Mirror and Shadow Lakes

Waupaca County, Wisconsin

Comprehensive Management Plan

October 2022

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Friends of Mirror & Shadow Lakes
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Acknowledgements

This management planning effort was truly a team-based project and could not have been completed without the input of the following individuals:

Mirror and Shadow Lakes Planning Committee

Pat Cuellar	Carol Everly	Bob Fulmer
Lori Fulmer	Sharon Kjelland	Alan Kjelland
Mary Plautz	Ron Reynalds	Judy Shwonek
Sandy Testin	Andrew Whitman	Steve Cuellar

Organization

Friends of Mirror & Shadow Lakes
Waupaca Inland Lakes Protection & Rehabilitation District
City of Waupaca - Parks & Recreation Department

Wisconsin Dept. of Natural Resources

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1.0 INTRODUCTION

Mirror Lake and Shadow Lake are hydrologically connected deep headwater drainage lakes within the city limits of Waupaca in central Wisconsin. Mirror Lake is approximately 14.4 acres in size and flows south into Shadow Lake which is approximately 45 acres in surface area. Water from Shadow Lake flows south and into the Crystal River, which then flows into the Wolf River and ultimately into Lake Poygan of the Lake Winnebago system. These mesotrophic lakes have relatively small watersheds when compared to the size of the lakes. A higher number of native aquatic plant species are known to exist in Shadow Lake than in Mirror Lake, and six exotic plant species are present within or around the margins of the lakes. A public beach and swim area on Shadow Lake is a popular destination for people to utilize during the summer months.

Field Survey Notes

Given the urban setting of the lakes, much of the shorelands contained a buffer of natural grasses and shrubs along the water's edge.

The narrow channel connecting Mirror and Shadow lakes was navigable during early field visits, however had become impassible later in the summer.

Observed remnants of fish habitat structures anchored off shore in Shadow Lake.

Photograph 1.0-1. Shoreline restoration area near Mirror and Shadow lakes.

		Mirror Lake	Shadow Lake
Morphology	**Lake Surface Area (Acres)**	14.4	45
	Max. Depth (ft)	43	41
	Volume (Acre-ft)	346	738
	Mean Depth (ft)	25	17
Vegetation	**Number of Native Species (all survey years combined)**	33	38
	Non-Native Species	Curly-leaf pondweed, Eurasian watermilfoil, narrow-leaved cattail, pale-yellow iris, purple loosestrife, reed canary grass	
Water Quality	**Trophic State**	Mesotrophic	Mesotrophic
	Limiting Nutrient	Phosphorus	Phosphorus
	pH	8.6	8.4
	Sensitivity to Acid Rain	Not sensitive	Not sensitive
	Watershed to Lake Area Ratio	2:1	5:1

A description from the City of Waupaca webpage states: The Friends of Mirror Shadow Lakes is a group of concerned neighbors that work together to promote the health of the lakes. The Friends formed through a Lake Study Grant in 2003. This grant recommended that a citizen's group form, to continue to monitor and watch the overall health of the lake, as well as addressing new concerns and issues.

Members of the Friends group currently collect water quality data from the lakes as part of the Citizen's Lake Monitoring Network, and voluntarily assist with hand-removal of EWM and CLP.

The Waupaca Inland Lakes Protection & Rehabilitation District (WILPRD) has partnered with the Friends of Mirror Shadow Lakes and Waupaca County to complete this project and result in an updated Comprehensive Lake Management Plan for the lakes.

2.0 STAKEHOLDER PARTICIPATION

Stakeholder participation is an important part of any management planning exercise. During this project, stakeholders were not only informed about the project and its results, but also introduced to important concepts in lake ecology. The objective of this component in the planning process is to accommodate communication between the planners and the stakeholders. The communication is educational in nature, both in terms of the planners educating the stakeholders and vice-versa. The planners educate the stakeholders about the planning process, the functions of their lake ecosystem, their impact on the lake, and what can realistically be expected regarding the management of the aquatic system. The stakeholders educate the planners by describing how they would like the lake to be, how they use the lake, and how they would like to be involved in managing it. All of this information is communicated through multiple meetings that involve the lake group as a whole or a focus group called a Planning Committee and the completion of a stakeholder survey.

The highlights of this component are described below. Materials used during the planning process can be found in Appendix A.

General Public Meetings

The general public meetings were used to raise project awareness, gather comments, create the management goals and actions, and deliver the study results. These meetings were open to anyone interested and were generally held during the summer, on a Saturday, to achieve maximum participation.

Kick-off Meeting

In June 2020, a recorded project kick-off meeting was distributed to introduce the project to the general public. The meeting was announced through hosting on Onterra's YouTube website and shared by the Mirror Shadow Lake planning committee members. The video includes a presentation given by Todd Hanke and Brenton Butterfield, aquatic ecologists with Onterra. The presentation started with an educational component regarding general lake ecology and ended with a detailed description of the project including opportunities for stakeholders to be involved.

Project Wrap-up Meeting

An in-person project wrap-up meeting was conducted on the morning of August 13, 2022 at the Waupaca City Hall. During this meeting, Onterra staff presented the highlights of the management planning project and reviewed and discussed the items listed in the implementation plan.

Committee Level Meetings

Planning Committee Meeting I

On July 26, 2021, Onterra staff met with volunteer members from around Mirror and Shadow lakes comprising the Planning Committee for this project. During this approximate three-hour meeting, Onterra presented the results of the studies that have taken place and answered questions about Mirror and Shadow lakes. Following the meeting, committee members were tasked with reviewing the stakeholder survey results and compiling challenges they see facing the lake and the groups' ability to manage it.

Planning Committee Meeting II

On August 26, 2021, Onterra staff met once again with members serving on the Planning Committee for this project. During this approximately three-hour meeting, discussions revolved around meeting the challenges facing Mirror and Shadow lakes and developing a framework of management goals meant to meet these challenges. Specific actions were considered and facilitators were selected to oversee the completion of the action steps that were developed.

Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to planning committee members, Friends of Mirror & Shadow Lakes members, and riparian property owners around Mirror and Shadow lakes. The survey was designed by Onterra staff and planning committee members, and reviewed by a WDNR social scientist. During October-November of 2020, the eight-page, 35-question survey was posted online through Survey Monkey for stakeholders to answer electronically. If requested, a hard copy was sent to the survey-taker with a self-addressed stamped envelope for returning the survey anonymously. The returned hardcopy surveys were entered into the online version by a third-party for analysis. Thirty-eight percent of the surveys were returned. Please note that typically a benchmark of a 60% response rate is required to portray population projections accurately, and make conclusions with statistical validity. The data were analyzed and summarized by Onterra for use at the planning meetings and within the management plan. The full survey and results can be found in Appendix B, while discussion of those results is integrated within the appropriate sections of the management plan, and a general summary is discussed below.

Based upon the results of the Stakeholder Survey, much was learned about the people who use and care for Mirror and Shadow lakes. Eighty-six percent of respondents indicated that they live on the lake year-round, while 5% use it only part of the year. The remaining 9% indicated uses other than the available choices. Forty-one percent of respondents have owned their property for between 11-25 years, and 23% have owned their property for over 25 years.

Some of the top recreational activities on the lake include swimming, relaxing and entertaining, and the use of a non-motorized vessels (Question #15). The number one concern of survey respondents was the introduction of aquatic invasive species, followed by water quality degradation (Question # 16).

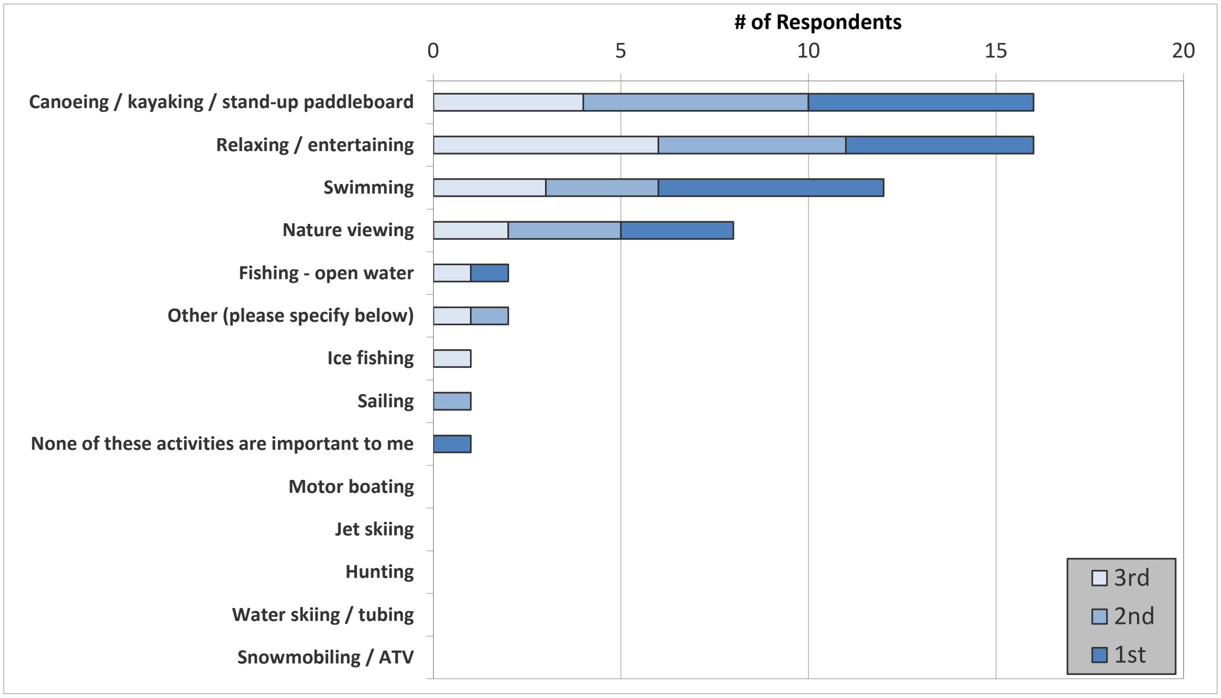
Management Plan Review and Adoption Process

On January 28, 2022, a draft of the Implementation Plan was sent to the Planning Committee for review. The Committee submitted comments after which Onterra made edits and updates to the draft. A second draft of the Implementation Plan was issued to the Committee on March 17, 2022. The Planning Committee provided final comments and accepted the Implementation Plan in late-March 2022.

The Official First Draft of the Management Plan was compiled in late-March 2022 and distributed to WDNR, County, FMSL, and other local project partners for official review. Official comments were received from WDNR on May 13, 2022. Onterra integrated WDNR comments and created a comment-response document (Appendix F) on July 12, 2022. The Plan was posted online for a

21-day public review and comment period in August 2022. No additional comments were received during the public review period.

Question 15: Please rank up to three activities that are important reasons for owning your property on or near Mirror and Shadow Lakes.



Question 16: Please rank your top three concerns regarding Mirror and Shadow Lakes.

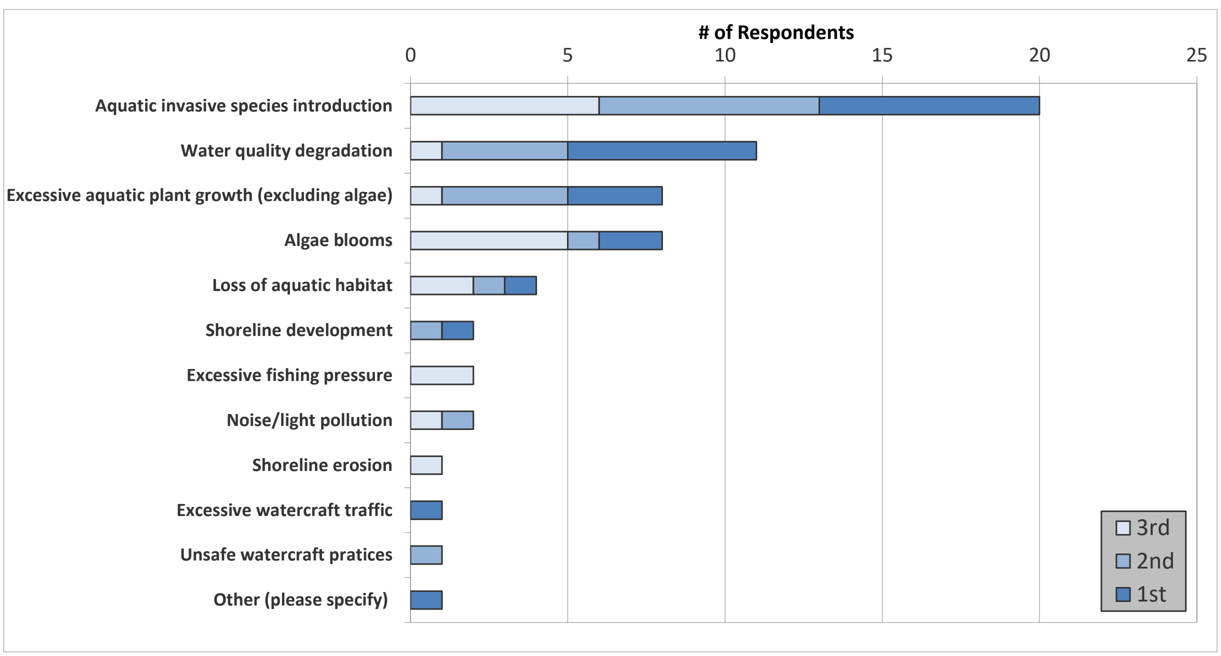


Figure 2.0-2. Select survey responses from the Mirror and Shadow lakes Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

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3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Primer on Water Quality Data Analysis and Interpretation

Reporting of water quality assessment results can often be a difficult and ambiguous task. Foremost is that the assessment inherently calls for a baseline knowledge of lake chemistry and ecology. Many of the parameters assessed are part of a complicated cycle and each element may occur in many different forms within a lake. Furthermore, water quality values that may be considered poor for one lake may be considered good for another because judging water quality is often subjective. However, focusing on specific aspects or parameters that are important to lake ecology, comparing those values to similar lakes within the same region and historical data from the study lake provides an excellent method to evaluate the quality of a lake's water.

Many types of analyses are available for assessing the condition of a particular lake's water quality. In this document, the water quality analysis focuses upon attributes that are directly related to the productivity of the lake. In other words, the water quality that impacts and controls the fishery, plant production, and even the aesthetics of the lake are related here. Specific forms of water quality analyses are used to indicate not only the health of the lake, but also to provide a general understanding of the lake's ecology and assist in management decisions. Each type of available analysis is elaborated on below.

As mentioned above, chemistry is a large part of water quality analysis. In most cases, listing the values of specific parameters really does not lead to an understanding of a lake's water quality, especially in the minds of non-professionals. A better way of relating the information is to compare it to lakes with similar physical characteristics and lakes within the same regional area. In this document, a portion of the water quality information collected on Mirror and Shadow lakes is compared to other lakes in the state with similar characteristics as well as to lakes within the northern region (Appendix C). The assessment can also be clarified by limiting the primary analysis to parameters that are important in the lake's ecology and trophic state (see below). Three primary water quality parameters are focused upon in the water quality analysis:

> **Phosphorus** is the primary nutrient that regulates the growth of planktonic algae and some larger, vascular plants (macrophytes) in the vast majority of Wisconsin lakes. Monitoring and evaluating concentrations of phosphorus within the lake helps to create a better understanding of the current and potential growth rates of the plants within the lake.
>
> **Chlorophyll-*a*** is the green pigment in plants used during photosynthesis. Chlorophyll-*a* concentrations are directly related to the abundance of free-floating algae in the lake. Chlorophyll-*a* values increase during algal blooms.
>
> **Secchi disk transparency** is a measurement of water clarity. Of all limnological parameters, it is the most frequently employed and the easiest for non-professionals to understand. Furthermore, measuring Secchi disk transparency over long periods of time is one of the best methods of monitoring the health of a lake. The measurement is conducted by lowering a weighted, 20-cm diameter disk with alternating black and white quadrants (a Secchi disk) into the water and recording the depth just before it disappears from sight.

These three parameters are often correlated with one another. Phosphorus controls algal abundance, which is measured by chlorophyll-*a* levels. Water clarity, as measured by Secchi disk transparency, is directly affected by the particulates that are suspended in the water. In the majority of natural Wisconsin lakes, the primary particulate matter is algae; therefore, algal abundance directly affects water clarity. In addition, studies have shown that water clarity is used by most lake users to judge water quality – clear water equals clean water (Canter et al.1994; Dinius 2007; Smith et al. 1991).

Trophic State

Total phosphorus, chlorophyll-*a*, and water clarity values are directly related to the trophic state of the lake. As nutrients, primarily phosphorus, accumulate within a lake, its productivity increases and the lake progresses through three trophic states: oligotrophic, mesotrophic, and finally eutrophic. Oligotrophic lakes have the lowest amounts of nutrients and biological productivity, and are generally characterized by having high water clarity and a lower abundance of aquatic plants. Mesotrophic lakes have moderate levels of nutrients and biological productivity and generally support more abundant aquatic plant growth. Eutrophic lakes have higher levels of nutrients and biological productivity, and generally have a high abundance of aquatic plants.

Most lakes will naturally progress through these states under natural conditions (i.e., not influenced by the activities of humans), but this process can take tens of thousands of years. Unfortunately, human development of watersheds and the direct discharge of nutrient-rich effluent has accelerated this natural aging process in many Wisconsin lakes, and this is termed cultural eutrophication. The excessive input of nutrients through cultural eutrophication has resulted in some lakes becoming hypereutrophic. Hypereutrophic lakes have the highest levels of nutrients and biological productivity. These lakes are typically dominated by algae, have very poor water clarity, and little if any aquatic plant growth.

It is important to note that both natural factors and human activity can affect a lake's trophic state, and that some lakes can be naturally eutrophic. Monitoring the trophic state of a lake gives stakeholders a method by which to gauge the productivity of their lake over time. Yet, classifying a lake into one of three trophic states often does not give clear indication of where a lake really exists in its trophic progression because each trophic state represents a range of productivity. Therefore, two lakes classified in the same trophic state can actually have very different levels of production.

However, through the use of a trophic state index (TSI), an index number can be calculated using phosphorus, chlorophyll-*a*, and Secchi disk depth values that represent the lake's position within the eutrophication process. This allows for a clearer understanding of the lake's trophic state while facilitating clearer long-term tracking. (Carlson, 1977) presented a trophic state index that gained great acceptance among lake managers.

Limiting Nutrient

The limiting nutrient is the nutrient which is in shortest supply and controls the growth rate of algae and some larger vascular plants within the lake. This is analogous to baking a cake that requires four eggs, and four cups each of water, flour, and sugar. If the baker would like to make four cakes, they need 16 of each ingredient. If they are short two eggs, they will only be able to make three cakes even if they have sufficient amounts of the other ingredients. In this scenario, the eggs are the limiting nutrient (ingredient).

In most Wisconsin lakes, phosphorus is the limiting nutrient controlling the production of plant biomass. As a result, phosphorus is often the target for management actions aimed at controlling plants, especially algae. The limiting nutrient is determined by calculating the nitrogen to phosphorus ratio within the lake. Normally, total nitrogen and total phosphorus values from the surface samples taken during the summer months are used to determine the ratio. Results of this ratio indicate if algal growth within a lake is limited by nitrogen or phosphorus. If the ratio is greater than 15:1, the lake is considered phosphorus limited; if it is less than 10:1, it is considered nitrogen limited. Values between these ratios indicate a transitional limitation between nitrogen and phosphorus.

Temperature and Dissolved Oxygen Profiles

Temperature and dissolved oxygen profiles are created simply by taking readings at different water depths within a lake. Although it is a simple procedure, the completion of several profiles over the course of a year or more provides a great deal of information about the lake. Much of this information relates to whether the lake thermally stratifies or not, which is determined primarily through the temperature profiles. Lakes that show strong stratification during the summer and winter months often need to be managed differently than lakes that do not. Normally, deep lakes stratify to some extent, while shallow lakes (less than 17 feet deep) do not.

Lake stratification occurs when temperature and density gradients are developed with depth in a lake. During stratification, the lake can be broken into three layers: The ***epilimnion*** is the surface layer with the lowest density and has the warmest water in the summer months and the coolest water in the winter months. The ***hypolimnion*** is the bottom layer the highest density and has the coolest water in the summer months and the warmest water in the winter months. The ***metalimnion***, often called the thermocline, is the layer between the epilimnion and hypolimnion where temperature changes most rapidly with depth.

Dissolved oxygen is essential in the metabolism of nearly every organism that exists within a lake. For instance, fish kills are often the result of insufficient amounts of dissolved oxygen. However, dissolved oxygen's role in lake management extends beyond this basic need by living organisms. In fact, its presence or absence impacts many chemical processes that occur within a lake. Internal nutrient loading is an excellent example that is described below.

Internal Nutrient Loading

In general, lakes tend to act as phosphorus sinks, meaning they tend accumulate phosphorus over time and export less phosphorus than the amount that is loaded to the lake from its watershed. In most lakes, there is a net movement of phosphorus from the water to bottom sediments where it accumulates over time. The retention of this phosphorus within bottom sediments depends on a number of physical, chemical, and biological factors (Wetzel, 2001). If this phosphorus remains bound within bottom sediments, it is largely unavailable for biological use. However, under certain conditions, this phosphorus can be released from bottom sediments into the overlying water where it may become biologically available. This release of phosphorus (and other nutrients) from bottom sediments into the overlying water is termed *internal nutrient loading*. While phosphorus can be released from bottom sediments under a few varying conditions, it occurs most often when the sediment-water interface becomes devoid of oxygen, or anoxic.

When water at the sediment-water interface contains oxygen, phosphorus largely remains bound to ferric iron within the sediment. When the water at the sediment-water interface becomes anoxic, or devoid of oxygen, ferric iron is reduced to ferrous iron and the bond between iron and phosphorus is broken. Under these conditions, iron and phosphorus are now soluble in water and are released from the sediments into the overlying water (Pettersson, 1998). Anoxia at the sediment-water interface typically first develops following thermal stratification, or the formation of distinct layers of water based on temperature and density.

As surface waters warm in late-spring/early summer, it becomes less dense and floats atop the colder, denser layer of water below. The large density gradient between the upper, warm layer of water (*epilimnion*) and lower, cold layer of water (*hypolimnion*) prevents these layers from mixing together and eliminates atmospheric diffusion of oxygen into bottom waters. If there is a high rate of biological decomposition of organic matter in the bottom sediments, anoxic conditions within the hypolimnion can develop as oxygen is consumed and is not replaced through mixing. The loss of oxygen then results in the release of phosphorus from bottom sediments into the hypolimnion.

The development of an anoxic hypolimnion and subsequent release of phosphorus from bottom sediments occurs in many lakes in Wisconsin. However, in deeper, dimictic lakes which remain stratified during the summer, internal nutrient loading is often not problematic as the majority of the phosphorus released from bottom sediments is confined within the hypolimnion where it is largely inaccessible to phytoplankton at the surface. Dimictic lakes are those which remain stratified throughout the summer (and winter) and experience only two complete mixing events (turnover) per year, one in spring and one in fall. In dimictic lakes, phosphorus released from bottom sediments into the hypolimnion during stratification only becomes available to phytoplankton in surface waters during the spring and fall mixing events. While these spring and fall mixing events can stimulate diatom and golden-brown phytoplankton blooms, these mixing events generally to not stimulate cyanobacterial (blue-green algae) blooms because water temperatures are cooler.

Internal nutrient loading can become problematic in lakes when sediment-released phosphorus becomes accessible to phytoplankton during the summer months when surface temperatures are at their warmest. Sediment-released phosphorus can be mobilized to surface waters during the summer in polymictic lakes, or lakes which have the capacity to experience multiple stratification and mixing events over the course of the growing season. Some polymictic lakes tend to straddle the boundary between deep and shallow lakes, and have the capacity to break stratification in summer when sufficient wind energy is generated. Consequently, phosphorus which has accumulated in the anoxic hypolimnion during periods of stratification is mobilized to the surface during partial or full mixing events where it then can spur nuisance phytoplankton blooms at the surface.

Phosphorus from bottom waters can also be mobilized to the surface in polymictic lakes through entrainment, or the continual deepening of the epilimnion and erosion of the metalimnion below (Wetzel, 2001). Wind-driven water generates turbulence across the thermal barrier between the epilimnion and the metalimnion and the metalimnion is eroded, mixing sediment-released nutrients into the epilimnion above. Both periodic mixing and entrainment act as “nutrient pumps” in polymictic lakes, delivering sediment-released nutrients in bottom waters to surface waters (Orihel, et al., 2015). While a continuum exists between dimictic and polymictic lakes, the Osgood Index (Osgood, 1988) is used to determine the probability that a lake will remain stratified during the summer. This probability is estimated using the ratio of the lake's mean depth to its surface area. Lakes with an Osgood Index of less than 4.0 are deemed polymictic. Mirror and Shadow lakes have Osgood Index values of 31.7 and 12.3, respectively, indicating both lakes are dimictic, remaining stratified during the summer and mixing two times per year.

To determine if internal nutrient loading occurs and has a detectable effect on these lakes' water quality, the dynamics of near-surface phosphorus concentrations over the course of the growing season were examined. In dimictic lakes that experience internal nutrient loading, near-surface concentrations will often be highest in the fall following fall turnover when the phosphorus-rich bottom waters are mixed throughout the water column. In shallower lakes that experience internal loading and periodic mixing throughout the growing season, near-surface phosphorus concentrations will often increase over the course of the growing season as sediment-released phosphorus is periodically mobilized to the surface. In addition, near-bottom phosphorus concentrations are also measured during periods of stratification to determine if significant levels of phosphorus are accumulating in bottom waters.

Finally, watershed modeling was used to determine if measured phosphorus concentrations were similar to those predicted based on watershed size, land cover, and precipitation. If predicted phosphorus concentrations are significantly lower than those measured, this indicates that source(s) of phosphorus are entering the lake that were not accounted for in the model. This unaccounted source of phosphorus is often attributable to the internal loading of phosphorus.

Comparisons with Other Datasets

The WDNR document *Wisconsin 2018 Consolidated Assessment and Listing Methodology* (WDNR, Wisconsin 2018 Consolidated Assessment and Listing Methodology (WisCALM), 2018) is an excellent source of data for comparing water quality from a given lake to lakes with similar features and lakes within specific regions of Wisconsin. Water quality among lakes, even among lakes that are located in close proximity to one another, can vary due to natural factors such as depth, surface area, the size of its watershed and the composition of the watershed's land cover. For this reason, the water quality of Mirror and Shadow lakes is compared to lakes in the state with similar physical characteristics.

The WDNR classifies Wisconsin's lakes into ten natural communities based on size, hydrology, and depth (Figure 3.1-1). First, the lakes are classified into three main groups: (1) lakes and reservoirs less than 10 acres, (2) lakes and reservoirs greater than or equal to 10 acres, and (3) a classification that addresses special waterbody circumstances. The last two categories have several sub-categories that provide attention to lakes that may be shallow, deep, play host to cold water fish species or have unique hydrologic patterns. Overall, the divisions categorize lakes based upon their size, stratification characteristics, and hydrology. An equation developed by (Lathrop & Lillie, 1980), which incorporates the maximum depth of the lake and the lake's surface area, is used to predict whether the lake is considered a shallow (mixed) lake or a deep (stratified) lake. The lakes are further divided into classifications based on their hydrology and watershed size:

Seepage Lakes have no surface water inflow or outflow in the form of rivers and/or streams.

Drainage Lakes have surface water inflow and/or outflow in the form of rivers and/or streams.

Headwater drainage lakes have a watershed of less than 4 square miles.

Lowland drainage lakes have a watershed of greater than 4 square miles.

Using these criteria, both Mirror and Shadow lakes are classified as a deep (stratified) headwater drainage lakes (class 3). The water quality from Mirror and Shadow lakes will be compared to water quality of other deep headwater drainage lakes in Wisconsin.

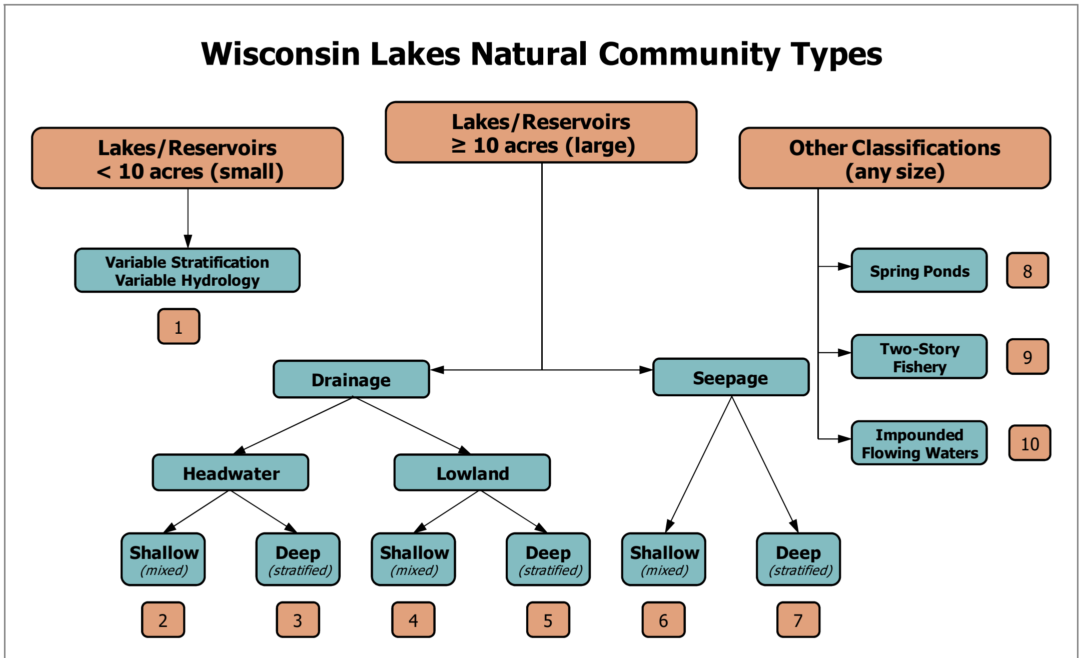

Figure 3.1-1. Wisconsin Lake Natural Communities. Mirror and Shadow lakes are classified as deep headwater drainage lakes (class 3).

Garrison et al. 2008 developed state-wide median values for total phosphorus, chlorophyll-*a*, and Secchi disk transparency for six of the lake classifications. Though they did not sample sufficient lakes to create median values for each classification within each of the state's ecoregions, they were able to create median values based on all of the lakes sampled within each ecoregion (Figure 3.1-2). Ecoregions are areas related by similar climate, physiography, hydrology, vegetation and wildlife potential. Comparing ecosystems in the same ecoregion is sounder than comparing systems within manmade boundaries such as counties, towns, or states. Mirror and Shadow lakes are within the North Central Hardwood Forests (NCHF) ecoregion of Wisconsin (Figure 3.1-2).

The Wisconsin Consolidated Assessment and Listing Methodology document also helps stakeholders understand the health of their lake compared to other lakes within the state. Looking at pre-settlement diatom population compositions from sediment cores collected from numerous lakes around the state, they were able to infer a reference condition for each lake's water quality prior to human development within their watersheds. Using these reference conditions and current water quality data, the assessors were able to rank phosphorus, chlorophyll-*a*, and Secchi disk transparency values for each lake class into categories ranging from excellent to poor.

These data along with data corresponding to statewide natural lake means, historical, current, and average data from Mirror and Shadow lakes are displayed and discussed in the subsequent section. *Growing season* refers to data collected at any time between April and October, while *summer* refers to data collected in June, July, or August. Most of the data were collected from near-surface samples as these represent the depths at which algae grow.

Most of the data presented in the following section were collected by volunteers through the WDNR Citizens Lake Monitoring Network. Onterra ecologists collected supplemental data in 2020/2021 as part of this lake management planning project. All data presented in this section were collected at each lake's deep hole sampling location.

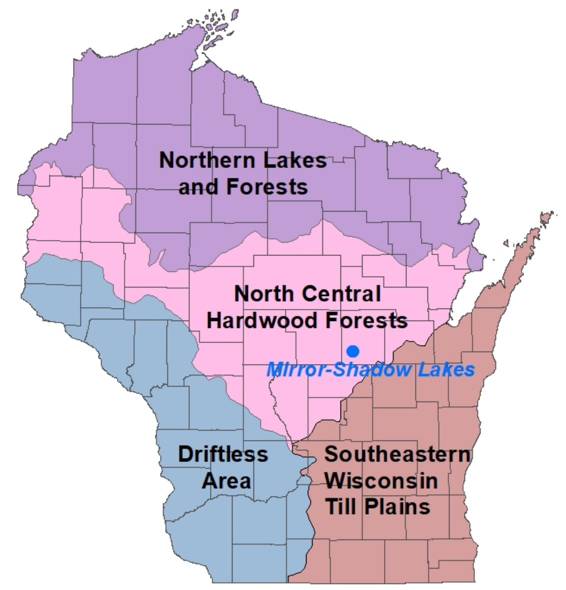

Figure 3.1-2. Location of Mirror and Shadow lakes within the ecoregions of Wisconsin. After Nichols 1999.

Mirror and Shadow Lake Water Quality Analysis

Mirror Lake Long-term Trends

During the 1970s there was considerable limnological study done on Mirror Lake because of the algal blooms during spring and fall turnover and the frequent winter fish kills. It was found that storm sewers that discharged into the lake were contributing enough phosphorus to fuel these algal blooms. In 1976 the storm sewers were diverted into the Waupaca River away from Mirror and Shadow lakes. Because of the phosphorus release from the bottom sediments in both lakes an alum treatment was done in the lakes in May 1978. The purpose of this treatment was to accelerate the improvement in water quality conditions that were expected to result from the storm sewer diversion. Alum largely eliminates sediment phosphorus release because iron bound phosphorus is replaced with aluminum bound phosphorus. Phosphorus associated with iron is susceptible to sediment release during anoxic conditions because iron is transformed from the insoluble iron +3 state to iron +2 state which is soluble in water. As the iron moves from the sediments into the overlying water, phosphorus also is released. Insoluble aluminum bound phosphorus does not experience a transformation under anoxic conditions.

The studies also found that the driver of the winter fish kills was the high chemical and biological oxygen demand that occurred during fall turnover in Mirror Lake. In years when turnover occurred within a few days of the onset of ice cover, dissolved oxygen concentrations were low, often less than 5 mg/L, at the beginning of ice cover and in those years a fish kill occurred. To provide maximum oxygen in the water prior to the formation of ice cover, a destratification system was installed and operated for at least 3 weeks during November. This destratification system was also operated in the spring to enhance spring turnover which rarely occurred.

There is considerable total phosphorus data are available for Mirror Lake for the period 1977-1982 and then more limited summer data in 2001 and 2003. Phosphorus data during spring and fall turnover is available for the period 2010-2017, and Onterra staff collected data in 2020. The diversion of the storm sewers and the alum treatment resulted in a considerable reduction in summer phosphorus concentrations. Prior to the treatments the phosphorus was in the *good* range but following the alum treatment in 1978 through 2020, phosphorus concentrations have been in the *excellent* range (Figure 3.1-3). The summer average phosphorus concentration for the period 1978-82 was 16.4 µg/L, and in July 2020 it was 14.6 µg/L indicating that the storm sewer diversion and alum treatment is still effective. The 2020 summer phosphorus concentration is similar to the median concentration of other deep headwater drainage lakes and much lower than the median value (52 µg/L) for all lake types in the Northcentral Hardwood Forest Ecoregion (NCHF).

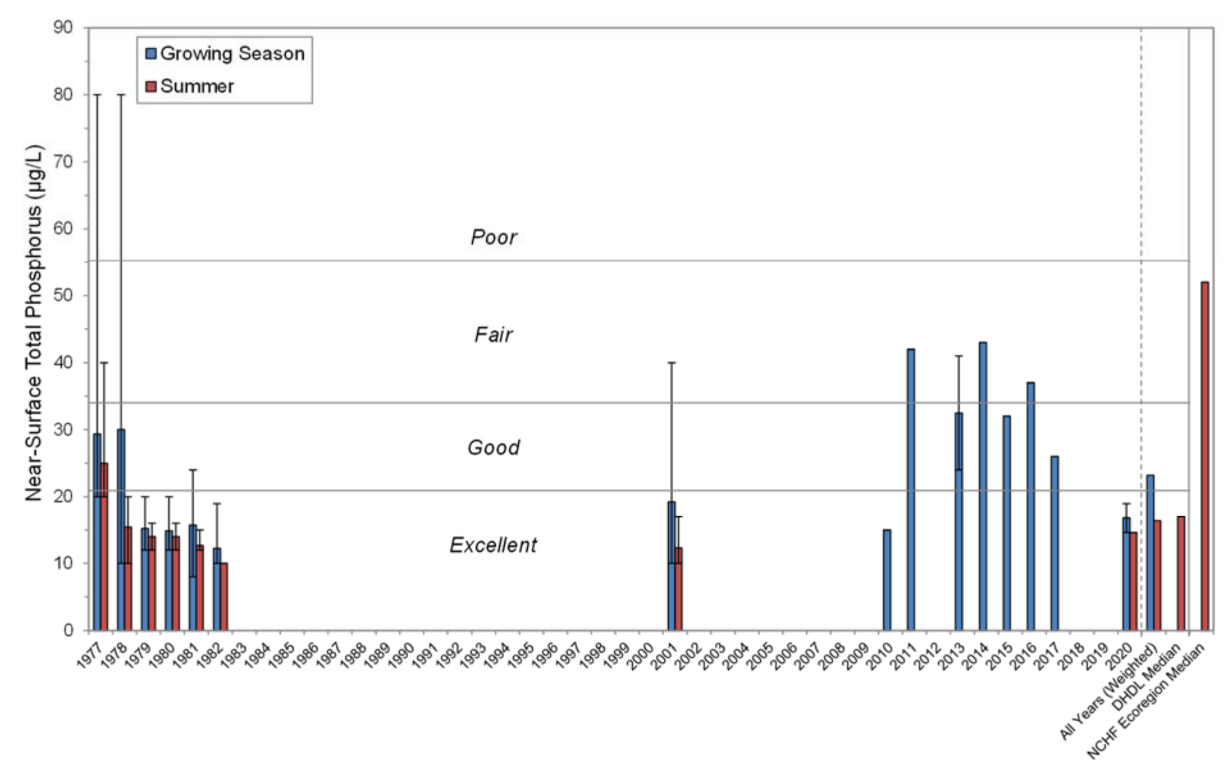

Figure 3.1-3. Mirror Lake, statewide headwater drainage lakes and regional total phosphorus concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

During the period 2011-2017 samples were mostly collected during spring turnover when phosphorus concentrations were higher. These higher concentrations likely are the result of elevated levels of the red colored alga *Planktothrix rubescens* (formerly called *Oscillatoria rubescens*). This alga prefers cool temperatures and during the summer is found near the top of the hypolimnion. During turnover it is brought to the surface waters. In the spring with high light levels and phosphorus which enters the lake during spring runoff, the alga blooms resulting in elevated phosphorus levels. With the onset of stratification, the alga moves down into the hypolimnion taking much of the phosphorus with it.

Figure 3.1-4 shows the long-term concentrations in the top and bottom of Mirror Lake. Phosphorus concentrations following the alum treatment were significantly reduced in the bottom waters and they remain low 43 years later. The alum treatment combined with the storm sewer diversion is still effective in keeping phosphorus concentrations in the excellent range. If the alum treatment was no longer effective phosphorus levels in the bottom waters would be much higher, likely over 500 µg/L.

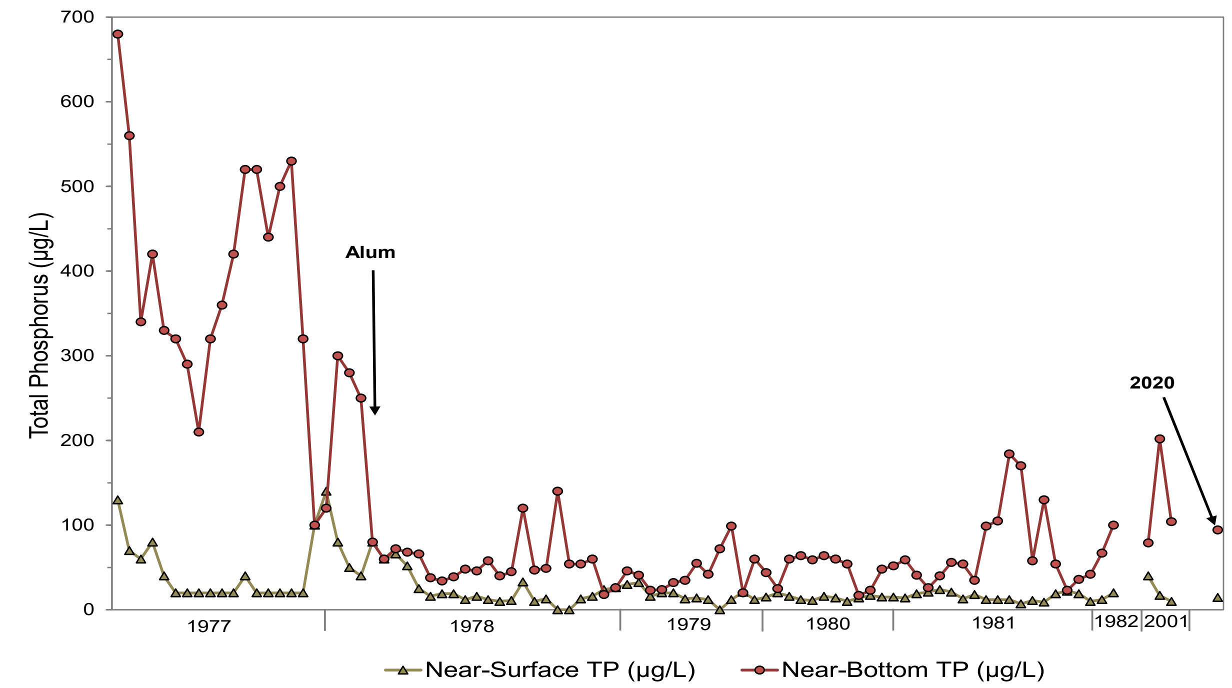

Figure 3.1-4. Mirror Lake total phosphorus concentrations in the top and bottom waters. Concentrations in the bottom samples were greatly reduced following the alum treatment in 1978 and have remained low through 2020.

Summer chlorophyll-*a* concentrations, a measure of phytoplankton abundance, are available in Mirror Lake for most of the time period as phosphorus concentrations, 1977-82, 2001, and 2020 (Figure 3.1-5). The July chlorophyll-*a* concentration in 2020 was 3.04 µg/L, placing the lake in the *excellent* category, for deep headwater drainage lakes in Wisconsin. The 2020 summer phosphorus concentration is similar to the median concentration of other deep headwater drainage lakes and much lower than the median value (15.2 µg/L) for all lake types in the NCHF ecoregion.

Secchi disk transparency data, a measure of water clarity, are available from Mirror Lake for more years than either phosphorus or chlorophyll-*a*: 1979, 1998-2001, and 2006-2020 (Figure 3.1-6). The summer Secchi disk transparency places the lake in the *excellent* category for all years with the exception of 2007. The summer long-term average is 10.6 feet which is very similar to the median value for other deep headwater drainage lakes and much better than all lake types in the NCHF ecoregion (5.3 feet).

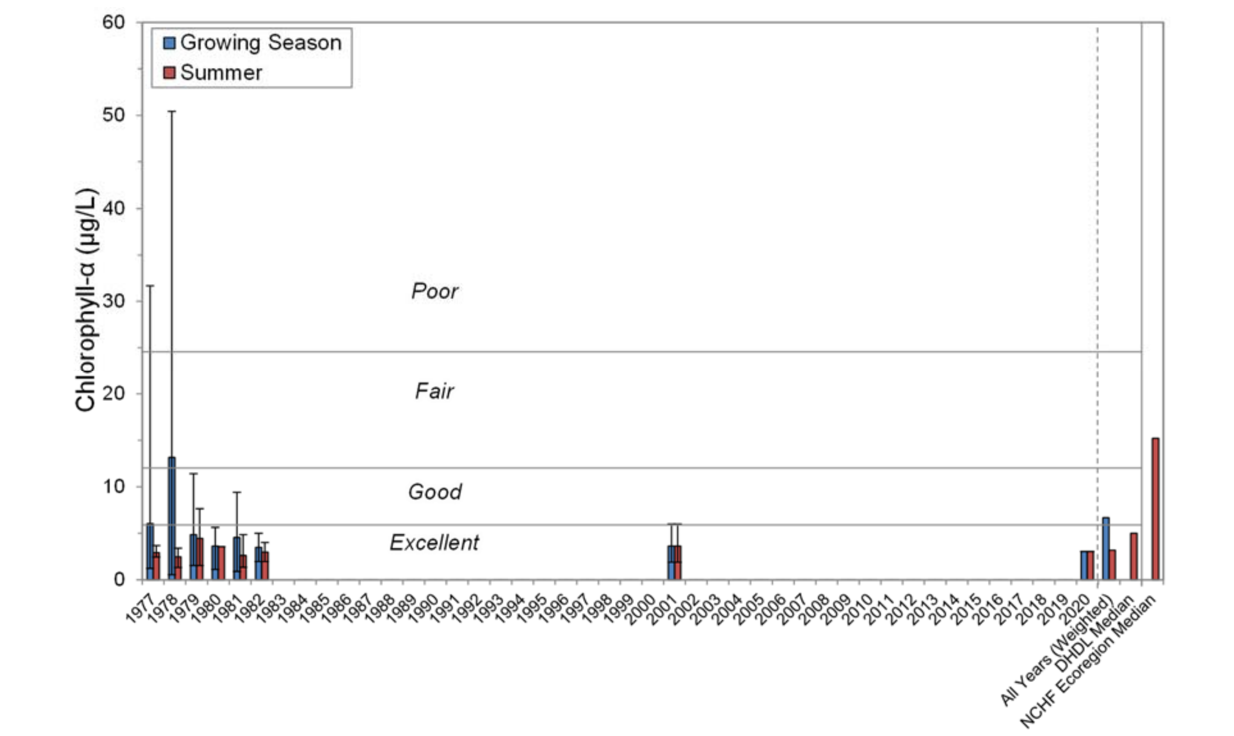

Figure 3.1-5. Mirror Lake, statewide headwater drainage lakes and regional chlorophyll-*a* concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

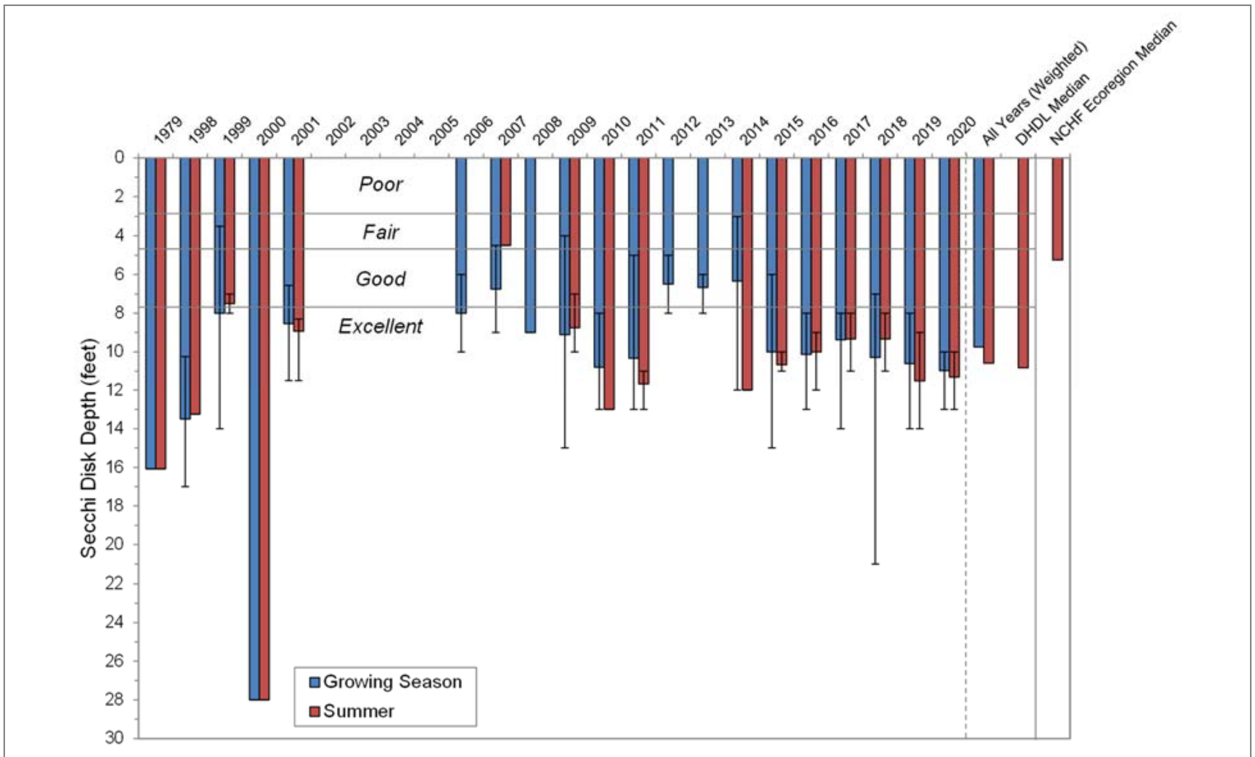

Figure 3.1-6. Mirror Lake, statewide headwater drainage lakes and regional Secchi disk clarity values. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Limiting Plant Nutrient of Mirror Lake

Using mid-summer nitrogen and phosphorus concentrations from Mirror Lake, a nitrogen:phosphorus ratio of 33:1 was calculated. This finding indicates that Mirror Lake is indeed phosphorus limited as are the vast majority of Wisconsin lakes. In general, this means that phosphorus is the primary nutrient regulating algal growth within the lake, and increases in phosphorus will likely result in increased algal production and lower water clarity. Watershed and shoreland conservation and/or restoration efforts for Mirror Lake should have a primary focus on limiting the input of phosphorus to the lake.

