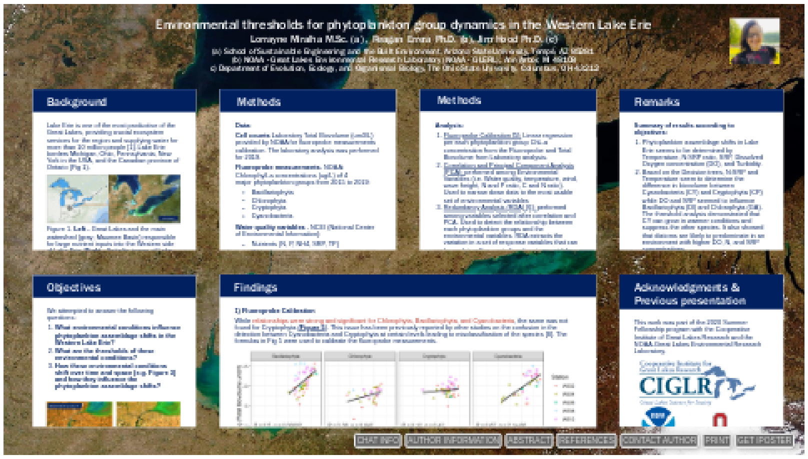
Environmental thresholds for phytoplankton group dynamics in the Western Lake Erie



Lorrayne Miralha M.Sc. (a) , Reagan Errera Ph.D. (b), Jim Hood Ph.D. (c)

(a) School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85281
(b) NOAA - Great Lakes Environmental Research Laboratory (NOAA - GLERL), Ann Arbor, MI 48108
c) Department of Evolution, Ecology, and Organismal Biology, The Ohio State University, Columbus, OH 43212

PRESENTED AT:

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BACKGROUND

Lake Erie is one of the most productive of the Great Lakes, providing crucial ecosystem services for the region and supplying water for more than 10 million people [1]. Lake Erie borders Michigan, Ohio, Pennsylvania, New York in the USA, and the Canadian province of Ontario (Fig 1).

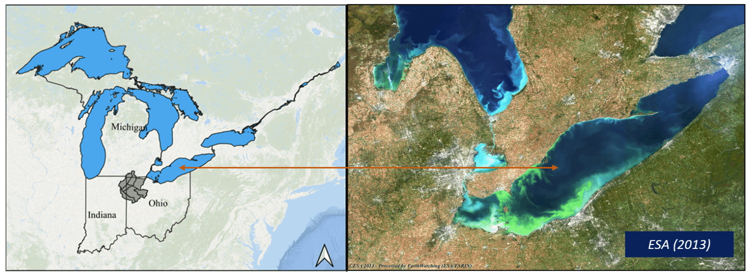


Figure 1. **Left -** Great Lakes and the main watershed (gray; Maumee Basin) responsible for large nutrient inputs into the Western side of Lake Erie. **Right** - Sattelite image of Lake Erie showing the impact in water quality conditions due to nutrient inputs in Western Lake Erie - harmful algal blooms (HABs).

- As one of the symptoms of Eutrophication, HABs are one of the major phytoplankton species responsible for releasing toxins, disrupting food-webs, and impacting human health [2,3].

- **Therefore, understanding how these phytoplankton species behave is important.**

Several factors can control the dominance of phytoplankton species in a freshwater ecosystem (Fig 2).

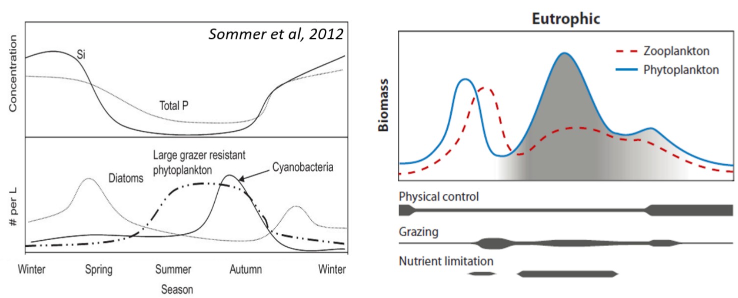


Figure 2.This figure shows regime shifts that need to be better investigated. **Left** - Illustration of the classical shift from diatom (Bacillariophyta) dominated community to cyanobacteria (HABs) dominated, which is primarily controlled by Silica and Phosphorus present in the system, **Right**- Eutropic system such as Lake Erie where phytoplankton species will tend to dominate from Spring to Fall controlled by both physical and nutrient characteristics [4].

