ROB SUMMERFIELD
STATE REPRESENTATIVE • 67th ASSEMBLY DISTRICT

January 30, 2020

Representative Kitchens, Chair
Representative Oldenburg, Vice-Chair
Members of the Assembly Committee on Environment

Testimony on 2019 Assembly Bill 798

Relating to: biomanipulation projects to improve the water quality of lakes and impoundments and making an appropriation

Dear Chairman Kitchens, Vice-Chairman Oldenburg, and Committee Members:

Thank you for providing me with the opportunity to testify at today's public hearing on Assembly Bill 798.

Biomanipulation is the deliberate altering of an ecosystem by humans through adding or removing species; chiefly prey. This can cause a shift in predator/prey populations of an area which has an effect on the entire food chain and ecosystem.

Many of the impaired lakes and impoundments in Wisconsin have an excess amount of phosphorus and other nitrates. Bottom-feeding fish (ex: carp), and phytoplankton thrive in these conditions and create harmful algal blooms (HABs). Sedentary bodies of water rarely have their ecosystems change organically; thus, even if/when outside phosphorus/nitrate sources are reduced or eliminated, there can still remain a vicious cycle of ever-increasing bottom-feeding fish and phytoplankton populations.

In these situations, however, biomanipulation can be used as an ecological tool for water quality management when larger amounts of predatory game fish (ex: bass, pike) that feast on bottom-feeding fish are introduced into the lake or impoundment. As bottom-feeding fish decrease, rooted vegetation, beneficial zooplankton, and water clarity and quality increase.

This process has been successfully implemented before; such as with Lake Finjasjon in Sweden, Lake Vesijärvi in Finland, Big Wall Lake in Iowa, and Wingra Lake right here in Madison.

Ab 798 creates a one-time, $150,000 competitive grant application process to fund water quality improvement projects using biomanipulation on impaired lakes and impoundments across Wisconsin. This type of eco-science has the potential to transform how our state addresses water quality issues moving forward, so I thank you again for your time and careful consideration of this impactful legislation.

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From: **Senator Kathy Bernier**

To: **The Assembly Committee on Environment**

Re: **Testimony on Assembly Bill 798**

Relating to: biomanipulation projects to improve the water quality of lakes and impoundments and making an appropriation

Date: **January 30, 2020**

Chairman Kitchens and members of the committee, thank you for hearing Assembly Bill 798 today. This bill came out of the Speaker's Task Force on Water Quality and is one of many tools that we would hope to give the people of Wisconsin when addressing water quality issues in our many waterways.

Assembly Bill 798 would create a grant program for the DNR to administer that would fund biolmanipulation projects in the state. Biomanipulation is the process of introducing or removing species in the lake's ecosystem in order to reduce algae blooms and other hazards that are harmful to water quality. The DNR is already able to do these projects under current law, this bill would just provide the Department with resources to help lake groups that want to use this method as a means of cleaning up their lake.

Everyone understands that biomanipulation is not the answer to water quality. If the source of the water quality issue is not addressed, biomanipulation will not solve the problem for very long. Biomanipulation is the last step in a process to clean up lakes and other waterways, but, it is an important and useful tool in that process. The more we can find out about it and its effectiveness, the more lakes can be rehabilitated.

For a relatively small investment, we can see what sort of results we can achieve using this scientific method to help lakes get healthy. I hope you will join me and Representative Summerfield in supporting AB 798 and ensuring that everyone has access to clean, healthy water in Wisconsin.

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WISCONSIN
DEPT. OF NATURAL RESOURCES

Assembly Committee on Environment

2019 Assembly Bill 798

Biomanipulation projects to improve the water quality of lakes and impoundments and making an appropriation

January 30, 2020

Good morning Chairman Kitchens and members of the Committee. My name is Meredith Penthorn, and I am the Fisheries Management policy specialist with the Wisconsin Department of Natural Resources. I am joined by Todd Kalish, Fisheries Management Deputy Bureau Director. Thank you for the opportunity to testify, for informational purposes, on Assembly Bill 798 (AB 798) relating to biomanipulation projects to improve the water quality of lakes and impoundments and making an appropriation.

This bill would provide an additional funding source for biomanipulation studies and activities with the overarching goal of improving water quality for lakes and impoundments on the impaired waters list. While the Department of Natural Resources periodically conducts biomanipulation projects for various purposes, including enhancing sport fisheries and rehabilitating aquatic ecosystems, this bill would create a new appropriation to assist local water improvement groups in conducting similar projects specifically for improving water quality under the oversight of the Department.

The new appropriation could benefit waters of the state by allowing more work to be conducted on certain impaired waters that the Department alone cannot accomplish with current funding or staffing levels. This would also allow local water improvement groups to assume a greater role in management of the waters in their communities. However, the Department cautions that biomanipulation may not be efficient or effective at improving water quality on waters with excessive nutrient or pollutant inputs, without concurrent reduction of those inputs. Biomanipulation may also be less successful on shallow waterbodies connected to flowing waters due to an increased risk of recolonization by detrimental fish species. In addition, anoxic conditions could limit the success of fish introductions aimed to control undesirable fish species.

Some biomanipulation projects, namely those involving the removal or addition of fish, could impact angler activity on the water. This could lead to a perception of user conflict if anglers feel excluded from any plans to remove fish by methods other than fishing, especially game fish that are considered to be detrimental in the waterbody, or if angler harvest pressure on stocked piscivorous fish is high. Outreach and education to anglers in the vicinity of the waterbody could help reduce any concerns and increase public buy-in.

The DNR estimates that the proposed one-time appropriation of $150,000 would fund biomanipulation projects on one to two waterbodies during the biennium. To ensure that the projects are feasible for meeting the goal of improved water quality, the Department could utilize an existing surface water grants program to administer these grants, which would draw from a pool of eligible applicants and would require a formal plan to be submitted with the application materials. Grants could also be solicited and awarded for surveys, studies, and developing plans for biomanipulation projects. The Department could publish an announcement soliciting applications for biomanipulation projects, including the screening process and procedures for monitoring grant activities specific to these grants, in its annual grant application guidance. These processes would entail collaboration between the Bureaus of Fisheries Management, Watershed Management, Office of Applied Science and potentially other DNR programs. Costs associated with implementing this bill would include staff time to create the needed guidance, review applications, process grants, and oversee grant project activities.

Finally, this bill states that activities allowed under the appropriation shall include comprehensive fish studies, removal of zooplanktivorous and benthivorous fish, and the introduction of piscivorous fish. Requiring all activities for each project would substantially limit the number of eligible grant applications. The DNR appreciates the bill authors' demonstrated willingness to explore potential options for allowing a combination of those activities and other types of ecological activities that may achieve water quality goals, such as water level management.

On behalf of the Bureau of Fisheries Management, I would like to thank you for your time today. We would be happy to answer any questions you may have.

Center for Limnology
University of Wisconsin–Madison

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

January 28, 2020

Subject: Public hearing testimony on SB 725 and AB 798 in support of "Biomanipulation" lake management grants administered by DNR

Dear Senate and Assembly committee members:

My name is Richard Lathrop. I earned a PhD in Oceanography and Limnology from UW-Madison in 1998 and a M.S. in Natural Resources (Aquatic Ecology) at the Univ. of Michigan in 1975. I was a Research Limnologist for the Wis. DNR for 33 years until retiring in 2010. In that capacity I have studied and implemented techniques to improve lake water quality in nutrient-rich lakes including the Madison area lakes and Devil's Lake. For the past 21 years, I have also held an Honorary Fellow position at UW's Center for Limnology where I continue to collaborate on many research projects including the UW's North-Temperate Lakes Long-Term Ecological Research Project funded by NSF. Specific to the issues of this public hearing, I am very knowledgeable about "biomanipulation" – the manipulation of a lake's biota – to achieve improvements in lake water quality and/or overall ecosystem health.

I was a co-investigator on the DNR's and UW's collaborative Lake Mendota biomanipulation project from its inception in 1987, and I was the lead author of the project's peer-reviewed synthesis paper published in 2002. This project focused on increasing the lake's predator (piscivorous) fish population densities (i.e., walleye and northern pike) via stocking and harvest regulations in order to reduce the density of smaller zooplankton-eating (planktivorous) fish so that increased densities of large-bodied water fleas (*Daphnia*) would be able to reduce by grazing the free-floating algae (phytoplankton) in the open water area of the lake. The goal was to increase water clarity and reduce blue-green algae in the lake, which occurred in Lake Mendota. This type of biomanipulation project is considered a "top-down" approach to lake management via alternations in a lake's food web. Reviews of the technique indicate it has been most successfully applied to moderately fertile lakes.

I was also the lead DNR-UW researcher who spearheaded the biomanipulation of Lake Wingra by drastically reducing its overabundant bottom-feeding (benthivorous) carp population comprised of large long-lived individuals. In partnership with DNR fish management and the Friends of Lake Wingra, commercial seining of carp in 2008 caused the lake to completely switch from a turbid algal state with very poor water clarity and dense blue-green algae to a state of clear water that allowed sunlight penetration for aquatic plants to grow. This project was summarized in an article I published with co-authors in 2013 and has been a springboard for other such carp removal projects throughout Wisconsin. Such biomanipulations of shallow lakes have been widely conducted not only in the U.S., but throughout Europe and elsewhere.

In summary, I whole-heartedly support the Legislature providing $150,000 to the DNR for biomanipulation grants to improve lake water quality.

