Carp Removal to Increase Water Clarity in **Shallow Eutrophic Lake Wingra**

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Introduction

In simplest terms, shallow eutrophic lakes typically have either of two alternative stable states – an algal-turbid state, or a clear-water/aquatic-plant state (Scheffer et al. 1993; Scheffer and van Nes 2007). The first state is characterized by very poor water clarity that restricts the growth of submersed aquatic plants (macrophytes) due to blue-green algal blooms and/or suspended sediments. The clear-water state has relatively good water clarity that allows macrophytes to grow throughout much of the lake. Scientists, managers, and lake users generally consider the latter state as having higher ecological and recreational value.

Shallow lakes can be stuck in the turbid-algal state because the top layer of the lakes' bottom sediments remain unconsolidated due to the feeding activities of dense populations of carp or other bottom-feeding fish (e.g., bullheads). Wind-induced water currents then can easily resuspend these "fluffy" sediments while enhancing nutrient recycling that promotes algae growth. In such lakes, carp populations dominated by large individuals of the long-lived fish can cause the stable state to persist.

When populations of carp and other bottom-feeding fish are significantly reduced through management efforts (or natural die-offs such as winterkill due to low dissolved oxygen levels), the water begins to clear. Increased water clarity allows aquatic macrophytes to grow more luxuriantly and in deeper water, resulting in improved conditions for sight-feeding fish as well as many prey fish species. The macrophytes dampen water current velocities, which in turn cause bottom sediments to consolidate making them even more resistant to resuspension while also reducing nutrient recycling. Water clarity further increases, creating a positive feedback loop that produces even lower water velocities, greater water clarity, and more macrophytes. Thus, this clear-water state is stable as long as carp densities remain low. Studies have shown that intensive feeding on carp eggs and fry by fish such as bluegills greatly reduces carp recruitment (Przemyslaw and Sorensen, 2010). If such fish predation is not present, then carp densities can quickly rebound.

To enhance desirable fisheries, lake managers in Wisconsin and elsewhere have used chemicals for whole-lake carp eradications since at least the 1950s. However, such chemical treatments are not always effective or long-lasting because of the size of the lake or the presence of interconnecting waters where carp can escape eradication. And in urban settings, chemically eradicating fish is not always possible due to public opposition. This article summarizes recent efforts to use large seines to reduce overabundant carp populations in Lake Wingra, a heavily-utilized shallow eutrophic lake located in Madison, Wisconsin.

Lake Wingra

Lake Wingra is a 140-hectare, shallow headwater lake with mean and maximum depths of 2.7 m and 3.8 m, respectively (Figure 1). The lake is fed by urban stormwater runoff and groundwater. Water flows from the lake's outlet over a low head dam (Figure 2) through Wingra Creek to much larger Lake Monona, one of the Yahara River chain of lakes. For years, Lake Wingra has supported mixed recreational opportunities including non-motorized and "no-wake" boating, fishing, and swimming. The typical warmwater fishery of bluegills, crappies, and largemouth bass was enhanced by heavy stocking of non-breeding muskellunge in the early 2000s. The resultant fishery has attracted a loyal following of muskie anglers from southern Wisconsin and beyond.

Soon after carp were introduced to the Yahara lakes in the late 1800s,

Figure 1. Aerial photo of Lake Wingra taken Sept. 22, 2007 showing dense blue-green algal bloom in the lake. Rectangular carp exclosure with clear water is visible along northern shoreline (photo: Emily Sievers, UW-Madison).

Figure 2. Photo taken July 28, 2013 shows low head dam at the outlet of Lake Wingra emptying into Wingra Creek, which flows with little elevation change to Lake Monona, one of the Yahara lakes. On that date, Lake Monona was approximately 1.3 feet higher than its normal summer maximum level, but one foot lower than the level reached in late June 2013 due to excessive precipitation (photo: R. Lathrop).

historical accounts indicate Lake Wingra became turbid with poor water clarity. In the mid-1950s, carp were removed by seining (Neess et al. 1957), but carp apparently repopulated quickly. Along with the establishment and proliferation of the invasive Eurasian watermilfoil (EWM) in the early 1960s, poor water clarity has persisted for many years as documented by a number of University of Wisconsin–Madison (UW) research studies including the North Temperate Lakes Long-Term Ecological Research (NTL-LTER) project since 1996.