- **Studies worldwide have focused on understanding the ecological conditions or thresholds driving the dominance of one phytoplankton species over another. <u>However, these thresholds have still to be investigated in Lake Erie.</u>**

METHODS

Data:

Cell counts Laboratory Total Biovolume (um3/L) provided by NOAA for fluoroprobe measurements calibration. The laboratory analysis was performed for 2019.

Fluoroprobe measurements- NOAA: Chlorophyll-a concentrations (ug/L) of 4 major phytoplankton groups from 2015 to 2019:

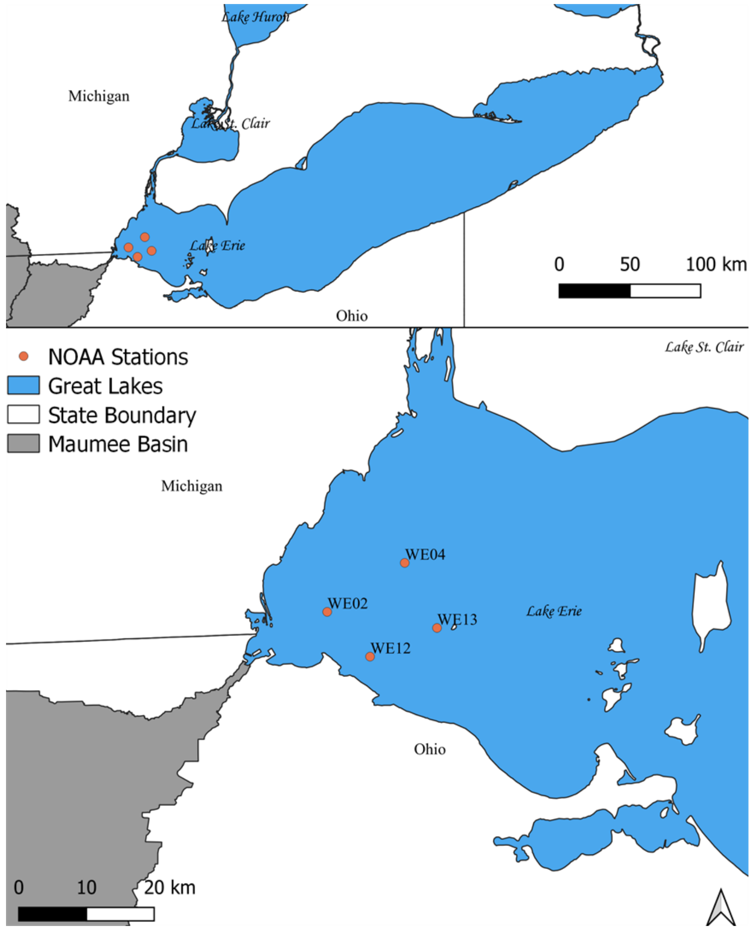
- Bacillariophyta
- Chlorophyta
- Cryptophyta
- Cyanobacteria

Water quality variables - NCEI (National Center of Environmental Information):

- Nutrients (N, P, NH4, SRP, TP)
- Water temperature
- Wind speed and Wave Height

NCEI data coincides with the weekly Fluorophore measurements and were merged. Both datasets are collected among 10 stations located in the Western Lake Erie (Fig 4),

Figure 4. Illustration of Lake Erie and Western Lake Erie with the location of the main 4 stations used in all steps of the analysis in this study (i.e. Stations We02, WE04, WE12, WE13).