Sincerely,

Richard C. Lathrop

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Carp Removal to Increase Water Clarity in Shallow Eutrophic Lake Wingra

Richard C. Lathrop, David S. Liebl, and Kurt Welke

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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,

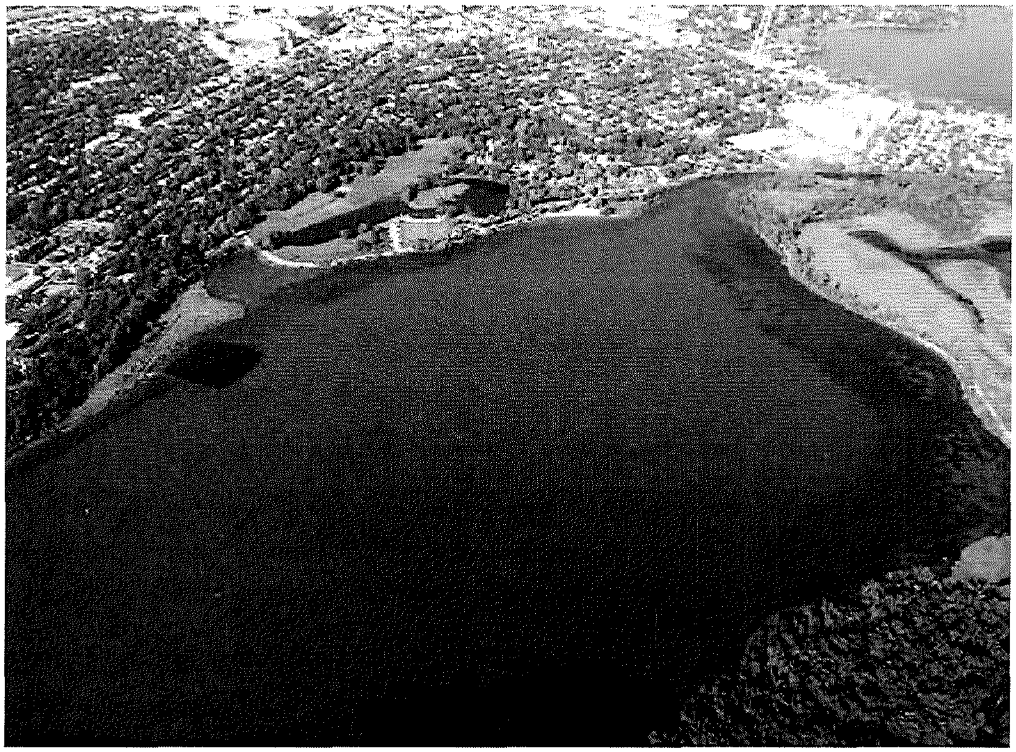

Figure 1. Aerial photo of Lake Wingra taken Sept. 22, 2007 showing dense blue-green algal bloom in the lake. Rectangular carp exclosure with clear water is visible along northern shoreline (photo: Emily Sievers, UW-Madison).

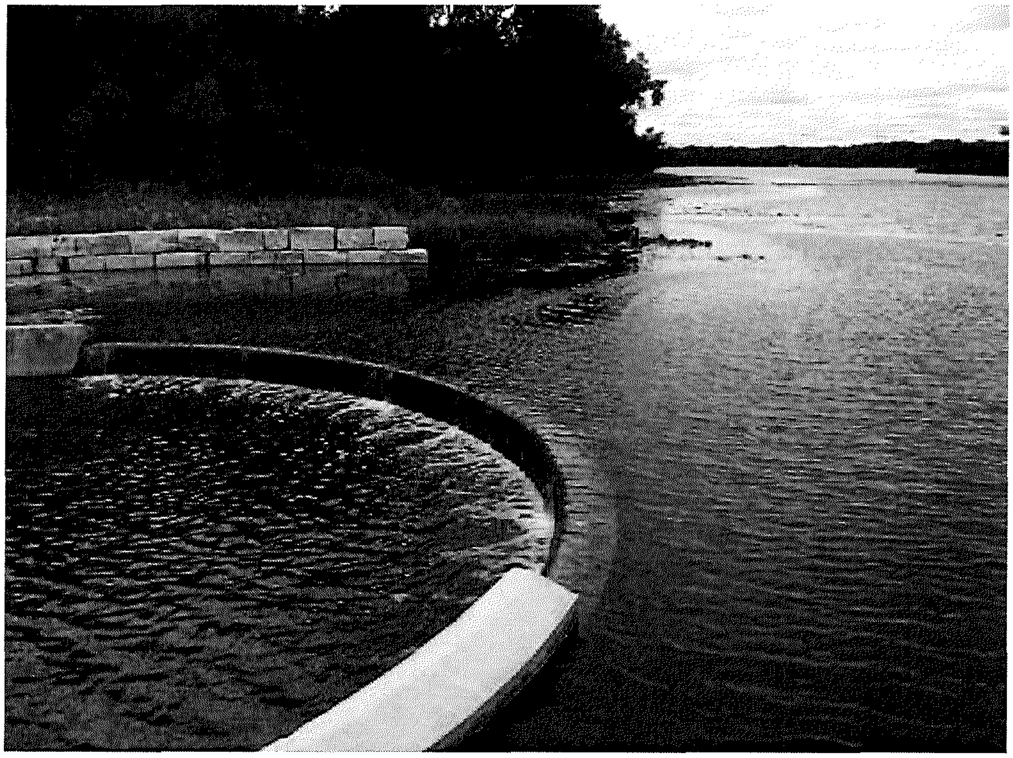

Figure 2. Photo taken July 28, 2013 shows low head dam at the outlet of Lake Wingra emptying into Wingra Creek, which flows with little elevation change to Lake Monona, one of the Yahara lakes. On that date, Lake Monona was approximately 1.3 feet higher than its normal summer maximum level, but one foot 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.

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.

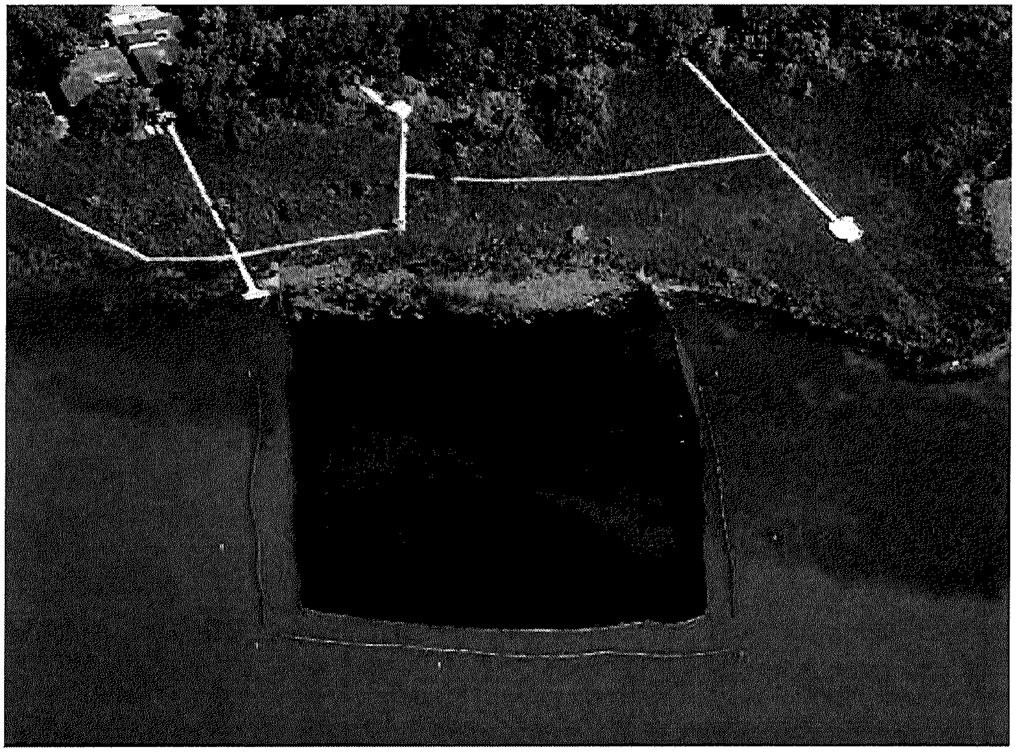

Figure 3. Aerial photo of 1-hectare carp exclosure in Lake Wingra taken July 7, 2007 showing clear water inside the exclosure contrasted with blue-green algal bloom in lake water surrounding the exclosure. Difference in growth extent of Eurasian watermilfoil inside and outside the exclosure is visible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

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).

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).

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.

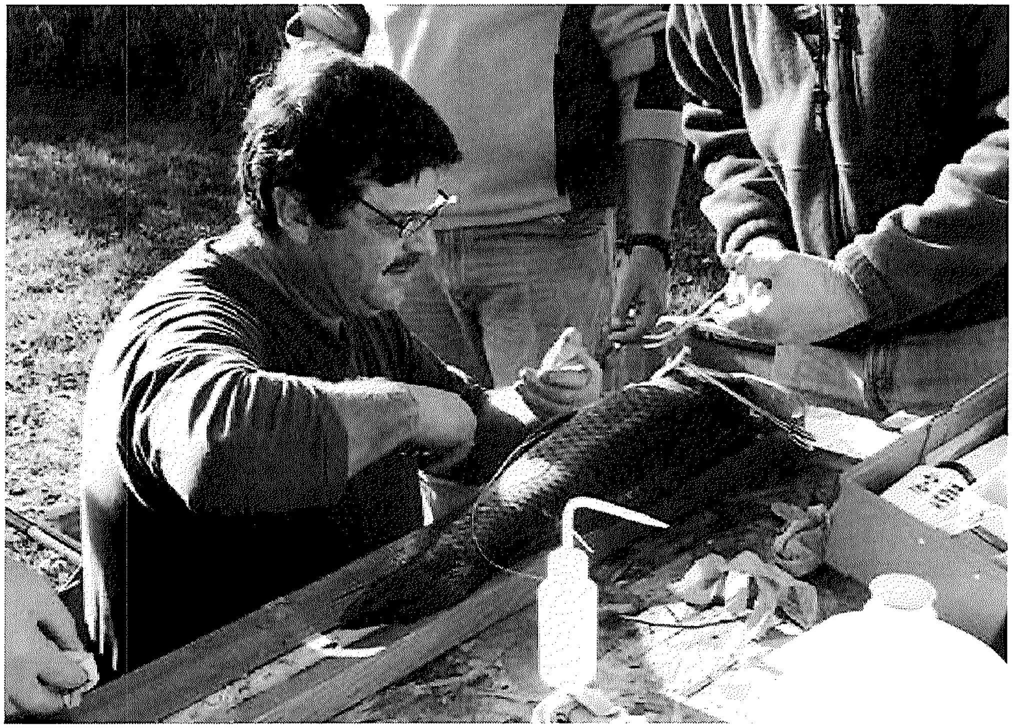

Figure 4. Wisconsin DNR fish manager Kurt Welke implanting radio transmitters in anesthetized carp captured from Lake Wingra, September 2005 (photo: R. Lathrop).

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

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.

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.

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).

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

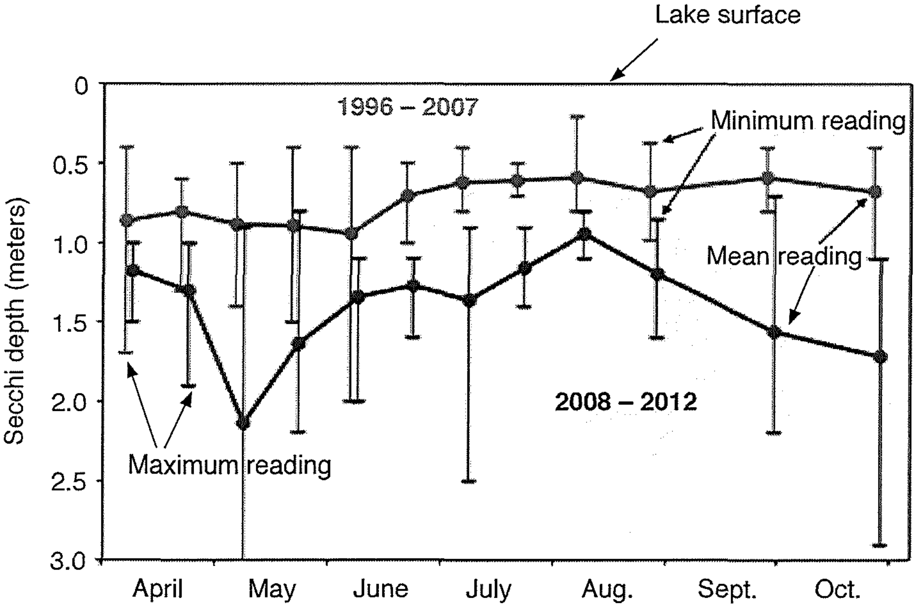

Figure 8. Secchi disc graph showing seasonal mean, maximum and minimum readings for 12 years (1996-2007) prior to the March 2008 carp removal (green line) and seasonal Secchi readings for 5 years (2008-2012) following carp removal (blue line). (Data source: UW Center for Limnology).

