Silver Lake

Waushara County, Wisconsin

Comprehensive Lake Management Plan

November 2023

Sponsored by:

Silver Lake Management District

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Onterra, LLC
Lake Management Planning

Silver Lake

Waushara County, Wisconsin

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

Silver Lake Planning Committee

Greg Barczak	Jim Morgenroth
Mark Magnusson – AIS Chair	Todd Chesbro
Barbara Bartel	

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1.0 INTRODUCTION

At the time of this report, the most current orthophoto (aerial photograph) was from the *National Agriculture Imagery Program* (NAIP) collected in 2022. Based on heads-up digitizing of the water level from that photo, the lake was determined to be 351.7 acres. Silver Lake, Waushara County, is a seepage lake with a maximum depth of 50 feet and a mean depth of 21 feet. This mesotrophic lake has a relatively small watershed when compared to the size of the lake (6:1).

The Geographic Names Information System (GNIS) is the Federal and national standard for geographic nomenclature. Sometimes locally referred to as Big Silver Lake, the GNIS officially calls this waterbody Silver Lake. Interestingly, the 1878 Historical Atlas of Wisconsin labeled this lake as *Wolf Lake*.

When water levels are above full pool (>867.61 NGVD29), water exchange occurs with Irogami Lake via a culvert under State Hwy 21 (Figure 1.0-1). In 1993, FEMA created an emergency high-water weir from Irogami Lake to a marsh complex that leads to Bruce Creek. A culvert under 20th Street further assisted with surface connection of Irogami Lake to the recently impounded Alpine Lake (in 1970).

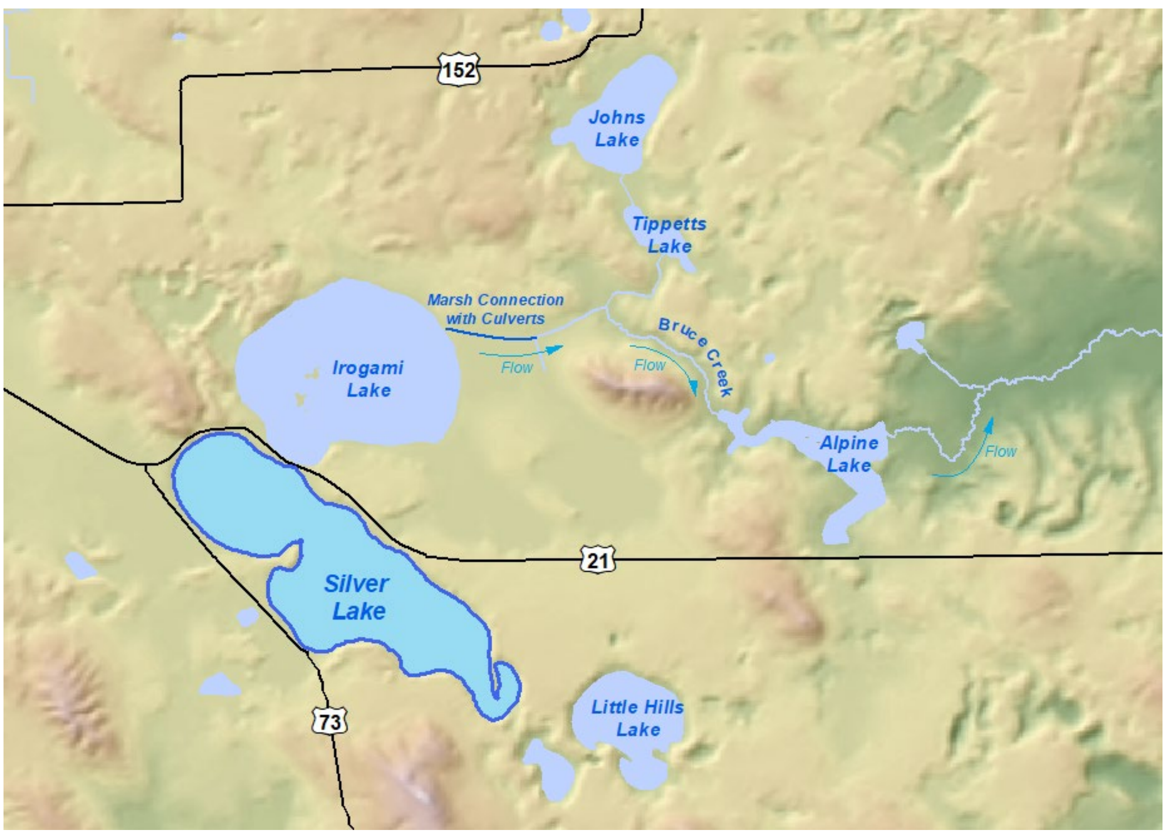

Figure 1.0-1 Silver Lake, Waushara County.

Four exotic species are known to exist in Silver Lake: banded mystery snail, curly-leaf pondweed (*Potamogeton crispus,* CLP), Eurasian watermilfoil (*Myriophyllum* spicatum, EWM), and zebra mussels. Genetic analysis confirms that the invasive milfoil population is comprised of both EWM and hybrid water milfoil (*M. spicatum x sibiricum*, HWM). Subsequent discussions using "HWM" will represent the collective invasive milfoil population of Silver Lake unless specifically referenced otherwise.

The Silver Lake Management District (SLMD) is the local citizen-based organization leading the management of Silver Lake. The group has worked for years to protect and enhance the lake, including an increased effort in recent years to control HWM within the lake. The SMLD created a Lake Management Plan through a cooperative project with Waushara County and UWSP (April 2017). The SLMD was worked with Onterra annually to develop a specific control plan and updated HWM management vision that is supported by the Lake Management Plan.

Starting in 2022, the SLMD began the process of updating their *Comprehensive Management Plan* without the aid of grant funds. This endeavor would result in a holistic investigation of Silver Lake's water quality, watershed, shoreland condition, aquatic plants, invasives species, fisheries, and stakeholder perceptions. The lessons learned as part of the project assisted with the modification of HWM management goals and actions moving forward.

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, the completion of a stakeholder survey, and updates within the district.

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

2.1 Strategic Planning Committee Level Meetings

Planning committee meetings, similar to general public meetings, were used to gather comments, create management goals and actions and to deliver study results. These two meetings were open only to the planning committee and were held during the week. The first, following the completion of the draft report sections of the management plan. The planning committee members were supplied with the draft report sections prior to the meeting and much of the meeting time was utilized to detail the results, discuss the conclusions and initial recommendations, and answer committee questions. The objective of the first meeting was to fortify a solid understanding of their lake among the committee members. The second planning committee meeting was held a few weeks after the first and concentrated on the development of management goals and actions that make up the framework of the implementation plan.

Planning Committee Meeting I

On March 28, 2023, Eddie Heath of Onterra met with five members of the Silver Lake Planning Committee for 3.5 hours. In advance of the meeting, attendees were provided an early draft of the study report sections (1.0-3.6) to facilitate better discussion. The primary focus of this meeting was the delivery of the study results and conclusions to the committee. All study components including Eurasian watermilfoil treatment results, aquatic plant inventories, water quality analysis, and watershed modeling were presented and discussed. Many topics were discussed by the committee, including enhancing organizational function, managing EWM, educational initiatives, and water levels.

Planning Committee Meeting II

On May 3, 2023, Eddie Heath again met with the five-member Planning Committee to discuss the stakeholder survey results and begin developing management goals and actions for the Silver Lake management plan. This also included detailed discussion of aquatic plant management alternatives, herbicide risk assessment, and evolution of regulatory perspectives on EWM population level management.

2.2 Management Plan Review and Adoption Process

On June 28, 2023, the Official First Draft of the SLMD's Comprehensive Lake Management Plan for Silver Lake was supplied to WDNR (lakes and fisheries programs and Waushara County by Onterra via email. At that time, the Official First Draft was made available for public review on an Onterra-hosted website and advertised as an official comment period through a combination of SLMD outreach events which included multiple email blasts to district members. The public comment period remained active until Ted Johnson approved the management plan on September 1, 2023. No additional public or agency comments were received.

2.3 Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to all Silver Lake Management District Members. The survey was designed by Onterra staff and the Silver Lake Management District (SLMD) planning committee and reviewed by a WDNR social scientist. During March and April of 2022, the nine-page, 35-question survey was posted online through Survey Monkey for survey-takers to answer electronically. Stakeholders were invited to participate in the survey via a mailed postcard or email containing information on how to participate. If requested, a hard copy was sent with a self-addressed stamped envelope for returning the survey anonymously. The returned hardcopy surveys were entered into the online version by a Silver Lake Management District volunteer for analysis.

Of the 290 surveys distributed, 196 (68%) of the surveys were completed. In instances where stakeholder survey response rates are 60% or above, the results can generally be interpreted as being a statistical representation of the entire population invited to participate in the survey.

The data were analyzed and summarized by Onterra for use at the planning meetings and within the management plan. The full survey 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 Silver Lake. Approximately 68% of respondents have owned their lake property for over 10 years (Figure 2.3-1).

Question 2: How many years have you owned or rented your property on or near Silver Lake?

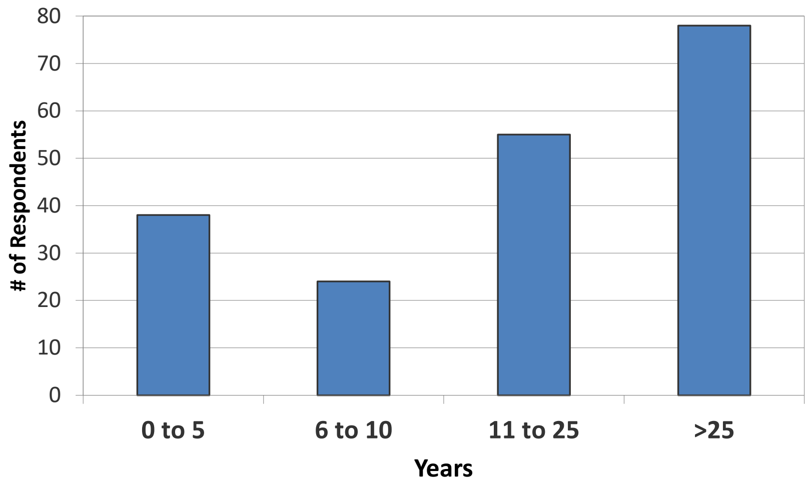

Figure 2.3-1. Select survey responses from the SLMD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Approximately 18% of stakeholder respondents use their property more than 300 days per year while 31% use their property one to three months out of the year (Figure 2.3-2).

Question 3: Considering the past three years, how many days each year is your property used by you or others?

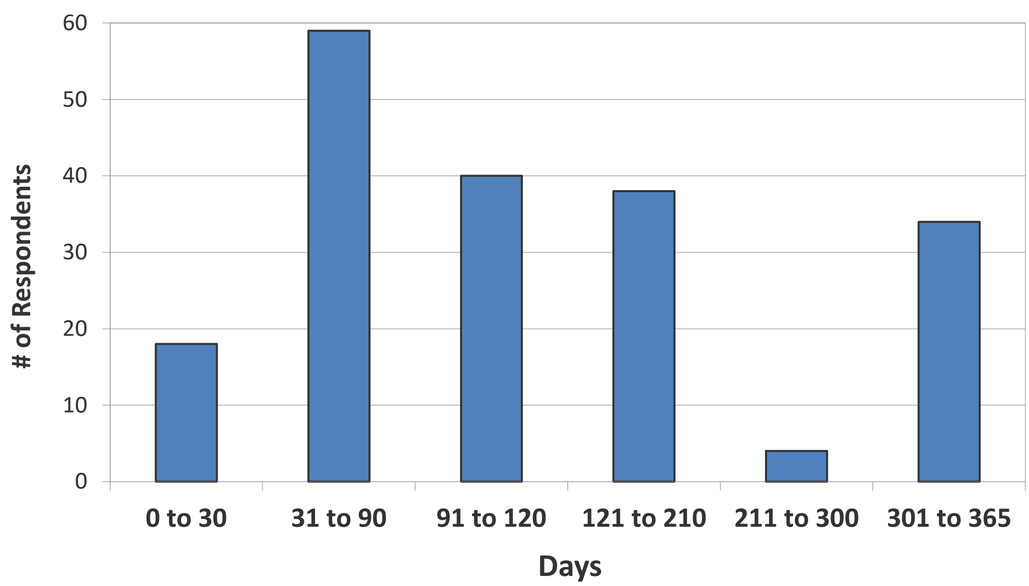

Figure 2.3-2. Select survey responses from the SLMD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Relaxing/entertaining was the highest ranked activities when riparians were asked why they own property on Silver Lake (Figure 2.3-3). Riparian respondents also ranked swimming, boating, and water skiing/tubing as top reasons they choose to be on the system.

Question 5: Please rank up to three activities that are important reasons for owning your property on or near Silver Lake, with the 1st being most important.

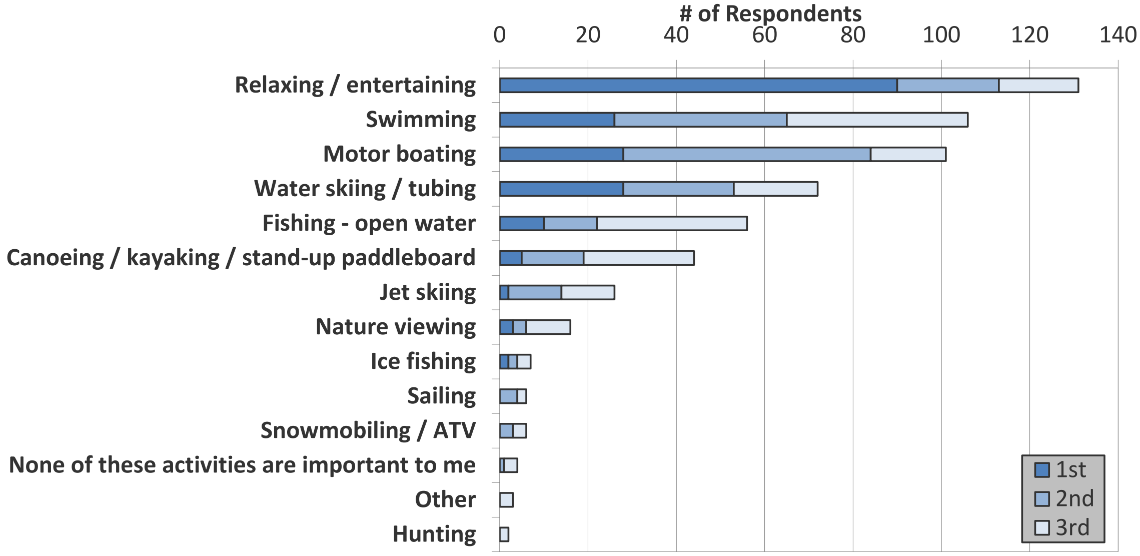

Figure 2.3-3. Select survey responses from the SLMD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Even though silent sports such as canoeing/kayaking/paddle boarding were ranked by respondents as the 6th highest activity on the lakes (Figure 2.3-3), 74% of respondents indicated they use that type of watercraft on the lakes (Figure 2.3-4). Approximately 60% of survey respondents indicated they use a pontoon boat and 49% indicated that they use a motor boat with greater than 25 hp motor.

Question 13: What types of watercraft do you currently use on Silver Lake?

