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Rationale and Research Questions

Harmful algal blooms (HABs) are characterized by rapid algae population growth coupled with toxin production in an aquatic system (NOAA, 2016). In recent history HABs have been shown to be increasing in prevalence with documented observations throughout the U.S. and the world (U.S. National Office for HABs, n.d.). This increased prevalence of HABs poses a threat to both public and ecosystem health (U.S. EPA, 2022a). Generally, HABs are associated with an influx of environmental nutrients into an aquatic system; however, other regional or lake-specific variables such as temperature, physical chemical properties, and lake structure can influence the development of HABs (CDC, 2022). Although HABs have been largely stated to have increased through time, many of these variables are challenging to generalize across water bodies due to the complexity of algal bloom formation. It is for this reason that this report will focus on HAB development in one water body: Lake Erie.

Lake Erie has been affected by seasonal HABs since the 1990s (NSF, 2019). Lake Erie is adjacent to multiple metropolitan areas with populations that exceed 50,000 people and provides drinking water for 12 million people (U.S. EPA, 2022b). In 2015 Lake Erie had a bloom which covered over 300 square miles, thus making it one of the largest algal blooms documented in recent history (LEF, n.d.). Algae and toxin production has public health implications for surrounding populations as exposure can occur through recreation and consumption of contaminated drinking water (Dierkes, 2014; U.S. EPA, 2022b). Algal blooms can also create anoxic conditions when algae undergo decomposition in the environment which also influences ecosystem health (CDC, 2022). Due to the historical and current public health and ecosystem prevalence, data collection efforts have been implemented within Lake Erie to aid with forecasting future bloom severity. These data in the western basin are evaluated in this report.

Lake Erie is the shallowest of the great lakes with an average depth of 19 meters (m); the western portion, which comprises approximately 20% of the lake, has an average depth of 7.4 m and a maximum depth of 19 m (U.S. EPA, 2022b). Western Lake Erie is expected to undergo stratification for a short period of time during the summer months, leading to a warmer surface layer (epilimnion) and cooler bottom layer (hypolimnion; U.S. EPA, 2022b). Nutrient inputs come from a variety of sources which include wastewater treatment plants and agriculture which can influence algal bloom production (Dean, 2022). Microcystis is the most common species and microcystin, a potent hepatotoxin, is the most common toxin documented in HABs in Lake Erie. Considering the characteristics of Western Lake Erie, this report evaluates the following questions:

What are the drivers of harmful algal blooms in western Lake Erie?

1. Which variables (i.e., temperature, nitrate/nitrite, and/or phosphorus) contribute to microcystin production, Microcystis population growth, and dissolved oxygen?
2. How does Microcystis and microcystin concentration change over time?
3. Are there differences between toxin and algae concentrations at different lake depths?

Dataset Information

The NOAA Great Lakes Environmental Research Laboratory (NOAA GLERL) is a federal research laboratory designed to monitor and research the ecology and hydrology of the Great Lakes Region. The NOAA GLERL provides data critical to studying the presence and harmful impacts of algal blooms in the great lakes region.

The NOAA GLERL studies the movement, size, and concentration of toxins and nutrients typically associated with HABs, such as microcystin, nitrogen, phycocyanin, and chlorophyll. They also measure other factors that impact HABs, such as temperature and Dissolved oxygen (DO) concentrations. The lab's primary goal is to characterize the growth and abundance of microcystin concentrations and how their presence affects the toxicity of the lake.

The data from Western Lake Erie comes from nine sites sampled weekly, four of which have buoys collecting data continuously at 15-minute intervals. Only some sampled areas gather data on the same parameters, resulting in occasional missing data.

The sourced data set contains information on parameters ranging from 2012 - 2018 and a final data set that monitors the toxin and nutrient concentration from 2022.