Following EWM's invasion, the plant reached extremely dense conditions in the 1970s; in subsequent years EWM has continued to dominate the lake's shallow waters although at somewhat reduced densities. However, a diverse community of submersed native macrophytes has persisted in shallow water along the lake shoreline even though water clarity has been poor. The native plants have likely survived because the lake has had little aquatic macrophyte management (herbicide treatments or mechanical cutting/harvesting) to control EWM because most of the lake's shoreline is natural habitat and in public ownership.

Since 1998, an active citizen's group called the Friends of Lake Wingra (FOLW, http://lakewingra.org/) has been working with local lake managers and scientists to improve the lake's overall ecological health (Lorman and Liebl 2005). One of FOLW's goals has been to increase water clarity and reduce blue-green algae blooms. Toward that end, much effort has focused on implementing watershed management practices for reducing phosphorus and sediment inputs to the lake.

Realizing that water quality improvements in Lake Wingra also required addressing an overabundant carp problem, two studies were initiated in late summer 2005. One study was a carp exclosure experiment to demonstrate the water clarity increase from reduced nutrient recycling and sediment resuspension while also testing the response of EWM and native macrophytes to clear water. The second study used radio-telemetry to determine when and where carp might be vulnerable to targeted removals by large seines. Results from these studies were so encouraging that carp removal by seining was conducted under the ice during March 2008 followed by a minor removal in March 2009 after ice-out. The exclosure demonstration, the telemetry study, the carp removal, and the lake's water clarity and aquatic macrophyte responses in five summer seasons (2008-2012) following reduced carp densities are described below.

Figure 3. Aerial photo of 1-hectare carp exclosure in Lake Wingra taken July 7, 2007 showing clear water inside the exclosure contrasted with blue-green algal bloom in lake water surrounding the exclosure. Difference in growth extent of Eurasian watermilfoil inside and outside the exclosure is visible in the photo. Wave dissipater booms are also visible outside the exclosure walls (photo: Mike DeVries, *The Capital Times*).

Carp Exclosure Demonstration

The carp exclosure was a low risk demonstration project conducted for three years at a scale that allowed lake managers/researchers and especially the general public to evaluate whether a whole-lake restoration project centered on reducing carp densities would be worth pursuing. While recognizing that the exclosure experiment was not a true test of a whole-lake carp removal, the exclosure dampened water currents and stabilized bottom sediments quickly mimicking what would occur in the lake when macrophytes responded to clear water.

The exclosure was installed in the lake during August 2005, but the endwall was not closed until later in September when the carp were removed by electroshocking and seining. The few carp that remained inside the exclosure were later removed by trammel nets with the lack of carp verified by scuba divers.

Exclosure design/construction. The rectangular exclosure had an area of 2.5 acres (1.0 ha) with one endwall being the lake shoreline (Figure 3). The material of the exclosure was 2.5 mil vinyl plastic with a three-year UV exposure life expectancy. The exclosure's floatation collar consisted of ten-foot sections of Styrofoam tubes with a stainless steel tension cable in the wall underneath the collar. The two sidewalls of the exclosure were 340-380 feet in length and the lake endwall was 300 feet. The walls were fabricated to fit the depth profile of the lake with enough extra wall height added for minor fluctuations in lake level. The southwest and southeast exclosure corners had water depths of 2.7 m and 2.5 m, respectively. A ballast chain was fabricated in the bottom of each wall, and a three-foot skirt with an additional ballast chain was added to ensure a tight seal with the bottom sediments. *Environetics, Inc.* (Lockport, Illinois), a company specializing in water baffles and liners for various environmental engineering applications, fabricated the exclosure with design specifications provided by project leaders.

