Seasonal dynamics in stratification, bottom-water dissolved oxygen, and water chemistry in Balsam Lake, Wisconsin: 2016-17

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Objective

Research on East Balsam Lake in 2015 found the occurrence of bottom water anoxia during the summer. Although soluble Fe and SRP temporarily increased in the water column above the sediment-water interface during these periods, the Fe:P ratio was very low. This pattern suggested that soluble Fe was not diffusing into the water column. As a result, there was not enough Fe to bind and remove all the SRP during subsequent mixing periods. SRP buildup in the bottom waters during anoxia is, thus, directly available for algal uptake and growth.

However, seasonal biweekly sampling conducted in 2015 did not provide enough resolution to detect other possible periods of temporary anoxia. More detailed information on dissolved oxygen patterns at the sediment-water interface and water column temperature stratification patterns is needed to better quantify relationships between temporary stratification, anoxia, diffusive P flux from sediment, and algal bloom development in order to clarify linkages between internal P loading and cyanobacteria in East Balsam Lake.

The objectives of these investigations are to expand on the 2015 findings:

1. Examine the development of thermal stratification using thermistors (i.e., temperature data loggers) deployed in the lake at ~ 0.5-m to 1-m intervals to record temperature hourly over the course of the summer to better document temporary stratification patterns,
2. deploy a dissolved oxygen monitor near the lake bottom to record changes at 2-hour intervals to quantify periods and duration of bottom water anoxia in the lake,

East Balsam Lake temperature and dissolved oxygen patterns are very dynamic, requiring remote data loggers to capture periods of stratification and dissolved oxygen depletion that might occur at night or during intermittent periods of stratification. This higher resolution information is needed to better understand the role of internal P loading in driving cyanobacterial blooms.

Approach

Task 1. Thermal stratification and bottom water dissolved oxygen dynamics in East Balsam Lake.

The objectives of this task were to examine stratification and bottom dissolved oxygen patterns over the summer of 2016-17 to document periods of anoxia above the sediment-water interface in relation to summer polymixis (i.e., stratifies and mixes several times during the summer). A centrally-located station was established in the lake for in situ monitoring purposes between ~ June and September (Fig. 1). Data logging thermistors (HOBO temperature loggers, Onset, Corp) were deployed at 0.5- to 1-m intervals from the lake surface to near bottom at this station to record temperature at 1-hour intervals to quantify the frequency of occurrence of stratification and mixing periods. For instance, stratification and isolation of the bottom waters can occur temporarily during warm summer days and become disrupted at night, resulting in temporary pulses of P from the sediment and mixing into the water column for algal uptake. In addition, a YSI 6600 data sonde (Yellow Spring Instruments, Yellow Springs, OH) equipped with an optical dissolved oxygen sensor and temperature probe was deployed ~ 0.5 m above the sediment-water interface during each year. In 2017, an additional sonde was placed ~ 1 m above the sediment surface. The deepest sonde did not record in 2017 so the one deployed ~ 1 m above the sediment surface was used for analysis. Dissolved oxygen and temperature were recorded at 2-hour intervals. The in-situ logging station recorded vertical temperature and bottom dissolved oxygen over the entire summer period.

Task 2. Limnological monitoring.

Similar to 2015, monitoring was conducted at biweekly for surface chlorophyll and total phosphorus and bottom water concentrations of phosphorus. The intent was to examine chlorophyll dynamics in relation to periods of temporary stratification and the development of bottom water anoxia in order to better understand the role of internal P loading in driving algal blooms.

In situ vertical profiles of temperature, dissolved oxygen, pH, and specific conductance were collected at 1-m intervals between the lake's surface and bottom using a YSI 6600 data sonde that was precalibrated against known buffers and dissolved oxygen concentration. Water samples were collected from the lake surface with a 2-m integrated samplers and bottom samples (0.5 m above the lake bottom) were collected using a peristaltic pump (Masterflex) and tubing. Samples for soluble reactive P (SRP) were pumped directly into a 60-cc syringe without exposure to air and filtered into a 60-mL polypropylene bottle using a 0.45 µm pore size filter. Water samples for TP were digested with potassium persulfate according to APHA (2011) before colorimetric determination. Chlorophyll was determined via a fluorometric technique following extraction in a 90% solution of acetone and sonication for 20 min (Welschmeyer 1994).