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).

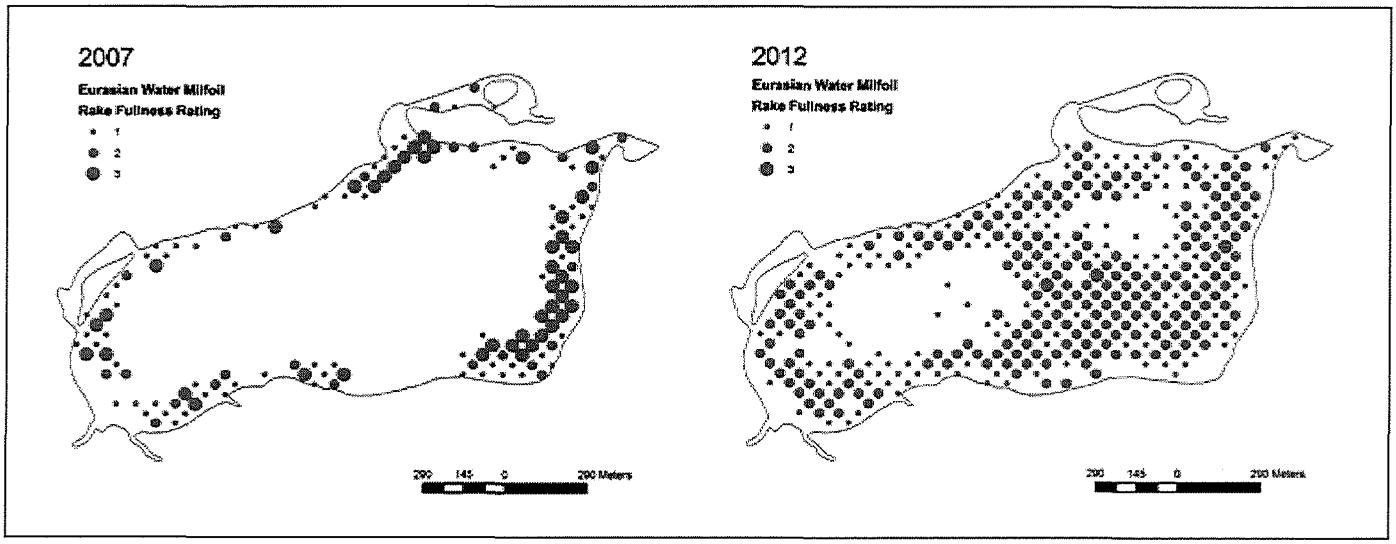

Figure 10. Distribution maps for Eurasian watermilfoil (EWM) in Lake Wingra for late summer 2007 and 2012 showing the spread of EWM after five growing seasons following the March 2008 carp removal. The density of EWM is indicated by rake fullness ratings from 1 to 3. The maps were created from rake surveys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

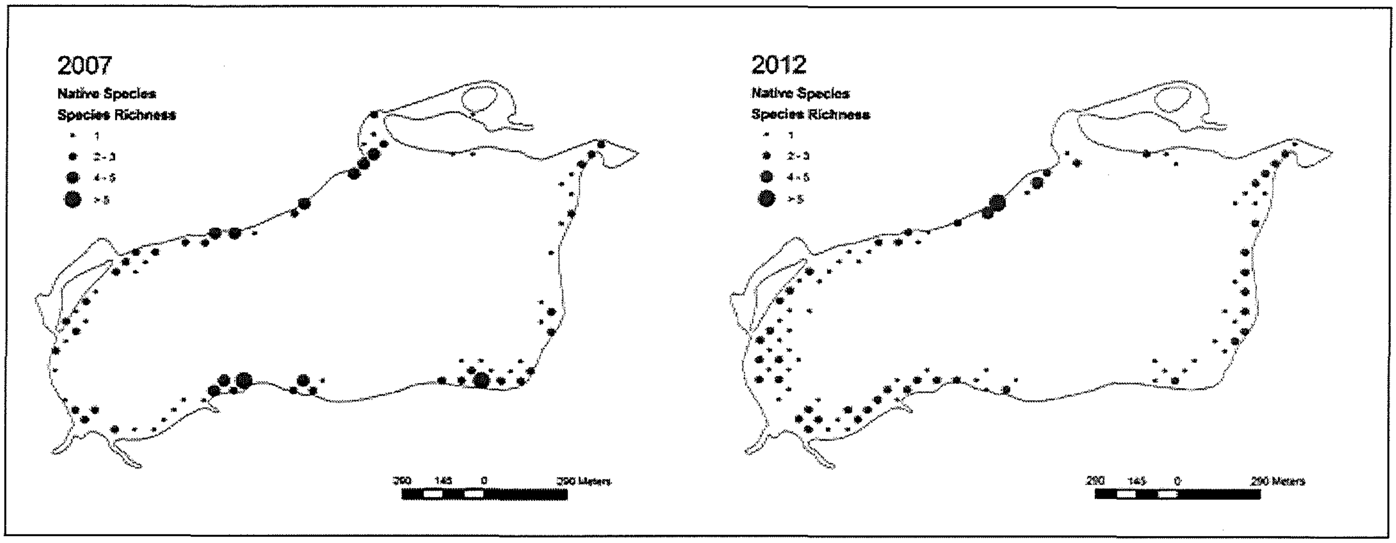

Figure 11. Species richness maps for native aquatic macrophytes (excluding coontail) in Lake Wingra for late summer 2007 and 2012 showing the location of native plant species after five growing seasons following the March 2008 carp removal. The maps were created from rake surveys at grid points established 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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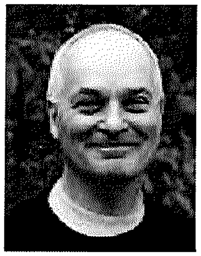

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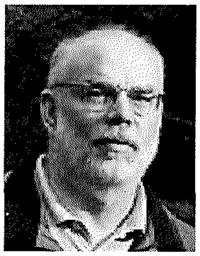

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Stocking piscivores to improve fishing and water clarity: a synthesis of the Lake Mendota biomanipulation project

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SUMMARY

1. A total of 2.7×10^6 walleye fingerlings and 1.7×10^5 northern pike fingerlings were stocked during 1987–99 in eutrophic Lake Mendota. The objectives of the biomanipulation were to improve sport fishing and to increase piscivory to levels that would reduce planktivore biomass, increase *Daphnia* grazing and ultimately reduce algal densities in the lake. The combined biomass of the two piscivore species in the lake increased rapidly from < 1 kg ha^{-1} and stabilised at 4–6 kg ha^{-1} throughout the evaluation period.
2. Restrictive harvest regulations (i.e. increase in minimum size limit and reduction in bag limit) were implemented in 1988 to protect the stocked piscivores. Further restrictions were added in 1991 and 1996 for walleye and northern pike, respectively. These restrictions were essential because fishing pressure on both species (especially walleye) increased dramatically during biomanipulation.
3. Commencing in 1987 with a massive natural die-off of cisco and declining yellow perch populations, total planktivore biomass dropped from about 300–600 kg ha^{-1} prior to the die-off and the fish stocking, to about 20–40 kg ha^{-1} in subsequent years. These low planktivore biomasses lasted until a resurgence in the perch population in 1999.
4. During the period prior to biomanipulation when cisco were very abundant, the dominant *Daphnia* species was the smaller-bodied *D. galeata mendotae*, which usually reached a biomass maximum in June and then crashed shortly thereafter. Beginning in 1988, the larger-bodied *D. pulicaria* dominated, with relatively high biomasses occurring earlier in the spring and lasting well past mid-summer of many years.
5. In many years dominated by *D. pulicaria*, Secchi disc readings were greater during the spring and summer months when compared with years dominated by *D. galeata mendotae*. During the biomanipulation evaluation period, phosphorus (P) levels also changed dramatically thus complicating our analysis. Earlier research on Lake Mendota had shown that *Daphnia* grazing increased summer Secchi disc readings, but P concentrations linked to agricultural and urban runoff and to climate-controlled internal mixing processes were also important factors affecting summer readings.
6. The Lake Mendota biomanipulation project has been a success given that high densities of the large-bodied *D. pulicaria* have continued to dominate for over a decade, and the

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diversity of fishing opportunities have improved for walleye, northern pike and, more recently, yellow perch.

7. Massive stocking coupled with very restrictive fishing regulations produced moderate increases in piscivore densities. Larger increases could be realised by more drastic restrictions on sport fishing, but these regulations would be very controversial to anglers.
8. If the lake's food web remains in a favourable biomanipulation state (i.e. high herbivory), further improvements in water clarity are possible with future reductions in P loadings from a recently initiated non-point pollution abatement programme in the lake's drainage basin.

Keywords: biomanipulation, *Daphnia* grazing, Lake Mendota, piscivore stocking, trophic cascade

Introduction

Shapiro, Lamarra & Lynch (1975) first proposed 'biomanipulation' as a lake restoration technique where fish populations would be manipulated to produce reductions in algal densities. In the strictest sense, we refer to the technique where smaller planktivorous fish are reduced directly (e.g. by seining) or indirectly by increasing the density and biomass of piscivorous fish, the effect of which then cascades to lower trophic levels allowing more herbivorous *Daphnia* to graze on algae. This technique incorporates the earlier discoveries of Hrbáček *et al.* (1961), Brooks & Dodson (1965) and others, and has since been extensively evaluated both experimentally and theoretically (Carpenter, Kitchell & Hodgson, 1985; McQueen, Post & Mills, 1986; Benndorf, 1990; Reynolds, 1994; Hansson *et al.*, 1998; Meijer *et al.*, 1999; Carpenter *et al.*, 2001; Benndorf *et al.*, 2002; Mehner *et al.*, 2002). Special symposia have been convened to synthesise experiences for a variety of lake systems (Gulati *et al.*, 1990; Kasprzak *et al.*, 2002) and guidelines have been written that review the technique (e.g. Cooke *et al.*, 1993; de Bernardi & Giussani, 1995). However, a majority of the biomanipulation projects reported to date have been conducted in shallow unstratified lakes where major short-term successes have been achieved if nutrient levels are not excessive (Benndorf, 1990; Jeppesen *et al.*, 1990; Gulati, 1995; Meijer *et al.*, 1999).