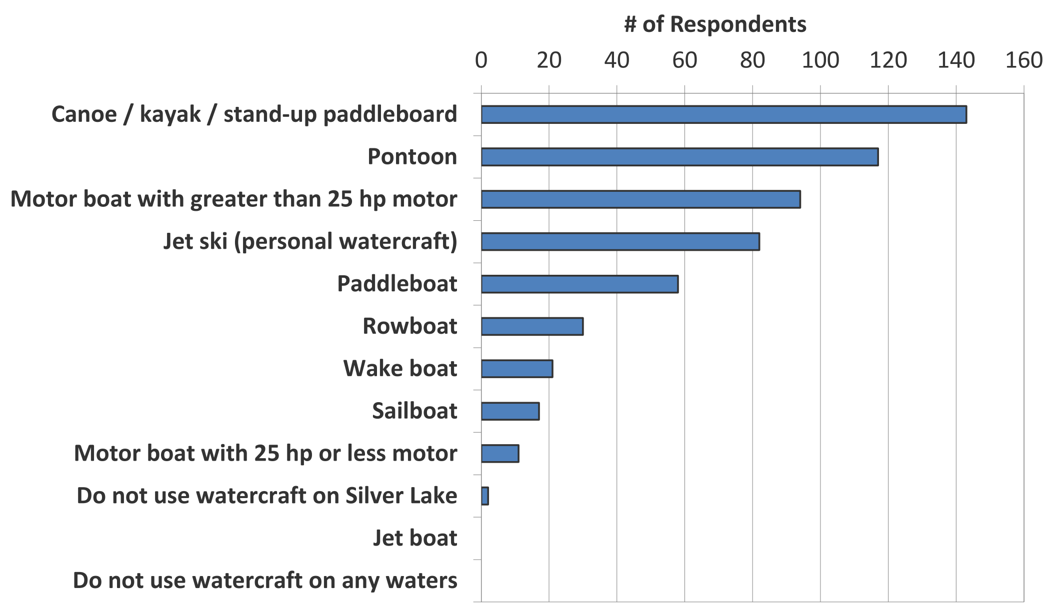

Figure 2.3-4. Select survey responses from the SLMD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

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 Silver Lake is compared to other lakes in the state with similar characteristics as well as to lakes within the northern region. In addition, 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 water quality parameters are focused upon in the Silver Lake water quality analysis:

Phosphorus is the nutrient that controls the growth of plants in the vast majority of Wisconsin lakes. It is important to remember that in lakes, the term "plants" includes both algae and macrophytes. 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 used 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.

The parameters described above are interrelated. 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. Every lake will naturally progress through these states and under natural conditions (i.e. not influenced by the activities of humans) this progress can take tens of thousands of years. Unfortunately, human influence has accelerated this natural aging process in many Wisconsin lakes. 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.

> Trophic states describe the lake's ability to produce plant matter (production) and include three continuous classifications: Oligotrophic lakes are the least productive lakes and are characterized by being deep, having cold water, and few plants. Eutrophic lakes are the most productive and normally have shallow depths, warm water, and high plant biomass. Mesotrophic lakes fall between these two categories.

However, through the use of a trophic state index (TSI), an index number can be calculated using phosphorus, chlorophyll-*a*, and clarity values that represent the lake's position within the eutrophication process. This allows for a more clear 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 macrophytes 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, he needs 16 of each ingredient. If he is short two eggs, he will only be able to make three cakes even if he has 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 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 gradients are developed with depth in a lake. During stratification the lake can be broken into three layers: The epilimnion is the top layer of water which is the warmest water in the summer months and the coolest water in the winter months. The hypolimnion is the bottom layer and contains the coolest water in the summer months and the warmest water in the winter months. The metalimnion, often called the thermocline, is the middle layer containing the steepest temperature gradient.

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 process that occur within a lake. Internal nutrient loading is an excellent example that is described below.

*Internal Nutrient Loading**

In lakes that support stratification, whether throughout the summer or periodically between mixing events, the hypolimnion can become devoid of oxygen both in the water column and within the sediment. When this occurs, iron changes from a form that normally binds phosphorus within the sediment to a form that releases it to the overlaying water. This can result in very high concentrations of phosphorus in the hypolimnion. Then, during turnover events, these high concentrations of phosphorus are mixed within the lake and utilized by algae and some macrophytes. In lakes that mix periodically during the summer (polymictic lakes), this cycle can *pump* phosphorus from the sediments into the water column throughout the growing season. In lakes that only mix during the spring and fall (dimictic lakes), this burst of phosphorus can support late-season algae blooms and even last through the winter to support early algal blooms the following spring. Further, anoxic conditions under the winter ice in both polymictic and dimictic lakes can add smaller loads of phosphorus to the water column during spring turnover that may support algae blooms long into the summer. This cycle continues year after year and is termed "internal phosphorus loading"; a phenomenon that can support nuisance algal blooms decades after external sources are controlled.

The first step in the analysis is determining if the lake is a candidate for significant internal phosphorus loading. Water quality data and watershed modeling are used to determine actual and predicted levels of phosphorus for the lake. When the predicted phosphorus level is well below the actual level, it may be an indication that the modeling is not accounting for all of the phosphorus sources entering the lake. Internal nutrient loading may be one of the additional contributors that may need to be assessed with further water quality analysis and possibly additional, more intense studies.

Non-Candidate Lakes

- Lakes that do not experience hypolimnetic anoxia.
- Lakes that do not stratify for significant periods (i.e. days or weeks at a time).
- Lakes with hypolimnetic total phosphorus values less than 200 µg/L.

Candidate Lakes

- Lakes with hypolimnetic total phosphorus concentrations exceeding 200 µg/L.
- Lakes with epilimnetic phosphorus concentrations that cannot be accounted for in watershed phosphorus load modeling.

Specific to the final bullet-point, during the watershed modeling assessment, the results of the modeled phosphorus loads are used to estimate in-lake phosphorus concentrations. If these estimates are much lower than those actually found in the lake, another source of phosphorus must be responsible for elevating the in-lake concentrations. Normally, two possibilities exist: 1) shoreland septic systems, and 2) internal phosphorus cycling. If the lake is considered a candidate for internal loading, modeling procedures are used to estimate that load.

Comparisons with Other Datasets

The WDNR document *Wisconsin 2020 Consolidated Assessment and Listing Methodology* (WDNR 2019) 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 Silver Lake will be compared to lakes in the state with similar physical characteristics. The WDNR groups Wisconsin's lakes into ten natural communities (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 and Lillie (Lathrop and 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.

Because of its depth, relatively small watershed, and hydrology, Silver Lake is classified as a deep seepage lake (class 7 on Figure 3.1-1).

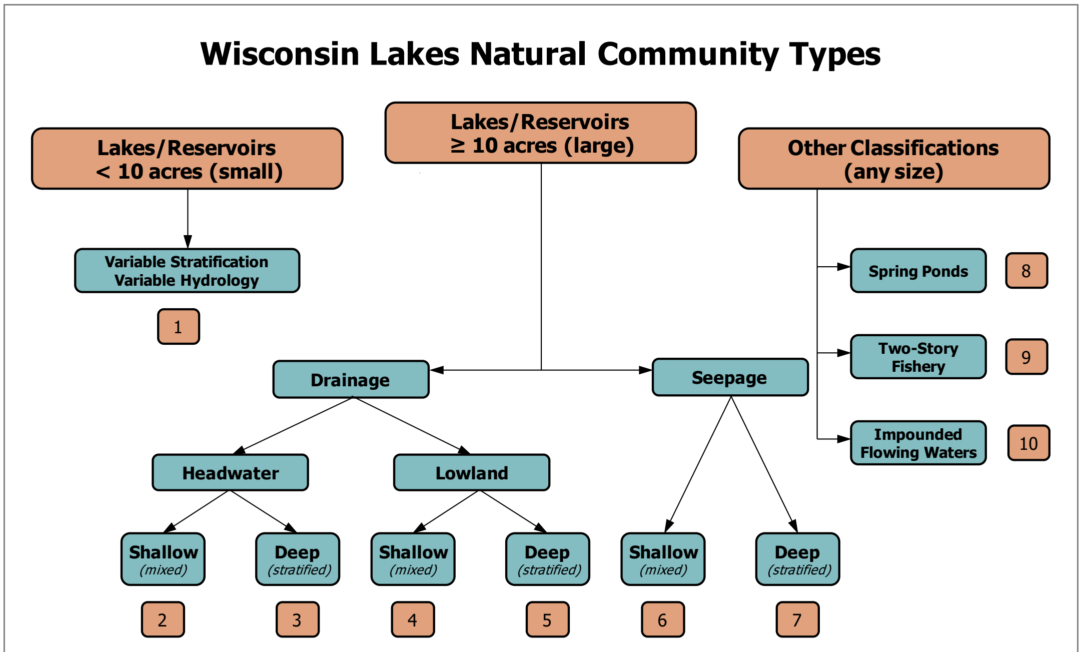

Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2017.

(Garrison, Jennings et al. 2008) developed statewide 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. Silver Lake is within the North Central Hardwood Forests ecoregion.

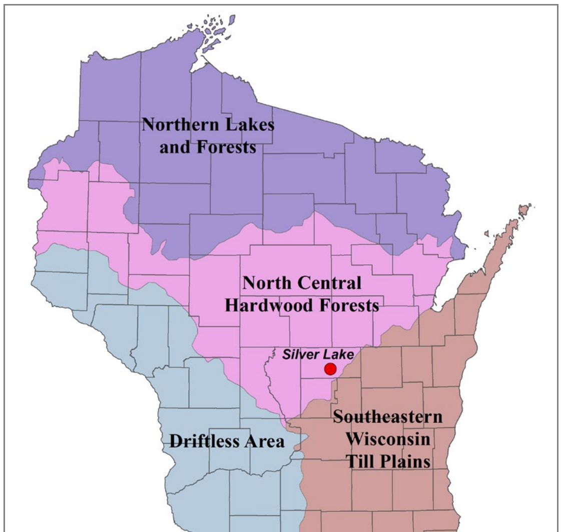

Figure 3.1-2. Location of Silver Lake within the ecoregions of Wisconsin. After Nichols 1999.

The Wisconsin 2020 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, historic, current, and average data from Silver Lake is displayed in Figures 3.1-3 - 3.1-6. Please note that the data in these graphs represent concentrations and depths taken only during the growing season (April-October) or summer months (June-August). Furthermore, the phosphorus and chlorophyll-*a* data represent only surface samples. Surface samples are used because they represent the depths at which algae grow and depths at which phosphorus levels are not greatly influenced by phosphorus being released from bottom sediments.

Silver Lake Water Quality Analysis

Silver Lake Long-term Trends

Silver Lake has two active water quality sampling stations; Station Number 703120 is located in the deepest area of the north basin, and Station 703018 is located in the deepest area of the south basin. The north basin has no recent water quality data and historical data limited to Secchi disk transparency from 2004-2007, and total phosphorus and chlorophyll-*a* from 2007. The south basin site, which is in the deepest part of Silver Lake, as a whole, has an excellent recent and historical dataset consisting of Secchi disk transparency, total phosphorus, chlorophyll-*a*, and other parameters stretching back to the early 2000s. There are also several years of temperature and dissolved oxygen profiles for the site. Therefore, the water quality discussion below is focused upon the data collected in the south basin. Typical limnological sampling includes collections from the deepest part of the lake in question because that is the location that the reflects the characteristics of the lake in general. So, water quality data from the south basin is considered an excellent representation of the entire lake.

Total phosphorus data for Silver Lake are shown in Figure 3.1-3. Growing season and summer month average concentrations fluctuate minorly over the years, but remain in the *Excellent* category throughout the dataset. These means are inline with the median value of other Deep Seepage Lakes in the state and well below all lake types in the North Central Hardwood Forest (NCHF)ecoregion. Seasonal variations in total phosphorus concentrations and other interesting water quality aspects of Silver Lake are discussed below.

As described in the Water Quality Data Analysis and Interpretation Section above, the level of free-floating algae (phytoplankton) in most Wisconsin lakes is controlled by phosphorus levels because phosphorus, as opposed to some other nutrient, like nitrogen, carbon, potassium, etc., is in the least supply and considered the limiting nutrient. The limiting nutrient in a lake can typically be determined by comparing midsummer concentrations of nitrogen and phosphorus. Using July 2022 nitrogen and phosphorus concentrations from Silver Lake, a nitrogen to phosphorus ratio of 41:1 was calculated. This finding indicates that Silver Lake is indeed phosphorus limited, so a strong relationship between phosphorus concentrations and abundance of phytoplankton, as measured by chlorophyll-*a* levels in the lake, should be expected.

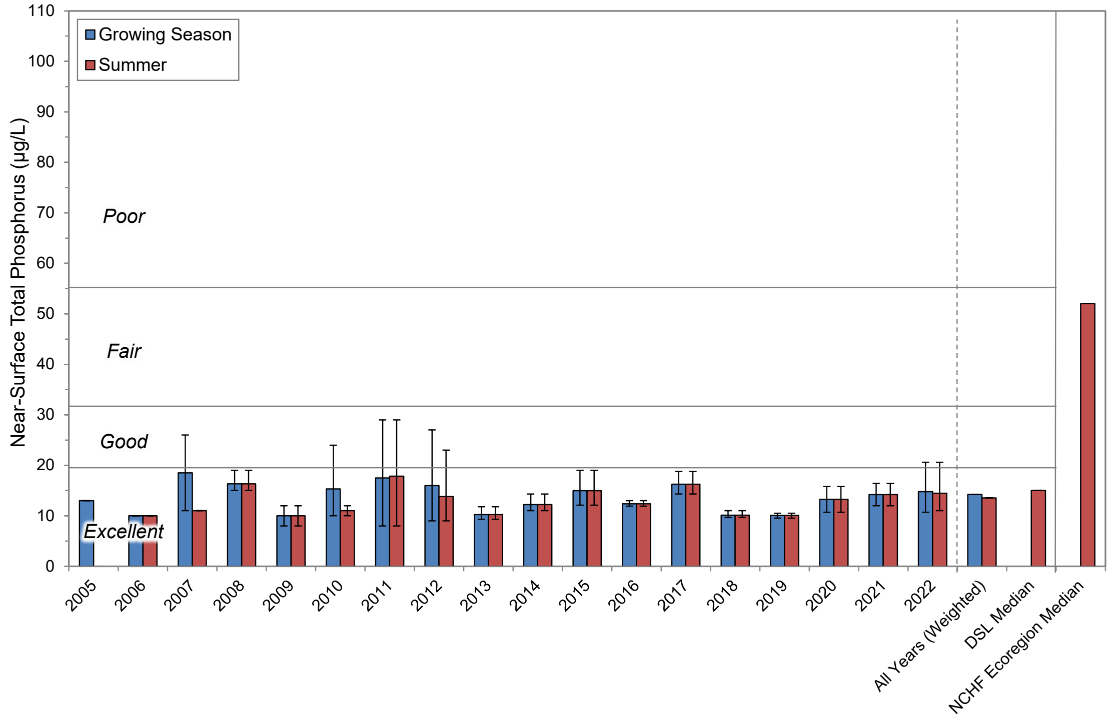

Figure 3.1-3. Silver Lake, statewide class 7 lakes, and regional total phosphorus concentrations. Median values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Silver Lake chlorophyll-*a* data are displayed in Figure 3.1-4. Like the phosphorus data, Silver Lake's chlorophyll-*a* growing season and summer month means are considered *Excellent* throughout the available dataset. The weighted mean for Silver Lake utilizing all of the chlorophyll-*a* data is slightly below the median value of Wisconsin's Deep Seepage Lakes, and well below all lake types in the NCHF ecoregion.

Photograph 3.1-1. Filamentous algae on Silver Lake. Photo credit SLMD, 6/26/2020

It is important to note that the chlorophyll-*a* data discussed above and shown in Figure 3.1-4 is representative of phytoplankton abundance and not other general categories of algae, such as periphyton that grows on substrates, like macrophytes, submerged equipment, and rocks; nor does it include filamentous algae like *Cladophora sp.* that gathers in the lake and gets tangled in near-shore plants. Mats of filamentous algae have been reported in Silver Lake (Photograph 3.1-1), but these algae are not accounted for with the chlorophyll-*a* levels found in open-water samples. In fact, this type of algae does not extract its phosphorus from the open water concentrations discussed above, but instead start growing on the lake's bottom and extract nutrients directly from the sediment. As the biomass builds, trapped gasses below the forming mat begin to lift it from the sediment. The biomass gathers at the surface and often gets tangled in vascular plants or washes up on the shoreline. Unfortunately, the growth and prevalence of filamentous algae species are increased due to the gluttonous feeding of zebra mussels, which extracts nutrients from the open water and then concentrates those nutrients in the pseudofeces they produce and deposit in the sediment. The filamentous algae productions is not only propagated by the addition of nutrients to the sediments by zebra mussels, but also by the enhanced clearing of the water their feeding produces. This ultimately increases light penetration to deeper parts of the lake increasing potential surface area for filamentous growth.

