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Incomplete Spring Turnover in Small Deep Lakes in SE Michigan

Lisa Denys
Eastern Michigan University, ldenys@emich.edu

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Lisa Denys
Dr. Kristin Judd, Mentor

ABSTRACT

While temperate lakes are commonly thought to turnover twice annually, in the fall and the spring, there are several factors that can reduce the probability of turnover. Whether or not a lake turns over has important implications for nutrient dynamics and food webs. In this study, we investigated several small deep lakes in SE Michigan to determine whether spring turnover had occurred. One factor affected by lake turnover is the distribution of oxygen in the lake. Lakes receive oxygen from the atmosphere at their surface and from small plant-like organisms called phytoplankton within the body of the lake. Photosynthesizing phytoplankton are typically more productive in the in the upper water layers because light is extinguished with depth. Oxygen is consumed over winter by bacteria in sediments at the bottom of the lake, which respire as they decompose debris, releasing nutrients. Wind forces and temperature changes in the spring and fall drive the water layers to mix. This process helps maintain a balance by circulating oxygen from the epilimnion (upper water layer) to the hypolimnion (bottom water layer) and nutrients from the hypolimnion to the upper layers. Factors that could affect whether a lake mixes include higher densities (from salinity), depth, temperature, and the shape of the lake in relation to wind direction. If a lake does not mix, we expect to find anoxic (oxygen depleted) conditions in the hypolimnion and lower nutrient concentrations in the epilimnion, resulting in a change in the distribution and productivity of phytoplankton.

Whether spring mixing events are occurring in small deep lakes in SE Michigan was the focus of this study. The results of the research show that complete mixing in spring occurred in only 2 of 5 lakes surveyed. In lakes with incomplete mixing, we found anoxic conditions in the hypolimnion and higher phytoplankton productivity in the metalimnion (middle layer) instead of the epilimnion. While the importance of monitoring lakes is acknowledged by the state of Michigan, annual surveys are

rare due to budget constraints. More frequent monitoring would allow us to determine whether lack of turnover varies annually and what combination of factors increases the probability of turnover in small deep lakes.

INTRODUCTION

In temperate climates most lakes undergo spring and fall turnover events that supply bottom waters with oxygen and surface waters with nutrients to fuel primary production. In the summer, lakes stratify when surface waters warm and become less dense than the underlying cooler bottom waters, resulting in little mixing between the two layers. These layers are termed the *epilimnion* (warm surface layer), the *metalimnion* (region of rapidly changing temperature), and *hypolimnion* (cooler, low light, bottom waters). During stratification, phytoplankton consume nutrients and produce oxygen in the upper water column and organisms at the bottom consume oxygen and dead organic matter, which releases nutrients. By the end of the summer there can be excess oxygen in the upper water column and excess nutrients and depletion of oxygen at the lake bottom. Lake mixing patterns in the spring and fall affect the chemistry and biology of the lake by circulating oxygen and nutrients throughout the lake. When water temperatures on the surface cool, the upper layer becomes denser while wind forces aid the lake water in mixing. Fish and other organisms, including phytoplankton, zooplankton, and microbes, depend on mixing to redistribute nutrients and oxygen. (Wetzel & Likens, 2000; Bronmark & Hansson, 2005)

Lake turnover is closely linked to issues of water quality, because failure to turnover results in anoxic hypolimnia, which can be inhospitable for aquatic organisms. Monitoring the chemical and biological conditions and whether there are changes in lake mixing frequency is important because if the tendency for a lake to mix is disrupted it could reduce the quality of the lake for humans and wildlife (Bronmark & Hansson, 2005). Lakes provide a source of food from fishing and are a recreational resource. Michigan lakes bring in billions of dollars of revenue each year (Fuller & Minnerick, 2008). Clean lakes are also better for local property values and provide places for recreational activities. Some lakes serve as drinking water supplies. Since the lake may become increasing anoxic in the bottom layers when it does not circulate, lack of turnover may result in fish deaths, since fish also need to breath oxygen, and a reduced food source for fish, since other organisms they eat may have reduced survival under anoxic conditions (Bronmark & Hansson, 2005).