METHODS

Analysis:

1. Fluoroprobe Calibration [5]: Linear regression per each phytoplankton group ChL-a concentration from the Fluoroprobe and Total Biovolume from Laboratory analysis.
2. Correlation and Principal Component Analysis (PCA): performed among Environmental Variables (i.e. Water quality, temperature, wind, wave height, N and P ratio, C and N ratio). Used to narrow down data to the most usable set of environmental variables
3. Redundancy Analysis (RDA) [6]: performed among variables selected after correlation and PCA. Used to detect the relationship between each phytoplankton groups and the environmental variables. RDA extracts the variation in a set of response variables that can be explained by a set of explanatory variables. It is a gradient analysis based on the distance among the explanatory to the response variables. It is also composed of multiple linear regression with a stepwise selection.
4. Decision Trees: Used to investigate the most important environmental conditions determining high and low calibrated biovolume of each phytoplankton group and prior to the investigation of thresholds.
5. Changepoint Analysis [7]: Detection of Thresholds based on a segmented regression where Y was the calibrated biovolume of each phytoplankton group and Xs were Year and Week to account for temporal variability.
6. Visualization over time and space - Boxplots - simple grid visualization categorized by phytoplankton group to determine if a high biovolume of phytoplankton was linked to the variable threshold investigated in Steps 4 and 5.

Question 1 - Steps 2, 3, and 4

Question 2 - Steps 4 and 5

Question 3 - Step 6

REMARKS

Summary of results according to objectives:

1. Phytoplankton assemblage shifts in Lake Erie seems to be determined by Temperature, N:SRP ratio, SRP, Dissolved Oxygen concentration (DO), and Turbidity.
2. Based on the Decision trees, N:SRP and Temperature seem to determine the difference in biovolume between Cyanobacteria (CY) and Cryptophyta (CP) while DO and SRP seemed to influence Bacillariophyta (DI) and Chlorophyta (GA). The threshold analysis demonstrated that CY can grow in warmer conditions and suppress the other species. It also showed that diatoms are likely to predominate in an environment with higher DO, N, and SRP concentrations.
3. Our visualization demonstrated that as the concentration and magnitude of main environmental parameters shift over space and time so does the biovolume of the phytoplankton groups analyzed in this study.

Overall:

- **This study shows the usefulness of Fluoroprobe measurements when evaluating phytoplankton dynamics, and highlights the potential misclassification of Cryptophyta species.**
- **It also highlights the importance of N concentrations in the dominance of one phytoplankton species over another.**

OBJECTIVES

We attempted to answer the following questions:

1. **What environmental conditions influence phytoplankton assemblage shifts in the Western Lake Erie?**
2. **What are the thresholds of these environmental conditions?**
3. **How these environmental conditions shift over time and space (e.g. Figure 3) and how they influence the phytoplankton assemblage shifts?**

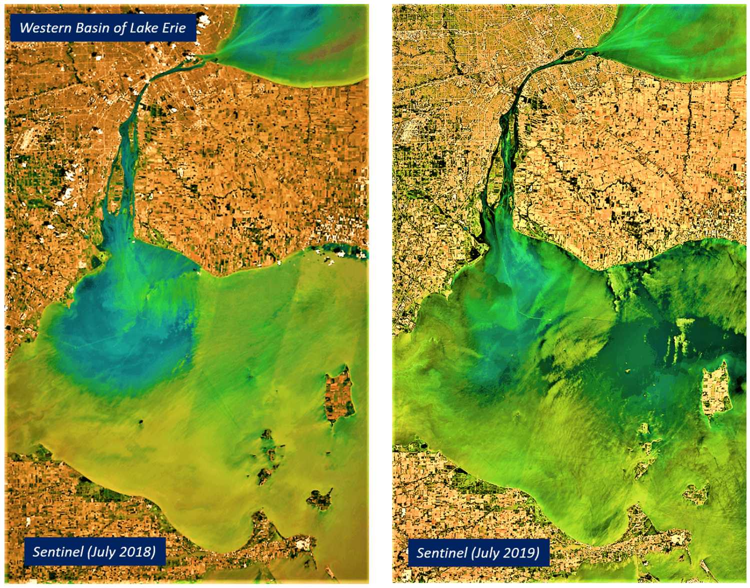


Figure 3. What environmental conditions led to the spatial patterns of HABs observed in 2018 that are different from 2019?