Exploratory Analysis

Table 1. Summary Statistics: Harmful Algal Bloom and Lake Characteristics of Lake Erie at Bottom and Surface Depths

Summary Statistics: Lake Erie Harmful Algal Bloom Characteristics at Bottom and Surface Depths

	Oberservations	Mean	Standard Deviation	Median
Bottom				
Dissolved Oxygen (mg/L)	295	6.88	1.38	6.63
Temperature (deg C)	295	22.20	2.87	22.90
Dissolved Microcystin (ug/L)	160	0.22	0.12	0.18
Chlorophyll a (ug/L)	300	21.40	58.27	12.47
Surface				
Dissolved Oxygen (mg/L)	587	7.70	1.19	7.73
Temperature (deg C)	587	22.21	3.69	23.20
Dissolved Microcystin (ug/L)	327	0.24	0.17	0.18
Chlorophyll a (ug/L)	598	38.94	279.14	15.92
Nitrate/Nitrite Concentration (mg/L)	566	1.00	1.44	0.41
Dissolved Phosphorus (ug/L	598	22.57	31.15	9.91

Table 2. Summary Statistics: Harmful Algal Bloom and Lake Characteristics of Lake Erie 2012 through 20187

Summary Statistics: Lake Erie Harmful Algal Bloom Characteristics in 2012 through 2018

	Oberservations	Mean	Standard Deviation	Median
2012				
Chlorophyll a (ug/L)	62	33.58	49.87	16.18
Nitrate/Nitrite Concentration (mg/L)	51	0.31	0.28	0.32
Dissolved Phosphorus (ug/L	60	10.89	6.69	9.68
2013				
Dissolved Oxygen (mg/L)	96	7.37	0.54	7.50
Temperature (deg C)	93	22.01	3.53	22.60
Chlorophyll a (ug/L)	97	52.66	54.74	36.53
Nitrate/Nitrite Concentration (mg/L)	92	1.29	1.69	0.64
Dissolved Phosphorus (ug/L	92	13.35	15.24	7.66
2014				
Dissolved Oxygen (mg/L)	114	8.16	1.08	8.20
Temperature (deg C)	114	20.20	4.73	22.05
Dissolved Microcystin (ug/L)	49	0.50	0.45	0.31
Chlorophyll a (ug/L)	126	27.28	47.15	12.76
Nitrate/Nitrite Concentration (mg/L)	124	0.48	0.87	0.19
Dissolved Phosphorus (ug/L	125	10.72	9.59	7.38
2015				
Dissolved Oxygen (mg/L)	248	8.23	1.18	8.21
Temperature (deg C)	248	21.49	3.32	22.10

Dissolved Microcystin (ug/L)	125	0.24	0.13	0.20
Chlorophyll a (ug/L)	248	67.81	434.36	24.62
Nitrate/Nitrite Concentration (mg/L)	134	1.06	1.50	0.35
Dissolved Phosphorus (ug/L	145	34.37	46.06	13.42
2016				
Dissolved Oxygen (mg/L)	226	7.38	1.04	7.45
Temperature (deg C)	226	23.02	3.12	23.80
Dissolved Microcystin (ug/L)	143	0.25	0.22	0.19
Chlorophyll a (ug/L)	227	16.30	19.97	7.77
Nitrate/Nitrite Concentration (mg/L)	135	0.65	1.14	0.27
Dissolved Phosphorus (ug/L	151	15.46	14.59	9.80
2017				
Dissolved Oxygen (mg/L)	237	6.97	1.61	6.77
Temperature (deg C)	237	21.11	4.01	22.00
Dissolved Microcystin (ug/L)	116	0.23	0.13	0.18
Chlorophyll a (ug/L)	242	25.47	43.43	15.75
Nitrate/Nitrite Concentration (mg/L)	164	1.29	1.64	0.56
Dissolved Phosphorus (ug/L	168	22.11	29.78	7.83
2018				
Dissolved Oxygen (mg/L)	190	7.12	0.84	7.14
Temperature (deg C)	190	23.46	2.29	24.10
Dissolved Microcystin (ug/L)	113	0.18	0.07	0.17
Chlorophyll a (ug/L)	200	17.88	12.15	15.70
Nitrate/Nitrite Concentration (mg/L)	134	0.95	1.31	0.55
Dissolved Phosphorus (ug/L	134	18.38	21.88	9.21

Analysis

Question 1: Which variables (i.e., temperature, nitrate/nitrite, and/or phosphorus) contribute to microcystin production, Microcystis population growth, and dissolved oxygen?

Question 2: How does Microcystis and microcystin concentration change over time?

Question 3: Are there differences between toxin and algae concentrations at different lake depths?

