Is Low Dissolved Oxygen in Spawning Areas an Impediment to Lake Herring Restoration and Recruitment in the Great Lakes?

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Overview

Lake herring, or cisco (*Coregonus artedi*) populations in Lakes Michigan, Huron, Erie, and Ontario collapsed between 1925 and 1960. We hypothesize that degradation of cisco spawning areas due to low dissolved oxygen conditions caused by eutrophication and paper mill discharges, in conjunction with overfishing, was primarily responsible for these collapses. In Lake Michigan, Green Bay was believed to be the major spawning area for the lake. A report by the U. S. Environmental Protection Agency (EPA) has documented very low (< 1 mg/L) dissolved oxygen (DO) concentrations near lake bottom and on lake bottom in lower Green Bay during winter months as early as 1938, with the problem considerably more serious by 1955. DO levels near 1 mg/L can result in high mortality of cisco eggs. DO surveys underneath the ice in lower Green Bay have not been performed since 1970. Discharges of material high in biological oxygen demand (BOD) from the paper industry into the lower Fox River, the main tributary to Green Bay, have continued to the present day. Efforts to stock cisco into Green Bay or Saginaw Bay would be a waste of time and money if low DO conditions during winter months in Green Bay and Saginaw Bay have persisted to the present time.

Objective

Increase number of fish stocks managed at sustainable levels

Proposed Work

We will test the hypothesis that low DO conditions still exist on former cisco spawning grounds in lower Green Bay and Saginaw Bay during winter, and impede cisco egg survival. The overall objective of our study is to determine whether habitat in the key spawning area of Green Bay Lake Michigan, and Saginaw Bay, Lake Huron is suitable for successful reproduction by cisco. Our approach toward accomplishing this objective would be to compare environmental conditions and cisco egg survival in Green Bay with environmental conditions and cisco egg survival at a control site where a “healthy” cisco population is known to exist. We chose the St. Mary’s River to be the control site, because the St. Mary’s River cisco population has supported substantial sport and commercial fisheries for the past few decades (Fielder 2000). In contrast, the cisco stock in Green Bay is believed to be extirpated (Madenjian et al. 2002). A small population of cisco is believed to inhabit Grand Traverse Bay of Lake Michigan (Madenjian et al. 2002; R. Claramunt, Michigan Department of Natural Resources, Charlevoix Fisheries Research Station, 96 Grant St., Charlevoix, Michigan 49720, personal communication). Given its apparent importance in Green Bay as discussed above, we chose to focus on DO concentrations during the winter as the most critical water quality parameter determining the

suitability of the spawning habitat for cisco. Low DO conditions could very well occur under the ice when high BOD loadings have been added to the aquatic ecosystem during the summer and fall months because ice prevents any re-aeration by wind. When the air-water interface is open, wind re-aeration tends to keep the water saturated with dissolved oxygen; the stronger the wind, the greater the tendency for the water to be oxygen saturated.

To test this hypothesis, we propose the following specific objectives:

a. Measure the geographic extent and duration of low DO conditions in lower Green Bay and Saginaw Bay during winter.
b. Determine whether low DO conditions exist in Grand Traverse Bay (Lake Michigan) and the St. Mary's River where cisco currently spawn.
c. Conduct egg incubation experiments to compare overwinter survival of fertilized cisco eggs in lower Green Bay and Saginaw Bay with egg survival in Grand Traverse Bay and St.Mary's River (control sites).

Approach

We will conduct water quality surveys of lower Green Bay and the St. Mary's River during January, February, and March of 2008 and 2009. For lower Green Bay, we plan on completing six transects running northwest–southeast across the bay during each survey. Along each transect, 5 to 30 sites will be sampled. We plan on renting a gas–powered air boat or Hovercraft to conduct the surveys in lower Green Bay. At each site, a hole will be drilled through the ice using a gas–powered ice auger. Water temperature, pH, and DO profiles will be recorded using pH and DO meters and probes. Each profile will extend from near surface to bottom. A hand–held global positioning system (GPS) will be used to determine the coordinates of each sampling location. We will incorporate the water quality measurements into a GIS database to generate water quality maps of lower Green Bay. Percent ice cover on lower Green Bay will be estimated for each survey from NOAA AVHRR satellite imagery. Each DO survey of lower Green Bay will take two or three days to complete.

We will employ similar methods for the St. Mary's River. We will rent a snowmobile to conduct the water quality surveys in a region identified by David Fielder (Michigan DNR) and Mark Ebener (Chippewa-Ottawa Resource Authority) to have a high density of cisco eggs. For each survey, we will complete four east–west transects through this region, with 5 to 10 sampling sites per transect. Again, at each site, a hole will be drilled through the ice using a gas–powered ice auger. Water temperature, pH, and DO will be recorded. GPS will be used to determine coordinates of each sampling location, and data will be entered into a GIS database to generate water quality maps of the St. Mary's River site. Each survey of the St. Mary's River site will take one day to complete.

