiser, 2020; US EPA, 2013). Multiple types of fertilization methods exist, but the three most common sources of nitrogen and other required nutrients are animal manure, nitrogen that results from symbiotic nitrogen fixating organisms, and synthetic fertilizers (Lasaletta et al., 2014; US EPA, 2013). Although these nutrients are of immense value to crop production, over fertilization often occurs and ends up in water systems via runoff (Lasaletta et al., 2014). Presently, over 50% of nitrogen from fertilizers escape their target, not only wasting the nutrients found in fertilizers but also causing adverse effects including a threat to aquatic ecosystems and water quality (Lasaletta et al., 2014). As an example, about 8% of all fertilizers used in the corn-belt ends up in the Gulf of Mexico (Good & Beatty, 2011).

In addition to being detrimental to the environment, nutrient surpluses also generate significant social and economic consequences, which affect agricultural workers directly as well as the economy indirectly (Good & Beatty, 2011). For farmers, fertilizers are costly, and when improperly managed, over application can result in lost income (Schnitkey & Gentry, 2019). Many trials have been conducted across states in the corn belt to find the optimum amount of nitrogen per acre for maximum productivity, known as the maximum return to nitrogen (MRTN) (Schnitkey & Gentry, 2019). Applying 10 lbs of nitrogen over the MTRN costs $3.70 per acre for anhydrous ammonia-based fertilizer and $5.00 for 28% nitrogen solution fertilizer, reducing net income because of higher expenditures without increased yields (Schnitkey & Gentry, 2019). The nutrients are not always used efficiently by the crops, resulting in excess levels of fertilizers not contributing to increased productivity (Good & Beatty, 2011). Nitrogen fertilization for corn in the US surpasses the best nutrient management practice, which determines the optimal amount of nutrients necessary for certain crops, by approximately 35% (Good & Beatty, 2011). Reducing levels of nitrogen fertilizer application has shown promising results; after implementing the best nutrient management practices in the EU, fertilizer usage decreased by 56% from 1987 to 2007, and when Minnesota farmers reduced nitrogen use for corn by 21%, no reduction in productivity was observed (Good & Beatty, 2011). Other studies have found that crops receiving excess nitrogen from synthetic fertilizers yielded lower productivity than those fertilized with nitrogen from nitrogen fixation and manure (Lasaletta, 2014; Smith et al., 2019). When crops are unable to fully utilize excess fertilizers, the nutrients are either lost during precipitation events, ending up in rivers, lakes, streams, and other water systems, or they may seep into the soil and accumulate in groundwater (Good &Beatty, 2011; US EPA, 2013).

Another significant nonpoint source of nutrient pollution comes from urbanization (US EPA, 2015a). Precipitation events lead to runoff of garden fertilizers and pesticides, pet waste, and other pollutants of human origin containing nutrients found on streets around cities (US EPA, 2015a). Soaps, detergents, healthcare products, as well as food and beverages commonly used in households were once significant sources of phosphorus pollution, but recently many countries and states have imposed regulations on the concentration of phosphates allowed in such products (Peltier, 2019). Starting in 1990, the U.S. banned phosphates in laundry detergents (Peltier, 2019). In 2010, seventeen states banned phosphates in dishwater detergents, and currently at least eleven states restrict phosphates in non-agricultural fertilizers (Keiser, 2020; Peltier, 2019). However, an argument has been made that regulations placed on industrial phosphates will probably not result in measurable differences in water quality because U.S.

agricultural use accounts for more than 95% of phosphates that are found in water systems (Keiser, 2020). Although these regulations on industrial phosphates may not be effective at curbing large-scale pollution to water bodies, they do raise awareness, which is evidenced by many people now buying cleaning products carrying the label of "phosphate-free." Labelling products helps increase awareness of environmental issues and encourages actions that result in more sustainable living (Keiser, 2020; Peltier, 2019).