In this paper, we report the results of a long-term biomanipulation project on Lake Mendota, a relatively large, stratified eutrophic lake (Table 1) located near major population centres in southern Wisconsin, USA. The project planning began in early 1986 and the piscivore stockings started in 1987. The early results of the project through 1989 have been reported elsewhere (Kitchell, 1992), but a complete synthesis of the long-term data set has not been conducted because of the need to wait until the stockings of the long-lived piscivores – walleye (*Stizostedion vitreum* Mitchell) and northern pike (*Esox lucius* L.) – had their full impact in the lake.

Because the Lake Mendota biomanipulation project and its evaluation in such a relatively large stratified lake was projected to be expensive, a number of reasons for initiating the project were identified to garner support within governmental agencies, local fishing clubs, and the general public before commencing biomanipulation. The reasons were:

- Algal blooms continued to be a problem in Lake Mendota even after sewage diversion and the implementation of non-point source pollution control programmes (Lathrop, 1992; Lathrop *et al.*, 1998; Carpenter & Lathrop, 1999).
- Other studies (e.g. Shapiro *et al.*, 1975; Carpenter *et al.*, 1987) have shown that biomanipulation could reduce algal densities in certain lakes, although uncertainty existed about whether it would work in eutrophic lakes (e.g. McQueen *et al.*, 1986; Benndorf, 1990).
- Federal monies for fishery projects in the state had recently increased and as such uncommitted state funding was available within the Wisconsin Depart-

Table 1 Characteristics of Lake Mendota

Characteristic	Value
Surface area (ha)	3985
Maximum depth (m)	25.3
Mean depth (m)	12.7
Catchment area (km^2)	604
Water residence time (year)*	4.6
Phosphorus loading (g P m^{-2} year^{-1})*	0.85

*From Lathrop *et al.* (1998).

ment of Natural Resources (WDNR) to conduct the expensive project, thus avoiding the difficult problem of reallocating existing fishery management monies in the agency (Addis, 1992).

- Long-term data on fish, zooplankton, algal densities and nutrients for Lake Mendota were available to evaluate the effect of biomanipulation (Kitchell, 1992).
- A strong partnership existed between the WDNR and the University of Wisconsin-Madison Center for Limnology (UW-CFL) to conduct such a large research/management project (Addis, 1992).

Specific fishery management objectives were identified to justify the stocking programme. To enhance the sport fishery in Lake Mendota, fishing opportunities had to be diversified. This included increasing the overall size and catch rates of walleyes and northern pike, increasing the catch of trophy-size northern pike, and increasing the growth rate of popular planktivorous fish, especially yellow perch (*Perca flavescens* Mitchell). Another objective was to sustain the piscivore enhancement by fostering natural reproduction. More restrictive harvest regulations were needed to protect the stocked piscivores to build up spawner populations. Thus, public education for sustainable management was a key component of the project. The fishing public needed to recognise that Lake Mendota was impaired, sacrifices and support were required to carry out the biomanipulation project, and water quality was valuable to all lake users including anglers. Specifically, blue-green algal blooms were not only noxious and unaesthetic, but also impaired the sports fishery.

Thus, biomanipulation of eutrophic Lake Mendota was deemed an important opportunity to test the biomanipulation theory in a real world setting where the outcome could not only be fully evaluated scientifically, but where it was hoped that the project would produce significant, long-lasting water quality and fishing benefits for a heavily used urban lake. The objective of this paper is to synthesise our insights from monitoring the long-term dynamics in Lake Mendota from both a scientific and management point of view.

Methods

Piscivore stocking

A total of 2.7×10^6 walleye fingerlings were stocked into Lake Mendota during the biomanipulation project between 1987 and 1999 (Fig. 1). Prior to biomanipulation, few walleyes had been stocked throughout the 1970s and early 1980s, although a local fishing club had raised and stocked modest numbers of walleye fingerlings in 1985–86 to improve fishing. During 1987–89 – the first 3 years of the biomanipulation project – about 500 000–650 000 (125–162 ha^{-1}) walleye fingerlings were stocked each year. In addition, 20 million walleye fry were stocked each spring, but their survival was considered negligible and therefore the fry stocking was not continued. In 1990–92, the heavy stocking rates were reduced to half, corresponding to about 250 000–300 000 fingerlings $year^{-1}$. In subsequent years, an alternate-year stocking programme at relatively low rates was instituted; no walleyes were stocked in 1993, 1995 and 1997, and only a very few fingerlings were stocked in 1999. Walleyes were generally stocked during June and early July at a total length of about 50 mm throughout the project.

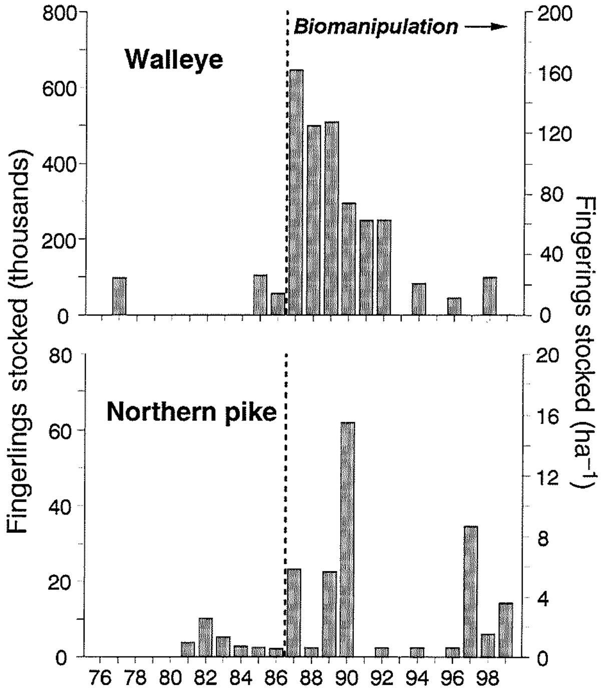

Fig. 1 Walleye (*Stizostedion vitreum*) and northern pike (*Esox lucius*) fingerling stockings to Lake Mendota in thousands of fish (left axis) and number of fish stocked per hectare of lake area (right axis) 1976–99.

Managers hoped that the heavy stocking of walleye fingerlings in 1987–92 would build up the adult spawner population sufficiently to allow for natural reproduction to sustain the population at high densities. The alternate year stocking schedule in later years allowed for assessment of the young-of-the-year fish stocks by electrofishing in autumn, which indicated whether natural reproduction was occurring in years without stocking. Natural reproduction apparently was not extensive for most years without stocking; only in the fall of 1993 were modest numbers of small fish recorded.

Stocking rates of northern pike fingerlings (1.7×10^5 fingerlings between 1987 and 1999) were much less than for walleyes (Fig. 1), because the supply of hatchery-raised northern pike was very limited. Before biomanipulation started, the WDNR stocked relatively low numbers of northern pike fingerlings throughout the 1980s. The heaviest stocking in the early years of the biomanipulation was in 1990 (62 000 fingerlings, 16 ha^{-1}); over 20 000 northern pike fingerlings were stocked in 1987 and 1989. In 1987–89, 10 million northern pike fry were also stocked each year, but similar to the walleye fry stocking, the northern pike fry survival was determined to be very low and was later discontinued. No northern pike fingerlings were stocked in 1991, 1993 and 1995; fall surveys indicated natural reproduction was poor in the lake.

In 1996, a wetland rearing pond for northern pike was built on one of the major river tributaries to Lake Mendota. The addition of northern pike fingerlings to the lake has been relatively high since then, and may increase in future years because of plans to develop more wetland rearing sites in the lake's drainage basin (K. Welke, WDNR Fisheries Manager, personal communication). Northern pike fingerlings raised in hatchery ponds were usually stocked in late summer at a mean size of about 250 mm total length. Fingerlings released from the wetland rearing pond were stocked in the spring at about 50 mm.

Harvest regulations

Restrictive harvest regulations were implemented on Lake Mendota beginning in 1988 to protect stocked walleye and northern pike for the biomanipulation and to rebuild adult spawner populations of both species (Table 2). These regulations included both an increase in the minimum size limit and a reduction in the daily bag limit of fish permitted to be harvested from the lake (i.e. three walleyes, one northern pike). The minimum size limit was further increased in 1991 and 1996 for walleye (46 cm total length) and northern pike (102 cm total length), respectively, to further protect adult populations. In the case of northern pike, the regulations were also implemented to promote a 'trophy' fishery.

Table 2 Harvest regulations for walleye and northern pike in Lake Mendota during four time periods

Period	Species	Minimum size limit (cm)	Daily bag limit
Before 1988	Walleye	None	5
	Northern pike	None	5
1988 to April 1991	Walleye	38	3
1988–95	Northern pike	81	1
May 1991 to present	Walleye	46	3
1996 to present	Northern pike	102	1

Piscivore assessment

We used a variety of approaches to assess fish populations and sports fishery dynamics in Lake Mendota. Adult walleye and northern pike abundances were estimated by mark–recapture techniques (Ricker, 1975). Fyke nets were used for marking during spring, and creel survey and gill nets to obtain recapture samples during the following summer and fall (Johnson *et al.*, 1992a; WDNR, unpublished fish management progress reports). Abundance estimates were computed within size classes to minimise gear selectivity bias. Biomass variances were computed from variances of abundance estimates and the mean weight of fish in each size class (Ricker, 1975); variance was not estimated for northern pike because of small recapture sample sizes. Age–length and length–weight relationships, and size structure were assessed using fyke nets, electrofishing, gill nets, and creel surveys (Johnson *et al.*, 1992a). A combination of stratified-random gill net surveys and radio-telemetry were used to determine seasonal depth distributions and thermal experience of walleyes and northern pike (Johnson *et al.*, 1992a).

Piscivore diets were determined by stomach analysis of fishes sampled from the electrofishing, gill net and creel catches (Johnson *et al.*, 1992a). Prey consumption by age 2 and older walleye and northern pike was estimated with a bioenergetics model (Hewett & Johnson, 1987; Hanson *et al.*, 1997). Energy density of predators and fish prey were assumed to be 5 kJ g^{-1} wet weight (Johnson *et al.*, 1992b).