The corners of the exclosure were attached to heavy blocks with pipe driven into the cattail marsh shoreline, and to long heavy-duty galvanized iron pipe pushed deep into the lake's soft bottom sediments with the ends extending above the water line. The lake corners of the exclosure were attached to the pipes, which were connected by long cables to two sets of heavy concrete anchors placed far from each corner in line with the respective walls so that tension on the exclosure walls could be maintained. Side pipes (with outside anchoring) were attached every 50 feet along the three walls to help maintain the exclosure's rectangular shape.

Because the exclosure's walls were subject to strong water currents during periods of high winds, 300-foot long "wave dissipater booms" were installed to absorb some of the water current energy. The booms were constructed of 8 oz. Polypropylene Geotextile fabric with a Styrofoam boom collar, tension cable, and an 18-inch hanging curtain weighted with a ballast chain. Heavy anchors and cabling stretched each boom in a direction parallel to each exclosure wall with a separation of about 25 feet (Figure 3). Cement blocks were also attached along the length of each boom wall for further anchoring.

Exclosure experiment results. Water clarity increased rapidly once the exclosure was installed (Lorman and Liebl 2005), but the contrast between the lake and the exclosure was most dramatic during summer when blue-green algae growth was most abundant (Figures 1, 3). As expected, the density and depth distribution of aquatic macrophytes increased in response to the much clearer water, but most of the increased growth was due to EWM, which had completely colonized the exclosure by summer 2008 before the exclosure was removed in September. Native plants expanded their depth distribution slightly after 3 years of clear water and no carp browsing because dispersal rates are much slower for most native submersed macrophytes compared to EWM. However, in spite of the prospect of increased EWM growth, the exclosure's demonstration of how much clearer the lake water could become galvanized public support for removing carp even as early as August 2006 when one of Madison's local newspapers published a front-page article along with an aerial photo of the exclosure (similar to Figure 3).

Figure 4. Wisconsin DNR fish manager Kurt Welke implanting radio transmitters in anesthetized carp captured from Lake Wingra, September 2005 (photo: R. Lathrop).

Carp Radio-Telemetry Study

The carp radio-tracking study in Lake Wingra was initiated in the fall of 2005 because muskie anglers at an earlier public meeting had expressed their strong opposition to a whole-lake carp eradication with rotenone (a plant derivative used for fishing by indigenous Indians in Brazil) for fear that Lake Wingra's high density of stocked muskies would be harmed. From that public meeting it was obvious that a whole-lake carp eradication was not going to be possible; carp would have to be removed by other means such as commercial fishers using large seines. Thus, funding to partially support the tracking study was obtained from a local fishing organization (Madison Fishing Expo). After Wis. Dept. Natural Resources' fish managers implanted radio-transmitters in 14 carp captured from the lake (Figure 4), UW scientists regularly tracked the location of the tagged fish for two years (fall 2005 through summer 2007) until the transmitter batteries died (Figure 5).

Figure 5. Research staff from UW Center for Limnology recording locations of 14 radio-tagged carp in Lake Wingra (photo: UW Center for Limnology).

Results of the tracking study indicated that carp spent most of the open water season in relatively shallow water around the perimeter of the lake with many carp exhibiting fidelity to the same location. One important finding, however, was that in mid-November immediately prior to the lake freezing over, carp congregated in the center region of the lake in water depths generally >3.0 m where they remained during most of the winter. This provided an opportunity for winter commercial seining to reduce carp densities.

Carp Removal

During 2007, arrangements were made between project personnel and a commercial fisher to remove carp from the lake using long large-mesh seines deployed under the ice, a practice regularly used for fishing carp on other Wisconsin lakes. A subsidy was paid to the commercial contractor because the amount of fishing effort was significant for relatively small Lake Wingra where the profit from selling captured carp (and big mouth buffalo) was not enough incentive for doing the work. While the ideal time would have been earlier in the winter to seine carp based on the tracking study results, the lake was fished in mid-March 2008 shortly before the ice became unsafe.