Results and Discussion

Stratification and bottom dissolved oxygen patterns

East Balsam Lake was polymictic during both summers (Fig. 2). Temporary stratification developed in late June-early July 2016 but was disrupted in mid-July 2016 during the passage of a cold front and high wind activity. During this stratified period, bottom dissolved oxygen declined to near zero for ~ 10 days, resulting in the potential for diffusive P flux from anaerobic sediment. Extended bottom anoxia and the potential for anaerobic diffusive P flux from sediment occurred during a much longer period of stratification between late July and mid-August 2016. Water column cooling between mid-August and the end October coincided with brief periods of temporary stratification in early and mid-September and development of bottom anoxia. Otherwise, the water column was mixed, and aerobic conditions were maintained above the sediment-water interface during that period.

Similar polymixis occurred during the summer of 2017 (Fig. 2). Temporary stratification developed in conjunction with the start of the growing season in early June and also during early through mid-July and mid-July through early August. During those periods, bottom waters approached anoxia, particularly in mid-June, early, mid-, and late July. Bottom anoxia below the sonde depth of ~ 4.5 m (i.e., 1 m above the sediment interface) probably occurred for longer periods. A cold front and windy conditions in early August 2017 resulted in water column cooling and mixing. Very intermittent and short-term stratification developed between August and the end of September, resulting in several periods of bottom anoxia in August 2017. An extended period of anoxia occurred in conjunction with temporary stratification in mid-September.

Thus, the potential for sediment diffusive P flux under anaerobic conditions was high through the summers of 2016-17 due to frequent periods of temporary stratification. Between June and September, bottom anoxic conditions (i.e., DO ≤ 1 mg/L) occurred for a total of 1084 hrs (45.1 d) in 2016 and 636 hours (26.5 d) in 2017. Greater hours of bottom anoxia in 2016 versus 2017 most likely reflected differences in the position of the sonde relative to the sediment interface (i.e., 0.5 m above the bottom in 2016 versus 1.0 m above the bottom in 2017).

Limnological patterns in 2017

The biweekly limnological sampling interval used in 2017 was clearly too long compared to the much more dynamic patterns of temporary stratification and development of bottom anoxia (Fig. 3). This sampling schedule rarely captured P dynamics during periods of temporary bottom anoxia and chlorophyll concentration increases in July could not be directly linked to bottom anoxia, internal P loading, and temporary buildup of soluble P in the hypolimnion. For instance, limnological sampling coincided with only one period of hypolimnetic anoxia (early August 2017). On that date, bottom total P and SRP increased substantially due to internal P loading from anaerobic sediment. However, other limnological sampling dates did not coincide with or capture periods of bottom anoxia and potential internal P loading in, for instance, early, mid-, and late July 2017. In contrast, continuous in situ monitoring documented a period of anoxia in early July that occurred before the rapid increase in chlorophyll, suggesting a link between internal P loading and algal uptake for growth. Algal assimilation of these internal P loads in July likely fueled bloom conditions into August 2017.

Conclusions

These investigations suggested that temporary stratification and bottom anoxia developed many times during the summer, resulting in internal P loading from sediment under anaerobic conditions. Biweekly limnological sampling captured the occurrence of bottom anoxia and high soluble P concentrations only twice in 2015 and once in 2017. However, bottom anoxia and potential internal P loading can develop numerous times in June and July as found by continuous in situ monitoring. The timing of these dynamics coincided with chlorophyll increases in 2017, suggesting a strong link between algal growth and internal P loading in East Balsam Lake. Use of aluminum sulfate to bind sediment P and reduce internal P loading will result in tremendously improve water quality conditions in the lake.