Mirror Lake Trophic State

The Trophic State Index (TSI) values for Mirror Lake were calculated using summer near-surface total phosphorus, chlorophyll-*a*, and Secchi disk transparency data collected as part of this project along with historical data (Figure 3.1-7). In general, the best values to use in judging a lake's trophic state are the biological parameters of total phosphorus and chlorophyll-*a* as Secchi disk transparency can be influenced by factors other than algae. Mirror Lake is solidly in the *mesotrophic* range. Mirror Lake's TSI is slightly better than other deep headwater drainage lakes and much better than most other lakes in the NCHF ecoregion which tend to be in the eutrophic range.

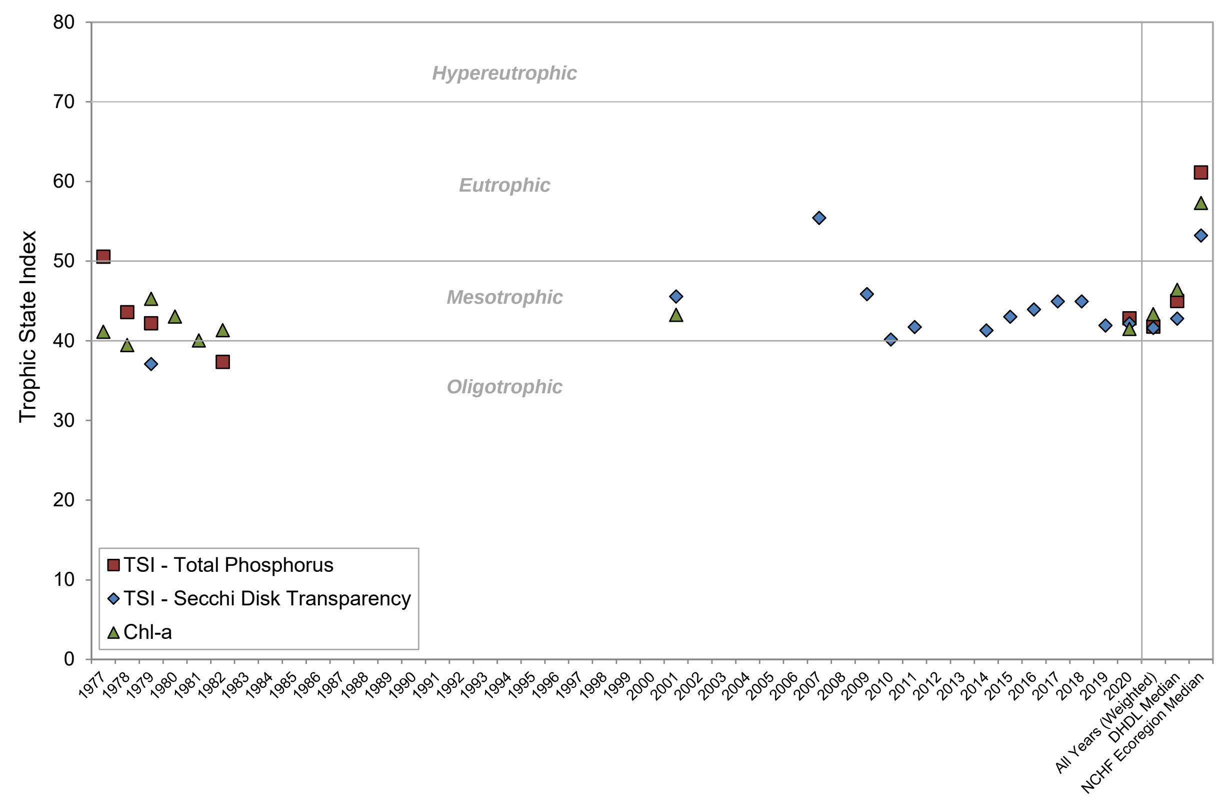

Figure 3.1-7. Mirror Lake, statewide headwater drainage lakes and regional Trophic State Index values. Values calculated with summer month surface sample data using WDNR PUB-WT-193.

Dissolved Oxygen and Temperature in Mirror Lake

Mirror Lake has an active volunteer collecting water quality samples; therefore, this project included one visit to the lake by Onterra staff to collect samples. Dissolved oxygen and temperature were measured during the visits and their profiles are displayed in Figure 3.1-8. Mirror Lake is *dimictic* meaning the lake mixes during the spring and fall but is stratified summer. As stated previously, prior to the installation of the destratification system in 1977 spring mixing rarely, if ever occurred and fall mixing was often insufficient to prevent winter fish kills.

In 2020, the destratification unit was sufficient in providing complete mixing in the spring and fall such that dissolved oxygen levels were as high as expected. There is a metalimnetic oxygen maxima in June and especially July. This is because there is a significant algal community in the metalimnion. It is likely that chlorophyll-*a* concentrations in the water column are highest in the metalimnion. Algal growth is elevated in at this depth since the upper waters are clear enough to allow sufficient light to reach the metalimnion to allow photosynthesis. Also, nutrient levels are often higher in this region and the cooler water is denser which retards the settling of algal cells out of the photic zone. The profile in February 2021 showed sufficient oxygen in the lake to support fish.

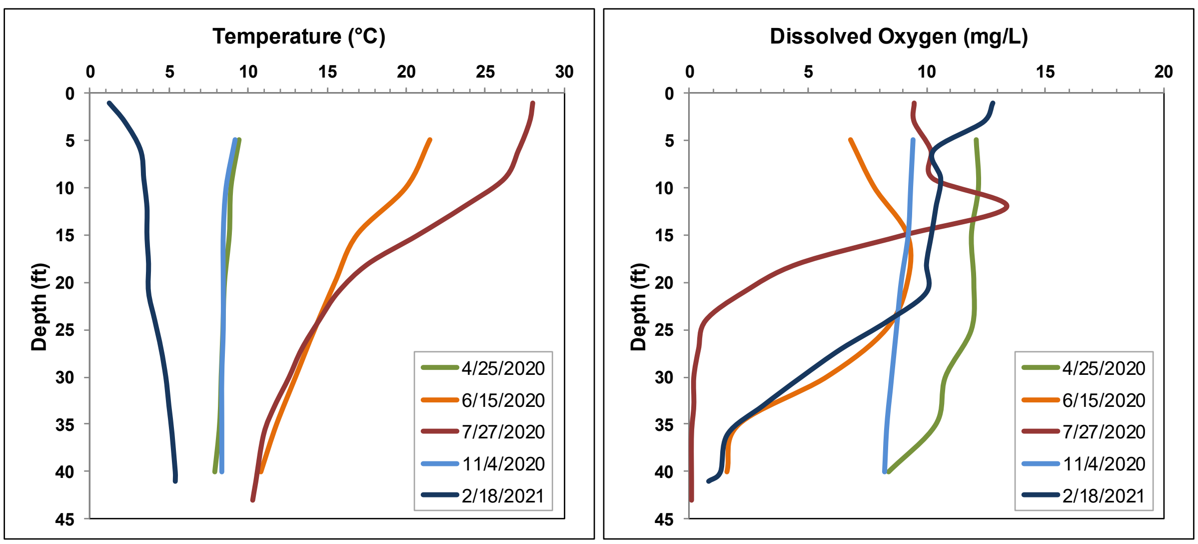

Figure 3.1-8. Temperature and dissolved oxygen profiles collected in Mirror Lake in 2020.

Additional Water Quality Data Collected at Mirror Lake

The water quality section is centered on lake eutrophication. However, parameters other than water clarity, nutrients, and chlorophyll-*a* were collected as part of the project. These other parameters were collected to increase the understanding of Mirror Lake's water quality and are recommended as a part of the WDNR long-term lake trends monitoring protocol. These parameters include pH, alkalinity, and calcium.

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-) and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic; meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl lakes. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985). The mid-summer pH of the water in Mirror Lake was found to be alkaline with a value of 8.6 and falls within the normal range for Wisconsin Lakes (Figure 3.1-9).

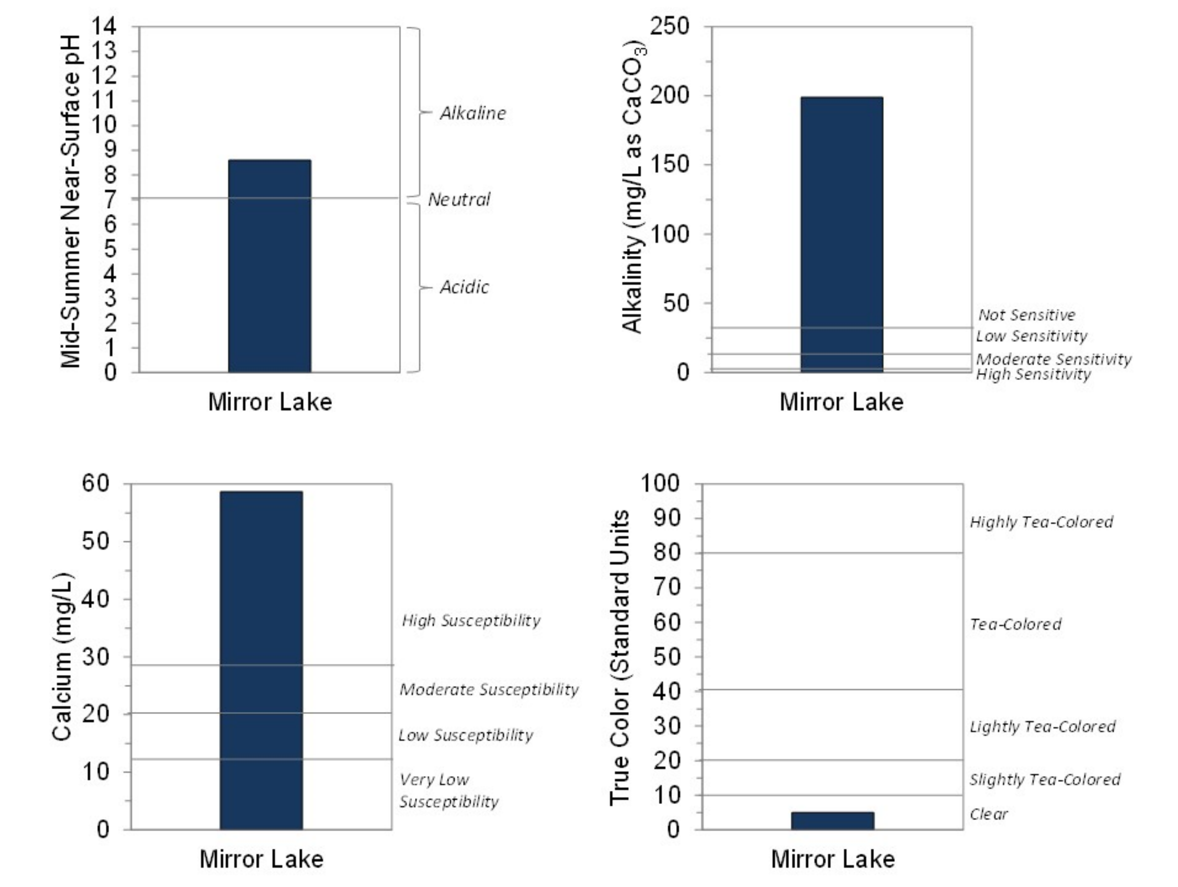

Figure 3.1-9. Additional water quality parameters collected on Mirror Lake: pH, alkalinity, calcium & zebra mussel susceptibility, and true color. Parameters collected from the near-surface.

Alkalinity is a lake's capacity to resist fluctuations in pH by neutralizing or buffering against inputs such as acid rain. The main compounds that contribute to a lake's alkalinity in Wisconsin are bicarbonate (HCO_3^-) and carbonate (CO_3^-), which neutralize hydrogen ions from acidic inputs. These compounds are present in a lake if the groundwater entering it comes into contact with minerals such as calcite ($CaCO_3$) and/or dolomite ($CaMgCO_3$). A lake's pH is primarily determined by the amount of alkalinity. Rainwater in northern Wisconsin is slightly acidic naturally due to dissolved carbon dioxide from the atmosphere with a pH of around 5.0. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The alkalinity in Mirror Lake was measured at 199 (mg/L as $CaCO_3$), indicating that the lake has a capacity to resist fluctuations in pH and is not sensitive to acid rain (Figure 3.1-9). Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed.

Recently, the combination of calcium concentration and pH has been used to determine what lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, so Mirror Lake's pH of 8.6 falls within this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. The calcium concentration of Mirror Lake was found to be 58.7 mg/L, falling in the *high susceptibility* range for zebra mussels (Figure 3.1-9). As is discussed further in this report, both Mirror and Shadow lake contain established populations of zebra mussels.

A measure of water clarity once all of the suspended material (i.e., phytoplankton and sediments) have been removed, is termed *true color*, and measures how the clarity of the water is influenced by dissolved components. True color was measured at 5 SU (standard units) in July, indicating the lake's water was *clear colored* in 2020 (Figure 3.1-9).

Chloride levels in Mirror Lake have been monitored in 1975, 1977, 1978, 1981, and annually from 2010-2020 (Figure 3.1-10). Chloride occurs naturally in Wisconsin's waters at low levels (2-3 mg/L). Higher levels of chloride or trends in increasing chloride levels have been associated with the application of chloride-based road salts (typically sodium chloride) within the lake's watershed (Dugan et al. 2017). Studies have shown that ecological impacts are often observed when chloride concentrations increase into the 100-1000s mg/L (Dugan et al. 2017), and the Canadian government considers concentrations within this range to be chronically toxic (exposure to elevated concentrations over extended time periods) (Evans and Frick, 2001).

Chloride concentrations in Mirror Lake from 1975-1981 were already elevated, ranging from 35-56 mg/L, indicating salinity was above normal levels at this time. Annual chloride monitoring from 2010-2020 shows there has been a significant, increasing trend in chloride levels over this period (Figure 3.1-10). Concentrations have increased from near 60 mg/L in 2010 to nearly 130 mg/L in 2020, an increase of 122%. Sodium concentrations show a similar trend, increasing from 37 mg/L in 2015 to 59.1 mg/L in 2020, an increase of 60%.

The WDNR has set the chronic toxicity criterion for chloride at 395 mg/L, over three times higher than the concentration measured in Mirror Lake in 2020. However, if the current increasing trend in chloride concentrations continue at the same level, this chronic concentration can be expected to be reached in approximately 40 years. However, as mentioned previously, the Canadian chronic toxicity level for chloride in lakes is 150 mg/L, and negative environmental impacts have been observed at 100 mg/L.

As is discussed further in the Aquatic Plant Section (Section 3.4), the plant studies completed on Mirror Lake in 2011, 2018, and 2020 indicate a degradation of ecological condition over this period. A number of species considered more sensitive to environmental disturbance have declined significantly or went undetected in 2020. In addition, disturbance-tolerant species which some studies have shown tend to increase in abundance with increasing salinity, were found to be more prevalent in 2020. The degradation of Mirror Lake's plant community over this period occurred despite no detectable change in nutrient levels or water clarity. It is possible that these changes in terms of a reduction in sensitive species and increase in disturbance-tolerant species are the result of the lake's increasing salinity over the past 11 years.

There are a number of pathways by which road salt may be entering Mirror Lake. Road salts can be carried by runoff into drainage ditches, streams, and wetlands, and eventually the lake soon after application. Salt which has accumulated in soils along roadsides can also be flushed into the lake following heavy precipitation events. Road salts can also leach into groundwater which makes its way into the lake. While Mirror Lake has a relatively small surface watershed at 42 acres, the UW-Stevens Point study (Turyk et al. 2004) found that Mirror Lake's groundwater watershed is significantly larger, encompassing an area of approximately 704 acres, underlying urban areas to the west-northwest. While this study did not determine the pathways by which road salts are entering Mirror Lake, it is likely through a combination of surface and groundwater inflow.

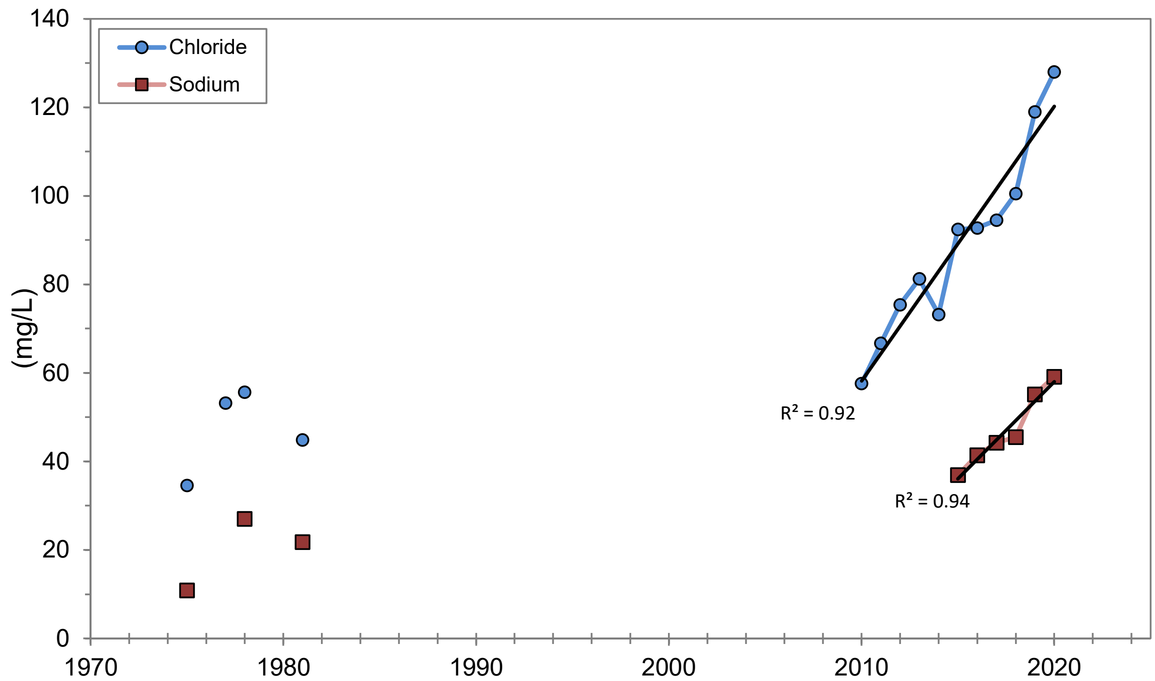

Figure 3.1-10. Mirror Lake chloride and sodium concentrations. The large increase since 2011 is likely the result of salt applied to roadways within the watershed.

Shadow Lake Long-term Trends

There is less data available for Shadow Lake compared with Mirror Lake. There is considerable data available for the period from 1977-1981 but much less data since then, especially during the summer. There were some data collected during spring and fall turnover periods but these data are not suitable to compare with other lakes in the state. A summer sample was collected by Onterra staff in July 2020. The diversion of the storm sewers and the alum treatment resulted in a considerable reduction in summer phosphorus concentrations. Prior to the treatments, phosphorus concentrations were in the *good* range with a summer average concentration of 23 µg/L. Following the alum treatment in 1978, phosphorus concentrations have been in the *excellent* range with a mean summer concentration of 12.9 µg/L (Figure 3.1-11). The storm sewer diversion and alum treatment are still effective after 43 years. The 2020 summer phosphorus concentration is slightly lower than the median concentration of other deep headwater drainage lakes (17 µg/L) and much lower than the median value (52 µg/L) for all lake types in the Northcentral Hardwood Forest Ecoregion (NCHF).

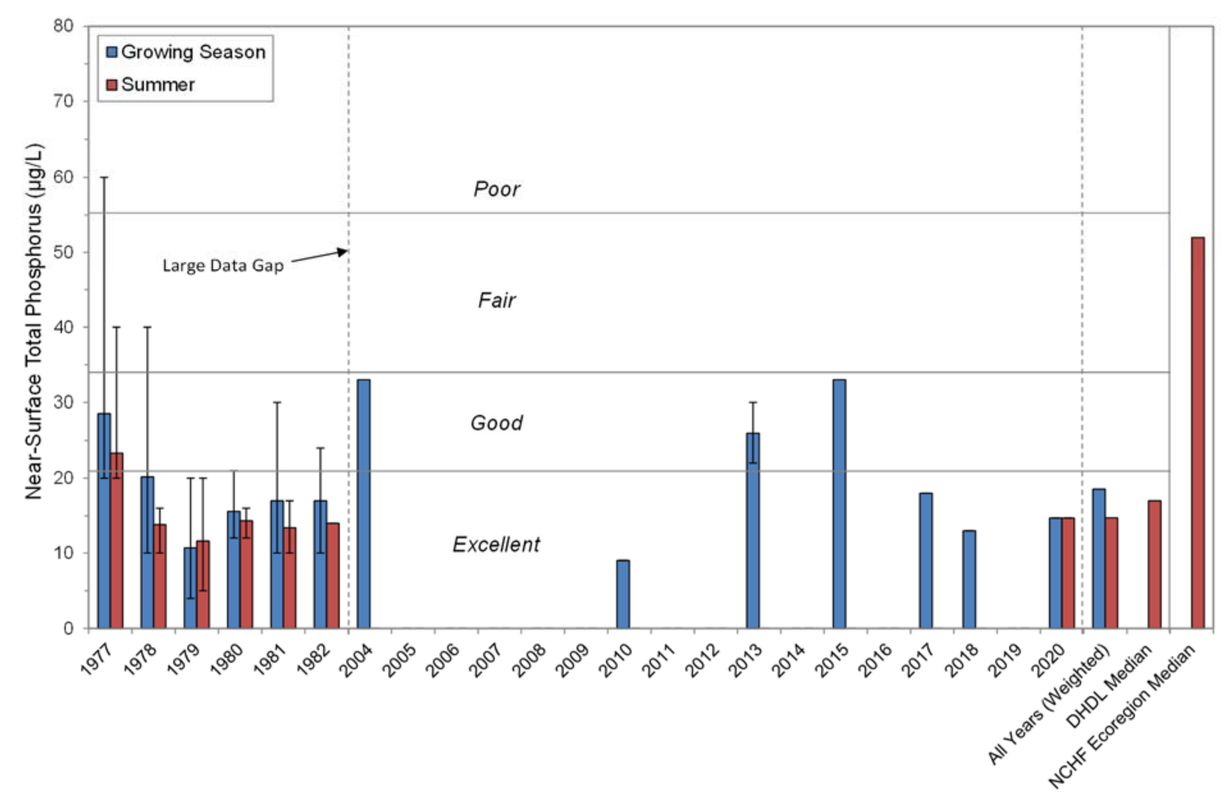

Figure 3.1-11. Shadow Lake, statewide headwater drainage lakes and regional total phosphorus concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

During the period 2003-04 and 2013-2017 samples were only collected during spring and fall turnover when phosphorus concentrations were higher. As in Mirror Lake, these higher concentrations likely are the result of elevated levels of the red colored alga *Planktothrix rubescens* (formerly called *Oscillatoria rubescens*). This alga prefers cool temperatures and during the summer is found near the top of the hypolimnion. During turnover it is brought to the surface waters. In the spring with high light levels and phosphorus which enters the lake during spring runoff, the alga blooms resulting in elevated phosphorus levels. With the onset of stratification, the alga moves down into the hypolimnion taking much of the phosphorus with it.

Figure 3.1-12 shows the long-term concentrations in the top and bottom of Shadow Lake. Phosphorus concentrations following the alum treatment were significantly reduced in the bottom waters following the alum treatment. In July 2020 the bottom concentration was similar to the pre-alum levels. This elevated value suggests that the alum treatment may no longer be effective in reducing the release of phosphorus from the sediment. However, the relatively low phosphorus concentration during fall turnover suggests that not a significant amount of internal loading is occurring in Shadow Lake. The important point is the storm sewer diversion has been very effective in reducing phosphorus input from the watershed as reflected in the average summer phosphorus concentration being in the excellent range and lower than other similar lakes.

Summer chlorophyll-*a* concentrations, a measure of phytoplankton abundance, are available in Shadow Lake for 1977-82 and 2020 (Figure 3.1-13). Even before the storm sewer diversion and alum treatment, summer chlorophyll-*a* concentrations were in the *excellent* range. Algal levels appear to remain relatively low at the present time as the July 2020 chlorophyll-*a* concentration was 1.9 µg/L, placing the lake in the *excellent* category for deep headwater drainage lakes in Wisconsin. The 2020 summer phosphorus concentration is lower than the median concentration of other deep headwater drainage lakes (5.0 µg/L) and much lower than the median value (15.2 µg/L) for all lake types in the NCHF ecoregion. In both Mirror and Shadow lakes, there is a larger algal community in the metalimnion of these lakes than in the surface waters. This is documented in the study during 1977-1981 and is indicated by the dissolved oxygen profile taken in July 2020. This is described in more detail in the dissolved oxygen section.

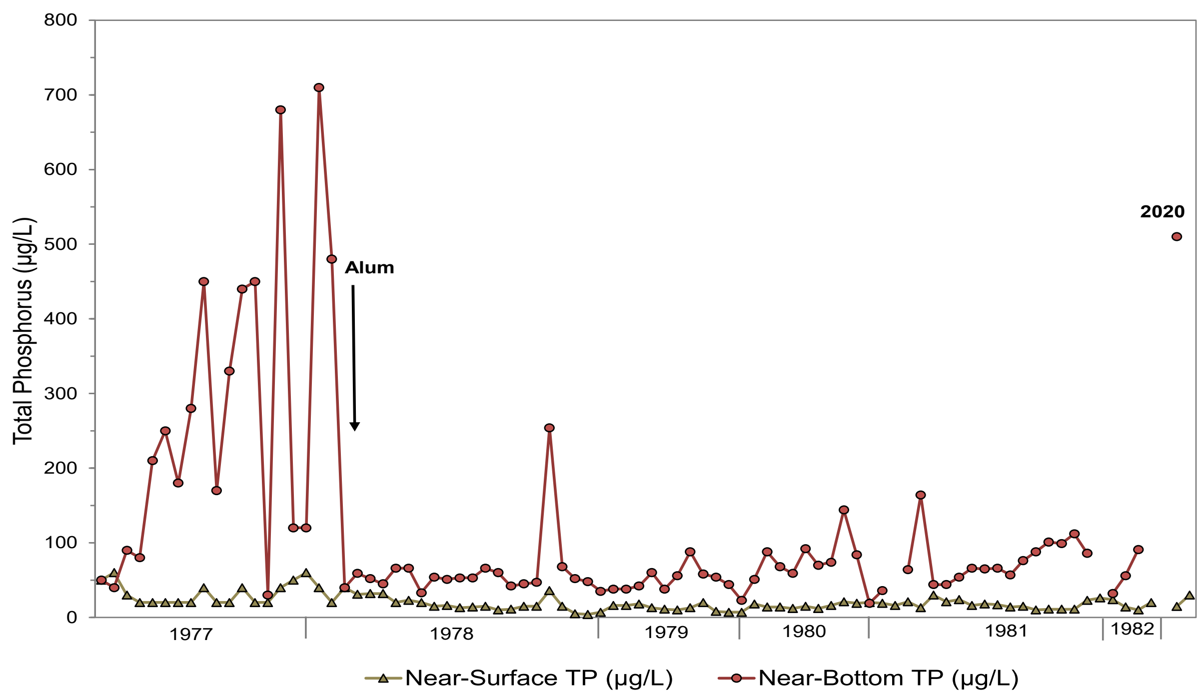

Figure 3.1-12. Shadow Lake total phosphorus concentrations in the top and bottom waters. Concentrations in the bottom samples were greatly reduced following the alum treatment in 1978 but were near pre-alum concentrations in 2020.

Secchi disk transparency data, a measure of water clarity, are available from Shadow Lake for more years than either phosphorus or chlorophyll-*a*: 1979, 1998-2001 and 2009-2020 (Figure 3.1-14). The summer Secchi disk transparency places the lake in the *excellent* category for all years. The summer long-term average is 10.6 feet which is very similar to the median value for other deep headwater drainage lakes (10.8 feet) and much better than all lake types in the NCHF ecoregion (5.3 feet). The long-term summer average is the same in both Mirror and Shadow lakes.

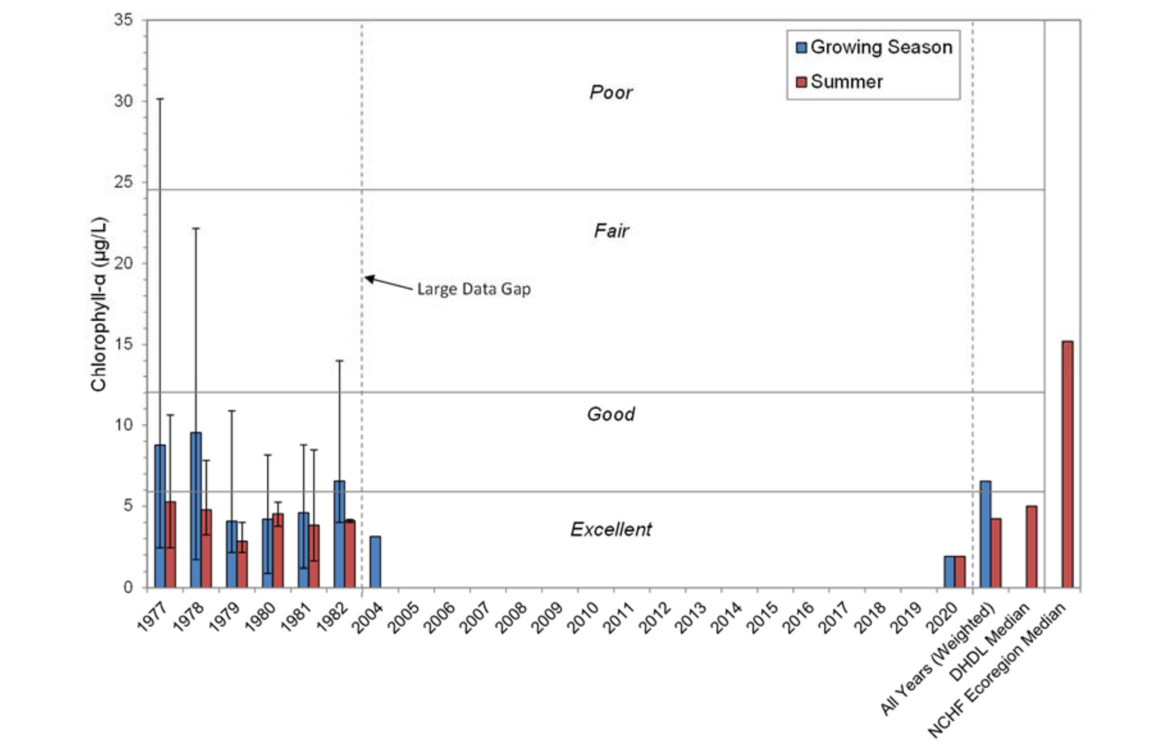

Figure 3.1-13. Shadow Lake, statewide headwater drainage lakes and regional chlorophyll-*a* concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

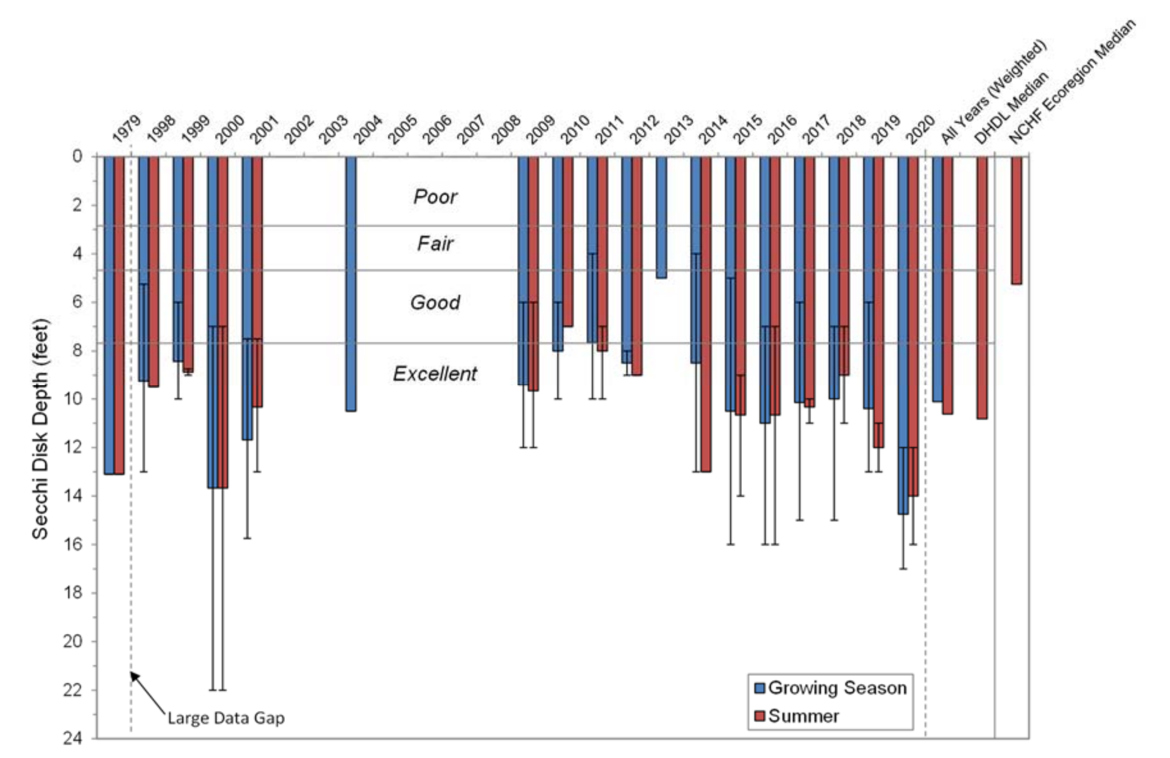

Figure 3.1-14. Shadow Lake, statewide headwater drainage lakes and regional Secchi disk clarity values. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Limiting Plant Nutrient of Shadow Lake

Using mid-summer nitrogen and phosphorus concentrations from Shadow Lake, a nitrogen:phosphorus ratio of 27:1 was calculated. This finding indicates that Shadow Lake is indeed phosphorus limited as are the vast majority of Wisconsin lakes. In general, this means that phosphorus is the primary nutrient regulating algal growth within the lake, and increases in phosphorus will likely result in increased algal production and lower water clarity. Watershed and shoreland conservation and/or restoration efforts for Shadow Lake should have a primary focus on limiting the input of phosphorus to the lake.

Shadow Lake Trophic State

The Trophic State Index (TSI) values for Shadow Lake were calculated using summer near-surface total phosphorus, chlorophyll-*a*, and Secchi disk transparency data collected as part of this project along with historical data (Figure 3.1-15). In general, the best values to use in judging a lake's trophic state are the biological parameters of total phosphorus and chlorophyll-*a* as Secchi disk transparency can be influenced by factors other than algae. Shadow Lake is on the border between *oligotrophic* and *mesotrophic* range. Shadow Lake's TSI is better than other deep headwater drainage lakes and much better than most other lakes in the NCHF ecoregion which tend to be in the eutrophic range.

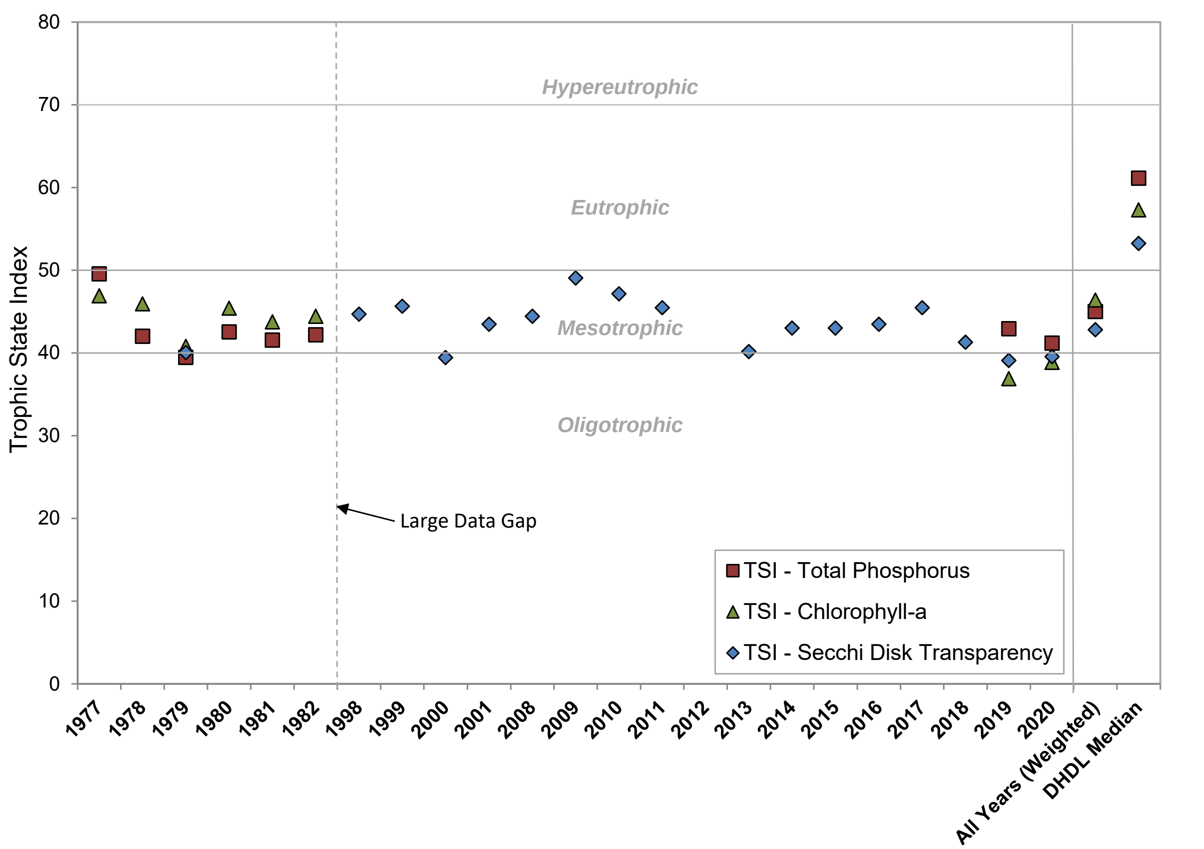

Figure 3.1-15. Shadow Lake, statewide headwater drainage lakes and regional Trophic State Index values. Values calculated with summer month surface sample data using WDNR PUB-WT-193.

Dissolved Oxygen and Temperature in Shadow Lake

Shadow Lake has an active volunteer collecting water quality samples; therefore, this project included two visits to the lake by Onterra staff to collect samples. Dissolved oxygen and temperature were measured during the visits and their profiles are displayed in Figure 3.1-19. Shadow Lake is *dimictic* meaning the lake mixes during the spring and fall but is stratified summer. As with Mirror Lake, there is a metalimnetic oxygen maxima in June and especially July. This is because there is a significant algal community in the metalimnion. It is likely that chlorophyll-*a* concentrations in the water column are highest in the metalimnion. Algal growth is elevated in at this depth since the upper waters are clear enough to allow sufficient light to reach the metalimnion to allow photosynthesis. Also, nutrient levels are often higher in this region and the cooler water is denser which retards the settling of algal cells out of the photic zone. The profile in February 2021 showed sufficient oxygen in the lake to support fish.

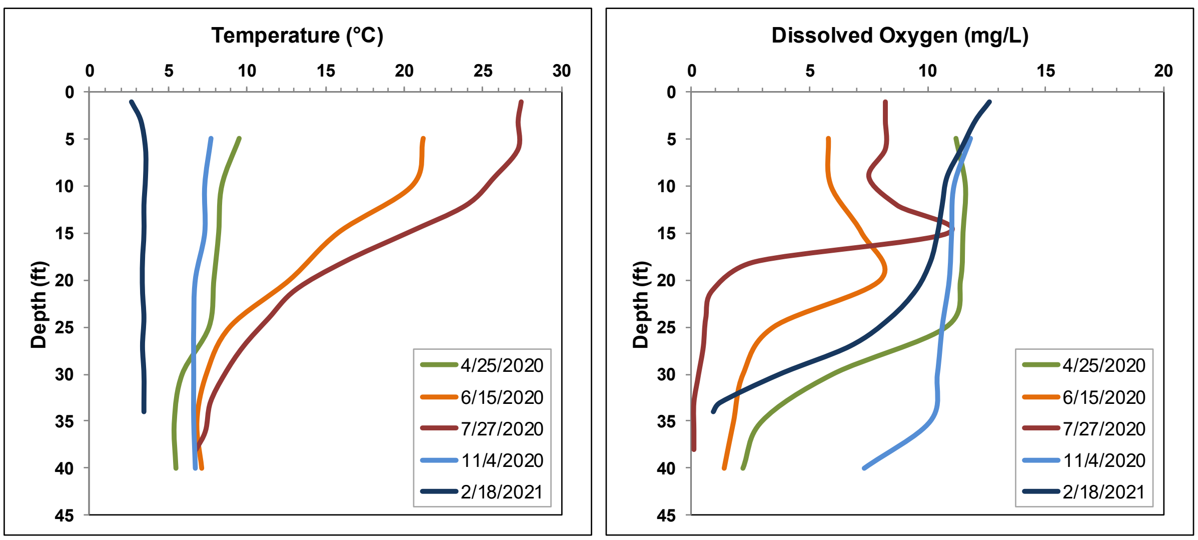

Figure 3.1-16. Temperature and dissolved oxygen profiles collected in Shadow Lake in 2020.

Additional Water Quality Data Collected at Shadow Lake

The water quality section is centered on lake eutrophication. However, parameters other than water clarity, nutrients, and chlorophyll-*a* were collected as part of the project. These other parameters were collected to increase the understanding of Shadow Lake's water quality and are recommended as a part of the WDNR long-term lake trends monitoring protocol. These parameters include pH, alkalinity, and calcium.

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-) and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic; meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl lakes. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited

(Shaw and Nimphius 1985). The mid-summer pH of the water in Shadow Lake was found to be alkaline with a value of 8.4 and falls within the normal range for Wisconsin Lakes (Figure 3.1-17).

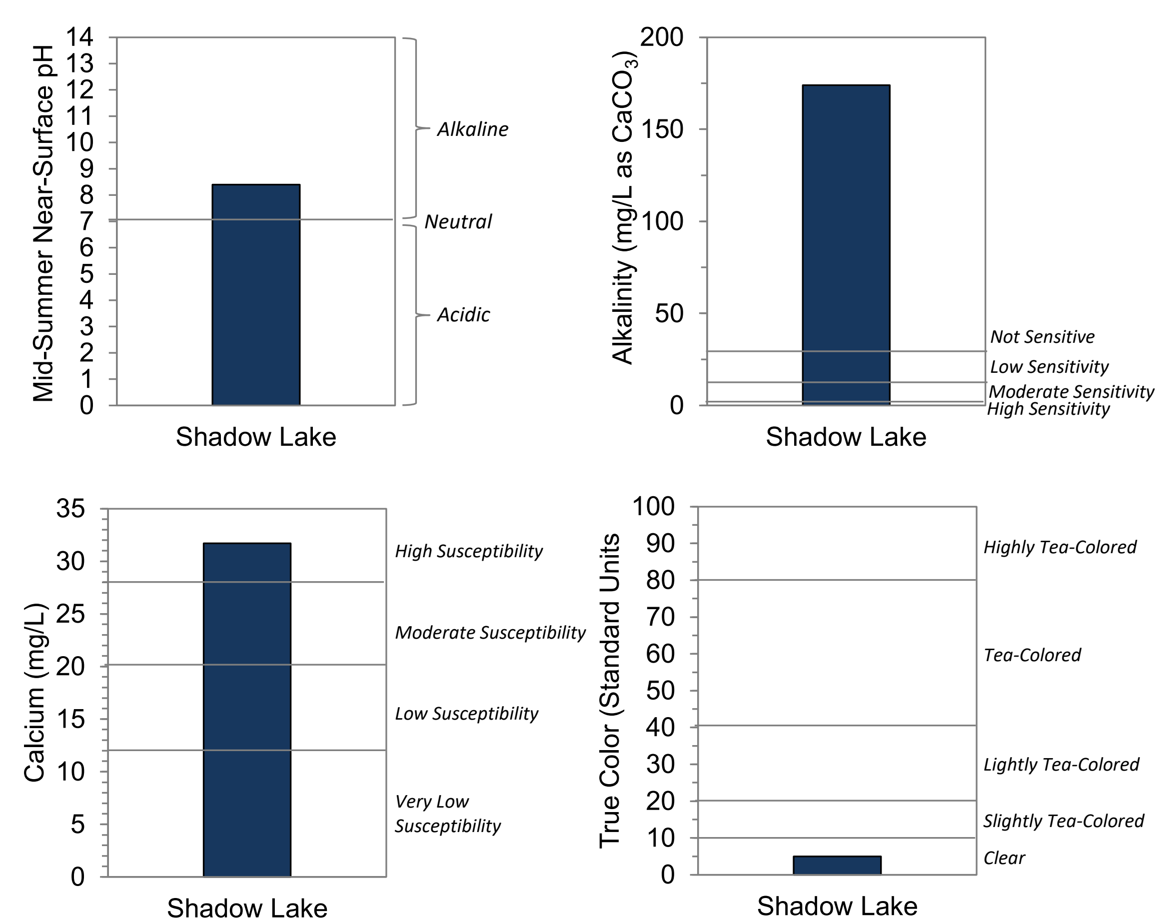

Figure 3.1-17. Additional water quality parameters collected on Shadow Lake: pH, alkalinity, calcium & zebra mussel susceptibility, and true color. Parameters collected from the near-surface.

Alkalinity is a lake's capacity to resist fluctuations in pH by neutralizing or buffering against inputs such as acid rain. The main compounds that contribute to a lake's alkalinity in Wisconsin are bicarbonate (HCO_3^-) and carbonate (CO_3^-), which neutralize hydrogen ions from acidic inputs. These compounds are present in a lake if the groundwater entering it comes into contact with minerals such as calcite ($CaCO_3$) and/or dolomite ($CaMgCO_3$). A lake's pH is primarily determined by the amount of alkalinity. Rainwater in northern Wisconsin is slightly acidic naturally due to dissolved carbon dioxide from the atmosphere with a pH of around 5.0. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The alkalinity in Shadow Lake was measured at 174 (mg/L as $CaCO_3$), indicating that the lake has a capacity to resist fluctuations in pH and is not sensitive to acid rain (Figure 3.1-17). Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed.