Most lakes in temperate climates are expected to mix twice annually; however, there are several factors that may reduce the probability of a lake mixing (Wetzel & Likens, 2000). For example deep lakes require more wind energy to mix completely. Also, if salts have accumulated in the bottom waters, more energy is required for turnover to occur (Wetzel & Likens, 2000). High salinity can be the result of road salts (accumulating in surface or ground water), reduced vegetation to absorb pollutants (due to more paved surfaces), or diverting freshwater that would normally replenish the lake (for agriculture or other uses) (Williams, 2001). Third Sister Lake (TSL) is one such lake with reduced turnover owing to very high salinity that contributes to it not turning over regularly in the spring and fall (Bridgeman et al., 2000; Judd et al., 2005). Reducing salt and fertilizer inputs and restoring wetlands that help reduce the quantities of these pollutants before they reach the lakes could improve many of the human uses of lakes and the surrounding land areas. Monitoring these lakes would alert us as to whether changes are occurring that could are the result of human inputs that may be avoidable (Fritz, 2001).

Currently, there is no regular monitoring program for Southeastern Michigan's small deep lakes, so it is difficult to determine whether trends in the frequency of lake turnover are changing. This study surveyed five of 75 Washtenaw county lakes listed by the state of Michigan; of those only one of the lakes, North Lake, was also surveyed by the state (twice in a 20 year span). Another lake monitoring program contracted by the Department of Environmental Quality (DEQ) is run by the Michigan Clean Water Corps and conducted by volunteers. The monitoring is done more frequently and includes chlorophyll and dissolved-oxygen testing to determine if spring mixing events occurred, but again, the number of lakes tested is limited. While this monitoring program also includes measuring phosphorus levels and Secchi depth (a measure of water clarity) it does not include all four tests for all lakes. Of the lakes in this study, two lakes had been surveyed by Michigan Clean Water Corps for Secchi depth. North Lake was surveyed in 1993 and Pickerel Lake was surveyed in 2005. There is no known consistent monitoring of all or even a majority of SE Michigan lakes; only small sporadic studies have been conducted on inland lakes. More complete monitoring, such as testing conductivity for increases in salinity or testing for dissolved oxygen annually, would provide information on whether seasonal mixing regimes are changing, which may indicate potential environmental problems that need to be addressed (Bronmark & Hansson, 2005). For instance, more is known about Third Sister Lake, one of the lakes in this study, because it has had several studies conducted on it by local universities. Unfortunately there is no known available data for the other lakes in the immediate area of TSL to determine if salinity is an issue specific to TSL or if this is common for other nearby lakes.

Third Sister Lake has had a decreased number of occurrences in which the lake has turned over in the spring and fall. The salinity of Third Sister Lake has been increasing, causing a higher density of the bottom water layer and possibly resulting in a reduced ability to mix (Bridgeman et al., 2000; Judd et al., 2005). Salinity may affect whether turnover will occur because it increases the density of the water, causing a heavy layer that sits on the bottom. The bottom layer would have the highest salinity and, as you move up the water column, diffusion with fresher water will cause it to have less salinity. Highly saline layers can be even heavier then the cold waters that would normally sink to the lake bottom, therefore temperature and wind forces may not overcome the greater difference in water density and the lake will not mix. While it is thought that salinity is the cause of TSL not turning over, more studies need to be conducted to see if there are other contributing causes.

To determine whether conditions in TSL are common in the region, my study surveyed a number of small deep lakes in SE Michigan. In TSL, reduced turnover has caused anoxic conditions below 6 meters that may have affected phytoplankton productivity. An anoxic hypolimnion is problematic for many species. Many organisms lay their eggs in the bottom sediment, and these may not develop and hatch in anoxic conditions. Organisms such as zooplankton, which remain in the darker bottom waters in the day to avoid predation and come to the surface to feed at night, may have altered behavioral patterns (Wetzel & Likens, 2000, Bronmark & Hansson, 2005). If oxygen levels are too low in the darker waters, zooplankton may be forced into lighter upper layers, making them easier to be seen by predators. Disruption of zooplankton could cascade to the entire lake community because zooplankton feed on phytoplankton, and zooplankton are eaten by fish (Bronmark & Hansson, 2005).

Turnover influences the distribution of nutrients in a lake, thereby affecting patterns of phytoplankton productivity. Bacterial organisms in the bottom of lake release nutrients as they feed on debris. Turnover allows these nutrients to mix throughout the lake. Since phytoplankton are photosynthetic and require light to be productive, along with adequate nutrients, phytoplankton in a lake that has mixed would likely be most productive in the epilimnion. A biological change that may occur if a lake does not turn over in the spring is less productivity from phytoplankton in the epilimnion and more phytoplankton productivity in the metalimnion (middle layer). Without turnover fewer nutrients would be available in the upper layer, and the phytoplankton in the middle area of the lake would have greater production because they would get more nutrients diffused from the bottom waters. Therefore, in a lake that has not turned over in the spring, we may expect to see greater quantities of phytoplankton biomass in the metalimnion.