Average prespawn weights-at-age (males and females combined) for simulations of bioenergetics were estimated from scales during 1987–93 as growth increments, assuming an average loss of 13 and 10% of body mass during spawning for walleyes (Colby, McNicol & Ryder, 1979) and northern pike (Diana, 1983), respectively. Natural mortality rates were estimated from the literature (walleye: Colby *et al.*, 1979; northern pike: Kempinger & Carline, 1978; Snow, 1978) and fishing mortality rates were estimated from the mark-recapture abundance estimates and numbers of fish harvested estimated from creel surveys (Johnson & Staggs, 1992).

Planktivore assessment

Population abundances of planktivorous fish for 1981–95 were estimated with a 70-kHz Simrad EY-M echo sounder during night hydroacoustic surveys using methods described in Rudstam, Lathrop & Carpenter (1993). Returning acoustic signals were recorded on audio (1981–87) and digital audio tape (1988–95) and analysed with Hydroacoustic Data Acquisition Software (Lindem, 1990). From 1997 to 1999, a split beam, Hydroacoustic Technologies 120 kHz system was used. The software settings for the sounder included depth strata defined at 1-m intervals, pulse duration of 0.4 ms, and a pulse rate of two per second. Standard target calibration was performed shortly before each sampling date, and maximum target strength never varied significantly from the known target strength of the calibration sphere. Analysis procedures included eliminating any bottom anomalies using Echoscape postprocessing software (Hydroacoustic Technologies Inc., Seattle, WA, USA, v. 1.51) and estimation of fish density at each depth strata using echo integration and mean target strength after correcting for system configuration. All acoustic estimates were conducted during August or early September when the fish were restricted to the upper one-half of the water column because the hypolimnion was anoxic. Transducer signal noise prevented recording fish in the upper top metre of the water column, because the transducer was located just below the lake surface. However, vertical gill net data (see below) indicated few fish stay near the surface, especially at night.

The vertical distribution and species composition of fish caught in a suite of vertical gillnets placed near the transects were used to estimate the proportion of each species at each depth. This information allowed us to assign species to the targets observed in the hydroacoustic data set for each year. The graded-mesh vertical gillnets were 4 m wide, 23 m deep, and with 25, 38, 51, 64, and 89-mm stretch mesh. Cisco (*Coregonus artedi* Lesueur), yellow perch, white bass (*Morone chrysops* Rafinesque) and freshwater drum (*Aplodinotus grunniens* Rafinesque) comprised 94–100% of the offshore fish community between 1981 and 1999 (UW-CFL, unpublished data). Adult freshwater drum are benthivorous, while all life stages of the other three species are almost exclusively zooplanktivorous in Lake Mendota (Johnson & Kitchell, 1996). Further, drum rarely comprised more than 10% of the abundance (median value 1.8%), so our remaining analyses will focus on cisco, yellow perch and white bass.

Whole lake fish biomass for each species of fish was determined by comparing species, size and depth distribution of all fishes captured in gillnets with corresponding depth strata from the acoustics abundance estimates. Species-specific biomass in each year was converted to age-specific biomass using expected growth and age composition information. Whole-lake biomass estimates are conservative as acoustic data could not be collected in shallow waters of the littoral zone. Detailed description of the population characteristics can be found in Johnson & Kitchell (1996).

Bioenergetic models (Hanson *et al.*, 1997) were used to estimate predation by cisco, yellow perch and white bass using species- and site-specific information on diet, energy density of fish and prey, temperatures to which the fish were exposed and growth rates. Diet of fishes was determined by gut content analyses conducted during 1987–89 (Luecke, Rudstam & Allen, 1992) and 1993 (Johnson & Kitchell, 1996). General characteristics of the diet (proportion of planktivory relative to other feeding modes) did not change between the two periods and was considered unlikely to change over the years of our analyses (Rudstam *et al.*, 1993; Johnson & Kitchell, 1996). Energy density of fish was determined from water content of tissues, while energy densities of most prey items were determined by bomb calorimetry (Hewett & Johnson, 1987). Temperatures experienced by the fishes throughout the year were estimated from thermal profiles recorded about every 2 weeks from ice-off until freeze-up each year (WDNR & UW-CFL, unpublished data). Based on the thermal preferences for fish in Lake Mendota (Rudstam & Magnuson, 1985), we assumed adult fish would be distributed close to their preferred temperature (15.8 °C for cisco, 23 °C for yellow perch and 27.8 °C for white bass), although low hypolimnetic oxygen concentrations (< 4 mg L^{-1}) could force fish into warmer water during the summer and early fall. Temperature regimes to which larval and juvenile fishes had been exposed were estimated from temperatures recorded at 1-m depth and the water surface, respectively. A more comprehensive description of the energetic modelling can be found in Johnson & Kitchell (1996).

Daphnia biomass

The abundance and biomass of *Daphnia* species were estimated from vertical tow samples collected with conical zooplankton nets during 1976–99 (Lathrop, 1998). Sampling was conducted biweekly during the open water period and at least once through the ice at the deepest region of the lake in water depths of about 23–24 m. In 1976–94, zooplankton samples were collected using a net with a 15-cm diameter opening (small net) lowered to within 0.5 m of the lake bottom. Beginning in 1991, samples were collected using a 30-cm diameter closing-style net (large net) to a standardised depth of 20 m. The nets were made of Nitex screening with a mesh size of 75–80 μm for all years except for 1976 when the mesh size was 153 μm. Direct comparisons showed that *Daphnia* density, biomass and species composition determined by the large and small nets were not significantly different (Lathrop, 1998). For our analyses, *Daphnia* data for the small net were used for the period 1976–94; large net data were used for 1995–99.

Daphnia in each zooplankton sample were counted and measured to the nearest 0.01 mm under a microscope. Dry weights (dw, μg) for both juveniles and adults were computed from the average length data (Length, mm) based on equations given in Lynch, Weider & Lampert (1986) for *D. galeata mendotae* ($\mathrm{dw} = 5.48\ \mathrm{Length}^{2.20}$) and *D. pulicaria* ($\mathrm{dw} = 10.67\ \mathrm{Length}^{2.09}$), the two major *Daphnia* species encountered in Lake Mendota. The average weights were then multiplied by their respective densities to compute raw biomass concentrations (mg dw L^{-1}). Biomass concentrations for the summer and early fall stratification periods when the hypolimnion was anoxic were adjusted to the tow depth that was above a dissolved oxygen threshold concentration of 1 mg L^{-1}.

Another factor that affects *Daphnia* biomass concentrations was zooplankton net efficiency, that is the reduction in organisms entering the net because of hydraulic resistance as the fine-meshed net is towed through the water. Both the small and large nets used for sampling *Daphnia* had reduced net efficiencies when algal densities were high (because of mesh clogging) compared with periods of clear water (Lathrop, 1998). During clear water periods, net efficiencies for the two nets were about 0.6–0.7, based on comparative analyses with flexible tube samplers. Net efficiencies declined to about 0.4 during periods of summer algal blooms. Because these differences are small compared with the very large range in *Daphnia* biomasses that we observed, and because we did not quantitatively analyse *Daphnia* biomass data in the analyses presented in this paper, we did not correct biomasses for net efficiency.

Results

Piscivores and piscivory

Walleye biomass increased steadily from a little over 1 kg ha^{-1} in 1987 to over 3 kg ha^{-1} in 1993 and reached a peak of 3.5 kg ha^{-1} in 1998, the last year when population estimates were made (Fig. 2). The standard error of biomass estimates averaged 0.37 over 1987–98. Because the 1993 and 1998 estimates were similar and piscivore biomass generally changes rather slowly, walleye biomass probably was stable during 1993–98 at a level about two to three times the 1987 biomass.

Northern pike biomass increased rapidly in the initial years of the study to over 4 kg ha^{-1} (Fig. 2), apparently because of excellent survival and growth of fingerlings stocked in 1987. Subsequent year-classes did not appear to fare as well. Stocking rate dropped greatly in 1991, and despite very restrictive harvest regulations, recruitment and survival were not adequate to maintain the population biomass achieved early in the study. Biomasses stabilised at 2.5 kg ha^{-1} through 1993, then dropped in 1998. Mean length of adult northern pike in spring sampling increased only modestly from 58 cm in 1987 to 71 cm in 1998.

Estimated biomass of prey consumed by walleye and northern pike populations increased rapidly

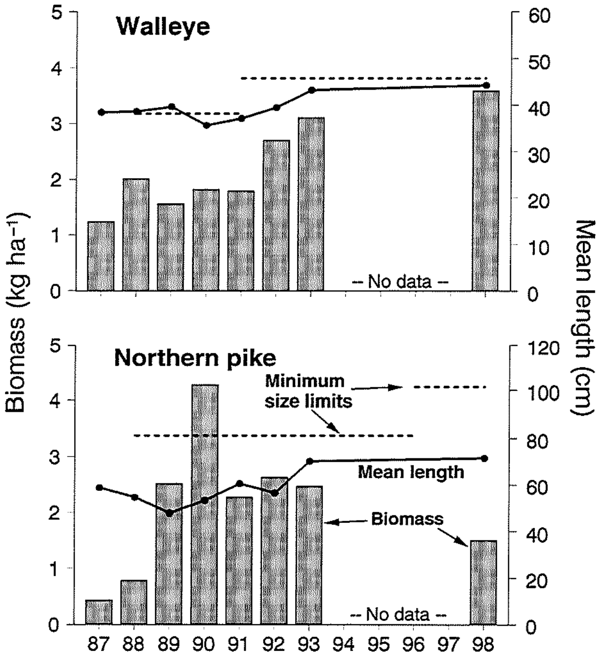

Fig. 2 Walleye and northern pike biomass estimates, and mean fish lengths and minimum size limit regulations for Lake Mendota, 1987–99.

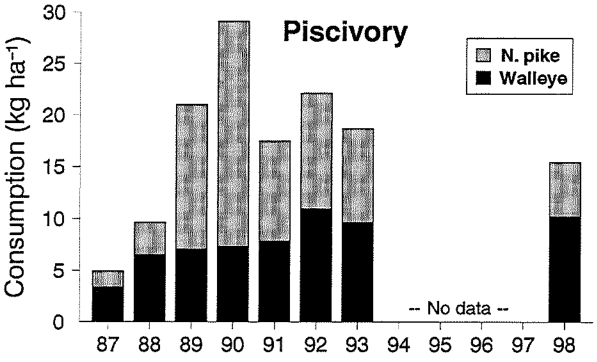

Fig. 3 Bioenergetic estimates of piscivory consumption on planktivorous fish for Lake Mendota, 1987–99.

during 1987–90 (Fig. 3), particularly as a result of the large increase in northern pike biomass (Fig. 2). Prey consumption declined somewhat in 1991 and remained relatively stable through 1998 (Fig. 3), but at levels much higher than prior to the period of heavy stocking of piscivores. We estimated that walleye and northern pike together consumed an average of 17 kg ha^{-1} of prey fishes year^{-1} during the biomanipulation years.