During December 2008 through April or May of 2009, we plan on incubating fertilized cisco eggs in replicated plexiglass chambers at three locations in lower Green Bay, three locations at the St. Mary's River site (control site), and at the Michigan DNR's Wolf Lake Hatchery. Fertilized eggs will be obtained from the Wolf Lake Hatchery. We plan on incubating five chambers at each location. In each chamber, fertilized eggs will be place separately in each of 50 individual

wells, and the chamber will be covered with fine–mesh Nitex screening to prevent egg predation. We will also deploy additional uncovered chambers with fertilized eggs at each site to obtain an index of egg predation in both habitats. Water quality parameters will be monitored at all egg incubation locations throughout the winter. Egg survival will be determined by visual examination of some of the chambers periodically throughout the winter. Hatching rate and survival will also be determined at the end of the experiment.

ATP concentrations in sediments may provide an index of past and current dissolved oxygen conditions. To characterize sediments types and ATP concentrations, in December 2008 and April or May of 2009 we will take three replicate sediment samples from each of the egg incubation locations using a coring device. Additionally, we will sample sediments at 10 other locations at both lower Green Bay and the St. Mary's River site, and at selected sites in inner Saginaw Bay and Grand Traverse Bay. DO concentrations near bottom will also be measured at the same time and location at which the sediment samples will be taken. The samples will be frozen, and then transported to the laboratory (to be determined), where the sediment type and ATP concentrations will be determined. Analytical procedures outlined by Karl and Craven (1980) will be followed to determine the sediment ATP concentrations.

We will use the GIS database to map water quality characteristics of lower Green Bay and the St. Mary's River site and estimate the proportion of lower Green Bay's surface area with hypoxic (< 4 mg/L) bottom DO concentrations. In laboratory studies, egg survival was relatively high for DO concentrations above 4 mg/L, but egg survival decreased precipitously when DO concentration declined from 4 to 2 mg/L (Brooke and Colby 1980). Using the laboratory work of Brooke and Colby (1980) as a yardstick, we will determine if the winter DO concentrations observed during the surveys had the potential to constitute a major impediment to cisco rehabilitation in lower Green Bay by estimating the proportion of the bay with DO concentrations < 2mg/L. We will also compare the proportion of the surface area with bottom concentrations less than 2 mg/L at the St. Mary's River site with that for lower Green Bay.

We will use a balanced, nested analysis of variance (ANOVA) to determine whether cisco egg survival at the St. Mary's River site was significantly greater than cisco egg survival in lower Green Bay. The main effect would be site (St. Mary's River site vs. lower Green Bay), and each of the three locations at each of the two sites would be nested within site. Each cell in the ANOVA design would include the five replicate values of egg survival. The egg survival observations would be appropriately transformed prior to ANOVA. The F–test for the main effect would be used to determine whether cisco egg survival varied significantly between the two sites.

To determine whether sediment ATP concentration is a reliable predictor of winter DO concentrations, we will perform correlation analysis of sediment ATP with winter DO concentrations. The Pearson correlation coefficient between sediment ATP concentration and winter DO concentration will be calculated. In addition, the regression line of winter DO concentration as a function of sediment ATP concentration will be developed. The reliability of sediment ATP concentration as a predictor of winter DO concentration will be assessed.

Scientific Rationale

Madenjian et al. (in review) proposed that the cisco collapses in Lakes Michigan, Huron, Erie, and Ontario were primarily due to environmental degradation of key spawning areas in conjunction with overfishing. Destruction of key spawning habitat preceded collapse of the cisco populations in Lakes Michigan, Huron, and Erie by 10 to 15 years. Given that cisco is a long–lived species, the cisco collapses in Lakes Erie, Huron, and Michigan were better synchronized with degradation of spawning habitat than with alewife or rainbow smelt invasions. Dissolved oxygen (DO) concentrations below 1 mg/L were observed in lower Green Bay under the ice, on lake bottom, as early as 1938; and the problem had substantially worsened by 1955 (Epstein et al. 1974). Further, burrowing mayflies were extirpated from Green Bay during the 1950s, presumably due to low DO concentrations. Cisco typically spawn in November, and their eggs incubate under the ice, and then hatch in April (Cucin and Faber 1985). DO concentrations of 1 mg/L result in greater than 90% cisco egg mortality (Brooke and Colby 1980). Although DO concentrations under the ice in inner Saginaw Bay have apparently not been measured, the bay received high biochemical oxygen demand (BOD) loadings during 1930-1970 (Freedman 1974). Extirpation of burrowing mayflies from Saginaw Bay during the 1950s has been attributed to low DO concentrations. Because cisco longevity exceeds 20 years (Schreiner and Schram 2001), the collapse of the cisco fishery in Lake Michigan by 1960 and in Lake Huron by 1956 was probably linked to low DO concentrations under the ice during the 1940s and 1950s in lower Green Bay and inner Saginaw Bay.