That year 23,600 kg of carp were removed (Figure 6) while captured game fish were quickly returned to the lake by fish managers overseeing the seining. Captured carp and buffalo were shipped live via truck to eastern markets. A second carp removal arranged for March 2009 after ice-out netted only 1,500 kg more carp, although some carp may have been lost due to the net getting snagged while being pulled to shore. Together, the two seining efforts removed 6,722 adult-sized carp.

Observations of carp in the lake during subsequent summers indicated that carp densities were not abundant, and a 2009 winter survey of the lake using side-scanning sonar failed to identify significant numbers of carp. Carp recruitment has also been minimal as almost no small carp were captured during regular NTL-LTER fish samplings conducted during August 2008-2012. Following the 2008 carp removal, the dam was rebuilt in 2009 with a spillway design making it more difficult for carp to migrate into Wingra.

Nonetheless, high water in downstream Lake Monona during an intense period of rainfall in June 2013 allowed carp to move across the flooded dam and into Lake Wingra. At the time of this writing, it is too soon to tell whether enough migrants entered the lake to cause the lake to return to an algal-turbid state.

Figure 6. Commercial fishers removing carp captured by seining under the ice in Lake Wingra during mid-March 2008 (photo: D. Liebl).

Figure 7. Photo of Lake Wingra's popular Vilas Beach taken July 29, 2011 showing good water clarity (photo: R. Lathrop).

Water Clarity Responses to Carp Reduction

Water clarity in Lake Wingra increased soon after the March 2008 carp removal, which has resulted in noticeable improvements in water quality at the popular Vilas Beach (Figure 7). Informal interviews with life guards each summer indicated the beach has been one of the "nicest places to swim" in Madison since the carp removal, although beach closures still occurred periodically due to fecal coliform contamination due to goose droppings washed in during rainstorms. Since the carp removal, no summer beach closures due to excessive algae have occurred.

This increase in water clarity is well documented in NTL-LTER's Secchi disc record where recent readings have been consistently greater than the average seasonal readings for the 12 years (1996-2007) prior to the carp removal (Figure 8). In fact, many seasonal readings during 2008-2012 have been greater than the maximum seasonal readings observed during the pre-carp removal years, a condition that is particularly pronounced in the summer months when blue-green algal blooms have been historically dense.

Because of the improved summer water clarity, total phosphorus (TP) concentrations (reflective of blue-green algae and suspended sediment