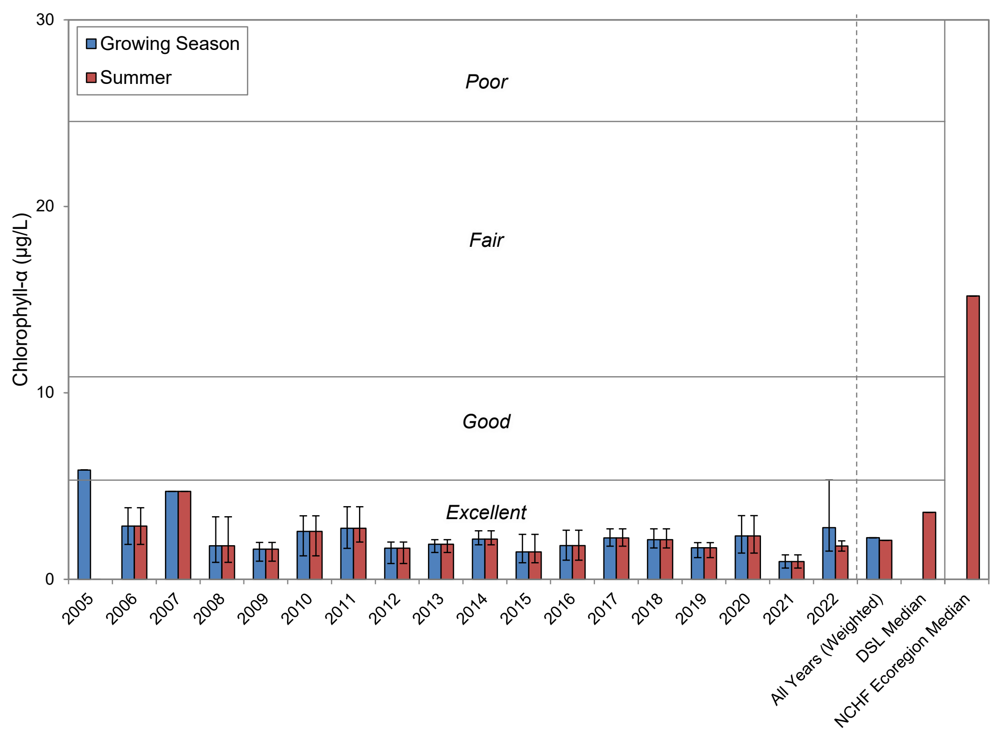

Figure 3.1-4. Silver Lake, statewide class 7 lakes, and regional chlorophyll-a concentrations. Median values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Secchi disk transparency data for Silver Lake, like total phosphorus and chlorophyll-*a* is considered *Excellent* and for the extent of the dataset is better than that found in other Deep Seepage Lakes in the state and the lakes of the NCHF ecoregion. While all Secchi disk readings collected at Silver Lake have been deep enough to be in the *Excellent* category, the sample frequency within years has changed over the course of the dataset and that does factor into the reliability of year-to-year comparisons. Specifically, from 2007-2012, at least 6 Secchi disk readings were taken each growing season, with some of the years having as many as 9 readings. During 2013-2021, most of the years have only 3 readings, with some having only 2 or a single reading.

Silver Lake Trophic State

Figure 3.1-6 contain the TSI values for Silver Lake. The TSI values calculated with Secchi disk, chlorophyll-*a*, and total phosphorus values range in values spanning from oligotrophic to mid-mesotrophic. In general, the best values to use in judging a lake's trophic state are the biological parameters; therefore, relying primarily on total phosphorus and chlorophyll-*a* TSI values, it can be concluded that Silver Lake is in an oligotrophic lake based upon this analysis.

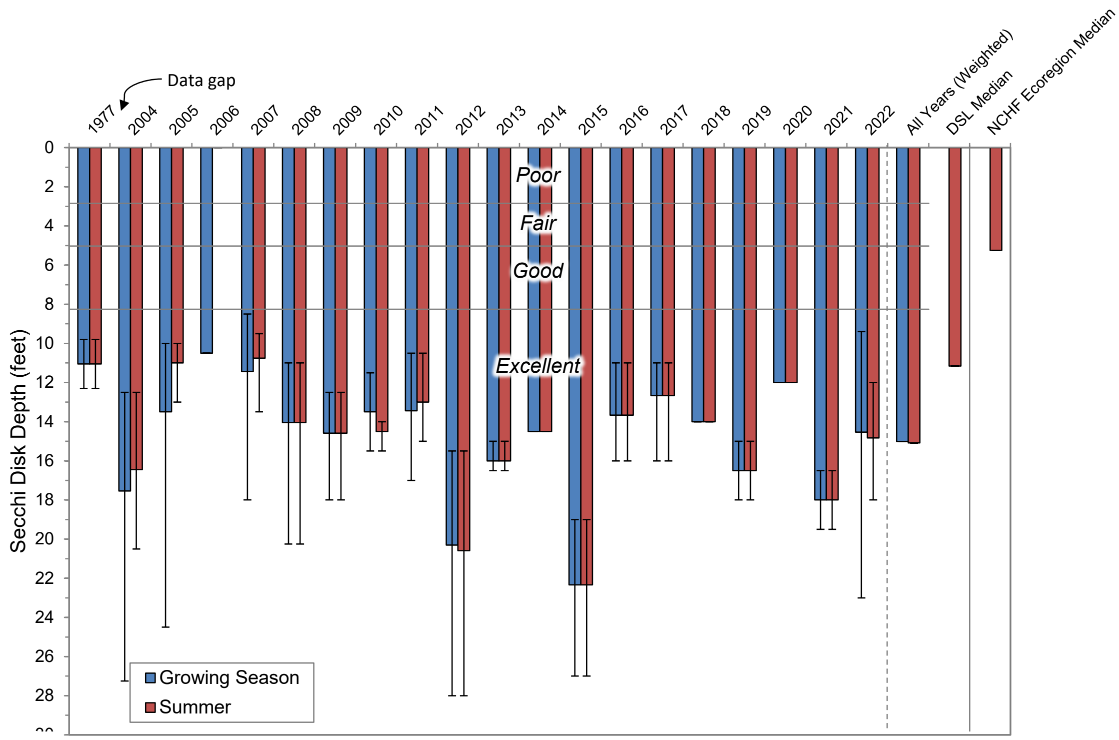

Figure 3.1-5. Silver Lake, statewide class 7 lakes, and regional Secchi disk clarity values. Median values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

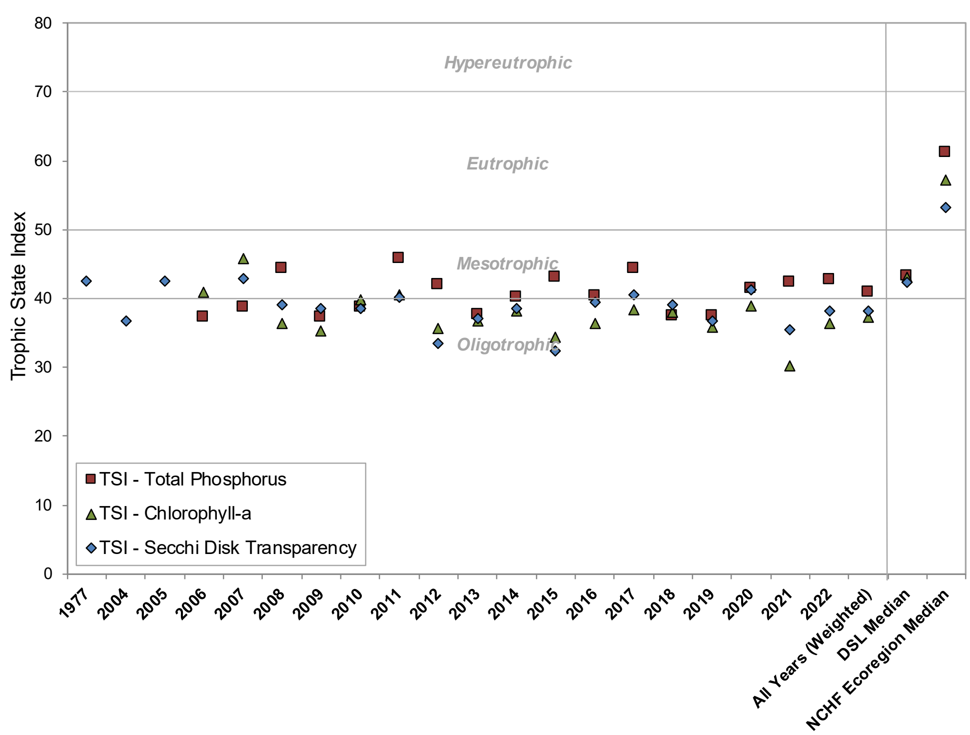

Figure 3.1-6. Silver Lake, statewide class 7 lakes, and regional Trophic State Index values. Values calculated with summer month surface sample data using WDNR PUB-WT-193.

Dissolved Oxygen, Temperature, and Internal Phosphorus Loading in Silver Lake

As explained in the Water Quality Data Analysis and Interpretation Section above, internal nutrient loading is the recycling of nutrients, typically phosphorus within a lake. Silver Lake is considered a dimictic lake, meaning that it turns over (mixes) in the spring and fall, and is thermally stratified during the summer and winter. Silver, like many dimictic lakes, develops an anoxic hypolimnion during the summer. In other words, the bottom layer of water, which is the coldest and densest water in the summer, does not have dissolved oxygen in it because of bacterial decomposition in the sediments. Due to differences in density, the chemicals, including dissolved oxygen, iron, phosphorus, etc. do not mix greatly between the layers. So, what is in the hypolimnion pretty much stays in the hypolimnion until the lake turns over in the fall. When the hypolimnion becomes anoxic, iron, which binds with phosphorus and holds it in the sediment when oxygen is present, dissolve in the overlaying water and releases the phosphorus. As a result, the phosphorus concentrations in the hypolimnion can become very high over the summer. For the most part, algae and other plants do not have access to the high levels of phosphorus because they are too deep and out of reach. When the lake mixes in the fall, a portion of that hypolimnetic phosphorus is available to algae. Much of it is immediately made unavailable because it is bound to iron in the presence of oxygen. In many cases, by the time the lake turns over in the fall, algae growth is limited by the cooler water.

Again, most dimictic lakes experience some level of internal phosphorus recycling, but it does not really impact the biology of the lake because only a small amount of phosphorus is recycled and/or the water temperatures are too low for algae to increase. However, in some dimictic lakes, the amount of phosphorus released during the fall is great enough to sustain high levels in the water through the winter and spur algae blooms the following spring. So, internal loading occurs in many dimictic lakes, but it is only issue in some lakes, especially those that have had unnaturally high loads of phosphorus added to them via agriculture or industry.

On September 20, 2022, Onterra staff visited Silver Lake with the intention of collecting phosphorus profiles from the north and south basin sampling stations. The first step in the process is to create a temperature and dissolved oxygen profile to determine the stratification depths of the epilimnion (upper layer), metalimnion (middle layer), and the hypolimnion (deepest layer). Water samples are then collected with a parabolic pump at several depths, with the majority being in the hypolimnion, and then lesser samples in the upper layers. The objective is to collect several hypolimnetic samples to allow for an accurate mass of phosphorus to be calculated for the hypolimnion.

During the September 2022 visit, the north basin was found to have already mixed, so no phosphorus samples were collected from that location. The south basin was still strongly stratified so 8 samples were collected from that site. The results (Table 3.1-1) follow the typical pattern of decreasing concentrations of phosphorus as the distance from the bottom increases. The total mass of phosphorus in the hypolimnion, which started at 30 feet, was approximately 192 lbs. During the spring turnover, samples were also collected on April 27, 2022. The mass of phosphorus during that sample in depths 30 feet and greater was approximately 34 lbs. From the April sampling to the September sampling, the hypolimnion gained 158 lbs of phosphorus, which is about 1.08 lbs per day. Adding the 158 lbs of phosphorus to the mass of phosphorus that was found in the entire lake during the April sampling (247 lbs) totals 405 lbs, which is very close to the total mass of phosphorus found in the lake during the fall turnover sampling in October of 444 lbs. in other words, adding the summer hypolimnetic phosphorus to the whole lake spring overturn phosphorus in the lake roughly equals the mass of phosphorus in the lake during the fall overturn, so the mass balance works out well. Overall, the internal phosphorus load would not be considered high.

So, what happens to the increased phosphorus over the fall and winter? It obviously does not remain in the water column until the following spring. In Silver Lake, there are two processes that remove the internally loaded phosphorus from the water column during the fall and winter. One is the binding of phosphorus with iron in the presence of oxygen. Ultimately, the phosphorus is returned to the sediment. The other process is an interesting process that is evident in the mid-summer dissolved oxygen profiles found in Figure 3.1-7.

Table 3.1-1. September 20, 2022, Silver Lake phosphorus profile collection results. Data collected at deep-hole site in south basin.

Depth Feet	Total Phos. µg/L	Thermal Layer
3	15.0	Epilimnion
12	14.8	
24	17.6	Metalimnion
30	17.6	Hypolimnion
36	45.7	
42	154.0	
45	344.0	
48	495.0	

Dissolved oxygen and temperature were measured during water quality sampling visits to Silver Lake by Onterra staff and Silver Lake volunteers during 2022. Profiles depicting these data are displayed in Figure 3.1-7. The lake was obviously turning over during the April sampling and by the June visit, the lake was stratified. It should be noted here that it appears that the dissolved oxygen probe used by the Silver Lake volunteers was not properly calibrated during the 2022, and possibly earlier seasons, or the data are incorrectly entered is SWIMS, the WDNR lake database. As listed in SWIMS, many of the readings were 18 mg/L or higher, which during the mid-summer, would be well over twice as much as the water could dissolve at those temperatures (percent saturations would be over 200%). However, it appears that the readings are relatively accurate if 10 mg is subtracted from each reading collected with the volunteer probe. The profiles with an asterisk in the legend were adjusted in this manner.

The second process that removes phosphorus from the water column during the fall and winter is brought on by phenomenon called *metalimnetic oxygen maxima*. This phenomenon is evident by the mid-depth oxygen increase (bulge) found in the June, July, and August dissolved oxygen profiles. The increase is brought on by a community of algae suspended at those depths in the water column. Some species of algae have gas vacuoles that allow them to move up and down within the water column. One common type of blue-green algae, Oscillatoria, can control its depth in this manner. Note that Oscillatoria does not produce cytotoxins.

In clear, low productivity lakes like Silver, the algae will gather at these mid-depths to access slightly increased nutrient levels and avoid the warm surface waters. During the fall, these algae are mixed in the water column during the turnover event. As they mix, they absorb phosphorus and other nutrients from the open water. Then, as fall progresses, the algae die-off and the nutrients are settled to the bottom with the algal biomass. So, this harmless process helps keep spring phosphorus levels low.

On February 15, 2023, Onterra staff visited the lake and recorded a temperature/dissolved oxygen profile through the ice. The water column was oxygenated to the bottom during this visit and ranged from 12.8 mg/L at the surface to 2.0 mg/L at 48 feet.

