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Survival of Fishes in a Stormwater Retention Pond at the Watershed Nature Center, Edwardsville, Illinois

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ABSTRACT

A study of the Upper Pond at the Edwardsville Watershed Nature Center (WNC) was conducted to discover the potential cause of fish kills in the small stormwater retention pond and to determine how the current populations of bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*), common carp (*Cyprinus carpio*) and largemouth bass (*Micropterus salmoides*) can survive in the pond based on prevailing environmental conditions. Dissolved oxygen (DO) was measured from June 19 to December 5, 2019 at a site in the center of the open lake (4 m deep) and from a dock near the shore (1.1 m deep). Water temperature was measured intermittently at both sites from June 19 to November 4. In the open lake, oxygen levels reached a peak of 11.6 mg/L at the surface on July 2. Below 2.5 m DO remained less than 1.5 mg/L until Oct. 8 when it slowly began to rise reaching a high of 10.8 on Nov. 20. The dock station had similar oxygen levels. Temperature varied from a high of 31.2 °C on July 21 to a low of 6.5° C on November 3. The low DO in the pond results from a nearly continuous cover of duckweed (*Lemna* sps) which prevents interchange of oxygen with the atmosphere. It is likely that the low oxygen levels select for fish species that are physiologically and behaviorally capable of surviving hypoxia.

INTRODUCTION

Before becoming a nature preserve in the early 1990s, the Watershed Nature Center (WNC) was a sewage lagoon for the City of Edwardsville (Kendall, 2010). The lagoon, which was about 1-3 meters in depth, operated for about 20 years. With community support, the lagoon was transformed into a stormwater retention pond (SWRP) and Nature Center in the early 90s. SWRP's collect drainage from urban areas. Some benefits of SWRP's include filtering nutrients, improving water quality, providing habitat for a variety of plant and animal species and serving as an outdoor recreation area for residents (Hassall 2014). Many SWRP's have problems with anoxia in summer (Chen et al. 2019). Today, the WNC is an important nature preserve for the city providing numerous natural services for wildlife and the public but the ponds suffer from seasonal anoxia. The ponds are extremely eutrophic because of extremely high inputs of plant nutrients (Sage 2014).

The Lower and Upper Ponds at the Nature Center (Fig. 1) together occupy about 3 hectares (Sage 2014). The entire nature preserve contains approximately 16.2 hectares (40 acres) of prairie, forest, and wetland habitat (Zambrana Engineering 2000).

Summer water quality in the Upper Pond is impaired because of its high nutrient inflow (Sage 2014) which supports an abundant stand of macrophytes. Aquatic macrophytes can create conditions that reduce DO (Miranda and Hodges 2000, Caraco and Coles 2002, Vilas et al. 2018a,b, Sand-Jensen et al. 2019). Fisheries surveys in 2013 and 2018 have shown large shifts in species composition between the two dates. Our goal was to test whether this shift might be a result of degraded water quality due to excessive macrophyte growth. We examined temperature and DO measurements and compared them with literature values for the temperature and DO requirements of the fish species in the watershed ponds. We chose to focus our attention on 4 species -- largemouth bass (*Micropterus salmonoides*), blue gill sunfish (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*) and common carp (*Cyprinus carpio*). These species were chosen for attention because they are the dominant species in the Upper Pond (Table 1). Our hypothesis is that low oxygen levels caused by the abundance of macrophytes limit the fish population to species that can withstand long periods of hypoxia.

METHODS

The WNC Upper Pond was surveyed once a week for approximately six months, beginning on June 19, 2019 and ending December 4, 2019. We measured DO from two different sites within the pond (Fig. 1). We measured temperature at 0, .7 and 1.12 m depth at Site 1 (dock) and 0,1,2,3, and 4m using Onset HOBO data loggers. Although the sensors logged temperature at 15-minute intervals, only data from the 12-midnight (00:01 AM) measurement was used in this study. Because of equipment failures, temperature measurements were not consistently taken at all sites. We measured DO at 10 cm depth intervals at the Dock (Site 1 in Fig, 1) and 50 cm intervals at the center of the pond (Site 2 in Fig. 1) using a Milwaukee MW600 DO probe. DO measurements were made at 10:00 AM on the sampling days.