Recently, the combination of calcium concentration and pH has been used to determine what lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, so Shadow Lake's pH of 8.4 falls within this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. The calcium concentration of Shadow Lake was found to be 58.7 mg/L, falling in the *high susceptibility* range for zebra mussels (Figure 3.1-22). As is discussed further in this report, both Mirror and Shadow lake contain established populations of zebra mussels.

Zebra mussels (*Dreissena polymorpha*) are small bottom dwelling mussels, native to Europe and Asia, that found their way to the Great Lakes region in the mid-1980s. They are thought to have come into the region through ballast water of ocean-going ships entering the Great Lakes, and they have the capacity to spread rapidly. Zebra mussels can attach themselves to boats, boat lifts, and docks, and can live for up to five days after being taken out of the water. These mussels can be identified by their small size, D-shaped shell and yellow-brown striped coloring. Once zebra mussels have entered and established in a waterway, they are nearly impossible to eradicate. Best practice methods for cleaning boats that have been in zebra mussel infested waters is inspecting and removing any attached mussels, spraying your boat down with diluted bleach, power-washing, and letting the watercraft dry for at least five days.

A measure of water clarity once all of the suspended material (i.e., phytoplankton and sediments) have been removed, is termed *true color*, and measures how the clarity of the water is influenced by dissolved components. True color was measured at 5 SU (standard units) in July, indicating the lake's water was *clear colored* in 2020 (Figure 3.1-17).

Chloride concentrations in Shadow Lake are available from 1977, 1978. 1981, and most years between 2009-2020 (Figure 3.1-18). Like in Mirror Lake, concentrations in 1977 and 1978 were already elevated above natural levels. Chloride concentrations in 2020 are approximately 487% higher than they were in 1981. Concentrations in 2020 were not as high as in Mirror Lake, but are approaching 100 mg/L. The WDNR has set the chronic toxicity criterion for chloride at 395 mg/L.

As is discussed further in the Aquatic Plant Section (Section 3.4), the plant studies completed on Shadow Lake in 2011, 2018, and 2020 also indicate a degradation of ecological condition over this period. A number of species considered more sensitive to environmental disturbance have declined significantly or went undetected in 2020. In addition, disturbance-tolerant species which some studies have shown tend to increase in abundance with increasing salinity, were found to be more prevalent in 2020. The degradation of Shadow Lake's plant community over this period occurred despite no detectable change in nutrient levels or water clarity. It is possible that the reduction in sensitive species and increase in disturbance-tolerant species are the result of the lake's increasing salinity.

There are a number of pathways by which road salt may be entering Shadow Lake. Road salts can be carried by runoff into drainage ditches, streams, and wetlands, and eventually the lake soon after application. Salt which has accumulated in soils along roadsides can also be flushed into the lake following heavy precipitation events. Road salts can also leach into groundwater which makes its way into the lake. While Shadow Lake has a relatively small surface watershed at 284 acres, the UW-Stevens Point study (Turyk et al. 2004) found that Shadow Lake's groundwater watershed is significantly larger, encompassing an area of approximately over 1,400 acres, underlying urban areas to the west-northwest. While this study did not determine the pathways by which road salts are entering Shadow Lake, it is likely through a combination of surface and groundwater inflow.

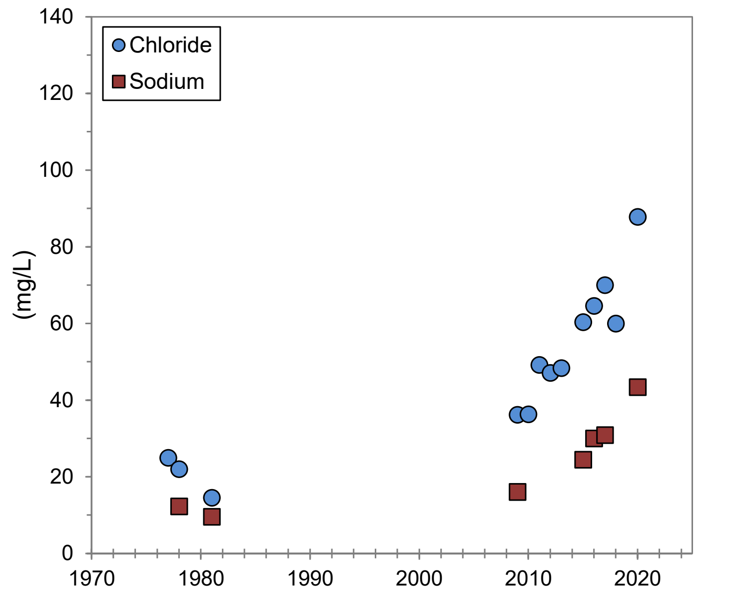

Figure 3.1-18. Shadow Lake chloride and sodium concentrations. The large increase from 2009-2020 is likely the result of salt applied to roadways in the watershed.

Stakeholder Survey Responses to Mirror and Shadow Lakes Water Quality

As discussed in section 2.0, the stakeholder survey asks many questions pertaining to perception of the lake and how it may have changed over the years. Figures 3.1-25 and 3.1-26 display the responses of stakeholders to questions regarding water quality and how it has changed over their years visiting Mirror and Shadow lakes.

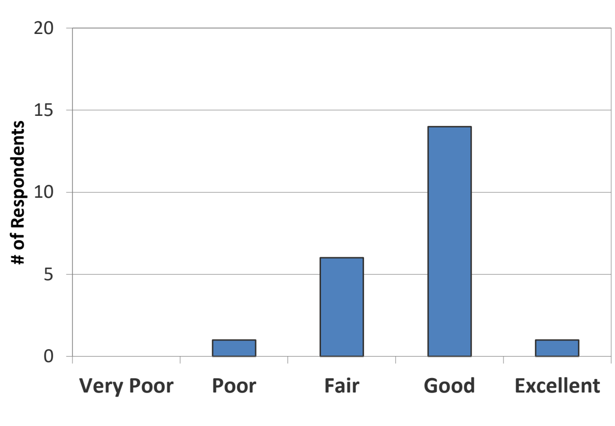

Figure 3.1-19. Stakeholder survey response Question #17. How would you describe the overall current water quality of Mirror and Shadow lakes?

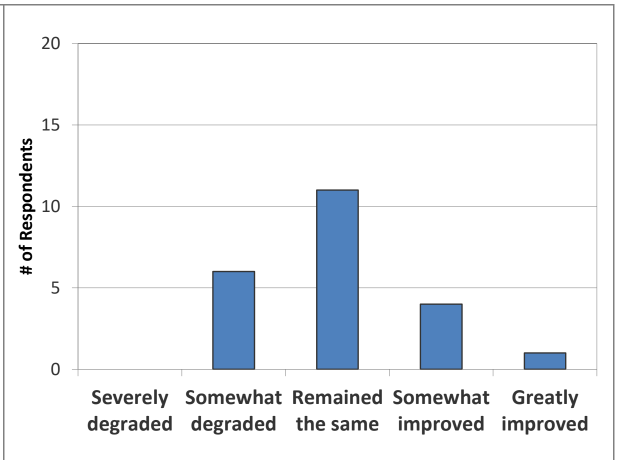

Figure 3.1-20. Stakeholder survey response Question #18. How has the overall water quality changed in Mirror and Shadow lakes since you first visited them?

Paleoecology

Primer on Paleoecology and Interpretation

Questions often arise concerning how a lake's water quality has changed through time as a result of watershed disturbances. In most cases, there is little or no reliable long-term data. They also want to understand when the changes occurred and what the lake was like before the transformations began. Paleoecology offers a way to address these issues. The paleoecological approach depends upon the fact that lakes act as partial sediment traps for particles that are created within the lake or delivered from the watershed. The sediments of the lake entomb a selection of fossil remains that are more or less resistant to bacterial decay or chemical dissolution.

These remains include frustules (silica-based cell walls) of a specific algal group called diatoms, cell walls of certain algal species, and subfossils from aquatic plants. The diatom community is especially useful in reconstructing a lake's ecological history as they are highly resistant to degradation and are ecologically diverse. Diatom species have unique features which enable them to be readily identified (Photo 3.3-1). Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. Some species float in the open water areas while others grow attached to substrates such as aquatic plants or the lake bottom.

The chemical composition of the sediments may indicate the composition of particles entering the lake as well as the past chemical environment of the lake itself. By collecting an intact sediment core, sectioning it off into layers, and utilizing all of the information described above, paleoecologists can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

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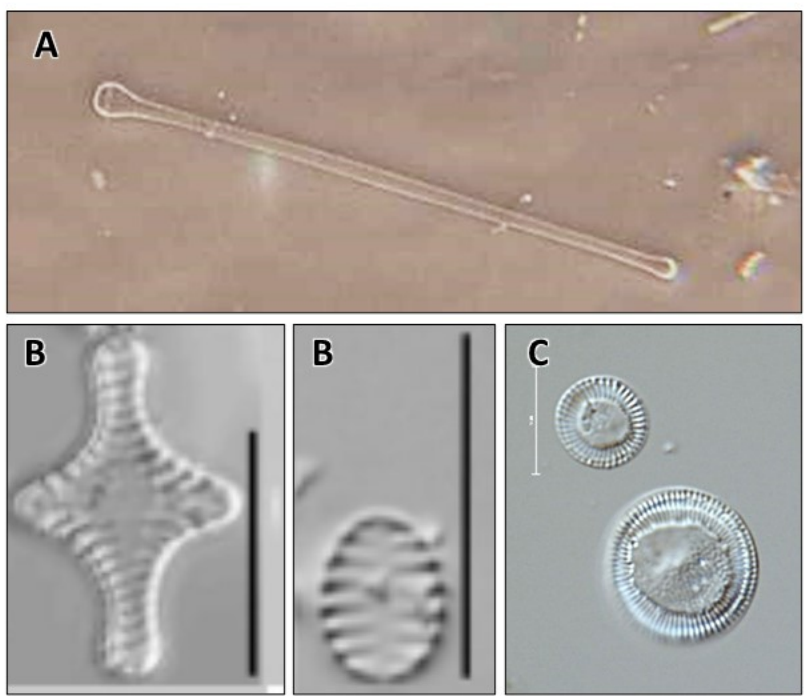
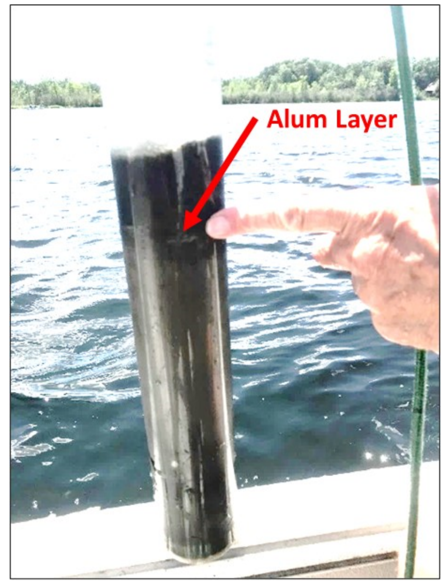


Photograph 3.1-1. Diatoms commonly found in the sediment core from Shadow Lake. The top diatom (A) is *Asterionella formosa* is common with moderate phosphorus levels but also indicates higher nitrogen concentrations. This diatom is most common in the top sample of the sediment core. *Staurosira construens* (B left) and *S. construens* var. *venter* (B right) are typically found growing on macrophytes and lake sediments and are common components of benthic *Fragilaria*. *Cyclotella michiganiana* (C) floats in the open water and is generally found in lakes with good water quality

Shadow Lake Paleoecological Results

A sediment core was extracted from the deep area of Shadow Lake on July 27, 2020 (Photo 3.1-1) to determine how the water quality and lake ecology has changed during the last century. The total length of the core was 31 cm. The top 5 cm was black in color, 5-25 cm medium gray, 25-27 cm dark brown, and 27-31 cm was light gray in color. The top 1 cm was kept for diatom analysis as it is assumed to represent present day water quality conditions. The section 28-30 cm was kept for analysis of the diatom community and radiochemical analysis. The radiochemical analysis indicated that the bottom section was deposited at least 130 years ago, which is prior to any significant changes in the watershed from European settlement.



Photograph 3.1-2. Sediment core collected from Shadow Lake. The finger points to where the alum layer was visible.

Multivariate Statistical Analysis

In order to make a comparison of environmental conditions between the bottom and top samples of the core from Shadow Lake, an exploratory detrended correspondence analysis (DCA) was performed (CANOCO 5 software, per Braak and Smilauer, 2012). The DCA analysis has been done on many WI lakes to examine the similarities of the diatom communities between the top and bottom samples of the same lake.

During sampling, the alum layer was visible in the core (Photo 3.1-2). The results revealed two clear axes of variation in the diatom data, with 37% and 24% of the variance explained by axis 1 and axis 2, respectively (Figure 3.3-21). Sites with similar sample scores occur in close proximity reflecting similar diatom composition. The arrows symbolize the trend from the bottom to the top samples. In Shadow Lake there is considerable separation between the bottom and the top samples (Figure 3.1-22) indicating the differences in the diatom communities. This suggests that there has been significant change in the lake's ecology during the last century.

While it is not possible to determine which were the most important environmental variables ordering the diatom communities, one trend is apparent. Axis 1 likely represents the alkalinity of the lakes. Other studies of Wisconsin and Vermont lakes indicate that the most important variable ordering the diatom communities is alkalinity. Lakes on the right side of the DCA graph tend to have the lowest alkalinity values while the highest are on the left side. A study by (Eilers et al. 1989) of 149 lakes in north central Wisconsin found that as a consequence of lake shore development, alkalinity and conductivity concentrations increase. This is because of the sediment that enters the lake during cottage and road construction. Even though at the present time there is more development around these lakes than there was historically, the alkalinity has changed little in these lakes. This is because these lakes have sufficient alkalinity such that development has not significantly changed the buffering capacity of the lakes. Soft water lakes are much more susceptible to having their alkalinity affected by development.

It is likely that the second axis reflects the abundance of benthic *Fragilaria* (Photo 3.1-1B). These diatoms are often associated with macrophytes. These diatoms are more common near the bottom of the graph. In Hatch and Squash lakes these diatoms are much more common at the present time compared with historically. The diatom community in Shadow Lake has the opposite trend with these taxa being much more common in the bottom sample. As described below, in Shadow Lake this probably does not signal a decline in macrophytes but instead is the result of a greater number of diatoms that float in the open water which has resulted in a decline in the relative abundance of benthic *Fragilaria* taxa.

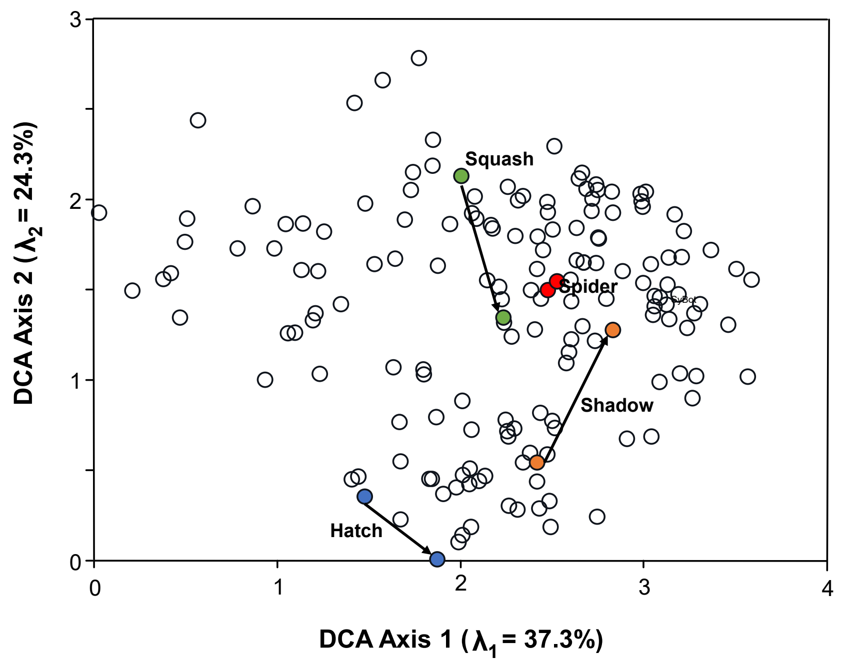


Figure 3.1-21. DCA plot of top/bottom samples highlighting lakes where Onterra staff collected sediment cores in 2020. The arrows connect bottom to top samples in the same lake. The open circles are other Wisconsin lakes where top/bottom samples have been analyzed. The diatom community in Shadow Lake has changed a significant amount since the arrival of Euro-American settlers over 150 years ago.

Diatom Community Changes

Analysis showed there is a significant difference between the diatom communities in the top and bottom samples in the sediment core as can be seen in Figure 3.1-22. The bottom sample is dominated by diatoms that grow attached substrates such as the lake sediment and macrophytes, e.g. benthic *Fragilaria*, while the top sample is dominated by diatoms that float in the open water, planktonic diatoms. Many studies have found that with an increase in nutrients, planktonic diatoms become more numerous as the reduction in water clarity reduces light penetration in the water column such that there is less bottom area that can sustain algal growth. Further evidence of the increase in nutrients is the reduction of *Cyclotella michiganiana* from the bottom to the top sample and its replacement by *Asterionella formosa*. *C. michiganiana* does better with lower phosphorus concentrations while *A. formosa* is known to signal increased nutrients, especially nitrogen.

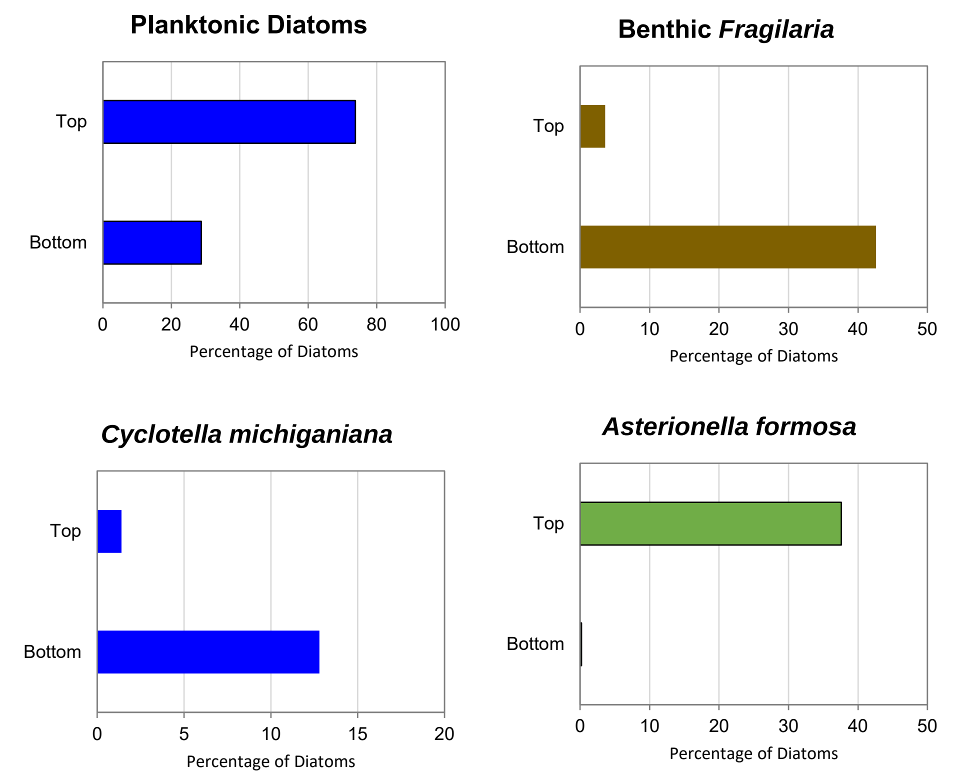


Figure 3.1-22. Changes in abundance of important diatoms found in the top and bottom of the sediment core from Shadow Lake. The increase of planktonic diatoms, especially *A. formosa* and the decline in benthic *Fragilaria* suggests an increase in nutrients at the present time.

Lake Diatom Condition Index

The Lake Diatom Condition Index (LDCI) was developed by Dr. Jan Stevenson, Michigan State University (Stevenson et al. 2013). The LDCI uses diatoms to assess the ecological condition of lakes. The LDCI ranges from 0 to 100 with a higher score representing better ecological integrity. The index is weighted towards nutrients, but also incorporates ecological integrity by examining species diversity where higher diversity indicates better ecological condition. The index also incorporates taxa that are commonly found in undisturbed and disturbed conditions. The breakpoints (poor, fair, good) were determined by the 25^{th} and 5^{th} percentiles for reference lakes in the Upper Midwest. The LDCI was used in the 2007 National Lakes Assessment to determine the biological integrity of the nation's lakes.

The LDCI analysis indicates the lake's biotic condition historically and now are in the good range (Figure 3.1-23). The index at the present time is not as good as it was historically and this is primarily the result of taxa that are indicative of higher phosphorus concentrations being more prevalent in the top sample.

Inference models

Diatom assemblages have been used as indicators of trophic changes in a qualitative way (Bradbury 1975), (Carney 1982), (Anderson, Rippey and Stevenson 1990) but quantitative analytical methods exist. Ecologically relevant statistical methods have been developed to infer environmental conditions from diatom assemblages. These methods are based on multivariate ordination and weighted averaging regression and calibration (Birks et al. 1990). Ecological preferences of diatom species are determined by relating modern limnological variables to surface sediment diatom assemblages. The species-environment relationships are then used to infer environmental conditions from fossil diatom assemblages found in the sediment core.

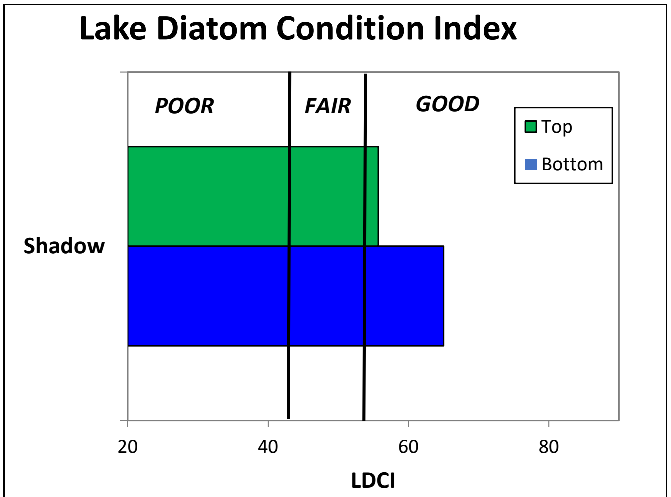


Figure 3.1-23. The Lake Diatom Condition Index (LDCI) for Shadow Lake. While the biotic integrity is good at the present time but was better historically.

Weighted averaging calibration and reconstruction (Birks et al. 1990) were used to infer historical water column summer average phosphorus concentration in the sediment cores. A training set that consisted of 60 stratified lakes was used. Training set species and environmental data were analyzed using weighted average regression software (C2; (Juggins 2014).

The diatom inferred phosphorus concentration in the top sample of Shadow Lake is 21 µg/L while the historical concentration was lower at about 15 µg/L (Table 3.1-1). This change in phosphorus concentration seems reasonable given the changes noted in the diatom community previously.

Table 3.1-1. Diatom inferred phosphorus concentrations in core samples (µg/L).

Lakes	Phosphorus
Shadow Top	21
Shadow Bottom	15

In summary, Shadow Lake has experienced an increase in nutrients during the last 100 years. This is indicated by a significant change in the diatom taxa and modelling indicates the increase in phosphorus has been about 6 µg/L. While there has been an increase in phosphorus concentration in the lake, the diatom community indicates the lake's biotic integrity is still in the good range.

Mirror Lake Paleoecological Results

A sediment core was taken from the deepest area (13m) of the lake in 1977. The total length of the core was 100 cm. Analyses performed on the core were: sediment dating, algal pigments, organic matter, calcium carbonate, and diatom community. The diatom analysis was performed by David Farris for his Master of Science degree from the University of Michigan.

The dating analysis indicates that the time period covered by the core is approximately 1,200 years. Analysis of the geochemistry and diatom community indicated that during this time the lake has experienced significant water level fluctuations primarily as a result of climate variability. Since the area was settled in the mid-1800s water levels appear to be more stable. The greatest change in the lake ecosystem occurred about 1950 which was when storm sewers began discharging into the lake. These sewers delivered more nutrients to the lake, especially phosphorus. The result was an increase in algal productivity, the lake's sedimentation rate, and phosphorus deposition. The changes induced by the storm sewers were greater than the lake had experienced in the previous 1,200 years.

The diatom community indicated that during the last 1,000 years there were 3 major shifts in the diatom flora signaling significant changes in the lake's ecosystem. The first two zones resulted from changes in the lake level, while the third zone was the result of human settlement altering the mixing regime of the lake and increasing nutrient input to the lake. Prior to the establishment of the city of Waupaca the landscape may have been mostly prairie which resulted in more wind energy impacting the lake and thus the lake experienced greater mixing. With the establishment of the city, trees were more prevalent and less wind energy reached the lake resulting in greater stagnation in the lake. The diatom community confirms results from the algal pigment analysis that indicates that with the introduction of storm sewers to the lake around 1950, more nutrients entered the lake and the greatest change to the lake's ecosystem occurred during the last 50 years.

3.2 Watershed Assessment

Watershed Modeling

A lake's **flushing rate** is simply a determination of the time required for the lake's water volume to be completely exchanged. **Residence time** describes how long a volume of water remains in the lake and is expressed in days, months, or years. The parameters are related and both determined by the volume of the lake and the amount of water entering the lake from its watershed. Greater flushing rates equal shorter residence times.

Two aspects of a lake's watershed are the key factors in determining the amount of phosphorus the watershed exports to the lake; 1) the size of the watershed, and 2) the land cover (land use) within the watershed. The impact of the watershed size is dependent on how large it is relative to the size of the lake. The watershed to lake area ratio (WS:LA) defines how many acres of watershed drains to each surface-acre of the lake. Larger ratios result in the watershed having a greater role in the lake's annual water budget and phosphorus load.

The type of land cover that exists in the watershed determines the amount of phosphorus (and sediment) that runs off the land and eventually makes its way to the lake. The actual amount of pollutants (nutrients, sediment, toxins, etc.) depends greatly on how the land within the watershed is used. Vegetated areas, such as forests, grasslands, and meadows, allow the water to permeate the ground and do not produce much surface runoff. On the other hand, agricultural areas, particularly row crops, along with residential/urban areas, minimize infiltration and increase surface runoff. The increased surface runoff associated with these land cover types leads to increased phosphorus and pollutant loading; which, in turn, can lead to nuisance algal blooms, increased sedimentation, and/or overabundant macrophyte populations.

In systems with lower WS:LA ratios, land cover type plays a very important role in how much phosphorus is loaded to the lake from the watershed. In these systems the occurrence of agriculture or urban development in even a small percentage of the watershed (less than 10%) can unnaturally elevate phosphorus inputs to the lake. If these land cover types are converted to a cover that does not export as much phosphorus, such as converting row crop areas to grass or forested areas, the phosphorus load and its impacts to the lake may be decreased. In fact, if the phosphorus load is reduced greatly, changes in lake water quality may be noticeable, (e.g. reduced algal abundance and better water clarity) and may even be enough to cause a shift in the lake's trophic state.

In systems with high WS:LA ratios, like those exceeding 10-15:1, the impact of land cover may be tempered by the sheer amount of land draining to the lake. Situations actually occur where lakes with completely forested watersheds have sufficient phosphorus loads to support high rates of plant production. In other systems with high ratios, the conversion of vast areas of row crops to vegetated areas (grasslands, meadows, forests, etc.) may not reduce phosphorus loads sufficiently to see a change in plant production. Both of these situations occur frequently in impoundments.

Regardless of the size of the watershed or the makeup of its land cover, it must be remembered that every lake is different and other factors, such as flushing rate, lake volume, sediment type, and many others, also influence how the lake will react to what is flowing into it. For instance, a deeper lake with a greater volume can dilute more phosphorus within its waters than a less voluminous lake and as a result, the production of a lake is kept low. However, in that same lake, because of its low flushing rate (high residence time, i.e., years), there may be a buildup of phosphorus in the sediments that may reach sufficient levels over time that internal nutrient loading may become a problem. On the contrary, a lake with a higher flushing rate (low residence time, i.e., days or weeks) may be more productive early on, but the constant flushing of its waters may prevent a buildup of phosphorus and internal nutrient loading may never reach significant levels.

A reliable and cost-efficient method of creating a general picture of a watershed's effect on a lake can be obtained through modeling. The WDNR created a useful suite of modeling tools called the Wisconsin Lake Modeling Suite (WiLMS). Certain morphological attributes of a lake and its watershed are entered into WiLMS along with the acreages of different types of land cover within the watershed to produce useful information about the lake ecosystem. This information includes an estimate of annual phosphorus load and the partitioning of those loads between the watershed's different land cover types and atmospheric fallout entering through the lake's water surface.

WiLMS also calculates the lake's flushing rate and residence times using county-specific average precipitation/evaporation values or values entered by the user. Predictive models are also included within WiLMS that are valuable in validating modeled phosphorus loads to the lake in question and modeling alternate land cover scenarios within the watershed. Finally, if specific information is available, WiLMS will also estimate the significance of internal nutrient loading within a lake and the impact of shoreland septic systems.

Mirror and Shadow Lakes Watershed Assessment

The watershed for the entire Mirror and Shadow lakes system encompasses approximately 284 acres in Waupaca county (Figure 3.2-1 and Map 2). Mirror Lake's watershed, which is a subwatershed of Shadow Lake's watershed, encompasses approximately 42 acres in Waupaca County. Water from Mirror Lake flows south into Shadow Lake. Water from Shadow Lake flows south and into the Crystal River, which ultimately flows into the Lake Winnebago system.

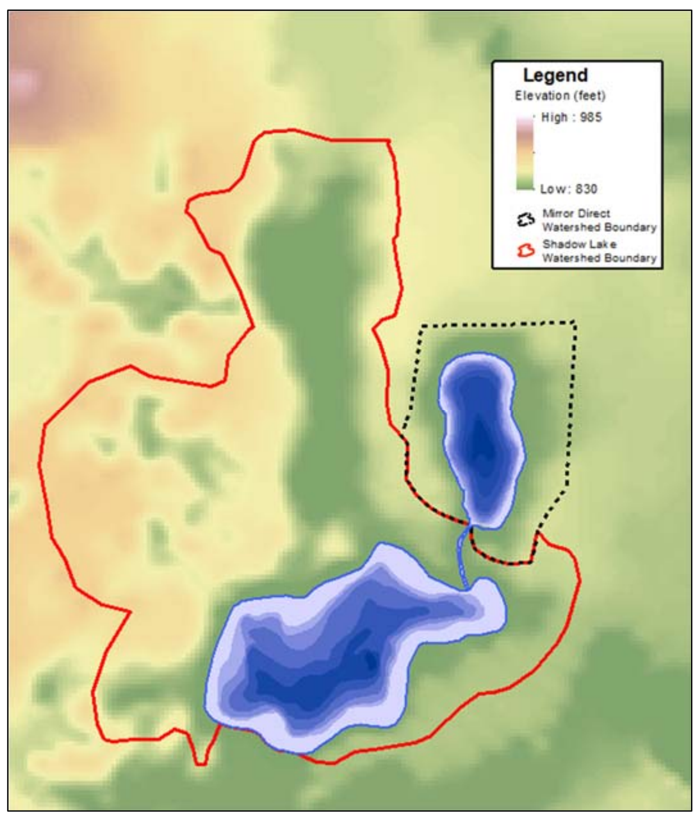


Figure 3.2-1. Shadow and Mirror lakes watershed and land elevation.

Wisconsin Lakes Modeling Suite (WiLMS) estimated that Shadow Lake has a water residence time of 2 years, while Mirror Lake has an estimated water residence time of 12 years; however, the residence time in Mirror Lake is likely lower as WiLMS does not account for groundwater input. In other words, the water is completely replaced on average in Shadow Lake once every 2 years and once every 12 years in Mirror Lake.

Shadow Lake's watershed is comprised of upland forests (25%), pasture/grass (18%), the lake's surface itself (15%), Mirror Lake subwatershed (15%), rural residential areas (12%), wetlands (12%), and urban – high & medium density (<1%) (Figures 3.2-2 and 3.2-3). Mirror Lake's watershed is comprised of the lake surface itself (34%), upland forests (20%), rural residential areas (20%), wetlands (19%), pasture/grass areas (6%), and urban – high & medium density areas (<1%) (Figures 3.2-2 and 3.2-3).

Using the land cover types and their acreages within the Shadow and Mirror lakes watersheds, WiLMS was utilized to estimate the annual potential phosphorus load delivered to each lake. In addition, data obtained from a stakeholder survey distributed in 2020 was also used to estimate the potential phosphorus loading to the lake from riparian septic systems. The model estimated that approximately 13.8 pounds of phosphorus are loaded to Mirror Lake on an annual basis from its watershed (Figure 3.2-4). Based on this estimated annual loading of phosphorus, WiLMS predicted that the in-lake average growing season total phosphorus concentrations should be 15.4 µg/L. The average measured growing season total phosphorus concentration in Mirror Lake is 22.9 µg/L, which is higher than the predicted value. The fact that average measured phosphorus concentrations in Mirror Lake are higher than model predictions indicates that there is a source of phosphorus being loaded to the lake that was not accounted for in the model.

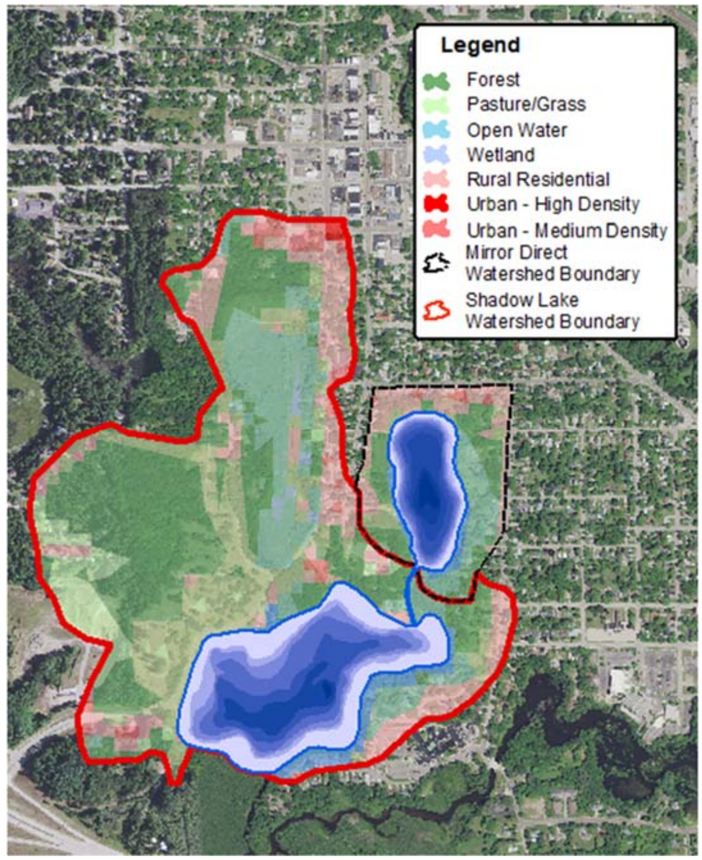


Figure 3.2-2. Shadow and Mirror lakes watershed and land cover types. Based upon National Land Cover Database (USGS 2019).

This unaccounted source of phosphorus is believed to be internal nutrient loading, or the loading of phosphorus from bottom sediments during summer stratification. As is discussed in the Mirror Lake Water Quality Section (Section 3.1), the data indicate that phosphorus is mobilized from bottom sediments to surface waters in some years, elevating surface phosphorus concentrations. To achieve the measured in-lake growing season phosphorus concentration of 22.9 µg/L, the model indicates Mirror Lake needs to receive an additional 7 pounds of phosphorus annually (Figure 3.2-3).

WiLMS estimated that Shadow Lake receives an estimated 42 pounds of phosphorus from its watershed on an annual basis (Figure 3.2-4). Based on this estimated phosphorus load, WiLMS predicted an in-lake average growing season total phosphorus concentration of 23 µg/L, which is slightly higher than the measured 18.7 µg/L. The measured phosphorus concentration into Shadow Lake may be lower than the predicted due to a wetland area north of the lake. Wetlands have the capability of filtering incoming phosphorus which may be reducing the phosphorus contribution from the urbanized areas in the northern most portion of the watershed. The storm drains near Shadow Lake may also be directing enough rainfall away from the lake decreasing phosphorus input.

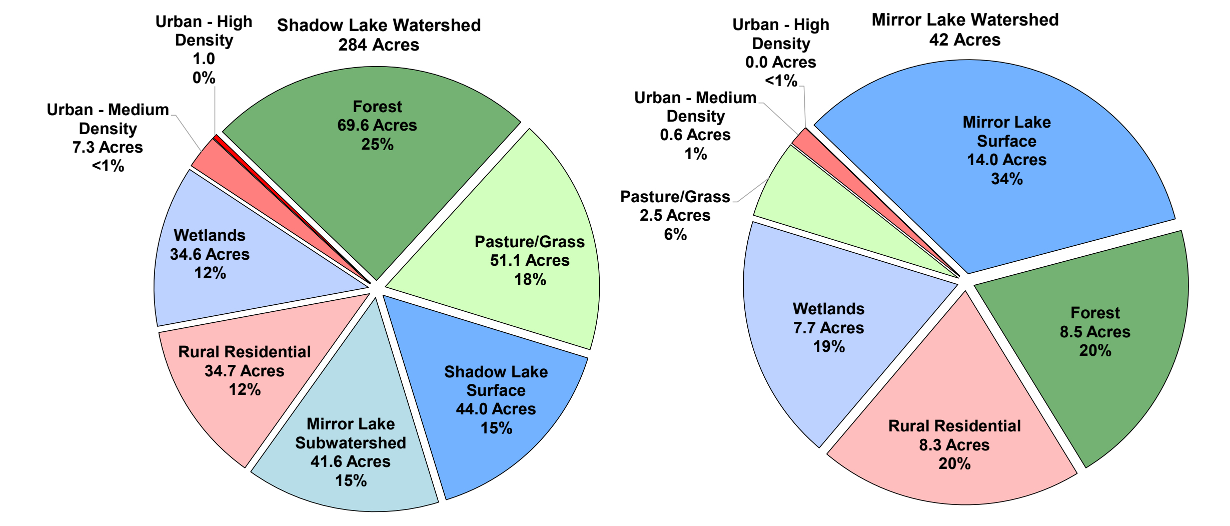


Figure 3.2-3. Proportion of land cover types within Shadow and Mirror lakes' watersheds. Based upon National Land Cover Database (USGS 2019)

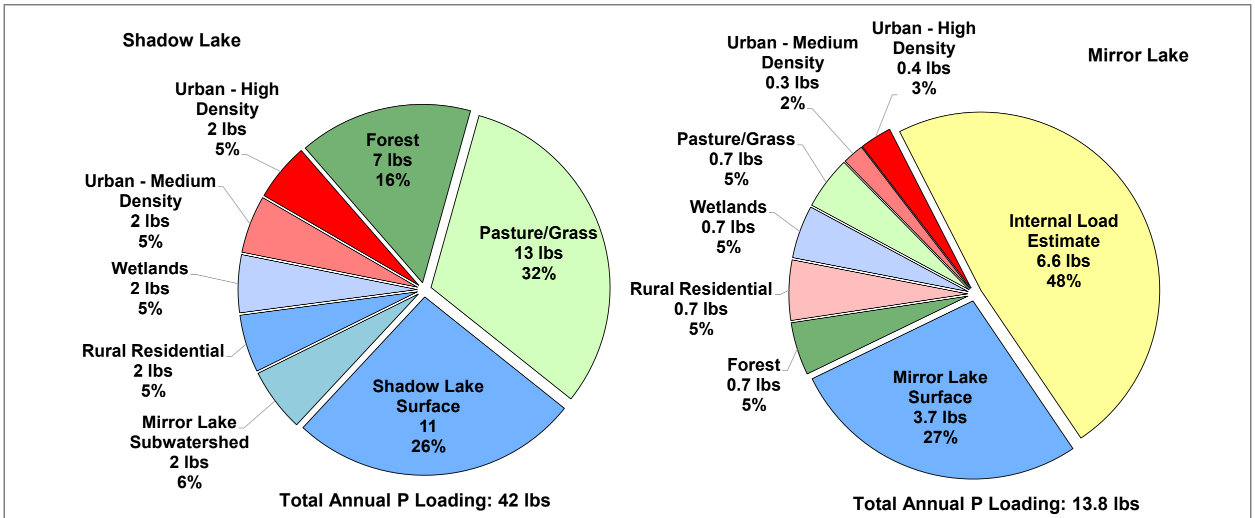


Figure 3.2-4. Shadow and Mirror lakes estimated annual phosphorus loading. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates.

Of the 82 pounds, 24% from urban – high density areas, 22% from pasture/grass, 13% from atmospheric deposition onto the lake's surface, 11% from rural residential, 11% from urban – medium density areas, 8% is estimated to originate from the Mirror Lake subwatershed, 8% from forested areas, and 3% from wetlands (Figure 3.2-4).

3.3 Shoreland Condition

The Importance of a Lake's Shoreland Zone

One of the most vulnerable areas of a lake's watershed is the immediate shoreland zone (approximately from the water's edge to at least 35 feet shoreland). When a lake's shoreland is developed, the increased impervious surface, removal of natural vegetation, and other human practices can severely increase pollutant loads to the lake while degrading important habitat. Limiting these anthropogenic (man-made) effects on the lake is important in maintaining the quality of the lake's water and habitat.

The intrinsic value of natural shorelands is found in numerous forms. Vegetated shorelands prevent polluted runoff from entering lakes by filtering this water or allowing it to slow to the point where particulates settle. The roots of shoreland plants stabilize the soil, thereby preventing shoreland erosion. Shorelands also provide habitat for both aquatic and terrestrial animal species. Many species rely on natural shorelands for all or part of their life cycle as a source of food, cover from predators, and as a place to raise their young. Shorelands and the nearby shallow waters serve as spawning grounds for fish and nesting sites for birds. Thus, both the removal of vegetation and the inclusion of development reduces many forms of habitat for wildlife.

Some forms of development may provide habitat for less than desirable species. Disturbed areas are often overtaken by invasive species, which are sometimes termed "pioneer species" for this reason. Some waterfowl, such as geese, prefer to linger upon open lawns near waterbodies because of the lack of cover for potential predators. The presence of geese on a lake resident's beach may not be an issue; however, the feces the geese leave are unsightly and pose a health risk. Geese feces may become a source of fecal coliforms as well as flatworms that can lead to swimmers itch. Development such as rip rap or masonry, steel or wooden seawalls completely remove natural habitat for most animals, but may also create some habitat for snails; this is not desirable for lakes that experience problems with swimmers itch, as the flatworms that cause this skin reaction utilize snails as a secondary host after waterfowl.

In the end, natural shorelines provide many ecological and other benefits. Between the abundant wildlife, the lush vegetation, and the presence of native flowers, shorelands also provide natural scenic beauty and a sense of tranquility for humans.

Shoreland Zone Regulations

Wisconsin has numerous regulations in place at the state level which aim to enhance and protect shorelands. Additionally, counties, townships and other municipalities have developed their own (often more comprehensive or stronger) policies. At the state level, the following shoreland regulations exist:

Wisconsin-NR 115: Wisconsin's Shoreland Protection Program

Wisconsin's shoreland zoning rule, NR 115, sets the minimum standards for shoreland development. First adopted in 1966, the code set a deadline for county adoption of January 1, 1968. By 1971, all counties in Wisconsin had adopted the code and were administering the shoreland ordinances it specified. Interestingly, in 2007 it was noted that many (27) counties had recognized inadequacies within the 1968 ordinance and had actually adopted stricter shoreland ordinances. Revised in February of 2010, and again in October of 2014, the finalized NR 115 allowed many standards to remain the same, such as lot sizes, shoreland setbacks and buffer sizes. However, several standards changed as a result of efforts to balance public rights to lake use with private property rights. The regulation sets minimum standards for the shoreland zone, and requires all counties in the state to adopt shoreland zoning ordinances. Counties were previously able to set their own, stricter, regulations to NR 115 but as of 2015, all counties have to abide by state regulations. Minimum requirements for each of these categories are described below.

- Vegetation Removal: For the first 35 feet of property (shoreland zone), no vegetation removal is permitted except for: sound forestry practices on larger pieces of land, access and viewing corridors (may not exceed 35 percent of the shoreline frontage), invasive species removal, or damaged, diseased, or dying vegetation. Vegetation removed must be replaced by replanting in the same area (native species only).

- Impervious surface standards: In general, the amount of impervious surface is restricted to 15% of the total lot size, on lots that are within 300 feet of the ordinary high-water mark of the waterbody. If a property owner treats their run off with some type of treatment system, they may be able to apply for an increase in their impervious surface limit, up to 30% for residential land use. Exceptions to this limit do exist if a county has designated highly-developed areas, so it is recommended to consult county-specific zoning regulations for this standard.

- Nonconforming structures: Nonconforming structures are structures that were lawfully placed when constructed but do not comply with distance of water setback. Originally, structures within 75 ft of the shoreline had limitations on structural repair and expansion. Language in NR-115 allows construction projects on structures within 75 feet. Other specifications must be met as well, and local zoning regulations should be referenced.

Mitigation requirements: Language in NR-115 specifies mitigation techniques that may be incorporated on a property to offset the impacts of impervious surface, replacement of nonconforming structure, or other development projects. Practices such as buffer restorations along the shoreland zone, rain gardens, removal of fire pits, and beaches all may be acceptable mitigation methods. Mitigation requirements are county-specific and any such projects should be discussed with local zoning to determine the requirements.

Wisconsin Act 31

While not directly aimed at regulating shoreland practices, the State of Wisconsin passed Wisconsin Act 31 in 2009 in an effort to minimize watercraft impacts upon shorelines. This act prohibits a person from operating a watercraft (other than personal watercraft) at a speed in excess of slow-no-wake speed within 100 feet of a pier, raft, buoyed area or the shoreline of a lake. Additionally, personal watercraft must abide by slow-no-wake speeds while within 200 feet of these same areas. Act 31 was put into place to reduce wave action upon the sensitive shoreland zone of a lake. The legislation does state that pickup and drop off areas marked with regulatory markers and that are open to personal watercraft operators and motorboats engaged in waterskiing/a similar activity may be exempt from this distance restriction. Additionally, a city, village, town, public inland lake protection and rehabilitation district or town sanitary district may provide an exemption from the 100-foot requirement or may substitute a lesser number of feet.

Shoreland Research

Studies conducted on nutrient runoff from Wisconsin lake shorelands have produced interesting results. For example, a USGS study on several Northwoods Wisconsin lakes was conducted to determine the impact of shoreland development on nutrient (phosphorus and nitrogen) export to these lakes (Graczyk et al. 2003). During the study period, water samples were collected from surface runoff and ground water and analyzed for nutrients. These studies were conducted on several developed (lawn covered) and undeveloped (undisturbed forest) areas on each lake. The study found that nutrient yields were greater from lawns than from forested catchments, but also that runoff water volumes were the most important factor in determining whether lawns or wooded catchments contributed more nutrients to the lake. Ground-water inputs to the lake were found to be significant in terms of water flow and nutrient input. Nitrate plus nitrite nitrogen and total phosphorus yields to the ground-water system from a lawn catchment were three or sometimes four times greater than those from wooded catchments.