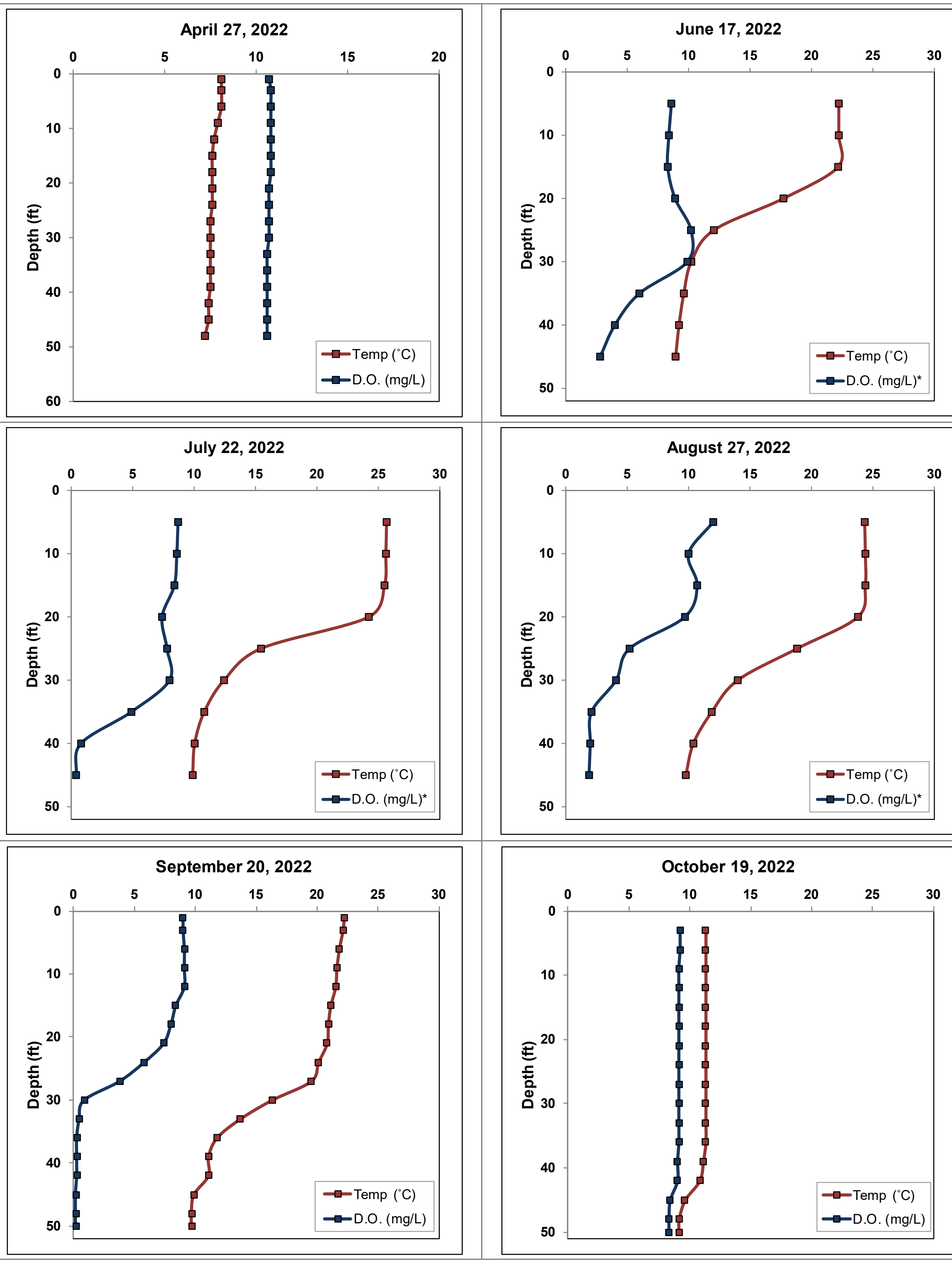

Figure 3.1-7. Silver Lake dissolved oxygen and temperature profiles. *These D.O. results were adjusted as described in the text.

Additional Water Quality Data Collected at Silver Lake

The water quality section is centered on lake nutrient levels and trophic state. 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 Silver 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 true color.

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 pH of the water in Silver Lake was found to be slightly alkaline with a value of 8.5, and falls within the normal range for Wisconsin Lakes (Figure 3.1-8).

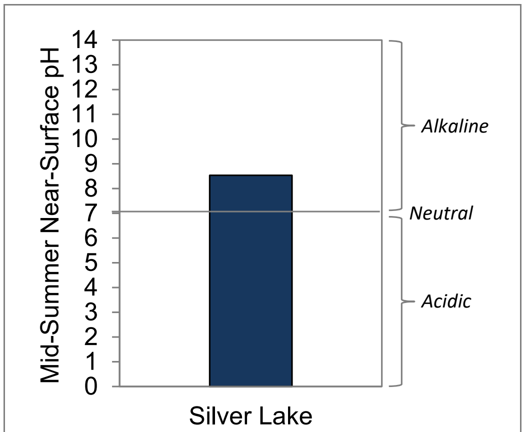

Figure 3.1-8. Silver Lake mid-summer near-surface pH value.

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 ($(CaMgCO_3)_2$). 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 Silver Lake was measured at 112 (mg/L as $CaCO_3$), indicating that the lake has a substantial capacity to resist fluctuations in pH and has a low sensitivity to acid rain (Figure 3.1-9).

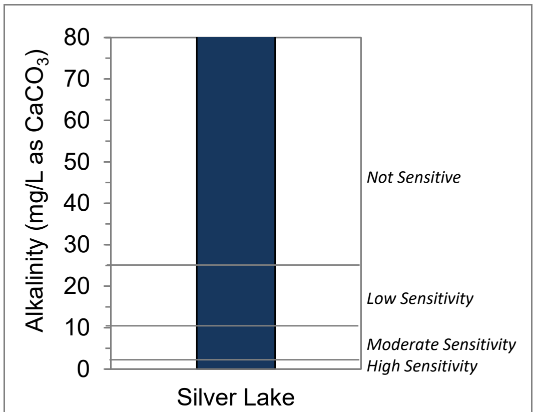

Figure 3.1-9. Silver Lake average growing season total alkalinity and sensitivity to acid rain. Samples collected from near-surface.

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 of 2022, indicating the lake's water was *clear colored* and was minimally impacted by tannins (Figure 3.1-10).

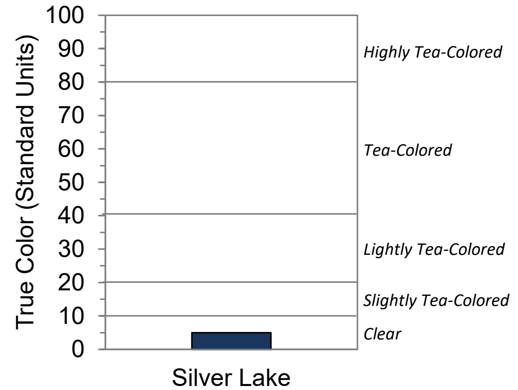

Figure 3.1-10. Silver Lake 2022 near-surface true color value.

Silver Lake Paleoecological Results

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 are 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. 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 objects such as aquatic plants or the lake bottom.

During 2013, Paul Garrison of the WDNR (now employed at Onterra) conducted a paleoecological study of eight lakes in Waushara County, including Silver Lake. Appendix C contains the full report of that investigation. One of the largest conclusions from that study was that the phosphorus concentrations at the present time are only slightly higher than they were before Europeans settled the area. The study was also able to decern significant changes in the near-shore habitat which has caused increased biomass of rooted aquatic plants and filamentous algae.

Stakeholder Survey Responses to Silver Lake 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. Most Silver Lake stakeholder respondents indicate the water quality is *good* or *excellent* (Figure 3.1-11), which conforms with the data presented in this section.

Stakeholders were given a list of practices and asked to rate their influence on the water quality of Silver Lake. Overall, the respondents undervalued many of the practices that protect the high water quality of Silver Lake (Figure 3.1-12).

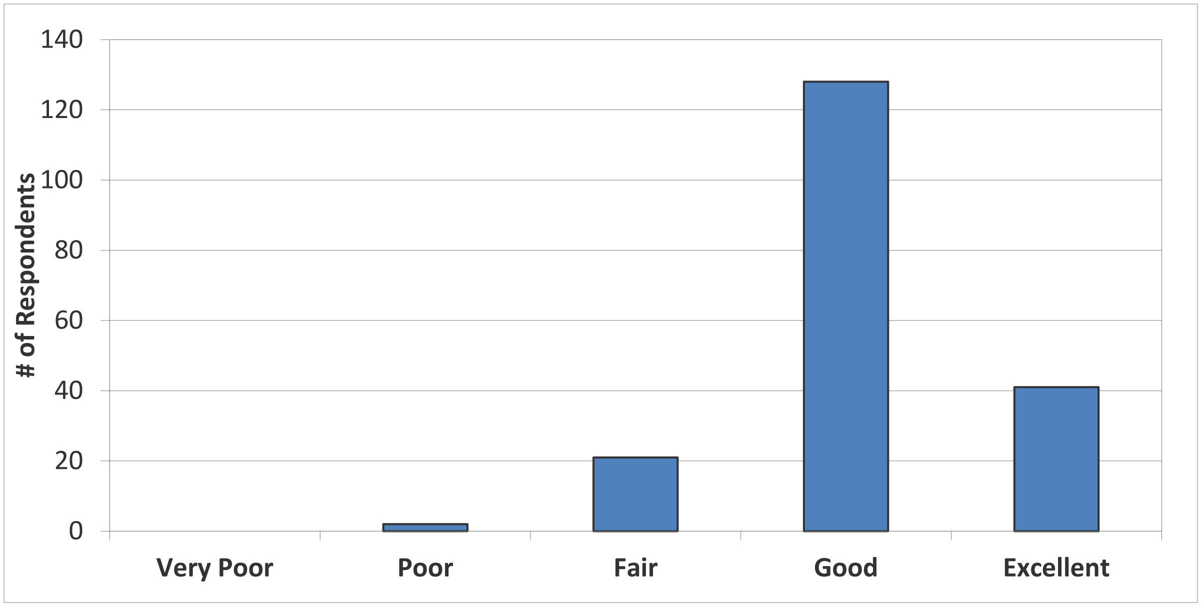

Figure 3.1-11. Stakeholder survey responses to Question #20. How would you describe the overall current water quality of Silver Lake?

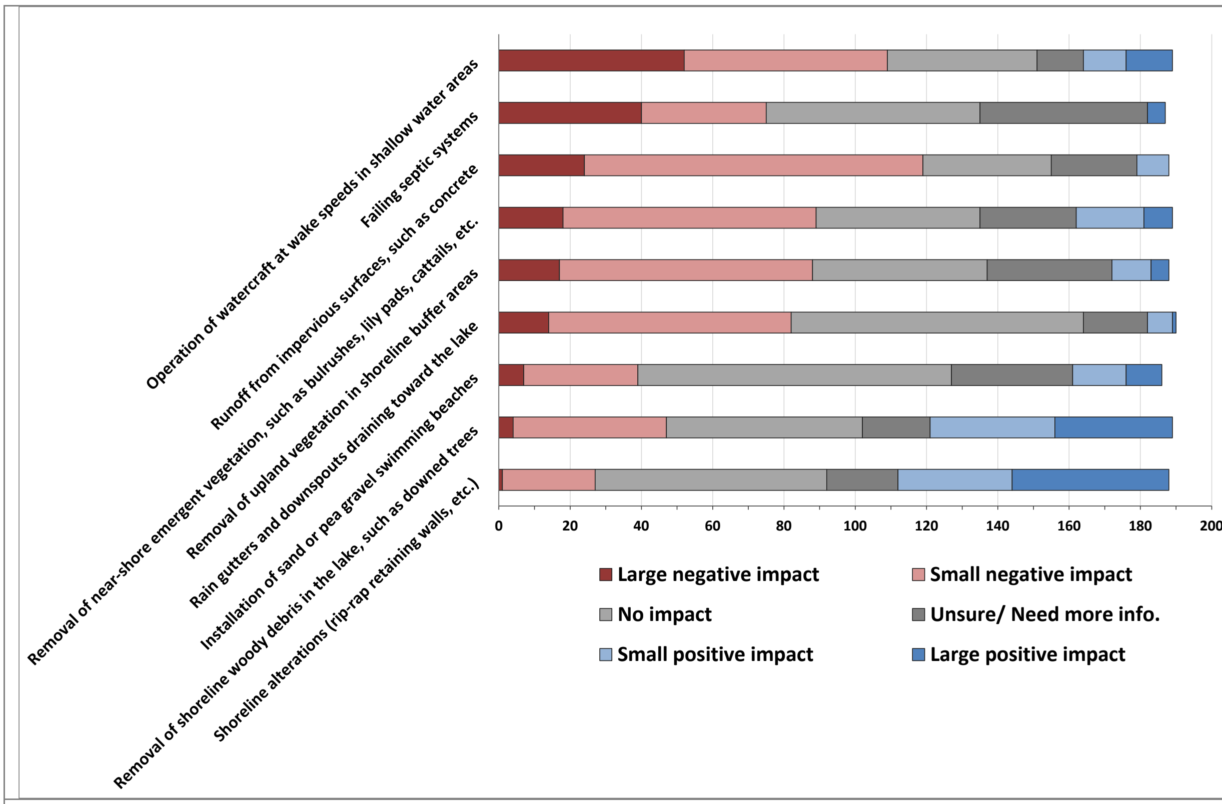

Figure 3.1-12. Stakeholder survey responses to Question #24. What impact, if any, do you believe each of the following practices have on the water quality of Silver Lake?

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. For these reasons, it is important to maintain as much natural land cover (forests, wetlands, etc.) as possible within a lake's watershed to minimize the amount runoff (nutrients, sediment, etc.) from entering the lake.

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 10-15:1 or higher, 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 (a residence time of years), there may be a buildup of phosphorus in the sediments that may reach sufficient levels over time and lead to a problem such as internal nutrient loading. 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.

Big Silver Watershed

The original objective of this section was to compare how landcover types have changed since the Silver Lake watershed was first assessed as a part of the 2016 planning effort. Creating the comparisons was not straight forward because the earlier assessment included the compartmentalization of watershed landcover types that could not be duplicated using updated landcover data from the 2019 National Land Cover Database (NLCD). Further, the watershed delineation line utilized in the earlier plan could not be made available in its native GIS format for use in this current effort; therefore, the watershed delineation line was digitized using the figures available in the earlier plan. Unfortunately, the acreages of the newly created digitized watershed delineation line and the acreage reported in the earlier plan do not match. The earlier plan states that the area of the Silver Lake surface watershed is 2,938 acres, while the new digitized watershed boundary is 2,543 acres. Despite several verification attempts, the nearly 400-acre discrepancy could not be reconciled.

WiLMS is an excellent tool for creating a *screening-level* watershed assessment. It provides a general idea of how a lake's surficial watershed impacts the lake's water quality, specifically total phosphorus concentrations. So, to provide some context of how surface water inputs impact the water quality of Silver Lake, the digitized watershed boundary from the earlier planning effort was used to model Silver Lake's watershed utilizing the 2019 NLCD information. Comparisons between this modeling effort, and that completed by the earlier planning project, should be avoided due to the differences in landcover classifications utilized and the total acreages of the watershed boundaries. The information discussed below is based upon the new watershed boundary acreage and the newest landcover data available.

The surface watershed of Silver Lake (Figure 3.2-1) is approximately 2,543 acres, yielding a watershed area to lake area ratio of 6:1. This means that for every acre of lake, about 6 acres of land drain to it. This is a moderate to small ratio, confirming that groundwater levels play an important role in Silver Lake's water levels. Still, the surface water reaching Silver Lake is important in determining the lake's water quality, especially the levels of phosphorus found in the lake.

Different types of landcover export varying amounts of phosphorus as water runs off the land and makes its way to a lake. Row crop agriculture and high-density development export the highest levels of phosphorus per acre, while forested areas and wetlands export the least. Figure 3.2-2 displays the partitioning of landcover types within the Silver Lake watershed. Forest, pasture/grass, wetlands, and the surface area of Silver Lake itself, which are all considered relatively low contributors of phosphorus make up about 68% of the watershed. Other areas of open water, which do not include the surface area of Silver Lake, make up about 6% of the watershed area. The 166 acres classified as open water were not included in the modeling because that acreage primarily consists of other seepage lakes that do not directly drain to Silver Lake.

