Proposed Paradise Lake Management Plan

Kristen Ball, Jackie Berens, Soverno Chen, Megan Greenwood, Grant Simons, and Elizabeth Woelmer

University of Michigan Biological Station
EEB 482 Freshwater Ecosystems: Limnology
17 August 2017
Paul Moore

Overview

Paradise Lake (Northern Emmet County, MI) is a mesotrophic lake currently faced with threats to the intended recreational use and health of the lake. These problems are twofold: Residents report nuisance muck along the Southeastern shore, and a high abundance of Eurasian milfoil at the Northwestern bay of Paradise Lake. Residents are concerned that the sudden nuisance muck is a problem for their health and safety, especially when engaging in water recreational activities such as swimming. The milfoil is disturbing their boating activity since the plant material collects in the motors and obstructs safe passage through the lake. Water, plant, and sediment samples were collected and chemically analyzed in order to gain a better understanding of the biochemical fingerprint of the lake and the origin of the nuisance muck. This management plan provides options for the residents to consider regarding controlling the muck.

Signed,

Elizabeth Woelmer Soverno Chen

Jacqueline Berens

Proposed Paradise Lake Management Plan
17 August 2017

Kristen Ball
Jackie Berens
Soverno Chen
Megan Greenwood
Grant Simons
Elizabeth Woelmer

Students of the 2017 UMBS limnology and algae courses

History

Paradise Lake is a part of the Carp River watershed. The lake has a surface area of 1,900 acres and is a relatively shallow lake, with the deepest recorded depths at around 5 meters. Paradise Lake has a moderate level of productivity from an abundance of aquatic plants and algae in the water column, which are due to the shallow nature of the lake allowing for light penetration to the benthos. The shore of the lake is inhabited by lake residents on all sides, and Carp Lake Township is located on the Northwestern bay of the lake. The watershed as a whole is predominantly undeveloped forest, wetland, and grassland.

In 2010, a Paradise Lake Management Plan was developed by Paul Moore (Bowling Green State University) and some of his undergraduate students from the University of Michigan Biological Station limnology course. This plan focused on three problems: an invasion of Eurasian milfoil, the presence of invasive zebra mussels, and unusual nutrient levels (Moore et al., 2009). The plan proposed several options for dealing with the three problems found on this lake including a boat washing station to prevent the spread of milfoil and zebra mussels c, which was implemented.

The lake has a previous history of an abundance of Eurasian watermilfoil (*Myriophyllum spicatum*), especially in the Northwestern basin of the lake (Moore et al., 2009). The problem stems back to more than 5 years ago. Milfoil is a submersed, perennial aquatic plant that typically grows in water around one to four meters deep, and obtains most of its nutrients through its root system (Smith, C. S., & Barko, J. W., 1990). Dispersal of milfoil's seeds occur when the plant is fragmented by natural disturbances such as water turbulence, and by human-caused disturbances such as boats cutting through the milfoil (Madsen, J. D., & Smith, D. H., 1997).

In an effort to reduce the abundance of the Eurasian milfoil, a bubbler array system was installed in 2010. The main function of a bubbler system is to increase available oxygen (O2) in an aquatic system through aeration. Low oxygen levels (anoxic conditions) reduce animal life and allow the milfoil to take over all depths in the lake. Aeration systems prevent anoxic conditions from spreading throughout the entire lake by adding oxygen to the water and to keep the organisms that are dependent on higher oxygen levels to survive and inhabit the top layers of the lake (DeMoyer et. al, 2003).

Residents report that nuisance muck appeared on the South Basin shortly after the bubbler was put in place, and has a habit of appearing on shore every summer following July 4th. Some locals speculate that the nuisance muck was showing up at the Southeastern basin because of prevailing winds depositing sediment turned up from the bubbler. The composition of the muck was unknown prior to this study.

Problem

Paradise Lake (Northern Emmet County, MI) is a mesotrophic lake currently faced with threats to the intended recreational use and health of the lake (Moore et al., 2009). These problems are twofold: Residents report nuisance muck along the Southeastern shore, and a high abundance of Eurasian milfoil at the Northwestern bay of Paradise Lake. Residents are concerned that the sudden nuisance muck is a problem for their health and safety, especially when engaging in water recreational activities such as swimming. The milfoil is disturbing their boating activity since the plant material collects in the motors and obstructs safe passage through the lake.

Sampling and Testing

In-Field Sampling

On July 31st, 2017, samples were collected in Paradise Lake. Tim Veverica, the University of Michigan Biological Station’s analytical chemist, determined 9 different data collection sites on the lake based on wind and water flow (sample locations are indicated in **Figure 1**). Sites 1-6 followed the flow of wind and water from the center of the bubbler array, site 1, to the Southeast basin containing the muck, site 6. Sites 7-9 were located in the Northeastern basin and were used as control sites because they were not downwind from the bubbler. Site 10 was selected as the site for the soil core because it was one of the deepest sites on the lake.

At each site, a hydrolab was used to measure physical characteristics and an Eckman grab was used to sample sediment. At sites 1-9, aquatic plant samples were taken using plant rakes. In addition, wind directionality and speed was taken with an anemometer. All 10 sites were visited for data collection in one day.