A separate USGS study was conducted on the Lauderdale Lakes in southern Wisconsin, looking at nutrient runoff from different types of developed shorelands – regular fertilizer application lawns (fertilizer with phosphorus), non-phosphorus fertilizer application sites, and unfertilized sites (Garn 2002). One of the important findings stemming from this study was that the amount of dissolved phosphorus coming off of regular fertilizer application lawns was twice that of lawns with non-phosphorus or no fertilizer. Dissolved phosphorus is a form in which the phosphorus molecule is not bound to a particle of any kind; in this respect, it is readily available to algae. Therefore, these studies show us that it is a developed shoreland that is continuously maintained in an unnatural manner (receiving phosphorus rich fertilizer) that impacts lakes the greatest. This understanding led former Governor Jim Doyle into passing the Wisconsin Zero-Phosphorus Fertilizer Law (Wis Statue 94.643), which restricts the use, sale and display of lawn and turf fertilizer which contains phosphorus. Certain exceptions apply, but after April 1 2010, use of this type of fertilizer is prohibited on lawns and turf in Wisconsin. The goal of this action is to reduce the impact of developed lawns, and is particularly helpful to developed lawns situated near Wisconsin waterbodies.

Shorelands provide much in terms of nutrient retention and mitigation, but also play an important role in wildlife habitat. Woodford and Meyer (2003) found that green frog density was negatively correlated with development density in Wisconsin lakes. As development increased, the habitat for green frogs decreased and thus populations became significantly lower (Woodford and Meyer 2003). Common loons, a bird species notorious for its haunting call that echoes across Wisconsin lakes, are often associated more so with undeveloped lakes than developed lakes (Lindsay, Gillum and Meyer 2002). And studies on shoreland development and fish nests show that undeveloped shorelands are preferred as well. In a study conducted on three Minnesota lakes, researchers found that only 74 of 852 black crappie nests were found near shorelines that had any type of dwelling on it (Reed 2001). The remaining nests were all located along undeveloped shoreland.

Photograph 3.3-1. Example of coarse woody habitat in a lake.

Emerging research in Wisconsin has shown that coarse woody habitat (sometimes called "coarse woody debris"), often stemming from natural or undeveloped shorelands, provides many ecosystem benefits in a lake. Coarse woody habitat describes habitat consisting of trees, limbs, branches, roots and wood fragments at least four inches in diameter that enter a lake by natural or human means. Coarse woody habitat provides shoreland erosion control, a carbon source for the lake, prevents suspension of sediments and provides a surface for algal growth which important for aquatic macroinvertebrates (Sass 2009). While it impacts these aspects considerably, one of the greatest benefits coarse woody habitat provides is habitat for fish species.

Coarse woody habitat has shown to be advantageous for fisheries in terms of providing refuge, foraging area as well as spawning habitat (Hanchin, Willis and St. Stauver 2003). In one study, researchers observed 16 different species occupying coarse woody habitat areas in a Wisconsin lake (Newbrey et al. 2005). Bluegill and bass species in particular are attracted to this habitat type; largemouth bass stalk bluegill in these areas while the bluegill hide amongst the debris and often feed upon in many macroinvertebrates found in these areas, who themselves are feeding upon algae and periphyton growing on the wood surface. Newbrey et al. (2005) found that some fish species prefer different complexity of branching on coarse woody habitat, though in general some degree of branching is preferred over coarse woody habitat that has no branching.

With development of a lake's shoreland zone, much of the coarse woody habitat that was once found in Wisconsin lakes has disappeared. Prior to human establishment and development on lakes (mid to late 1800's), the amount of coarse woody habitat in lakes was likely greater than under completely natural conditions due to logging practices. However, with changes in the logging industry and increasing development along lake shorelands, coarse woody habitat has decreased substantially. Shoreland residents are removing woody debris to improve aesthetics or for recreational opportunities (boating, swimming, and, ironically, fishing).

National Lakes Assessment

Unfortunately, along with Wisconsin's lakes, waterbodies within the entire United States have shown to have increasing amounts of developed shorelands. The National Lakes Assessment (NLA) is an Environmental Protection Agency sponsored assessment that has successfully pooled together resource managers from all 50 U.S. states in an effort to assess waterbodies, both natural and man-made, from each state. Through this collaborative effort, over 1,000 lakes were sampled in 2007, pooling together the first statistical analysis of the nation's lakes and reservoirs.

Through the National Lakes Assessment, a number of potential stressors were examined, including nutrient impairment, algal toxins, fish tissue contaminants, physical habitat, and others. The 2007 NLA report states that "*of the stressors examined, poor lakeshore habitat is the biggest problem in the nations lakes; over one-third exhibit poor shoreline habitat condition*" (USEPA 2009).

Furthermore, the report states that "*poor biological health is three times more likely in lakes with poor lakeshore habitat*".

The results indicate that stronger management of shoreline development is absolutely necessary to preserve, protect and restore lakes. This will become increasingly important as development pressured on lakes continue to steadily grow.

Native Species Enhancement

The development of Wisconsin's shorelands has increased dramatically over the last century and with this increase in development a decrease in water quality and wildlife habitat has occurred. Many people that move to or build in shoreland areas attempt to replicate the suburban landscapes they are accustomed to by converting natural shoreland areas to the "neat and clean" appearance of manicured lawns and flowerbeds. The conversion of these areas immediately leads to destruction of habitat utilized by birds, mammals, reptiles, amphibians, and insects (Jennings et al. 2003). The maintenance of the newly created area helps to decrease water quality by considerably increasing inputs of phosphorus and sediments into the lake. The negative impact of human development does not stop at the shoreland. Removal of native plants and dead, fallen timbers from shallow, near-shore areas for boating and swimming activities destroys habitat used by fish, mammals, birds, insects, and amphibians, while leaving bottom and shoreland sediments vulnerable to wave action caused by boating and wind (Jennings et al. 2003), (Radomski and Goeman 2001), and (Elias and Meyer 2003). Many homeowners significantly decrease the number of trees and shrubs along the water's edge in an effort to increase their view of the lake. However, this has been shown to locally increase water temperatures, and decrease infiltration rates of potentially harmful nutrients and pollutants. Furthermore, the dumping of sand to create beach areas destroys spawning, cover and feeding areas utilized by aquatic wildlife (Scheuerell and Schindler 2004).

Photograph 3.3-2. Example of a biolog restoration site.

In recent years, many lakefront property owners have realized increased aesthetics, fisheries, property values, and water quality by restoring portions of their shoreland to mimic its unaltered state. An area of shore restored to its natural condition, both in the water and on shore, is commonly called a shoreland buffer zone. The shoreland buffer zone creates or restores the ecological habitat and benefits lost by traditional suburban landscaping. Simply not mowing within the buffer zone does wonders to restore some of the shoreland's natural function.

Enhancement activities also include additions of submergent, emergent, and floating-leaf plants within the lake itself. These additions can provide greater species diversity and may compete against exotic species.

Wisconsin's Healthy Lakes & Rivers Action Plan

Starting in 2014, a program was enacted by the WDNR and UW-Extension to promote riparian landowners to implement relatively straight-forward shoreland restoration activities. This program provides education, guidance, and grant funding to promote installation of best management practices aimed to protect and restore lakes and rivers in Wisconsin. The program has identified five best practices aimed at improving habitat and water quality (Figure 3.3-1).

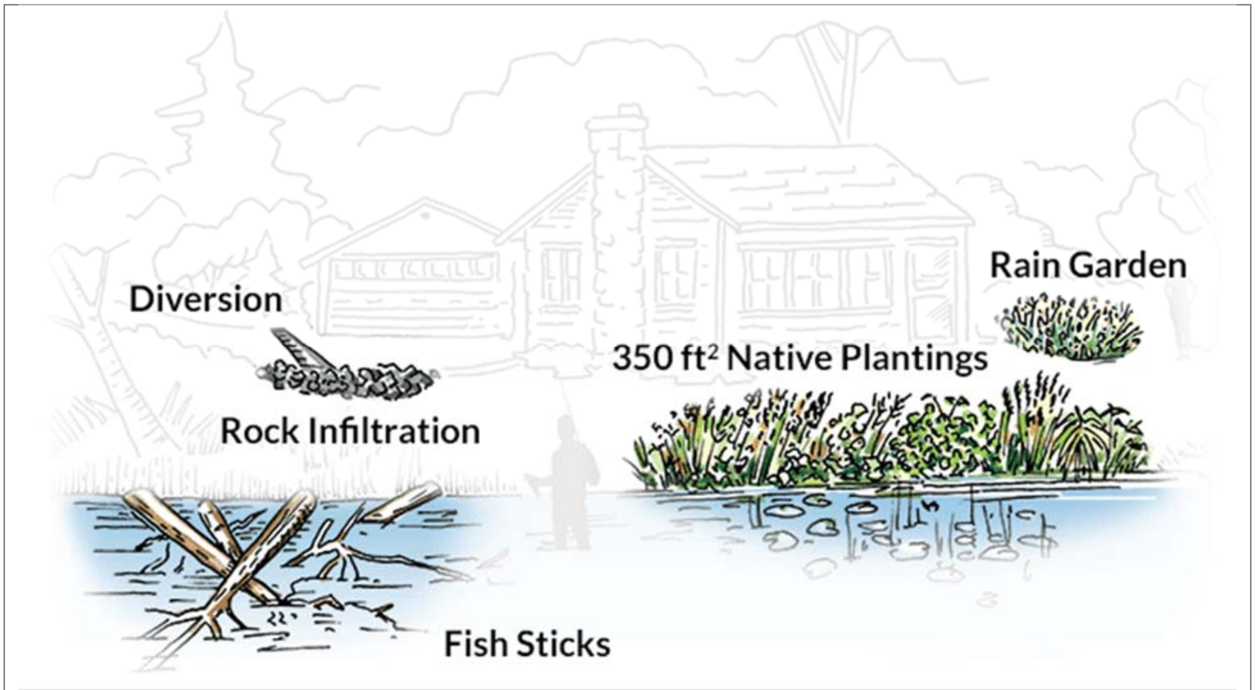


Figure 3.3-1. Healthy Lakes & Rivers 5 Best Practices. Illustration by Karen Engelbretson, extracted from healthylakeswi.com.

- Rain Gardens: This upland best practice consists of a landscaped and vegetated shallow depression aimed at capturing water runoff and allowing it to infiltrate into the soil.
- Rock Infiltration: This upland best practice is an excavated pit or trench, filled with rock, that encourages water to infiltrate into the soil. These practices are strategically placed at along a roof line or the downward sloping area of a driveway.
- Diversion: This best practice can occur in the transition or upland zone. These practices use berms, trenches, and/or treated lumber to redirect water that would otherwise move downhill into a lake. Water diversions may direct water into a Rock Infiltration or Rain Garden to provide the greatest reductions in runoff volumes.
- Native Plantings: This best practice aims to installing native plants within at least 350 square-foot shoreland transition area. This will slow runoff water and provide valuable habitat. One native planting per property per year is eligible.
- Fish Sticks: These in-lake best practices (not eligible for rivers) are woody habitat structures that provide feeding, breeding, and nesting areas for wildlife. Fish sticks consist of multiple whole trees grouped together and anchored to the shore. Trees are not felled from the shoreline, as existing trees are valuable in place, but brought from a short distance or dragged across the ice. In order for this practice to be eligible, an existing vegetated buffer or pledge to install one is required.

The Healthy Lakes and Rivers Grant Program allows partial cost coverage for implementing best practices. Competitive grants are available to eligible applicants such as lake associations and lake districts. The program allows a 75% state cost share up to $1,000 per practice. Multiple practices can be included per grant application, with a $25,000 maximum award per year. Eligible projects need to be on shoreland properties within 1,000 feet of a lake or 300 feet from a river. The landowner must sign a Conservation Commitment pledge to leave the practice in place and provide continued maintenance for 10 years. More information on this program can be found here:

https://healthylakeswi.com/

It is important to note that this grant program is intentionally designed for relatively simple, low-cost, and shovel-ready projects, limiting 10% of the grant award for technical assistance. Larger and more complex projects, especially those that require engineering design components may seek alternative funding sources potentially through the County. Small-Scale Lake Planning Grants can provide up to $3,000 to help build a Healthy Lakes and Rivers project. Eligible expenses in this grant program are surveys, planning, and design.

Mirror and Shadow Lake Shoreland Zone Condition

Shoreland Development

The entire shoreline of Mirror and Shadow lakes was surveyed in the summer of 2020. A draft WDNR Lake Shoreland & Shallows Habitat Monitoring Field Protocol (WDNR, Lake Shoreland & Shallows Habitat Monitoring Field Protocol 2020) was utilized to evaluate the shoreland zone on a parcel-by-parcel basis beginning at the estimated high-water level mark and extending inland 35 feet. The immediate shoreline was surveyed and classified based upon its potential to negatively impact the system due to development and other human impacts. Within the shoreland zone the natural vegetation (canopy cover, shrub/herbaceous) was given an estimate of the percentage of the plot which is dominated by each category (Photo 3.3-3). Human disturbances (impervious surface, manicured lawn, agriculture, number of buildings, boats on shore, piers, boat lifts, sea wall length and other similar categories) were also recorded by number of occurrence or percentage during the survey.

Photograph 3.3-3. Example of canopy, shrub and herbaceous layers.

For this management plan, the percent canopy cover, percent shrub/herbaceous, percent manicured lawn and percent impervious surfaces are primarily focused upon to assess the shoreline for development and determine a need for restoration. In general, developed shorelands impact a lake ecosystem in a negative manner, while definite benefits occur from shorelands that are left in their natural state or a near-natural state. In the following analysis, the shoreland attributes are combined for Mirror and Shadow lakes due to the fact that some parcels stretch the shoreline along each lake.

Canopy cover was defined as an area which is shaded by trees that are at least 16 feet tall (Photograph 3.4-3). Approximately 61% (1.2 miles) of the shoreland around Mirror and Shadow lakes have parcels with between 0-20% or 21-40% canopy cover (Figure 3.3-2, Map 3). Another 32% of parcels fell into either the 61-80% canopy cover or 81-100% canopy cover.

Shrub and herbaceous layers are small trees and plants without woody stems less than 16 feet tall (Photograph 3.4-3). The shoreland assessment survey indicates that 47% or Mirror and Shadow Lake's parcels contained between 81-100% shrub and herbaceous layers (Figure 3.3-2, Map 4). Another 22% had between 41-60% shrub and herbaceous layer present on the parcel.

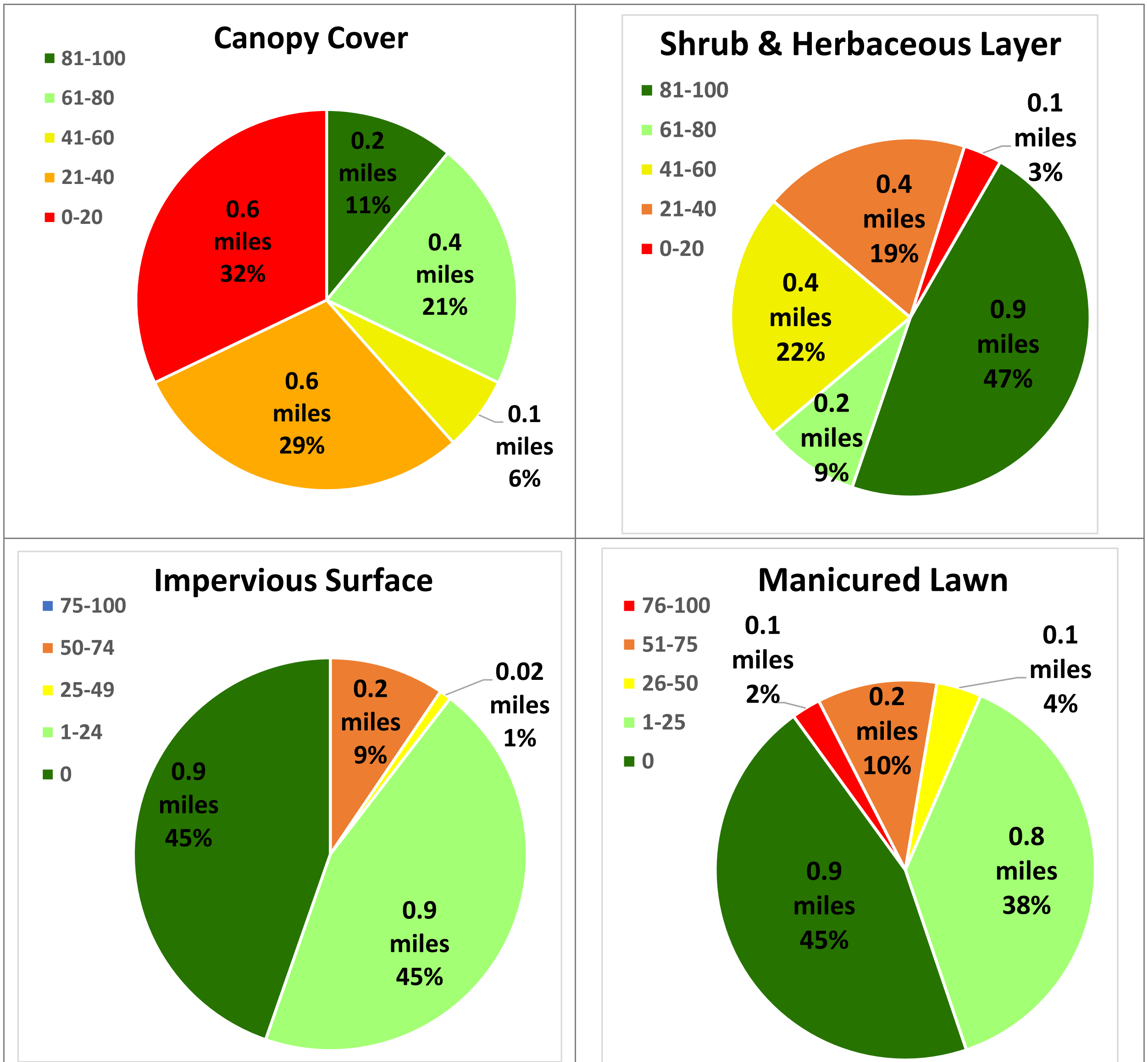


Figure 3.3-2. Mirror and Shadow Lakes 2020 shoreland parcel canopy cover, shrub-herbaceous cover, manicured lawn, and impervious surface. Data from Onterra 2020 Survey.

A manicured lawn is defined as grass that is mowed short and is direct evidence of urbanization. Having a manicured lawn poses a risk as runoff will carry pollutants, such as lawn fertilizers, into the lake. Approximately 45% of the parcels around the lakes had no manicured lawn within the shoreland zone and another 38% of parcels had between 1-24% of the shoreland zone containing manicured lawn (Figure 3.3-2, Map 5). Approximately 12% of the shoreland parcels contained manicured lawn on 51% or greater of the shoreland zone.

Impervious surface is an area that releases all or a majority of the precipitation that falls onto it (e.g. rooftops, concrete, stairs, boulders and boats flipped over on shore). Approximately 90% of the parcels had either zero or 1-24% of impervious surface within the shoreland zone (Figure 3.3-2, Map 6).

Sections of Mirror and Shadow Lake's shoreline that contain a manicured lawn and a small percentage of canopy, shrub and herbaceous cover are potential candidates for shoreline restorations. A management goal to maintain a 30-foot-deep vegetated buffer on all shorelands was included with a 2012 management plan drafted by UW – Stevens Point for the Friends Group. Actions related to this goal included educational initiatives, erosion and runoff mitigation, stormwater runoff reduction, protecting undeveloped vegetated areas, and implementing practices to deter Canadian geese.

Evidence of this former goal's implementation were apparent when assessing the shorelands around the lakes in 2020 including a rain garden on a city-owned parcel, shoreland restoration sites, and a majority of parcels with vegetated buffers along their shores. Considering the urban setting of the lakes, the shorelands around the lakes offered a high proportion of natural and vegetated conditions.

Coarse Woody Habitat

As part of the shoreland condition assessment, Mirror and Shadow lakes were also surveyed to determine the extent of its coarse woody habitat. Survey methodology was consistent with the WDNR Shoreland and Shallows Habitat Monitoring Field Protocol (WDNR 2016). All wood greater than 4 inches in diameter, at least 5 feet long and located between the high-water level (HWL) mark and 2-foot contour line was marked with a GPS waypoint. The coarse woody habitat was then given a complexity ranking (no branches, a few branches and tree trunk has a full crown), marked if the wood touched shore and whether the wood was mostly submerged in water. As discussed earlier, research indicates that fish species prefer some branching as opposed to no branching on coarse woody habitat, and increasing complexity is positively correlated with higher fish species richness, diversity and abundance (Newbrey et al. 2005).

During this survey, 41 pieces of coarse woody habitat were documented in Mirror Lake and 32 pieces were identified in Shadow Lake resulting in a ratio of 50 pieces per mile of shoreline for Mirror Lake and 27 pieces per mile in Shadow Lake (Maps 7 & 8). Of these pieces, most did not cross the high-water level, meaning they were between the shoreline and the two-foot depth contour. Just one piece of woody habitat was classified as a full canopy.

To put this into perspective, Wisconsin researchers have found that in completely undeveloped lakes, an average of 345 coarse woody habitat structures may be found per mile (Christensen et al. 1996). Please note the methodologies between the surveys done on Mirror and Shadow lakes and those cited in this literature comparison are much different, but still provide a valuable insight into what undisturbed shorelines may have in terms of coarse woody habitat.

Onterra has completed coarse woody habitat surveys on 128 lakes throughout Wisconsin since 2012, with the majority occurring in the Northern Lakes and Forests ecoregion. The number of coarse woody habitat pieces per shoreline mile in Mirror Lake falls in the 86th percentile for this group of lakes and Shadow Lake falls just above the median value or the 51st percentile (Figure 3.3-3 – right frame).

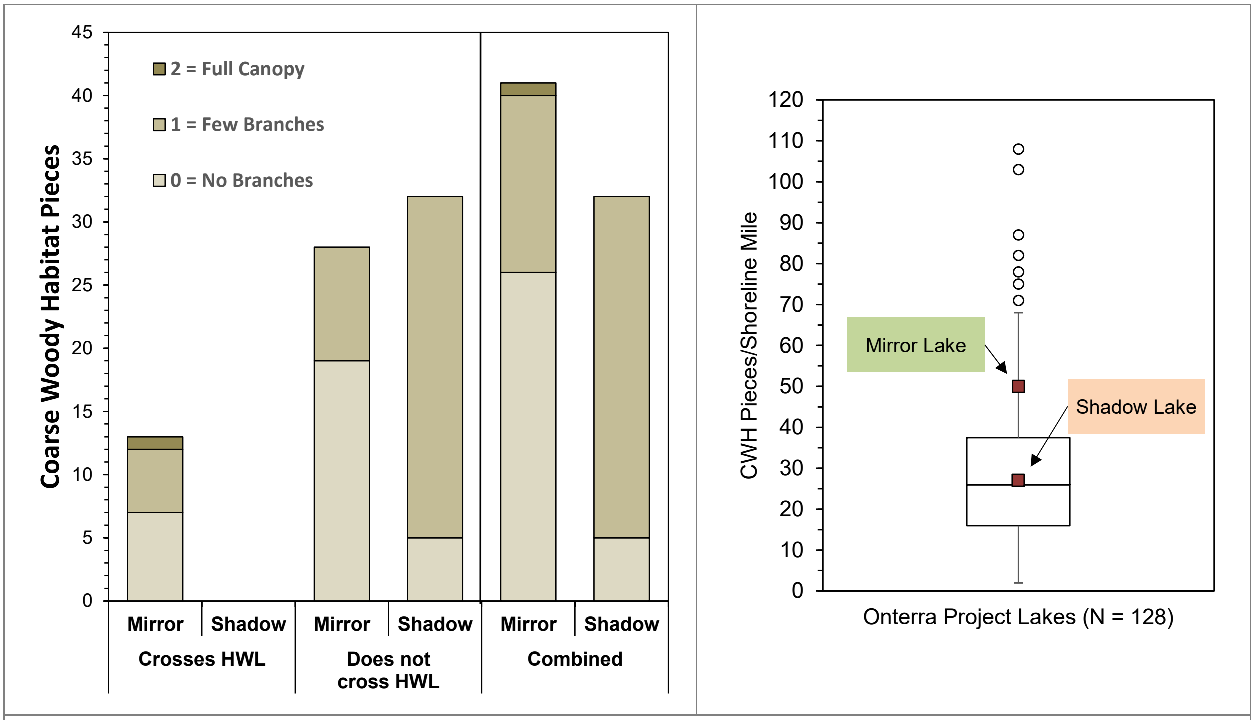


Figure 3.3-3. Mirror Lake and Shadow Lake's coarse woody habitat survey results. Based upon a summer 2020 survey. Locations of coarse woody habitat are displayed on Map 7.

Some of the pieces of coarse woody habitat that were observed off shore from County Road K in Shadow Lake were "fish sticks", a type of intentionally placed fisheries habitat enhancement structure. Three clusters of trees were initially placed in this location during the winter of 2013-2014 and additional clusters are presumed to have been placed in the same general area in more recent years. The fish sticks were still providing valuable habitat in 2020 although some amount of decomposition has occurred since they were placed.

3.4 Aquatic Plants

Introduction

Although the occasional lake user considers aquatic macrophytes to be "weeds" and a nuisance to the recreational use of the lake, the plants are actually an essential element in a healthy and functioning lake ecosystem. It is very important that lake stakeholders understand the importance of lake plants and the many functions they serve in maintaining and protecting a lake ecosystem. With increased understanding and awareness, most lake users will recognize the importance of the aquatic plant community and their potential negative effects on it.

Photograph 3.4-1. Example of emergent and floating leaf communities.

Diverse aquatic vegetation provides habitat and food for many kinds of aquatic life, including fish, insects, amphibians, waterfowl, and even terrestrial wildlife. For instance, wild celery (*Vallisneria americana)* and wild rice (*Zizania aquatica* and *Z. palustris*) both serve as excellent food sources for ducks and geese. Emergent stands of vegetation provide necessary spawning habitat for fish such as northern pike (*Esox lucius*) and yellow perch (*Perca flavescens*) In addition, many of the insects that are eaten by young fish rely heavily on aquatic plants and the periphyton attached to them as their primary food source. The plants also provide cover for feeder fish and zooplankton, stabilizing the predator-prey relationships within the system. Furthermore, rooted aquatic plants prevent shoreland erosion and the resuspension of sediments and nutrients by absorbing wave energy and locking sediments within their root masses. In areas where plants do not exist, waves can resuspend bottom sediments decreasing water clarity and increasing plant nutrient levels that may lead to algae blooms. Lake plants also produce oxygen through photosynthesis and use nutrients that may otherwise be used by phytoplankton, which helps to minimize nuisance algal blooms.

Under certain conditions, a few species may become a problem and require control measures. Excessive plant growth can limit recreational use by deterring navigation, swimming, and fishing activities. It can also lead to changes in fish population structure by providing too much cover for feeder fish resulting in reduced predation by predator fish, which could result in a stunted pan-fish population. Exotic plant species, such as Eurasian watermilfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*) can also upset the delicate balance of a lake ecosystem by out competing native plants and reducing species diversity. These species will be discussed further in depth in the Aquatic Invasive Species section. These invasive plant species can form dense stands that are a nuisance to humans and provide low-value habitat for fish and other wildlife.

When plant abundance negatively affects the lake ecosystem and limits the use of the resource, plant management and control may be necessary. The management goals should always include the control of invasive species and restoration of native communities through environmentally sensitive and economically feasible methods. No aquatic plant management plan should only contain methods to control plants, they should also contain methods on how to protect and possibly enhance the important plant communities within the lake. Unfortunately, the latter is often neglected and the ecosystem suffers as a result.

Aquatic Plant Management and Protection

Many times, an aquatic plant management plan is aimed at only controlling nuisance plant growth that has limited the recreational use of the lake, usually navigation, fishing, and swimming. It is important to remember the vital benefits that native aquatic plants provide to lake users and the lake ecosystem, as described above. Therefore, all aquatic plant management plans also need to address the enhancement and protection of the aquatic plant community. Below are general descriptions of the many techniques that can be utilized to control and enhance aquatic plants. Each alternative has benefits and limitations that are explained in its description. Please note that only legal and commonly used methods are included. For instance, the herbivorous grass carp (*Ctenopharyngodon idella*) is illegal in Wisconsin and rotovation, a process by which the lake bottom is tilled, is not a commonly accepted practice. Unfortunately, there are no "silver bullets" that can completely cure all aquatic plant problems, which makes planning a crucial step in any aquatic plant management activity. Many of the plant management and protection techniques commonly used in Wisconsin are described below.

Important Note:
Even though most of these techniques are not applicable to Mirror and Shadow lakes, it is still important for lake users to have a basic understanding of all the techniques so they can better understand why particular methods are or are not applicable in their lake**.** The techniques applicable to Mirror and Shadow lakes are discussed in Summary and Conclusions section and the Implementation Plan found near the end of this document.

Permits

The signing of the 2001-2003 State Budget by Gov. McCallum enacted many aquatic plant management regulations. The rules for the regulations have been set forth by the WDNR as NR 107 and 109. A major change includes that all forms of aquatic plant management, even those that did not require a permit in the past, require a permit now, including manual and mechanical removal. Manual cutting and raking are exempt from the permit requirement if the area of plant removal is no more than 30 feet wide and any piers, boatlifts, swim rafts, and other recreational and water use devices are located within that 30 feet. This action can be conducted up to 150 feet from shore. Please note that a permit is needed in all instances if wild rice is to be removed. Furthermore, installation of aquatic plants, even natives, requires approval from the WDNR.

Permits are required for chemical and mechanical manipulation of native and non-native plant communities. Large-scale protocols have been established for chemical treatment projects covering >10 acres or areas greater than 10% of the lake littoral zone and more than 150 feet from shore. Different protocols are to be followed for whole-lake scale treatments (≥160 acres or ≥50% of the lake littoral area). Additionally, it is important to note that local permits and U.S. Army Corps of Engineers regulations may also apply. For more information on permit requirements, please contact the WDNR Regional Water Management Specialist or Aquatic Plant Management and Protection Specialist.

Manual Removal

Manual removal methods include hand-pulling, raking, and hand-cutting. Hand-pulling involves the manual removal of whole plants, including roots, from the area of concern and disposing them out of the waterbody. Raking entails the removal of partial and whole plants from the lake by dragging a rake with a rope tied to it through plant beds. Specially designed rakes are available from commercial sources or an asphalt rake can be used. Hand-cutting differs from the other two manual methods because the entire plant is not removed, rather the plants are cut similar to mowing a lawn; however Wisconsin law states that all plant fragments must be removed. One manual cutting technique involves throwing a specialized "V" shaped cutter into the plant bed and retrieving it with a rope. The raking method entails the use of a two-sided straight blade on a telescoping pole that is swiped back and forth at the base of the undesired plants.

Photograph 3.4-2. Example of aquatic plants that have been removed manually.

In addition to the hand-cutting methods described above, powered cutters are now available for mounting on boats. Some are mounted in a similar fashion to electric trolling motors and offer a 4-foot cutting width, while larger models require complicated mounting procedures, but offer an 8-foot cutting width. Please note that the use of powered cutters may require a mechanical harvesting permit to be issued by the WDNR.

When using the methods outlined above, it is very important to remove all plant fragments from the lake to prevent re-rooting and drifting onshore followed by decomposition. It is also important to preserve fish spawning habitat by timing the treatment activities after spawning. In Wisconsin, a general rule would be to not start these activities until after June 15th.

Cost

Commercially available hand-cutters and rakes range in cost from $85 to $150. Power-cutters range in cost from $1,200 to $11,000.

Advantages	*Disadvantages*
• Very cost effective for clearing areas around docks, piers, and swimming areas. • Relatively environmentally safe if treatment is conducted after June 15th. • Allows for selective removal of undesirable plant species. • Provides immediate relief in localized area. • Plant biomass is removed from waterbody.	• Labor intensive. • Impractical for larger areas or dense plant beds. • Subsequent treatments may be needed as plants recolonize and/or continue to grow. • Uprooting of plants stirs bottom sediments making it difficult to conduct action. • May disturb benthic organisms and fish-spawning areas. • Risk of spreading invasive species if fragments are not removed.

Bottom Screens

Bottom screens are very much like landscaping fabric used to block weed growth in flowerbeds. The gas-permeable screen is placed over the plant bed and anchored to the lake bottom by staking or weights. Only gas-permeable screen can be used or large pockets of gas will form under the mat as the result of plant decomposition. This could lead to portions of the screen becoming detached from the lake bottom, creating a navigational hazard. Normally the screens are removed and cleaned at the end of the growing season and then placed back in the lake the following spring. If they are not removed, sediments may build up on them and allow for plant colonization on top of the screen.

Cost

Material costs range between $.20 and $1.25 per square-foot. Installation cost can vary largely, but may roughly cost $750 to have 1,000 square feet of bottom screen installed. Maintenance costs can also vary, but an estimate for a waterfront lot is about $120 each year.

Advantages	*Disadvantages*
• Immediate and sustainable control. • Long-term costs are low. • Excellent for small areas and around obstructions. • Materials are reusable. • Prevents fragmentation and subsequent spread of plants to other areas.	• Installation may be difficult over dense plant beds and in deep water. • Not species specific. • Disrupts benthic fauna. • May be navigational hazard in shallow water. • Initial costs are high. • Labor intensive due to the seasonal removal and reinstallation requirements. • Does not remove plant biomass from lake. • Not practical in large-scale situations.

Water Level Drawdown

The primary manner of plant control through water level drawdown is the exposure of sediments and plant roots/tubers to desiccation and either heating or freezing depending on the timing of the treatment. Winter drawdowns are more common in temperate climates like that of Wisconsin and usually occur in reservoirs because of the ease of water removal through the outlet structure. An important fact to remember when considering the use of this technique is that only certain species are controlled and that some species may even be enhanced. Furthermore, the process will likely need to be repeated every two or three years to keep target species in check.

Cost

The cost of this alternative is highly variable. If an outlet structure exists, the cost of lowering the water level would be minimal; however, if there is not an outlet, the cost of pumping water to the desirable level could be very expensive. If a hydro-electric facility is operating on the system, the costs associated with loss of production during the drawdown also need to be considered, as they are likely cost prohibitive to conducting the management action.

Advantages	***Disadvantages***
• Inexpensive if outlet structure exists. • May control populations of certain species, like Eurasian watermilfoil for a few years. • Allows some loose sediment to consolidate, increasing water depth. • May enhance growth of desirable emergent species. • Other work, like dock and pier repair may be completed more easily and at a lower cost while water levels are down.	• May be cost prohibitive if pumping is required to lower water levels. • Has the potential to upset the lake ecosystem and have significant effects on fish and other aquatic wildlife. • Adjacent wetlands may be altered due to lower water levels. • Disrupts recreational, hydroelectric, irrigation and water supply uses. • May enhance the spread of certain undesirable species, like common reed and reed canary grass. • Permitting process may require an environmental assessment that may take months to prepare. • Non-selective.

Mechanical Harvesting


Photograph 3.4-3. Mechanical harvester.

Aquatic plant harvesting is frequently used in Wisconsin and involves the cutting and removal of plants much like mowing and bagging a lawn. Harvesters are produced in many sizes that can cut to depths ranging from 3 to 6 feet with cutting widths of 4 to 10 feet. Plant harvesting speeds vary with the size of the harvester, density and types of plants, and the distance to the off-loading area. Equipment requirements do not end with the harvester. In addition to the harvester, a shore-conveyor would be required to transfer plant material from the harvester to a dump truck for transport to a landfill or compost site. Furthermore, if off-loading sites are limited and/or the lake is large, a transport barge may be needed to move the harvested plants from the harvester to the shore in order to cut back on the time that the harvester spends traveling to the shore conveyor. Some lake organizations contract to have nuisance plants harvested, while others choose to purchase their own equipment. If the latter route is chosen, it is especially important for the lake group to be very organized and realize that there is a great deal of work and expense involved with the purchase, operation, maintenance, and storage of an aquatic plant harvester. In either case, planning is very important to minimize environmental effects and maximize benefits.

Cost

Equipment costs vary with the size and features of the harvester, but in general, standard harvesters range between $45,000 and $100,000. Larger harvesters or stainless steel models may cost as much as $200,000. Shore conveyors cost approximately $20,000 and trailers range from $7,000 to $20,000. Storage, maintenance, insurance, and operator salaries vary greatly.

Advantages	***Disadvantages***
• Immediate results. • Plant biomass and associated nutrients are removed from the lake. • Select areas can be treated, leaving sensitive areas intact. • Plants are not completely removed and can still provide some habitat benefits. • Opening of cruise lanes can increase predator pressure and reduce stunted fish populations. • Removal of plant biomass can improve the oxygen balance in the littoral zone. • Harvested plant materials produce excellent compost.	• Initial costs and maintenance are high if the lake organization intends to own and operate the equipment. • Multiple treatments are likely required. • Many small fish, amphibians and invertebrates may be harvested along with plants. • There is little or no reduction in plant density with harvesting. • Invasive and exotic species may spread because of plant fragmentation associated with harvester operation. • Bottom sediments may be re-suspended leading to increased turbidity and water column nutrient levels.

Herbicide Treatment

Photograph 3.4-4. Liquid herbicide application. Photo credit: Amy Kay, Clarke.

The use of herbicides to control aquatic plants and algae is a technique that is widely used by lake managers. Traditionally, herbicides were used to control nuisance levels of aquatic plants and algae that interfere with navigation and recreation. While this practice still takes place in many parts of Wisconsin, the use of herbicides to control aquatic invasive species is becoming more prevalent. Resource managers employ strategic management techniques towards aquatic invasive species, with the objective of reducing the target plant's population over time; and an overarching goal of attaining long-term ecological restoration. For submergent vegetation, this largely consists of implementing control strategies early in the growing season; either as spatially-targeted, small-scale spot treatments or low-dose, large-scale (whole lake) treatments. Treatments occurring roughly each year before June 1 and/or when water temperatures are below 60°F can be less impactful to many native plants, which have not emerged yet at this time of year. Emergent species are targeted with foliar applications at strategic times of the year when the target plant is more likely to absorb the herbicide.

While there are approximately 300 herbicides registered for terrestrial use in the United States, only 13 active ingredients can be applied into or near aquatic systems. All aquatic herbicides must be applied in accordance with the product's US Environmental Protection Agency (EPA) approved label. There are numerous formulations and brands of aquatic herbicides and an extensive list can be found in Appendix F of (Gettys 2009).

Applying herbicides in the aquatic environment requires special considerations compared with terrestrial applications. WDNR administrative code states that a permit is required if "you are standing in socks and they get wet." In these situations, the herbicide application needs to be completed by an applicator licensed with the Wisconsin Department of Agriculture, Trade and Consumer Protection. All herbicide applications conducted under the ordinary high water mark require herbicides specifically labeled by the United States Environmental Protection Agency

Aquatic herbicides can be classified in many ways. Organization of this section follows Netherland (2009) in which mode of action (i.e. how the herbicide works) and application techniques (i.e. foliar or submersed treatment) group the aquatic herbicides (Netherland 2009). The table below provides a general list of commonly used aquatic herbicides in Wisconsin and is synthesized from Netherland (2009).

The arguably clearest division amongst aquatic herbicides is their general mode of action and fall into two basic categories:

1. Contact herbicides act by causing extensive cellular damage, but usually do not affect the areas that were not in contact with the chemical. This allows them to work much faster, but in some plants does not result in a sustained effect because the root crowns, roots, or rhizomes are not killed.
2. Systemic herbicides act slower than contact herbicides, being transported throughout the entire plant and disrupting biochemical pathways which often result in complete mortality.

General Mode of Action		Compound	Specific Mode of Action	Most Common Target Species in Wisconsin
Contact		Copper	plant cell toxicant	Algae, including macro-algae (i.e. muskgrasses & stoneworts)
		Endothall	Inhibits respiration & protein synthesis	Submersed species, largely for curly-leaf pondweed; invasive watermilfoil control when mixed with auxin herbicides
		Diquat	Inhibits photosynthesis & destroys cell membranes	Nusiance species including duckweeds, targeted AIS control when exposure times are low
		Flumioxazin	Inhibits photosynthesis & destroys cell membranes	Nusiance species, targeted AIS control when exposure times are low
Systemic	Auxin Mimics	2,4-D	auxin mimic, plant growth regulator	Submersed species, largely for invasive watermilfoil
		Triclopyr	auxin mimic, plant growth regulator	Submersed species, largely for invasive watermilfoil
		Florpyrauxifen -benzyl	arylpicolinate auxin mimic, growth regulator, different binding afinity than 2,4-D or triclopyr	Submersed species, largely for invasive watermilfoil
	In Water Use Only	Fluridone	Inhibits plant specific enzyme, new growth bleached	Submersed species, largely for invasive watermilfoil
	Enzyme Specific (ALS)	Penoxsulam	Inhibits plant-specific enzyme (ALS), new growth stunted	Emergent species with potential for submergent and floating-leaf species
		Imazamox	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
	Enzyme Specific (foliar use only)	Glyphosate	Inhibits plant-specific enzyme (ALS)	Emergent species, including purple loosestrife
		Imazapyr	Inhibits plant-specific enzyme (EPSP)	Hardy emergent species, including common reed

Both types are commonly used throughout Wisconsin with varying degrees of success. The use of herbicides is potentially hazardous to both the applicator and the environment, so all lake organizations should seek consultation and/or services from professional applicators with training and experience in aquatic herbicide use.

Herbicides that target submersed plant species are directly applied to the water, either as a liquid or an encapsulated granular formulation. Factors such as water depth, water flow, treatment area size, and plant density work to reduce herbicide concentration within aquatic systems. Understanding concentration and exposure times are important considerations for aquatic herbicides. Successful control of the target plant is achieved when it is exposed to a lethal concentration of the herbicide for a specific duration of time. Much information has been gathered in recent years, largely as a result of an ongoing cooperative research project between the Wisconsin Department of Natural Resources, US Army Corps of Engineers Research and Development Center, and private consultants (including Onterra). This research couples quantitative aquatic plant monitoring with field-collected herbicide concentration data to evaluate efficacy and selectivity of control strategies implemented on a subset of Wisconsin lakes and flowages. Based on their preliminary findings, lake managers have adopted two main treatment strategies; 1) whole-lake treatments, and 2). spot treatments.

Spot treatments are a type of control strategy where the herbicide is applied to a specific area (treatment site) such that when it dilutes from that area, its concentrations are insufficient to cause significant affects outside of that area. Spot treatments typically rely on a short exposure time (often hours) to cause mortality and therefore are applied at a much higher herbicide concentration than whole-lake treatments. This has been the strategy historically used on most Wisconsin systems.

Whole-lake treatments are those where the herbicide is applied to specific sites, but when the herbicide reaches equilibrium within the entire volume of water (entire lake, lake basin, or within the epilimnion of the lake or lake basin); it is at a concentration that is sufficient to cause mortality to the target plant within that entire lake or basin. The application rate of a whole-lake treatment is dictated by the volume of water in which the herbicide will reach equilibrium. Because exposure time is so much longer, target herbicide levels for whole-lake treatments are significantly less than for spot treatments.

Cost

Herbicide application charges vary greatly between $400 and $1,500 per acre depending on the chemical used, who applies it, permitting procedures, and the size/depth of the treatment area.

Advantages	*Disadvantages*
• Herbicides are easily applied in restricted areas, like around docks and boatlifts. • Herbicides can target large areas all at once. • If certain chemicals are applied at the correct dosages and at the right time of year, they can selectively control certain invasive species, such as Eurasian watermilfoil. • Some herbicides can be used effectively in spot treatments. • Most herbicides are designed to target plant physiology and in general, have low toxicological effects on non-plant organisms (e.g. mammals, insects)	• All herbicide use carries some degree of human health and ecological risk due to toxicity. • Fast-acting herbicides may cause fish kills due to rapid plant decomposition if not applied correctly. • Many people adamantly object to the use of herbicides in the aquatic environment; therefore, all stakeholders should be included in the decision to use them. • Many aquatic herbicides are nonselective. • Some herbicides have a combination of use restrictions that must be followed after their application. • Overuse of same herbicide may lead to plant resistance to that herbicide.

Biological Controls

There are many insects, fish and pathogens within the United States that are used as biological controls for aquatic macrophytes. For instance, the herbivorous grass carp has been used for years in many states to control aquatic plants with some success and some failures. However, it is illegal to possess grass carp within Wisconsin because their use can create problems worse than the plants that they were used to control. Other states have also used insects to battle invasive plants, such as water hyacinth weevils (*Neochetina spp.*) and hydrilla stem weevil (*Bagous spp.*) to control water hyacinth (*Eichhornia crassipes*) and hydrilla (*Hydrilla verticillata)*, respectively. Fortunately, it is assumed that Wisconsin's climate is a bit harsh for these two invasive plants, so there is no need for either biocontrol insect.

However, Wisconsin, along with many other states, is currently experiencing the expansion of lakes infested with Eurasian watermilfoil and as a result has supported the experimentation and use of the milfoil weevil (*Euhrychiopsis lecontei*) within its lakes. The milfoil weevil is a native weevil that has shown promise in reducing Eurasian watermilfoil stands in Wisconsin, Washington, Vermont, and other states. Research is currently being conducted to discover the best situations for the use of the insect in battling Eurasian watermilfoil. Currently the milfoil weevil is not a WDNR grant-eligible method of controlling Eurasian watermilfoil.

Cost

Stocking with adult weevils costs about $1.20/weevil and they are usually stocked in lots of 1000 or more.

Advantages	***Disadvantages***
• Milfoil weevils occur naturally in Wisconsin. • Likely environmentally safe and little risk of unintended consequences.	• Stocking and monitoring costs are high. • This is an unproven and experimental treatment. • There is a chance that a large amount of money could be spent with little or no change in Eurasian watermilfoil density.

Wisconsin has approved the use of two species of leaf-eating beetles (*Galerucella calmariensis* and *G. pusilla*) to battle purple loosestrife. These beetles were imported from Europe and used as a biological control method for purple loosestrife. Many cooperators, such as county conservation departments or local UW-Extension locations, currently support large beetle rearing operations. Beetles are reared on live purple loosestrife plants growing in kiddy pools surrounded by insect netting. Beetles are collected with aspirators and then released onto the target wild population. For more information on beetle rearing, contact your local UW-Extension location.

In some instances, beetles may be collected from known locations (cella insectaries) or purchased through private sellers. Although no permits are required to purchase or release beetles within Wisconsin, application/authorization and release forms are required by the WDNR for tracking and monitoring purposes.

Cost

The cost of beetle release is very inexpensive, and in many cases, free.

Advantages	***Disadvantages***
• Extremely inexpensive control method. • Once released, considerably less effort than other control methods is required. • Augmenting populations many lead to long-term control.	• Although considered “safe,” reservations about introducing one non-native species to control another exist. • Long range studies have not been completed on this technique.

Analysis of Current Aquatic Plant Data

Aquatic plants are an important element in every healthy lake. Changes in lake ecosystems are often first seen in the lake's plant community. Whether these changes are positive, such as variable water levels or negative, such as increased shoreland development or the introduction of an exotic species, the plant community will respond. Plant communities respond in a variety of ways. For example, there may be a loss of one or more species. Certain life forms, such as emergent or floating-leaf communities, may disappear from specific areas of the lake. A shift in plant dominance between species may also occur. With periodic monitoring and proper analysis, these changes are relatively easy to detect and provide very useful information for management decisions.

As described in more detail in the methods section, multiple aquatic plant surveys were completed on Mirror and Shadow lakes; the first looked strictly for the exotic plant, curly-leaf pondweed, while the others that followed assessed both native and non-native species. Combined, these surveys produce a great deal of information about the aquatic vegetation of the lake. These data are analyzed and presented in numerous ways; each is discussed in more detail below.

Primer on Data Analysis & Data Interpretation

Species List

The species list is simply a list of all of the aquatic plant species, both native and non-native, that were located during the surveys completed on Mirror and Shadow lakes in 2020. The list also contains the growth-form of each plant found (e.g. submergent, emergent, etc.), its scientific name, common name, and its coefficient of conservatism. The latter is discussed in more detail below. Changes in this list over time, whether it is differences in total species present, gains and losses of individual species, or changes in growth forms that are present, can be an early indicator of changes in the ecosystem.