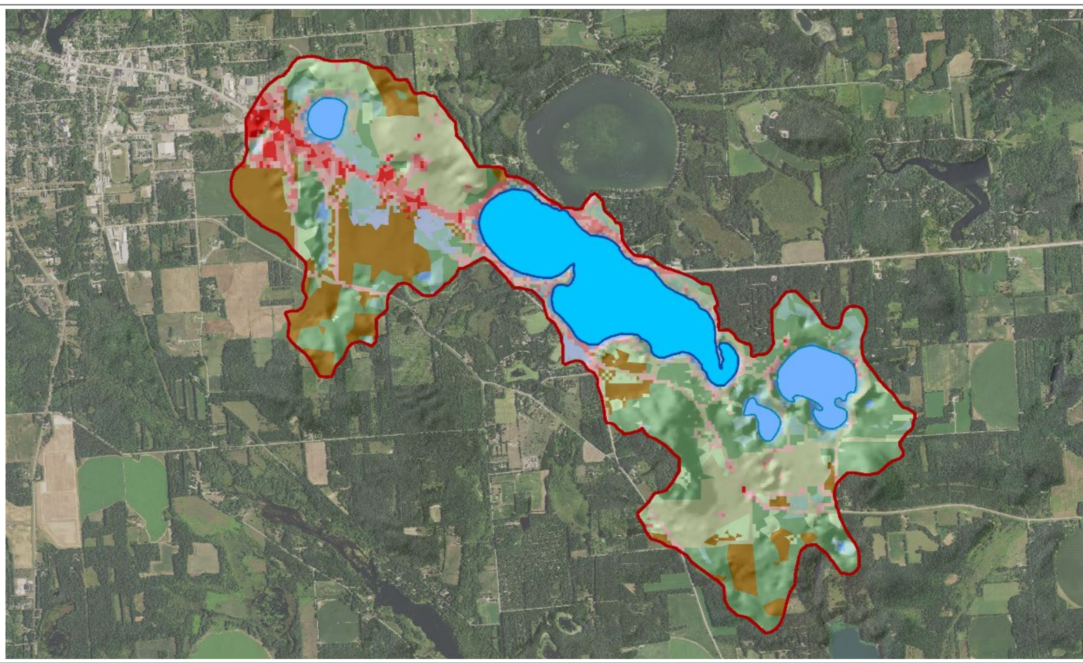

Figure 3.2-1. Silver Lake watershed landcover types. Based upon 2019 National Land Cover Database.

Landcover types such as urbanized areas and agricultural row crops occupy just over a quarter of the watershed area, but as shown in Figure 3.2-3, they account for nearly 60% of the estimated 736 pounds phosphorus that loads to Silver Lake on an annual basis. Still, 736 lbs of phosphorus entering a lake the size and depth of Silver Lake is not considered high. Predictive modeling estimates that an annual load of 736 lbs being added to Silver Lake would produce a growing season mean concentration of 17 µg/L, which is very close to the measured growing season mean of 18.2 µg/L. Overall, this means that the model is creating an accurate estimate of the watershed impact on Silver Lake. It also provides additional evidence to the conclusion drawn in the Water Quality Section 3.1, that internal phosphorus loading is not a significant contributor to Silver Lake's nutrient budget.

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Lake Management Planning

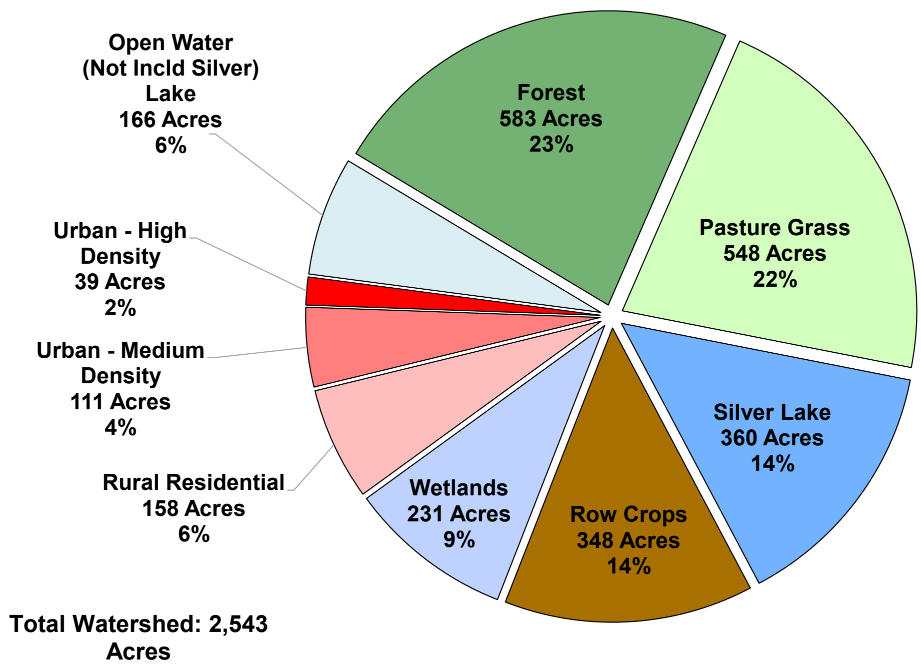


Figure 3.2-2. Silver Lake watershed land cover types in acres. Based upon 2019 National Land Cover Database .

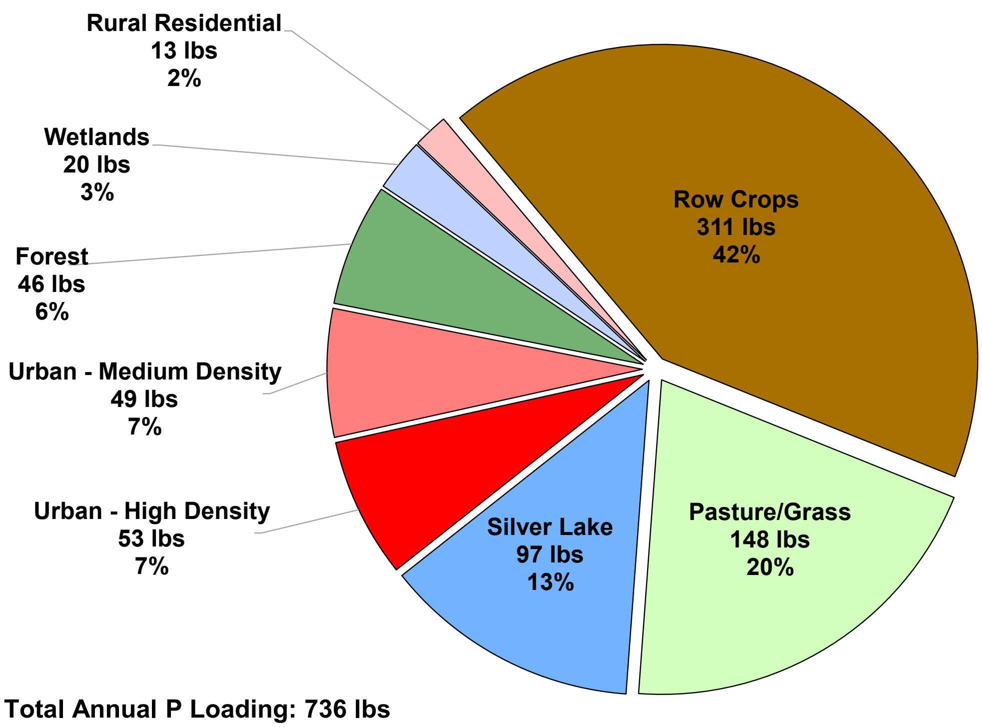


Figure 3.2-3. Silver Lake watershed phosphorus loading in pounds. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates.

3.3 Shoreland Condition

Lake Shoreland Zone and its Importance

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 inland). 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. Groundwater 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 found that green frog density was negatively correlated with development density in Wisconsin lakes (Woodford and Meyer 2003). As development increased, the habitat for green frogs decreased and thus populations became significantly lower. 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 et al. 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 is 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 et al. 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 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 such as 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 nation's 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.*" These results indicate that stronger management of shoreline development is absolutely necessary to preserve, protect, and restore lakes. Shoreland protection will become increasingly important as development pressure on lakes continues to 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) (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).

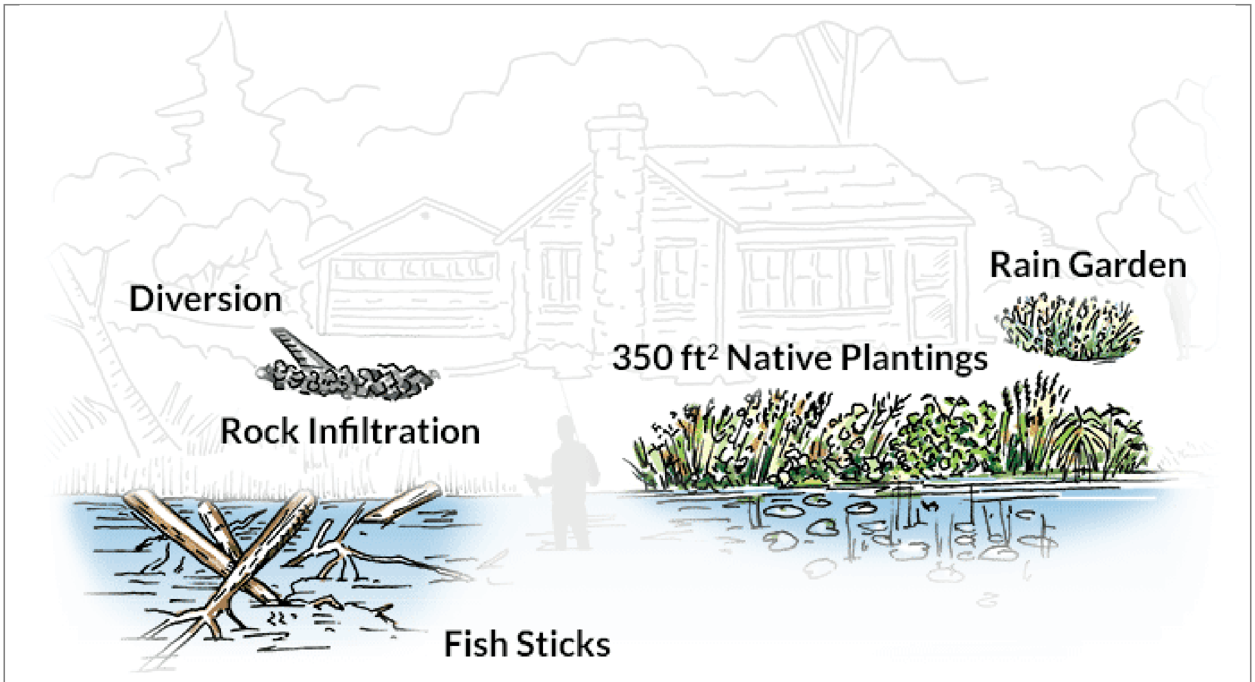


Figure 3.3-1. Healthy Lakes & Rivers 5 Best Practices. Illustration by Karen Engelbretson, extracted from healthylakeswi.com.

- 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:

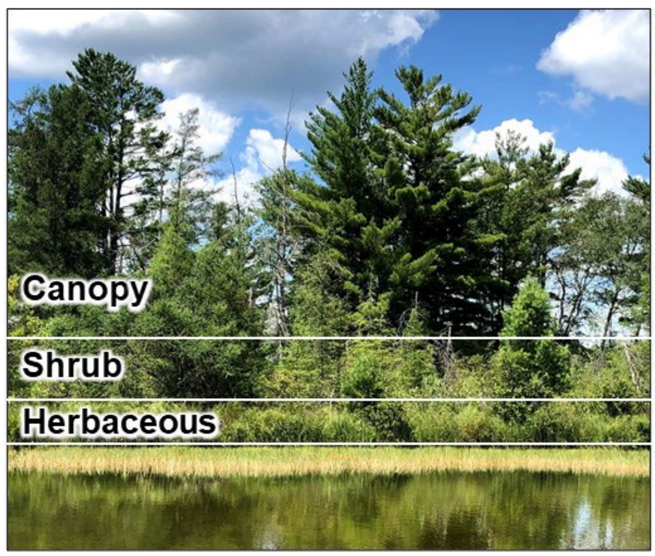
https://healthylakeswi.com/

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.

Silver Lake Shoreland Zone Condition

Shoreland Development

The entire shoreline of Silver Lake was surveyed during the summer of 2022. 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.

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.

Canopy cover was defined as an area which is shaded by trees that are at least 16 feet tall (Photograph 3.3-3). The vast majority (65%) of Silver's shoreline has less than 40% canopy cover (Map 2, Figure 3.3-2).

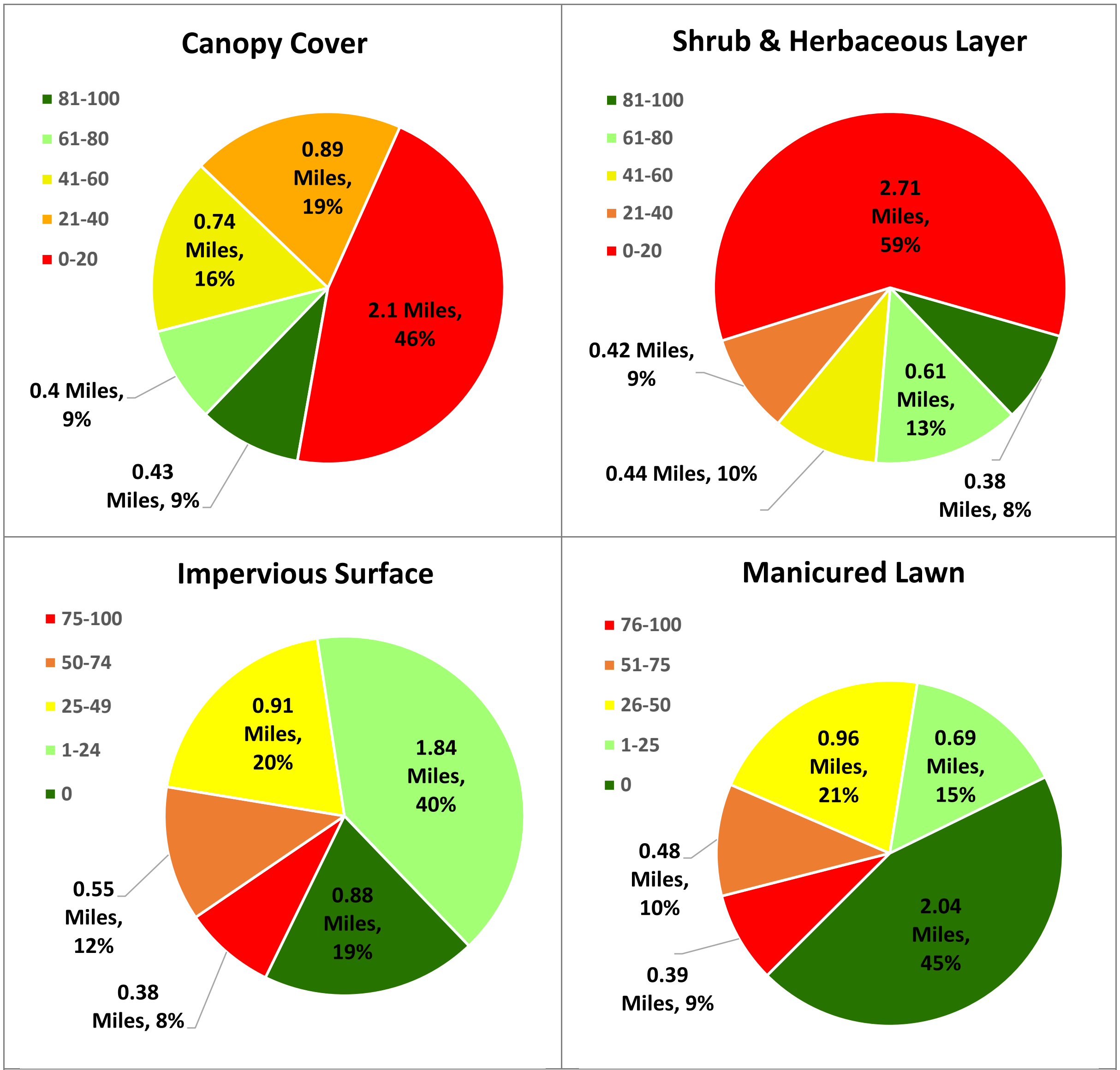


Figure 3.3-2. Silver Lake shoreland categories and total lengths. Based upon a Summer 2022 survey. Locations of these categorized shorelands can be found on Maps 2-5.