FINDINGS

1) Fluoroprobe Calibration

While relationships were strong and significant for Chlorophyta, Bacillariophyta, and Cyanobacteria, the same was not found for Cryptophyta (**Figure 5**). This issue has been previously reported by other studies on the confusion in the detection between Cyanobacteria and Cryptophyta at certain levels leading to misclassification of the species [8]. The formulas in Fig 5 were used to calibrate the fluoroprobe measurements.

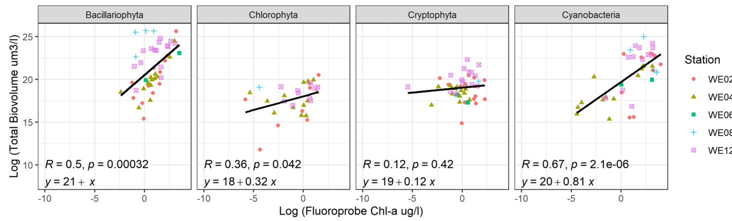
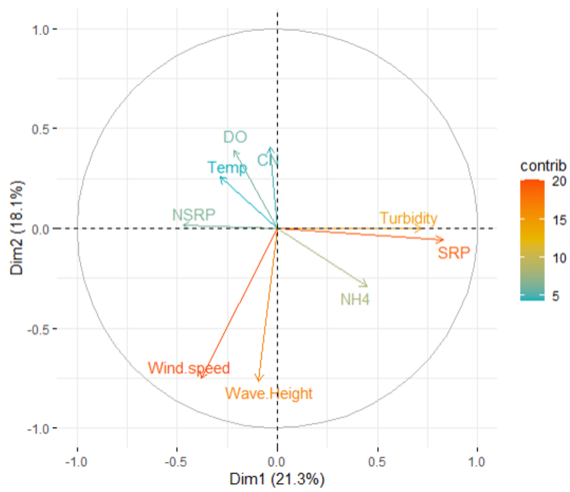


Figure 5. Relationship between Log Total biovolume and Log Fluoroprobe Chlorophyll-a concentration.

2) Correlation and PCA:

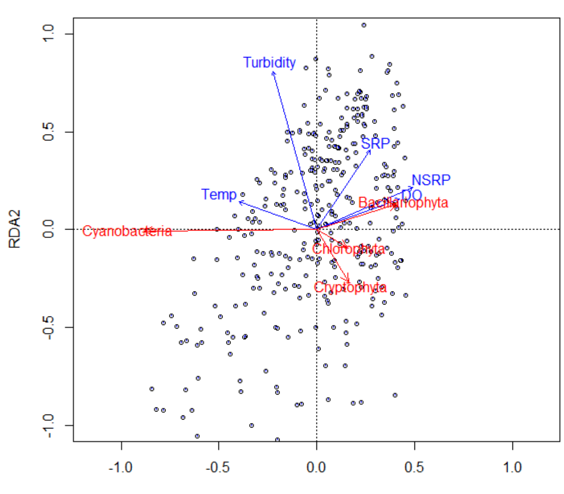
Results enable the selection of 9 environmental variables as seen in **Figure 6** **((Right)**- variable vectors with percentage contribution to the principal components illustrated by the colors). To not lose information from major variables that were highly correlated, we calculated ratios. For instance, N and SRP concentrations were used for the calculation of N:SRP (NSRP in Fig 6).



3) RDA results:

The most significant RDA model was driven by Turbidity, Temperature N:SRP, Dissolved Oxygen (DO), and SRP **(Fig 7-Left)**.

- In Figure 7, Cyanobacteria (CY) was correlated to Turbidity and Temperature. Results suggested that if CY is dominating in the water, this species might suppress the others.
- Bacillariophyta (or diatoms (DI)) was correlated with DO and N:SRP, showing the importance of N concentrations in the environment.



- Chlorophyta was mostly correlated with DO and N:SRP but less when compared to DI.
- Cryptophyta showed a weaker relationship with SRP an opposite relationship with Turbidity and Temperature.