After chemical analysis, sites 1-6 were used to make a biochemical fingerprint to track the trends in chemicals between the bubbler and the muck to help determine the origin and identity of the muck. Chemical analysis of sites 7-9 were used as a control for comparison.

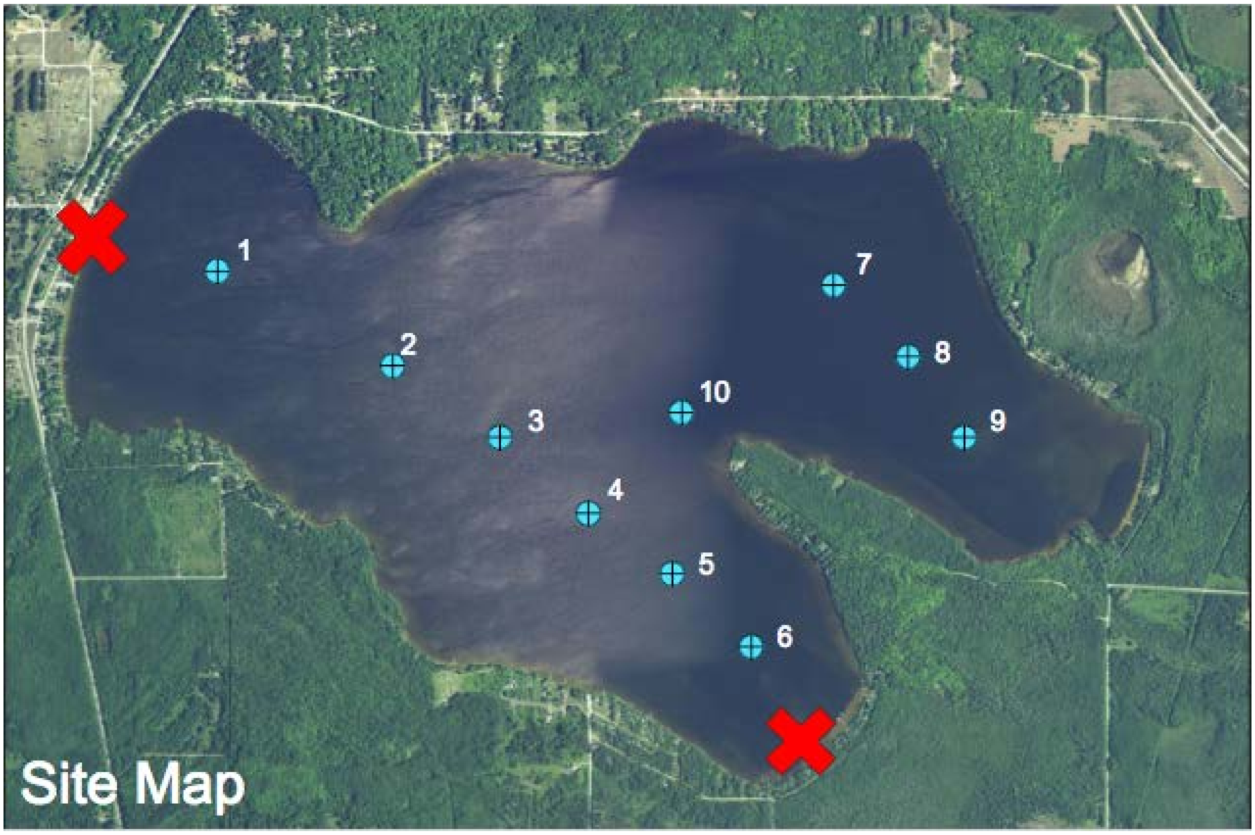

Figure 1. Map of the selected collection sites of Lake Paradise. Sites 1-6 move downwind from the bubbler to the site of where the nuisance sediment appears. Sites 7-9 were used as control sites. A sediment core was taken at site 10.

Sediment and Carbon History

At sites 1-9, an Eckman grab was used to collect sediment of the benthic layer of the lake. From this grab, a sample of the benthic layer was packaged into a Whirl-pak for lab analysis. At site 10, a short gravity corer was used to obtain a sediment core of the lake bottom. The core was obtained at approximately the deepest point in the lake (2.4 meters) in order to minimize the effects of sediment mixing. The core was separated into different cross-sections at each 1 cm interval and separated into individual Whirl-paks. The individual Whirl-paks were used for chemical analysis and a diatom ecosystem analysis. Additionally, samples of the nuisance muck were collected at the Southeastern shore for chemical analysis.

Water Chemistry

At every site, water samples were obtained using a Horizontal Van Dorn water bottle. Samples were taken near the surface of the lake and at the lake floor. For each Van Dorn water bottle sample, a syringe and filter were used to transfer water from the Van Dorn sample into a 250 mL acid-washed bottle for chemical analysis.

Aquatic Plants

At sites 1-9 a plant rake was tossed from 4 sides of the boat. Plants were separated by plant type (species or common name). Each plant type was given a percentage that expressed the representation each plant provided on the plant community. Samples of each plant were placed into whirl packs and brought back to lakeside laboratory for further identification and chemical analysis. Milfoil that was washed up on the northwest shore of Paradise Lake (upwind of the bubbler array system) was also collected for chemical analysis.