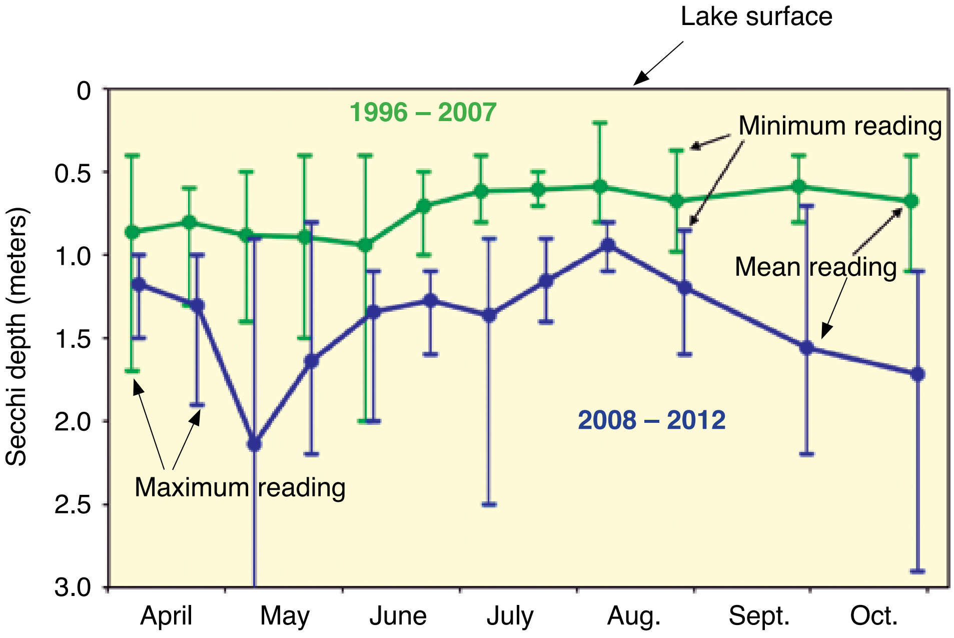

Figure 8. Secchi disc graph showing seasonal mean, maximum and minimum readings for 12 years (1996-2007) prior to the March 2008 carp removal (green line) and seasonal Secchi readings for 5 years (2008-2012) following carp removal (blue line). (Data source: UW Center for Limnology).

concentrations) in the lake's surface waters have also correspondingly responded. The median TP concentration for July-August 1996-2007 prior to the carp removal was 0.056 mg/L; median TP for July-August 2008-2012 was 0.033 mg/L.

Aquatic Macrophyte Response

Similar to the carp exclosure experiment, submersed aquatic macrophytes quickly began increasing their depth distribution in Lake Wingra with Eurasian watermilfoil (EWM) being the "first horse out of the gate," expanding into deeper lake regions where no plants grew before the 2008 carp removal (generally >1.8 m). Coontail, a native macrophyte that sometimes reaches nuisance levels in lakes, also expanded its depth distribution although not in densities as great as EWM. This expansion of EWM (and coontail) happened progressively during the growing seasons of 2008-2011 such that by 2012, most of the lake was filled with dense aquatic macrophytes (Figures 9-10). This caused some lake users to complain about the lack of boating opportunities (e.g., sailboating, motorized fish trawling), while other lake users appreciated viewing fish in the underwater "garden" while kayaking and canoeing. The EWM expansion motivated the county to conduct a public hearing on aquatic plant harvesting, with the outcome being that throughout much of the summer of 2012 the county harvesters tried to keep shore areas with fishing access free of milfoil as well as lanes for fishing from a boat (Figure 9).

Meanwhile native aquatic macrophytes (excluding coontail) have slowly increased their distribution throughout the lake (Figure 11). In many cases, the patches of native plants were occurring in locations where EWM no longer dominates. For the most part, the native plants have not posed a user access problem, and likewise are considered optimum habitat for fish.

Summary

Lake Wingra's water clarity increased rapidly and dramatically following the carp removal in March 2008 when a commercial fisher seined under the ice – a

Figure 9. Aerial photo of Lake Wingra taken July 7, 2012 showing harvester's cutting tracks through dense aquatic macrophytes (mostly Eurasian watermilfoil) growing over much of the surface area of Lake Wingra (Photo: Mike Kakuska).