Sport fishing

Fishing effort directed at walleyes in Lake Mendota increased more than sixfold during 1987–89 and remained high (~2 angler-hours ha^{-1} month^{-1}) for most years through the 1998 creel survey (Fig. 4). This increase in angler interest was in response to the publicity about the massive stocking programme that began with the fishing club efforts in 1985–86 followed by the biomanipulation project (Johnson & Carpenter, 1994). The density (number ha^{-1}) of walleyes >28 cm in length increased from the stockings and did not decline by 1998 (Fig. 4). Angler catch rates (both kept and released fish) generally increased with walleye density. In 1991 and 1998, anglers were less successful at catching walleyes, probably because large year-classes of prey fishes were present in those years, although angling effort remained high.

Despite restrictive bag and size limits, walleye harvest rates (fish kept and not released by anglers) were so high by 1990 that project managers and investigators were concerned that the build-up of piscivore biomass in the lake would be prevented (Johnson & Carpenter, 1994). Walleye harvest rates dropped precipitously in 1991 following the increased minimum size limit (46 cm length) that was imposed to prevent the smaller fish from being harvested before they reached their adult spawning size (about 43 cm length for females; Johnson & Staggs, 1992).

Catch rates of northern pike also tracked increases in northern pike abundance, increasing rapidly during 1987–90 in response to the stocking efforts (WDNR,

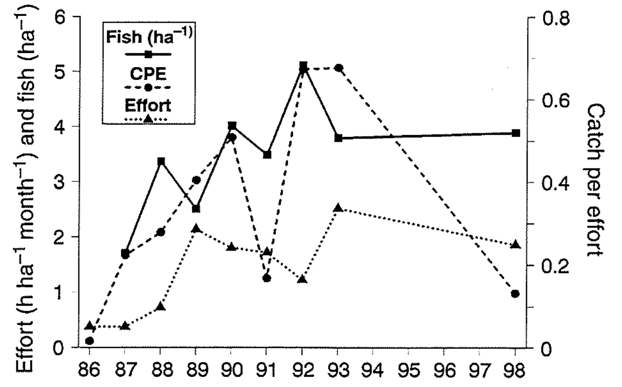

Fig. 4 Walleye density (fish ha^{-1}), fishing effort by anglers specifically seeking walleyes (angler-hour ha^{-1} month^{-1}), and catch per effort (CPE) by those anglers (walleyes caught per hour of fishing for walleyes) in Lake Mendota, 1986–99.

unpublished data). Catch rates decreased rapidly after 1990, as northern pike biomass (Fig. 2) and abundance declined when stocking was reduced.

Planktivores and planktivory

Cisco and yellow perch were the dominant planktivores in Lake Mendota prior to biomanipulation (Fig. 5). An unusually large year-class of crappies (*Pomoxis* spp.) also contributed to planktivory in the lake in the early 1980s (Lathrop *et al.*, 1992), but population densities of crappies have been low since then. Because large adult crappies are not captured by gill netting, they were not part of the biomass and planktivory estimates in those years. White bass had been abundant in the lake prior to a major die-off in 1976. They reappeared in low densities in the early 1990s and represented a minor increase in planktivory in 1992 (Fig. 5).

For many decades, cisco populations had been very low in the lake until populations increased dramatically in the late 1970s (Fig. 5). This increase was attributed to good recruitment in 1976 and especially 1977 (Rudstam *et al.*, 1993). As a result, total planktivory increased to very high levels by 1978, until rates declined sharply following a massive cisco die-off in the summer of 1987, 1 year before biomanipulation started (Fig. 5). A minor decrease occurred in 1983 resulting from a smaller die-off.

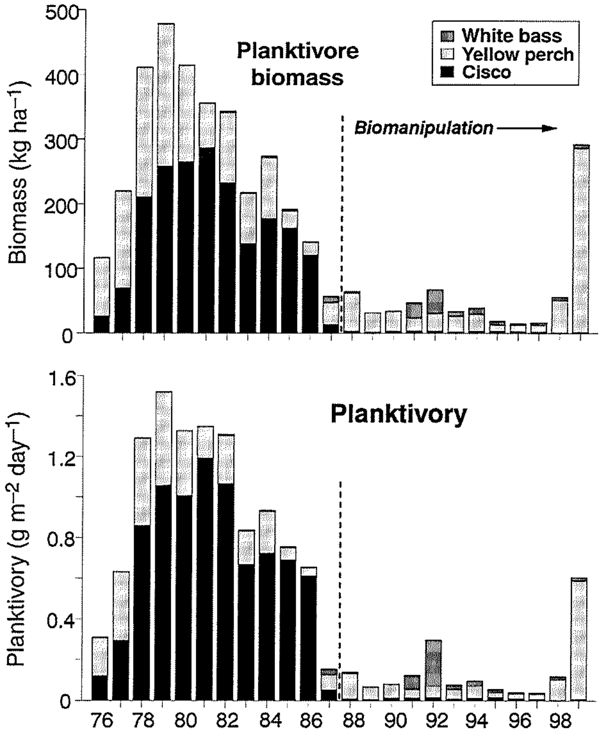

Fig. 5 Biomass estimates for planktivorous cisco (*Coregonus artedi*), yellow perch (*Perca flavescens*) and white bass (*Morone chrysops*), and bioenergetic estimates of *Daphnia* consumption in Lake Mendota, 1976–99. The biomanipulation effect is marked to begin in 1988, 1 year after the piscivore fingerling stocking was initiated.

Planktivory in the late 1970s and early 1980s was also augmented by yellow perch. Perch populations declined by the mid-1980s and remained low until a strong year-class occurred in 1997, which led to a pronounced increase in their biomass by 1999 (Fig. 5), the last year of our evaluation. Planktivory rates also increased in 1999, but the bioenergetic estimates were lower compared with situations when a similar biomass of cisco was present, because yellow perch has a lower *Daphnia* consumption rate (Johnson & Kitchell, 1996).

In summary, total planktivore biomasses and planktivory rates had changed greatly during 1976–99. The rapid increase in total planktivory after the strong 1977 year-class of cisco was apparent, followed by the sharp decrease in planktivory recorded in the late summer estimate of 1987. However, the 1977 increase in planktivory most probably occurred too late in the season to affect the spring and early summer *Daphnia* community that year. Likewise, the 1987 drop in planktivory occurred later in the summer; the spring and early summer *Daphnia* community was subjected to planktivory rates characteristic of the previous year. This 1987 drop in planktivory would also have occurred 1–2 years before piscivory increased as a result of the massive stocking programme. In subsequent years, extremely low planktivore biomass and planktivory were maintained, suggesting that piscivory could have been controlling densities of planktivore populations. However, the large increase in yellow perch in 1999 from the 1997 year-classes indicated that with a combination of the right conditions (i.e. low competition from other planktivores, ample zooplankton food resources, and favourable weather conditions for spawning), a strong year-class of planktivores can develop even with the relatively high piscivore biomass that was attained in the lake.

Daphnia

Daphnia pulicaria Forbes and *D. galeata mendotae* Brooks were the main *Daphnia* species in Lake

Mendota during the pre- and post-evaluation years of the biomanipulation project, which is consistent with historical records (Kitchell & Sanford, 1992; Lathrop, Carpenter & Rudstam, 1996). They are the dominant *Daphnia* found in many lakes throughout the region (Kasprzak, Lathrop & Carpenter, 1999). The only other species recorded was *D. retrocurva* during the early 1980s in late summer and fall, but in minor densities (Lathrop & Carpenter, 1992).

While *D. pulicaria* and *D. galeata mendotae* can attain the same total body length in Lake Mendota, *D. pulicaria* has a much larger body mass (Fig. 6) and thus can reach significantly greater algal grazing potentials than *D. galeata mendotae* (Kasprzak *et al.*, 1999). Consequently, zooplankton grazer length distribution has not been a good predictor of plankivory or herbivory effects in Lake Mendota (Lathrop & Carpenter, 1992), whereas *Daphnia* biomass has produced insightful results of the trophic cascade effects from planktivory (Rudstam *et al.*, 1993; Johnson & Kitchell, 1996) and responses to herbivory (Lathrop, Carpenter & Robertson, 1999).

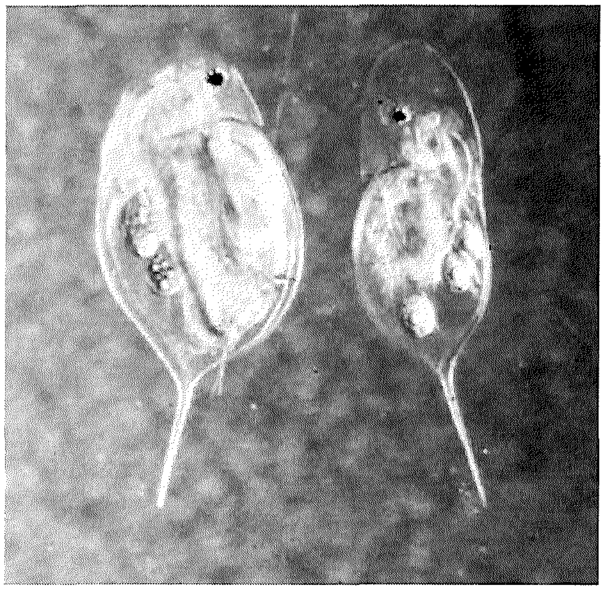

Fig. 6 Photograph of the larger-bodied *Daphnia pulicaria* and the smaller-bodied *D. galeata mendotae*, the two main species of *Daphnia* that dominated the crustacean zooplankton in Lake Mendota throughout the 1900s including the biomanipulation project years.

In most years, the spring and early summer *Daphnia* populations were dominated by only one species (Fig. 7). In 1976–77 and in 1988–99 (except for 1994), the larger-bodied *D. pulicaria* dominated ('*D. pulicaria*' years) when spring planktivory levels were low. In 1978–84 and again in 1987, the smaller-bodied *D. galeata mendotae* dominated ('*D. galeata*' years) when spring planktivory levels were high. Only in 1985–86 and in 1994 did both species codominate, but biomass density of neither species was high. In general, *Daphnia* biomass increased earlier in the spring, reached greater densities, and lasted longer into the summer in *D. pulicaria* years than in *D. galeata* years. In *D. galeata* years, the increase in biomass usually occurred in June and declined again to very low densities by early July. The relatively high *D. pulicaria* biomass in July and August of many *D. pulicaria* years would have resulted in a much greater grazing impact on algal communities in those years.

Water clarity

Secchi disc readings as a measure of water clarity were highly variable during spring turnover, early stratification and summer periods of 1976–99 in Lake Mendota (Fig. 8). (Secchi readings are highly correlated to chlorophyll concentrations, because abiotic seston is relatively unimportant in Lake Mendota; R. Lathrop, WDNR, unpublished data.) During spring turnover in many but not all years dominated by *D. pulicaria*, mean and maximum Secchi disc readings were greater than in *D. galeata*-dominated years. Minimum readings, which often occurred early in the spring when water temperature was still low, were similar between years before and after the start of biomanipulation, indicating that *Daphnia* grazing had not yet occurred. A large increase in water clarity during spring turnover occurred in *D. pulicaria* years because this species can grow and reproduce in much colder water than *D. galeata mendotae* (Burns, 1969; Threlkeld, 1980).