Frequency of Occurrence

Frequency of occurrence describes how often a certain aquatic plant species is found within a lake. Obviously, all of the plants cannot be counted in a lake, so samples are collected from pre-determined areas. In the case of the whole-lake point-intercept survey completed on Mirror and Shadow lakes, plant samples were collected from plots laid out on a grid that covered the lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. The occurrence of aquatic plant species is displayed as the *littoral frequency of occurrence*. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are within the maximum depth of plant growth (littoral zone), and is displayed as a percentage.

Floristic Quality Assessment

The floristic quality of a lake's aquatic plant community is calculated using its native *species richness* and their *average conservatism*. Species richness is the number of native aquatic plant species that were physically encountered on the rake during the point-intercept survey. Average conservatism is calculated by taking the sum of the coefficients of conservatism (C-values) of the native species located and dividing it by species richness. Every plant in Wisconsin has been assigned a coefficient of conservatism, ranging from 1-10, which describes the likelihood of that species being found in an undisturbed environment. Species which are more specialized and require undisturbed habitat are given higher coefficients, while species which are more tolerant of environmental disturbance have lower coefficients.

For example, algal-leaf pondweed (*Potamogeton confervoides*) is only found in nutrient-poor, acid lakes in northern Wisconsin and is prone to decline if degradation of these lakes occurs. Because of algal-leaf pondweed's special requirements and sensitivity to disturbance, it has a C-value of 10. In contrast, sago pondweed (*Stuckenia pectinata*) with a C-value of 3, is tolerant of disturbance and is often found in greater abundance in degraded lakes that have higher nutrient concentrations and low water clarity. Higher average conservatism values generally indicate a healthier lake as it is able to support a greater number of environmentally-sensitive aquatic plant species. Low average conservatism values indicate a degraded environment, one that is only able to support disturbance-tolerant species.

On their own, the species richness and average conservatism values for a lake are useful in assessing a lake's plant community; however, the best assessment of the lake's plant community health is determined when the two values are used to calculate the lake's floristic quality. The floristic quality is calculated using the species richness and average conservatism value of the aquatic plant species that were solely encountered on the rake during the point-intercept surveys (equation shown below). This assessment allows the aquatic plant communities of Mirror and Shadow lakes to be compared to other lakes within the region and state.

$$\text{FQI} = \text{Average Coefficient of Conservatism} * \sqrt{\text{Number of Native Species}}$$

Species Diversity

Species diversity is often confused with species richness. As defined previously, species richness is simply the number of species found within a given community. While species diversity utilizes species richness, it also takes into account evenness or the variation in abundance of the individual species within the community. For example, a lake with 10 aquatic plant species that had relatively similar abundances within the community would be more diverse than another lake with 10 aquatic plant species were 50% of the community was comprised of just one or two species.

An aquatic system with high species diversity is more stable than a system with a low diversity. This is analogous to a diverse financial portfolio in that a diverse aquatic plant community can withstand environmental fluctuations much like a diverse portfolio can handle economic fluctuations. A lake with a diverse plant community is also better suited to compete against exotic infestations than a lake with a lower diversity. The diversity of a lake's aquatic plant community is determined using the Simpson's Diversity Index (1-D):

$$D = \sum (n/N)^2$$

where:
n = the total number of instances of a particular species
N = the total number of instances of all species and
D is a value between 0 and 1

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from Mirror and Shadow lakes is compared to data collected by Onterra and the WDNR Science Services on 85 lakes within the North Central Hardwood Forests ecoregion and on 392 lakes throughout Wisconsin.

Community Mapping

A key component of any aquatic plant community assessment is the delineation of the emergent and floating-leaf aquatic plant communities within each lake as these plants are often underrepresented during the point-intercept survey. This survey creates a snapshot of these important communities within each lake as they existed during the survey and is valuable in the development of the management plan and in comparisons with future surveys. Examples of emergent plants include cattails, rushes, sedges, grasses, bur-reeds, and arrowheads, while examples of floating-leaf species include the water lilies. The emergent and floating-leaf aquatic plant communities in Mirror and Shadow lakes were mapped using a Trimble Global Positioning System (GPS) with sub-meter accuracy.

Exotic Plants

Because of their tendency to upset the natural balance of an aquatic ecosystem, exotic species are paid particular attention to during the aquatic plant surveys. Two exotics, curly-leaf pondweed and Eurasian watermilfoil are the primary targets of this extra attention.

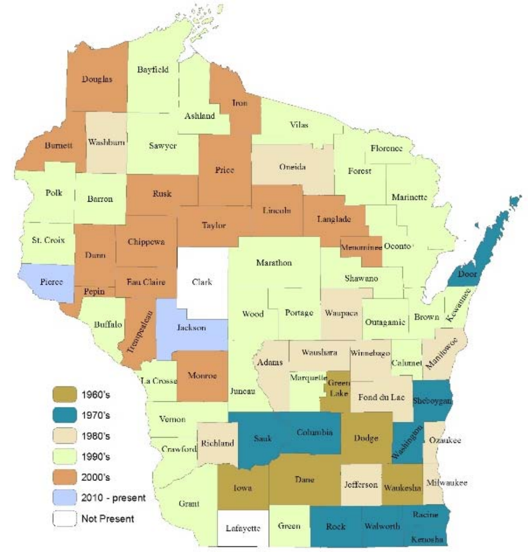


Figure 3.4-1. Spread of Eurasian watermilfoil within WI counties. WDNR Data 2015 mapped by Onterra.

Eurasian watermilfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.4-1). Eurasian watermilfoil is unique in that its primary mode of propagation is not by seed. It actually spreads by shoot fragmentation, which has supported its transport between lakes via boats and other equipment. In addition to its propagation method, Eurasian watermilfoil has two other competitive advantages over native aquatic plants, 1) it starts growing very early in the spring when water temperatures are too cold for most native plants to grow, and 2) once its stems reach the water surface, it does not stop growing like most native plants, instead it continues to grow along the surface creating a canopy that blocks light from reaching native plants. Eurasian watermilfoil can create dense stands and dominate submergent communities, reducing important natural habitat for fish and other wildlife, and impeding recreational activities such as swimming, fishing, and boating.

Curly-leaf pondweed is a European exotic first discovered in Wisconsin in the early 1900's that has an unconventional lifecycle giving it a competitive advantage over our native plants. Curly – leaf pondweed begins growing almost immediately after ice-out and by mid-June is at peak biomass. While it is growing, each plant produces many turions (asexual reproductive shoots) along its stem. By mid-July most of the plants have senesced, or died-back, leaving the turions in the sediment. The turions lie dormant until fall when they germinate to produce winter foliage, which thrives under the winter snow and ice. It remains in this state until spring foliage is produced in early May, giving the plant a significant jump on native vegetation. Like Eurasian watermilfoil, curly-leaf pondweed can become so abundant that it hampers recreational activities within the lake. Furthermore, its mid-summer die back can cause algal blooms spurred from the nutrients released during the plant's decomposition.

Because of its odd life-cycle, a special survey is conducted early in the growing season to inventory and map curly-leaf pondweed occurrence within the lake. Although Eurasian watermilfoil starts to grow earlier than our native plants, it is at peak biomass during most of the summer, so it is inventoried during the comprehensive aquatic plant survey completed in mid to late summer.

Aquatic Plant Survey Results

Mirror Lake

The first aquatic plant survey completed on Mirror Lake was an early-season aquatic invasive species (ESAIS) survey, on June 3, 2020. The goal of this survey is to identify and assess any new or existing occurrences of invasive plant species in the lake, with a particular focus on species that are most likely to be observed at this time of year: curly-leaf pondweed and pale-yellow iris. During this survey, Onterra ecologists observed curly-leaf pondweed and Eurasian watermilfoil within Mirror Lake, and pale-yellow iris in several areas around the lake's shoreline. Because of their ecological and sociological significance, these invasive species and their occurrences within Mirror Lake will be discussed in further detail in a subsequent section, Non-native Aquatic Plants in Mirror and Shadow lakes.

The whole-lake point-intercept (PI) survey was conducted on Mirror Lake on July 29-30, 2020 by Onterra staff (Figure 3.4-2). Additional surveys were completed by Onterra staff on these same dates to create the floating-leaf and emergent aquatic plant community map. Between these two surveys, a total of 30 aquatic plant species were located in Mirror Lake in 2020, five of which are considered non-native, invasive species: curly-leaf pondweed, Eurasian watermilfoil, pale-yellow iris, purple loosestrife, and reed canary grass.

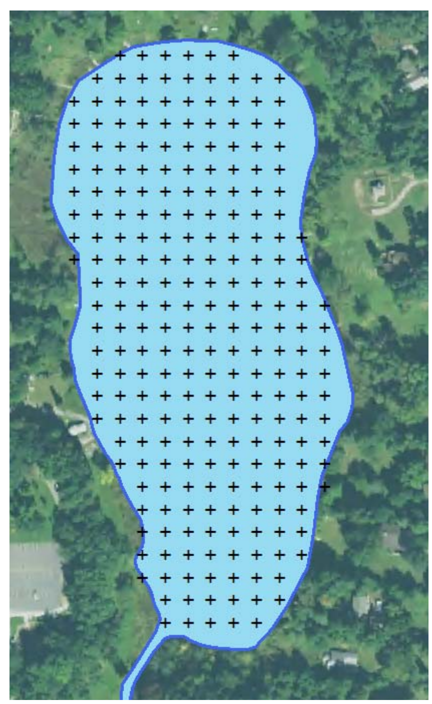


Figure 3.4-2. Mirror Lake point-intercept survey sampling locations. N = 244

Previous point-intercept surveys have been completed on Mirror Lake as well: a 2011 UW-Stevens Point PI survey and a 2018 PI survey by Golden Sands. Data from these surveys are integrated within the following analyses. Table 3.4-1 includes all aquatic plant species which were located during any of the three surveys. Taking all three surveys into account, a total of 41 species have been found in Mirror Lake. An "X" under the survey year on the species list indicates that the species was sampled directly on the rake during the PI survey. An "I", indicating incidental, indicates that the species was located visually within the lake during the survey, but not sampled on the rake. Incidental species typically include emergent and floating-leaf species that are often found growing on the fringes of the lake and submersed species that are rare within the plant community. Only species sampled directly on the rake are included within the following analyses.

Table 3.4-1. Aquatic plant species located on Mirror Lake during the 2011, 2018, and 2020 surveys.

Mirror Lake

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2011	2018	2020
Emergent	*Carex comosa*	Bristly sedge	Native	5			I
	Iris pseudacorus	Pale-yellow iris	Non-Native - Invasive	N/A	I		I
	Iris spp. (sterile)	Iris spp. (sterile)	N/A	N/A			I
	Iris versicolor	Northern blue flag	Native	5	I		
	Lythrum salicaria	Purple loosestrife	Non-Native - Invasive	N/A	I		I
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A			I
	Phragmites spp.	Reed species	N/A	N/A			I
	Sagittaria latifolia	Common arrowhead	Native	3			I
	Schoenoplectus acutus	Hardstem bulrush	Native	5	I		I
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4	I		
	Typha angustifolia	Narrow-leaved cattail	Non-Native - Invasive	N/A	I		
	Typha latifolia	Broad-leaved cattail	Native	1		I	I
FL	*Nuphar advena**	Yellow pondlily	Native - Special Concern	8	X		
	Nuphar variegata	Spatterdock	Native	6	X	X	I
	Nymphaea odorata	White water lily	Native	6	X	X	X
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X	X
	Chara spp.	Muskgrasses	Native	7	X	X	X
	Elodea canadensis	Common waterweed	Native	3		X	
	Heteranthera dubia	Water stargrass	Native	6	I		X
	Myriophyllum heterophyllum	Various-leaved watermilfoil	Native	7		X	
	Myriophyllum sibiricum	Northern watermilfoil	Native	7	X	X	X
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A		X	X
	Najas flexilis	Slender naiad	Native	6	X		
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A		X	I
	Potamogeton friesii	Fries' pondweed	Native	8		X	X
	Potamogeton gramineus	Variable-leaf pondweed	Native	7		X	X
	Potamogeton illinoensis	Illinois pondweed	Native	6	X	X	
	Potamogeton illinoensis X P. natans	Illinois pondweed X Floating-leaf pondweed	Native	N/A			X
	Potamogeton natans	Floating-leaf pondweed	Native	5			I
	Potamogeton nodosus	Long-leaf pondweed	Native	5		I	
	Potamogeton strictifolius	Stiff pondweed	Native	8			X
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6	X		X
	Ranunculus aquatilis	White water crowfoot	Native	8			X
	Ranunculus flabellaris	Yellow water crowfoot	Native	8	I		
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	Native	N/A	I		
	Stuckenia pectinata	Sago pondweed	Native	3	X	X	X
	Utricularia vulgaris	Common bladderwort	Native	7			X
	Vallisneria americana	Wild celery	Native	6	X	X	X
FF	*Lemna minor*	Lesser duckweed	Native	5			I
	Lemna trisulca	Forked duckweed	Native	6		X	X
	Wolffia spp.	Watermeal spp.	Native	N/A			I

X = Located on rake during point-intercept survey; I = Incidentally located; not located on rake during point-intercept survey
FL = Floating Leaf; FF = Free Floating
**Not verified; typically only found in southern WI*

Lakes in Wisconsin vary in their morphometry, water chemistry, water clarity, substrate composition, management, and recreational use, all factors which influence aquatic plant community composition. Like terrestrial plants, different aquatic plant species are adapted to grow in certain substrate types; some species are only found growing in soft substrates, others only in sandy/rocky areas, and some can be found growing in either. The combination of both soft sediments and areas of harder substrates creates different habitat types for aquatic plants, and generally leads to a higher number of aquatic plant species within the lake.

Mirror Lake has steep slopes along its perimeter and therefore gets deep very fast. Because of this, it supports a relatively small littoral area, and only 49 of the 244 sampling points were within the range of depth (≤ 16 feet) that could support aquatic plant growth. Of these sites that were shallow enough to be sampled with a pole, the proportion of sediment types were almost 50/50 between sand and soft organic sediments (Figure 3.4-3). Sites over 15' in depth are sampled with a rake head tied to the end of a rope and do not allow for the sampler to accurately "feel" the substrate type as can be done with the standard pole sampling method.

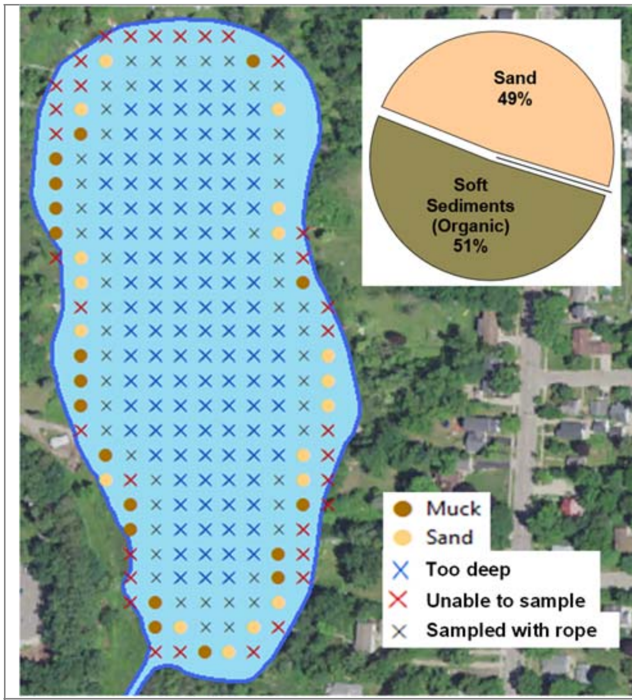


Figure 3.4-3. Mirror Lake proportion of substrate types within littoral areas. Created using data from the 2020 aquatic plant point-intercept survey.

Approximately 78% of the point-intercept sampling locations that fell within the maximum depth of aquatic plant growth (16 feet) in 2020 contained aquatic vegetation. This value was not statistically different to the littoral occurrence of vegetation of 79% recorded in 2018. Total rake fullness (TRF) is a measure of aquatic plant abundance and is illustrated in Figure 3.4-4. The 2020 TRF data indicated that where plants are present in Mirror Lake, they grow at a relatively high biomass with over 50% of the points containing vegetation having TRF ratings of 2 or 3.

The data collected from the whole-lake point-intercept survey was also used to quantify the abundance of individual plant species within the lake. Of the 15 native aquatic plant species that were sampled directly with the rake in 2020 in Mirror Lake, coontail, muskgrasses, sago pondweed, Fries' pondweed, and wild celery were the most frequently encountered (Figure 3.4-5).

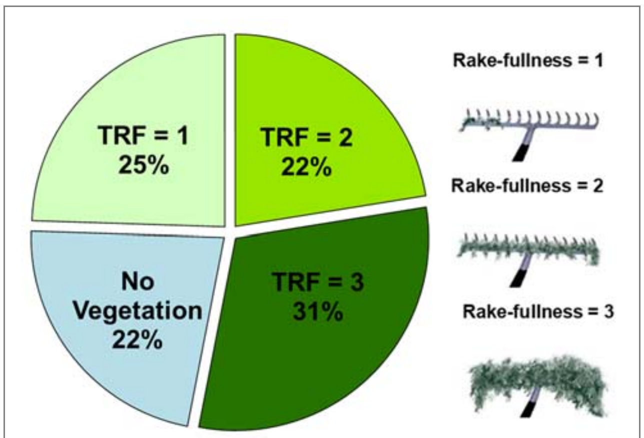


Figure 3.4-4. Mirror Lake aquatic vegetation total rake fullness (TRF) ratings. Created using data from the 2020 point-intercept survey.

Muskgrasses (*Chara* spp.) are a genus of macroalgae, of which there are ten documented species that occur in Wisconsin (Figure 3.4-6, upper middle). In 2020, muskgrasses had a littoral frequency of occurrence (LFOO) of just under 39% in Mirror Lake. This represents a statistically valid decrease in occurrence from the previous survey in 2018 which found a littoral frequency of over 57%. The 2011 survey had found an even higher LFOO of almost 80%.

Dominance of the aquatic plant community by muskgrasses is common in hardwater lakes and these macroalgae have been found to be more competitive against vascular plants (e.g., pondweeds, milfoils, etc.) in lakes with higher concentrations of calcium carbonate in the sediment (Kufel and Kufel 2002); (Wetzel 2001). Muskgrasses require lakes with good water clarity, and their large beds stabilize bottom sediments. Studies have also shown that muskgrasses sequester phosphorus in the calcium carbonate encrustations which form on these plants, aiding in improving water quality by making the phosphorus unavailable to phytoplankton (Coops 2002). Muskgrasses can be easily identified by their strong skunk-like odor. As well as providing a food source for waterfowl, muskgrasses often serves as a sanctuary for small fish and other aquatic organisms.

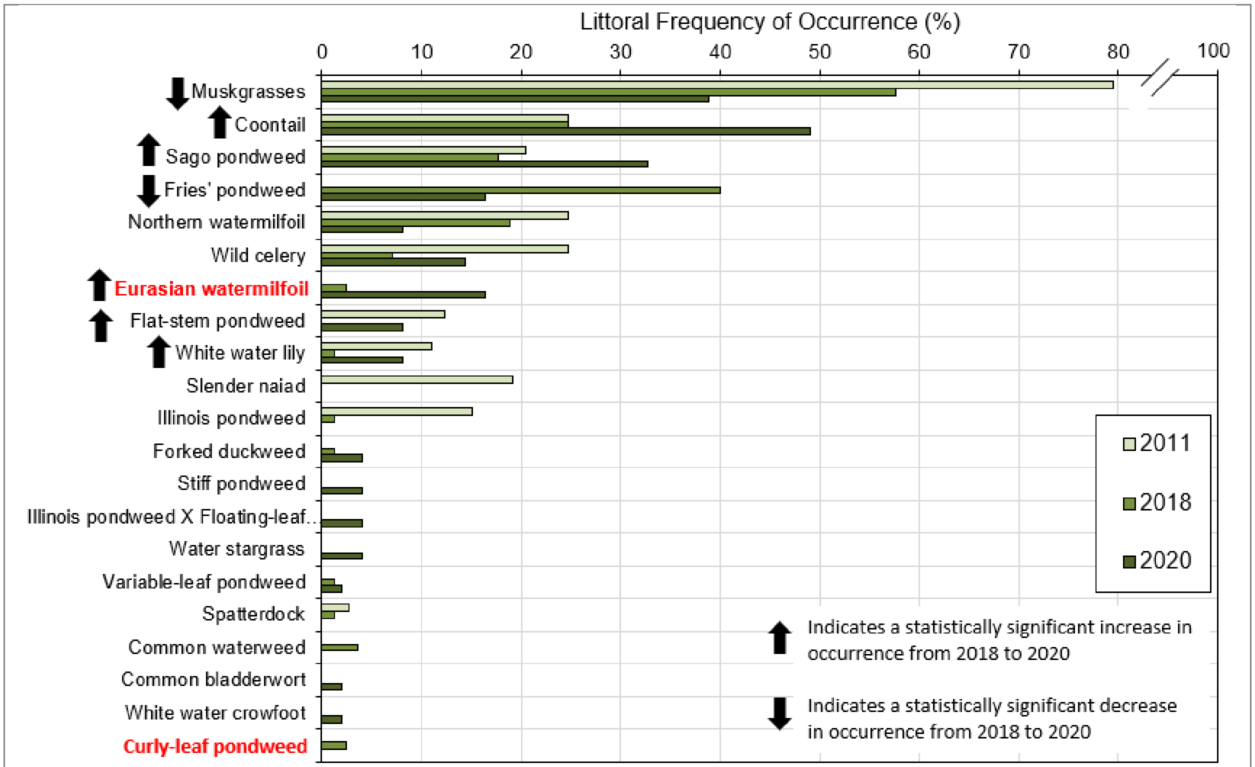


Figure 3.4-5. Littoral frequency of occurrence for Mirror Lake aquatic plant species. Created using data from the 2011, 2018, and 2020 aquatic plant point-intercept surveys. Only species with a 2% LFOO or greater during at least one of the survey years are displayed. (Chi-square; α = 0.05)

Coontail (*Ceratophyllum demersum*) was the most abundant aquatic plant in Mirror Lake in 2020 with a LFOO of 49% (Figure 3.4-5). This represented a statistically significant increase from 2018 and 2011 which had LFOO values of just under 25%. Unlike most of the submersed plants found in Wisconsin, coontail does not produce true roots and is often found growing entangled amongst other aquatic plants or matted at the surface. Because it lacks true roots, coontail derives all of its nutrients directly from the water (Gross, Erhard and Ivanyi 2003). This ability in combination with a tolerance for low-light conditions allows coontail to become more abundant in productive waterbodies with higher nutrients and lower water clarity. Coontail provides many benefits to the aquatic community. Its dense whorls for leaves provide excellent structural habitat for aquatic invertebrates and fish, especially in winter as this plant remains green under the ice (Figure 3.4-6, upper left).

Sago pondweed (*Stuckenia pectinata*) was the third-most frequently encountered aquatic plant in Mirror Lake with a littoral frequency of occurrence of over 32% in 2020. This was a statistically significant increase from 2018 which had an LFOO of just under 18%. The 2011 survey had a relatively similar frequency compared to 2018. Sago pondweed is a common rooted plant found in a variety of waterbodies throughout Wisconsin. It is highly tolerant of low-light conditions, and is often the last rooted plant able to survive in waterbodies with extremely turbid water (Borman, Korth and Temte 1997). To survive in these conditions, it produces numerous needle-like leaves that spread out near or at the water's surface in a fan-shape to gather light (Figure 3.4-6, top right). Sago pondweed has been found to be one of the most valuable food resources for waterfowl, producing numerous seeds and tubers.

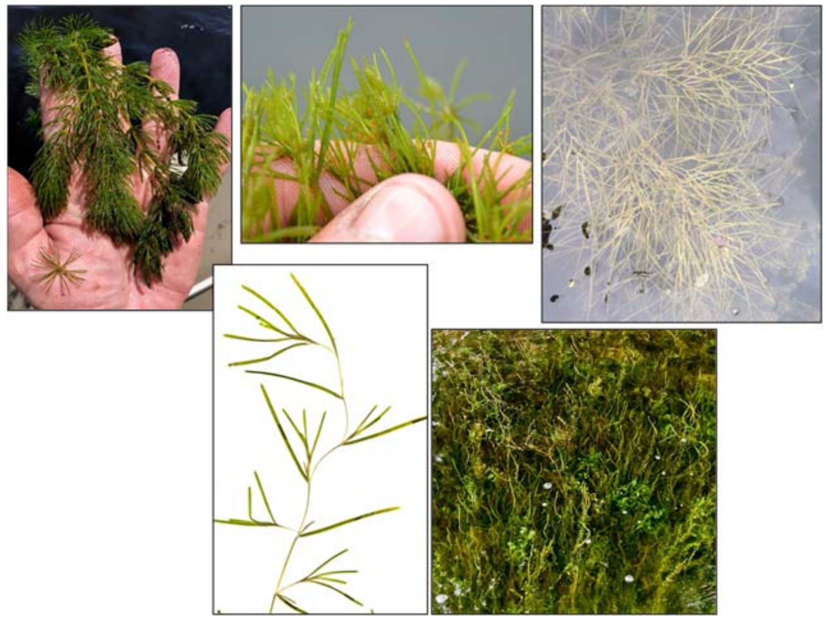


Figure 3.4-6. Five most frequently encountered aquatic plant species in Mirror Lake. Clockwise from upper left: coontail, muskgrasses, sago pondweed, Fries' pondweed, wild celery. Photo credit Onterra.

Fries' pondweed (*Potamogeton friesii*) was the fourth-most frequently encountered aquatic plant species during the 2020 point-intercept survey on Mirror Lake (Figure 3.4-6, bottom left). In 2018, a significantly higher LFOO of 40% had been recorded. The 2011 PI survey did not locate this species at all; however, the 2011 survey was completed later in the growing season (mid-August) than the other two surveys, and this plant is known to senesce earlier in the year than many other native plants. A common species in calcareous waters, Fries' pondweed is one of Wisconsin's several narrow-leaved pondweed species. It was found within a range of depths from 2-16 feet, and was one of only three native species observed growing at the max depth where plants were found (along with coontail and muskgrasses). Fries' pondweed plays a large role in aquatic ecosystems by providing structural habitat and sources of food to invertebrates, fish, and other wildlife. Often growing in deeper water, this species likely supplies oxygen to the deeper, colder layer of water that is sealed off from atmospheric oxygen during the summer.

Wild celery (*Vallisneria americana*), also known as tape or eelgrass, was the fifth-most frequently encountered native aquatic plant species in Mirror Lake in 2020 with a littoral frequency of occurrence of just over 14%. The 2018 survey found an LFOO of about half of this, while the 2011 survey had the highest LFOO of the three surveys for this species of almost 25%. Wild celery produces long, ribbon-like leaves which emerge from a basal rosette, and it prefers to grow over harder substrates and is tolerant of low-light conditions (Figure 3.4-6, bottom right). Its long leaves provide valuable structural habitat for the aquatic community while its network of roots and rhizomes help to stabilize bottom sediments. In mid- to late-summer, wild celery often produces abundant fruit which are important food sources for wildlife including migratory waterfowl.

During the 2011 point-intercept survey, UW-Stevens Point identified one species of special concern in Wisconsin: yellow pondlily (*Nuphar advena*). Yellow pondlily can be found in the southern third of Wisconsin, which lies on the extreme northwest edge of its range. There are currently no voucher records of this species from this lake, or anywhere in Waupaca County. It is possible that this was a case of mistaken identity, as this species was not located during the 2018 or 2020 surveys on Mirror Lake.

While Figure 3.4-5 indicates statistically valid changes in occurrence that have occurred between the 2018 and 2020 surveys, there have also been statistically valid changes that have occurred between 2011 and 2020. Some of the declines have been in species which are known to be sensitive to environmental degradation, such as northern watermilfoil and Illinois pondweed. Conversely, some species which are hardier and more tolerant of nutrient-rich water have increased, such as coontail and sago pondweed. Some studies have shown a positive correlation between coontail frequency and total phosphorus, although the water quality data do not show a rise in this parameter. Muskgrasses, which have seen the biggest population decline in Mirror Lake, are typically a hardy species, but do need good water clarity to thrive. The water quality data also do not show a decline in water clarity. Plants and animals are often more sensitive to pollutants than indicated by water chemistry (e.g., phosphorus). This is one of the reasons that algae and macrophytes are monitored to detect early warning of adverse ecological changes. Although the trophic parameters do not indicate a decline water quality, the recent changes in the macrophyte community suggest that the lake's ecological status is degrading. The reason(s) causing this degradation is not known at present, but warrants further investigation.

As explained above in the Primer on Data Analysis and Data Interpretation Section, the littoral frequency of occurrence analysis allows for an understanding of how often each of the plant species are located during the point-intercept survey. Because each sampling location may contain numerous plant species, relative frequency of occurrence is one tool to evaluate how often each plant species is found in relation to all other species found (composition of population). For example, while coontail was found at 49% of the littoral sampling locations in Mirror Lake in 2020, its relative frequency of occurrence is about 23%. Explained another way, if 100 plants were randomly sampled from Mirror Lake, 23 of them would be coontail. Looking at relative frequency of occurrence (Figure 3.4-7), three species alone comprise approximately 56% of the plant community in Mirror Lake.

When a lake contains a high number of native aquatic plant species, one might assume the aquatic plant communities have high species diversity. However, species diversity is also influenced by how evenly the plant species are distributed within the community (relative frequency). The dominance of Mirror Lake's plant community by just a few species results in a more moderate species diversity value. The diversity of Mirror Lake's aquatic plant community was found to be near the median value for lakes within the North Central Hardwood Forests ecoregion for the three survey years, with the highest diversity value (0.87) being recorded in 2020 (Figure 3.4-8). Lakes with diverse aquatic plant communities have higher resilience to environmental disturbances and greater resistance to invasion by non-native plants. A plant community with a mosaic of species with differing morphological attributes provides zooplankton, macroinvertebrates, fish and other wildlife with diverse structural habitat and various sources of food.

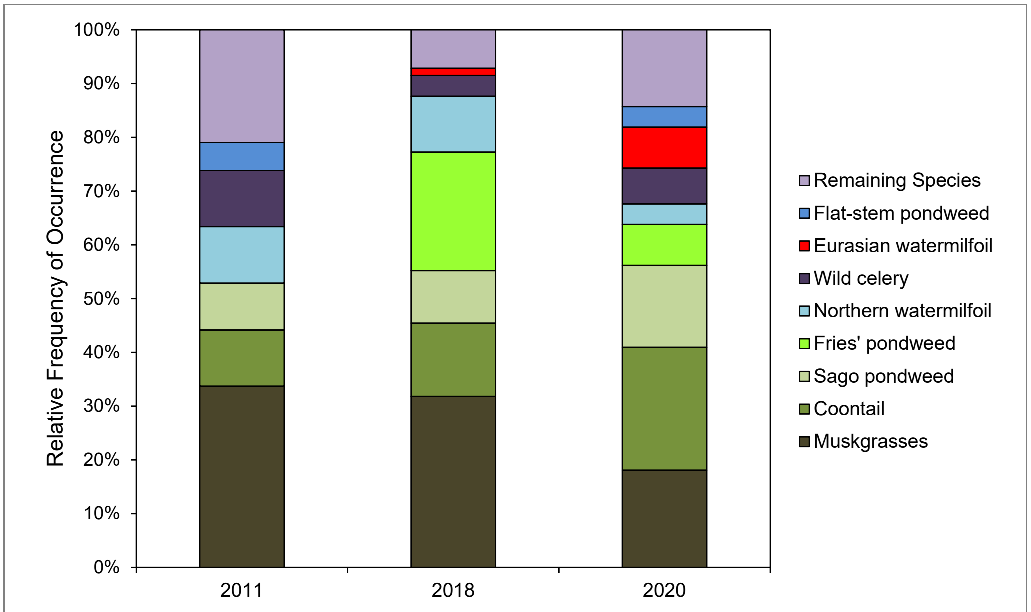


Figure 3.4-7. Relative frequency of occurrence of aquatic plant species in Mirror Lake. Created using data from the 2011, 2018, and 2020 point-intercept surveys.

As discussed in the primer section, the calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. Figure 3.4-9 shows that the native species richness for Mirror Lake fell below both the state and ecoregion median values.

The species that are present in Mirror Lake are indicative of near-average conditions. Data collected from the aquatic plant surveys show that the average conservatism value in 2020 (6.3) was slightly above the North Central Hardwood Forests Ecoregion median, and matched the Wisconsin state median (Figure 3.4-9), indicating that the lake contains a higher number of environmentally sensitive species compared to other lakes within this ecoregion.

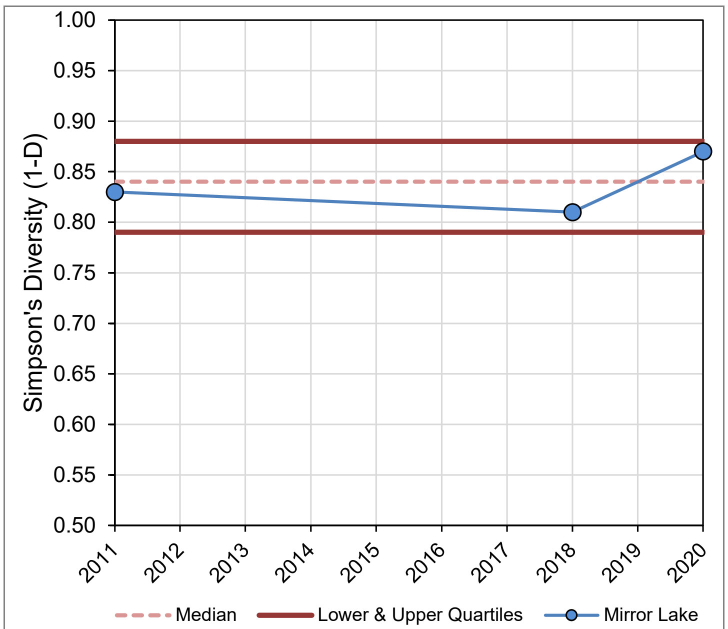


Figure 3.4-8. Mirror Lake species diversity index. Created using data from the 2011, 2018, and 2020 aquatic plant surveys. Ecoregion data provided by WDNR Science Services.

Combining Mirror Lake's aquatic plant species richness and average conservatism values to produce its Floristic Quality Index (FQI) results in a value of 24.4 in 2020 (equation shown below). This value falls between the ecoregion and state medians and was the highest recorded across the three surveys (Figure 3.4-9).

FQI = Average Coefficient of Conservatism (6.3) * √ Number of Native Species (15)
FQI = 24.4

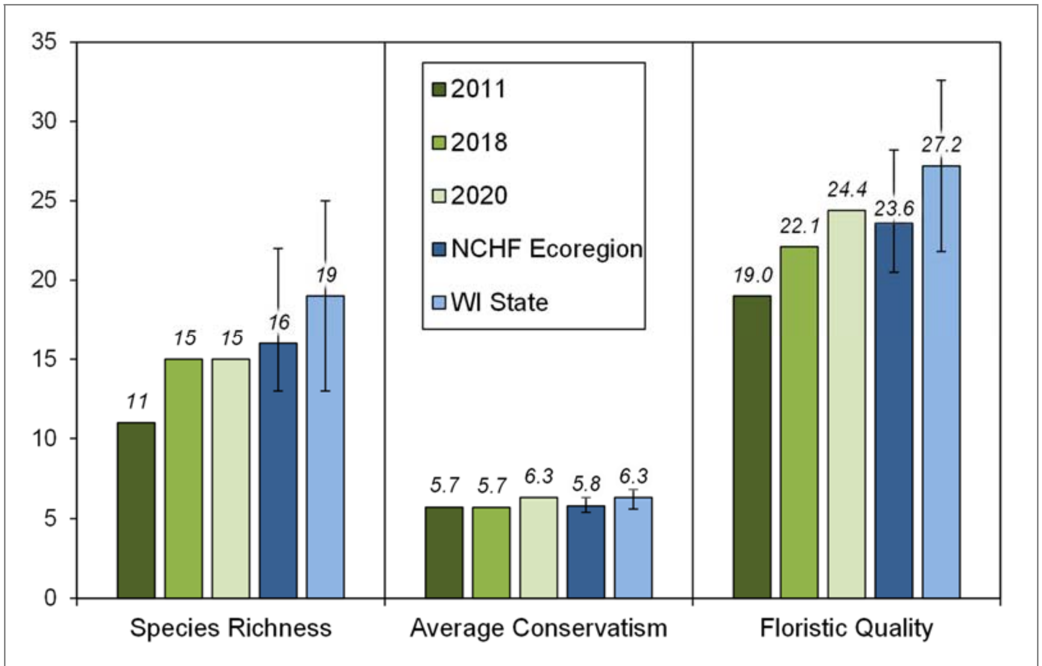


Figure 3.4-9. Mirror Lake Floristic Quality Assessment. Created using data from the 2011, 2018, and 2020 point-intercept surveys. Analysis following Nichols (1999) where NCHF = North Central Hardwood Forests Ecoregion.

The quality of Mirror Lake's plant community is also indicated by the relatively high incidence of emergent and floating-leaf plant communities that occur in near-shore areas around the lake. The 2020 community map indicates that approximately 2.5 acres (17.9%) of the 14-acre lake contain these types of plant communities (Table 3.4-2 and Map 9). Eleven floating-leaf and emergent species were located on Mirror Lake in 2020, providing valuable structural habitat for invertebrates, fish, and other wildlife. These communities also stabilize lake substrate and shoreland areas by dampening wave action from wind and watercraft. Some of the more abundant species of these community types around Mirror Lake included white water lily and cattail species.

Because the community map represents a 'snapshot' of the important emergent and floating-leaf plant communities, a replication of this survey in the future will provide a valuable understanding of the dynamics of these communities within Mirror Lake. This is important because these communities are often negatively affected by recreational use and shoreland development. Radomski and Goeman (2001) found a 66% reduction in vegetation coverage on developed shorelands when compared to the undeveloped shorelands in Minnesota lakes. Furthermore, they also found a significant reduction in abundance and size of northern pike (*Esox lucius*), bluegill (*Lepomis macrochirus*), and pumpkinseed (*Lepomis gibbosus*) associated with these developed shorelands.

Table 3.4-2. Mirror Lake acres of plant community types. Created from 2020 community mapping survey.

Plant Community	Acres
Emergent	0.8
Floating-leaf	1.0
Mixed Emergent & Floating-leaf	0.7
Total	**2.5**

The data that continues to be collected from Wisconsin lakes is revealing that aquatic plant communities are highly dynamic, and populations of individual species have the capacity to fluctuate, sometimes greatly, in their occurrence from year to year and over longer periods of time. These fluctuations are driven by a combination of interacting natural factors including variations in water levels, temperature, ice and snow cover (winter light availability), nutrient availability, changes in water flow, water clarity, length of the growing season, herbivory, disease, and competition (Lacoul and Freedman 2006). Seasonal and longer-term water level fluctuations are natural in Wisconsin's lakes and play an essential ecological role (e.g., maintaining emergent plant communities).

Shadow Lake

Some of the information in this section may sound repetitive if one is to read this report from cover to cover; however, this is done intentionally for those who only read the sections pertaining to their lake.

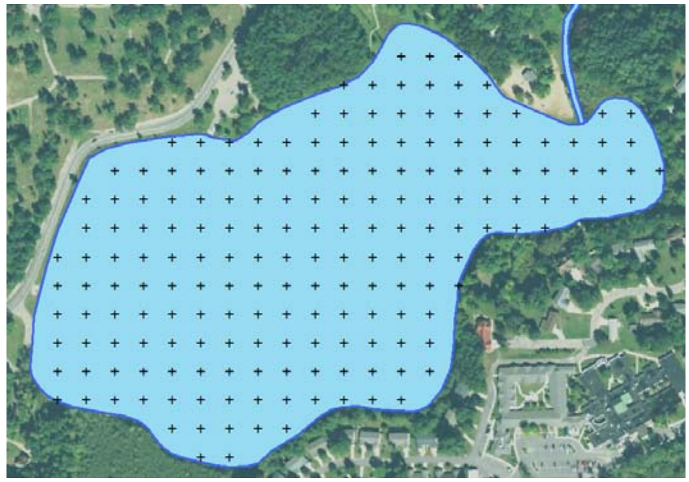


Figure 3.4-10. Shadow Lake point-intercept survey sampling locations. N = 185

The first aquatic plant survey completed on Shadow Lake was an early-season aquatic invasive species (ESAIS) survey, on June 3, 2020. The goal of this survey is to identify and assess any new or existing occurrences of invasive plant species in the lake, with a particular focus on species that are most likely to be observed at this time of year: curly-leaf pondweed and pale-yellow iris. During this survey, Onterra ecologists observed curly-leaf pondweed and Eurasian watermilfoil within Shadow Lake, and pale-yellow iris in several areas around the perimeter of the lake. Because of their ecological and sociological significance, these invasive species and their occurrences within Shadow Lake will be discussed in further detail in a subsequent section, Non-native Aquatic Plants in Mirror and Shadow Lakes.

The whole-lake point-intercept (PI) survey was conducted on Shadow Lake on July 29-30, 2020 by Onterra (Figure 3.4-10). Additional surveys were completed by Onterra on these same dates to create the floating-leaf and emergent aquatic plant community map. Between these two surveys, a total of 39 aquatic plant species were located in Shadow Lake in 2020, five of which are considered non-native, invasive species: curly-leaf pondweed, Eurasian watermilfoil, pale-yellow iris, purple loosestrife, and reed canary grass.

Previous point-intercept surveys have been completed on Shadow Lake as well: a 2011 UW-Stevens Point PI survey and a 2018 PI survey by Golden Sands. Data from these surveys are integrated within the following analyses. Table 3.4-3 includes all aquatic plant species which were located during any of the three surveys. Taking all three surveys into account, a total of 44 species have been found in Shadow Lake. An "X" under the survey year on the species list indicates that the species was sampled directly on the rake during the PI survey. An "I", indicating incidental, indicates that the species was located visually within the lake during the survey, but not sampled on the rake. Incidental species typically include emergent and floating-leaf species that are often found growing on the fringes of the lake and submersed species that are rare within the plant community. Only species sampled directly on the rake are included within the following analyses.

Lakes in Wisconsin vary in their morphometry, water chemistry, water clarity, substrate composition, management, and recreational use, all factors which influence aquatic plant community composition. Like terrestrial plants, different aquatic plant species are adapted to grow in certain substrate types; some species are only found growing in soft substrates, others only in sandy/rocky areas, and some can be found growing in either. The combination of both soft sediments and areas of harder substrates creates different habitat types for aquatic plants, and generally leads to a higher number of aquatic plant species within the lake.

In 2020, 75 of the 185 sampling points were within the range of depth that could support aquatic plant growth (littoral zone). Of these sites that were shallow enough to be sampled with a pole, the majority of them contained sand at the lake bottom (Figure 3.4-11). Sites over 15' in depth are sampled with a rake head tied to the end of a rope and do not allow for the sampler to accurately "feel" the substrate type as can be done with the standard pole sampling method.

Table 3.4-3. Aquatic plant species located on Shadow Lake during the 2011, 2018, and 2020 surveys.

Shadow Lake

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2011	2018	2020
Emergent	*Carex comosa*	Bristly sedge	Native	5			I
	Iris pseudacorus	Pale-yellow iris	Non-Native - Invasive	N/A		I	I
	Iris spp. (sterile)	Iris spp. (sterile)	N/A	N/A			I
	Lythrum salicaria	Purple loosestrife	Non-Native - Invasive	N/A	I		I
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A			I
	Sagittaria latifolia	Common arrowhead	Native	3			I
	Schoenoplectus acutus	Hardstem bulrush	Native	5		I	I
	Schoenoplectus pungens	Three-square rush	Native	5			I
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4			I
	Sparganium eurycarpum	Common bur-reed	Native	5			I
	Typha angustifolia	Narrow-leaved cattail	Non-Native - Invasive	N/A	I		
	Typha latifolia	Broad-leaved cattail	Native	1	I		
FL	*Nuphar advena**	Yellow pondlily	Native - Special Concern	8	I		
	Nuphar variegata	Spatterdock	Native	6	X	X	X
	Nymphaea odorata	White water lily	Native	6	X	X	X
	Persicaria amphibia	Water smartweed	Native	5			I
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X	X
	Chara spp.	Muskgrasses	Native	7	X	X	X
	Elodea canadensis	Common waterweed	Native	3	X		X
	Heteranthera dubia	Water stargrass	Native	6	X		I
	Myriophyllum sibiricum	Northern watermilfoil	Native	7	X	X	X
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A			X
	Najas flexilis	Slender naiad	Native	6	X	X	X
	Nitella spp.	Stoneworts	Native	7			X
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A		X	I
	Potamogeton friesii	Fries' pondweed	Native	8		X	X
	Potamogeton gramineus	Variable-leaf pondweed	Native	7		X	X
	Potamogeton illinoensis	Illinois pondweed	Native	6	X	X	
	Potamogeton illinoensis X *P. natans*	Illinois pondweed X Floating-leaf pondweed	Native	N/A			X
	Potamogeton natans	Floating-leaf pondweed	Native	5			I
	Potamogeton nodosus	Long-leaf pondweed	Native	5		X	
	Potamogeton richardsonii	Clasping-leaf pondweed	Native	5			X
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6	X		X
	Ranunculus aquatilis	White water crowfoot	Native	8			X
	Stuckenia pectinata	Sago pondweed	Native	3	X	X	X
	Utricularia minor	Small bladderwort	Native	10			I
	Utricularia vulgaris	Common bladderwort	Native	7	X	X	X
	Vallisneria americana	Wild celery	Native	6	X	X	X
FF	*Lemna minor*	Lesser duckweed	Native	5		X	
	Lemna trisulca	Forked duckweed	Native	6	X	X	X
	Lemna turionifera	Turion duckweed	Native	2			I
	Riccia fluitans	Slender riccia	Native	7			I
	Spirodela polyrhiza	Greater duckweed	Native	5		X	X
	Wolffia columbiana	Common watermeal	Native	5		X	X

X = Located on rake during point-intercept survey; I = Incidentally located; not located on rake during point-intercept survey
FL = Floating-leaf; FF = Free-floating
**Not verified; typically only found in southern WI*

Approximately 57% of the navigable point-intercept sampling locations that fell within the maximum depth of aquatic plant growth (25 feet) in 2020 contained aquatic vegetation. This value was far higher in 2018, with a total of 90% of the littoral sampling locations containing aquatic vegetation, and in 2011 it was 97%. Total rake fullness (TRF) is a measure of aquatic plant abundance and is illustrated in Figure 3.4-12. During the 2020 point-intercept survey, the majority of the littoral sampling sites either contained no vegetation, or the highest density rating of TRF = 3 (Figure 3.4-12).

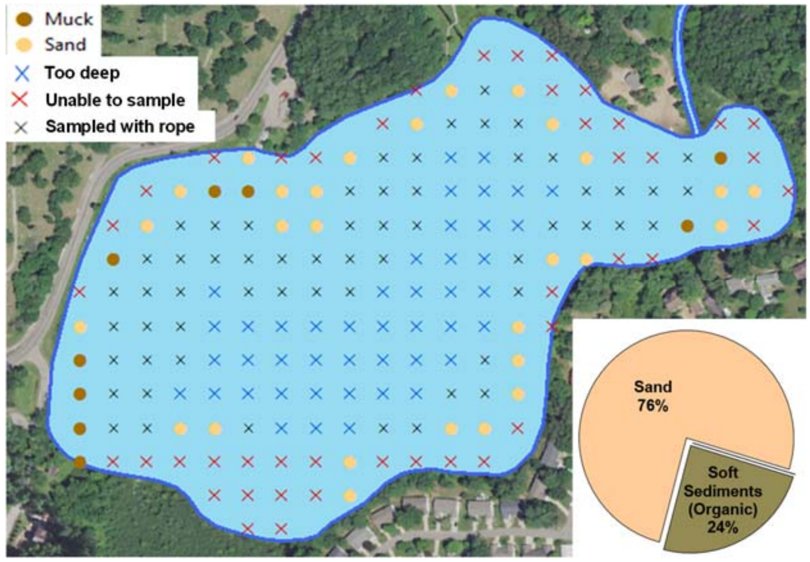


Figure 3.4-11. Shadow Lake proportion of substrate types within littoral areas. Created using data from the 2020 aquatic plant point-intercept survey. Points unable to be sampled with the pole are indicated by "x"

The data collected from the whole-lake point-intercept survey was also used to quantify the abundance of individual plant species within the lake. Of the 20 native aquatic plant species that were sampled directly with the rake in 2020 in Shadow Lake, coontail, muskgrasses, wild celery, flat-stem pondweed, and sago pondweed were the most frequently encountered (Figure 3.4-13).