Physical Data

At sites 1-9 a hydrolab and an anemometer were used. The hydrolab measured the depth, temperature, pH, dissolved oxygen, conductivity, and turbidity. Measurements were recorded at the each third of the depth of the lake for each site. An anemometer and compass were also used to measure wind speed and direction.

Lab Techniques

After samples of muck and water were taken from the lake, they were brought back to the University of Michigan Biological Station’s Lakeside Laboratory, and analyzed under the supervision of Tim Veverica, the analytical chemist, Bob Pillsbury, professor of Ecology, and Rex Lowe, professors specializing in diatom analysis.

Carbon History

The sediment core taken at site 10 was cross-sectioned into 26 1-inch layers. Each cross-section was analyzed for inorganic carbon and organic carbon. The topmost and bottommost slides were analyzed for diatom genera presence and relative abundance, and the rest of the slides are currently being analyzed by Bob Pillsbury. Diatoms were identified using compound light microscopes, immersion oil, and naphrax mounting media. The sediment from sites 1-9 were analyzed for inorganic and organic carbon as well. Inorganic carbon was analyzed using a mass spectrometer, and organic carbon was analyzed using a CHN spectrometer.

Identification of Muck Origin

For each water sample, benthic layer sample, and detritus sample analysis across 12 different inorganic and organic elements was performed through stable isotoping, mass spectrometry, CHN spectrometry, high pressurized liquid chromatography (HPLC), and ArcGIS mapping technology. Once analyzed, biochemical fingerprint trends between sites will be compared to help determine the source of the nuisance muck.

Results

Biological Confirmation of Muck

A muck sample from the lake revealed that the nuisance sediment is largely composed of broken down filamentous green algae and diatoms immersed in milfoil detritus. Filamentous green algae is typically found to be growing in cottony forms on milfoil. The nuisance sediment has been confirmed to contain algae of the genera *Mougeotia, Oedogonium*, and in small amounts *Spirogyra*. The chemical composition of the muck is currently under analysis and remains unknown.

Diatom Composition of Sediment Core

Diatom compositions were different between the bottom of the sediment core (representing oldest sediment) and the top of the core (representing most recent sediment) (**Figure 2)**, thus the sediment composition of the lake has changed at some point, suggesting that the nuisance sediment may be a new property and not a natural property of the lake. The genus *Cocconeis* was the third most abundant in the top slide, but it was absent in the bottom. Since *Cocconeis* is an epiphyte, this increase in abundance could be due to *Cocconeis* using the milfoil as a substrate.

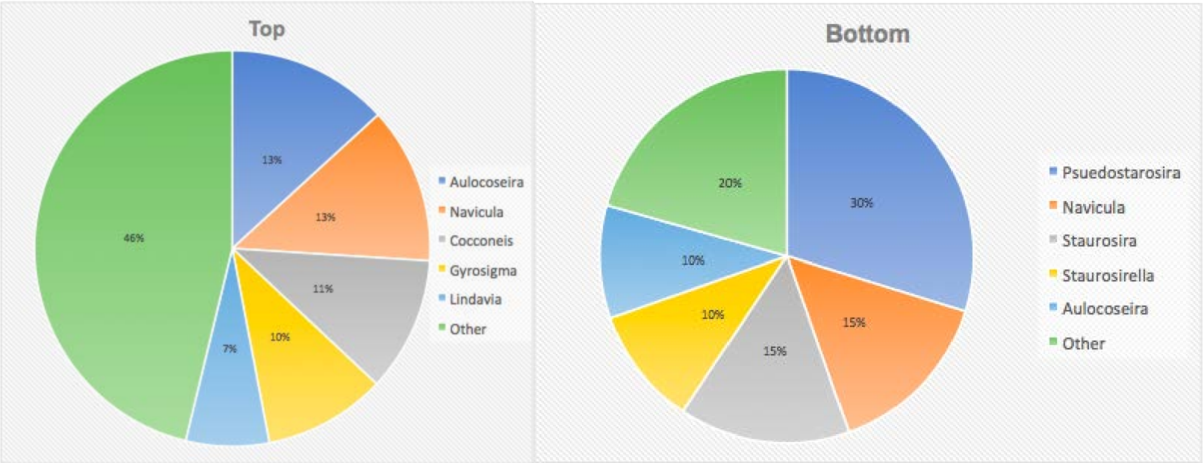

Figure 2. Diatom compositions found at the bottom and top of the site 10 sediment core.

Inorganic Chemical Analysis with Mass Spectrometry, Excel, and ArcGIS

Within the water chemistry data, the isotopic ratio Barium 135/132 showed a significant negative correlation (with respect to longitude) as sites moved downwind from the bubbler to the southeast bay (R^2=0.894) (**Figure 3a** and **Figure 3b**). Chemical analysis of organic material demonstrated an inverse relationship with the water chemical composition of the Barium 135/132 ratio (**Figure 3c**). For the organic material, as sites moved downwind from the bubbler (sites 1-6), the isotopic ratio increased. This demonstrated that in the chemical composition of the organic material, isotopic weight was increasing as sites moved downwind. This provides implications that as sites are moving downwind from bubbler, plants are taking up more barium 135 into their biomass. This can be concerning for plant health as barium has records of being a plant toxin, which can be upsetting plant health (Lamb et. al, 2013). Additionally, the water chemistry data provides implications that the bubbler could be loosening up barium isotopes and putting them into the water system.