Wastewater is considered a point source of nutrient pollution and is regulated by the EPA. Both municipal and industrial wastewater treatment facilities must obtain the necessary NPDES permit in order to discharge water, setting limits to the concentration of pollutants, including nitrogen and phosphorus (US EPA, 2013). However, sometimes sewer and septic systems do not remove enough nitrogen and phosphorus found in human waste, food, and household cleaning products, or the removal system becomes defective (US EPA, 2013). This can result in these nutrients being released into water bodies (US EPA, 2013). After filtration and treatment, this water, called effluent, usually enters natural water systems and may contribute to nutrient pollution (US EPA, 2013). Stormwater is more difficult to classify as point or nonpoint source pollutant because it can have multiple sources (US EPA, 2015a). The EPA regulates certain sources of stormwater discharge including municipal separate storm sewer systems and construction activities, but stormwater can also be a large contributor of nonpoint source pollution when it picks up debris and toxins from unregulated roadsides or construction sites (US EPA, 2015a).

Figure 12. Mississippi River drainage and Gulf of Mexico hypoxia zone (Rabotyagov et al., 2014).

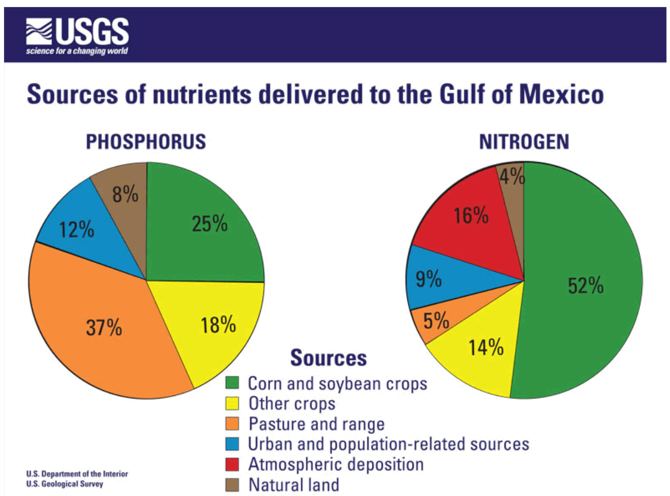

Figure 13. Nutrient sources to the Gulf of Mexico (https://water.usgs.gov/nawqa/sparrow/gulf_findings/primary_sources.html).

The Mississippi River basin/Gulf of Mexico is a prime example of the direct effect nutrient loads may have on water systems. The Mississippi River drains waters from 31 states or 41% of the contiguous states, which then drains into the Gulf of Mexico, shown by Figure 12 (US EPA, 2014a). Many agricultural states border the river, leading to an accumulation of a large amount of nutrients in runoff. The nutrient-rich runoff enters the Gulf of Mexico and causes a dead zone, or a low-oxygen zone to form, where little to no life can exist (US EPA, 2014a). More than 70% of the nutrients (nitrogen and phosphorus, Figure 13) in the hypoxic region of the Gulf of Mexico result from agricultural runoff (Rabotyagov et al., 2014). Research is inconclusive as to whether this dead zone has a large impact on the Gulf's economic value, but a task force was created in 1997 to reduce, mitigate, and control hypoxia by reducing nutrient input (Rabotyagov et al., 2014; US EPA, 2014a). In 2017, a record dead zone of 8,776 square miles formed in the Gulf of Mexico, while the goal remains to reduce the dead zone to less than 1,930 square miles by 2035 (US EPA, 2014a).

While the EPA regulates maximum contaminant levels for pollutants and contaminants found in public water systems intended for drinking water, the states are allowed to set limits for the levels of pollutants in their surface waters (US EPA, 2014b). Impacts of nutrient pollution are becoming better understood as having serious consequences, so following the advice of the EPA, many states have begun to enact nutrient regulations of their own (US EPA, 2016c). As of 2020, 24 states have set some regulations for nitrogen and phosphorus in certain bodies of water, such as Michigan, where the nitrogen limit for all surface waters is 2 mg/L and 1 mg/L for phosphorus (US EPA, 2016c). For public drinking water, the maximum contaminant level set by the EPA for nitrate-nitrogen is 10 mg/L, above which human health effects have been observed, but there are no regulations for phosphorus (US EPA, 2015b). The recommendation for phosphorus levels in lakes is to not exceed 0.05 mg/L to prevent eutrophication (Longanathan et al., 2014).