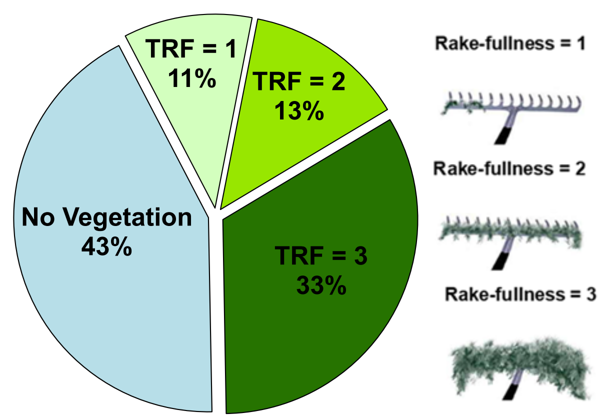


Figure 3.4-12. Shadow Lake aquatic vegetation total rake fullness (TRF) ratings. Created using data from the 2020 point-intercept survey.

Muskgrasses (*Chara* spp.) are a genus of macroalgae, of which there are ten documented species that occur in Wisconsin (Figure 3.4-14, upper middle). In 2020, muskgrasses had a littoral frequency of occurrence (LFOO) of just under 27% in Shadow Lake. This represents a statistically valid decrease in occurrence from the previous survey in 2018 which found a littoral frequency of 47%. The 2011 survey had found an even higher LFOO of 68% (Figure 3.4-13). Dominance of the aquatic plant community by muskgrasses is common in hardwater lakes and these macroalgae have been found to be more competitive against vascular plants (e.g., pondweeds, milfoils, etc.) in lakes with higher concentrations of calcium carbonate in the sediment (Kufel and Kufel 2002; Wetzel 2001). Muskgrasses require lakes with good water clarity, and their large beds stabilize bottom sediments. Studies have also shown that muskgrasses sequester phosphorus in the calcium carbonate encrustations which form on these plants, aiding in improving water quality by making the phosphorus unavailable to phytoplankton (Coops 2002). Muskgrasses can be easily identified by their strong skunk-like odor. As well as providing a food source for waterfowl, muskgrasses often serves as a sanctuary for small fish and other aquatic organisms.

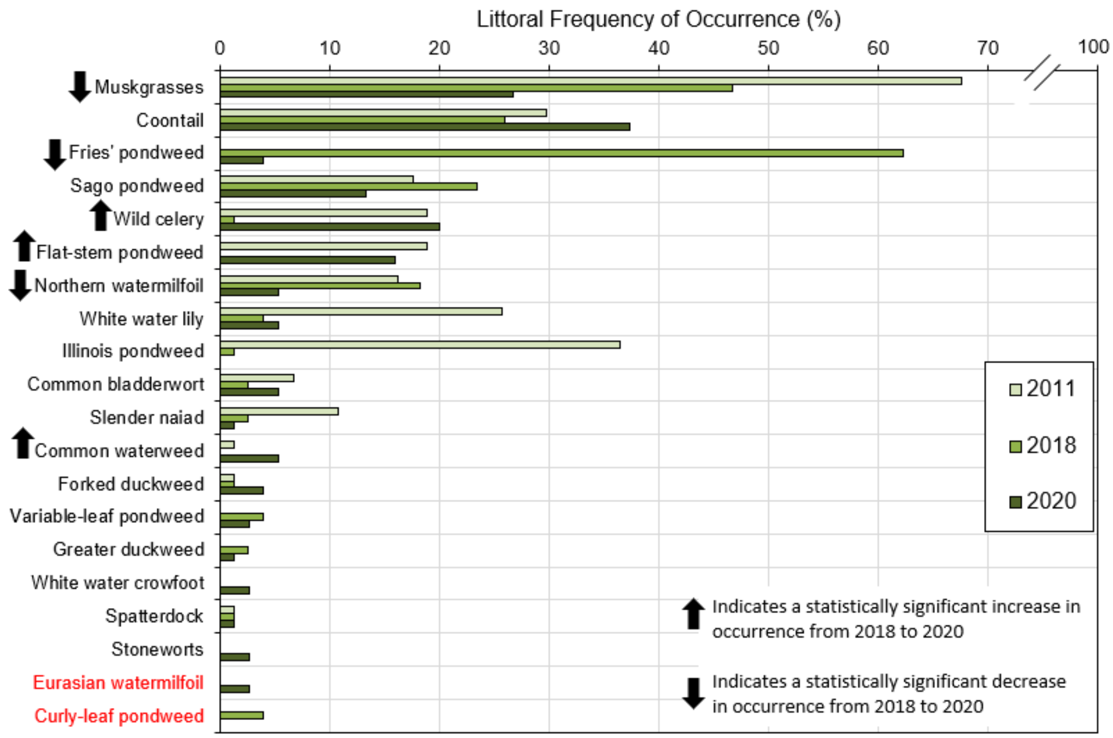


Figure 3.4-13. Littoral frequency of occurrence for Shadow Lake aquatic plant species. Created using data from the 2011, 2018, and 2020 aquatic plant point-intercept surveys. Only species with a 2% LFOO or greater during at least one of the survey years are displayed.

Coontail (*Ceratophyllum demersum*) was the most abundant aquatic plant in Shadow Lake in 2020 with an LFOO of 37% (Figure 3.4-13). This 2020 value was higher than in 2018 and 2011 which had LFOO values of 26% and 30%, respectively. Unlike most of the submersed plants found in Wisconsin, coontail does not produce true roots and is often found growing entangled amongst other aquatic plants or matted at the surface. Because it lacks true roots, coontail derives all of its nutrients directly from the water (Gross, Erhard and Ivanyi 2003). This ability in combination with a tolerance for low-light conditions allows coontail to become more abundant in productive waterbodies with higher nutrients and lower water clarity. Coontail provides many benefits to the aquatic community. Its dense whorls for leaves provide excellent structural habitat for aquatic invertebrates and fish, especially in winter as this plant remains green under the ice (Figure 3.4-14, upper left).

Wild celery (*Vallisneria americana*), also known as tape or eelgrass, was the third most frequently encountered native aquatic plant species in Shadow Lake in 2020 with a littoral frequency of occurrence of 20%. The 2018 survey had found an LFOO of only 1.3%, while the 2011 survey was at about 19%. Wild celery produces long, ribbon-like leaves which emerge from a basal rosette, and it prefers to grow over harder substrates and is tolerant of low-light conditions (Figure 3.4-14, top right). Its long leaves provide valuable structural habitat for the aquatic community while its network of roots and rhizomes help to stabilize bottom sediments. In mid- to late-summer, wild celery often produces abundant fruit which are important food sources for wildlife including migratory waterfowl.

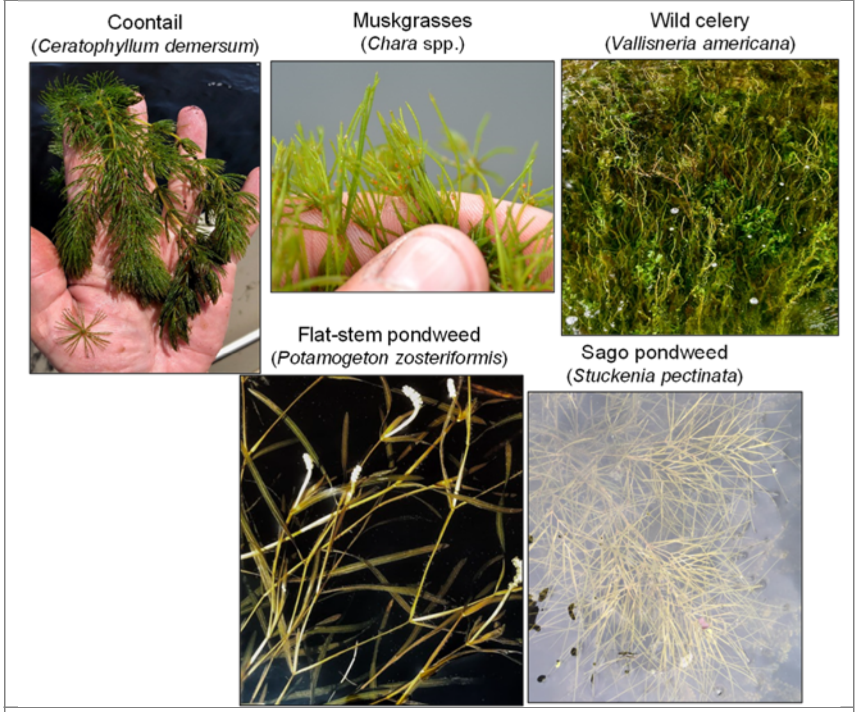


Figure 3.4-14. Five most frequently encountered aquatic plant species in Shadow Lake. Clockwise from upper left: coontail, muskgrasses, sago pondweed, Fries' pondweed, wild celery. Photo credit Onterra.

Flat-stem pondweed (*Potamogeton zosteriformis*) was the fourth most frequent aquatic plant encountered in 2020. Its LFOO of 16% in 2020 was a 100% increase from the previous survey in 2018 which did not find this species at all, while the 2011 survey yielded the highest LFOO across the three survey years of about 19% (Figure 3.4-13.) Flat-stem pondweed is often more abundant in productive lakes with soft sediments. As its name implies, it can be distinguished from other thin-leaved pondweeds by its conspicuously flattened stem (Figure 3.4-14, bottom left).

Sago pondweed (*Stuckenia pectinata*) was the fifth most frequently encountered aquatic plant in Shadow Lake with a littoral frequency of occurrence of over 13% in 2020. Sago pondweed is a common rooted plant found in a variety of waterbodies throughout Wisconsin. It is highly tolerant of low-light conditions, and is often the last rooted plant able to survive in waterbodies with extremely turbid water (Borman, Korth and Temte 1997). To survive in these conditions, it produces numerous needle-like leaves that spread out near or at the water's surface in a fan-shape to gather light (Figure 3.4-14, bottom right). Sago pondweed has been found to be one of the most valuable food resources for waterfowl, producing numerous seeds and tubers.

During the 2011 point-intercept survey, UW-Stevens Point identified one species of special concern in Wisconsin: yellow pondlily (*Nuphar advena*). Yellow pondlily can be found in the southern third of Wisconsin, which lies on the extreme northwest edge of its range. There are currently no voucher records of this species from this lake, or anywhere in Waupaca County. It is possible that this was a case of mistaken identity, as this species was not located during the 2018 or 2020 surveys on Shadow Lake.

While Figure 3.4-13 indicates statistically valid changes in occurrence that have occurred between the 2018 and 2020 surveys, there have also been statistically valid changes that have occurred from 2011-2018. Some of the declines have been in species which are known to be sensitive to environmental degradation, such as northern watermilfoil and Illinois pondweed. Conversely, some species which are hardier have increased, such as wild celery and common waterweed. Muskgrasses, which have seen a 60% reduction in population in Shadow Lake from 2011-2020, are typically a hardy species, but do need good water clarity to thrive. The water quality data for Shadow Lake however do not show a decline in water clarity, and actually appear to be slightly better in 2020 compared to the last several years.

Perhaps the most evident change in Shadow Lake is the overall littoral frequency of occurrence of aquatic vegetation (discussed previously), losing 33% between 2018 and 2020. Plants and animals are often more sensitive to pollutants than indicated by water chemistry (e.g., phosphorus). This is one of the reasons that algae and macrophytes are monitored to detect early warning of adverse ecological changes. Although the trophic parameters do not indicate a decline water quality, the recent changes in the macrophyte community suggest that the lake's ecological status is degrading. The reason(s) causing this degradation is not known at present, but warrants further investigation.

As explained above in the Primer on Data Analysis and Data Interpretation Section, the littoral frequency of occurrence analysis allows for an understanding of how often each of the plant species are located during the point-intercept survey. Because each sampling location may contain numerous plant species, relative frequency of occurrence is one tool to evaluate how often each plant species is found in relation to all other species found (composition of population). For example, while coontail was found at 37% of the littoral sampling locations in Shadow Lake in 2020, its relative frequency of occurrence is about 23%. Explained another way, if 100 plants were randomly sampled from Shadow Lake, 23 of them would be coontail. Looking at relative frequency of occurrence (Figure 3.4-15), 3 species alone comprised approximately 52% of the plant community in Shadow Lake in 2020.

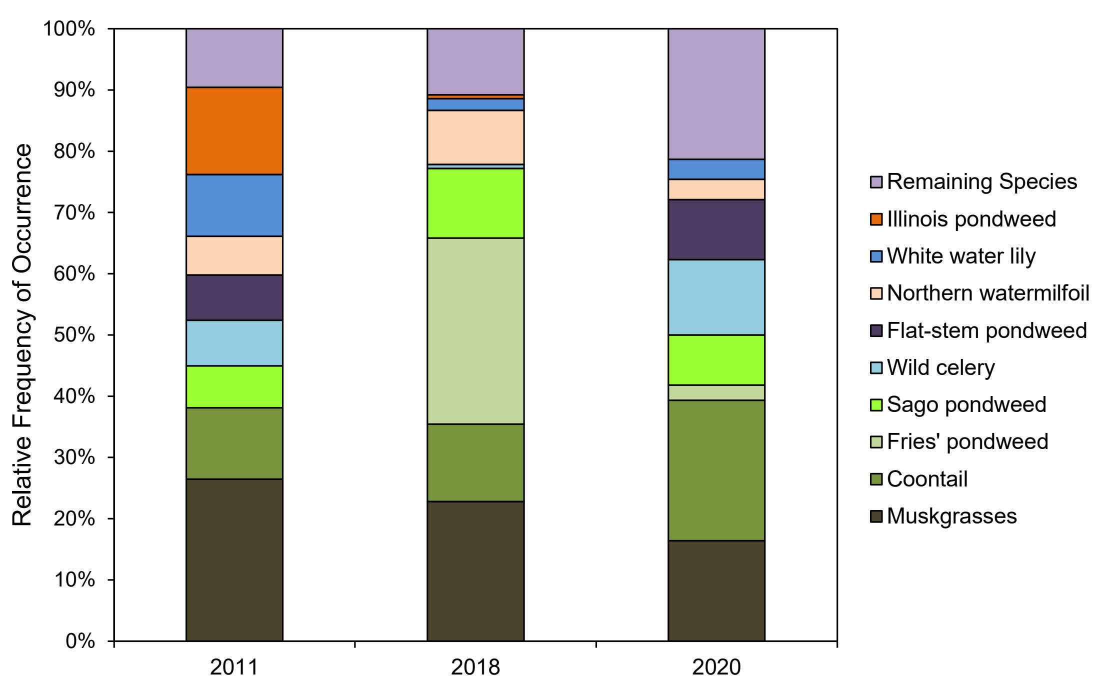


Figure 3.4-15. Relative frequency of occurrence of aquatic plant species in Shadow Lake. Created using data from the 2011, 2018, and 2020 point-intercept surveys.

When a lake contains a high number of native aquatic plant species, one might assume the aquatic plant communities have high species diversity. However, species diversity is also influenced by how evenly the plant species are distributed within the community (relative frequency). The dominance of Shadow Lake's plant community by just a few species results in a more moderate species diversity value. The diversity of Shadow Lake's aquatic plant community was found to be near the median value for lakes within the North Central Hardwood Forests ecoregion for the three survey years, with the highest diversity value being recorded in 2020 (0.88) (Figure 3.4-16). Lakes with diverse aquatic plant communities have higher resilience to environmental disturbances and greater resistance to invasion by non-native plants. A plant community with a mosaic of species with differing morphological attributes provides zooplankton, macroinvertebrates, fish and other wildlife with diverse structural habitat and various sources of food.

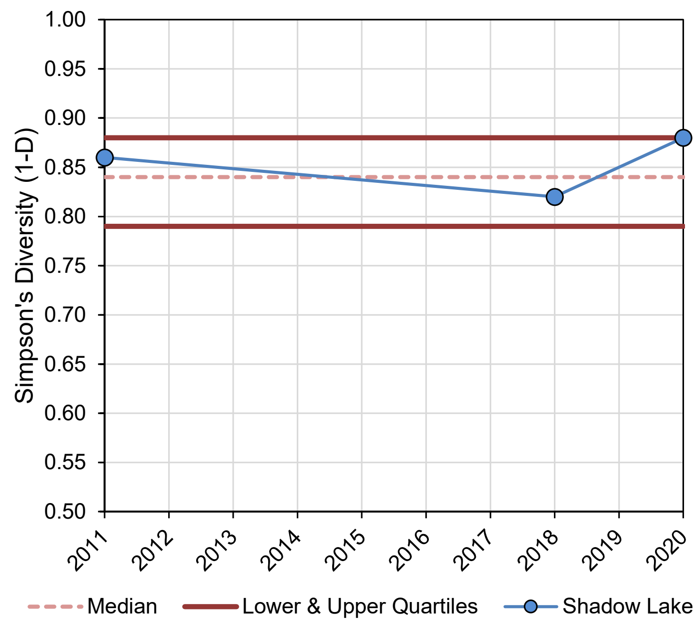


Figure 3.4-16. Shadow Lake species diversity index. Created using data from the 2011, 2018, and 2020 aquatic plant surveys. Ecoregion data provided by WDNR Science Services.

As discussed in the primer section, the calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. Figure 3.4-17 shows that the native species richness for Shadow Lake in 2020 was above both the median value for lakes within the North Central Hardwood Forests Ecoregion as well as the Wisconsin state median.

Data collected from the aquatic plant surveys show that the average conservatism value in 2020 (5.6) was slightly below the ecoregion and state medians (Figure 3.4-17), indicating that many of the plant species found in Shadow Lake are not considered to be sensitive to environmental disturbance and their presence signifies average environmental conditions. Species richness in 2020 in Shadow Lake however, was higher than both the ecoregion and state median values.

Combining Shadow Lake's aquatic plant species richness and average conservatism values to produce its Floristic Quality Index (FQI) results in a value of 25.0 in 2020 (equation shown below). This value falls between the ecoregion and state medians and was the highest recorded across the three surveys (Figure 3.4-17).

FQI = Average Coefficient of Conservatism (5.6) * √ Number of Native Species (20)
FQI = 25.0

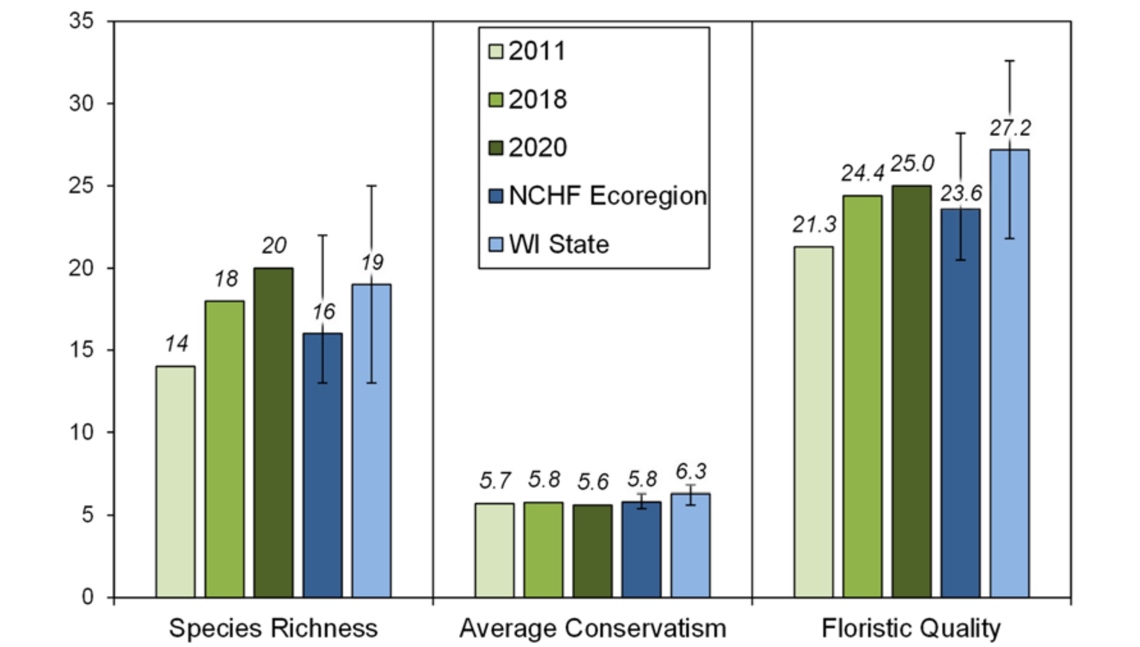


Figure 3.4-17. Shadow Lake Floristic Quality Assessment. Created using data from the 2011, 2018, and 2020 point-intercept surveys. Analysis following Nichols (1999) where NCHF = North Central Hardwood Forests Ecoregion.

The quality of Shadow Lake's plant community is also indicated by the relatively high incidence of emergent and floating-leaf plant communities that occur in near-shore areas around the lake. The 2020 community map indicates that approximately 10.6 acres (24%) of the 44-acre lake contain these types of plant communities (Table 3.4-4 and Map 10). These communities provide valuable structural habitat for invertebrates, fish, and other wildlife, as well as stabilize lake substrate and shoreland areas by dampening wave action from wind and watercraft. Some of the more abundant species of these community types around Shadow Lake included white water lily and spatterdock.

Table 3.4-4. Shadow Lake acres of plant community types. Created from 2020 community mapping survey.

Plant Community	Acres
Emergent	1.9
Floating-leaf	8.7
Mixed Emergent & Floating-leaf	0.0
Total	**10.6**

Because the community map represents a 'snapshot' of the important emergent and floating-leaf plant communities, a replication of this survey in the future will provide a valuable understanding of the dynamics of these communities within Shadow Lake. This is important because these communities are often negatively affected by recreational use and shoreland development. Radomski and Goeman (2001) found a 66% reduction in vegetation coverage on developed shorelands when compared to the undeveloped shorelands in Minnesota lakes. Furthermore, they also found a significant reduction in abundance and size of northern pike (*Esox lucius*), bluegill (*Lepomis macrochirus*), and pumpkinseed (*Lepomis gibbosus*) associated with these developed shorelands.

The data that continues to be collected from Wisconsin lakes is revealing that aquatic plant communities are highly dynamic, and populations of individual species have the capacity to fluctuate, sometimes greatly, in their occurrence from year to year and over longer periods of time. These fluctuations are driven by a combination of interacting natural factors including variations in water levels, temperature, ice and snow cover (winter light availability), nutrient availability, changes in water flow, water clarity, length of the growing season, herbivory, disease, and competition (Lacoul and Freedman 2006). Seasonal and longer-term water level fluctuations are natural in Wisconsin's lakes and play an essential ecological role (e.g., maintaining emergent plant communities).

Non-native Aquatic Plants in Mirror and Shadow Lakes

Curly-leaf pondweed (*Potamogeton crispus*)

On June 3, 2020, an early-season aquatic invasive species (ESAIS) survey was completed on Mirror and Shadow lakes. This survey focused on finding curly-leaf pondweed within the lakes, along with any other invasive species that might be growing this early in the season. During this meander-based survey, the entire littoral area of the lake is surveyed through visual observations from the boat. If an AIS population is found, it is mapped using sub-meter GPS technology by using either 1) point-based or 2) area-based methodologies. Large colonies >40 feet in diameter are mapped using polygons (areas) and are qualitatively attributed a density rating based upon a five-tiered scale from *highly scattered* to *surface matting*. Point-based techniques are applied to AIS locations considered as *small plant colonies* (<40 feet in diameter), *clumps of plants*, or *single or few plants*. Areas mapped using the polygon method allow for the calculation of total acreages, while point-based mapping does not.

Curly-leaf pondweed was first verified in Mirror and Shadow lakes in 2011, so its presence within the lakes was already known. In June 2020, a total of 0.5-acre of CLP was mapped in Mirror Lake, and over 2.5 acres of CLP were mapped in Shadow Lake. Aside from a very small *dominant* area of CLP in Mirror Lake, the remainder of the CLP mapped was of the two lowest density ratings, *highly scattered* and *scattered*. The largest contiguous colony of CLP mapped was along the western shoreline of Shadow Lake (Figure 3.4-18).

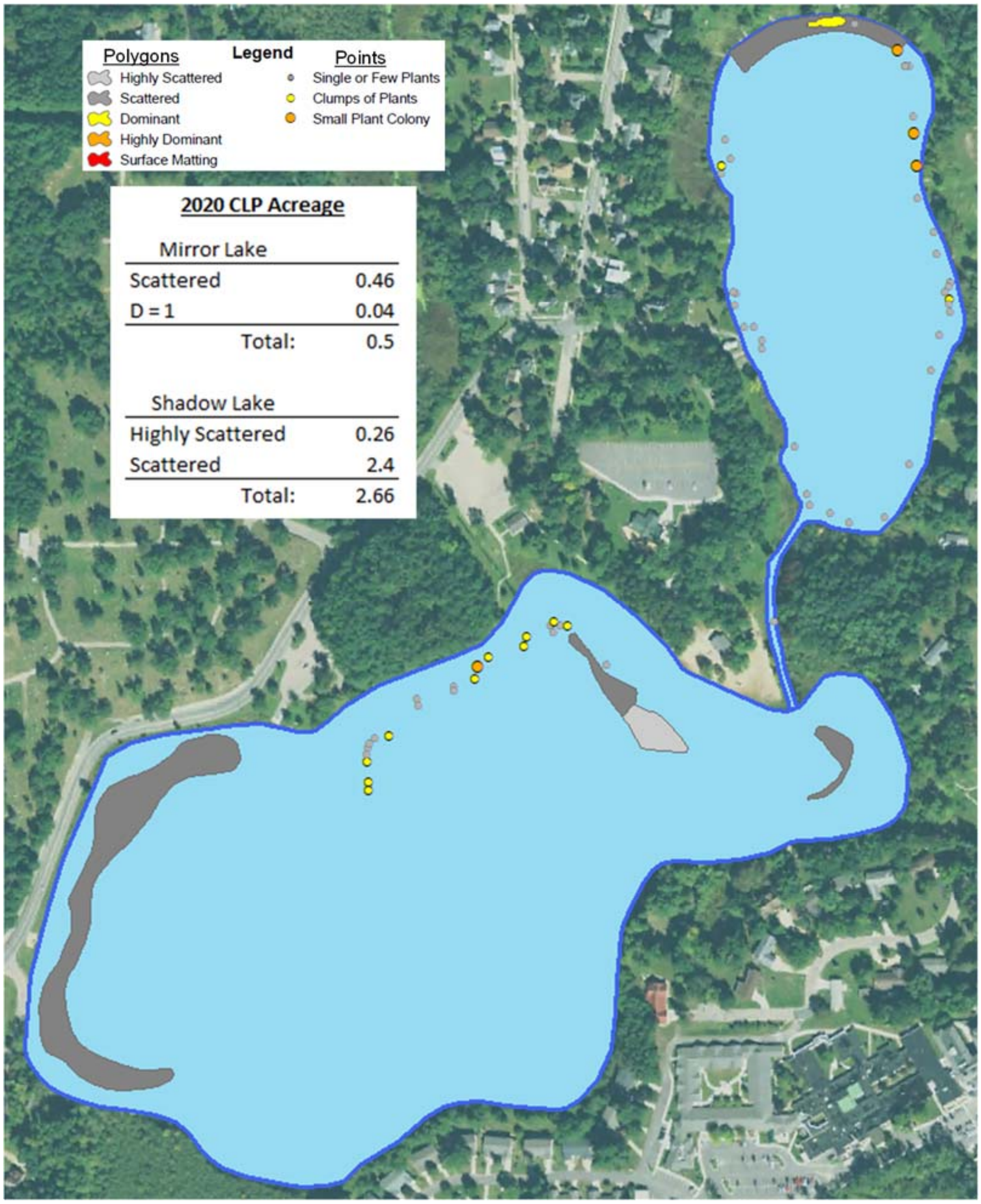


Figure 3.4-18. Curly-leaf pondweed locations on Mirror and Shadow lakes. Created using data from the June 2020 ESAIS survey.

Pale-yellow iris (*Iris pseudacorus*)

Pale yellow iris (*Iris pseudacorus*) is a large, showy iris with bright yellow flowers (Photo 3.4-5). Native to Europe and Asia, this species was sold commercially in the United States for ornamental use and has since escaped into Wisconsin's wetland areas, sometimes forming large monotypic colonies and displacing valuable native wetland species. Pale-yellow iris is typically in flower during the second half of June. The foliage of pale-yellow iris and northern blue flag iris (a valuable native species) is too similar to make a definitive identification based off of the foliage alone. Positive identification needs to come from the flowers or the seed pods, which develop after the flower is pollinated. Pale-yellow iris was first verified in Mirror and Shadow lakes in 2011, and was observed by Onterra growing in many areas around both lakes during the 2020 surveys (Figure 3.4-19).

Photograph 3.4-5. Pale-yellow iris in a shoreland area. Photo credit Onterra.

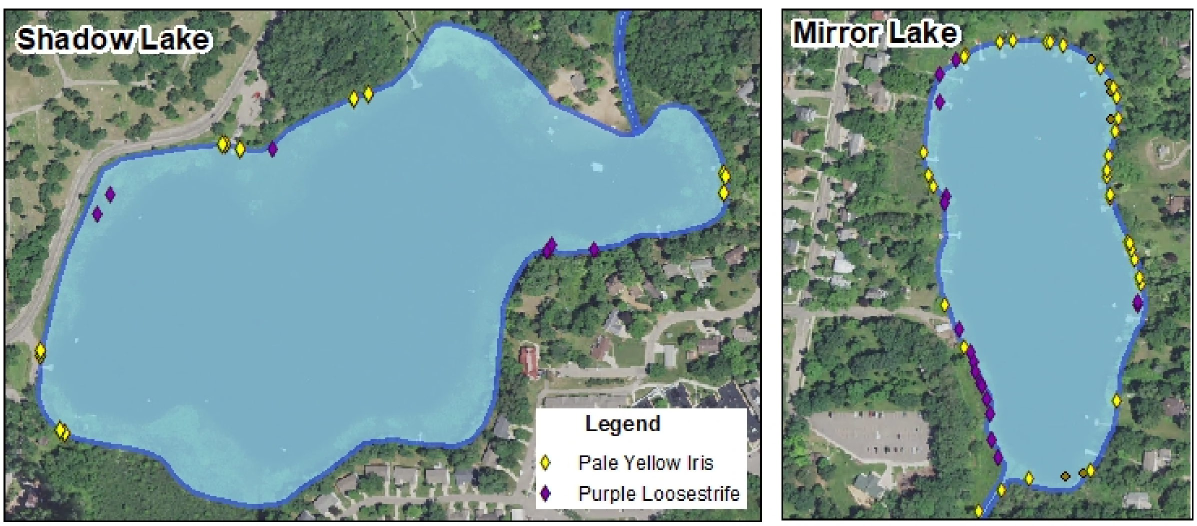


Figure 3.4-19. Pale-yellow iris and purple loosestrife locations around Mirror and Shadow lakes. Created using data from the June 2020 ESAIS survey and the late-July Community Mapping survey.

Purple loosestrife (*Lythrum salicaria*)

Purple loosestrife (*Lythrum salicaria*) is a perennial herbaceous plant native to Europe that was likely brought over to North America as a garden ornamental (Photo 3.4-6). This plant escaped from its garden landscape into wetland environments where it is able to out-compete our native plants for space and resources. First detected in Wisconsin in the 1930's, it has now spread to 70 of the state's 72 counties. Purple loosestrife largely spreads by seed, but also can vegetatively spread from root or stem fragments. It was first verified in Mirror and Shadow lakes in 2011, and was observed by Onterra in 2020 in several areas of both lakes during the community mapping survey in late-July when it was in bloom. These 2020 purple loosestrife locations are displayed on Figure 3.4-19, as well as on the emergent and floating-leaf community map.

Photograph 3.4-6. Purple loosestrife. Photo credit Onterra.

Reed canary grass (*Phalaris arundinacea*)

Reed canary grass (*Phalaris arundinacea*) is a large, coarse perennial grass that can reach up to six feet in height. Often difficult to distinguish from native grasses, this species can form dense, highly productive stands that outcompete native species. Unlike native grasses, few wildlife species utilize the grass as a food source, and the stems grow too densely to provide cover for small mammals and waterfowl. It grows best in moist soils such as wetlands, marshes, stream banks and lake shorelines. Once established, it is difficult to eradicate and is quite resilient to herbicide applications. Although no attempt was made to document all occurrences of reed canary grass around the shores of the lakes, one stand of reed canary grass was observed by Onterra in 2020 along the northern shore of Shadow Lake. This location can be found on the Shadow Lake Emergent and Floating-leaf Aquatic Plant Communities Map (Map 10).

Narrow-leaved cattail

Narrow-leaved cattail (*Typha angustifolia*) is a perennial wetland plant that is found throughout Wisconsin and is listed by the WDNR as restricted. It can grow very aggressively and outcompete and displace native plants, decreasing biodiversity. The easiest way to tell this species apart from the native variety (broad-leaved cattail) is the space between the male and female portions of the flowers which is not usually visible on the native cattail. Control for invasive narrow-leaved cattail is most often accomplished through manual removal. Both the native broad-leaved cattail (*Typha latifolia*) and the non-native narrow-leaved cattail were vouchered from Mirror Lake during 2020 with the identifications confirmed by staff at the UW-Stevens Point Freckmann Herbarium. Visual occurrences of narrow-leaved cattail were also noted by UW-Stevens Point surveyors during studies completed in 2011.

Due to difficultly in distinguishing between the native and non-native varieties of cattail in the field, and the fact that the species often hybridize, the cattail occurrences located around the margins of Mirror and Shadow lakes were identified only to Genus level. A closer inspection of each occurrence would be necessary to attempt to distinguish between the native or non-native species.

Eurasian watermilfoil (*Myriophyllum spicatum*)

Eurasian watermilfoil (EWM) was first verified in Mirror and Shadow lakes in 2011. In recent years, the Friends of Mirror and Shadow Lake and the city of Waupaca have partnered with Golden Sands RC&D to implement targeted EWM hand removal efforts. The EWM population in Mirror and Shadow lakes was assessed on two mapping surveys conducted by Onterra in 2020, first during the June ESAIS survey, and also during a late-season AIS survey on September 18, 2020.

Additionally, a quantitative assessment of the EWM population can be made through analysis of the point-intercept surveys.

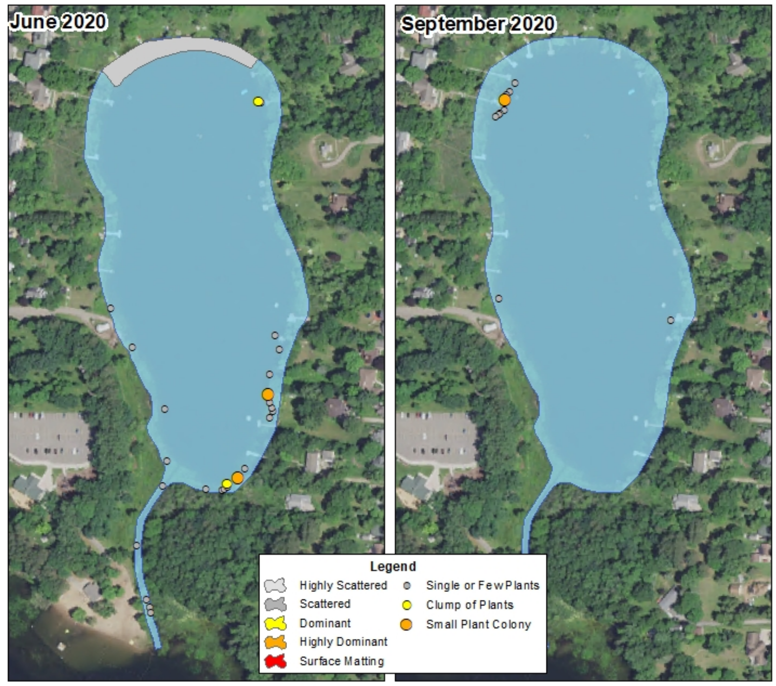


Figure 3.4-20. Eurasian watermilfoil locations in Mirror Lake. Created using data from Onterra June and September 2020 EWM Mapping Surveys.

During the June 2020 ESAIS survey, the EWM population in Mirror Lake included an area of highly scattered plants along the northern shoreline of the lake as well as a number of isolated single or few plants, clumps of plants, or small plant colonies in other littoral areas of the lake (Figure 3.4-20, left frame). Eurasian watermilfoil continues to grow throughout the summer, typically reaching its peak growth stage or "peak biomass" by late-summer. The September 2020 EWM mapping survey aimed to assess this population at its maximum expected footprint. The results of the September 2020 mapping survey for Mirror Lake are displayed on the right frame of Figure 3.4-20 and indicate a reduced population compared to the June survey. It is unclear as to the reason for the reduced EWM population later in the growing season; however, extensive native aquatic plant or algae growth may have obscured some plants from view by the surveyors at the time of the survey.

Figure 3.4-21 displays the June 2020 and September 2020 EWM mapping results from Shadow Lake. The EWM population in Shadow Lake during 2020 consisted of isolated point-based occurrences including single plants, clumps of plants, or small plant colonies. No larger contiguous colonies requiring area-based mapping techniques were located anywhere in the lake. Hand harvesting efforts led by Golden Sands RC& D took place between the two mapping surveys and likely accounts for the disappearance of the small plant colony that had been located in June out from South Park Beach on the northeast part of the lake.

EWM has an affinity for softer sediments. As shown in the previous sections, much of the sediment in the littoral zone of Mirror and Shadow lakes is comprised of sand (not soft, organic sediments). This, in combination with deeper water which does not allow for aquatic plant growth, could be factors as to why EWM has not expanded to a greater degree, despite it being present in the lakes for about a decade. Even in systems that have more ideal growth conditions, EWM does not always expand to unacceptable levels, even in unmanaged lakes.

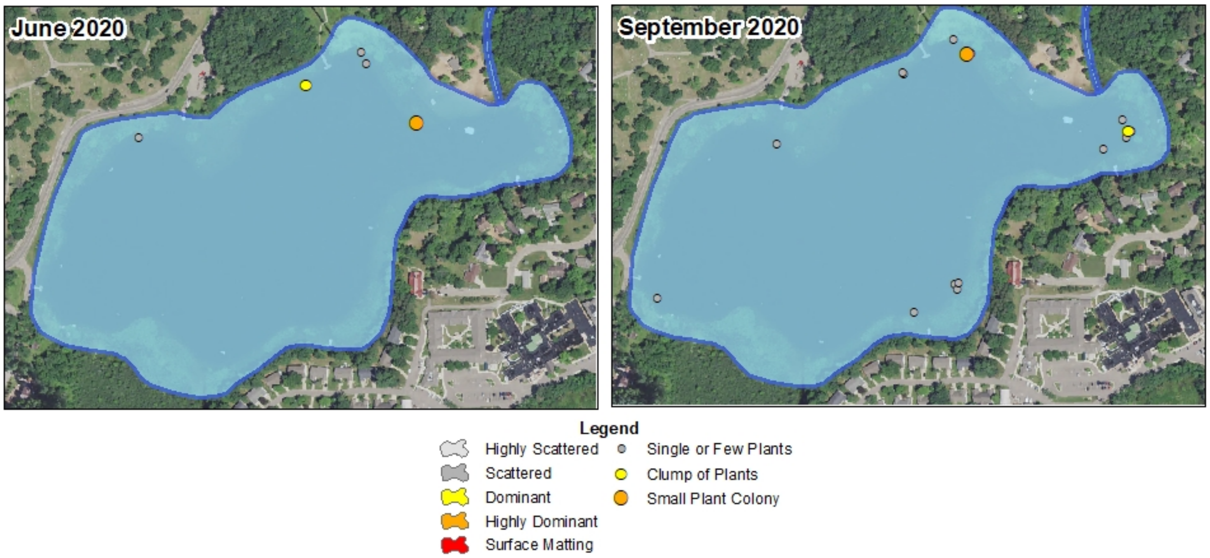


Figure 3.4-21. Eurasian watermilfoil locations in Shadow Lake. Created using data from Onterra June and September 2020 EWM Mapping Surveys.

WDNR Long-Term EWM Trends Monitoring Research Project

Starting in 2005, WDNR Science Services began conducting annual point-intercept aquatic plant surveys on a set of unmanaged lakes to understand how EWM populations vary over time. This was in response to commonly held beliefs of the time that once EWM becomes established in a lake, its population would continue to increase over time. This information is presented here to understand how unmanaged systems in this ecoregion compare to Mirror and Shadow Lake.

Like other aquatic plants, EWM populations are dynamic and annual changes in EWM frequency of occurrence have been documented in many lakes, including those that are not being actively managed for EWM control (no herbicide treatment or hand-harvesting program). Figure 3.4-22 shows the EWM populations of three unmanaged lakes with EWM in the Northern Central Hardwood Forests ecoregion. To clarify, these lakes have not conducted herbicide treatments or any other forms of strategic EWM management. The EWM population of Montana Lake (Oconto-Marinette counties) has been variable over time, whereas the EWM population of Crystal Lake (Marquette County) has been extremely stable at around 20% during the timeframe of study. After first being detected in 2005, the EWM population of Crooked Lake (Adams County) was below 3% for at least 10 years, and then increased to 7.4% in 2019 after being in the lake for 14 years.

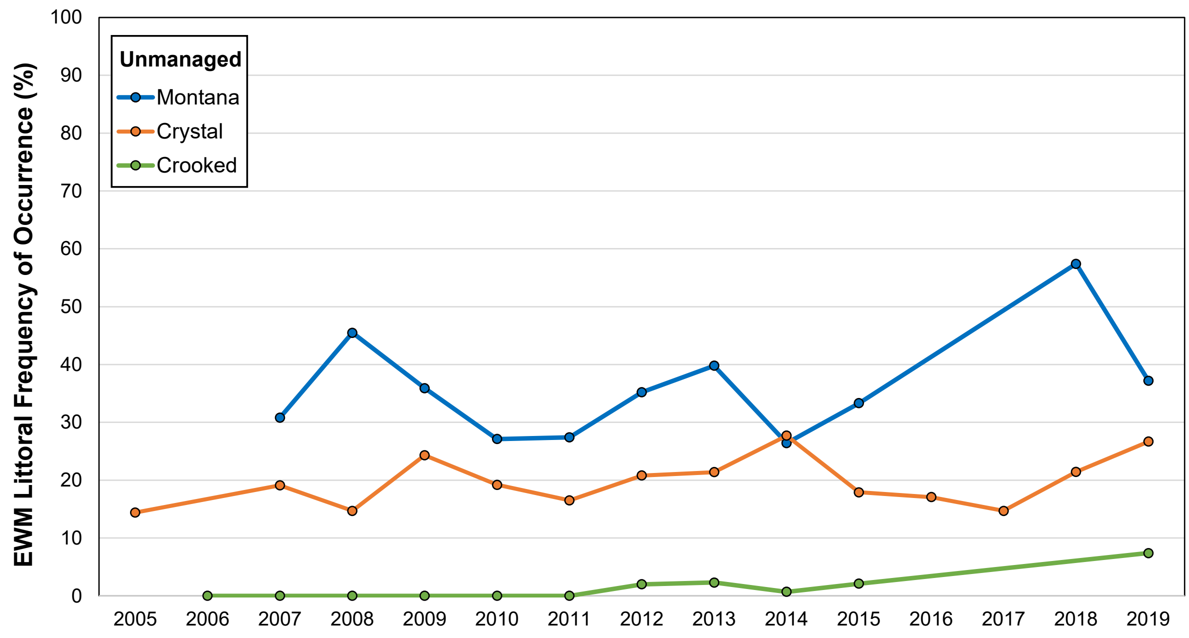


Figure 3.4-22. Littoral frequency of occurrence of Unmanaged EWM populations in the Northern Central Hardwood Forests ecoregion. Data provided by and used with permission from WDNR.

The Science Behind the "So-Called" Super Weed (Nault 2016)

In 2015, the WDNR investigated the most recent point-intercept data from almost 400 Wisconsin Lakes that had confirmed EWM populations. These data show that approximately 65% of these lakes had EWM populations of 10% or less (Figure 3.4-23). At these low population levels, there is not likely to be impacts to recreation and navigation, nor changes in ecological function. At the time of this writing, Mirror Lake's most recent point-intercept survey (2020) yielded EWM at 16.3% of the littoral sampling locations, and Shadow Lake's EWM LFOO was at 2.7%. Only approximately 15% of the lakes in the study had EWM populations of 30% or higher. This may be due to the fact that the EWM population in some lakes may never reach that level, or that management activities may have been enacted to suppress the EWM population to lower levels.

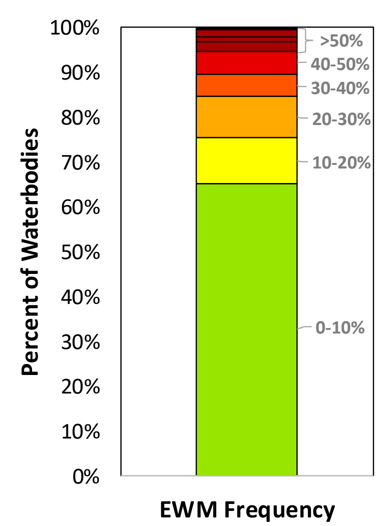


Figure 3.4-23. EWM littoral frequency of occurrence in 397 WI lakes with EWM populations. Data provided by and used with permission from WDNR.

Despite the EWM occurrences in 2020 on Mirror and Shadow lakes being relatively sparse, it is important to note that of the three-point intercept surveys that have been completed on the lakes, 2020 marked the highest EWM littoral frequency of occurrence in Mirror Lake (Figure 3.4-24). The EWM increase in Mirror Lake from 2.4% occurrence in 2018 to 16.3 % occurrence in 2020 was statistically significant, while the change in Shadow Lake was not. Eurasian watermilfoil has the capacity to fluctuate widely in occurrence from year to year. Future invasive species monitoring will be important to continue to assess these population changes which may occur from year to year.

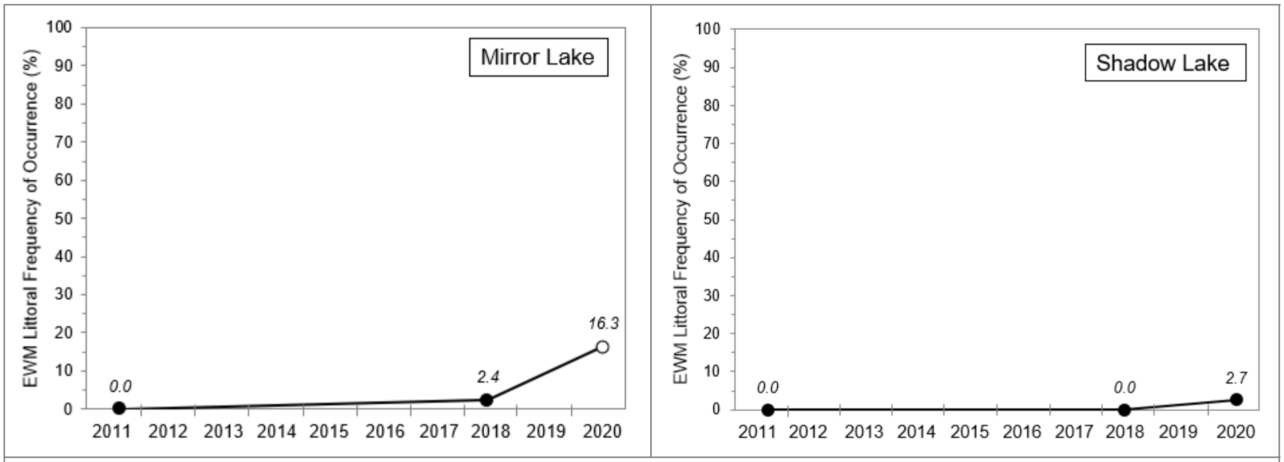


Figure 3.4-24. Littoral frequency of occurrence of EWM in Mirror and Shadow Lake. Created using data from the 2011, 2018, and 2020 point-intercept surveys. An open circle on the data point indicates a statistically significant change in occurrence from the previous survey (Chi-square; α = 0.05).