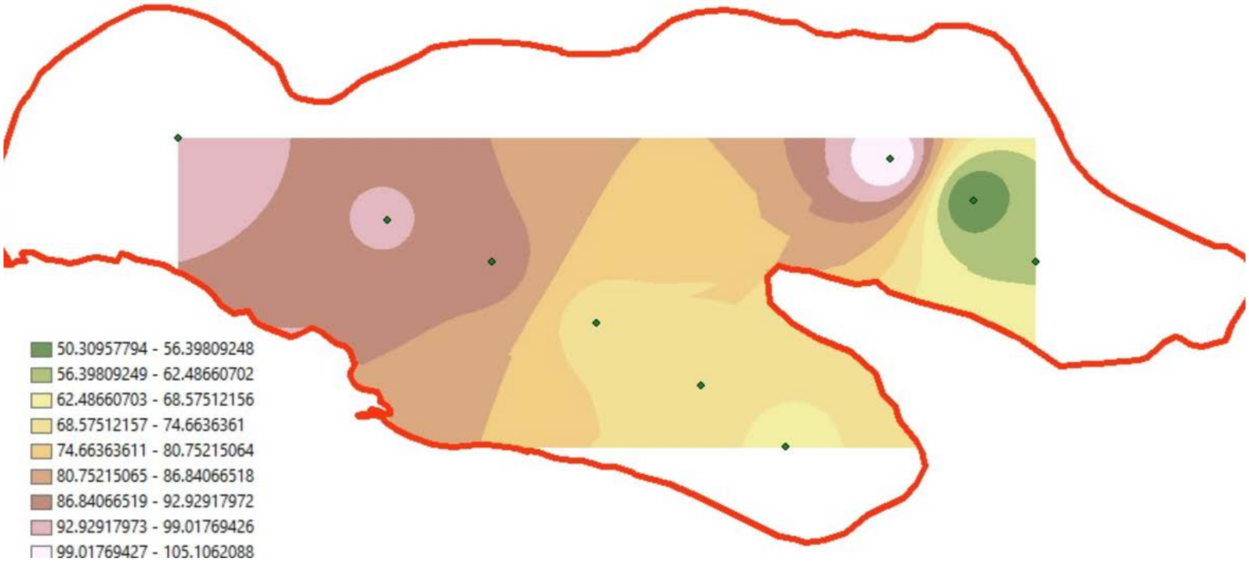

Figure 3a. ArcGIS interpolation map of water Barium 135/132 (bottom of lake) ratios throughout Paradise Lake. Barium 135/132 ratios decrease moving downwind from site 1 to site 6.

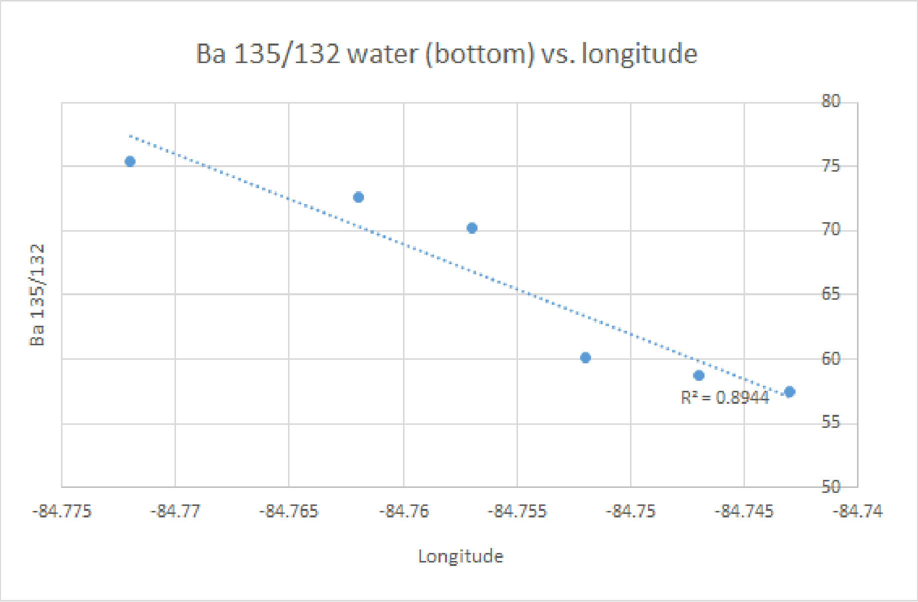

Figure 3b. Regression analysis of water Ba 135/132 ratio with respect to longitude as sites move downwind from site 1 to site 6.

