

Effects of River Current Inflow on Dissolved Oxygen and Temperature of Refuge Zones for Cisco in Lake Bemidji

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The objectives of this study were to (1) determine if the inflow current from the Mississippi River affects temperature and dissolved oxygen in Lake Bemidji, (2) determine how the amount of suitable cisco *Coregonus artedii* habitat changes over the summer in Lake Bemidji, and (3) predict how much cisco habitat would be available under a climate warming scenario. Summer fish kill of cisco occurs in most years on Lake Bemidji resulting from low dissolved oxygen in the hypolimnion and high water temperatures in the epilimnion. Dissolved oxygen and temperature profiles provided evidence to suggest the north basin is more suitable for cisco than the south basin containing the Mississippi river inlet. Throughout the sampling period, on average 52.73% of the north basin cross section was suitable for cisco compared to 40.91% of the south basin cross section. An increase in water temperature of 1°C for the climate warming simulation lowered the average percentage of suitable habitat for cisco in the north and south basin cross sections to 22.73% and 22.73%, respectively. The Mississippi River increased water temperatures between 1.5 to 2.5°C near the inlet and outlet. This increase in water temperature decreased the dissolved oxygen concentrations between 1 to 2 mg·L⁻¹ near the inlet and outlet of the south basin.

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Introduction

Most lakes are connected to each other through rivers or streams and have current at the inflow and outflow areas. Lake Bemidji is a lake in northern Minnesota with the Mississippi River flowing through the lake's south basin. Rivers have the ability to provide lakes with various types of materials and chemicals, both inorganic and organic. Whether these materials or chemicals are beneficial is entirely dependent upon the composition and concentration. If the river is highly oxygenated, resulting from lower rates of respiration and higher rates of photosynthesis, it is expected that the areas of the lake near the current inflow will have higher dissolved oxygen quantities compared to areas that are relatively distant from inflow currents (Wilcock et al, 1998). However, river currents may also bring water with higher temperatures and nutrient loads which would reduce the dissolved oxygen concentration of the water in the lake near the inflow.

When dissolved oxygen concentrations are reduced, aquatic organisms are forced to alter their breathing patterns or lower their activity level (Cox, 2003). In this study the species of interest was cisco *Coregonus artedii*. Cisco require well-oxygenated (>3.1 ± 1.3 mg·L⁻¹; Aku, 1997) water with temperatures below 20°C (Jacobson, et al. 2011) to reproduce, grow, and survive. Although Lake Bemidji has a self-sustaining cisco population, a summer fish kill of at least a portion of the population does occur in most years as a result of lower dissolved oxygen levels in the hypolimnion and higher water temperatures in the epilimnion.

It is imperative to identify potential refuge areas for the cisco population of Lake Bemidji. The potential loss of cisco, a primary consumer, from Lake Bemidji, or other similar lakes, as result of future climate warming would have cascading effects on the energy dynamics of entire ecosystems. Habitats of cisco begin to decrease in volume

throughout the summer as the concentrations of dissolved oxygen in the suitable cold waters are reduced (Jacobson et al., 2011). In many lakes of northern Minnesota summer oxygen depletion is largely restricted to lower water layers where reaeration is limited by density stratification of the water column (Breitburg, 1994; Cox, 2003). In previous research the highest densities of cisco occurred in water with mean dissolved oxygen concentration of $3.1 \pm 1.3 \text{ mg} \cdot \text{L}^{-1}$ and temperatures below 20°C (Aku, 1997). Other studies indicate that cisco is most abundant at temperatures between $17\text{--}18^\circ\text{C}$ (Derosier, 2007). The juvenile stage of cisco is found above temperatures of 20°C and have an upper lethal temperature of 26°C (Derosier, 2007). Fish habitat in lakes is strongly constrained by water temperature and available dissolved oxygen (Jacobson et al. 2011). With climate warming the distribution of these water quality parameters will change (Liping Jiang, 2012). The objectives of this study were to (1) determine whether river inflow currents affect dissolved oxygen and temperature in a significant manner in the south basin compared to the north basin, (2) to determine how the amount of suitable cisco-habitat changes over the summer, and (3) predict suitable volume available in a climate change scenario.