Stakeholder Survey Responses to Aquatic Vegetation within Mirror and Shadow Lakes

As discussed in section 2.0, the stakeholder survey asked many questions pertaining to perception of the lake and how it may have changed over the years. Figures 3.4-25 and 3.4-26 display the responses of members of Mirror and Shadow lake stakeholders to questions regarding aquatic plants' impact on enjoyment of the lakes, and levels of support for different plant management techniques. The top two issues among respondents who felt that aquatic plants had a negative impact on their lake enjoyment were with aesthetics and swimming. In response to support or opposition for different aquatic plant management techniques, survey respondents were the most supportive of hand-removal by divers, and were least supportive of doing nothing to manage plants.

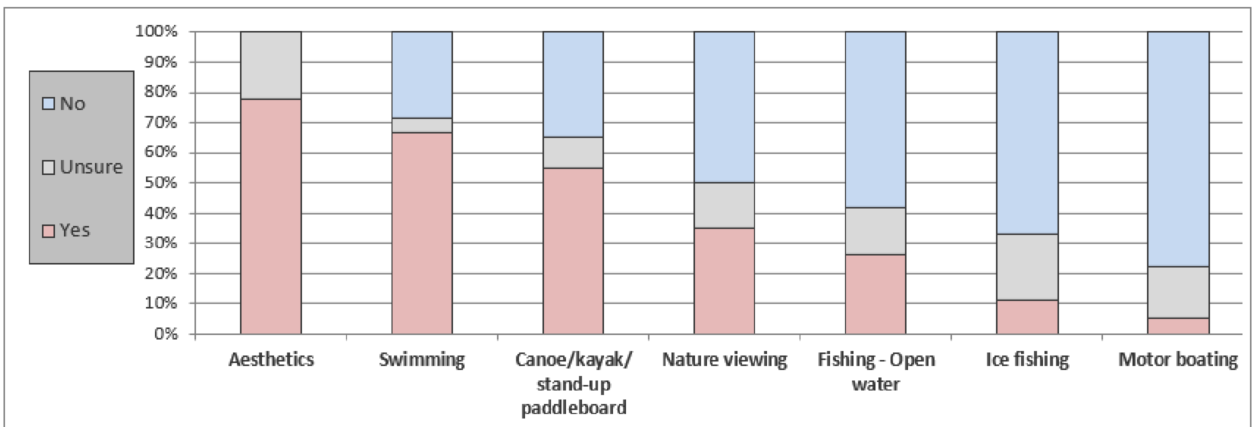


Figure 3.4-25. Stakeholder survey response Question #23. *Have aquatic plants ever had a negative impact on your enjoyment of Mirror and/or Shadow Lake?*

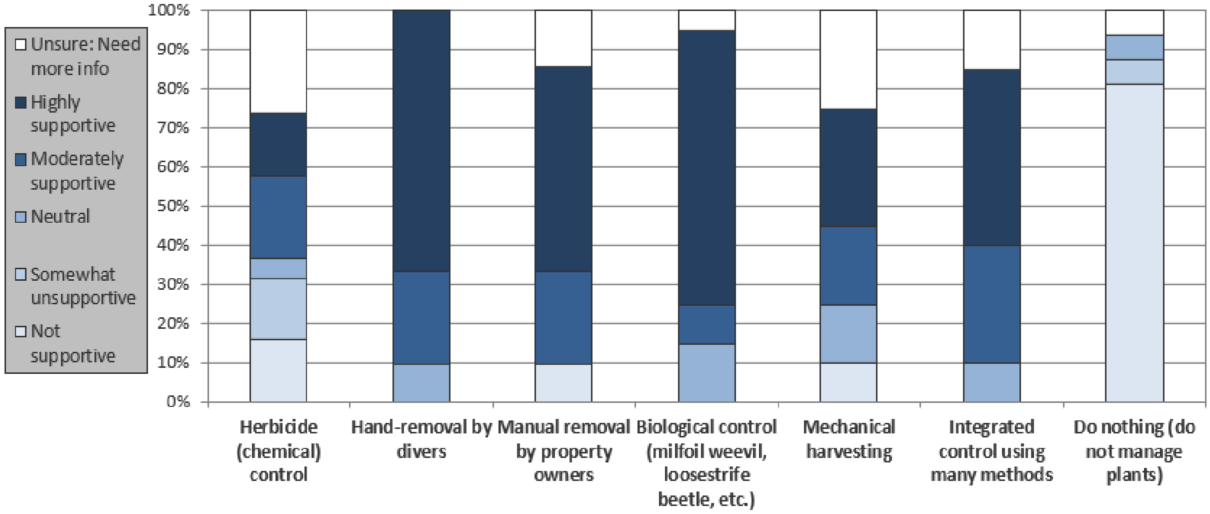


Figure 3.4-26. Stakeholder survey response Question #24. *Aquatic plants can be managed using many techniques. What is your level of support for the responsible use of the following techniques on Mirror and Shadow lakes?*

3.5 Aquatic Invasive Species in Mirror and Shadow Lakes

As is discussed in section 2.0 Stakeholder Participation, Mirror and Shadow Lake stakeholders were asked about aquatic invasive species (AIS) and their presence in the lakes within the anonymous stakeholder survey. Onterra and the WDNR have confirmed that there are eight AIS present (Table 3.5-1).

Table 3.5-1. AIS present within Mirror and Shadow Lakes

Type	Common name	Scientific name	Location within the report
Plants	Eurasian watermilfoil	*Myriophyllum spicatum*	Section 3.4 – Non-native Aquatic Plants
	Curly-leaf pondweed	*Potamogeton crispus*	Section 3.4 – Non-native Aquatic Plants
	Purple loosestrife	*Lythrum salicaria*	Section 3.4 – Non-native Aquatic Plants
	Pale-yellow iris	*Iris pseudacorus*	Section 3.4 – Non-native Aquatic Plants
	Reed canary grass	*Phalaris arundinacea*	Section 3.4 – Non-native Aquatic Plants
	Narrow-leaved cattail	*Typha angustifolia*	Section 3.4 – Non-native Aquatic Plants
Invertebrates	Zebra mussel	*Dreissena polymorpha*	Section 3.1 – Water Quality
	Banded mystery snail	*Viviparus georgianus)*	Section 3.5 - Below

Figure 3.5-2 displays the aquatic invasive species that stakeholder survey respondents believe are in Mirror and Shadow lakes. Only the species actually present in the lakes are discussed below or within their respective locations listed in Table 3.5-1. While it is important to recognize which species stakeholders believe to be present within the lakes, it is more important to share information on the species present and possible management options. More information on these invasive species or any other AIS can be found at the following links:

- http://dnr.wi.gov/topic/invasives/
- https://nas.er.usgs.gov/default.aspx
- https://www.epa.gov/greatlakes/invasive-species

Aquatic Animals

Mystery snails

There are two types of mystery snails found within Wisconsin waters, the Chinese mystery snail (*Cipangopaludina chinensis*) and the banded mystery snail (*Viviparus georgianus*). Both snails can be identified by their large size, thick hard shell and hard operculum (a trap door that covers the snail's soft body). These traits also make them less edible to native predators. These species thrive in eutrophic waters with very

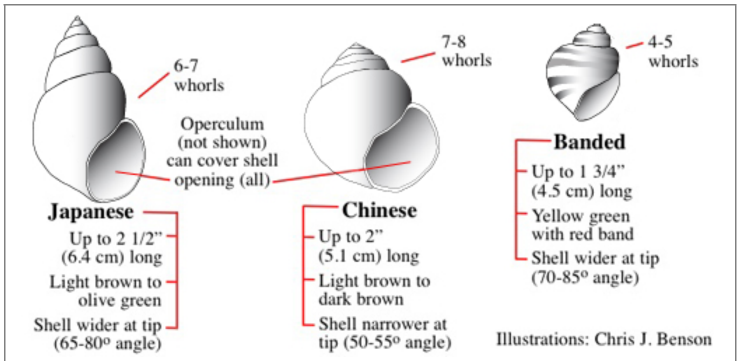


Figure 3.5-1. Identification of non-native mystery snails. Courtesy of Minnesota Sea Grant: (http://www.seagrant.umn.edu/ais/mysterysnail).

little flow. They are bottom-dwellers eating diatoms, algae and organic and inorganic bottom materials. One study conducted in northern Wisconsin lakes found that the Chinese mystery snail did not have strong negative effects on native snail populations (Solomon et al. 2010). However, researchers did detect negative impacts to native snail communities when both Chinese mystery snails and the rusty crayfish were present (Johnson et al. 2009). Only the banded mystery snail has been verified in Mirror and Shadow lakes.

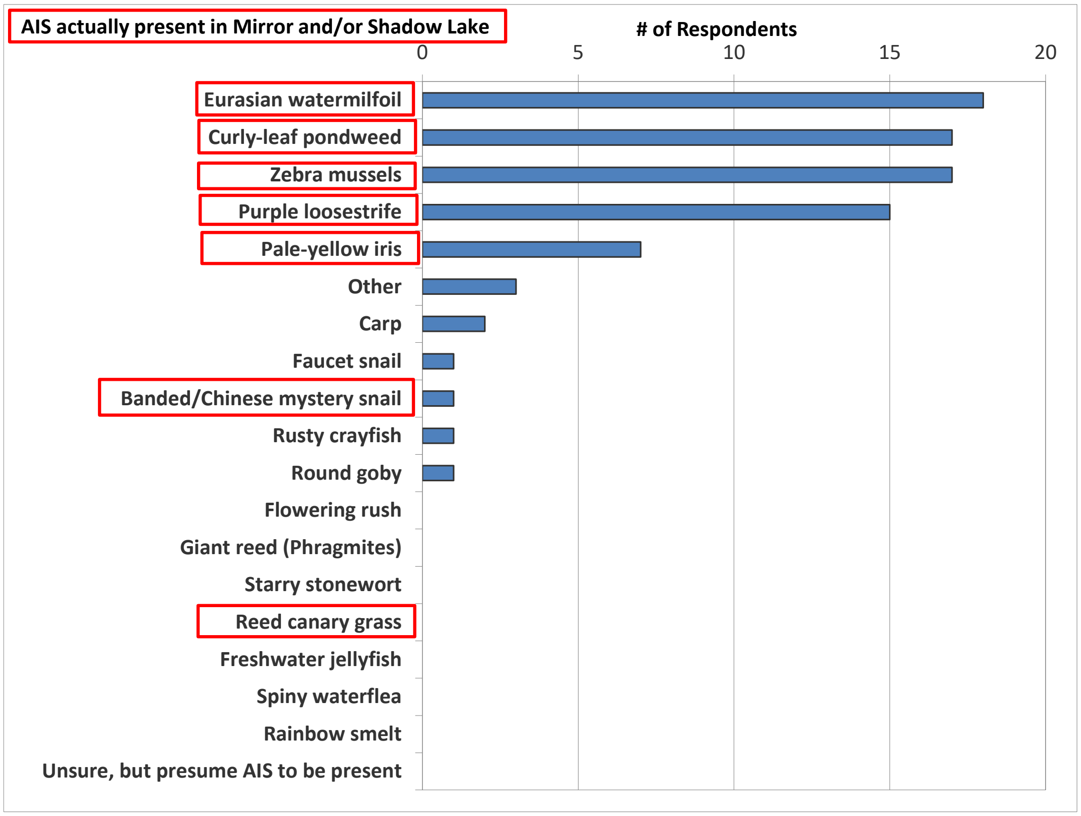


Figure 3.5-2. Stakeholder survey response Question #22. Which aquatic invasive species do you believe are in or immediately around Mirror and Shadow lakes?

3.6 Fisheries Data Integration

Fishery management is an important aspect in the comprehensive management of a lake ecosystem; therefore, a brief summary of available data is included here as a reference. The following section is not intended to be a comprehensive plan for the lake's fishery, as those aspects are currently being conducted by the fisheries biologists overseeing Mirror and Shadow lakes. The goal of this section is to provide an overview of some of the data that exists. Although current fish data were not collected as a part of this project, the following information was compiled based upon data available from the Wisconsin Department of Natural Resources (WDNR) and personal communications with DNR Fisheries Biologist Jason Breeggemann.

Mirror and Shadow Lake Fishery

Energy Flow of a Fishery

When examining the fishery of a lake, it is important to remember what drives that fishery, or what is responsible for determining its mass and composition. The gamefish in Mirror and Shadow lakes are supported by an underlying food chain. At the bottom of this food chain are the elements that fuel algae and plant growth – nutrients such as phosphorus and nitrogen, and sunlight. The next tier in the food chain belongs to zooplankton, which are tiny crustaceans that feed upon algae and plants, and insects. Smaller fish called planktivores feed upon zooplankton and insects, and in turn become food for larger fish species. The species at the top of the food chain are called piscivores, and are the larger gamefish that are often sought after by anglers, such as bass and walleye.

A concept called energy flow describes how the biomass of piscivores is determined within a lake. Because algae and plant matter are generally small in energy content, it takes an incredible amount of this food type to support a sufficient biomass of zooplankton and insects. In turn, it takes a large biomass of zooplankton and insects to support planktivorous fish species. And finally, there must be a large planktivorous fish community to support a modest piscivorous fish community. Studies have shown that in natural ecosystems, it is largely the amount of primary productivity (algae and plant matter) that drives the rest of the producers and consumers in the aquatic food chain. This relationship is illustrated in Figure 3.6-1.

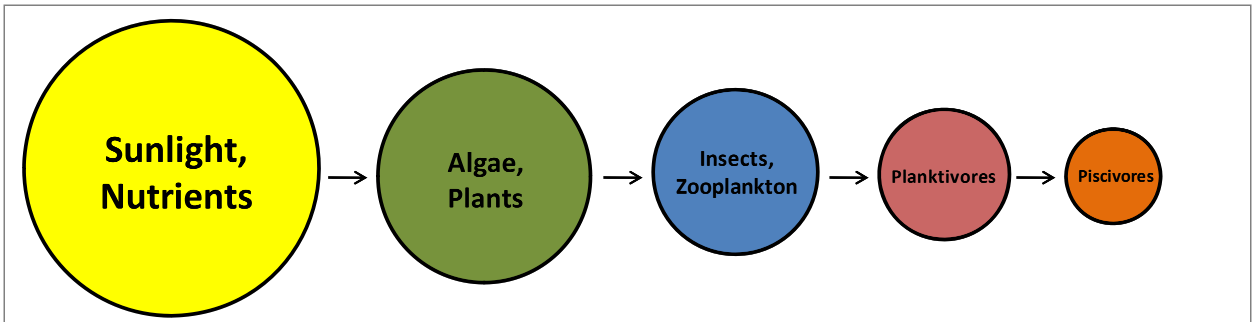


Figure 3.6-1. Aquatic food chain. Adapted from (Carpenter, Kitchell and Hodgson 1985).

As discussed in the Water Quality section, Shadow Lake is between an oligotrophic and mesotrophic system, meaning it has fairly high water clarity, but still a low amount of nutrients and thus low primary productivity. Simply put, this means it is difficult for the lake to support a large population of predatory fish (piscivores) because the supporting food chain is relatively small. Table 3.6-1 shows the popular game fish present in the system. Although not an exhaustive list of fish species in the lake, additional species documented in past WDNR surveys of Shadow Lake include bluntnose minnow (*Pimephales notatus*), golden shiner (*Notemigous crysoleucas*), johnny darter (*Etheostoma nigrum*), logperch (*Percina caprodes*), mottled sculpin (*Cottus bairdii*), shorthead redhorse (*Moxostoma macrolepidotum*), and white sucker (*Catostomus commersonnii*).

As discussed in the Water Quality section, Mirror Lake is a mesotrophic system, meaning it has a moderate amount of nutrients and thus a moderate amount of primary productivity. This is relative to an oligotrophic system, which contains fewer nutrients (less productive) and a eutrophic system, which contains more nutrients (more productive). Simply put, this means Mirror Lake should be able to support an appropriately sized population of predatory fish (piscivores) when compared to eutrophic or oligotrophic systems.

Table 3.6-1. Gamefish present in Mirror and Shadow with corresponding biological information (Becker 1983).

Common Name (*Scientific Name*)	Max Age (yrs)	Spawning Period	Spawning Habitat Requirements
Black Crappie (Pomoxis nigromaculat	7	May - June	Near Chara or other vegetation, over sand or fine gravel
Bluegill (Lepomis macrochirus)	11	Late May - Early August	Shallow water with sand or gravel bottom
Largemouth Bass (Micropterus salmo	13	Late April - Early July	Shallow, quiet bays with emergent vegetation
Muskellunge (Esox masquinongy)	30	Mid April - Mid May	Shallow bays over muck bottom with dead vegetation, 6 - 30 in.
Northern Pike (Esox lucius)	25	Late March - Early April	Shallow, flooded marshes with emergent vegetation with fine leaves
Pumpkinseed (Lepomis gibbosus)	12	Early May - August	Shallow warm bays 0.3 - 0.8 m, with sand or gravel bottom
Rock Bass (*Ambloplites rupestris*)	13	Late May - Early June	Bottom of course sand or gravel, 1 cm - 1 m deep
Smallmouth Bass (Micropterus dolom	13	Mid May - June	Nests more common on north and west shorelines over gravel
Walleye (Sander vitreus)	18	Mid April - Early May	Rocky, wavewashed shallows, inlet streams on gravel bottoms
Yellow Bullhead (*Ameiurus natalis*)	7	May - July	Heavy weeded banks, beneath logs or tree roots
Yellow Perch (Perca flavescens)	13	April - Early May	Sheltered areas, emergent and submergent veg

Survey Methods

In order to keep the fishery of a lake healthy and stable, fisheries biologists must assess the current fish populations and trends. To begin this process, the correct sampling technique(s) must be selected to efficiently capture the desired fish species. A commonly used passive trap is a fyke net (Photograph 3.6-1). Fish swimming towards this net along the shore or bottom will encounter the lead of the net, be diverted into the trap and through a series of funnels which direct the fish further into the net. Once reaching the end, the fisheries technicians can open the net, record biological characteristics, mark (usually with a fin clip), and then release the captured fish.

The other commonly used sampling method is electrofishing (Photograph 3.6-1). This is done, often at night, by using a specialized boat fit with a generator and two electrodes installed on the front touching the water. Once a fish comes in contact with the electrical current produced, the fish involuntarily swims toward the electrodes. When the fish is in the vicinity of the electrodes, they become stunned making them easier to net and place into a livewell to recover. Contrary to what some may believe, electrofishing does not kill the fish and after being placed in the livewell fish generally recover within minutes. As with a fyke net survey, biological characteristics are recorded and any fish that has a mark (considered a recapture from the earlier fyke net survey) are also documented before the fish is released.

The mark-recapture data collected between these two surveys is placed into a statistical model to calculate the population estimate of a fish species. Fisheries biologists can then use this data to make recommendations and informed decisions on managing the future of the fishery.

Photograph 3.6-1. Fyke net positioned in the littoral zone of a Wisconsin Lake (left) and an electroshocking boat (right).

Fish Stocking

Photograph 3.6-2. Largemouth bass fingerling.

To assist in meeting fisheries management goals, the WDNR may permit the stocking of fingerling or adult fish in a waterbody that were raised in permitted hatcheries (Photograph 3.6-2). Stocking a lake may be done to assist the population of a species due to a lack of natural reproduction in the system, or to otherwise enhance angling opportunities. Mirror Lake was stocked from 1972-2019 consistently with brown and rainbow trout (Table 3.6-2). No trout stockings occurred in 2020 and are not planned for 2021 (WDNR communications 2021). Shadow Lake was stocked several times during the 1970's with walleye, largemouth bass, and northern pike (Table 3.6-3).

Table 3.6-2. Stocking data available for trout in Mirror Lake (1990-2019).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
2019	RAINBOW TROUT	ERWIN	YEARLING	804	9
2018	RAINBOW TROUT	ERWIN	YEARLING	713	9
2014	RAINBOW TROUT	ERWIN	YEARLING	742	9.2
2013	RAINBOW TROUT	ERWIN	YEARLING	643	9.2
2011	RAINBOW TROUT	ERWIN	YEARLING	1,547	8.9
2010	BROWN TROUT	ST. CROIX	YEARLING	650	9.1
2010	RAINBOW TROUT	ERWIN	YEARLING	650	9
2009	BROWN TROUT	ST. CROIX	YEARLING	650	9.2
2008	BROWN TROUT	ST. CROIX	YEARLING	650	7
2008	RAINBOW TROUT	ERWIN	YEARLING	650	7.7
2007	BROWN TROUT	WILD ROSE	YEARLING	650	8
2007	RAINBOW TROUT	ERWIN	YEARLING	650	8.2
2006	BROWN TROUT	WILD ROSE	YEARLING	650	8.7
2006	RAINBOW TROUT	ERWIN	YEARLING	647	7.7
2003	BROWN TROUT	WILD ROSE	YEARLING	650	8.5
2003	RAINBOW TROUT	ERWIN	YEARLING	650	7.4
2002	BROWN TROUT	WILD ROSE	YEARLING	500	9.3
2002	RAINBOW TROUT	ERWIN	YEARLING	499	8.5
2001	BROWN TROUT	WILD ROSE	YEARLING	500	8
1997	BROWN TROUT	WILD ROSE	YEARLING	375	8.3
1994	RAINBOW TROUT	UNSPECIFIED	YEARLING	1,500	7.9
1992	RAINBOW TROUT	UNSPECIFIED	YEARLING	1,500	8
1991	RAINBOW TROUT	UNSPECIFIED	YEARLING	1,500	7.4
1990	RAINBOW TROUT	UNSPECIFIED	YEARLING	1,500	8

Table 3.6-3. Stocking data available for gamefish in Shadow Lake (1972-1974).

Year	Species	Age Class	# Fish Stocked	Avg Fish Length (in)
1974	WALLEYE	FINGERLING	9,990	3
1972	WALLEYE	FINGERLING	6,000	3
1972	WALLEYE	FRY	549,000	1
1972	LARGEMOUTH BASS	FINGERLING	2,140	3
1972	NORTHERN PIKE	FRY	430,000	1

Fishing Activity

Based on data collected from the stakeholder survey (Appendix B), fishing (open-water) was the fifth most important reason for owning property on or near Mirror and Shadow lakes (Question #15). Figure 3.6-2 displays the fish that Mirror and Shadow lakes stakeholders enjoy catching the most, with bluegill/sunfish, northern pike, and largemouth bass being the most popular. Approximately 64% of these same respondents believed that the quality of fishing on the lake was either excellent or good (Figure 3.6-3). Approximately 82% of respondents who fish Mirror and Shadow lakes believe the quality of fishing has remained the same or has gotten somewhat better since they first started to fish the lake (Figure 3.6-4).

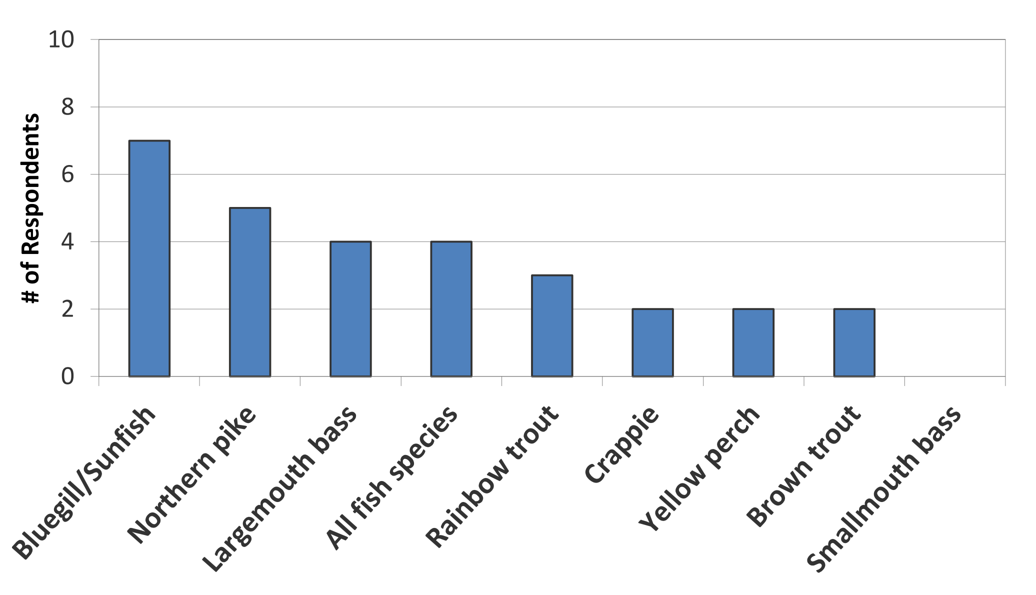


Figure 3.6-2. Stakeholder survey response Question #9. What species of fish do you like to catch on Mirror and Shadow lakes?

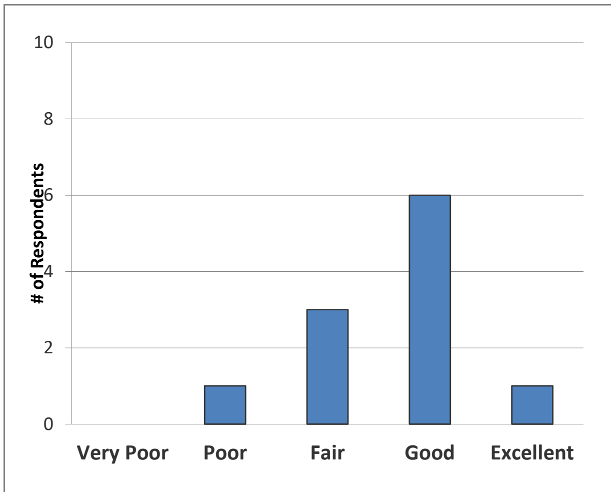


Figure 3.6-3. Stakeholder survey response Question #10. How would you describe the current quality of fishing on Mirror and Shadow lakes?

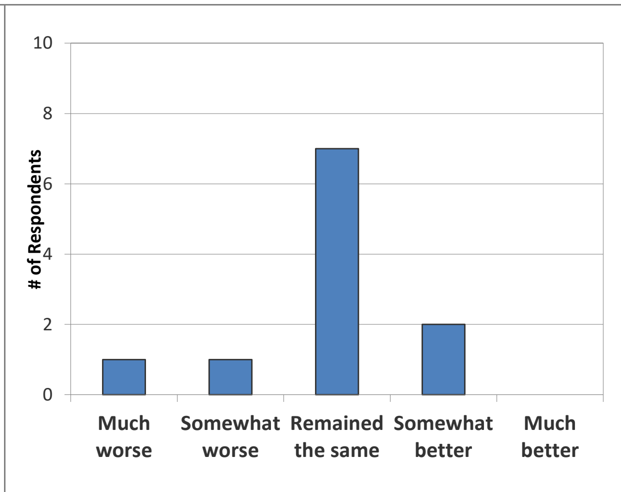


Figure 3.6-4. Stakeholder survey response Question #11. How has the quality of fishing changed on Mirror and Shadow lakes since you started fishing the lake?

Fish Populations and Trends

Utilizing the fish sampling techniques mentioned above and specialized formulas, WDNR fisheries biologists can estimate populations and determine trends of captured fish species. One method used in calculating the numbers captured is catch per unit effort (CPUE). This number provides a standardized way to compare fish abundances between years when the amount of fishing effort (number of nights' fyke nets are set) differs. When comparing within the same year, CPUE indexes are compared to statewide data by percentiles (Neibur 2015). For example, if a CPUE is in the 90th percentile, it is higher than 90% of the other CPUEs in the state (Neibur 2015). Another index that is commonly used is the Proportional Stock Density (PSD). This metric is used to assess size structure within a species by calculating dividing the number of quality size fish by the number of stock fish. PSD values in the 40-60 percent range generally describe a balanced fish population (Cite). Tables 3.6-4, 3.6-5, and 3.6-6 provide total and calculated fishery data for fish captured during the electroshocking survey on Shadow Lake in October 2016. Crews specifically targeted panfish during this survey. Any gamefish species caught during this survey are considered by-catch but were still recorded. The survey covered the entire shoreline perimeter of Shadow Lake. Ultimately this data shows a healthy population of fish from moderate to high abundances. The lowest percentile rank of species captured was yellow perch (60th) and the highest being largemouth bass (93rd). This is one example of how data is analyzed by fisheries biologists to better understand the fishery and how it should be managed.

Table 3.6-4. Size Structure Metrics from 2016 WDNR Electroshocking Survey (WDNR 2016).

Species	Total	Average Length (inches)	Length Range (inches)	Stock and Quality Size (inches)	Stock No.	Quality No	PSD	Percentile Rank	Size Rating
BLUEGILL	195	5.7	2.4-8.2	3.0 and 6.0	182	98	54%	75th	Moderate-High
YELLOW PERCH	14	5.8	3.5-8.8	5.0 and 8.0	7	3	43%	93rd	High
LARGEMOUTH BASS	81	11.4	4.1-19.5	8.0 and 12.0	58	43	74%	72nd	Moderate-High
PUMPKINSEED	17	4.6	3.7-6.6	5.0 and 8.0	17	1	6%	15th	Low

Table 3.6-5. Abundance Metrics from 2016 WDNR Electroshocking Survey (WDNR 2016).

Species	CPUE Total (no per mile)	Percentile Rank	Overall Abundance Rating	Length Index	Length Index CPUE	Percentile rank	Abundance Rating
BLUEGILL	262.7	85th	Moderate-High	≥ 7.0	66	96th	High
YELLOW PERCH	13.7	60th	Moderate	≥ 8.0	2.9	89th	Moderate-High
LARGEMOUTH BASS	79.4	93rd	High	≥ 14.0	20.5	97th	High
PUMPKINSEED	16.7	71st	Moderate-High	≥ 7.0	0		Low

Table 3.6-6. Growth Metrics from 2016 WDNR Electroshocking Survey (WDNR 2016).

Species	Total (n)	Length Bin (inches)	Mean Age (years)	Age Range (years)	Percentile Rank	Growth Rating
BLUEGILL	9	6	5.1	4.0-7.0	38th	Moderate-Slow
BLUEGILL	13	7	5.8	5.0-7.0	31st	Moderate-Slow

Gamefish

The gamefish present on Mirror and Shadow lakes represent different population dynamics depending on the species. The results for the stakeholder survey show landowners prefer to catch bluegill and sunfish on the lakes (Figure 3.6-2). Brief summaries of gamefish with fishable populations in Mirror and Shadow lakes are provided based off of the report submitted by WDNR fisheries biologist Jason Breeggemann following the fisheries survey completed in 2016 (Appendix E).

Largemouth bass are found in both Mirror and Shadow lakes. In the 2016 survey of Shadow Lake, both size structure and abundance metrics for largemouth bass were recorded at moderate-high levels. Approximately 36% of bass captured were larger than 14 inches, with the largest fish measuring 19.5 inches (Tables 3.6-4 and 3.6-5). The number of bass measuring greater than 14 inches ranks in the 97th percentile.

Walleyes are considered present in Shadow Lake. According to fisheries biologist Jason Breeggemann, walleye have not been stocked in Shadow Lake since 1980; however, two fish have been captured in surveys conducted in 2004 and 2010. It is possible that a very small population of naturally-reproducing walleye reside in Shadow Lake, but it is more likely those fish came from the Crystal River from walleye stocking events in the Waupaca Chain O' Lakes (DNR Communications 2021).

Northern Pike are present in both Mirror and Shadow lakes. The 2016 panfish survey conducted on Shadow Lake did not record any pike catches.

Panfish

The panfish present on Shadow Lake have different population dynamics depending on the species. In an effort to increase the panfish size structure, a special panfish regulation was put in effect in spring of 2016. A one-night electrofishing survey was conducted along the shoreline of Shadow Lake in 2016 in an attempt to assess the panfish population prior to the special regulation. Moderate panfish populations were present, however, growth rates were below average. Brief summaries of panfish with fishable populations in Shadow Lake are provided based off of the WDNR fisheries survey completed in 2016 (Appendix E).

Bluegill are the most abundant panfish in Shadow Lake. A total of 268 bluegills were captured in the 2016 survey. Size structure, abundance, and growth rate metrics were calculated from this sample. Of the 268 bluegills captured, 195 fish were sampled to assess size structure. The average length was 5.7 inches and largest fish measured 8.2 inches. Bluegills measuring greater than 7 inches accounted for 26% of the sample size. Overall, the size rating for bluegill is considered moderate-high and falls in the 75th percentile rank (Table 3.6-4). In addition, 22 fish were sampled to assess growth rate. Bluegills measuring 6 and 7 inches ranked in the 38th and 31st percentile, respectively, and were given a moderate-slow growth rating (Table 3.6-6).

Pumpkinseed were not found in as high of abundance as bluegill. In total, 17 pumpkinseed were captured. All fish measured below 7 inches and recorded a low size rating, ranking in the 15th percentile (Table 3.6-4).

Yellow perch were not found in as high of abundance as bluegill or pumpkinseed. In total, 14 perch were captured, ranging in length from 3.5-8.8 inches (Table 3.6-4). Several quality sized perch were captured, with three fish measuring over eight inches. Perch were found in moderate abundance, ranking in the 60th percentile (Table 3.6-5).

Black crappie are present in both Mirror and Shadow lakes, however no black crappie were captured during the 2016 survey.

Mirror and Shadow Lakes Fish Habitat

Substrate Composition

Just as forest wildlife require proper trees and understory growth to flourish, fish require certain substrates and habitat types to nest, spawn, escape predators, and search for prey. Lakes with primarily a silty/soft substrate, many aquatic plants, and coarse woody debris may produce a completely different fishery than lakes that are largely sandy/rocky, and contain few aquatic plant species or coarse woody habitat.

Substrate and habitat are critical to fish species that do not provide parental care to their eggs. Northern pike is one species that does not provide parental care to its eggs (Becker 1983). Northern pike broadcast their eggs over woody debris and detritus, which can be found above sand or muck. This organic material suspends the eggs above the substrate, so the eggs are not buried in sediment and suffocate as a result. Walleye are another species that does not provide parental care to its eggs. Walleye preferentially spawn in areas with gravel or rock in places with moving water or wave action, which oxygenates the eggs and prevents them from getting buried in sediment. Fish that provide parental care are less selective of spawning substrates. Species such as bluegill tend to prefer a harder substrate such as rock, gravel or sandy areas if available, but have been found to spawn and care for their eggs in muck as well.

According to the point-intercept survey conducted by Onterra in 2020, 51% of the substrate sampled in the littoral zone of Mirror Lake were soft sediments and 49% was composed of sand. According to the point-intercept survey conducted by Onterra in 2020, 76% of the substrate sampled in the littoral zone of Shadow Lake was sand and 24% was composed of soft sediments.

Woody Habitat

As discussed in the Shoreland Condition Section, the presence of coarse woody habitat is important for many stages of a fish's life cycle, including nesting or spawning, escaping predation as a juvenile, and hunting insects or smaller fish as an adult. Unfortunately, as development has increased on Wisconsin lake shorelines in the past century, this beneficial habitat has often been the first to be removed from the natural shoreland zone. Leaving these shoreland zones barren of coarse woody habitat can lead to decreased abundances and slower growth rates in fish (Sass 2009). A fall 2020 survey documented 41 pieces of coarse woody along the shores of Mirror Lake, resulting in a ratio of approximately 50 pieces per mile of shoreline. The fall 2020 survey also documented 32 pieces of coarse woody along the shores of Shadow Lake resulting in a ratio of approximately 27 pieces per mile of shoreline. Fisheries biologists do not suggest a specific number of fish sticks for a lake but rather highly encourage their installation wherever possible. To learn how Mirror and Shadow lakes coarse woody habitats are compared to other lakes in its region please refer to section 3.3.

Fish Habitat Structures

Some fisheries managers may look to incorporate fish habitat structures on the lakebed or littoral areas extending to shore for the purpose of improving fish habitats and spawning areas. These projects are typically conducted on lakes lacking significant coarse woody habitat in the shoreland zone. The "Fish sticks" program, outlined in the WDNR best practices manual, adds trees to the shoreland zone restoring fish habitat to critical near shore areas. Typically, every site has 3 – 5 trees which are partially or fully submerged in the water and anchored to shore (Photograph 3.6-3). The WDNR recommends placement of the fish sticks during the winter on ice when possible to prevent adverse impacts on fish spawning or egg incubation periods. The program requires a WDNR permit and can be funded through many different sources including the WDNR, County Land & Water Conservation Departments or partner contributions. In 2014, Shadow Lake received a five year permit to place fish sticks along the shores of the lake.

Photograph 3.6-3. Examples of fish sticks (left) and half-log habitat structures. (Photos by WDNR)

Fish cribs are a type of fish habitat structure placed on the lakebed. These structures are more commonly utilized when there is not a suitable shoreline location for fish sticks. Installing fish cribs may also be cheaper than fish sticks; however, some concern exists that fish cribs can concentrate fish, which in turn leads to increased predation and angler pressure. Having multiple locations of fish cribs can help mitigate that issue.

Half-logs are another form of fish spawning habitat placed on the bottom of the lakebed (Photograph 3.6-3). Smallmouth bass specifically have shown an affinity for overhead cover when creating spawning nests, which half-logs provide (Wills 2004). If the waterbody is exempt from a permit or a permit has been received, information related to the construction, placement and maintenance of half-log structures are available online.

An additional form of fish habitat structure is spawning reefs. Spawning reefs typically consist of small rubble in a shallow area near the shoreline for mainly walleye habitat. Rock reefs are sometimes utilized by fisheries managers when attempting to enhance spawning habitats for some fish species. However, a 2004 WDNR study of rock habitat projects on 20 northern Wisconsin lakes offers little hope the addition of rock substrate will improve walleye reproduction (Neuswanger and Bozek 2004).

Placement of a fish habitat structure in a lake may be exempt from needing a permit if the project meets certain conditions outlined by the WDNR's checklists available online:

(https://dnr.wi.gov/topic/waterways/Permits/Exemptions.html)

If a project does not meet all of the conditions listed on the checklist, a permit application may be sent in to the WDNR and an exemption requested.

If interested, the Friends group and District may work with the local WDNR fisheries biologist to determine if the installation of fish habitat structures should be considered in aiding fisheries management goals for Mirror and Shadow lakes.

Fishing Regulations

Regulations for Wisconsin fish species as of May 2021 are displayed in Tables 3.6-3 and 3.6-4. Shadow Lake is one of 94 lakes chosen to participate in an experimental daily bag limit on panfish. Below are the three different daily bag limits selected to determine which is best at improving panfish size. Mirror Lake was not chosen in this study and remains under the 25 panfish per day year-round.

- 25/10 – A total of 25 panfish may be kept but only 10 of any one species.
- Spawning season 15/5 – A total of 25 panfish may be kept except during May and June when a total of 15 panfish may be kept but no more than five of any one species.
- 15/5 – A total of 15 panfish may be kept but only five of any one species.

Shadow Lake was chosen to be under the spawning season 15/5 experimental regulation. The efficacy of the regulations as well as anglers support of the changes will be evaluated in 2021 and 2026 (WDNR 2017).

For specific fishing regulations on all fish species, anglers should visit the WDNR website (*www.http://dnr.wi.gov/topic/fishing/regulations/hookline.html)* or visit their local bait and tackle shop to receive a free fishing pamphlet that contains this information.

Table 3.6-3. WDNR fishing regulations for Mirror Lake (As of May 2021).

Species	Daily bag limit	Length Restrictions	Season
Panfish (bluegill, pumpkinseed, sunfish, crappie and yellow perch)	25	None	Open All Year
Largemouth bass and smallmouth bass	5	14"	May 1, 2021 to March 6, 2022
Muskellunge and hybrids	1	40"	May 29, 2021 to December 31, 2021
Northern pike	5	None	May 1, 2021 to March 6, 2022
Walleye, sauger, and hybrids	3	18"	May 1, 2021 to March 6, 2022
Bullheads	Unlimited	None	Open All Year
Cisco and whitefish	10	None	Open All Year

Table 3.6-4. WDNR fishing regulations for Shadow Lake (As of May 2021).

Species	Daily bag limit	Length Restrictions	Season
Panfish (bluegill, pumpkinseed, sunfish, crappie and yellow perch)	During May and June, 15 panfish may be kept, but only 5 of any one species. During the remainder of the year, 25 panfish may be kept	None	Open All Year
Largemouth bass and smallmouth bass	5	14"	May 1, 2021 to March 6, 2022
Muskellunge and hybrids	1	40"	May 29, 2021 to December 31, 2021
Northern pike	5	None	May 1, 2021 to March 6, 2022
Walleye, sauger, and hybrids	3	18"	May 1, 2021 to March 6, 2022
Bullheads	Unlimited	None	Open All Year
Cisco and whitefish	10	None	Open All Year

Mercury Contamination and Fish Consumption Advisories

Freshwater fish are amongst the healthiest of choices you can make for a home-cooked meal. Unfortunately, fish in some regions of Wisconsin are known to hold levels of contaminants that are harmful to human health when consumed in great abundance. The two most common contaminants are polychlorinated biphenyls (PCBs) and mercury. These contaminants may be found in very small amounts within a single fish, but their concentration may build up in your body over time if you consume many fish. Health concerns linked to these contaminants range from poor balance and problems with memory to more serious conditions such as diabetes or cancer. These contaminants, particularly mercury, may be found naturally to some degree. However, the majority of fish contamination has come from industrial practices such as coal-burning facilities, waste incinerators, paper industry effluent and others. Though environmental regulations have reduced emissions over the past few decades, these contaminants are greatly resistant to breakdown and may persist in the environment for a long time. Fortunately, the human body is able to eliminate contaminants that are consumed however this can take a long time depending upon the type of contaminant, rate of consumption, and overall diet. Therefore, guidelines are set upon the consumption of fish as a means of regulating how much contaminant could be consumed over time.

General fish consumption guidelines for Wisconsin inland waterways are presented in Figure 3.6-5. There is an elevated risk for children as they are in a stage of life where cognitive development is rapidly occurring. As mercury and PCB both locate to and impact the brain, there are greater restrictions on women who may have children or are nursing children, and also for children under 15.

Fish Consumption Guidelines for Most Wisconsin Inland Waterways

	Women of childbearing age, nursing mothers and all children under 15	Women beyond their childbearing years and men
Unrestricted*	-	Bluegill, crappies, yellow perch, sunfish, bullhead and inland trout
1 meal per week	Bluegill, crappies, yellow perch, sunfish, bullhead and inland trout	Walleye, pike, bass, catfish and all other species
1 meal per month	Walleye, pike, bass, catfish and all other species	Muskellunge
Do not eat	Muskellunge	-

**Doctors suggest that eating 1-2 servings per week of low-contaminant fish or shellfish can benefit your health. Little additional benefit is obtained by consuming more than that amount, and you should rarely eat more than 4 servings of fish within a week.*

Figure 3.6-5. Wisconsin statewide safe fish consumption guidelines. Graphic displays consumption guidance for most Wisconsin waterways. Figure adapted from WDNR website graphic (http://dnr.wi.gov/topic/fishing/consumption/)

Fishery Management & Conclusions

Shadow Lake is currently on an eight-year sampling plan with the WDNR. The main management objective is to monitor the fishery and increase the bluegill size structure. A special panfish regulation was enacted in 2016 in an attempt to accomplish this objective. A survey to assess panfish populations has been tentatively been scheduled for 2021.

4.0 SUMMARY AND CONCLUSIONS

The design of this project was intended to fulfill three objectives:

1) Collect baseline data to increase the general understanding of the Mirror and Shadow lakes ecosystem.
2) Collect detailed information regarding invasive plant species within the lake, with the primary emphasis being on Eurasian watermilfoil and curly-leaf pondweed.
3) Collect sociological information from Mirror and Shadow lakes riparian stakeholders regarding their use of the lake and their thoughts pertaining to the past and current condition of the lake and its management.

These three objectives were fulfilled during the project and have led to an understanding of the Mirror and Shadow lakes ecosystem, the people that care about the lakes, and what needs to be completed to protect and enhance these lakes.

A volunteer group of Friends of Mirror Shadow Lakes (FMSL) members and other local partners formed a planning committee for this project and were instrumental in the development of the subsequent Implementation Plan. The planning committee served to provide the local perspective related to recreational use of the lakes and in developing the FMSL and WILPRD's role in protecting, enhancing, and managing Mirror and Shadow lakes for the years to come. Pairing the understanding of the technical data that has been collected over time as well as the local sociological needs through this planning project has led to the creation of a realistic management plan for the FMSL and WILPRD to implement in managing Mirror and Shadow lakes.

Historical data, as well as data collected during the management planning project indicate Mirror and Shadow lakes have excellent water quality for deep headwater drainage lakes based on phosphorus and chlorophyll-a levels. Paleocore analysis indicates that there have been some increases in phosphorus within the last century. An increasing trend in chloride concentrations are evident within each lake and is likely the result of local salt applications on area roadways during winter months. The FMSL and WILPRD have developed actions within the Implementation Plan to monitor chloride concentrations in the lakes and work towards raising awareness of the issue.

The shoreland condition assessment identified areas of the lake's shoreland that are important to protect and maintain in their natural state and also identified areas where restoration actions would have the most benefit. The shorelands around the lakes are mostly in good condition with many vegetated buffers present.

The watersheds are relatively small and comprised of a variety of land covers including significant percentages of urbanization/residential areas, wetlands, and forests. Modeling indicates that internal nutrient loading in Mirror Lake accounts for approximately seven pounds of annual phosphorus loading.

Studies indicate an overall good quality aquatic plant community with some signs of recent degradation. Some species that are sensitive to environmental degradation have declined over time while other species that are hardier and more tolerant to nutrient-rich waters have increased.

Eurasian watermilfoil (EWM) and curly-leaf pondweed (CLP) have been present in the Mirror and Shadow lakes system since at least 2011. Active management through hand pulling has occurred in the past. The EWM and CLP populations were monitored in 2020 as a part of this management planning project. The EWM monitoring showed a relatively modest population with most occurrences consisting of isolates single plants, clumps or small plant colonies. Some colonized areas of CLP were documented during 2020 including on the north end of Mirror Lake and in multiple locations in Shadow Lake.

No areas of EWM or CLP were causing significant nuisance conditions that would interfere with recreational use of the lake at the time of the 2020 survey although local observations suggest a recently increasing AIS population. Continued monitoring of the EWM and CLP populations is important in documenting the population dynamics and the distribution within the lakes. Monitoring will be instrumental in guiding potential active management strategies of either species in future years, particularly if the population expands to levels that significantly impede recreational activities in the lake. As a part of this management planning project, the FMSL and WILPRD has outlined how they will monitor EWM and CLP and the management approach they will take moving forward. The FMSL and WILPRD have also developed plans to prevent further introductions of AIS into Mirror and Shadow lakes through the potential participation in the WDNR's Clean Boats Clean Waters program.

Several other non-native species were identified within or around the margins of the lakes during studies completed during this project. The FMSL and WILPRD have created management actions towards monitoring and potentially managing species including pale-yellow iris, purple loosestrife, narrow-leaf cattail, and reed canary grass.

Mirror and Shadow Lake's fishery is managed by the WDNR for trout and panfish. The FMSL and WILPRD has made a management goal of working with WDNR fisheries managers to investigate ways to maintain the fishery resource in the lake including the potential for making habitat improvements.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the Friends of Mirror-Shadow Lakes Planning Committee, City of Waupaca Parks and Recreation staff, and ecologist/planners from Onterra. It represents the path the Friends of Mirror-Shadow Lake and Waupaca Inland Lakes Protection & Rehabilitation District will follow in order to meet their lake management goals. The goals detailed within the plan are realistic and based upon the findings of the studies completed in conjunction with this planning project and the needs of the Mirror and Shadow Lake stakeholders as portrayed by the members of the Planning Committee, the returned stakeholder surveys, and numerous communications between Planning Committee members and the lake stakeholders. The Implementation Plan is a living document in that it will be under constant review and adjustment depending on the condition of the lake, the availability of funds, level of volunteer involvement, and the needs of the stakeholders.