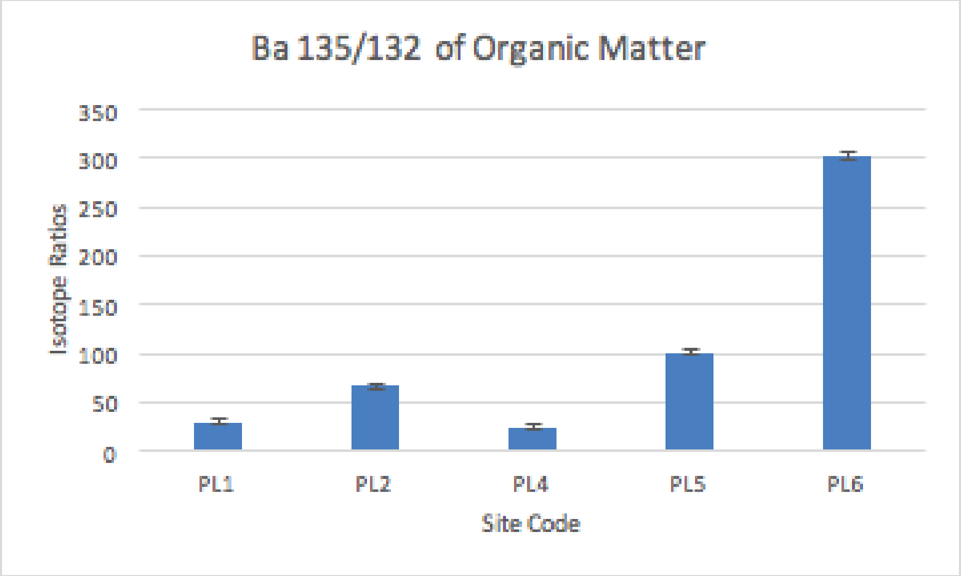

Figure 3c. Aquatic plant Barium 135/132 ratios at sites 1, 2, 4, 5, and 6. Demonstrates that Ba 135/132 biomatter concentrations increase downwind from site 1 to site 6.

Groundwater Flow and ArcGIS Mapping Analysis

Uranium is used worldwide in the scientific community to analyze groundwater flow behavior (Grabowski & Bem, 2012). The chemical compositions observed in water analysis shows that uranium 138 decreases as the sites move downwind (Figure 4a). In water systems, typically uranium will be in relatively higher concentrations in areas in which ground water is entering the water system and in relatively lower concentrations in areas in which groundwater is not entering the system (Meyer, 2013 & "Types of…", 2017). This indicates that groundwater input is higher in regions near the bubbler array and decrease as sites move downwind from site 1 to site 6.

Temperature increases moving from site 1 to site 6 (Figure 4b). Since groundwater input is commonly associated with colder water temperatures, the temperature distribution of the water agrees with the uranium 138 distribution that groundwater input is greater towards the bubblers and lower towards the southeast bay.

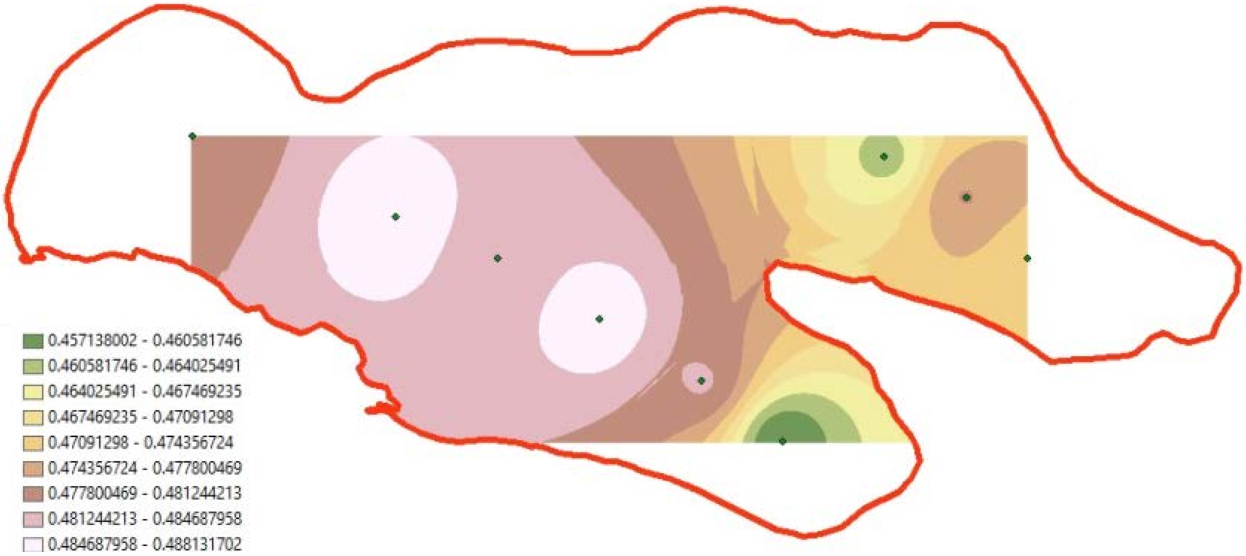

Figure 4a. ArcGIS interpolation map of Uranium 138 water (bottom of lake) concentrations throughout Paradise Lake. Uranium 138 relatively decreases moving downwind from site 1 to site 6.