During the early stratification period when both *Daphnia* species reached their peak biomasses, relatively high Secchi disc readings (>8 m) were recorded in some but not all the *D. pulicaria* years (Fig. 8). In general, mean readings were greater in *D. pulicaria* years after biomanipulation began. The lowest Secchi disc readings during the late spring/early summer period occurred in 1979 and 1990. In 1979, a very low biomass of *D. galeata mendotae* occurred during a year of very high planktivory (Fig. 5). In 1990, *D. pulicaria*

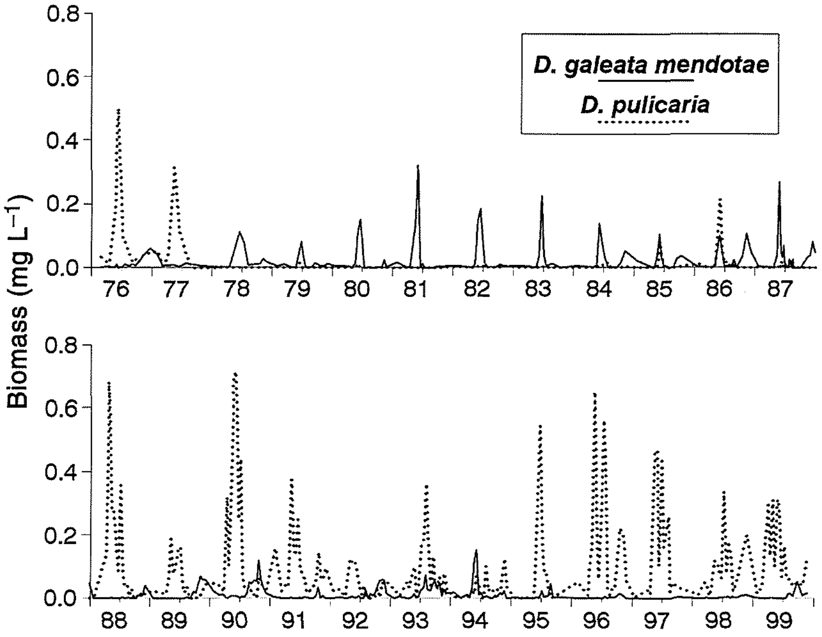

Fig. 7 Biomass concentrations of *Daphnia pulicaria* and *D. galeata mendotae* in Lake Mendota, 1976–99. Concentration data have not been corrected for net efficiency such that actual concentrations are higher (see text).

biomass was very high, coincident with a very dense bloom of the blue-green alga, *Aphanizomenon flos-aquae*.

During the mid-summer months, Secchi disk readings were generally greater in the biomanipulation years, although a few years in the mid-1980s prior to biomanipulation also had rather high water transparency (Fig. 8). Exceptionally good clarity occurred during the summer of 1988 with a mean Secchi depth of 3.5 m and a maximum >4 m. Similar maximum readings also occurred in 1989 and 1997. Even in 1990 when *Aphanizomenon* blooms were particularly prominent during the spring, the mean summer Secchi depth was similar to readings from other biomanipulation years and greater than summer readings of most previous years.

Nutrient levels

Changing nutrient levels in Lake Mendota as indicated by spring turnover phosphorus (P) concentrations (Fig. 9) complicated our evaluation of the biomanipulation effects on algal densities and water clarity. In the late 1970s, P concentrations were high, probably as a result of higher than normal runoff in previous years (Lathrop, 1990). Phosphorus concentrations steadily declined throughout the 1980s to a minimum in 1988 as a result of very low runoff during a 2-year drought in the region. Phosphorus concentrations increased again after the biomanipulation commenced and reached very high levels resulting from large P inputs from runoff in 1993 (Lathrop *et al.*, 1998). Phosphorus concentrations have remained relatively high since then. Because spring P concentrations have been shown to be significant predictors of blue-green algal densities and water clarity during the summer months in the lake (Stow, Carpenter & Lathrop, 1997; Lathrop *et al.*, 1999), higher nutrient supply rates could have offset gains from increased algal grazing during the biomanipulation years.

Discussion

The heavy stocking rates of walleyes in the early years of the project represented a major share of the state's walleye hatchery production – a controversial commitment of resources that were diverted away from popular walleye stocking programmes in the northern regions of the state where many of the fish were raised (Johnson & Staggs, 1992). Northern pike stocking rates were almost an order of magnitude lower because of the difficulty in obtaining fingerlings from local hatcheries. Most of the walleyes were stocked in 1987–92; northern pike stockings were heaviest in the early and later years of the 1987–99 evaluation period. The survivorship of stocked fry for both species was

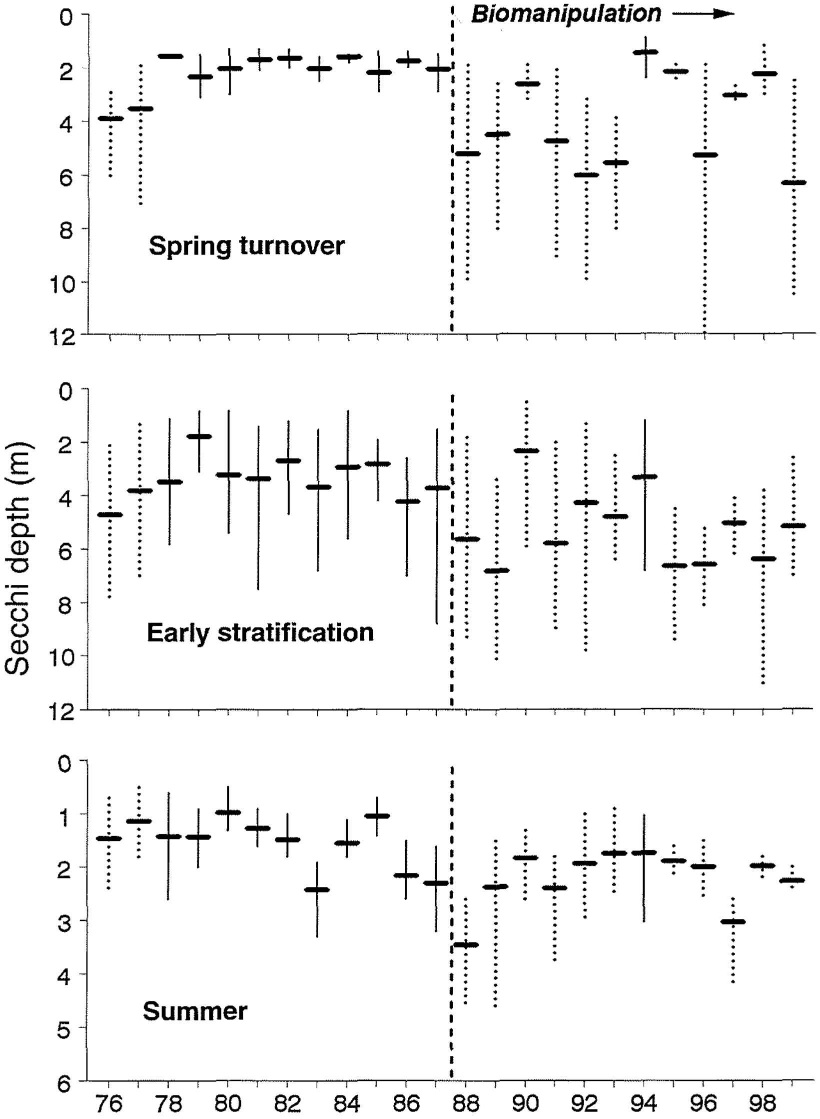

Fig. 8 Secchi disc readings as measure of water clarity and algal densities for three different time periods for Lake Mendota, 1976–99. (Spring Turnover = ice-out to 10 May; Early Stratification = 11 May to 29 June; Summer = 30 June to 2 September. Fat short horizontal bars are seasonal mean Secchi disc readings measured from the top of each graph. Vertical dotted lines are ranges of disk readings for years dominated by the larger-bodied *D. pulicaria*; vertical solid lines are ranges of disc readings for years dominated by the smaller-bodied *Daphnia galeata mendotae* or codominated by both species).

poor and was discontinued after the first 3 years of the project.

The biomass of both piscivore species substantially increased in the lake as a result of the stocking. In general, the combined biomass of both species ranged about 4–6 kg ha^{-1} from 1989 throughout the rest of the study years. While the combined piscivore biomass indicated a substantial increase compared with prebiomanipulation years (< 1 kg ha^{-1}), the levels are lower than those reported for other biomanipulation projects (e.g. >20 kg ha^{-1}; Benndorf, 1990). However, other piscivorous fish species (e.g. largemouth and smallmouth bass, *Micropterus salmoides* Lacepède and *M. dolomieu* Lacepède) are also found in Lake Mendota and so would raise our piscivorous fish estimates to an extent.

The magnitude of the planktivorous fish changes in Lake Mendota is even more striking, decreasing from 300 to 600 kg ha^{-1} in prebiomanipulation years to 20–40 kg ha^{-1} after 1987 – an order of magnitude decline. Another indicator of fish conditions in lakes is the ratio of planktivore to planktivore plus piscivore biomasses. Jeppesen *et al.* (1990) found that this ratio was around 0.8–0.9 for shallow Danish lakes with high P concentrations (P > 0.10 mg L^{-1}), but dropped considerably for shallow lakes with lower P concentrations. While these ratios for shallow lakes are not directly comparable with deeper Lake Mendota, the

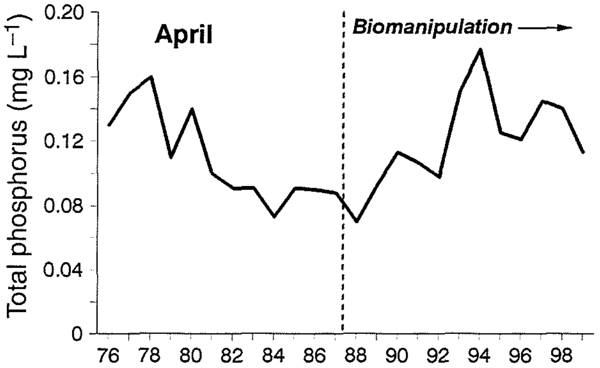

Fig. 9 Total phosphorus concentrations in the surface waters of Lake Mendota for mid-April, 1976–99.

ratio for the fish species summarised in our analyses changed from >0.99 before biomanipulation to approximately 0.85 after biomanipulation.