Environmental degradation of key spawning areas still may represent a serious impediment to lakewide recovery of cisco populations in these four lakes today. Although phosphorus, sediment, and BOD loadings to lower Green Bay from the Fox River have decreased from the 1950s to 1990, deliveries of these materials from the Fox River to lower Green Bay still occur at a relatively high rate compared with rates for other tributaries to Lake Michigan (Epstein et al. 1974; Robertson 1997). Even though early signs of a burrowing mayfly recovery in the lower Fox River have been detected, the burrowing mayfly population in lower Green Bay has yet to recover (Cochran 1992; Cochran and Kinziger 1997). To the best of our knowledge, no measurements have been made since 1970 of DO in lower Green Bay during winter months under the ice. Apparently no observations of DO have ever been made in inner Saginaw Bay during winter under the ice. The burrowing mayfly population in inner Saginaw Bay has yet to recover. The high BOD loadings of the sugar beet industry from the Saginaw River to Saginaw Bay have continued to the present day. Areas believed to be key cisco spawning areas in Lake Ontario, including Hamilton Harbour and Irondequoit Bay, have remained highly degraded (Fitzsimons and O'Gorman 2006).

We will test the hypothesis that low DO concentrations during the winter in lower Green Bay still represent a serious impediment to rehabilitation of the cisco population to Lake Michigan. Upon completion of the proposed work, we should be able to conclude either that the DO concentrations in lower Green Bay are sufficiently low over an extensive portion of the bay to substantially interfere with cisco reproduction in the bay, or that the effects of low DO on cisco egg survival in lower Green Bay are minimal. Our approach for hypothesis testing would be a direct comparison of physical habitat conditions and cisco egg survival in lower Green Bay with

physical habitat conditions and cisco egg survival in the St. Mary's River (control site). Assuming pH and temperature conditions are not adverse, a combination of low DO conditions over a large portion of lower Green Bay and relatively poor cisco egg survival (via comparison with the St. Mary's River site) would indicate that low DO during the winter represents a serious impediment to cisco rehabilitation in lower Green Bay. In contrast, a combination of relatively high DO concentrations over most of the lower bay and relatively good cisco egg survival would indicate the low DO conditions during winter do not represent a serious impediment to cisco rehabilitation in lower Green Bay.

Governmental/Societal Relevance

The proposed research directly addresses one of the long–term goals of the Great Lakes Regional Collaboration Strategy, namely to insure that the open and nearshore waters possess a full array of safe natural habitats required to meet the reproductive needs of cisco (lake herring). In addition, the proposed research directly addresses guiding principles for Lake Michigan's Fish Community Objectives of restoring native fish species and maintaining diversity of planktivore species.

Rehabilitation of cisco populations in Lakes Michigan, Huron, Erie, and Ontario is a highly desirable goal of fishery managers for two reasons. First, recovery of the cisco populations would facilitate the rehabilitation of lake trout (*Salvelinus namaycush*) in all four lakes and of Atlantic salmon (*Salmo salar*) in Lake Ontario (Fitzsimons and O'Gorman 2006). Ketola et al. (2000) concluded that Atlantic salmon were extirpated from Lake Ontario via early mortality syndrome (EMS) significantly interfering with their reproduction, and the EMS was strongly linked with a diet rich in alewives. An alewife–rich diet has been strongly linked to EMS in salmonines, whereas a diet rich in ciscoes does not cause EMS (Fitzsimons et al. 1999). Although the effects are not as severe on lake trout as on Atlantic salmon, EMS has also been shown to impair lake trout reproduction in the Great Lakes. Thus, recovery of the cisco populations would promote rehabilitation of the lake trout and Atlantic salmon populations. Second, increasing the proportion of cisco in the planktivore community would stabilize the food web in these four lakes. Ciscoes, which are native to the Great Lakes, do not exhibit frequent die–offs as do alewives and, to a lesser extent, rainbow smelt. Moreover, the cisco is a long-lived fish in comparison with the relatively short-lived alewife and rainbow smelt (Fitzsimons and O'Gorman 2006).

Relevance to Ecosystem Forecasting

This project will aid predictions that cisco populations can be restored through stocking, and can reproduce successfully in Green Bay, Lake Michigan and Saginaw Bay, Lake Huron