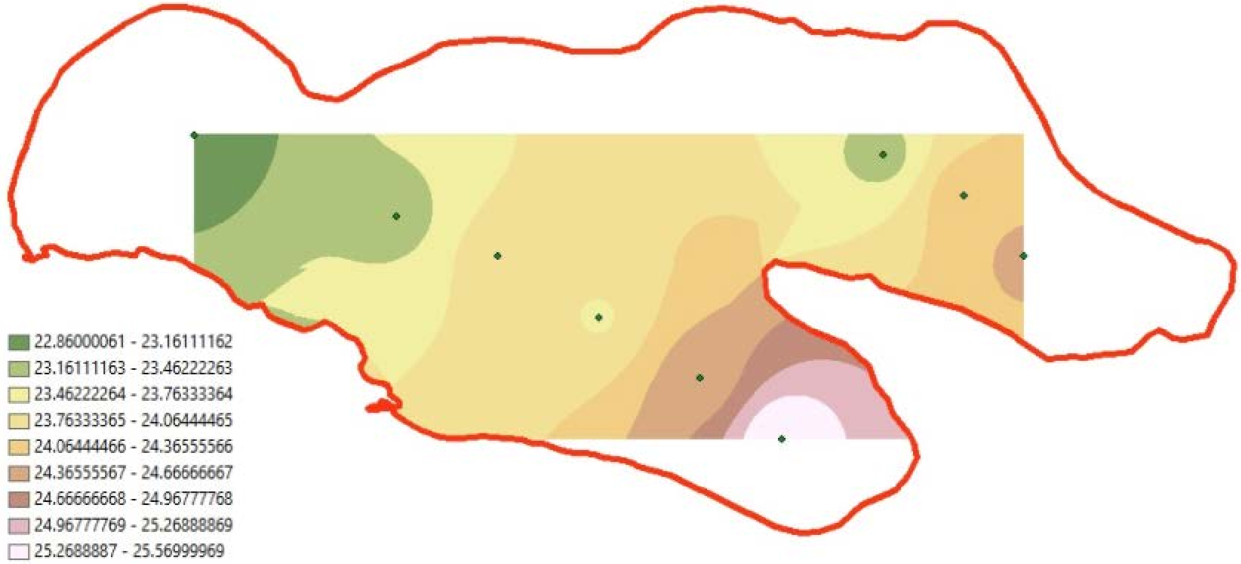

Figure 4b. ArcGIS interpolation map of water temperature throughout Paradise Lake. Temperature relatively increases as sites move downwind from site 1 to site 6.

Bubbler Influence on Dissolved Oxygen and Ammonium

Ammonium was relatively evenly distributed with the exception of sites 1 and 2, having site 1 being dramatically higher than sites 2-6 (**Figure 5a)**. Though the total nitrogen has no significant correlation as sites move downwind from the bubbler array (**Figure 5c**), nitrogen is used by plants when nitrogen is in the form of ammonium. Thus the high concentration of ammonium at site 1 signifies a high productivity in the west bay of the lake.

Dissolved oxygen concentration had an inverse relationship; the dissolved oxygen was relatively high with the exception of site 1 **(Figure 5b)**. Considering ammonium requires anoxic or hypoxic conditions to form, it would be expected to find high ammonium concentrations at site 1; therefore, the ammonium and dissolved oxygen concentrations complement each other.

Given that high ammonium levels correlate with high productivity, and high productivity leads to algal blooms and eventually anoxic or hypoxic conditions, it appears the ammonium and dissolved oxygen levels are contributing towards each other leading to what was observed in the water chemistry data. Ultimately, both the ammonium and dissolved oxygen concentrations point towards a high productivity at site 1.

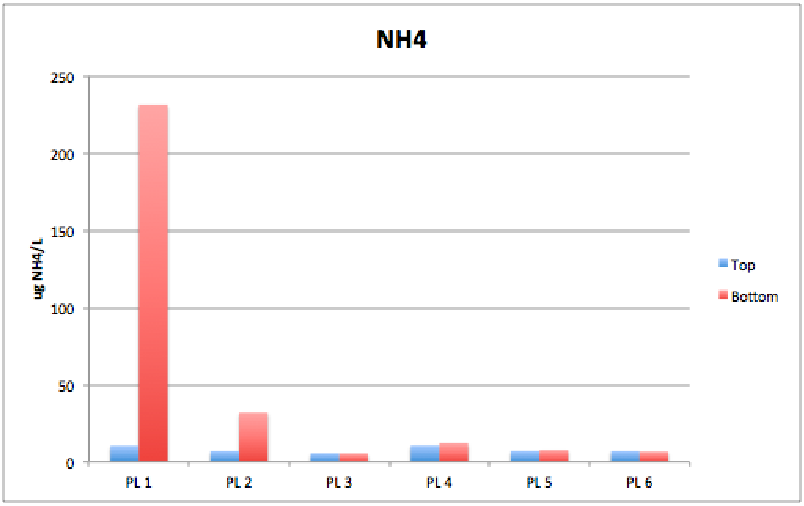

Figure 5a. This figure shows ammonium concentrations (ug NH4/L) at sites 1-6. NH4 presence in water samples from the surface of the water is shown in blue. NH4 presence in water samples from the bottom of the lake are shown in red.