4) Decision Trees:

- Using the 9 variables selected in regression trees, we model each phytoplankton group calibrated biovolume. The trees illustrate different phytoplankton-environment-lake dynamics **(Fig 8 - Trees)**.
- The first split of each tree determines the following splits; therefore it is the most important.

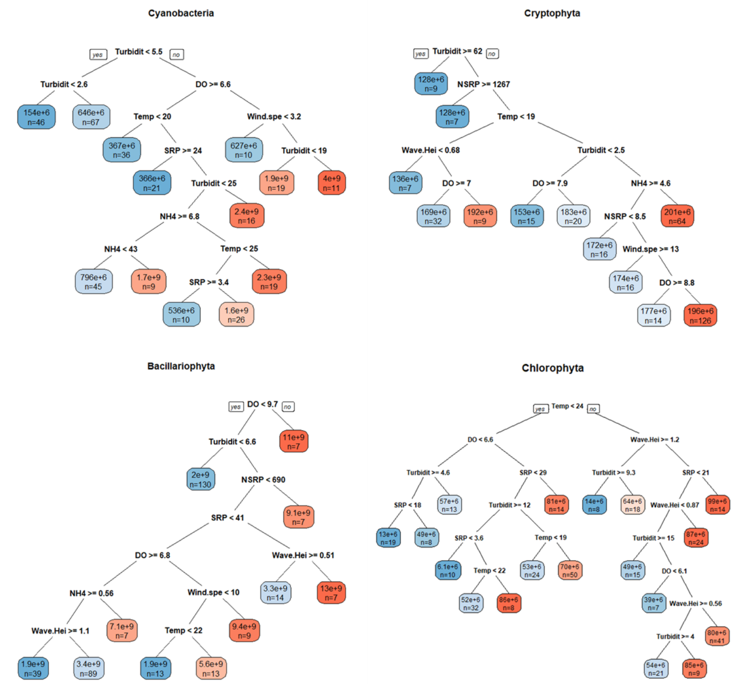
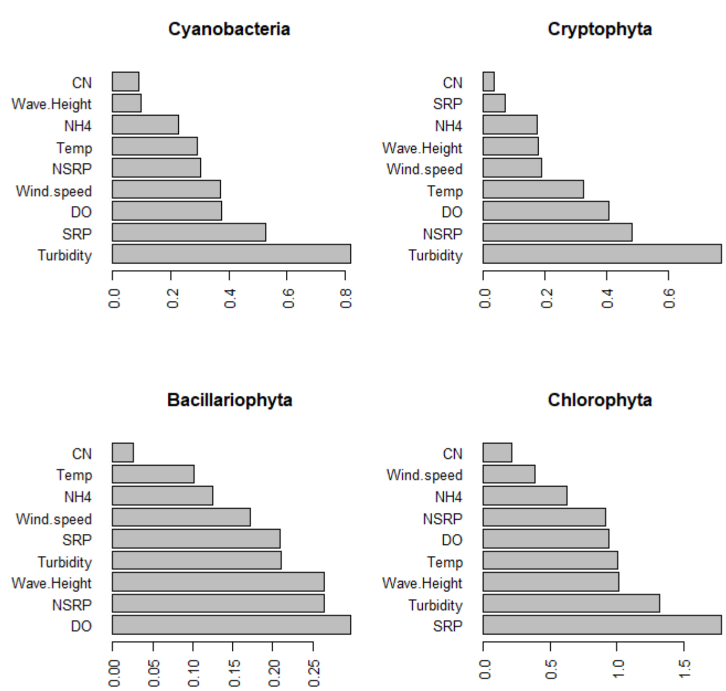


Figure 8. Trees per phytoplankton group where blue indicates low biovolume and red indicates high biovolume.