Methods

Sample locations included cross sections through the north and south basins of Lake Bemidji. The north basin cross section (NCS) began on the west side of the lake at -94.870° latitudinal and 45.514° longitudinal and ended on the east side of the north basin at -94.817° latitudinal and 47.525° longitudinal. The location of the north basin cross section was selected because the location was across the deepest portion of Lake Bemidji.

The NCS had a total length of 4.32 km. Through NCS, eleven profiles were evenly spaced by a distance of 393 m. In the south basin there was one cross section (SCS) from west to east. The location of SCS was selected because the cross section included profiles near the mouth of the Mississippi River inlet and outlet. The SCS started on the west side of the south basin (-94.877 latitudinal, 47.467 longitudinal) and ended on the east side (-94.834 latitudinal, 47.492 longitudinal). The total length of SCS was 4.08 km and consisted of eleven evenly spaced profiles separated by a distance of 371 m.

At each of the eleven profiles within each cross section the dissolved oxygen (mg/L) and temperature ($^\circ\text{C}$) were measured using a Professional Plus YSI meter. Measurements were taken at two meter intervals from the surface to a depth of 16 m. The north basin cross section had a maximum depth of

22.9 m and the Professional Plus YSI had cable length of only 16 m. Dissolved oxygen levels below 12 m were not suitable for cisco. Therefore, depths below 16 m were considered non suitable cisco habitats. In order to obtain data as accurate as possible the watercraft was anchored at each profile location while measurements were made. After all the data was obtained at each profile the watercraft was driven to the next profile location and the process was repeated. This process was done at all 22 profile locations every two weeks from 21-June-13 to 31-August-13.

Data analysis

Interpolation of dissolved oxygen concentrations and temperature levels across cross sections was accomplished using the package akima in Program R (R Core Team, 2012) to create filled contours plots. Water temperatures below 20°C were considered suitable as were dissolved oxygen concentrations above $3 \text{ mg} \cdot \text{L}^{-1}$. Suitability was represented by either a 2 (both dissolved oxygen and temperature were suitable) or a 0 (either dissolved oxygen or temperature was not suitable). Suitability was determined for each depth interval within each profile location. To determine the percentage of each cross section that was suitable on each sample date, a count of all suitable locations in the cross section was divided by the total number of locations in the cross section.

A climate warming scenario was simulated by increasing water temperature 1°C . Temperature was increased for depth intervals at all profile locations. The percentage of suitable cisco habitat for the north and south basin cross sections during each sampling date was then estimated as described previously.

Data from surface readings of dissolved oxygen and temperature were used to determine the average river inlet effects of surface dissolved oxygen concentrations and temperature levels. Surface recordings from each profile during the sampling dates were constructed in X Y plots. To eliminate variation due to weekly air temperature fluctuations, dissolved oxygen and temperature were standardized in relation to the overall average mean values of each cross section throughout the sampling period.

Results

The suitable area for cisco changed throughout summer. At the beginning of the study (21 June 13), 80% of the north basin and 64% of the south basin was suitable habitat for cisco (Figures 1, 2, and 3). Two weeks later suitable habitat decreased to 64% in the north basin and only 18% of the south basin cross section was suitable for cisco habitat. A week later (19 July 13), the suitable habitat for cisco decreased to 0% for the north and south basin. Cisco suitable

habitat percentages in the north and south basin cross sections increased to 100% on 3-Aug-13. A week later (18 Aug 13), suitable cisco habitat decreased to 73% in the north basin and 64% in the south basin. During the final sampling date, suitable cisco habitat of the north and south basin cross sections decreased to 0%.

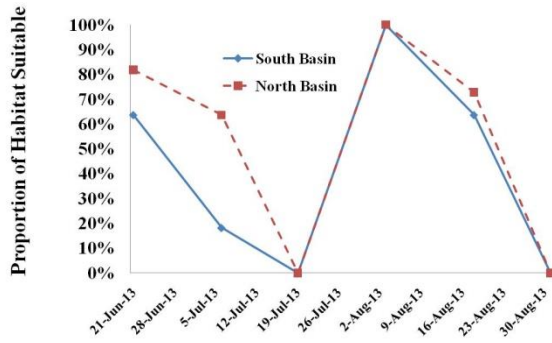


Figure 1. – Cisco suitable habitat of north and south basin cross sections throughout the sampling period.