Regarding the third question it is hypothesized that both microcystin and chlorophyll a concentrations will be greater at surface depths opposed to bottom depths in Lake Erie. These hypotheses are stated below:

Hypotheses for microcystin concentration at surface vs. bottom depth

Ho: Surface depth microcystin concentrations are <= bottom depth microcystin concentrations

HA: Surface depth microcystin concentrations are > bottom depth microcystin concentrations

Hypotheses for chlorophyll a concentration at surface vs. bottom depth

Ho: Surface depth Chlorophyll a concentrations are <= bottom depth microcystin concentrations

HA: Surface depth Chlorophyll a concentrations are > bottom depth microcystin concentrations

Hypotheses for dissolved oxygen concentration at surface vs. bottom depth

Ho: Surface depth dissolved oxygen concentrations are <= bottom depth microcystin concentrations

HA: Surface depth dissolved oxygen concentrations are > bottom depth microcystin concentrations

Before assessing these claims, a Shapiro-Wilk test for normality was conducted for the microcystin, chlorophyll a, and dissolved oxygen data. The test rejected the null hypothesis which states that the data are normally distributed in all cases as shown in Table ###. In result, the Wilcoxon Rank Sum test was employed to evaluate the means between surface and bottom layers for each variable. These results can be found in Table ###.

Table ###. Shapiro-Wilk Test for Normality Results

Shapiro-Wilk Test Results

Data	Statistic	P-Value
Dissolved Microcystin	0.667	0
Chlorophyll a	0.055	0
Dissolved Oxygen	0.989	0

Table ###. Wilcoxin Rank Sum Test for Bottom versus Surface Depths

Wilcoxin Rank Sum Test Results

Data	Statistic	P-Value
Dissolved Microcystin	24799.5	0.175
Chlorophyll a	78211.5	0.001
Dissolved Oxygen	51923.5	0.000

When looking at microcystin concentrations at surface and bottom depths, the Wilcoxin Rank Sum test showed a nonsignificant result and thus a failure to reject the null hypothesis which states that microcystin concentrations at surface depth are less than or equal to microcystin concentrations at bottom depth (W = 24800, p-value = 0.1753). Figure ### shows these data. When looking at chlorophyll a concentrations at surface and bottom depths, the Wilcoxin Rank Sum test showed a significant result and a rejection of the null hypothesis which states that chlorophyll a concentrations at surface depth are less than or equal to chlorophyll a concentrations at bottom depth (W = 78212, p-value = 0.0008634). Figure ### shows these data. Lastly, when looking at dissolved oxygen concentrations, the Wilcoxin Rank Sum test showed a significant result and a rejection of the null hypothesis which states that dissolved oxygen concentrations at surface depth are less than or equal to dissolved concentrations at bottom depth (W = 51924, p-value < 2.2e-16). Figure ### shows these data.