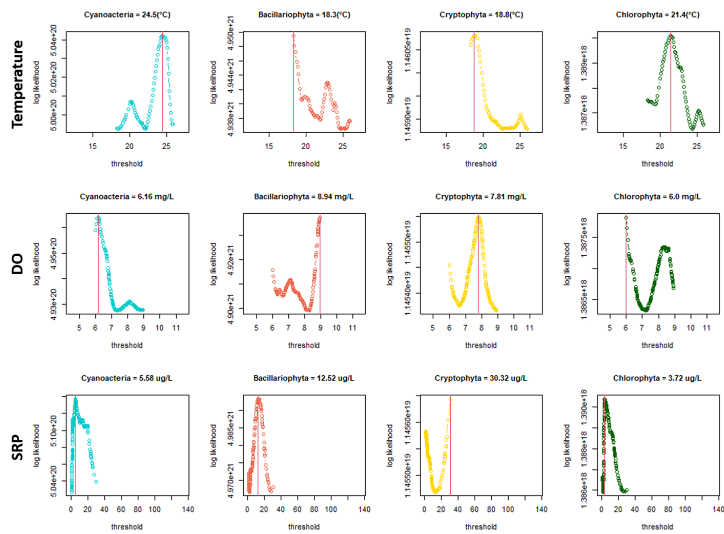
- For Cyanobacteria (CY;top-left), Turbid conditions higher than 5.5 indicated higher biovolume of this species in the lake coupled with low DO concentrations, windy conditions, higher temperatures, and low SRP and NH4 in the lake.
- For Cryptophyta (CP; top-right), N:SRP (second split of the tree) conditions seems to determine whether we will find low or high biovolume of CP in the lake. High N:SRP (i.e. higher N in the water) with temperatures higher than 19 degrees celsius, lower wind and lower DO concentrations seem to drive the predominance of CP in the lake.
- For Bacillariophyta (DI; bottom-left), DO seems to play the most important role, followed by less turbid conditions, high N:SRP, high SRP, and lower waves.
- Chlorophyta (GA; bottom right) tree resulted in more complex dynamics, which led us to infer that this species will dominate when the other species' conditions do not meet the necessary thresholds of N:SRP, Temperature, Turbidity, and DO. However, we see that water Temperature plays a major role in the presence of GA. Based on the variable importance (Fig 9), however, SRP plays the most important role in modeling the dynamics of GA. **Figure 9** - Variable Importance per phytoplankton group regression tree.



5) Changepoint Analysis:

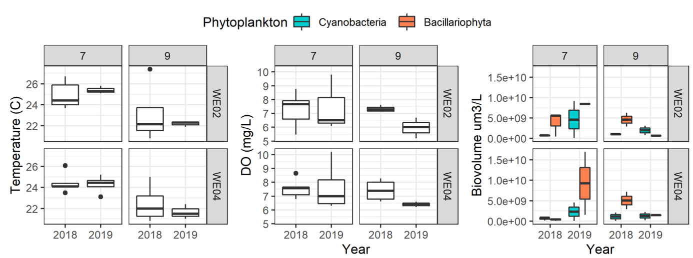
Since N:SRP and Temperature seem to determine the difference between CY and CP, while DO and SRP seemed to drive DI and GA biovolume, these are the variables we used to investigate the thresholds. **Figure 10 (below)** illustrates the threshold for temperature, DO, ad SRP per phytoplankton assemblage.

- Results clear thresholds that influence the predominance of one species over another.
- In general, CY are able to grow in higher temperature environments but they do not grow when DO concentrations are high giving space for GA, CP, and DI respectively.
- The thresholds also illustrate the dominance of CY when SRP is limited in the system.
- When SRP is high, CP and DI are more likely to predominate.



6) Boxplots over time and space:

Figure 11 illustrates the spatial and temporal patterns of CY and DI biovolume in comparison with Temperature and DO concentrations. We focus on 2018 and 2019 July and September patterns in Stations 2 and 4.

- In 2018, we had lower temperatures and higher DO concentrations on average in comparison to 2019 which lead to the predominance of DI over CY principally in station 2.
- In 2019, higher temperatures and lower DO concentration, in general, favored the growth of CY during the bloom season. In September (month 9 in the plot) shows CY dominating over DI in 2019.
- 

ACKNOWLEDGMENTS & PREVIOUS PRESENTATION

This work was part of the 2020 Summer Fellowship program with the Cooperative Institute of Great Lakes Research and the NOAA-Great Lakes Environmental Research Laboratory.