Site Description. Land use in the vicinity of the WNC is urban residential (Zambrana Engineering 2000). The site receives run-off from 154 ha. (381 acres) of urban residential landscape. Water enters the Upper Pond from 2 storm drains (labelled A and C in Fig.1). Inflow A is controlled by a gate valve. Water flows from the Upper Pond into the Lower Pond through a small stream controlled by a stop-log (labelled B in Fig 1). A third storm sewer enters the Lower Pond (labeled D in Fig, 1). Water leaves the site through a drain from the Lower Pond which is also controlled by a second stop-log (labelled E in Fig. 1). Flow leaves the site through 3 check valves draining into Cahokia Creek (off site).

Both Ponds can be considered SWRP's because most of their water input is runoff from local storm sewers. They are extremely eutrophic with high nutrient levels (Sage, 2014). During the summer, aquatic macrophyte growth is dominated by duckweed (*Lemna* spp.) and *Ceratophyllum demersum*. Duckweed covers almost the entire surface of the lakes (Fig. 1). *Ceratophyllum* occupies the entire water column in summer (pers. obs.). The ponds were flooded on April 18, 2013 (pers. obs.) and Dec. 31, 2015 (Kamp 2015) allowing fish to colonize from Cahokia Creek. A large fish kill was reported from the lakes in September, 2015 (Horrell 2015). The ponds freeze over in winter with a few centimeters of ice.

RESULTS

Water Temperature Data. Surface water temperature for site 1 (dock) ranged from 6.5°C on Nov. 14 to 31.2 °C in the open lake on July 21. These were the highest and lowest temperatures recorded during this study. Overall, temperatures gradually declined from July 21 to November for both sites, and all depths (Fig 2).

There is only a small difference in temperatures between the deepest and shallowest samples from the open lake. This result indicates that, unlike a temperate zone dimictic lake (Hutchinson and Löffler 1956), the Upper Pond does not stratify seasonally but it remains nearly isothermal throughout the summer. Cougar Lake (2.5 km from the WNC Ponds) is 13 m deep. Its thermocline begins at 5m depth (Brady and Brugam 2002) suggesting that the WNC Upper Pond is too shallow to stratify.

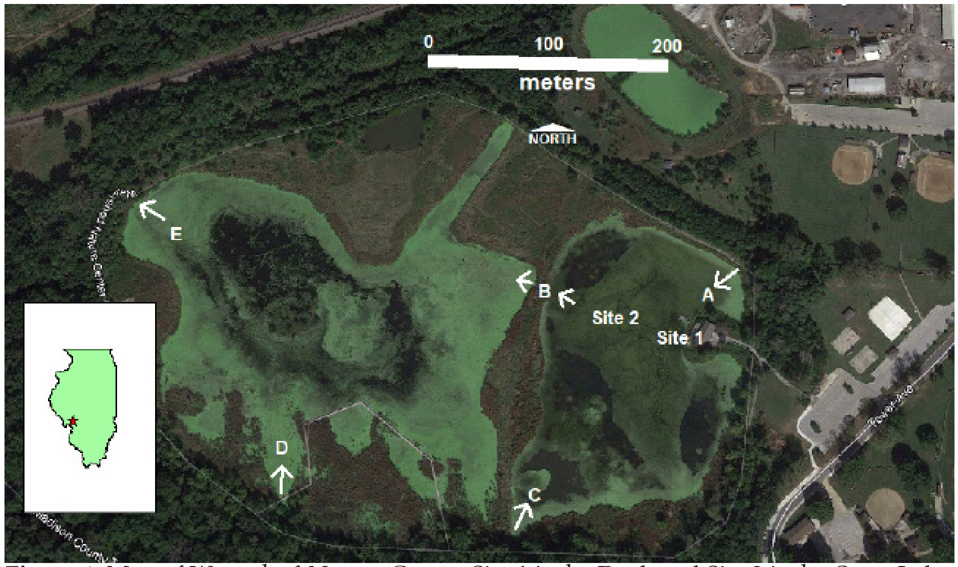

Figure 1. Map of Watershed Nature Center. Site 1 is the Dock and Site 2 is the Open Lake. Letters and arrows indicate direction of water flow. Inset shows the location of the site within the state of Illinois.

Table 1. Explanation of units within the study area, their size and prescribed treatments.