Shrub and herbaceous layers are small trees and plants without woody stems less than 16 feet tall (Photograph 3.3-3). The shoreland assessment survey indicates that 0.38 miles, or 8% Silver's parcels contained between 81-100% shrub and herbaceous layers (Figure 3.3-2, Map 3). Another 2.71 miles (59%) only had between 0 and 20% shrub and herbaceous layer present on the parcel.

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 59% of the shoreline had parcels with less than 24% of impervious surface within the shoreland zone (Figure 3.3-2, Map 4).

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 lake had no manicured lawn within the shoreland zone and another 15% of parcels had between 1-25% of the shoreland zone containing manicured lawn (Figure 3.3-2, Map 5). Approximately 19% of the shoreland parcels contained manicured lawn on 75% or greater of the shoreland zone.

Over half of stakeholder respondents believe the development of Silver Lake is *just right* (Figure 3.3-3). While producing a completely natural shoreland is ideal for a lake ecosystem, it is not always practical from a human's perspective. However, riparian property owners can take small steps in ensuring their property's impact upon the lake is minimal. Choosing an appropriate landscape position for lawns is one option to consider. Placing lawns on flat, un-sloped areas or in areas that do not terminate at the lake's edge is one way to reduce the amount of runoff a lake receives from a developed site. And, allowing tree falls and other natural habitat features to remain along a shoreline may result not only in reducing shoreline erosion, but creating wildlife habitat also.

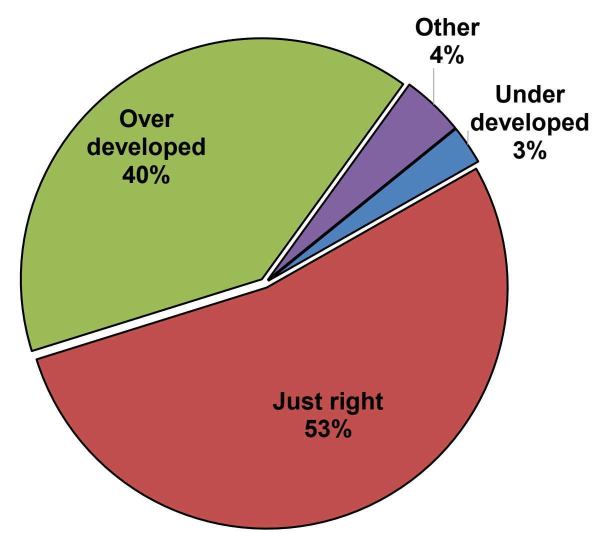


Figure 3.3-3. Stakeholder survey responses to Question #22. Which of the following descriptions do you believe most accurately describes the development (residential and commercial) of the Silver Lake shoreline?

Coarse Woody Habitat

As part of the shoreland condition assessment, Silver Lake was also surveyed to determine the extent of its coarse woody habitat. Coarse woody habitat was identified, and classified in three size categories (2-8 inches in diameter, 8+ inches in diameter, or clusters of pieces) as well as four branching categories: no branches, minimal branches, moderate branches, and full canopy. 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, no coarse woody habitat was observed on the shoreline. This is most likely due to the urbanization of Silver Lake's shoreline, as the majority of land is dominated by development and household private property.

Shoreland Modification Practices

The importance of the shoreland zone of a lake is well discussed above. It is important to also acknowledge that natural shorelines are dynamic and are naturally altered over time from shoreland erosion and impacts from ice shoves. While the impacted shorelines continue to provide valuable wildlife habitat, the changes are undesired by the property owners. Seawalls are commonly constructed to reduce shoreline erosion and protect adjacent upland properties from wave action and winter ice shoves. However, these structures reduce the natural complexity of the nearshore habitat and reduce biodiversity. Therefore, these artificial shoreland modification practices are generally discouraged.

On large lakes like Silver Lake, erosion and ice shoves can be extremely damaging to valuable shoreline properties. Water levels above the ordinary high water level can also cause damage, particularly when coupled with wave action. When a circumstance justifies the need for shoreland modifications to protect property, the WDNR favors properly implemented rip-rap/rock. These structures mimic a type of native shoreline, providing a level of environmental benefit in addition to shoreland stabilization.

3.4 Aquatic Plants

Introduction

Although the occasional lake user may consider 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

Important Note:
Even though most of these techniques are not applicable to Silver Lake, 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 Silver Lake are discussed in Summary and Conclusions section and the Implementation Plan found near the end of this document.

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.

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 (Hand-Harvesting & DASH)

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.

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

Manual removal or hand-harvesting of aquatic invasive species has gained favor in recent years as an alternative to herbicide control programs. Professional hand-harvesting firms can be contracted for these efforts and can either use basic snorkeling or scuba divers, whereas others might employ the use of a Diver Assisted Suction Harvest (DASH) which involves divers removing plants and feeding them into a suctioned hose for delivery to the deck of the harvesting vessel. The DASH methodology is considered a form of mechanical harvesting and thus requires a WDNR approved permit. DASH is thought to be more efficient in removing target plants than divers alone and is believed to limit fragmentation during the harvesting process.

<u>Cost</u>

Contracting aquatic invasive species removal by third-party firm can cost approximately $1,500 per day for traditional hand-harvesting methods whereas the costs can be closer to $2,500 when DASH technology is used. Additional disposal, travel, and permitting fees may also apply.

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.

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. Contracting mechanical harvesting is approximately $2,500-$3,500 per day, with minimum contract size and mobilization costs also needing to be factored in.

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. • 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. 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.

Table 3.4-1. Common herbicides used for aquatic plant management.

	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)
Contact		Endothall	Inhibits respiration & protein synthesis	Submersed species, largely for curly-leaf pondweed; invasive watermilfoil control when mixed with auxin herbicides
Contact		Diquat	Inhibits photosynthesis & destroys cell membranes	Nusiance species including duckweeds, targeted AIS control when exposure times are low
Contact		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
Systemic	Auxin Mimics	Triclopyr	auxin mimic, plant growth regulator	Submersed species, largely for invasive watermilfoil
Systemic	Auxin Mimics	Florpyrauxifen -benzyl	arylpicolinate auxin mimic, growth regulator, different binding afinity than 2,4-D or triclopyr	Submersed species, largely for invasive watermilfoil
Systemic	In Water Use Only	Fluridone	Inhibits plant specific enzyme, new growth bleached	Submersed species, largely for invasive watermilfoil
Systemic	Enzyme Specific (ALS)	Penoxsulam	Inhibits plant-specific enzyme (ALS), new growth stunted	Emergent species with potential for submergent and floating-leaf species
Systemic	Enzyme Specific (ALS)	Imazamox	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
Systemic	Enzyme Specific (foliar use only)	Glyphosate	Inhibits plant-specific enzyme (ALS)	Emergent species, including purple loosestrife
Systemic	Enzyme Specific (foliar use only)	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.

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. Recent studies have shown background populations of these weevils are typically in hundreds of thousands in some lakes already, so adding a few thousand may not yield a significant increase in the overall weevil population in some lakes. Currently the milfoil weevil is not a WDNR grant-eligible method of controlling Eurasian watermilfoil.

Cost

Stocking with adult weevils costs about $1.50/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 is free.

Advantages	***Disadvantages***
• Extremely inexpensive control method. • Once released, considerably less effort than other control methods is required. • Augmenting populations may 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 Silver Lake; 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 in Silver Lake in 2016. 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 Silver Lake, 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 community of Silver Lake to be compared to other lakes within the region and state.

FQI = Average Coefficient of Conservatism * √ 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 Silver Lake is compared to data collected by Onterra and the WDNR Science Services on 77 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 Silver Lake were mapped using a Trimble Global Positioning System (GPS) with sub-meter accuracy.

Silver Lake Aquatic Plant Survey Results

The whole-lake point-intercept and community mapping surveys were conducted on Silver Lake on July 29, 2022 and August 1, 2022, respectively. During the 2022 surveys, a total of 29 aquatic plant species were located (Table 3.4-2). Two are considered to be non-native, invasive species: hybrid watermilfoil (HWM) and curly-leaf pondweed (CLP). These non-native plant species are discussed in the subsequent *Non-Native Aquatic Plants in Silver Lake* section. Point-intercept surveys were also completed every year from 2012 to 2022 with the exception of 2016. From all 10 point-intercept surveys and one community mapping survey, the total number of aquatic plant species located in Silver Lake is 44.

Whole-lake point-intercept surveys are used to quantify the abundance of individual species within the lake. Of the 29 aquatic plant species located in Silver Lake in 2022, 24 were encountered directly on the rake during the whole-lake point-intercept survey (Figure 3.4-5). The remaining five species were located incidentally, meaning they were observed by Onterra ecologists while on the lake but they were not directly sampled on the rake at any of the point-intercept sampling locations. 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 relatively rare within the plant community.

Table 3.4-2. Aquatic plant species located on Silver Lake.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2012	2013	2014	2015	2017	2018	2019	2020	2021	2022
Emergent	*Acorus americanus*	Sweetflag	Native	7								X		
	Schoenoplectus acutus	Hardstem bulrush	Native	5				I						
	Schoenoplectus pungens	Three-square rush	Native	5						X				I
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4										I
	Scirpus hattorianus	Mosquito bulrush	Native	3										I
	Typha spp.	Cattail spp.	Unknown (Sterile)	N/A				I						
FL	*Nuphar variegata*	Spatterdock	Native	6								X		
	Nymphaea odorata	White water lily	Native	6	X	I						X	I	I
Submergent	*Bidens beckii*	Water marigold	Native	8			X		X	X	X	X	X	X
	Ceratophyllum demersum	Coontail	Native	3	X	X	X	X	X	X	X	X	X	X
	Chara spp.	Muskgrasses	Native	7	X	X	X	X	X	X	X	X	X	X
	Chara spp. & Nitella spp.	Charophytes	Native	7	X	X	X	X	X	X	X	X	X	X
	Elodea canadensis	Common waterweed	Native	3	X	X	X	X		X	X	X	X	X
	Elodea nuttallii	Slender waterweed	Native	7		X								
	Heteranthera dubia	Water stargrass	Native	6	X	X	X		X	X	X	X	X	X
	Myriophyllum sibiricum	Northern watermilfoil	Native	7	X	X	X	X						
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A	X	X	X	X	X	X	X	X	X	X
	Myriophyllum verticillatum	Whorled watermilfoil	Native	8									X	
	Najas flexilis	Slender naiad	Native	6	X	X	X	X		X	X	X	X	X
	Najas flexilis & N. guadalupensis	Slender naiad and Southern naiad	Native	N/A	X	X	X	X	X	X	X	X	X	X
	Najas guadalupensis	Southern naiad	Native	7	X	X	X	X	X	X	X	X	X	X
	Nitella spp.	Stoneworts	Native	7	X	X	X	X	X	X	X	X	X	X
	Potamogeton amplifolius	Large-leaf pondweed	Native	7	X	I	X			X	X	X	X	X
	Potamogeton berchtoldii	Slender pondweed	Native	7							X		X	X
	Potamogeton berchtoldii & P. pusillus	Slender and Small pondweeds	Native	N/A		X	X	X	X	X	X	X	X	X
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A	X			X	X		X	X	X	X
	Potamogeton foliosus	Leafy pondweed	Native	6	X	X	X	X	X	X	X	X	X	X
	Potamogeton friesii	Fries' pondweed	Native	8	X	X	X	X	X	X	X	X	X	X
	Potamogeton gramineus	Variable-leaf pondweed	Native	7	X	X	X	X	X	X	X	X	X	X
	Potamogeton illinoensis	Illinois pondweed	Native	6	X	X	X	X	X	X	X	X	X	X
	Potamogeton natans	Floating-leaf pondweed	Native	5		X	X	X		X	X	X	X	X
	Potamogeton praelongus	White-stem pondweed	Native	8	X	X	X	X	X	X	X	X	X	X
	Potamogeton pusillus	Small pondweed	Native	7		X	X	X	X	X	X	X	X	X
	Potamogeton richardsonii	Clasping-leaf pondweed	Native	5								X		X
	Potamogeton spirillus	Spiral-fruited pondweed	Native	8					X					
	Potamogeton strictifolius	Stiff pondweed	Native	8					X	X	X	X	X	
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6	X	X	X	X	X	X	X	X	X	X
	Ranunculus aquatilis	White water crowfoot	Native	8			X	X			X	X	X	X
	Stuckenia pectinata	Sago pondweed	Native	3	X	X	X	X	X	X	X	X	X	X
	Utricularia geminiscapa	Twin-stemmed bladderwort	Native	9						X				
	Vallisneria americana	Wild celery	Native	6	X	X	X	X	X	X	X	X	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5			X	X	X	X		X		
	Schoenoplectus subterminalis	Water bulrush	Native	9										I
FF	*Spirodela polyrhiza*	Greater duckweed	Native	5					X					

X = Located on rake during point-intercept survey; I = Incidentally located; not located on rake during point-intercept survey
FL = Floating-leaf; F/L = Floating-leaf & Emergent; S/E = Submergent and/or Emergent; FF = Free-floating

During the 2022 point-intercept survey, information regarding substrate type was collected at locations sampled with a pole-mounted rake (less than 15 feet). These data indicate 77% of the point-intercept locations contained soft organic sediments, 22% contained sand, and 1% contained rock (Figure 3.4-1). Areas of soft organic and sand were the primary sediments found in shallower, near-shore areas of the lake. The sediment within littoral areas of Silver Lake is very conducive for supporting lush aquatic plant growth.

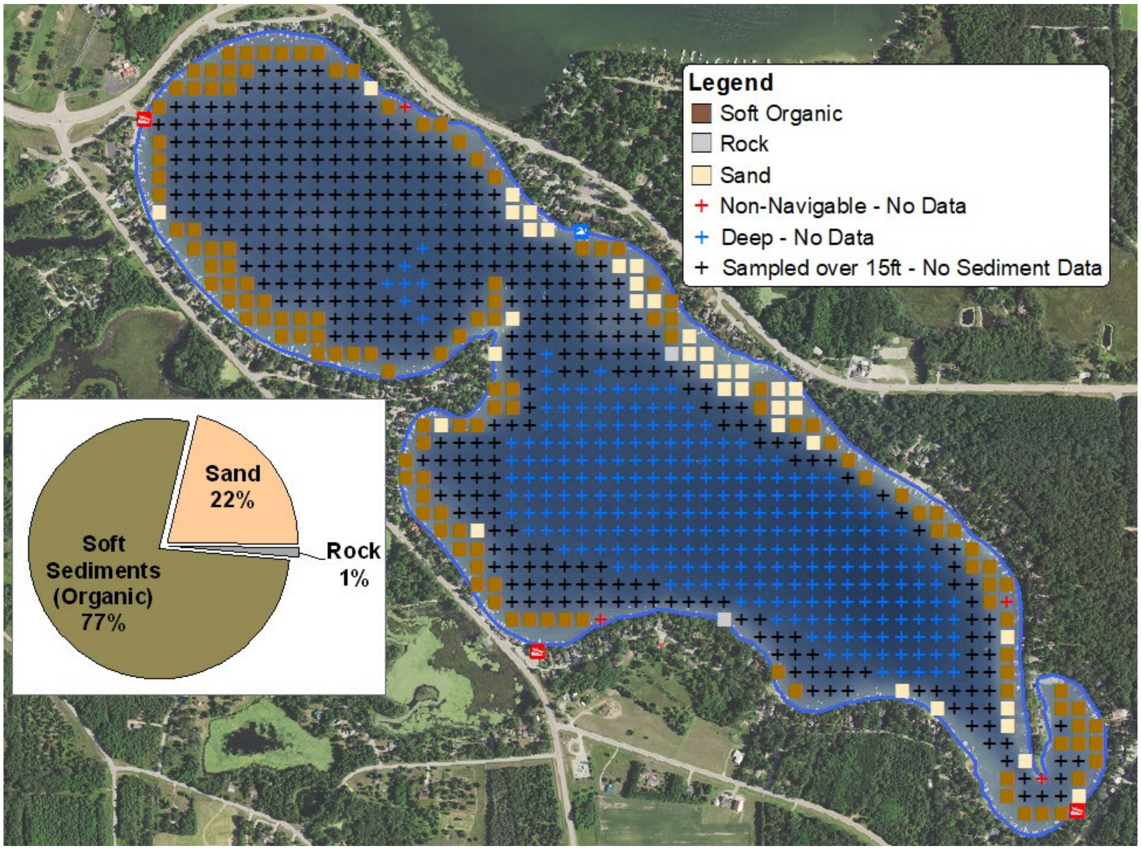


Figure 3.4-1. Silver Lake proportion of substrate types within littoral areas. Created from 2022 aquatic plant point-intercept survey.