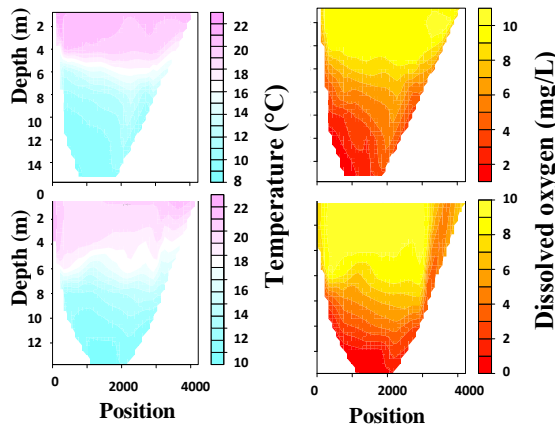


Figure 2. – 21-June-13 Dissolved oxygen levels (right) and temperature (left) profiles of the north (top) and south (bottom) basin cross sections.

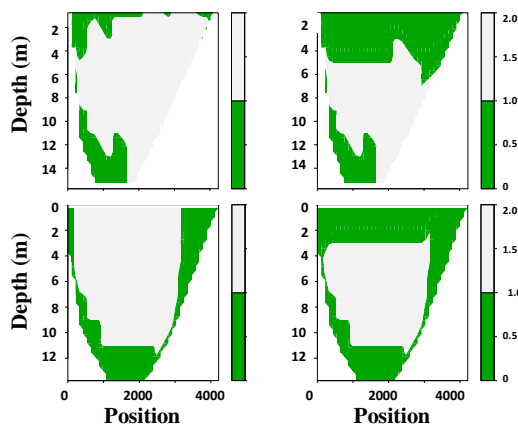


Figure 3. – 21-June-13 Suitable and climate warming scenario graphs for the north and south basin cross sections.

When a climate warming scenario represented a temperature increase of 1°C, the suitable areas between the north and south basin differed after the first sampling date (Figure 4). The north and south basin were 64% suitable for cisco with the climate change scenario on 21-June-13. After a two week period (6 July 13), the suitable cisco habitat decreased to 55% in the north basin. The suitable habitat of the cross section in the south basin decreased to 0%. On 19-July-13, cisco suitable habitat decreased to 0% in the north and maintained 0% in the south basin. A week later (3 Aug 13), the cisco suitable habitat increased to 36% in the south basin. The suitable habitat for the north basin cross section increased to 18%. On 18-Aug-13 cisco suitable habitat maintained at 37% while the north basin suitable decreased to 0%. On the final sampling date (31 Aug 13), cisco suitable habitat decreased to 0% on the cross sections of the north and south basin.

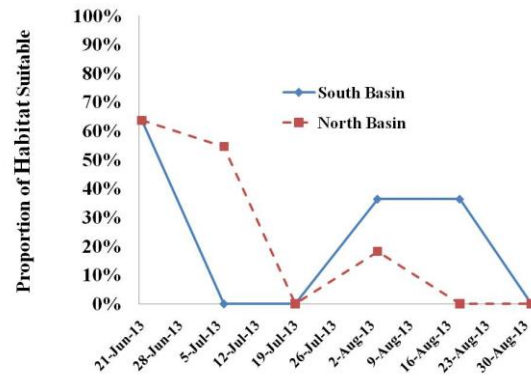


Figure 4. – Cisco suitable habitat of north and south basin cross sections during climate change scenario throughout the sampling period.

The north and south basin temperature and dissolved oxygen concentrations varied respectively. The Mississippi River appeared to influence the temperature in the south basin. The average level of dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$) between depths of 0 to 8 m in the south basin was around $8 \text{ mg}\cdot\text{L}^{-1}$ (Figure 2). The north basin experienced an average dissolved oxygen concentration of $8 \text{ mg}\cdot\text{L}^{-1}$ at a depth range between 0 m to 4 m. In the north basin the average water temperature was 20°C at a depth of 5 m. The south basin had the same temperature average of 20°C however, it also occurred at a depth of 6 m. The dissolved oxygen concentration and temperature differentiate near the Mississippi inlet and outlet between the north and south basin as seen in Figure 2. In the south basin there was clearly an increase in temperature (Figure 5 and 6) and a decrease in dissolved oxygen (Figure 7 and 8) concentrations near the inlet and outlet.