Fish species	24-May-15	18-Jun-18
Largemouth bass (*Micropterus salmoides*)	Very high numbers and great condition. Bass were collected in several size classes with a high percentage of large fish. Many of the bass collected were between 15-22 inches.	Low numbers, mostly smaller fish, 6-12 inches.
Bluegill (*Lepomis macro-chirus*)	Good numbers of sunfish were collected. Several size classes were collected with some reaching 7 inches. The sunfish size quality appeared a little better in the upper pond.	Very high numbers, mostly smaller fish, 1-5 inches.
Common Carp (*Cyprinus carpio*)	Several collected and more seen, mostly large fish.	Very high numbers, all size classes.
Redear sunfish (*Lepomis microlophus*)	Not Collected	High numbers, similar in size to the bluegill.
Black and White Crappie (*Pomoxis nigromaculatus/ annularis*)	Not Collected	Very few, 6-7 inches.
Yellow bullhead (*Ameiurus natalis*)	Not Collected	Only one collected, large adult.
Warmouth (*Lepomis gulosus*)	Not Collected	A few, 4-6 inches.
Bigmouth buffalo (*Ictiobus cyprinellus*)	Not Collected	A few, all adult fish.
Yellow bass (*Morone mississippiensis*)	A few collected from both ponds with most 6-10 inches.	Not Collected
Golden Shiner (*Notemigonus crysoleucas*)	A few collected.	Not Collected
Gizzard Shad (*Dorosoma cepedianum*)	Fairly high numbers collected ranging from 3-12 inches.	Not Collected

Dissolved Oxygen Levels. DO values are presented as contour plots (Figs 3 and 4) which summarize date (x-axis), depth (y-axis) and DO (contours). Lower DO values are indicated by red/orange (indicating hypoxic/anoxic conditions) and higher DO values by blue (indicating normoxic conditions). The vertical distribution of DO in both sites shows > 2.0 mg/l DO was present above the 50 cm depth at the beginning of sampling (Figs 3 and 4). However, by early July, DO had declined below 2 mg/L throughout the water column at both sampling sites with only occasional higher levels near the pond surface during the summer. DO remained low until mid-November (Figs 3 and 4).

DISCUSSION

The Cause of Seasonal Anoxia in the WNC Ponds. Our measurements show that the Upper Pond is hypoxic during summer and early fall (Figs. 3 and 4). There is strong evidence from other studies that floating aquatic plants like those in the Upper Pond cause hypoxia (Vilas et al. 2017a,b). Caraco et al. (2006) see aquatic macrophytes as "Ecosystem Engineers" which control ecological conditions in shallow lakes. They point out that floating-leaved macrophytes release oxygen into the atmosphere but increase organic matter in ponds when they die at the end of the season resulting in an imbalance between gross primary production (GPP) and ecosystem respiration (ER). Frodge et al. (1990) provide a field example of this effect by showing the impact of floating leaved plants on a shallow pond. They compared DO in a lake with only submersed vegetation with one that supported *Brasenia schreberi* -- a floating-leaved plant. Those investigators found hypoxia in the lake with *Brasenia* but in the lake with submersed plants DO rose as high as 30 mg/L. Miranda and Hodges (2000) studied the shallow backwater area of Aliceville Lake on the Tombigbee River and found DO was <1 mg/L in areas with >50% surface coverage by macrophytes. Low DO areas had smaller populations of *Lepomis* spp than locations with less macrophyte growth.

Rackliffe et al. (2021) found that GPP under a canopy of duckweed was less than ER which resulted in anoxia. Sand-Jensen et al. (2019), consistent with Caraco et al. (2006), suggested that the source of organic matter that supports ER in ponds covered with floating macrophytes is organic matter from previous years' growth of macrophytes. Although duckweed is a photosynthetic organism it cannot oxygenate the water column because its stomata are on the upper surfaces of its fronds (Kaul 1976). The oxygen it produces cannot enter the water. Any oxygen produced by duckweed will be lost to the atmosphere. However, the organic matter produced by duckweed remains in the pond. The existence of the duckweed canopy also prevents gas exchange between the water column and the atmosphere preventing re-oxygenation of the water column by diffusion from the atmosphere (Sand-Jensen 2019). As Frodge et al. (1990) found, fully submersed macrophytes exchange gases with the surrounding water providing oxygen to the water column but floating macrophytes prevent oxygenation.

