Eutrophication and salinization of urban and rural kettle lakes in Kalamazoo and Barry Counties, Michigan, USA

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A B S T R A C T

Salinization and eutrophication caused by runoff of road salt and nutrients was assessed in three kettle lakes, two (Woods and Asylum Lakes) located in urban Kalamazoo, MI, and one (Brewster Lake) in rural Hastings, MI. Profiles of dissolved O₂, conductivity, pH, and temperature were measured in situ, at half meter intervals. Water samples were collected at discrete depth intervals of 1 m and analyzed for Fe(II), Mn(II), ammonium, alkalinity, Cl⁻, Na, Mg, K and Ca. Results of this study indicate that all three lakes are eutrophic with anoxic bottom waters. Conductivity was much greater, and Cl⁻ levels were more than 100 times greater, in the two urban lakes compared to the rural lake, demonstrating the significant impact of road salt deicers on urban lake water chemistry.

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1. Introduction

Lakes with excessive input of limiting nutrients, typically of P and N, may undergo anthropogenic eutrophication. In eutrophic lakes, primary production is greatly stimulated due to the increased nutrient influx, especially of P associated with detergents, fertilizers, and leaking septic systems (Wetzel, 2001). Large algal blooms may develop; as the algae eventually die and sink to the bottom of the lake, organic matter decomposition consumes O₂, starving fauna of needed O₂. Anoxic conditions in the lake bottom waters force organisms to respire with other electron acceptors, which can result in accumulation of reduced chemical species including Fe(II) and Mn(II) produced by reductive dissolution of Fe(III) and Mn(IV) oxy(hydr)oxides, and ammonium produced by organic matter mineralization (Stumm and Morgan, 1996). Salinization of dimictic lakes may exacerbate eutrophication, because waters with greater concentrations of salt may maintain physical stratification later into the seasons and could potentially transition to permanently stratified conditions (Judd, 1970; Bubeck et al., 1971; Bubeck and Burton, 1989; Novotny et al., 2008). This prevents seasonal mixing of oxygenated surface waters into the deeper portions of lakes, which could create permanent dead zones in lake bottom waters, greatly impacting aquatic ecosystem dynamics.

The objective of this study is to determine whether urban lakes in SW Michigan are more eutrophic and affected by salinization due to anthropogenic additions of limiting nutrients and road salt than rural lakes.

2. Sites

Woods Lake is a ~9.7 ha (24 acres), ~14 m deep kettle lake located in urban Kalamazoo MI and is surrounded by residential and light commercial areas. It has no natural inflow or outflows, but several storm water drains channel runoff directly into the lake (Kieser and Associates, 1997). One profile was taken at Woods Lake on three dates: 12 May, 25 June, and 2 July 2010. Asylum Lake is ~19.8 ha (49 acres) with a depth of ~16 m, and is also located in urban Kalamazoo. It is surrounded by a state highway to the west, a dump to the south, and a small trailer park to the NW. Two profiles were sampled on 17 May and single profiles were measured on 13 and 15 July 2010. Brewster Lake is ~11.3 ha (13 acres) with a maximum depth of ~8.5 m. It is located in rural Hastings, MI, ~48 km NE of Kalamazoo, at the Pierce Cedar Creek Institute, and is surrounded by meadows, forests, foot trails and a dirt country road. Three profiles were sampled on 24 May and two profiles were assessed on 28 May and 2 June 2010.

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3. Methods

Dissolved O₂, conductivity, pH and temperature were measured in situ at 1 m intervals using a YSI multiprobe sonde dropped from the side of a boat. Water samples were collected at 1 m intervals with a Van Dorn vertical water sampler and immediately filtered with a 0.45 µm syringe filter into 25 mL HDPE vials. Four samples were taken at each depth, two of which were preserved with two drops of concentrated HNO₃. Samples not analyzed directly after collection were stored under refrigeration. Total alkalinity, Fe(II), Mn(II), and ammonium were measured using a UV–Vis spectrophotometer using techniques described in Koretsky et al., (2007), and Cl⁻ was measured using a Dionex ion chromatograph. Acidified samples were prepared with 1000 µg/L Y internal standard and analyzed for Ca, K, Na and Mg on a Perkin Elmer ICP-OES.

4. Results and discussion

Although temperature varies by sampling date, with warmer surface waters later in summer, the general shape of the profiles remains similar from lake to lake. The surface waters are relatively well-mixed; temperature is steady with depth in the upper ~1–2 m (Fig. 1A). Below this, temperature falls off precipitously in the metalimnion between ~2 and 7–10 m depth, marking the border between well-mixed, oxygenated surface waters and deeper, denser waters where more chemically reduced species are present.

As might be expected from the temperature profiles, dissolved O₂ (DO) concentrations are high and relatively constant with depth in the well-mixed surface waters (Fig. 1B). At depths between ~2 and 4 m, a subsurface peak in DO, consistent with subsurface photosynthetic production of DO, is apparent in all 3 lakes. Below this, DO quickly falls to anoxic conditions by 6–7 m depth, consistent with consumption of O₂ by labile organic C produced in the surface waters.

Total alkalinity in these lakes is likely dominated by carbonate alkalinity, which is created by anaerobic respiration and carbonate dissolution. Alkalinity increases steadily with depth in Asylum and Woods Lakes, and increases below ~2 m depth at Brewster Lake (Fig. 2A).

The pH is relatively constant with depth in the surface waters of all three lakes (Fig. 2B). Subsurface maxima in pH at Woods and Asylum Lakes, coincide with the subsurface peaks in DO at these lakes (Fig. 1B). Below this, pH decreases, consistent with the decrease in DO (Fig. 1B). Photosynthesis consumes protons, whereas aerobic respiration produces acidity. Thus, the subsurface maxima in pH also point to increased photosynthetic production of organic matter at ~3–4 m depth. The decrease in DO deeper in the lakes is likely due to aerobic respiration and reaction of O₂ with reduced solutes (e.g. Fe(II), Mn(II), sulfide, ammonia) diffusing upwards in the lake column.

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Fig. 1. (A) Temperature and (B) dissolved oxygen profiles at Woods Lake (filled circles), Brewster Lake (open circles) and Asylum Lake (crosses).

Fig. 2. (A) Total alkalinity and (B) pH profiles at Woods Lake (filled circles), Brewster Lake (open circles) and Asylum Lake (crosses).