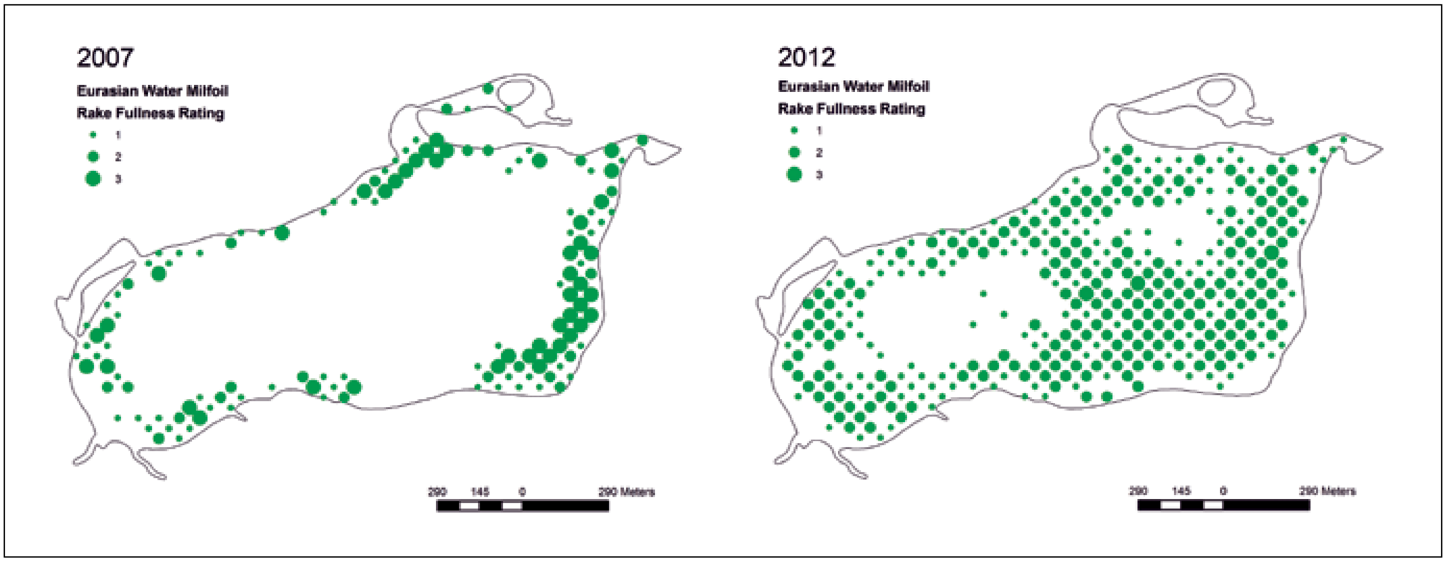

Figure 10. Distribution maps for Eurasian watermilfoil (EWM) in Lake Wingra for late summer 2007 and 2012 showing the spread of EWM after five growing seasons following the March 2008 carp removal. The density of EWM is indicated by rake fullness ratings from 1 to 3. The maps were created from rake surveys at grid points established every 50 m across the lake surface. (Map preparation: Martha Barton, WDNR)