Research Question*: Is lack of turnover common in small deep lakes?*

To answer this question I surveyed five small lakes with maximum depths of 14.8 to 20 meters, and took depth measurements at increments of 1 to 2 meters, in addition to measuring temperature, percent dissolved oxygen, and conductivity (which gauges salinity). Water samples from the epilimnion and metalimnion were taken for chlorophyll analysis to determine patterns of phytoplankton productivity.

METHODS

Chemical and Physical Profile

All lakes were located in Washtenaw County, Michigan. Five lakes were selected based on a depth of 14.8 to 20.4 meters in the deepest basin, measured using a sonar depth finder. Samples were taken over a five week time span, about a week apart in spring, and each lake was visited once (Table 1). Measurements for percent dissolved oxygen, conductivity, pH, and temperature were taken using a YSI model 6600 sonde. The sonde meter has a probe that is lowered into the water to each desired depth and gives "real-time" data, so measurements were immediately recorded in depth increments of one to two meters. The positions of the metalimnion and hypolimnion layers of the lake were determined from temperature and oxygen readings. Phytoplankton samples were taken from the epilimnion and metalimnion layers of the lake with a Kemmerer sampler. The sample from the Kemmerer was immediately transferred into acid-washed dark 1L Nalgene bottles and returned to the lab. Within two hours of collection, the samples were filtered for phytoplankton through glass fiber filters (~0.8µm). Between 200–300 mL of water was measured and poured through the filter and two filters were collected for each lake sample depth. Filters were stored in the freezer overnight until chlorophyll analysis the next day to determine phytoplankton biomass.

Phytoplankton biomass. Phytoplankton biomass was estimated by measuring chlorophyll α (Bronmark & Hansson, 2005). Chlorophyll α is the main pigment that photosynthetic organisms use to photosynthesize; its absorbance can be measured at a certain wavelength that excludes other chlorophylls, which then reflects the amount of active photosynthesizing phytoplankton in the sample (Wetzel & Likens, 2000). In a dim room (to prevent chlorophyll breakdown) the filters containing the phytoplankton were lysed to extract the chlorophyll by placing the filter in a polypropylene centrifuge tube and adding a recorded amount of 3 or 4 mL of 90 percent ethanol alcohol per tube. Tubes were then placed in a pre-heated 80 degree Celsius bath for 5 minutes and refrigerated overnight. The tubes were then mixed for an evenly distributed sample of the isolated chlorophyll and 2 mL were pipetted into a sterile semi-micro cuvette. The absorbance was then measured at 665nm and 750nm wavelengths, then each sample was acidified with 0.05 mL of HCl, and the absorbance re-measured at each wavelength to isolate active chlorophyll from the non-functional chlorophyll. The equation $(\mu\ g1^{-1}) = ((Abs_{665} - Abs_{750}) \times 28.66 \times V)$ V for volume of EtOH (Sartory & Grobelaar, 1984), was used to determine chlorophyll α concentration (Bronmark & Hansson, 2005).

Date	Lake	Depth (m)	Area (acres)
12-May-09	Third Sister Lk.	17.13	9.5
28-May-09	Pickerel Lk.	16.4	19.9
04-Jun-09	North Lk.	18	227
09-Jun-09	Bruin Lk.	14.8	136
15-Jun-09	South Lk.	20.4	197

Table 1. Survey information for study lakes.

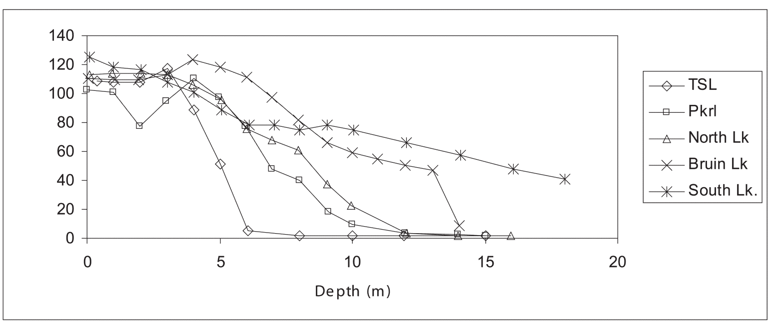

Figure 1. Percentage of dissolved oxygen in the water at each depth for the five surveyed lakes. Zero indicates oxygen depleted zones. Where the lines stop indicates the maximum depth measured in the lake.