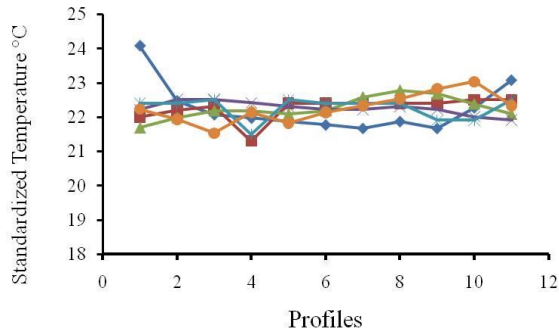


Figure 5. – North basin surface standardized temperatures (°C) representing the cross sections throughout the entire sampling period in relation to the overall average mean values of the cross sections.

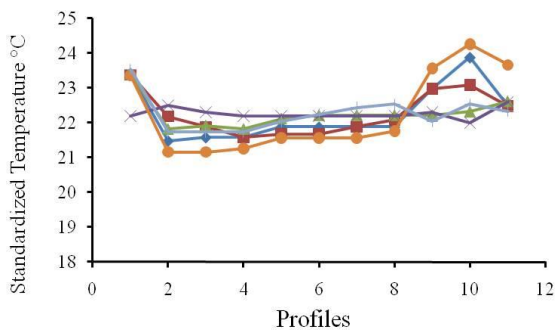


Figure 6. – South basin surface temperatures (°C) for the cross sections throughout the entire sampling period in relation to the overall average mean values of each cross section.

Surface recordings of temperature and dissolved oxygen $\text{mg}\cdot\text{L}^{-1}$ were used to analyze the effect of the Mississippi River on these water properties. The surface water temperature in the north basin was consistent at 22°C for profile 1 (west side) (Figure 5). At profile 10 (east side), the average temperature increased to 23°C (Figure 5). The average surface water temperature of the south basin at profile 1 (west side), containing the Mississippi River inlet, was 23.5°C . Surface temperature decreased to 21.5°C on average at profile 2 (approximately 742 m from the river inlet). On average, the surface temperature remained constant around 21.5°C until an average increase between profiles 8 and 11 of 2.5°C to a temperature of 24°C (Figure 6).

Surface recordings of dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$) in the north basin were consistent throughout the cross sections (Figure 7). At profile 1 (west side), the average dissolved oxygen concentration was $7\text{ mg}\cdot\text{L}^{-1}$. Throughout the cross section profiles 2 to 10 throughout the sampling period the average surface dissolved oxygen concentration increased $1\text{ mg}\cdot\text{L}^{-1}$ and resulted in an average dissolved oxygen concentration of $8\text{ mg}\cdot\text{L}^{-1}$. At profile 11 (east side), the cross sections throughout the entire sampling

period decreased by $1\text{ mg}\cdot\text{L}^{-1}$ which resulted in an average dissolved oxygen concentration of $7\text{ mg}\cdot\text{L}^{-1}$ (Figure 7)

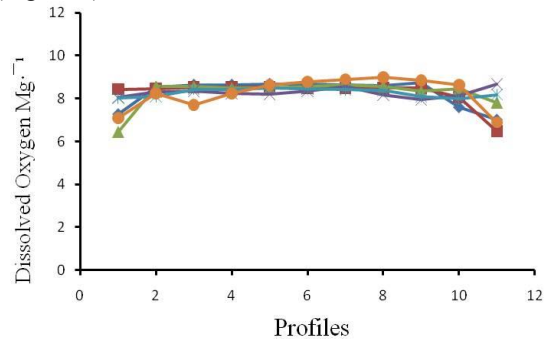


Figure 7. – North basin surface dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$) levels of the cross sections throughout the entire sampling period in relation to the overall average mean values of each cross section.