Recent Fish population Changes in the Upper Pond. Fred Cronin, District 16 fisheries biologist from the Illinois Department of Natural Resources (IDNR) led electrofishing surveys on April 24, 2013 (just after the 2013 flood) and June 18, 2018 (3 years after the 2015 flood) at the two WNC ponds to evaluate the fish population. The 2013 data showed that both ponds supported a healthy fish community (Table 1). This community probably represents colonization of the ponds by fishes brought in by the flood. The 2018 survey revealed a decline of largemouth bass and a rise of bluegill, redear and common carp. We suggest that this change in the fish community is a consequence of seasonal hypoxia resulting from the duckweed canopy selecting among the colonizers from the previous flood for species that are tolerant of hypoxia.

Temperature and the Fish Fauna of the WNC Ponds. We examined the literature to determine the tolerance of the target species for the high temperatures and low DO in the WNC Pond.

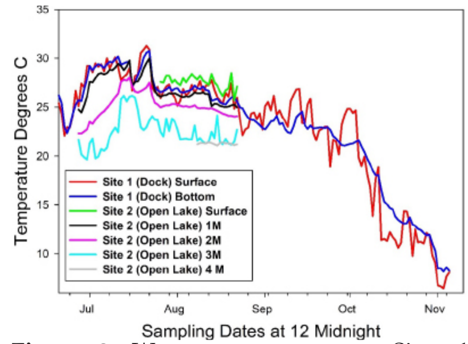

Figure 2. Water temperature at Sites 1 (Dock) and 2 (Open Lake).

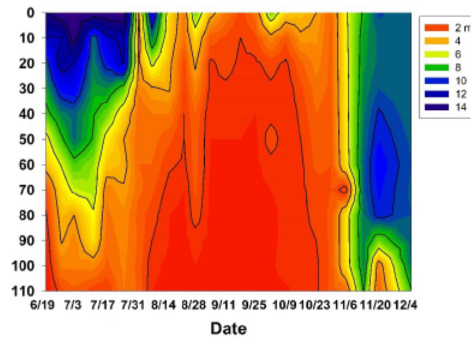

Figure 3. Contour plot of DO levels at different depths and sampling days at Site 1 (Dock).

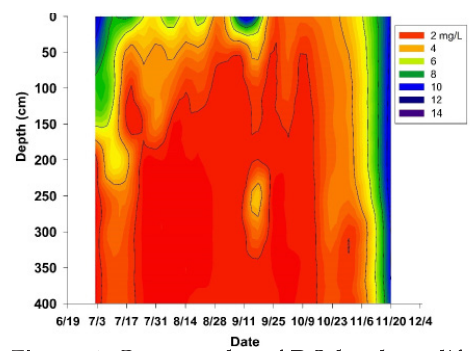

Figure 4. Contour plot of DO levels at different depths and sampling days at Site 2 (Open Lake).

Fish species have differing abilities to survive at high temperatures depending on species and acclimatization (Beitinger et al. 2000). The four target species considered here are very tolerant of warm water. All temperature results are from the literature where fishes were acclimated at 25 to 30°C.

Loss of equilibrium (LOE) was used to measure the critical maximum temperature (CTmax). CTmax for redear is 34.1°C, for bluegill 37.4°C, for bass 38°C (Beitinger et al. 2000), and for carp (ornamental koi) 40.2°C (Yanar et al. 2019). These published tolerances for the target species are higher than any temperature encountered in the Upper Pond indicating that the species should be well able to survive the pond temperatures. The change in the fish fauna of the WNC ponds is unlikely to be a result of high temperatures.

Dissolved Oxygen and the Fish Fauna of the WNC Ponds. Oxygen solubility is strongly dependent on water temperature. At 4° C saturation DO is 12.7 mg/L at 760mm Hg atmospheric pressure and at 30° C saturation is 7.53 at 760mm Hg (Truesdale and Downing 1954). As a result, when water temperature rises, fish are likely to endure more hypoxic stress (Borowiec et al. 2016).