Water quality is important for recreational activities, drinking, tourism, property value, fishing, and more, so poor water quality as a result of nutrient overloads can impact the economy (Dodds et al., 2009). Dodds et al. estimated a yearly cost of $2.2

billion in the US due to impacts of freshwater eutrophication, and Good & Beatty, researchers from the University of Alberta, estimated a similar $3.6 billion after including impacts on the Gulf of Mexico to the previous amount (Dodds et al., 2009; Good & Beatty, 2011). Thus, economic and social consequences are inevitable when water quality suffers.

As mentioned, nutrient pollution is major problem and one of the greatest predictors for algal growth. While some federal regulations regarding nutrient output do exist, a problem remains because of the nonpoint source pollutants. It would be too difficult to control these pollutants and assessing the scope of their adverse effects is just as problematic. Thus, additional measures must be taken to prevent nutrients from entering water systems in the first place. The other option is to discover ways to remove nutrients after they have entered the water systems. The topic of preventions and solutions are currently in the focus of much scientific research.

Preventions: Controlling the Sources of HABs

To consider preventative measures, the goal must be well understood. As previously discussed, preventative measures, also known as backwards reasoning, search for ways to prevent a problem from developing. Using this reasoning method, one may conclude that climate change and nutrient enrichment are two primary factors contributing to the increase of HABs (Brooks et al., 2018). These two factors are often interdependent, and while I have focused on the nutrient enrichment aspect, it is important to note that climate change and its contributions are equally significant. When considering nutrient enrichment, in order to reduce the threat of HABs, nutrient discharge into waterbodies needs to be reduced whether originating from agriculture or more urban settings.

Much research has been conducted recently investigating environmental problems due to agriculture and also ways to make agriculture more sustainable. In addition to nutrient pollution, agricultural practices have also been found to contribute to greenhouse gas emissions, soil degradation, loss of biodiversity, deforestation, and freshwater exhaustion among others (Garibaldi et al., 2017). In light of these negative impacts, ways to develop more environmentally friendly agricultural practices are being investigated. There have been numerous ideas proposed by researchers and policy makers. These include everything from efficient nutrient management, aquaculture, crop rotation and management, and crop-livestock integration, to more technological approaches such as crop engineering that results in greater nutrient efficiency, and finally more human-centered solutions such as reducing food waste and animal-based product consumption (Bodirsky & Müller, 2014; Garibaldi et al., 2017; Svanbäck et al., 2019). It is important when considering ideas such as these to integrate the three sustainability policy components previously discussed: protecting the environment from the adverse effects of agriculture, maintaining economic stability for a country and the estimated 1.3 billion people worldwide in the farming occupation, and finally assuring social wellbeing including human health and continued access to agricultural produce (Garibaldi et al., 2017).

Agriculture can be divided into crop and livestock production, which share similar environmental impacts. The Baltic Sea, which has one of the world's largest dead zones, demonstrates how crop and livestock often go hand in hand and must be better integrated to decrease harmful impacts (Rabotyagov et al., 2014). Starting in the 1970s, eutrophication in the Baltic Sea caught the attention of the EU resulting in the development of plans that encourage bordering countries to decrease nutrient pollution (Rabotyagov et al., 2014). In one study, nutrient surpluses were shown to be greatest where livestock density was highest, primarily due to the feed that had to be purchased and grown for the livestock (Svanbäck et al., 2019). This is similar to another study stating that agriculture contributes 1/5 of overall nitrogen and 1/3 of overall phosphorus in the Baltic Sea (Rabotyagov et al., 2014). Additional research provides several methods to decrease the nutrient levels entering the Baltic as a result of agriculture, from both crop and livestock production. These methods include an increase in nutrient recycling, feeding livestock according to their nutritional requirements rather than over-feeding, reducing livestock numbers, efficiently using manure as fertilizer, and employing better management practices to increase crop production without increasing synthetic fertilizers (Svanbäck et al., 2019). Many EU countries have already begun to see reductions in nutrient surpluses by utilizing better management practices, but more can still be done (Good & Beatty, 2011; Svanbäck et al., 2019).