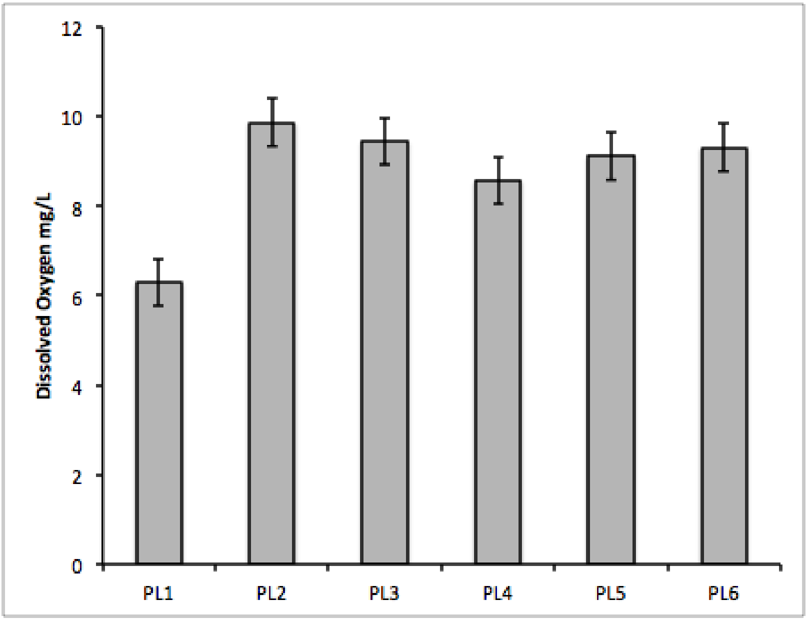

Figure 5b. This figure shows averages for dissolved oxygen (mg/L) at sites (PL1 - PL6).

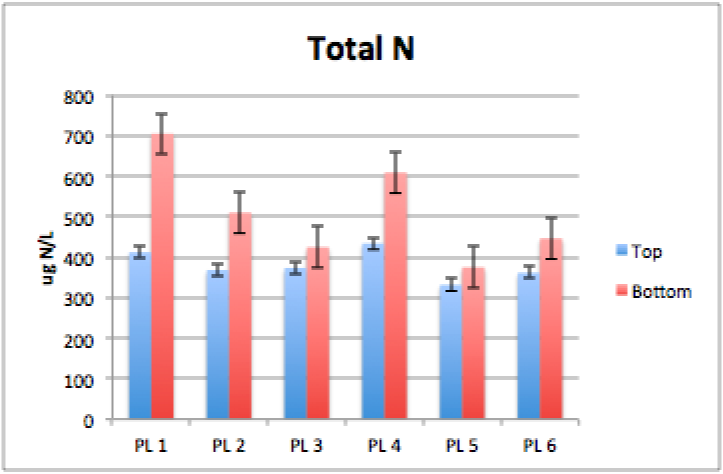

Figure 5c. This figure shows the total nitrogen (N) content for sites 1-9. Total N at the surface of the lake is indicated in red. Total N for the bottom of the lake is indicated in blue.

Speculations of Nuisance Sediment Mechanism and Origin

From chemical analysis of the organic and inorganic composition of the lake (water, benthic soil, and plant biomass), the bubblers seem to be propelling isotopic analytes and nutrients into the water system, upsetting the lake’s ecosystem. When the bubblers aerate the water, they create a small vacuum at the bottom of the lake. This vacuum causes groundwater to flow into the lake at a higher rate and it also brings up sediment from the bottom. Sediment and groundwater have higher ammonium and since the bubbler is causing them to mix with the water of the lake, it is increasing the ammonium in that area of the lake (Figure 5a). High ammonium levels correlate with high plant concentrations and algal blooms.

Through biological analysis of the nuisance sediment, the muck seems to be composed of filamentous soft green algae of the genera *Mougeotia, Oedogonium,* and small amounts of *Spirogyra*. Although this algae is generally known as having weak attachment points, the algae is not seen floating through or on top of the water, leading us to the conclusion that is is traveling to the SE basin attached to a substrate. There are small amounts of milfoil in the muck as well. Milfoil is known for fragmenting due to boat traffic and other natural disturbances such as turbulence in the lake. Therefore, based on our data, the substrate the algae is traveling on from the NW shore to the SE basin may be fragmented milfoil, which results in the nuisance sediment that is washing up on shore.

Recommendations

Table 1. Possible solutions for controlling muck/milfoil in Paradise Lake

Treatment	Advantages	Disadvantages
Remove the Bubbler Array	Prevents increase in N and P from groundwater and sediment.	Expensive. Upsetting because the bubblers were a large investment.
Keep the Bubbler Array	No cost of removal.	Bubbler seems to increase ammonium and heavy barium isotopes in the lake.
Harvest the Milfoil	Dramatically reduce milfoil in a short time period.	Cost is labor based. May be expensive.
Shoreline Survey	Free and easy.	May not be the source.
Weevils	Natural eradication of milfoil.	Expensive. 15,000 per treatment every 3-4 years.