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.

The data that continues to be collected from Wisconsin lake's 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 can be driven by a combination of natural factors including variations in temperature, ice and snow cover (winter light availability), nutrient availability, water levels and flow, water clarity, length of the growing season, herbivory, disease, and competition (Lacoul and Freedman 2006). Adding to the complexity of factors which affect aquatic plant community dynamics, human-related disturbances such as the application of herbicides for non-native plant management, mechanical harvesting, watercraft use, and pollution runoff also affect aquatic plant community composition (Asplund and Cook 1997; Lacoul and Freedman 2006).

The following figures and discussion will investigate changes in the aquatic plant population of Silver Lake over time. Aquatic plant populations are displayed as frequency of occurrence within only the part of the lake that light sufficiently penetrates to support aquatic plant growth, called the littoral zone. 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. Aquatic plants have been historically found growing out to 31-32 feet of water, although slightly shallower prior to 2016 (Figure 3.4-2). Considering the difference in water levels between these time periods, the footprint of the littoral zone is like relatively constant.

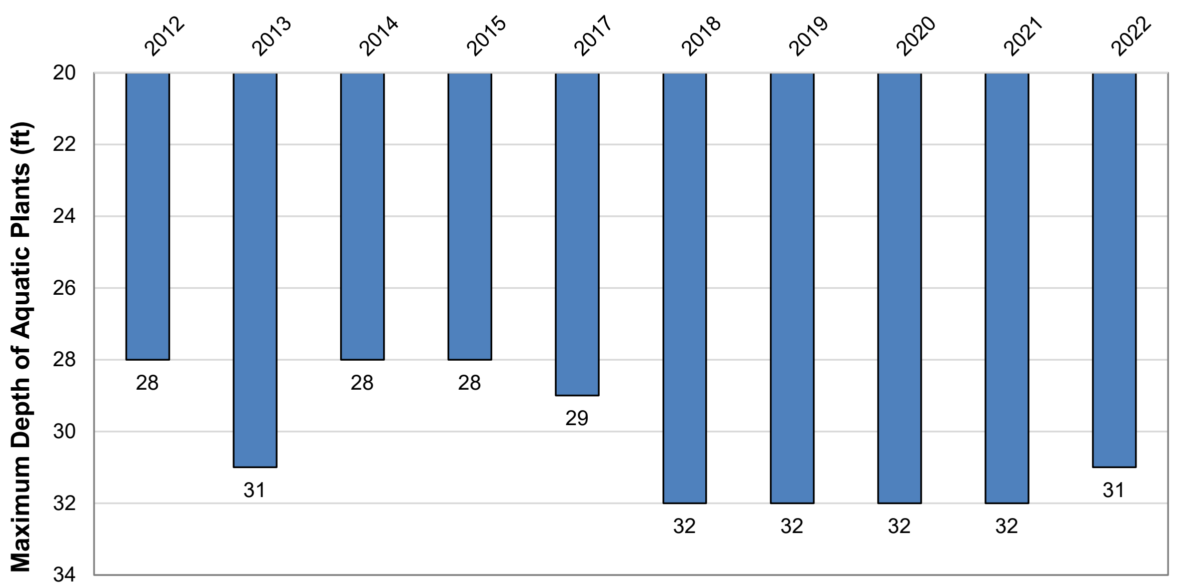


Figure 3.4-2. Maximum depth of plants in Silver Lake.

Acknowledging the multitude of factors discussed above, the two primary drivers of the Silver Lake aquatic plant community are 1) herbicide management, and 2) water levels. Two major herbicide treatment events, which will be discussed at length in the subsequent *Non-Native Aquatic Plants in Silver Lake* sub-section, a whole-lake triclopyr treatment during the spring of 2014 and a whole-lake fluridone treatment during the entire open water season of 2016. Water levels in mean sea level were approximately 865-866 in 2012-20115, and around 868 in 2017-2022. Therefore the 2012-2015 period experienced lower water levels and was prior to the whole-lake fluridone treatment. The 2017-2022 period experienced about 3-foot higher water levels and was after the year-long treatment.

Figure 3.4-3 displays littoral frequency of occurrence of all aquatic plants from point-intercept surveys completed between 2012-2022 in Silver Lake. It is clear to see that more of the littoral zone contained aquatic plants in 2012-2015 compared with 2017-2022. However, the 2017-2022 data contained slightly higher rake fullness ratings, indicating denser plant communities where present. The 2021 survey showed the least amount of sampling locations within the littoral zone with plants at 45% and 2014 showed the highest amount at 81%.

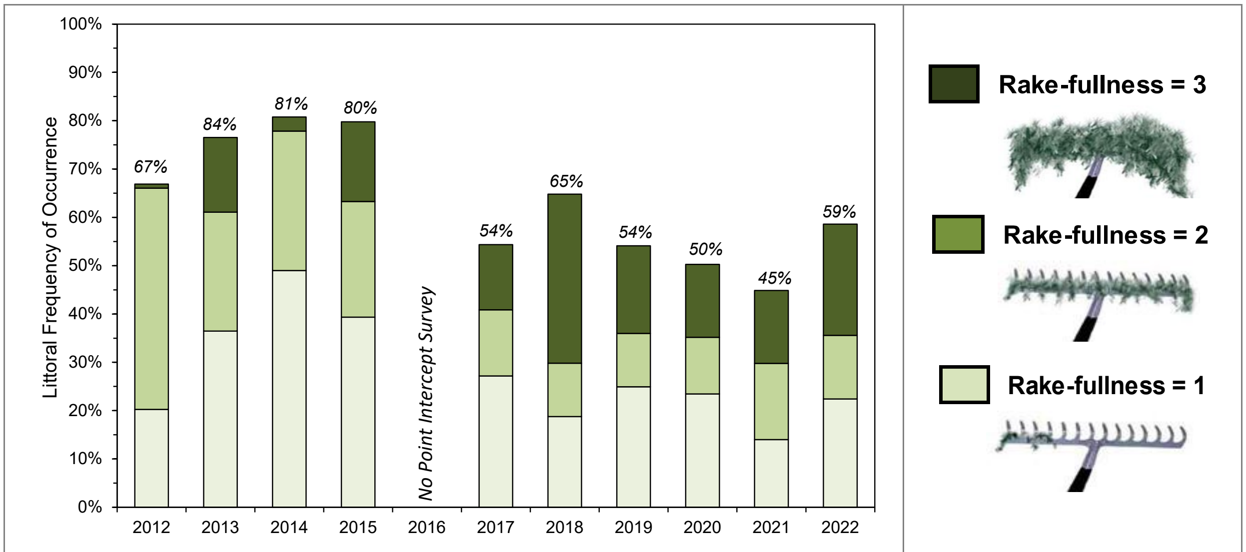


Figure 3.4-3. Silver Lake LFOO and TRF ratings. Created using data from 2012-2015 and 2017-2022 point-intercept surveys. LFOO = littoral frequency of occurrence. TRF = total rake fullness.

Approximately 59% of the point-intercept sampling locations in 2022 that fell within the maximum depth of aquatic plant growth (31 feet), or the littoral zone, contained aquatic vegetation (Figure 3.4-3). Aquatic plant rake fullness data collected in 2022 indicates that 22% of the 500 littoral sampling locations contained vegetation with a total rake fullness rating (TRF) of 1, 13% had a TRF rating of 2, and 23% had a TRF rating of 3 indicating overall aquatic plant biomass in Silver Lake is moderate (Figure 3.4-3).

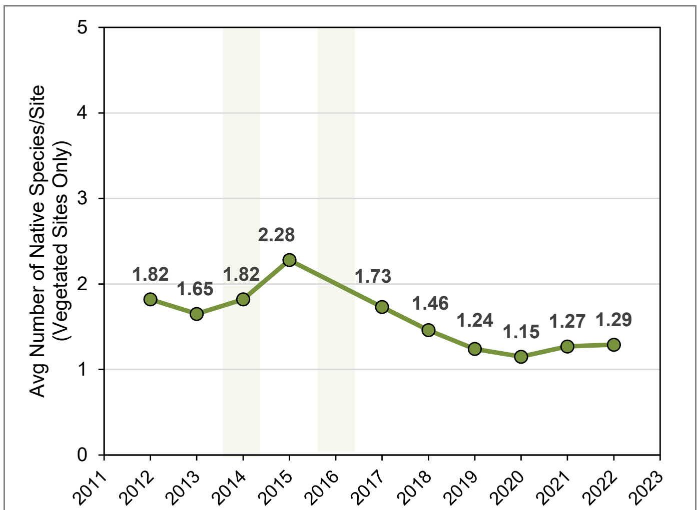


Figure 3.4-4. Average number of native species per sampling site. Shaded stripes indicate whole-lake herbicide treatments

Figure 3.4-4 shows the average number of native species present on the sampling rake for vegetated sites only on Silver Lake. This metric helps to indicate the species abundance and distribution across sampling locations. Silver Lake's native species distribution peaked in 2015 then steadily declined from 2017 to 2020. Recently, 2021 and 2022 showed a slight rebound in average species per sampling location (Figure 3.4-4). The largest decline occurred between 2015 and 2017, coinciding both the with the 3-foot increase in water levels and the whole-lake fluridone treatment.

Of the 24 species directly sampled with the rake during the point-intercept survey, coontail, wild celery, and muskgrasses were the three-most frequently encountered plants in 2022 (Figure 3.4-5). In the field, it is often difficult to distinguish between certain species of aquatic plants that are very similar morphologically, especially when flowering/fruiting material is not present. Because of this, the littoral occurrences of the following morphologically-similar species were combined for this analysis: slender (*Najas flexilis*) and southern naiad (*N. guadalupensis*), small pondweed (*Potamogeton pusillus*) and slender pondweed (*P. berchtoldii*)., as well as leafy (*P. foliosus*) and stiff pondweed (*P. strictifolius*). Muskgrasses (*Chara* spp.) and stoneworts (*Nitella* spp.) were also combined and will be referred to as charophytes within the subsequent text.

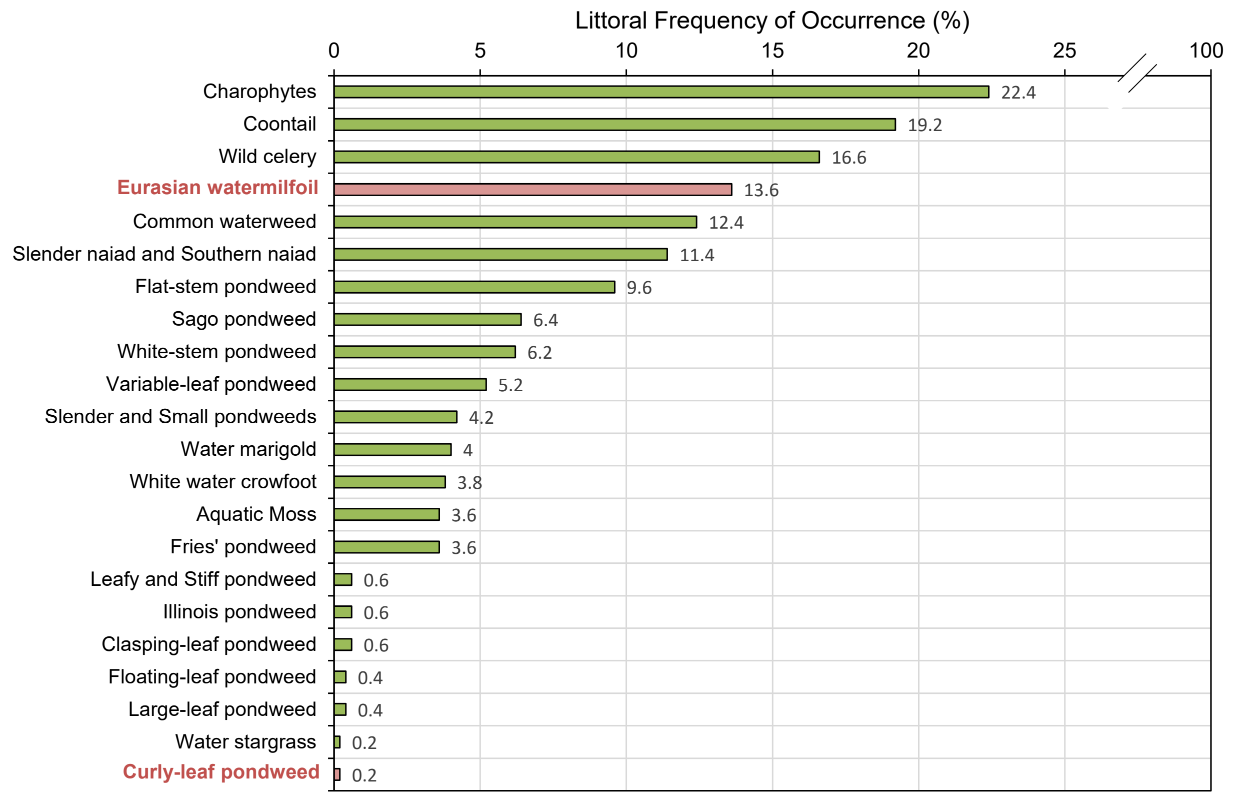
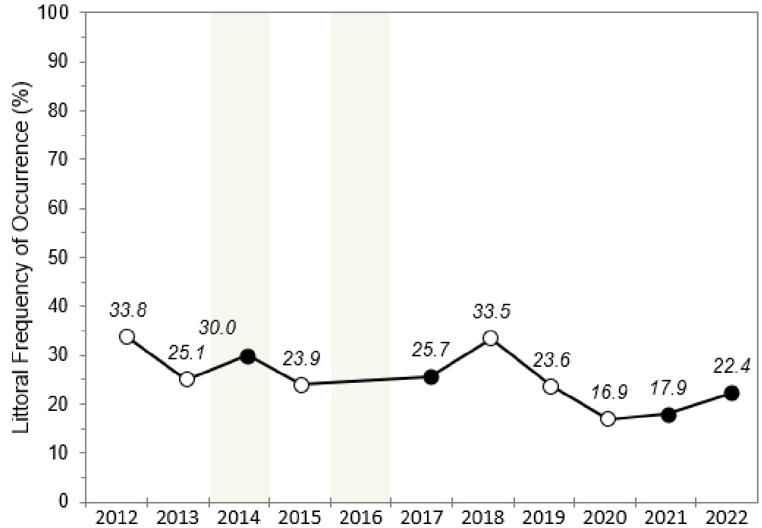


Figure 3.4-5. Silver Lake littoral frequency of occurrence. Created using data from the 2022 survey.