This research was developed in partnership with NOAA-GLREL scientists and collaborators from The Ohio State University.

Watch the project presentation with results before the Fluoroprobe calibration, which was still useful to analyze the phytoplankton assemblage dynamics:

[VIDEO] https://www.youtube.com/embed/bIO-_MuSp-k?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

AUTHOR INFORMATION

Lorrayne Miralha is a Ph.D. candidate in the CIvil, Environmental, and Sustainable Engineering program at Arizona State University. She was a 2020 SummerFellow at the Cooperative Institute of Great Lakes Research (CIGLR) in Michigan, where she developed the present study under the supervision of Dr. Regan Errera, Research Ecologist at the National Oceanic and Atmospheric Administration - Great Lakes Environmental Research Laboratory (NOAA-GLERL), and Dr. Jim Hood, Assistant Professor at The Ohio State University.

Lorrayne's Research focus is on water quality and environmental modeling where she has investigated spatial patterns associated with water quality variables (here (https://www.researchgate.net/publication/323268214_Accounting_for_and_Predicting_the_Influence_of_Spatial_Autocorrelation_i as well as environmental concerns linked to excess nutrients from highly agricultural regions in the United States, principally in the Great Lakes region (here (https://www.researchgate.net/publication/345546012_Bias_correction_of_climate_model_outputs_influences_watershed_model_n Her skills involve hydrological modeling, spatial-temporal analysis, machine learning, remote sensing, and GIS. Lorrayne earned a Master's in Physical Geography from the University of Kentucky and a Bachelor's degree in Forest Engineering from the Federal Rural University of Rio de Janeiro together with an exchange program of 1 year and 6 months at Oregon State University. Her goals are to develop research that may guide environmental policymakers and modelers to investigate and implement solutions that result in optimal sustainable outcomes.

She is currently looking for Postdoctoral positions!

e-mail: lmiralha@asu.edu

phone: +1 541-829-9020

Twitter: @LorrayneMiralha (https://twitter.com/LorrayneMiralha)

ABSTRACT

Introduction: Environmental factors influencing phytoplankton assemblage dynamics in freshwater ecosystems are an area of ongoing research in the Great Lakes, particularly Lake Erie where harmful algal blooms have impacted the system. Due to impacts on aquatic life and public health, studies worldwide have investigated environmental thresholds influencing the emergence and abundance of phytoplankton species. These thresholds are useful in the evaluation of ecosystem health and the implementation of conservation strategies.

Objectives: However, **how these thresholds influence the phytoplankton assemblage shifts over time and space have yet to be explored in Lake Erie, USA.** Our goal was to investigate the thresholds of environmental variables responsible for major phytoplankton group dynamics (cyanobacteria (CY), cryptophyta (CP), bacillariophyta (DI - diatoms), and chlorophyta (GA)) in the western basin of Lake Erie.

Methods: Using phytoplankton group concentrations determined by a Fluoroprobe (bbe) and water quality data collected between spring-fall from 2015 to 2019, we explored the most significant variables driving changes in phytoplankton concentration at 4 monitoring locations. We first calibrated the fluoroprobe measurements. Then, we applied a **multi-method approach,** starting with principal component analysis (PCA), Redundancy Analysis (RDA), Regression Trees, and ending with a change point analysis.

Findings: This approach was successful in the detection of major environmental variables and their thresholds responsible for the emergence and dominance of each phytoplankton group. Results revealed that **CY concentrations are primarily correlated to turbidity** conditions while **DI are more likely to dominate when dissolved oxygen concentrations are high**. The presence of **CP was mostly related to lower temperatures compared to CY.** Lastly, **N:SRP ratio was a strong predictor of GA**. These environmental variables were relevant predictors of both seasonal and spatial dynamics. Our results reveal critical thresholds in environmental conditions that shape the predominance of each phytoplankton group in the western Lake Erie and emphasize how the spatial component of these conditions can affect phytoplankton assemblage dynamics. These findings may serve as a guide to modelers and decision-makers.

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