RESULTS

Third Sister Lake, Pickerel Lake, and North Lake all had oxygen depleted conditions (< 1 mg O_2 L^{-1}) in the bottom several meters of the lake (Fig. 1). Bruin Lake and South Lake both had up to 40 percent dissolved oxygen in the final depths of the lake.

Third Sister Lake was the only lake surveyed to have high conductivity; the other four lakes had similar low conductivity values (Fig. 2).

Phytoplankton biomass data show high chlorophyll α levels in the metalimnion in TSL, Pickerel (Pkrl), and North Lake, and higher levels in the epilimnion in South and Bruin lakes, Bruin Lake being the highest (Fig. 3). TSL and Pkrl had dramatically higher chlorophyll α at the metalimnion, while in the epilimnion chlorophyll α was similar to samples in the other three lakes (Fig. 3).

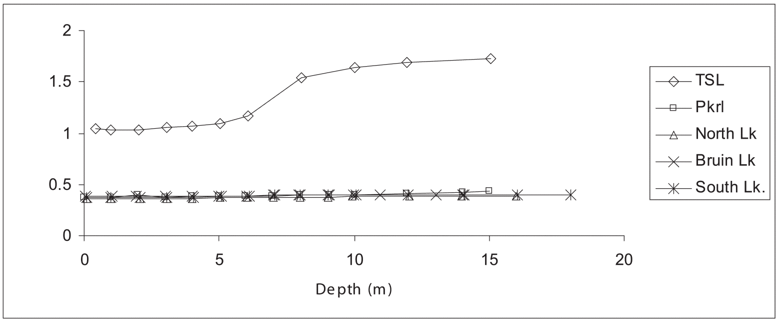

Figure 2. Conductivity (a measure of salinity) in millisiemens per depth for all five sites. Third Sister Lake had salinity levels increase around six meters, Pickerel, North, Bruin, and South lakes had similar low salinity values.

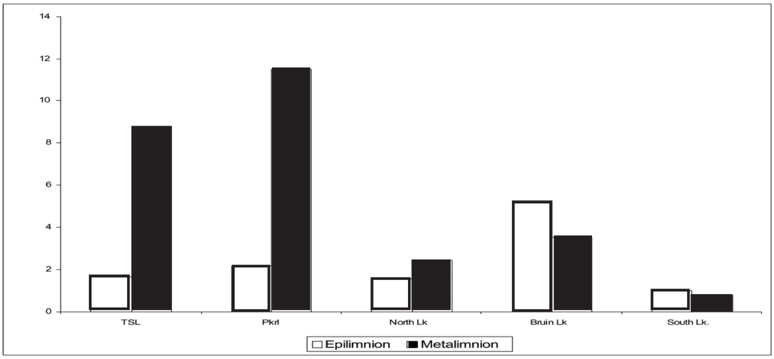

Figure 3. Biomass of phytoplankton as is represented by chlorophyll α concentrations. Mean chlorophyll α values ranged from 1.0 to 5.3 µg/L in the epilimnion and from 0.8 to 11.5 µg/L in the metalimnion.

DISCUSSION

Data from the lake profiles show that complete spring turnover does not occur in all small deep lakes in Southeastern Michigan. The results also suggest that failure to turnover affects patterns of primary productivity in the lake. Also it was found that high salinity is not the only cause of lakes failing to mix. In addition to Third Sister Lake, Pickerel, and North lakes showed evidence of incomplete turnover, even though they had low salinity levels and Bruin and South lakes with similar salinity levels did turnover.

In Third Sister, Pickerel, and North lakes oxygen was depleted as shallow as 6.5 meters from the lake surface, resulting in oxygen depleted zones of 6–11 m. In the most extreme example of oxygen depletion, Third Sister Lake, whose total depth is 17.3 meters, the oxygen level drops off around 6 meters, therefore there are 11 meters of lake, ~ two thirds, that lack enough oxygen for most aquatic life to survive. When comparing maximum depth to where the lake becomes anoxic in Pickerel Lake, there are 6.5 meters, and for North Lake, 8 meters that may be uninhabitable by most organisms. For comparison, Bruin Lake maintains ~50 percent dissolved oxygen saturation up until the last meter and South Lake had ~40 percent dissolved oxygen saturation down to the very bottom. In order for Third Sister, Pickerel, and North lakes to be so oxygen depleted in their bottom layer they would have had to have missed spring mixing events, whereas Bruin and South lakes did mix in the spring.