1. **Remove the bubblers.**

The graphs for uranium and temperature both show trends for increased ground water near the bubblers. Increased Uranium and decreased temperature indicate increased groundwater because groundwater is higher in uranium and lower in temperature. When the bubblers suction up air, they cause the water at the bottom of the lake to move towards the top and create a temporary absence of water at the very base of the lake, causing a small vacuum. To fill that gap, water from the sides rush in, but ground water from underneath the sediment also rushes up from the sediment pores. In the process, the bubblers also disturb the sediment and cause it to disperse in the water column.

Ground water influx and sediment disturbances seem to be disturbing the amount of analytes and nutrients present in the water system. Our data shows increases in ammonium along with other isotopic analytes in the site near the bubblers. Removal of the bubblers would prevent the increase in analytes due to increased groundwater influx and sediment mixing. High nutrient environments support large algae and milfoil populations, therefore removal of the bubbler system, and reduction of nutrients, may lead to a reduction in algae and milfoil populations.

2. Harvest the milfoil

Harvesting the milfoil would substantially reduce the milfoil in Paradise Lake. Removing the milfoil reduces the nitrogen in the lake because when milfoil decomposes, it releases nitrogen, feeding more nitrogen to the other milfoil in the lake. Once harvested, the milfoil would need to be moved to an offsite location because if it decomposed on the shore, the nitrogen would seep back into the lake feeding future milfoil.

3. Shoreline survey

A shoreline survey could be conducted to try and reduce nitrogen flowing into the lake. This is free and easy. Tip of the mitt watershed council gives free training on how to check your lake to see if septic systems are leaking nitrogen or phosphorous into the lake. They provide checklists and you can go around in boats to each site checking the answers to questions on the sheet. The answers to the checklists tell you if there is septic leakage, and then further action to fix the septic tanks can be done.

4. Weevils

Weevils are specific to watermilfoil and consume it. They are a natural solution to eradicating milfoil. In the past, weevils were used as a biological control agent for the Eurasian watermilfoil in Paradise Lake. Members of the Paradise Lake Association have reported that the density of the Eurasian watermilfoil decreased after these applications of the weevil.

Overall, bubbler removal is a simpler solution, but if it not favored, direct milfoil removal through harvesting would be an alternative solution. Locating possible septic leakage and stopping it would also help reduce nitrogen and phosphorous levels in the lake. Weevils would also provide a solution to the milfoil problem, although they are the most expensive option.

Acknowledgements

We would like to thank Tim Veverica, the University of Michigan Biological Station’s analytical chemist, for his guidance and enthusiasm throughout our sample processing and chemical data analysis. Thanks to the UMBS chemistry lab assistants Kate and Anya for their constant support and help during chemical analysis. We would also like to thank Bob Pillsbury, UMBS researcher and professor of General Ecology, for helping with the core sampling and diatom analysis. Thanks to Professors Rex Lowe and Pat Kociolek for further assistance with identification of diatoms. Thanks to Jason Tallant, UMBS Data Manager, for his assistance with data input into the ArcGIS database. We would also like to thank our Limnology Professor Paul Moore and teaching assistants Chris West and Darbi O’Brien for their advisement on analysis of data results. Lastly, we would like to thank Paradise Lake residents Jim, Mel, and Donna for generously lending us their boat; our data collection would not have been possible without their assistance.

Works Cited

DeMoyer, C. D., Schierholz, E. L., Gulliver, J. S., & Wilhelms, S. C. (2003). Impact of bubble and free surface oxygen transfer on diffused aeration systems. *Water research*, *37*(8), 1890-1904.

Grabowski, P., & Bem, H. (2012). Uranium isotopes as a tracer of groundwater transport studies. Journal of Radioanalytical and Nuclear Chemistry, 292(3), 1043–1048. Retrieved from: http://doi.org/10.1007/s10967-011-1558-0

Lamb, D. T. et al. (2013) Bioavailability of Barium to Plants and Invertebrates in Soils Contaminated by Barite. *Environmental Science and Technology*. Retrieved from: http://pubs.acs.org/doi/abs/10.1021/es302053d

Madsen, J. D., & Smith, D. H. (1997). Vegetative spread of Eurasian watermilfoil colonies. *Journal of Aquatic Plant Management*, *35*, 63-68.

Meyer, F. W. (2013) Ground-Water Movement in the Floridan Aquifer System in Southern Florida: Ground-Water Movement Based on Natural Isotopes as Tracers. *USGS*. Retrieved from: https://sofia.usgs.gov/publications/papers/pp1403g/uranium.html

Michigan Technological University (2017) Types of Aquifers. Retrieved from: http://techalive.mtu.edu/meec/module04/Basics3.htm

Moore, P., Moore, R., Wiers, Avril., Phillips, Semoya,. Williams, Jeff. (2009) Proposed Paradise Lake Watershed Management. University of Michigan Biological Station.

Smith, C. S., & Barko, J. W. (1990). Ecology of Eurasian watermilfoil. *Journal of Aquatic Plant Management*, *28*(2), 55-64.