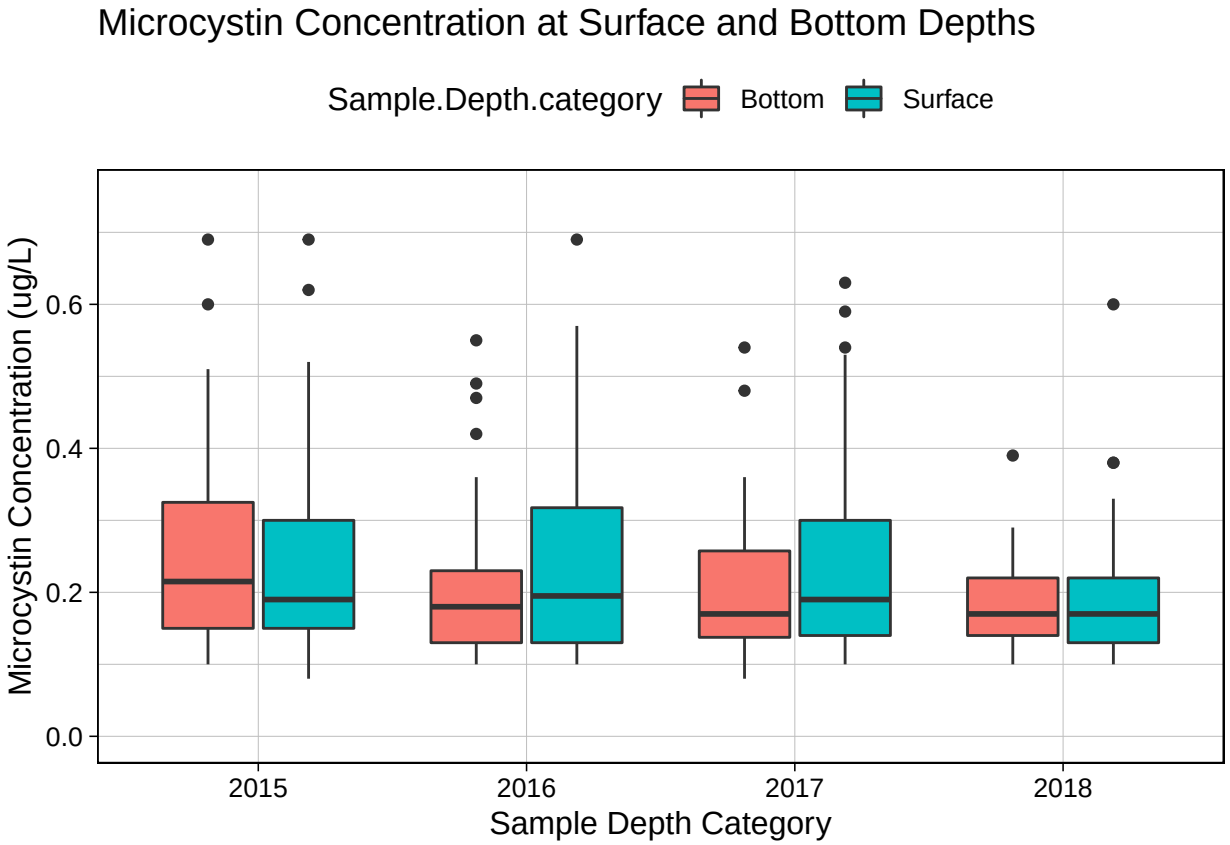

Figure ###. Microcystin Concentrations at Surface and Bottom Depth for years 2015 through 2018