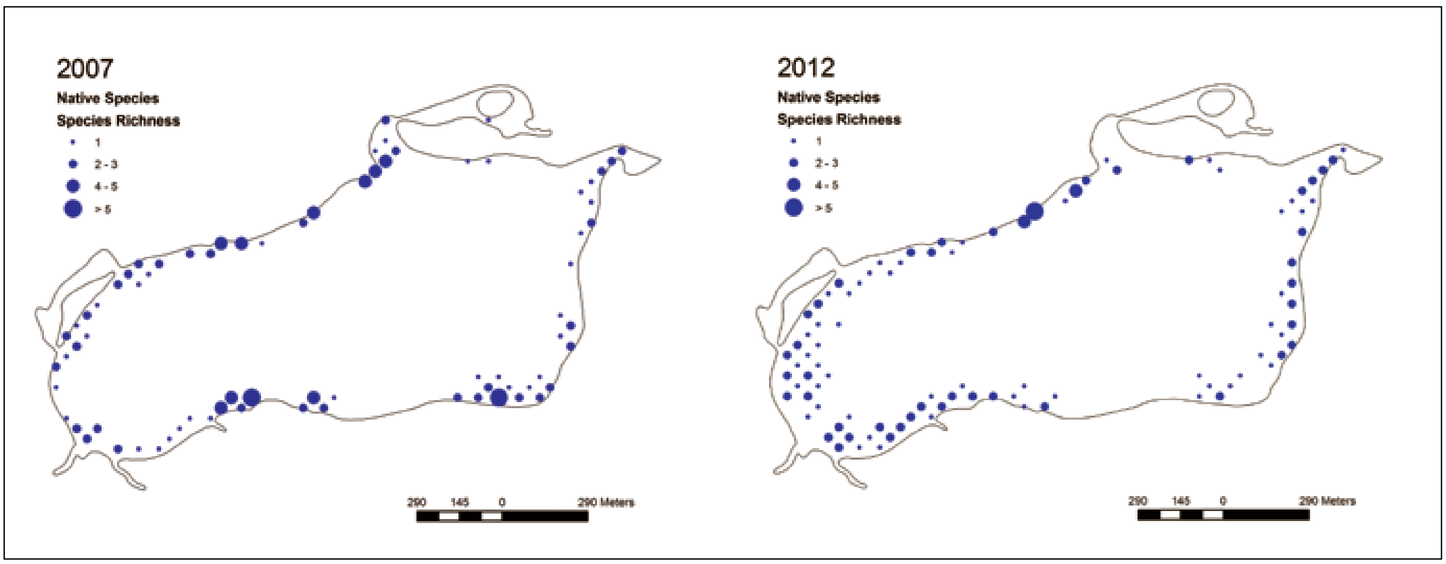

Figure 11. Species richness maps for native aquatic macrophytes (excluding coontail) in Lake Wingra for late summer 2007 and 2012 showing the location of native plant species after five growing seasons following the March 2008 carp removal. The maps were created from rake surveys at grid points established every 50 m across the lake surface. (Map preparation: Martha Barton, WDNR)

time that a radio-telemetry study indicated carp congregate in the deeper lake regions. This removal was not a whole-lake fish eradication, suggesting that carp densities need only be maintained at relatively low levels to keep the lake in its clear-water/aquatic-plant state rather than in its turbid-algal state typical of when carp densities were high. At least through 2012, carp populations have not rebounded in Lake Wingra since the seining, which suggests bluegills (known for their voracious appetite for carp eggs) may be suppressing carp recruitment as almost no small carp have been captured in August fish surveys.

Since the carp removal, Lake Wingra's aquatic macrophyte community has been in transition as the shallow lake has moved from the algal-turbid stable state to the clear-water/aquatic-plant state. During the summer of 2012, Eurasian watermilfoil became particularly dense throughout much of the deeper regions of the lake where aquatic macrophytes have not grown for almost a century (even before the early 1960s invasion of EWM). This EWM response required an aggressive aquatic plant harvesting effort to maintain areas open for fishing and boating.

Project leaders and other interested parties are hopeful that with time the native aquatic macrophytes will expand their depth coverage throughout the whole lake while EWM becomes less abundant. This will undoubtedly require aquatic plant harvesting to prevent EWM from forming a dense canopy at the lake surface that would otherwise prevent the expansion of native macrophytes in deeper water due to shading.

In conclusion, this project illustrates the complexities associated with managing shallow eutrophic lakes, and the tradeoffs associated with various management actions. While the algal-turbid state was undesirable for users, the clear-water/aquatic-plant state with the expansion of EWM has also incurred challenges for recreation. If EWM continues to grow densely throughout much of the lake in future years, then a discussion should occur about the trade-offs associated with how the lake is managed.

Conceivably, with continued recreational boating problems, the carp removal could be considered a "failed experiment" and the lake returned to an algal-turbid state by allowing the carp population to rebound. However, the public's desire to have waist-deep water clear enough to see their toes as well as have reduced exposure risk to blue-green algae toxins at the lake's popular swimming beach may dictate the clear-water/aquatic-plant state is worth "staying the course." If that is the case and enough carp find their way into Lake Wingra when its dam is periodically inundated during periods of flooding from heavy rains as occurred in June 2013, then another carp removal might be needed to maintain clear water in the lake.

Acknowledgments

We are thankful to the many unrecognized people who helped with the 2005 installation and subsequent maintenance of the carp exclosure in Lake Wingra. In that regard, special thanks are extended to Kelsy Anderson Frederico for her tireless efforts with the exclosure's installation effort. We also thank the many people who assisted with limnological sampling and aquatic macrophyte surveys.

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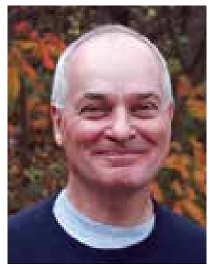

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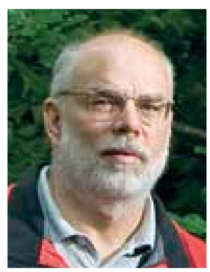

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