The higher levels of phytoplankton biomass in the middle layer of the three lakes coincided with the lakes that had depleted oxygen levels, indicating those lakes had not mixed. The likely explanation for this chlorophyll α maximum at depth is that phytoplankton would be more productive in the middle layer because they are getting more nutrients diffused from the bottom waters. The lack of turnover likely caused fewer nutrients to be available in the upper layer.

Future studies should include a greater number of area lakes in order to have more historical data to compare any new trends in lake turnover frequency. This will identify if any changes that are occurring in the frequency of lake turnover in order to address possible causes such as global warming or hazardous chemical inputs. Paleolimnology studies could be conducted to help fill in some historical data on the lakes. However such studies do not give complete information (Wetzel & Likens, 2000), so it would be invaluable to start monitoring a greater number of lakes more frequently for biodiversity and a chemical analysis (that includes the percentage of dissolved oxygen). Further studies should be done which all the lakes are tested within a more condensed time frame to rule out any changes from seasonal influences. It would be typical for an inland lake in a tropical climate to not turn over regularly, since the surface waters never cool enough for their density to increase and sink, but in Michigan it is generally expected that most inland lakes do turnover dimictically (two times a year), in the spring and fall. This study suggests that frequent lake monitoring is necessary to better understand the frequency of missed spring turnover events. Since only half the lakes turned over, further examination is needed to assess whether there are any potential environmental hazards developing.

Another area of research that would help determine whether lakes are mixing regularly would be to analyze the species present in the lake. Some species are more tolerant to, and thus become more abundant in a less oxygenated lake (because they would be at an advantage over species that are less tolerant to those conditions). Thus the amount of diversity of different species in a lake may indicate the health of the lake, as well as providing a useful history to indicate whether species are becoming extirpated (completely removed) from a particular lake.

CONCLUSION

When spring and fall turnovers fail to occur it affects the chemical composition and the biology of these lakes, which may have a measurable impact on the food chain that includes people and wildlife. This research indicates high salinity is not the only cause of lakes failing to mix. Other possible reasons should be investigated as to why the lakes did not mix. Contributing factors that reduce the ability of a lake to mix besides depth include size and shape in relation to the direction of wind patterns. A larger lake may be more likely to mix monomicticly (once a year) as is the case with the Michigan Great Lakes, or a small lake can be polymictic (mixes multiple times a year). While the lakes in this study were deep for inland lakes (> 14.8 meters) they were also all fairly small (< 227 acres). The low surface area could be a contributing cause of Third Sister Lake and Pickerel Lake not turning over. But, the surface area of North Lake, 227 acres, is a size comparably to South Lake, 197 acres, which indicates surface volume versus depth is not the cause of North Lake not turning over.

The state of Michigan acknowledges the importance of monitoring the lakes as essential for managing these resources (Fuller & Minnerick, 2008). The monitoring program began in 1973 at a time when Michigan's lakes were severely polluted (Fuller & Minnerick, 2008).

When the initial 1973 program began it was recognized that identifying changes in lake water quality was problematic because little data had previously been collected (Fuller & Minnerick, 2008), 36 years later the same problem exists. Unfortunately, the importance of establishing a history on lake conditions is acknowledged along with the funding limitations. As was stated in the report, surface water quality monitoring was reduced in the 1990s, and funds devoted to monitoring inland lakes through the Federal Clean Water Act (CWA) Clean Lakes Program (Section 314) were eliminated (Fuller & Minnerick, 2008). The State of Michigan's 2005 report and the results of my research reemphasize the importance of regularly monitoring Southeastern Michigan Lakes to maintain these freshwater resources for present and future use.

The study found it is not uncommon for small deep SE Michigan lakes to lack spring mixing events; it would be useful to determine if this is a recent phenomenon or has always been true of these particular lakes. Lack of turnover in the spring in these temperate, freshwater lakes could be a part of normal fluctuations over a longer time frame or they could be indicative of human influences due to increasing human population growth. Globally, people draw 50 percent of all the available freshwater, according to a 1998 study (Bronmark & Hansson, 2005); this demand will increase as the population continues to grow. If we start establishing a history of how lakes are being affected, potential overuse and misuse of these resources has a greater chance of being averted.

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