References

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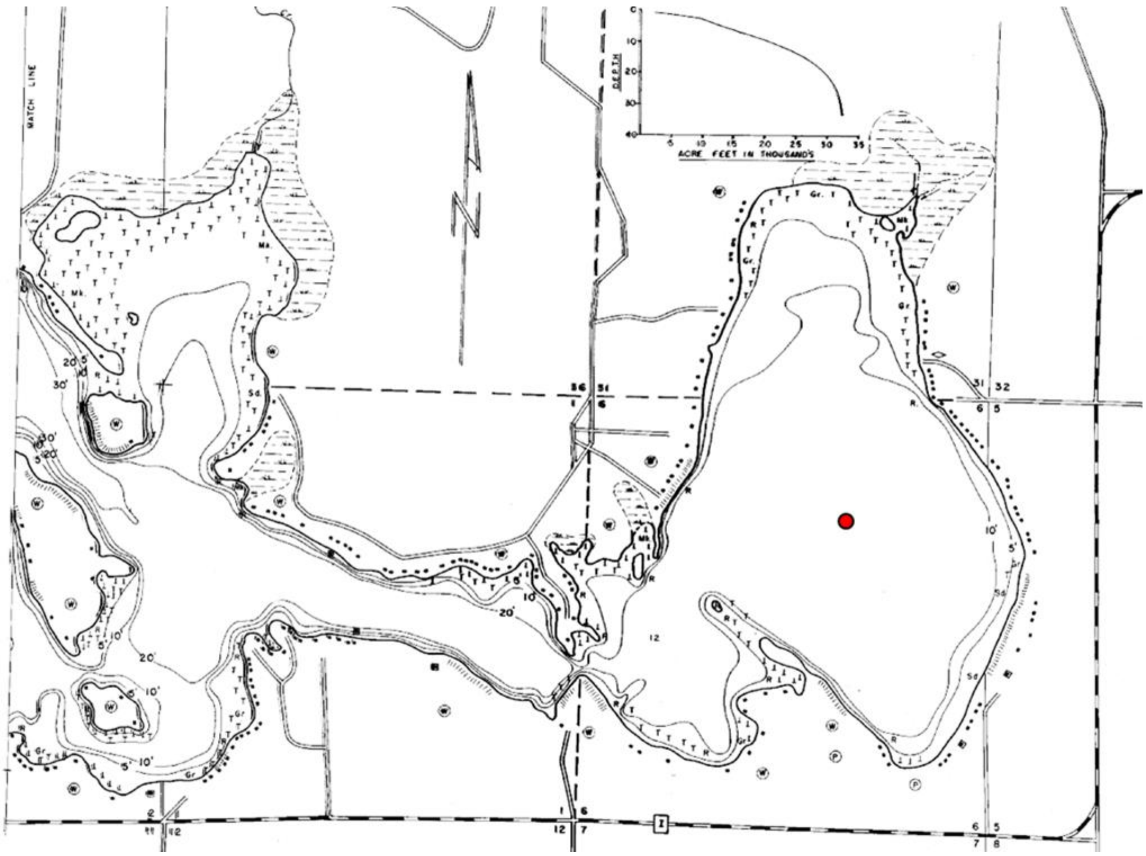

Fig. 1. Map of East Balsam Lake, WI. Red circle denotes the location of the in situ monitoring station in 2016 and 2017.