Agriculture is not the only contributor to nutrient pollution. Urban activities at both community and individual levels also contribute to the problem, so understanding what modifications can be made in urban lifestyles is important as well. Wastewater from businesses and homes play a large role, and some facilities are more efficient at removing nutrients than others (US EPA, 2013). In order to decrease nutrient output, facilities should be updated (US EPA, 2013). At an individual level, trends such as manicured lawns or washing cars at home are increasingly popular. These trends can contribute to nutrient pollution by over-fertilizing and overwatering to maintain a green yard or using large amounts of water and soap while car-washing, all of which ends up in runoff. As with agricultural fields, excess fertilizers on home lawns may run off with precipitation or frequent watering, ending up in storm drains or on roadsides that lead to local water systems (US EPA, 2013). There are simple modifications that can be made to urban lifestyles to improve sustainability, such as using fertilizers only when necessary and when weather conditions will not result in runoff, and using less soap when cleaning cars or washing cars on the lawn. Inside the house, homeowners should use phosphate-free household supplies and if using a septic system, people should ensure proper operation (US EPA, 2013). However, it is often difficult for people to make even simple changes in their lifestyle when something does not seem to directly affect them or if they have developed habits that are unsustainable (Manning, 2009). These changes require behavioral modifications.

My earlier discussion on the psychology of sustainability and environmental ethics shows that human behavior is different for each individual, but behavior is also adaptable according to situations or over time, especially when faced with personal relevancy. Therefore, in order to increase personal actions to help the environment, or ecocentric behaviors, Manning offers several recommendations from a psychological point of view on how to reinforce sustainable actions. These are mainly achieved through capturing the attention of individuals and showing how environmental problems can also result in human health problems (Manning, 2009). Some ideas include spreading factual information that may lead to positive feedback and sustainable actions, emphasizing personal relevance, and making sustainable actions the standard choice instead of the mindful one (Manning, 2009).

Solutions: Removing Nutrients from Waters before HABs Form

While some studies are looking for ways to prevent HABs by starting at the source, others are analyzing ways to prevent HABs from growing uncontrollably by removing excess nutrients directly from the water bodies. Multiple techniques have been uncovered that show potential for future use. One of these is sorption, a low-cost, convenient, available, and simple method of removing phosphorus from water (Longanathan et al., 2014). The sorbents can be made out of a variety of materials, such as metal oxides and hydroxides, Ca and Mg carbonates, industrial by-products, and organic wastes (Longanathan et al., 2014). For example, a sorbent made out of burned, calcined, and $FeCl_3$-enhanced rice hulls, as well as another sorbent made of washed iron-rich Sylhet sands, were found to remove 83% of phosphate following contact with samples of surface waters that had experienced extensive flooding (Sharmin et al., 2020). Another advantage to these techniques is the capability to extract much of the absorbed phosphate for reuse in fertilizers in the form of $FePO_4^{2-}$, meaning the sorbents themselves are reusable, resulting in reusable phosphorus (Longanathan et al., 2014; Sharmin et al., 2020). Nitrogen cannot be removed by sorption due to its level of solubility in water (Paerl et al., 2016).

Other options for removing nutrients or even HABs from water before they become hazardous have also been explored. Aside from the chemical methods above, physical approaches also exist. Physically removing algal blooms through skimming, disturbing vertical mixing so that deeper waters remain oxygenated, flushing affected waters with other lakes or streams, and lowering water levels so that bottom dwelling plants can compete with the algae are all ways to physically control HABs. While these methods have shown success in small water systems, it becomes increasingly difficult in larger systems because of fluctuating conditions and unpredictability (Paerl et al., 2016). Finally, biological approaches like manipulating food webs to increase competition have been tested, but without promising results (Paerl et al., 2016).

Further research and policymaking are needed to control HABs. There has been relative success so far, such as those mentioned in the EU and the regulations set up by the Clean Water Act. However, there is still much room for improvement, especially in finding ways to regulate nonpoint sources, since these are currently difficult to monitor. Ultimately, policies that prioritize the health of the economy, environment, and society must be reached in order to see widespread change in the occurrence and impact of HABs.

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