Surface recordings of the dissolved oxygen $\text{mg}\cdot\text{L}^{-1}$ concentration in the south basin were not consistent throughout the cross sections (Figure 8). At profile 1 (west side), the average dissolved oxygen concentration was $8.2\text{ mg}\cdot\text{L}^{-1}$. Throughout the cross sections, profiles 2 through 8 increased by $1\text{ mg}\cdot\text{L}^{-1}$. This resulted in an average dissolved oxygen concentration of $9\text{ mg}\cdot\text{L}^{-1}$. At profile 8 (east side), dissolved oxygen concentrations decreased by $2\text{ mg}\cdot\text{L}^{-1}$ and resulted in an average dissolved oxygen concentration of $6\text{ mg}\cdot\text{L}^{-1}$. At profile 11, dissolved oxygen concentrations increased by $1\text{ mg}\cdot\text{L}^{-1}$ which resulted in a final dissolved oxygen concentration of $7\text{ mg}\cdot\text{L}^{-1}$. (Figure 8).

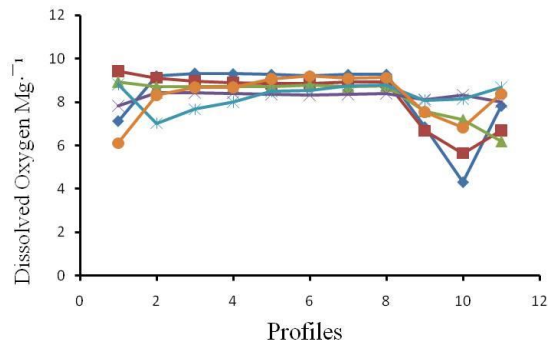


Figure 8. – South basin surface dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$) levels for cross sections throughout the entire sampling period in relation to the overall average mean values of each cross section.

Discussion

Several studies have examined the suitable temperature and dissolved oxygen ranges of cisco. The data analyzed from past studies indicated the average temperature range suitable for cisco is

between 0-20°C (Derosier, 2007). The most abundant densities of cisco are found in a range of 13-18°C (Aku, et al. 1997). The average dissolved oxygen levels for cisco suitability are above 3 mL⁻¹ (Aku, et al., 1997, Liping Jiang, 2012, Jacobson et al., 2001). The average water temperature on the west side of the south basin was 20°C at depths as low as 6 m. The average water temperature on the west side of the north basin of 20°C was found at a depth of only 4 m. This indicated that the river was bringing in water surface temperatures 1-2°C higher at profile 1 near the inlet compared to surrounding profiles. With higher temperatures near the inlet, dissolved oxygen concentrations decreased 1-2 mg·L⁻¹ compared to the surrounding profiles. However, during the summer of 2013, temperatures did not reach a critical limit which resulted in no major summer kills.

Throughout this study temperature increased and dissolved oxygen decreased therefore, the proportion of suitable water in the cross sections declined. Therefore, cisco suitable areas decreased and lethal limits were reached allowing a possible fish kill (Becker, 1983). As air temperature increased the water temperature increased and fewer suitable areas for cisco remained throughout the summer. A climate warming scenario was represented by a 1°C increase in water temperature. The scenario reduced cisco suitable areas significantly. Only three of the sampling dates throughout the entire sampling period in the cross sections were suitable for cisco under the climate warming simulations.

Lethal limit water temperatures of 20°C to 26°C (Derosier, 2007) did not occur throughout most of Lake Bemidji. High densities of cisco found at dissolved oxygen concentrations of $3.1 \pm 1.3 \text{ mg} \cdot \text{L}^{-1}$ (Aku et al. 1997) in previous studies explained that cisco may be able to survive at lethal dissolved oxygen concentrations for a short period of time. This allowed speculation of ciscoes true lethal limits and that made the interpretation of ciscoes temperature and dissolved oxygen lethal limits difficult to discover. This would explain the lack of a fish kill during this study as the proportion of suitable water in the cross sections changed significantly between the profile dates.

It appears the Mississippi River's influence to temperature °C in the south basin varies between 1.5 to 2.5°C on the west and east sides near the inlet and outlet. The Mississippi outlet affects the surface water temperature and dissolved oxygen concentrations more than the inlet. Therefore, the Mississippi River does indeed influence the water temperature as well as dissolved oxygen. The data suggested the Mississippi River affects the dissolved oxygen concentration more than temperature. Declinations near the inlet and outlet range from 1

mg·L⁻¹ to 5 mg·L⁻¹ were recorded in the south basin. This fluctuation may alter cisco suitable habitats frequently throughout the summer. Cisco suitable habitats in the north basin did not fluctuate as severe or as frequent in comparison to the south basin containing the Mississippi River current.

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