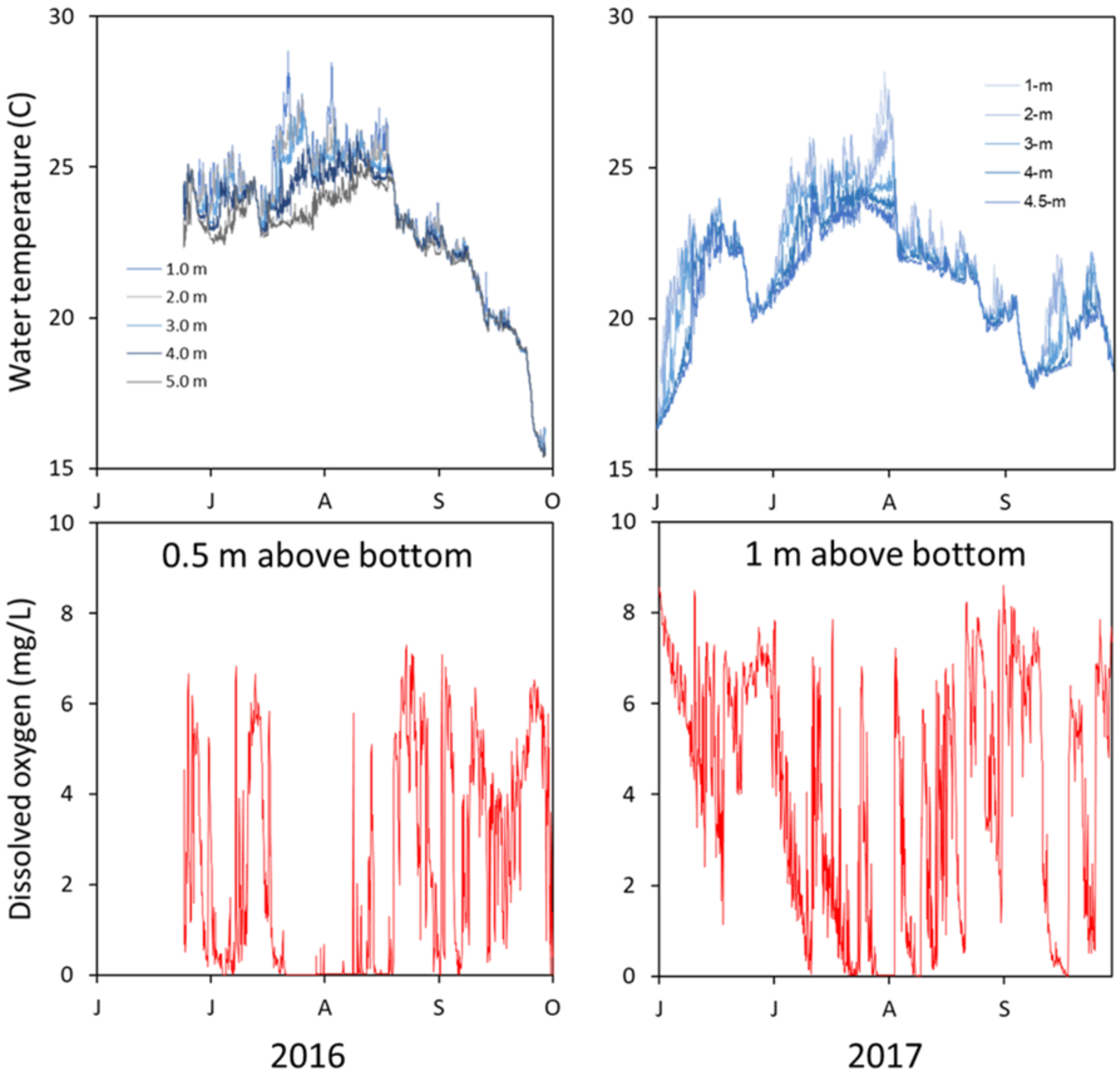

Fig. 2. Seasonal variations in water temperature at various depths and the concentration of dissolved oxygen above the lake bottom in 2016 and 2017. Please note that the dissolved oxygen probe was located ~ 0.5 m above the sediment interface in 2016 and 1.0 m above the sediment interface in 2017. Unfortunately, the dissolved oxygen monitor deployed at 0.5 m above the sediment interface in 2017 malfunctioned.

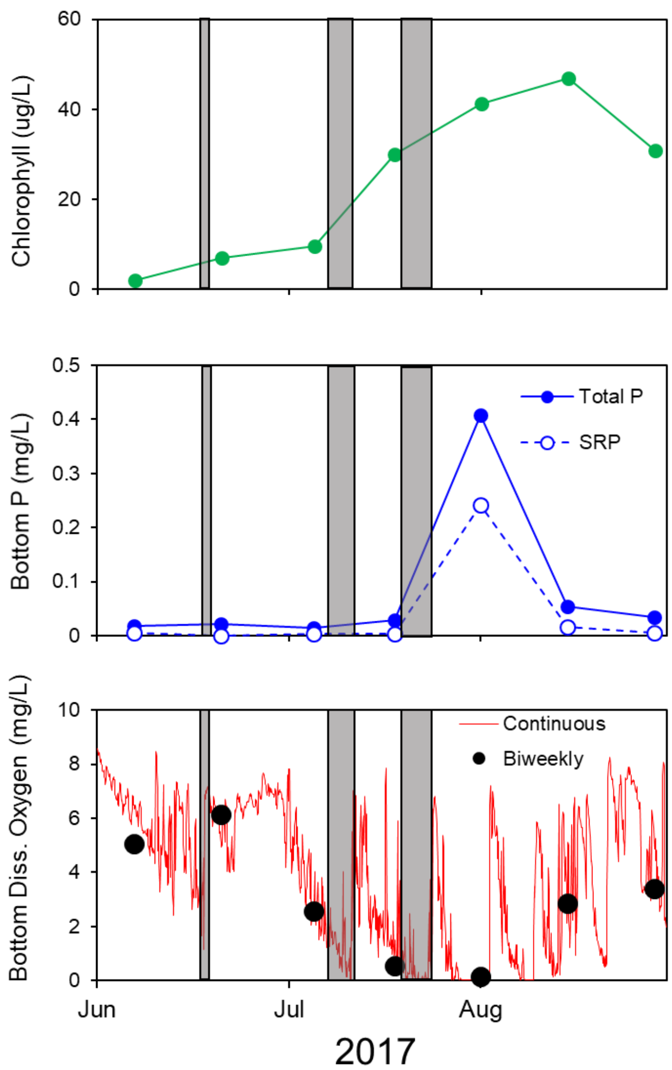

Fig. 3. A comparison of seasonal variations in surface chlorophyll (upper), bottom total phosphorus (P) and soluble P (middle), and near-bottom dissolved oxygen measured at 2-hour intervals (red line) or biweekly intervals (black circles) in 2017. Gray shaded areas denote periods of bottom water anoxia and potential internal P loading from anaerobic sediment in June and July that coincided with algal growth (as chlorophyll).