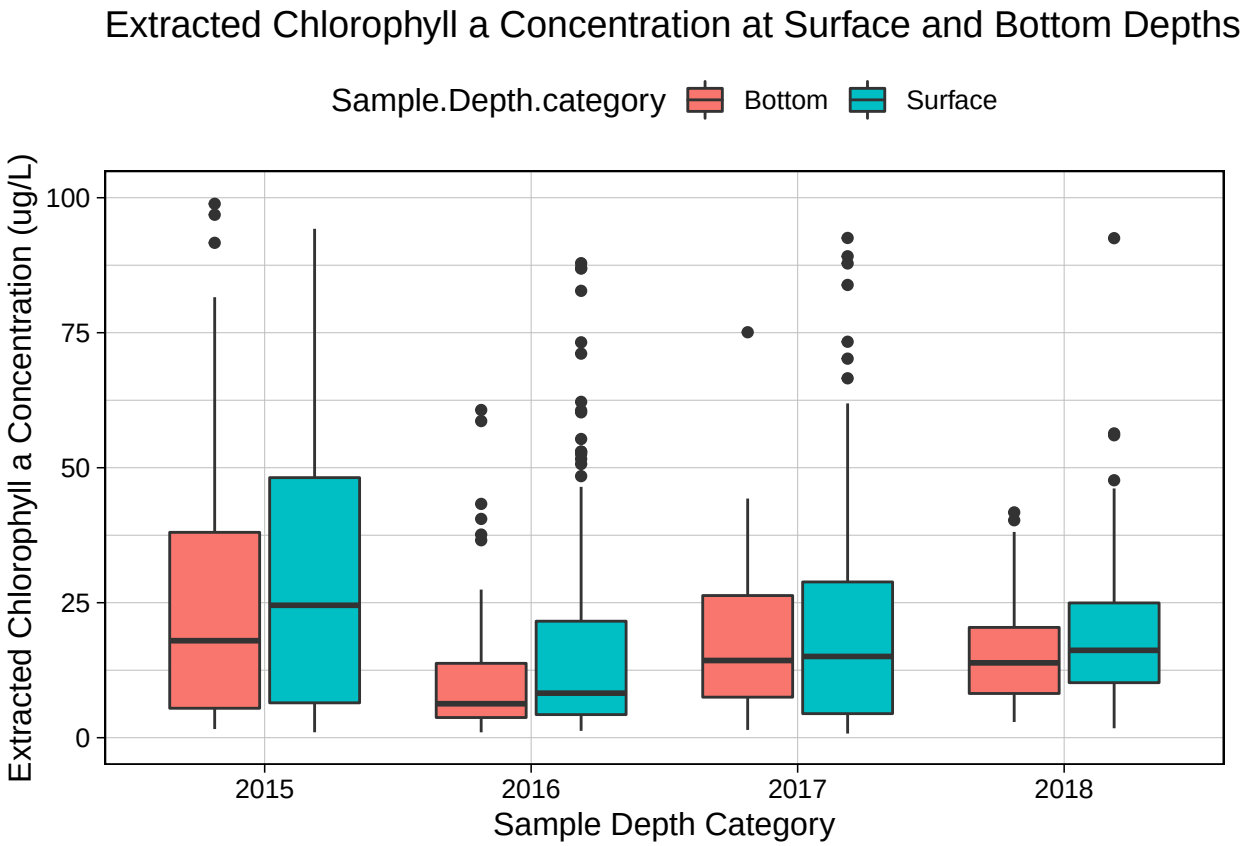

Figure ###. Chlorophyll a Concentrations at Surface and Bottom Depth for years 2015 through 2018

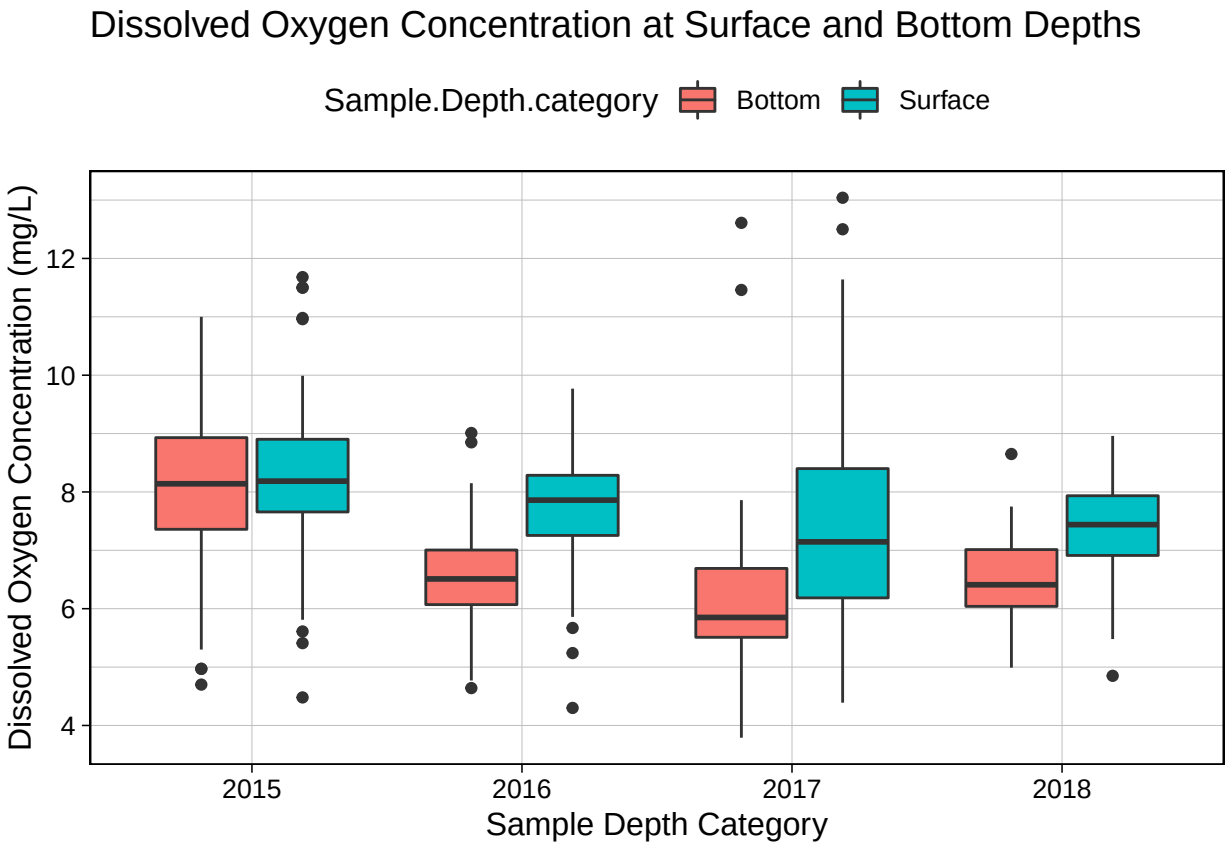

Figure ###. Dissolved Oxygen Concentrations at Surface and Bottom Depth for years 2015 through 2018

Summary and Conclusions

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