Literature values for DO requirements of the dominant fish species in the Upper Pond can indicate how the populations might respond to the low DO levels. Abdel-Tawwab et al (2019) note that if DO declines below 2 mg/L most fish species experience adverse effects. Such conditions are lethal for some species. However, many fish species have physiological and behavioral responses that reduce the effects of hypoxia (Mandic and Regan 2015). In dimictic lakes, fish are confronted with hypoxic hypolimnetic waters. A DO of 3 and 1.5 mg/L cause bass to reduce prey handling time and avoid the hypoxic depths (French and Wahl 2018). Bass remained outside the hypoxic zone only entering it to forage and quickly leaving. Species also vary in their ability to tolerate long-term hypoxia. Farwell et al (2007) tested pumpkinseed (*Lepomis gibbosus*) and bluegill and found that pumpkinseed are physiologically able to tolerate lower oxygen concentration than bluegill. The investigators noted that this physiological difference may explain why pumpkinseed can survive in northern ponds with winter hypoxia. Their work suggests that tolerance of hypoxia may be important in the distribution of some species. European carp are highly resistant to anoxia (Mandic and Regan 2018). They perform "Aquatic Surface Respiration" under hypoxic conditions allowing them to breathe air directly at the water surface. They are also capable of enlarging their gill area through growth to capture more oxygen during long periods of hypoxia (Dhillon et al. 2013). They can reduce their metabolic rate to survive periods of hypoxia (Mandic and Regan 2018).

Redear sunfish have become an important part of the WNC Pond fish fauna since the second flood. Odum and Caldwell (1955) studied the fish community in a hypoxic spring with a strong gradients in DO. Along the gradient in the spring, redear sunfish lived at a DO of 1.1 mg/L. Killgore and Hoover (2001) studied a shallow Arkansas bayou with a heavy growth of aquatic macrophytes including duckweed and a strong horizontal gradient of DO. These investigators noted the species found at DO concentrations < 1.0 mg/L. These included redear and bluegill sunfish.

Many investigators have investigated the ability of fish species to survive hypoxia using laboratory studies where DO is slowly reduced. In some studies, loss of equilibrium (LOE) was used as an indicator of anoxic distress. The results show that among our target species bass were most susceptible to hypoxia undergoing LOE at .4 mg/L (Crans et al. 2017). Bluegill undergo LOE at .24 mg/L – an intermediate value (Borowiec et al 2016). Carp are most resistant to anoxia with LOE at .02 mg/L (Fu et al. 2016). Unfortunately, there is no laboratory data for redear sunfish although the field data suggest that it is highly tolerant of hypoxia.

These results suggest that bass are most likely to be stressed by the conditions in the Upper Pond and that redear sunfish and European carp are least likely to be stressed. It may be that bass survive in the Pond by spending the summer in the shallowest, most oxygenated water by responding behaviorally to anoxia as they do in dimictic lakes (French and Wahl 2018). Carp and bluegill may also respond behaviorally to survive summer anoxia. Odum and Caldwell's (1955) results suggest that readear sunfish are highly tolerant of hypoxia.

Our review suggests that ponds with extensive surface coverage of duckweed (as at WNC) will likely become hypoxic when the plant is present in high abundance. The duckweed shades the water column reducing photosynthesis by the *Ceratophyllum* that is also present. Duckweed also presents a barrier for oxygen interchange with the atmosphere. The result is low DO and oxygen stress on aquatic organisms favoring fish species like carp and, perhaps redear. The ultimate cause of these conditions are high nutrient levels in the ponds that support the excessive plant growth.

Solutions to hypoxia in the WNC Ponds. The WNC is an important feature in the community and regional ecosystem because it provides numerous natural services for wildlife and the public. SWRP's are becoming more common as urban areas continue to grow and as cities look for ways to handle stormwater runoff (Chen et al. 2019). It is clear that the solution to the problem of excess plant growth in the WNC Ponds is reducing nutrient input. However, this is a difficult problem to solve. The source of the nutrients is likely stormwater run-off. It carries any contaminants deposited on public streets (Weibel et al. 1964, Paul and Meyer 2001, Brezonik and Stadelmann 2002, Hassal 2014). These contaminants can include fallen leaves, lawn fertilizer, yard waste, pet waste, road salt and fallout from air pollution. An additional problem at WNC might be legacy nutrients that still persist from the times when it was a sewage lagoon.

CONCLUSIONS

The Upper Pond at the WNC Nature Center, Edwardsville, IL is highly eutrophic because of the inflow of plant nutrients from urban streets by means of storm sewers. The resulting high nutrient levels support an excess growth of aquatic vegetation supporting extensive growths of duckweed and *Ceratophyllum*. By shading the water column and preventing oxygen exchange with the atmosphere from mid-summer until November the vegetation reduces water column oxygen levels. This hypoxia encourages survival of anoxia-tolerant European carp, redear and bluegill. Solving the problem of hypoxia will require a change in macrophyte cover that reduces Ecosystem Respiration (ER) in the pond water column.

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