Management Goal 1: Maintain and Enhance Current Water Quality Conditions in Mirror and Shadow Lakes

Management Action:	Expand water quality monitoring program through UWSP to align with WisCALM
Timeframe:	Beginning 2022
Facilitator:	FMSL Water Quality Sampling Volunteer
Description:	Monitoring water quality is an important aspect of every lake management planning activity. Collection of water quality data at regular intervals aids in the management of the lake by building a database that can be used for long-term trend analysis. Early discovery of negative trends may lead to the reason of why the trend is occurring. Volunteers from the FMSL have been monitoring water quality as a part of the UW-Stevens Point Center for Watershed Science program since 2006. This program includes the collection of water samples for testing a number of water chemistry metrics and nutrients during the spring and fall overturn events. Monthly dissolved oxygen and temperature profiles are also collected. The spring and fall turnover samples essentially measure the 'whole lake' phosphorus content, but this sampling regimen does not align with data used in the Wisconsin 2022 Consolidated Assessment and Listing Methodology (WisCALM) (WDNR 2022) and what most water quality monitoring models require. The FMSL will expand their water quality monitoring efforts through UWSP to include the collection and analysis of chlorophyll-a and total phosphorus samples during June, July, and August in addition to a continuation of the same spring and fall sampling that has been completed in recent years. Package C from UWSP's Water and Environmental Analysis Lab offers chlorophyll-a and total phosphorus testing (as well as nitrogen testing) for approximately $90 that would meet this objective. The addition of the summer chlorophyll-a and total

	phosphorus samples will align the group with the WisCALM monitoring program. Near-surface water samples would be collected from both Mirror and Shadow lakes during each sampling event. Furthermore, during each sampling event, Secchi disk transparency would be recorded and a temperature and dissolved oxygen profile would be completed.
Action Steps:	
1.	Facilitator contacts UWSP to acquire necessary materials and training for updated sampling regime.
2.	Trained volunteer(s) collects data and reports results to WDNR by entering into the SWIMS database as well as sharing with FMSL members.
3.	Water sampling volunteer and FMSL facilitate the recruitment of new volunteer(s) as needed.

Management Action:	Monitor chloride concentration in Mirror and Shadow lakes.
Timeframe:	Continuation of current effort
Facilitator:	FMSL Water Quality Sampling Volunteer
Description:	The FMSL will continue to collect samples from each lake annually to be tested for chloride concentrations. These samples will be collected in the spring and fall of each year from each lake as a continuation of the monitoring regimen already in place in recent years. As discussed in section 3.1 of this report, both Mirror and Shadow lakes have shown a rapidly increasing trend in the past decade of chloride and sodium concentrations. High chloride levels have also been documented in the nearby drinking water wells. The FMSL will communicate with the City of Waupaca to raise awareness of this issue and to see if salt applications can be modified to reduce salt runoff.
Action Steps:	
	See description above.

Management Goal 2: Protect and Enhance Ecological Health of Mirror and Shadow Lakes

Management Action:	Conduct periodic quantitative vegetation monitoring on Mirror & Shadow Lakes.
Timeframe:	Point-Intercept Survey every four years, Community Mapping every 10 years
Possible Grant:	WDNR Surface Water Planning Grant ($10,000 max)
Facilitator:	WILPRD
Description:	Point-intercept surveys have been completed in Mirror and Shadow lakes in 2011, 2018, and 2020. The WILPRD will plan to have a point-intercept survey completed on a maximum of a four-year interval with the next survey tentatively planned for 2024. The survey would be initiated sooner if perceived changes in the aquatic plant community are believed to be occurring or if the lake enters a period of significant active aquatic plant management. This will allow a continued understanding of the submergent aquatic plant community dynamics within Mirror and Shadow lakes. In order to understand the dynamics of the emergent and floating-leaf aquatic plant community in Mirror and Shadow lakes, a community mapping survey would be conducted every 10 years. A community mapping survey was conducted on Mirror and Shadow lakes in 2020 as a part of this management planning effort. The next community mapping survey will be planned to occur in 2030. The WILPRD may contract with a professional firm or partner with local organizations such as Golden Sands, RC&D to conduct these monitoring surveys. The WILPRD and FMSL may seek assistance from the City of Waupaca to aid in funding these monitoring efforts. Additionally, the FMSL and WILPRD may consider applying for a WDNR surface water planning grant that if awarded, would provide funds towards aquatic plant monitoring surveys.
Action Steps:	
	See description above.

Management Action:	Educate stakeholders on the importance of shoreland condition, shoreland restoration, and proper shoreland stewardship on Mirror and Shadow lakes.
Timeframe:	Initiate 2022 or 2023
Possible Grant:	Healthy Lakes Initiative Grant
Facilitator:	FMSL Board & WILPRD

Description:	The shoreland zone of a lake is highly important to the ecology of a lake. When shorelands are developed, the resulting impacts on a lake range from a loss of biological diversity to impaired water quality. Because of its proximity to the waters of the lake, even small disturbances to a natural shoreland area can produce ill effects. As discussed in the Shoreland Condition Section (3.3), the Healthy Lakes & Rivers Grant program provides cost share for implementing the following best practices: • Rain Garden • Rock Infiltration • Diversion • Native Plantings • Fish Sticks The cost share allows $1,000 per practice, up to $25,000 per annual grant application. More details and resources for the program are included within the Shoreland Condition Section (3.3) and can be found at: https://healthylakeswi.com Some shoreland areas of Mirror and Shadow lakes were found to contain developed or urbanized areas characterized by having impervious surface or manicured lawns (Figure 3.3-2). This limits shoreland habitat, but it also reduces natural buffering of shoreland runoff and allows nutrients to enter the lake. Much of the shoreline is undeveloped and in a natural condition. These areas provide important habitat and pollutant buffering benefits to the lake. Many riparian property owners do not understand the importance of shoreland condition and maintenance in the ecological health of their lake. The initial objective of this action will be to provide information to FMSL members and riparian property owners through a variety of educational opportunities, including newsletter articles, direct emailing of informational material, etc. Informational topics will include shoreland restoration resources, like the WDNR Healthy Lake Initiative grants, the importance of private, onsite septic system maintenance, and general good-neighbor practices like reducing litter in the lake and minimizing light and sound pollution. The UW-Extension Lakes Program (see Table 5.0-1) is an excellent source of information and articles. If shoreland property owners are interested in restoring all or a portion of their shoreline, the WDNR's Healthy Lakes Initiative Grant program allows partial cost coverage for native plantings in transition areas. This reimbursable grant program is intended for relatively

	straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through Waupaca County.
Action Steps:	
	See description above.

Management Goal 3: Maintain Current and Promote Future Fishing Opportunities on Mirror & Shadow Lakes

Management Action:	Coordinate with WDNR, local town and county agencies, and private landowners to expand coarse woody habitat in Mirror and Shadow lakes.
Timeframe:	Initiate 2022
Possible Grant:	Healthy Lakes Initiative Grant
Facilitator:	WILPRD & Waupaca Parks & Rec Department
Description:	Mirror and Shadow lakes offer a unique fishing experience for riparian property owners and the general public alike. The lakes are an important resource for the local community and fishing opportunities are available through several publicly owned frontages on the system. The lakes also receive a high amount of fishing pressure every year. The Lake District and FMSL would like to ensure the lakes contain a viable fishery into the future. Lake stakeholders realize the complexities and capabilities of the Mirror-Shadow Lake ecosystem with respect to the fishery it can produce. With this, an opportunity for education and habitat enhancement is present in order to help the ecosystem reach its maximum fishery potential. Often, property owners will remove downed trees, stumps, etc. from a shoreland area because these items may impede watercraft navigation, shore-fishing, or swimming. However, these naturally occurring woody pieces serve as crucial habitat for a variety of aquatic organisms, particularly fish. The Shoreland Condition Section (3.3) and Fisheries Data Integration Section (3.6) discuss the benefits of coarse woody habitat in detail. The WDNR's Healthy Lakes Initiative Grant allows partial cost coverage for coarse woody habitat improvements (referred to as "fish sticks"). This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through the county. • 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance • Maximum of $1,000 per cluster of 3-5 trees (best practice cap) • Implemented according to approved technical requirements (WDNR Fisheries Biologist) and complies with local shoreland zoning ordinances • Buffer area (350 ft^2) at base of coarse woody habitat cluster must comply with local shoreland zoning or: o The landowner would need to commit to leaving the area un-mowed

	- o The landowner would need to implement a native planting (also cost share through this grant program available) - Coarse woody habitat improvement projects require a general permit from the WDNR - Landowner must sign Conservation Commitment pledge to leave project in place and provide continued maintenance for 10 years
Action Steps:	
1.	Lake District/Parks & Rec Department facilitator to contact WDNR Lakes Coordinator and WDNR Fisheries Biologist to gather information on initiating and conducting further coarse woody habitat projects.

Management Action:	Continue the aeration program
Timeframe:	Ongoing
Facilitator:	Andrew Whitman - Waupaca Parks & Rec Department
Description:	The City of Waupaca Parks Department maintains and operates an aeration system in Mirror Lake. An aspect of the aeration program includes placing and removing the safety barriers required by Wisconsin statues. As discussed within the water quality section of this report (Section 3.1), this program seems to be meeting its objective in mixing waters within Mirror Lake during late-fall and resulting in sufficient oxygen levels during the winter ice-cover. The FMSL and Lake District will continue to support the aeration program to reduce the chances of fish kills and improve the health of the fishery.
Action Steps:	
	See description above

Management Goal 4: Increase the FMSL Capacity to Communicate with Lake Stakeholders and Facilitate Partnerships with Other Management Entities

Management Action:	Promote lake protection and enjoyment through stakeholder education
Timeframe:	Continuation of current efforts
Facilitator:	FMSL Board and appointees
Description:	Education represents an effective tool to address many lake issues. The FMSL aims to resume regular meetings or annual events (at least once per year) and provide regular content to the City of Waupaca to host on its website (*https://www.cityofwaupaca.org/parksnrec/friends-of-mirror-shadow-lakes/).* The FMSL will also form a social media account in an effort to increase outreach. These mediums allow for exceptional communication with lake stakeholders. This level of communication is important within a management group because it facilitates the spread of important news, educational topics, and even social happenings. The FMSL will continue to make the education of lake-related issues a priority. These may include educational materials, awareness events, and demonstrations for lake users as well as activities which solicit local and state government support. The FMSL will work with UW-Extension Lakes staff to use stock articles as appropriate to lessen the workload and ensure the messaging is accurate. *www.uwsp.edu/cnr-ap/UWEXLakes* *Example Educational Topics* • Specific topics brought forth in other management actions • Aquatic invasive species identification • Blue-green Algae • Basic lake ecology • Sedimentation • Septic system maintenance • Boating safety (promote existing guidelines) • Swimmer's itch • Shoreline habitat restoration and protection • Fireworks use and impacts to the lake • Noise and light pollution • Fishing regulations and overfishing • Minimizing disturbance to spawning fish • Recreational use of the lakes
Action Steps:	
	See description above.

<u>Management Action:</u>	Continue FMSL involvement with other entities that have responsibilities in managing Mirror and Shadow lakes
Timeframe:	Continuation of current efforts
Facilitator:	FMSL Board & WILPRD
Description:	The purpose of the FMSL is to promote the health of Mirror and Shadow lakes. The waters of Wisconsin belong to everyone and therefore this goal of protecting and enhancing these shared resources is also held by other entities. Some of these entities are governmental while others organizations rely on voluntary participation. It is important that the FMSL actively engage with all management entities to enhance the understanding of common management goals and to participate in the development of those goals. This also helps all management entities understand the actions that others are taking to reduce the duplication of efforts. Each entity will be specifically addressed in the table on the next page:
Action Steps:	
	See table guidelines on the next pages.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
City of Waupaca	Staff Parks & Recreation Director 715-258-4435	Partners the FMSL and WILPRD with the City of Waupaca.	As needed.	Provides a link between City and local organizations.
Golden Sands Resource Conservation & Development Council	Staff (715.343.6215)	Nonprofit organization that covers central WI	Once a year, or more as issues arise.	Provide information on conservation and natural resource preservation
Waupaca County Land & Water Conservation Department	County Conservationist (Brian Haase) – 715-258-6482)	Oversees conservation efforts for land and water projects.	Twice a year or more as needed.	Can provide assistance with shoreland restorations and habitat improvements.
Wisconsin Department of Natural Resources	Aaron O'Connell Fisheries Biologist https://dnr.wisconsin.gov/topic/Fishing/people/fisheriesbiologists.html	Manages the fishery of Mirror and Shadow lakes	Once a year, or more as issues arise.	Stocking activities, scheduled surveys, survey results, coarse woody habitat enhancement activities, volunteer opportunities for improving fishery.
	Lakes Coordinator (Ted Johnson – 920.362.0181)	Oversees management plans, grants, all lake activities.	Continuous as it relates to lake management activities	Information on updating a lake management plan (every 5 years) or to seek advice on other lake issues including AIS management.
	Citizens Lake Monitoring Network contact (Ted Johnson – 920.362.0181)	Provides training and assistance on CLMN monitoring, methods, and data entry.	Twice a year or more as needed.	Late winter: arrange for training as needed, in addition to planning out monitoring for the open water season. Late fall: report monitoring activities.
Wisconsin Lakes	General staff (800.542.5253)	Facilitates education, networking and assistance on all matters involving WI lakes.	As needed. May check website (www.wisconsinlakes.org) often for updates.	FMSL members may attend WL's annual conference to keep up-to-date on lake issues. WL reps can assist on grant issues, AIS training, habitat enhancement techniques, etc.

Management Goal 5: Minimize the negative impacts caused by Aquatic Invasive Species in the Mirror and Shadow Lakes ecosystem.

Management Action:	Monitor curly-leaf pondweed population.
Timeframe:	Every 3 years
Facilitator:	FMSL Board & WILPRD
Description:	Curly-leaf pondweed has been present in Mirror and Shadow lakes since at least 2011. A professional mapping survey conducted during June 2020 found several colonized areas of CLP in the system mainly of low to moderate densities (Figure 3.4-18). Local observations by riparian owners suggested that the population has expanded in recent years. At current levels, CLP is likely imparting some localized and seasonal impacts to navigability and recreational use of the lakes. The FMSL will seek funding assistance from the Lakes District to contract for a professional CLP mapping survey every three years, with the next survey tentatively planned to occur in 2023. This level of monitoring will aid in determining whether the population is expanding to cause significant issues on the lakes that may require consideration for conducting active management. The FMSL will encourage the continuation of a current volunteer effort of having riparian property owners conduct localized CLP hand pulling efforts in individual use areas including around private piers.
Action Steps:	
	See description above.

Management Action:	Monitor Eurasian watermilfoil population and conduct coordinated hand harvesting management efforts.
Timeframe:	Annually
Possible Grant	WDNR Surface Water AIS Grant
Facilitator:	FMSL Board & WILPRD
Description:	Eurasian watermilfoil has been present in Mirror and Shadow lakes since at least 2011. Since discovery, the EWM has been effectively managed at a low population through a hand harvesting effort conducted in partnership with Golden Sands RC&D. Professional EWM mapping surveys conducted in 2020 indicated that the population was relatively sparse in the system, mostly consisting of isolated occurrences. The FMSL and WILPRD will continue this partnership through annual monitoring by Golden Sands staff and potentially the Waupaca County Land and Water Department. Further, volunteer members of the FMSL

	will periodically monitor the lakes for EWM and inform resource managers of their findings. The WILPRD/City of Waupaca may also consider applying for a WDNR AIS grant in order to provide funding assistance towards a coordinated EWM hand harvesting program that utilizes paid professional harvesting. Having a recent and approved management plan will allow the group to be eligible to apply for AIS grants.
Action Steps:	
	See description above.

<u>Management Action:</u>	Promote Pale Yellow Iris and Purple Loosestrife control efforts.
Timeframe:	Annually
Facilitator:	FMSL Board & WILPRD
Description:	Efforts to control pale yellow iris and purple loosestrife around Mirror and Shadow lakes and have included cutting seed heads/flowering stalks and employing loosestrife weevils. Monitoring surveys conducted in 2020 documented the continued presence of these species around the fringes of both Mirror and Shadow lakes (Figure 3.4-19). Local observations suggests that the population in 2020 of these species was lower than it had been in the past – likely as a result of the management efforts that have taken place. The FMSL and WILPRD will provide educational materials, resources, and information to lake property owners including information related to nursery replacement options for property owners to consider to replace non-native species with native species. The FMSL & WILPRD will investigate avenues for conducting these efforts via local volunteers, City of Waupaca staff, or Golden Sands staff.
Action Steps:	
	See description above.

<u>Management Action:</u>	Investigate monitoring and control actions for reed canary grass and narrow-leaf cattail.
Timeframe:	Annually
Facilitator:	FMSL Board & WILPRD
Description:	Narrow-leaf cattail and reed canary grass have been documented along the margins of the lakes. The FMSL/WILPRD would like to increase awareness of these species through education and outreach. The FMSL/WILPRD will provide educational materials, resources, and information to lake property owners. The FMSL/WILPRD will investigate avenues for conducting monitoring and control efforts via local volunteers, City of Waupaca staff, or Golden Sands staff.

Action Steps:	
	See description above.

<u>Management Action:</u>	Monitor Mirror and Shadow Lake entry points for Aquatic Invasive Species
Timeframe:	Initiate 2023
Facilitator:	FMSL Board & WILPRD
Description:	Mirror and Shadow lakes are a popular regional destination by recreationists and beachgoers, making the lake vulnerable to new infestations of exotic species such as starry stonewort (*Nitellopsis obtusa*). The intent of a watercraft inspection program would not only be to prevent additional invasive species from entering the lake through its public access point, but also to prevent the infestation of other waterways with invasive species that originated in Mirror and Shadow lakes. The goal would be to cover the primary boat landing during the busiest times in order to maximize contact with lake users, spreading the word about the negative impacts of AIS on lakes and educating people about how they are the primary vector of its spread. The FMSL have participated in the WDNR's Clean Boats Clean Waters (CBCW) program in the past (2011-2013) through a partnership with Golden Sands RC&D. The FMSL/WILPRD will seek to participate in this program once again. The CBCW program is funded by non-competitive WDNR grants that provide funding to eligible sponsors. Eligible costs include payment to inspectors, administrative time entering data into SWIMS, time spent attending CBCW workshops or trainings, and CBCW clothing and supplies. Detailed information about the CBCW program is available on the WDNR's website: https://dnr.wisconsin.gov/topic/lakes/cbcw
Action Steps:	
1	Contact Environmental Grants Specialist to determine eligibility of the FMSL/WILPRD to apply for a WDNR Surface Water Grant for the CBCW program. Partnering with the City of Waupaca or another organization may be necessary to ensure eligibility.
2	Apply for a CBCW grant during the fall 2022 cycle. Grant intent notification to WDNR staff is due 60 days prior (September 2) to the grant deadline of November 1.
3	Implement the CBCW program during 2023 and beyond as resources allow.

Management Goal 6: Explore methods to improve navigability through the channel connecting Mirror and Shadow Lakes

Management Action:	Investigate options including dredging and/or harvesting of aquatic plants within the channel connecting Mirror and Shadow lakes
Timeframe:	Beginning 2022
Facilitator:	WILPRD
Description:	Mirror and Shadow lakes are connected by a channel that is approximately 30' wide and 520' long. Water depths within the channel are relatively shallow ranging from approximately 1-3' deep. Native white-water lilies and yellow lilies grow at the water's surface throughout most of the channel which limits navigability, particularly into the mid and late-summer portions of the growing season. In an effort to improve navigability through the channel, the removal of aquatic plant biomass could be explored. A WDNR permit is required to harvest native aquatic plants in Wisconsin waterbodies. Professional contracting companies offer services including the harvesting, cutting, and removal of aquatic vegetation from lakes. If applied in this setting, multiple harvesting events on an annual basis may be necessary to maintain navigability as aquatic plants continue to grow throughout the summer months and re-establish within previously cleared areas. Pioneer species such as Eurasian watermilfoil, are those that favor disturbed sites such as a newly cleared area of a lake and are often some of the first plants to establish in the site. The removal of aquatic plant material from the channel may provide sufficient access between Mirror and Shadow lakes without the need for the removal of sediment via dredging. However, in the absence of aquatic plants, water depth will limit the size of watercraft that is able to navigate the channel. Aside from the removal of aquatic plants from the channel, navigability may be improved by increasing the water depth through the removal of bottom sediment through dredging. WDNR permitting of dredging projects is a complex process that may entail conducting a sediment study to evaluate for pollutants in the project area. An engineering design may be needed to satisfy WDNR permit conditions. Costs for dredging projects can become cost prohibitive in many instances depending on the scale of the project. In this setting, a rough estimate to dredge a 10' wide area spanning the length of the channel two feet deeper may cost less than $8,000 (not including permitting and engineering fees) and thus be economically feasible. WDNR grant funds are not available for use in dredging projects. It can be anticipated that even with dredging the channel a few feet deeper than it is currently,

	aquatic plants are likely to re-establish within the channel and may still inhibit navigability to some degree.
Action Steps:	
1.	Determine the size of watercraft the lake group would like to be able to navigate through the channel.
2.	Contact professional contractors that offer services related to the mechanical harvesting and removal of aquatic plants, or dredging services.
3.	Communicate with WDNR regulators to understand any permitting requirements.

6.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in Mirror and Shadow lakes (e.g., elevated phosphorus levels, anaerobic conditions, etc.). Water quality was monitored at the deepest point on the lakes that would most accurately depict the conditions of each lake. Samples were collected using WDNR Citizen Lake Monitoring Network (CLMN) protocols which occurred twice during the summer. In addition to the samples collected by CLMN volunteers, professional water quality samples were collected at subsurface (S) and near bottom (B) depths once in summer and winter. Winter dissolved oxygen was determined with a calibrated probe and all samples were collected with a 3-liter Van Dorn bottle. Secchi disk transparency was also included during each visit.

All samples that required laboratory analysis were processed through the Wisconsin State Laboratory of Hygiene (WSLH). The parameters measured, sample collection timing, and designated collector are contained in the table below.

	Spring		June	July		August	Winter	
Parameter	**S**	**B**	**S**	**S**	**B**	**S**	**S**	**B**
Total Phosphorus	♦		♦	♦■	■	♦	■	■
Dissolved Phosphorus							■	■
Chlorophyll-*a*			♦	♦■		♦		
Total Nitrogen				■			■	■
True Color				■				
Laboratory Conductivity				■	■			
Laboratory pH				■	■			
Total Alkalinity				■	■			

♦ Indicates samples collected as a part of the Citizen Lake Monitoring Network.
■ Indicates samples collected by consultant under proposed project.

Watershed Analysis

The watershed analysis began with an accurate delineation of Mirror and Shadow lakes' drainage areas using U.S.G.S. topographic survey maps and base GIS data from the WDNR. The watershed delineation was then transferred to a Geographic Information System (GIS). These data, along with land cover data from the National Land Cover Database (USGS 2019) were then combined to determine the watershed land cover classifications. These data were modeled using the WDNR's Wisconsin Lake Modeling Suite (WiLMS) (Panuska and Kreider 2003).

Aquatic Vegetation

Curly-leaf Pondweed Survey

Surveys of curly-leaf pondweed were completed on Mirror and Shadow lakes during a June 3, 2020 field visit, in order to correspond with the anticipated peak growth of the plant. Visual inspections were completed throughout the lake by completing a meander survey by boat.

Comprehensive Macrophyte Surveys

Comprehensive surveys of aquatic macrophytes were conducted on Mirror and Shadow lakes to characterize the existing communities within the lake and include inventories of emergent, submergent, and floating-leaved aquatic plants within them. The point-intercept method as described in the Wisconsin Department of Natural Resource document, Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry, and Analysis, and Applications (WDNR PUB-SS-1068 2010) was used to complete this study on July 29-30, 2020 (Hauxwell et al. 2010). A point spacing of 31 meters was used for Shadow Lake, resulting in 185 points. A point spacing of 15 meters was used for Mirror Lake, resulting in 244 points.

Community Mapping

During the species inventory work, the aquatic vegetation community types within Mirror and Shadow lakes (emergent and floating-leaved vegetation) were mapped using a Trimble Pro6T Global Positioning System (GPS) with sub-meter accuracy. Furthermore, all species found during the point-intercept surveys and the community mapping surveys were recorded to provide a complete species list for the lake.

Representatives of any plant species located during the point-intercept and community mapping survey that were not recorded during previous surveys on the lakes were collected, vouchered, and sent to the University of Wisconsin – Steven's Point Herbarium.

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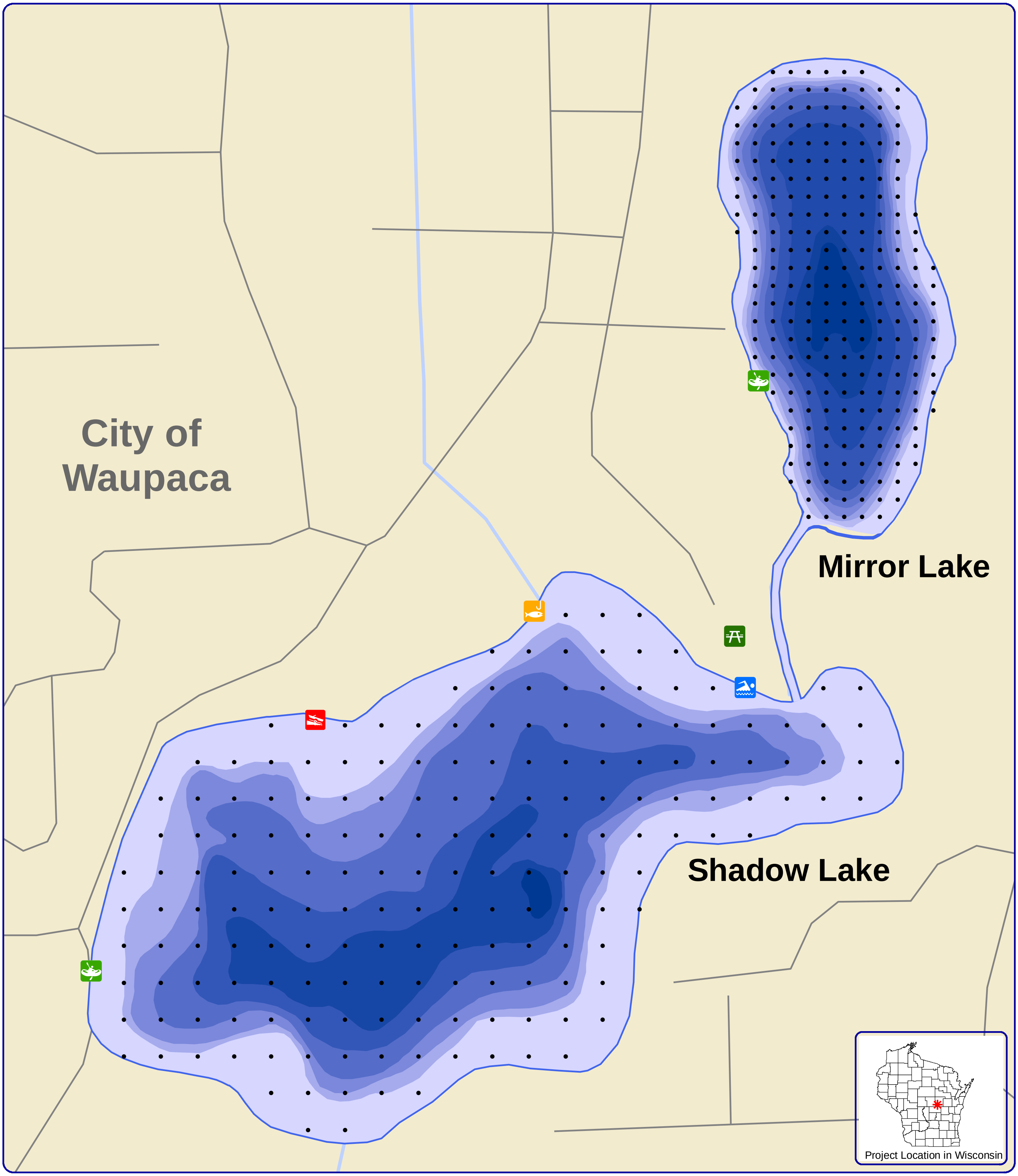


N
W E
S

340
Feet

Legend

Mirror ~ 14 acres
Shadow ~ 44 acres
DNR Definition

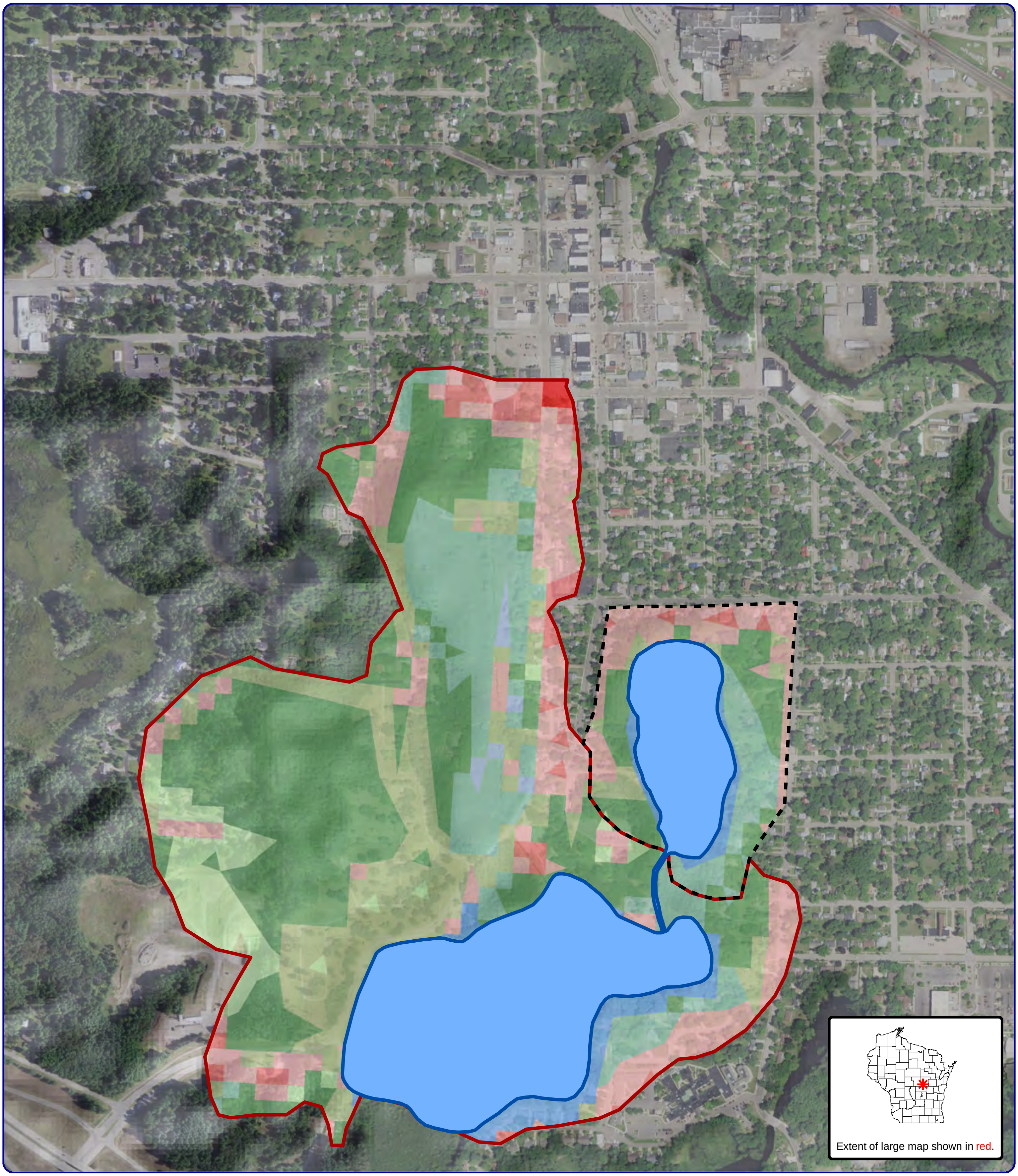
Point-intercept Sample Location
Mirror- 15 meter spacing,
Shadow- 31 meter spacing

Boat Launch
Swimming Beach
Carry-In Access
Fishing Pier
Public Park
City of Waupaca

Onterra LLC
Lake Management Planning
815 Prosper Rd
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources
Roads and Hydro: WDNR
Map Date: December 5, 2019 AMS
Filename: *Mirrow-Shadow-Waupaca_Location.mxd*

Map 1
Mirror &
Shadow Lakes
Waupaca County, Wisconsin
Project Location &
Lake Boundaries



N
W E
S

1,400

Feet

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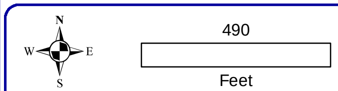
Sources:
Hydro: WDNR
Bathymetry: WDNR
Orthophotography: NAIP 2020
Land Cover: NLCD, 2016
Watershed Boundaries: Onterra, 2021
Map Date: May 4, 2021 JMB
File Name: Map2_Mirror-Shadow_WS.mxd

Legend

- Forest
- Forested Wetlands
- Pasture/Grass
- Open Water
- Wetland
- Mirror Direct Watershed Boundary
- Row Crop Agriculture
- Rural Open Space
- Rural Residential
- Urban - High Density
- Urban - Medium Density
- Shadow Lake Entire Watershed Boundary

Map 2
Mirror and Shadow Lakes
Waupaca, Wisconsin

Watershed Boundaries & Land Cover Types



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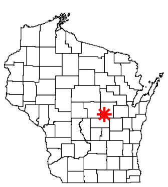
Sources
Hydro: WDNR
CWH Survey: Onterra, 2020
Orthophotography: NAIP, 2018
Map date: December 15, 2020 AMS



Project Location in Wisconsin

Legend

81 - 100
61 - 80
41 - 60
21 - 40
0 - 20

Local Road
Shoreland Parcels

Map 3
Mirror-Shadow Lake
Shadow Lake, Wisconsin

2020 Parcel Canopy Cover

Onterra LLC
Lake Management Planning
815 Prosper Rd
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources
Hydro: WDNR
CWH Survey: Onterra, 2020
Orthophotography: NAIP, 2018
Map date: December 15, 2020 AMS

Map 4
Mirror-Shadow Lake
Shadow Lake, Wisconsin

2020 Parcel Shrub-Herbaceous Cover

N
W E
S

490

Feet

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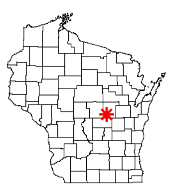
Sources
Hydro: WDNR
CWH Survey: Onterra, 2020
Orthophotography: NAIP, 2018
Map date: December 15, 2020 AMS



Project Location in Wisconsin

Legend

- 81 - 100
- 61 - 80
- 41 - 60
- 21 - 40
- 0 - 20
- Local Road
- Shoreland Parcels

Map 5
Mirror-Shadow Lake
Shadow Lake, Wisconsin
2020 Parcel Manicured Lawn


N
W
E
S
490
Feet
Onterra LLC
Lake Management Planning
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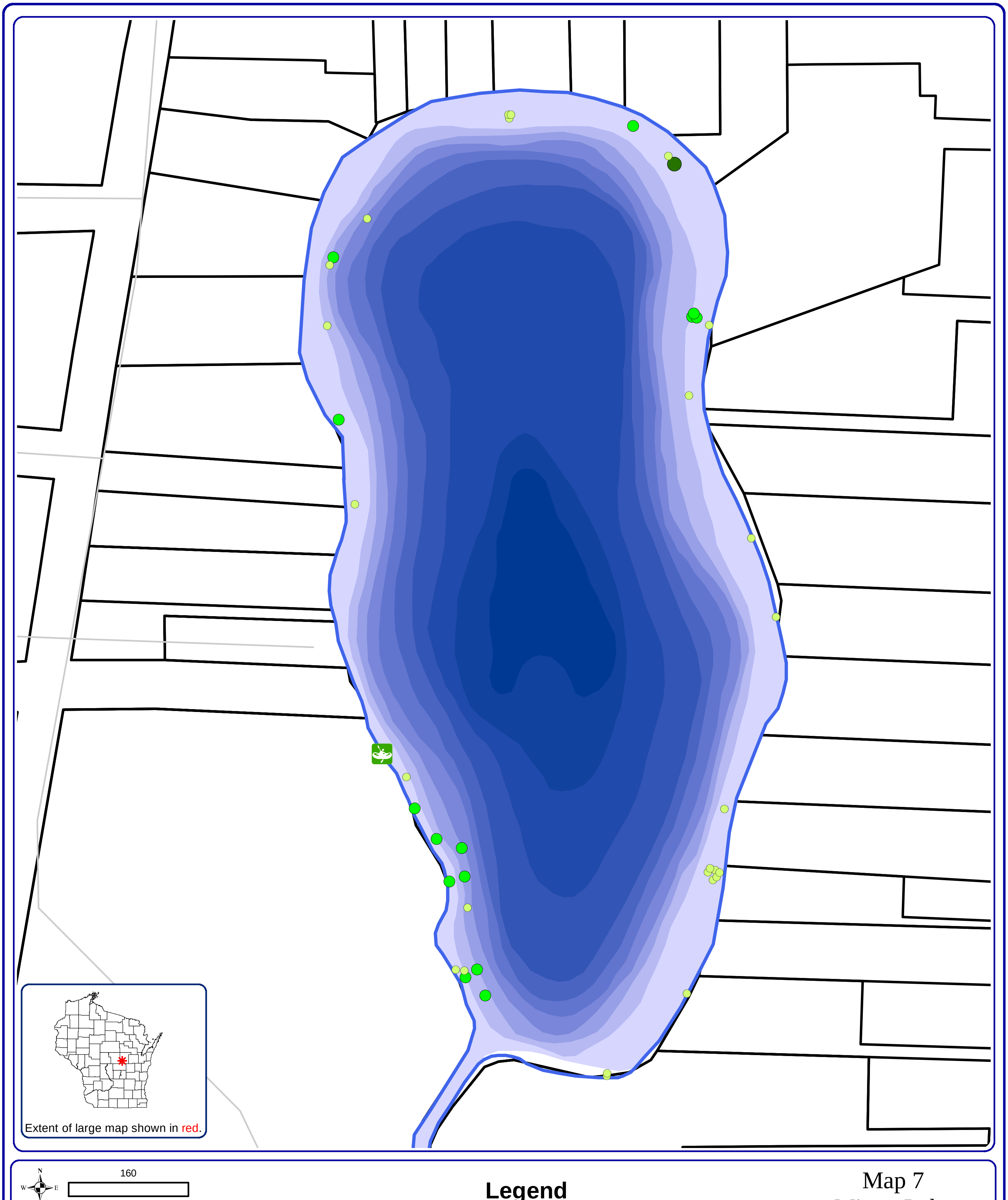
Sources
Hydro: WDNR
CWH Survey: Onterra, 2020
Orthophotography: NAIP, 2018
Map date: December 15, 2020 AMS
Project Location in Wisconsin
Legend
81 - 100
61 - 80
41 - 60
21 - 40
0 - 20
Local Road
Shoreland Parcels
Map 6
Mirror-Shadow Lake
Shadow Lake, Wisconsin
2020 Parcel
Impervious Surfaces



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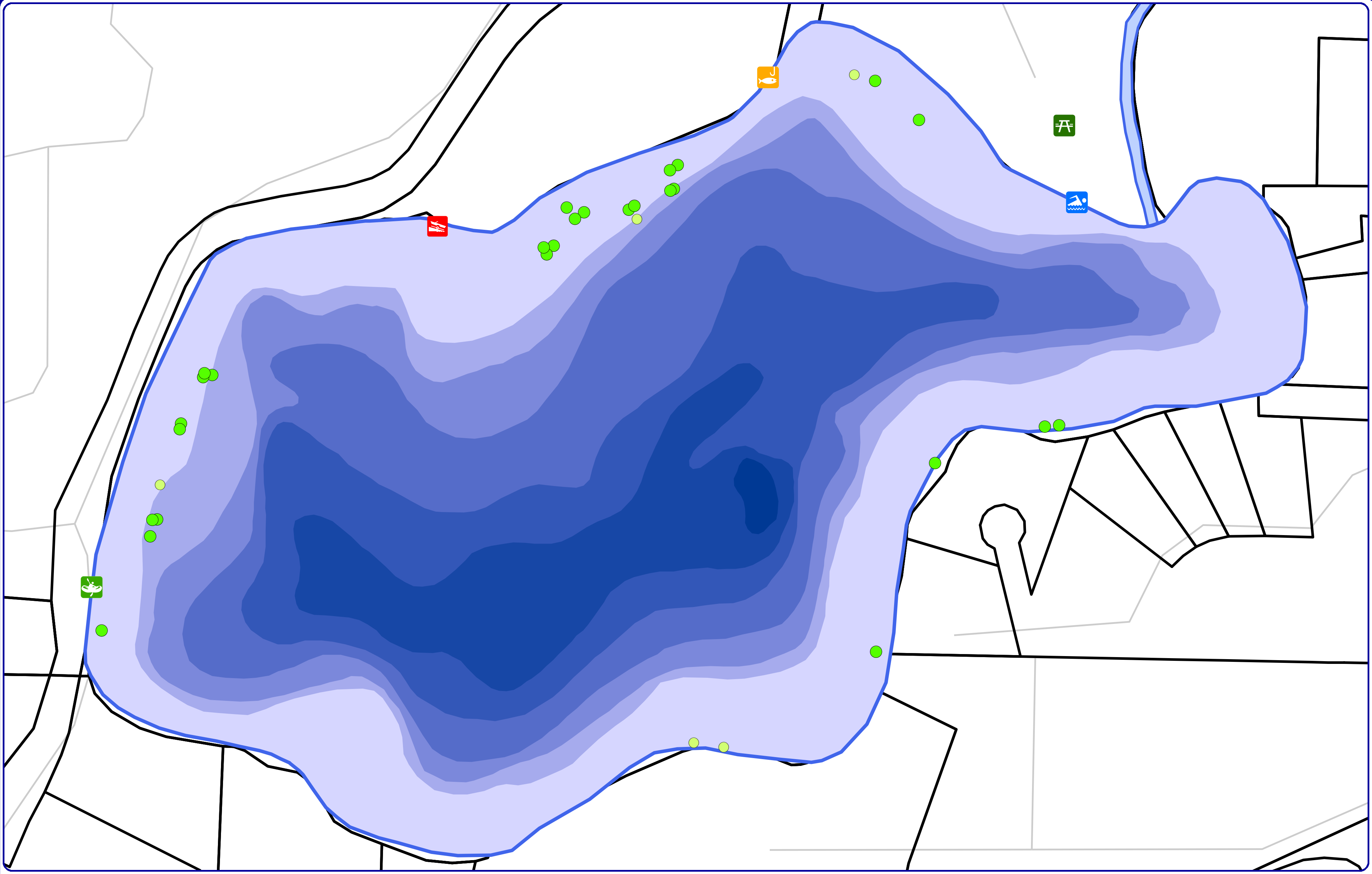
Sources
Hydro: WDNR
CWH Survey: Onterra, 2020
Orthophotography: NAIP, 2018
Map date: December 10, 2020 AMS
Filename: Insert Filename.mxd

Map 7
Mirror Lake
Waupaca County, Wisconsin

Coarse Woody Habitat



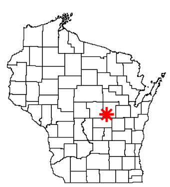
N W E S

240

Feet

Onterra LLC
Lake Management Planning
815 Prosper Rd
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources
Hydro: WDNR
CWH Survey: Onterra, 2020
Orthophotography: NAIP, 2018
Map date: December 10, 2020 AMS



Project Location in Wisconsin

Legend

- No Branches
- Some Branches
- Full Canopy
- Local Road
- Shoreland Parcels

Map 8

Shadow Lake

Waupaca County, Wisconsin

Coarse Woody Habitat

N
W E
S
150
Feet

Onterra LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
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Sources
Hydro: WDNR
Aquatic Plants: Onterra, 2020
Orthophotography: NAIP, 2018
Map date: December 10, 2020 AMS

Legend

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Exotics
- Purple Loosestrife
- Purple Loosestrife Colony

Map 9
Mirror Lake
Waupaca County, Wisconsin

2020 Emergent & Floating-Leaf Communities

Mirror Lake 2020 Emergent & Floating-Leaf Plant Species

Corresponding Community Polygons and Points are displayed on Mirror Lake- Map 9

Large Plant Community (Polygons)									
Emergent	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**	**Acres**
D	**Misc. Wetland Species**	**Cattail sp.**	**Bristly sedge**						0.55
E	**Reed canary grass**	**Misc. Wetland Species**	**Bristly sedge**	**Iris sp.**					0.08
F	**Purple loosestrife**								0.10
G	**Misc. Wetland Species**	**Cattail sp.**	**Hardstem bulrush**	**Common arrowhead**					0.09
I	**Misc. Wetland Species**								0.10
Floating-leaf	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**	**Acres**
J	**White water lily**								0.23
K	**White water lily**	**Spatterdock**							0.75
Floating-leaf & Emergent	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**	**Acres**
M	**White water lily**	**Misc. Wetland Species**	**Common arrowhead**	**Spatterdock**	Iris sp.	Reed canary grass			0.42
N	**White water lily**	**Misc. Wetland Species**	**Cattail sp.**	**Common arrowhead**	Iris sp.				0.31

Small Plant Community (Points)								
Emergent	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**
3	**Purple loosestrife**	**Cattail sp.**	**Softstem bulrush**	**Common arrowhead**				
4	**Common arrowhead**	**Bristly sedge**						
5	**Narrow-leaved cattail**	**Broad-leaved cattail**	**Iris sp.**					
6	**Iris sp.**	**Softstem bulrush**						
7	**Cattail sp.**	**Iris sp.**						
9	**Purple loosestrife**							
Floating-leaf	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**
14	**White water lily**							

Species are listed in order of dominance within the community; Scientifc names can be found in the species list in Table 3.4-1

N
W E
S

240
Feet

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Sources
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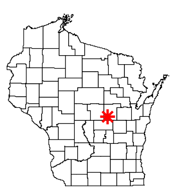

Project Location in Wisconsin

Legend

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Exotics
- Purple Loosestrife
- Reed Canary Grass

Map 10
Shadow Lake
Waupaca County, Wisconsin

2020 Emergent & Floating-Leaf Communities

Shadow Lake 2020 Emergent & Floating-Leaf Plant Species

Corresponding Community Polygons and Points are displayed on Shadow Lake - Map 10

Large Plant Community (Polygons)									
Emergent	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**	**Acres**
A	**Cattail sp.**								0.28
B	**Reed canary grass**	**Misc. Wetland Species**							0.16
C	**Misc. Wetland Species**	**Cattail sp.**	**Iris sp.**						0.15
H	**Misc. Wetland Species**	**Cattail sp.**							0.63
I	**Misc. Wetland Species**								0.75
Floating-leaf	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**	**Acres**
J	**White water lily**								0.30
K	**White water lily**	**Spatterdock**							5.60
L	**White water lily**	Spatterdock							2.70

Small Plant Community (Points)								
Emergent	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**
1	**Common bur-reed**	**Softstem bulrush**						
2	**Reed canary grass**							
8	**Cattail sp.**							
9	**Purple loosestrife**							
10	**Softstem bulrush**	**Iris sp.**	**Cattail sp.**					
11	**Common bur-reed**							
12	**Softstem bulrush**							
13	**Hardstem bulrush**							
Floating-leaf	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Species 7**	**Species 8**
14	**White water lily**							

Bold *species are dominant within the community; Scientifc names can be found in the species list in Table 3.4-1*