Of particular interest is whether a trophic cascade from piscivores to algae could improve water clarity in eutrophic Lake Mendota. Results from other biomanipulation projects suggested that lakes would not exhibit reduced algal densities following piscivore enhancement and/or planktivore reduction programmes if P loadings were high (McQueen *et al.*, 1986; Benndorf, 1990; Reynolds, 1994). Benndorf (Benndorf, 1990; Benndorf *et al.*, 2002) proposed a lake-specific P loading threshold ranging from 0.6 to 0.8 g P m^{-2} year^{-1}, above which biomanipulation measures would not reduce algal densities. Lakes with external P loadings below 0.6 g P m^{-2} year^{-1} had a high probability for biomanipulation to reduce algal densities. Lake Mendota has an average annual P loading rate of 0.85 g P m^{-2} year^{-1}, although annual loadings are highly variable (Lathrop *et al.*, 1998).

In 1988, the year following the sharp decline in planktivory caused by the cisco die-off, Lake Mendota experienced exceptionally good water clarity during summer coincident with high *Daphnia* biomass (Vanni *et al.*, 1990). This was also the year at the end of a prolonged drought with lower than average external P loadings (Lathrop *et al.*, 1998) and a hotter than normal summer with less internal loading because of greater water column stability (Lathrop *et al.*, 1999). The combined effect of lower P loadings and in-lake P concentrations plus increased *Daphnia* biomasses in 1988 supports Benndorf's (Benndorf, 1990; Benndorf *et al.*, 2002) proposed minimum P loading rate threshold for enhanced biomanipulation effects. In later years when in-lake P concentrations and external P loadings were higher than the upper P loading threshold range of 0.8 g m^{-2} year^{-1} (Benndorf *et al.*, 2002), summer water clarity in Lake Mendota remained greater than in years before the fish die-off. A greater *Daphnia* biomass since 1988 conceivably was an important contributing factor.

It is debatable whether the increased piscivore densities (and hence increased piscivory) after the cisco die-off in 1987 directly suppressed planktivorous fish populations and prevented their resurgence until perch recovered in the late 1990s. However, sport fishing for walleye and northern pike improved greatly as a result of the biomanipulation programme. To protect the sport fishery, restrictive harvest regulations (increased size limits and reduced bag limits) were placed on Lake Mendota in 1988 for both stocked piscivore species, and then made even more restrictive in 1991 and 1996 for walleye and northern pike, respectively. These restrictions stabilised the fishery at the higher biomass levels. However, further increases in piscivore biomass probably were not achieved because fishing pressure remained high. The slight drop in northern pike biomass in 1998, if real, should be augmented again by increasing stocking of fingerlings from the wetland rearing pond on one of the lake's tributaries and possibly additional wetland rearing sites that are being proposed. The recent resurgence of yellow perch with rapid growth rates, apparently resulting from abundant zooplankton food, is further viewed as a positive response to biomanipulation in the lake. However, the full trophic cascade effect on *Daphnia* and ultimately water clarity needs to be evaluated as planktivory by perch continues to increase.

In summary, the Lake Mendota biomanipulation project has been a success in that high densities of the large-bodied *D. pulicaria* have continued to dominate for over a decade, and fishing opportunities have improved for walleye, northern pike and, more recently, for yellow perch. In addition, scientists and managers have learned to what extent a large eutrophic urban lake can be influenced by biomanipulation. Massive stocking coupled with very restrictive fishing regulations produced moderate increases in piscivore densities. Larger increases could be realised by more drastic restrictions on sport fishing, such as trophy regulations, mandatory catch-and-release programmes, or outright closures of the fishery, accompanied by higher stocking rates or by habitat improvements to increase reproduction. However, many anglers, who now enjoy good fishing opportunities under the current stocking and harvest regimes, would undoubtedly be opposed to increased regulations.

Reduced planktivory in eutrophic Lake Mendota clearly did cascade to lower trophic levels, causing an increase in large *Daphnia*, reduced algal densities and increased water clarity. We are less certain whether the walleye and northern pike biomass (up to 6 kg ha^{-1}) attained in the lake directly controlled planktivory. After the cisco die-off 1 year before biomanipulation started, piscivory levels may have been high enough to suppress cisco and yellow perch recruitment for many years until conditions were favourable for perch to finally experience an exceedingly fast population growth. These perch are being heavily exploited by anglers; further perch recruitment will be needed to maintain their high biomass. Because yellow perch have lower planktivory rates on *Daphnia* than cisco (Johnson & Kitchell, 1996), the impact of the recent perch resurgence has not caused the larger-bodied *D. pulicaria* to be replaced by the smaller-bodied *D. galeata mendotae*. However, without the return of cisco, the lake's food web continues to be positioned (i.e. maintenance of high herbivory) to produce even further improvements in water clarity with future reductions in P loadings from a recently initiated drainage basin pollution abatement programme (Betz, 2000). Synergy between biomanipulation and non-point pollution control may be an important topic of future research and management initiatives in view of the increasing emphasis on controlling non-point nutrient loading of lakes in both Europe and North America.

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January 30, 2020

TESTIMONY TO ASSEMBLY COMMITTEE ON THE ENVIRONMENT IN OPPOSITION OF AB798

Thank you for the opportunity to testify today in opposition of AB798. My name is Michael Engleson, and I am the Executive Director of Wisconsin Lakes, also known as the Wisconsin Association of Lakes. Wisconsin Lakes is a statewide non-profit conservation organization of waterfront property owners, lake users, lake associations, and lake districts who in turn represent over 80,000 citizens and property owners. We are the only statewide association of lake organizations.

It is not often that I appear to argue against the spending of money for a conservation practice, but that is exactly what I am here to do today. While biomanipulation can be a useful tool for management of a limited number of lakes in Wisconsin, it is already adequately fundable through the surface water grant program of DNR, so long as it is part of an approved lake management plan.

Biomanipulation is a well studied and practiced lake management tool in Wisconsin but is often only a short-term solution. Many factors, including whether phosphorus continues to flow into a lake system, can lead the lake to revert to the state it was in prior to the biomanipulation, leading to the need to repeat the process. This makes biomanipulation, over the long haul, potentially quite expensive and intensive.

In addition, biomanipulation does not necessarily remove phosphorus from a lake system, even if no new phosphorus is entering the waterway. Instead, by controlling the fish, other animals, and plants in a lake's ecosystem, it attempts to limit the conditions where algae could grow. It essentially "parks" the phosphorus in the system such that it could eventually contribute to new algae growths and spur yet more spending on additional biomanipulation efforts in the future.

So while biomanipulation may be a useful tool to help maintain a stable condition that limits algae blooms in some lakes, Wisconsin Lakes sees no benefit in the state earmarking any additional taxpayer funds for the practice. Where it is useful and appropriate, such projects are already able to receive funding, and are done so in conjunction with a larger lake management planning effort. If we are to spend money on water quality projects, we should ensure that they go to efforts to solve the root problems we face, the problems the Speaker's Water Quality Task Force wanted to address. More money for biomanipulation projects doesn't fit that bill.

Wisconsin Lakes therefore asks you to put this money to a better use, or at the least not spend it where it simply is not needed, and ask you to oppose AB798.

Wisconsin Lakes is a statewide non-profit conservation organization of waterfront property owners, lake users, lake associations, and lake districts who in turn represent over 80,000 citizens and property owners. For over 20 years, Wisconsin Lakes has been a powerful bipartisan advocate for the conservation, protection, and restoration of Wisconsin's lake resources.

Testimony in Support of AB 798

01-28-2020

Dear Assembly Committee on Environment Members,

My name is Dr. Scott McGovern I am a researcher in cyanobacteria mitigation and the public health concerns that these algae-like organisms can pose by the toxins these organisms produce. Most of the lakes that are stated as having an algae problem are in fact affected by cyanobacteria, a photosynthetic prokaryotic organism. Most watershed mitigation techniques mainly focus on the reduction of phosphate through the control of agricultural runoff to address problems such as cyanobacteria blooms.

However, research has shown that these techniques have often not achieved the desired results (Sharpley et.al., 2014). Consequently, I have been interested in an approach to watershed mitigation that implements multiple techniques. The scientific literature has demonstrated that using multiple techniques rather than a single approach to watershed mitigation has been significantly more successful and biomanipulation has been a common element in the majority of the studies (Anandotter, 1999).

Biomanipulation offers an inexpensive and effective addition to mitigate lakes infested with cyanobacteria caused by excessive nutrients. Biomanipulation is widely used in Europe and is becoming more common in the United States as well as other parts of the world. This bill introducing support for biomanipulation can provide an important tool for the reduction of harmful cyanobacteria and I strongly believe it to be an important step for water quality improvement.

Biomanipulation is really balancing a lake ecosystem so that the natural food webs that exist within a lake can alleviate an imbalance such as excessive cyanobacteria growth. Three aspects of the lake ecosystem must change to realize an improvement in water clarity, an increase in the number of zooplankton, increased coverage of the lake with macrophytes (large aquatic plants) and the fish population must change to a more balanced population. Zooplankton such as daphnia, copepods and seed shrimp consume photosynthetic organisms; therefore, increasing zooplankton reduces cyanobacteria improving water clarity. Benthivorous or bottom-dwelling fish destroy macrophytes and their young consume zooplankton making their reduction important for two reasons. Similarly, lakes have zooplanktivorous fish that can negatively impact a lake by also eating zooplankton. Predator fish stocking to reduce zooplanktivorous fish and benthivorous fish removal are techniques to stop the consumption of zooplankton. The root cause may be nutrient enrichment, however; managing the lake in such a way will allow less predation on zooplankton. As a result, the reduction of the green organisms is accomplished by increased grazing. In addition, reducing benthivorous fish will increase macrophyte growth. Consequently, increasing lake macrophytes, (large aquatic plants) will provide refuge habitat for zooplankton and a method of reducing nutrients making it unavailable for cyanobacteria. Nutrient reduction is important but this method reduces harmful cyanobacteria by direct consumption, macrophyte competition for nutrients and the removal of benthivorous fish through stopping their perturbation of the bottom sediment and macrophyte destruction. Macrophytes, therefore, increase when benthivorous fish are removed and if further increases of macrophytes are needed seeds and entire plants can be added to increase the coverage to further benefit the lake ecosystem.

Biomanipulation is said to work the best in shallow eutrophic lakes although it has been used extensively in all types of lakes. The method is inexpensive compared to many other lake remediation techniques, effective, it can use nets rather than toxic chemicals to remove fish and can be adjusted to fit individual lake ecosystems. The biomanipulation process will improve the fish populations and habitat of lakes. There really is not a negative side of using biomanipulation techniques.

I strongly support Representative Rob Summerfield's biomanipulation in AB 798 and can not emphasize enough that these techniques should be part of Wisconsin's efforts to improve water quality, public safety and recreation of affected lakes.

Sincerely,

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