Muskgrasses and stoneworts, are a genus of macroalgae, are not true vascular plants, and are often abundant in waterbodies that are clear with higher alkalinity. Often growing in dense beds, muskgrasses and stoneworts to stabilize bottom sediments, provide excellent structural habitat for aquatic organisms, and are sources of food for fish, waterfowl, and other wildlife (Borman 2007). Charophytes were the most frequently encountered native aquatic plant species in Silver Lake in 2022, being found at depths ranging from 3 and 30 feet of water. (Figure 3.4-6 & Photograph 3.4-5). Charophytes were also the most frequently recorded plant in the 2018, 2017, and 2012 point-intercept surveys. The 25% increase in occurrence of charophytes between 2021 and 2022 was not statistically valid (Chi-Square $\alpha = 0.05$).

Charophytes
(*Chara* spp. & *Nitella* spp.)

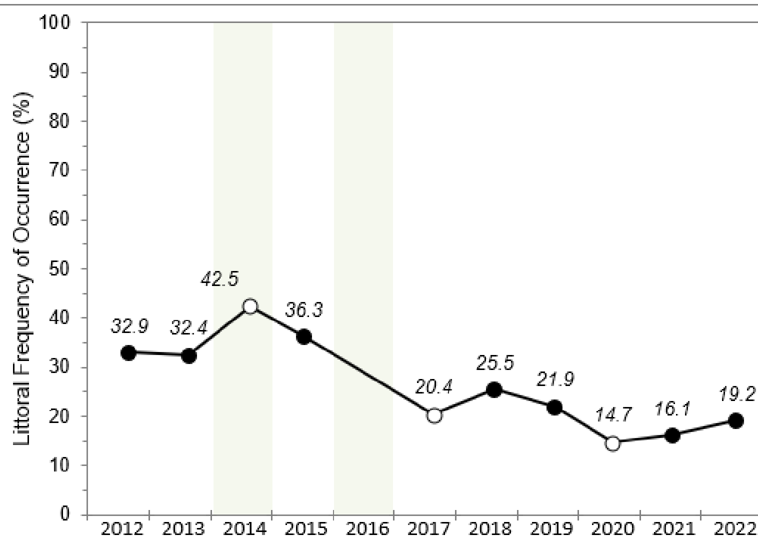


Photograph 3.4-5. Muskgrasses (*Chara* spp.). Photo credit Onterra.

Figure 3.4-6. Littoral frequency of occurrence of charophytes. Open circle indicates a statistically valid change in occurrence from the previous survey (Chi-Square α = 0.05).

Coontail was the second most frequently encountered native aquatic plant species in Silver Lake in 2022 with a littoral frequency of occurrence of 19% (Figure 3.4-7 & Photograph 3.4-6). Coontail was the most frequently recorded plant in the 2021, 2020, 2019, 2015, and 2014 point-intercept surveys (Figure 3.4-7). Coontail possess whorls of leaves which fork into two to three segments, and provides ample surface area for the growth of periphyton and habitat for invertebrates. 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 most of its nutrients directly from the water (Gross et al. 2003). This ability in combination with a tolerance for low-light conditions allows coontail to become more abundant in eutrophic waterbodies with higher nutrients and low water clarity. In 2022, coontail was abundant throughout most littoral areas of Silver Lake being found at depths ranging from 6 and 24 feet of water.

Coontail
(*Ceratophyllum demersum*)



Photograph 3.4-6. Coontail (*Ceratophyllum demersum*). Photo credit Onterra.

Figure 3.4-7. Littoral frequency of occurrence of coontail. Open circle indicates a statistically valid change in occurrence from the previous survey (Chi-Square α = 0.05).

Wild celery was the third most frequently encountered native aquatic plant species in Silver Lake in 2022 with a littoral frequency of occurrence of 17% (Figure 3.4-8 & Photograph 3.4-7). The 32% increase in occurrence of wild celery between 2021 and 2022 was not statistically valid. 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. 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. In 2022, wild celery was abundant throughout most littoral areas of Silver Lake being found at depths ranging from 5 and 15 feet of water.

Wild celery
(*Vallisneria americana*)

Photograph 3.4-7. Wild celery (*Vallisneria americana*). Photo credit Onterra.

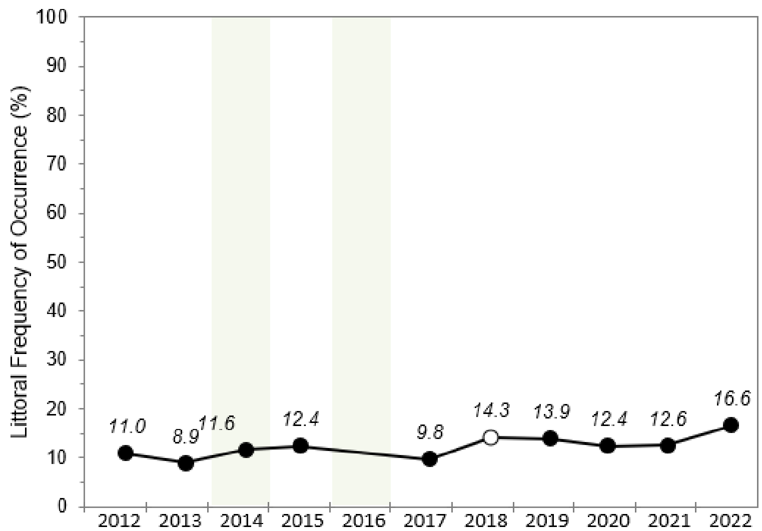


Figure 3.4-8. Littoral frequency of occurrence of wild celery. Open circle indicates a statistically valid change in occurrence from the previous survey (Chi-Square α = 0.05).

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 plants is 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 instance, while charophytes were found at 22% of the sampling locations in Silver Lake in 2022, its relative frequency of occurrence is 12%. Explained another way, if 100 plants were randomly sampled from Silver Lake, 12 of them would be charophytes. Looking at relative frequency of occurrence (Figure 3.4-9), 10 species comprise approximately 62% of the plant community in Silver Lake.

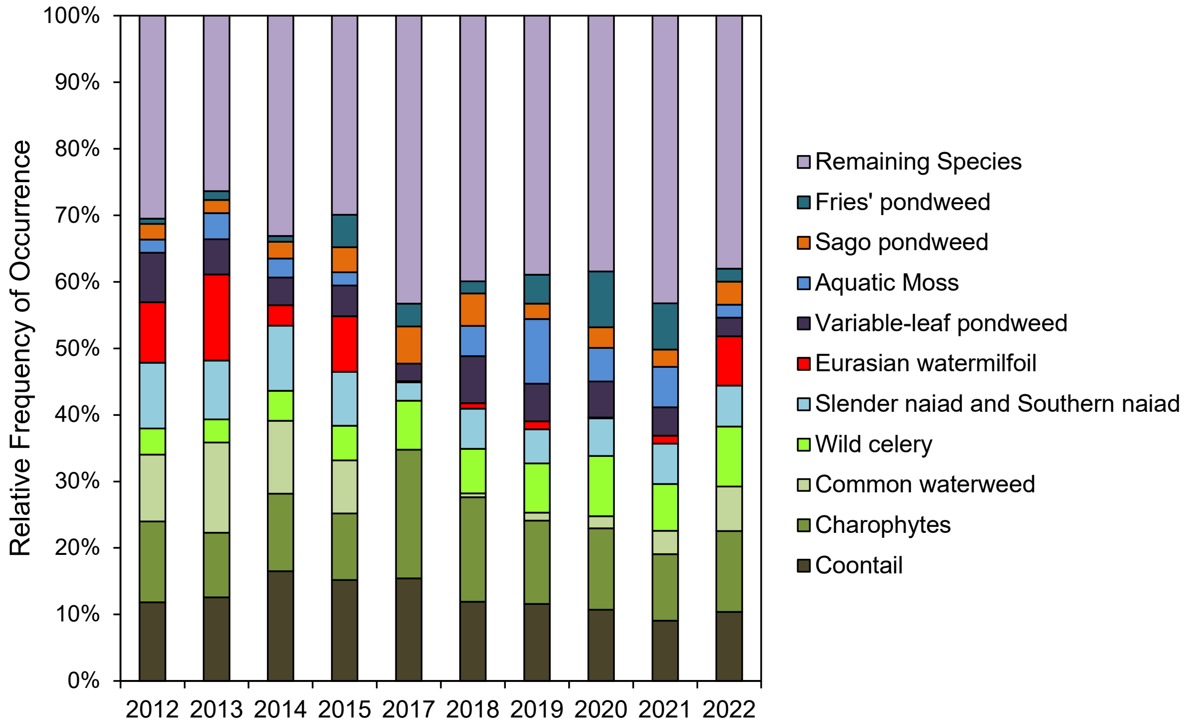


Figure 3.4-9. Silver Lake relative plant littoral frequency of occurrence. Created using data from 2012-2015 and 2017-2022 surveys.

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 3.4-10 shows that the native species richness for Silver Lake is above the North Central Hardwood Forests (NCHF) Ecoregion and Wisconsin State medians in 2022. Over the years this value has trended upward.

The species that are present in Silver Lake are indicative of high-quality conditions. Data collected from the aquatic plant surveys show that the 2022 conservatism value (6.4) is above the NCHF Ecoregion and Wisconsin State medians (Figure 3.4-10), indicating that the majority of the plant species found in Silver Lake are considered sensitive to environmental disturbance and their presence signifies good environmental conditions.

Combining Silver Lake's aquatic plant species richness and average conservatism values to produce its Floristic Quality Index (FQI) results in a high value of 31.4 (equation shown below); well above the median values for the ecoregion and state (Figure 3.4-10), and further illustrating the quality of Silver Lake's plant community.

FQI = Average Coefficient of Conservatism (6.4) * √ Number of Native Species (24)
FQI = 31.4

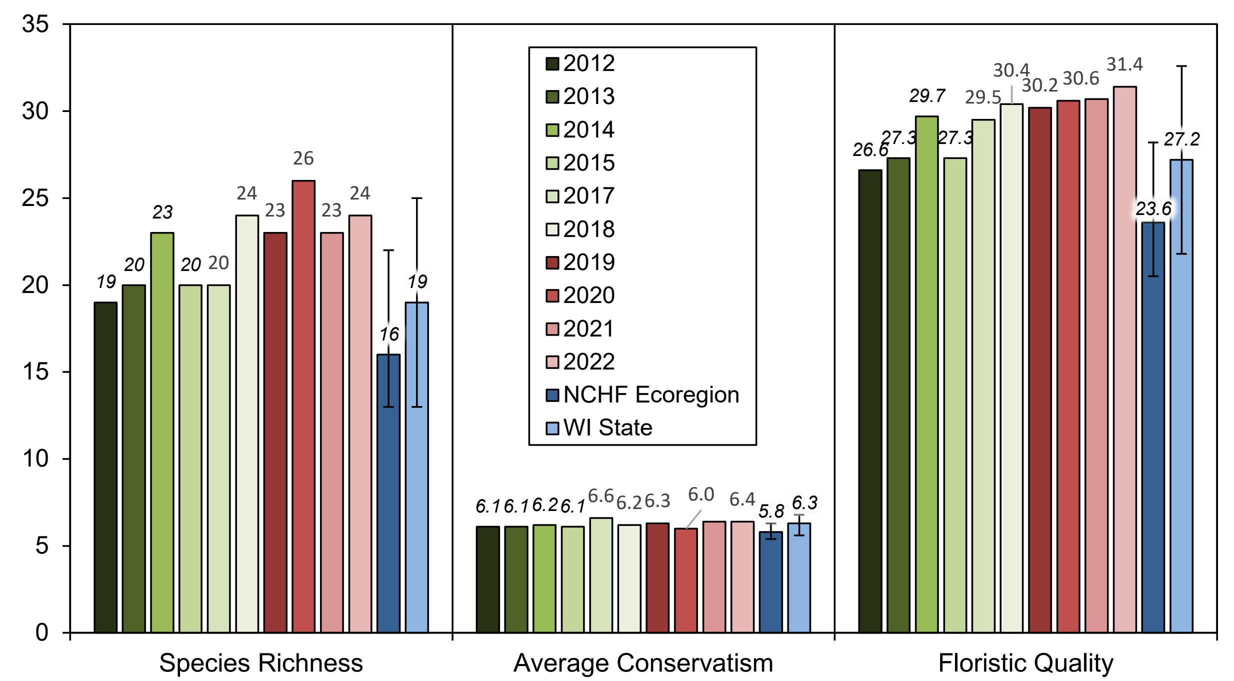


Figure 3.4-10. Silver Lake Floristic Quality Assessment. Created using data from 2012-2015 and 2017-2022 surveys. Analysis following (Nichols 1999) where NCHF Ecoregion.

Because Silver Lake contains a high number of native aquatic plant species, one may assume their aquatic plant communities have high species diversity. However, as discussed earlier, species diversity is also influenced by how evenly the plant species are distributed within the community.

The aquatic plant community in Silver Lake was found to be highly diverse, with a Simpson's diversity value of 0.92 (Figure 3.4-11). This value ranks above state and ecoregion upper quartiles. 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.

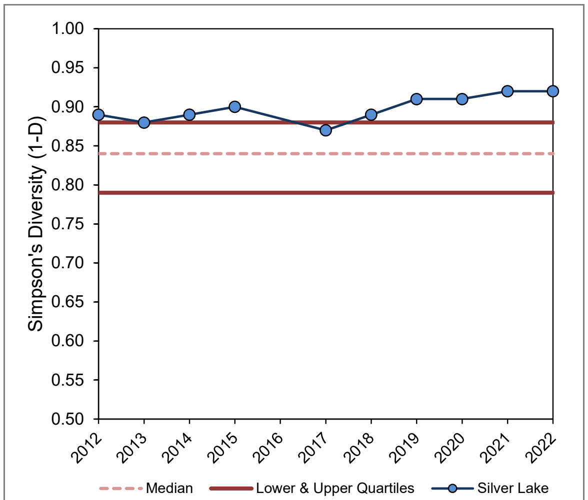


Figure 3.4-11. Silver Lake species diversity index. Ecoregion data provided by WDNR Science Services.

Silver Lake's emergent and floating leaf plant community was also mapped on August 1, 2022 in near-shore areas around the lake. The 2022 community map indicates that approximately 1.1 acres (0.3%) of the 352 acre-lake contain these types of plant communities (Table 3.4-12 and Map 6). Five floating-leaf and emergent species were located on Silver Lake, 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. Considering Silver Lake has 1.1 acres of these communities, they are likely having very little impact on reducing wave action in near shore areas.

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 Silver Lake. This is important because these communities are often negatively affected by recreational use and shoreland development. One study found a 66% reduction in vegetation coverage on developed shorelands when compared to the undeveloped shorelands in Minnesota lakes (Radomski and Goeman 2001). 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.

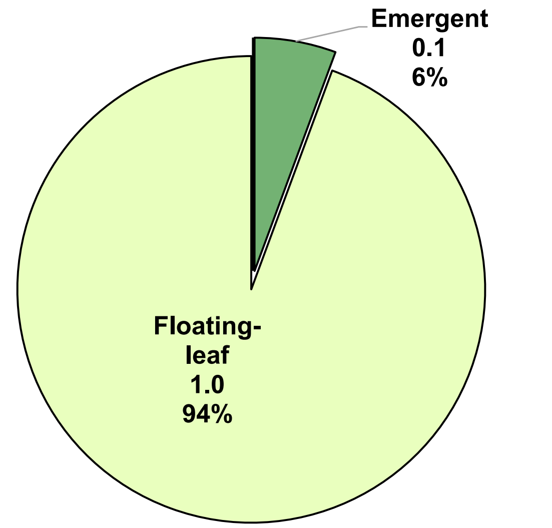


Figure 3.4-12. Silver Lake acres of plant community types. Created from 2022 community mapping survey.

Non-Native Aquatic Plants in Silver Lake

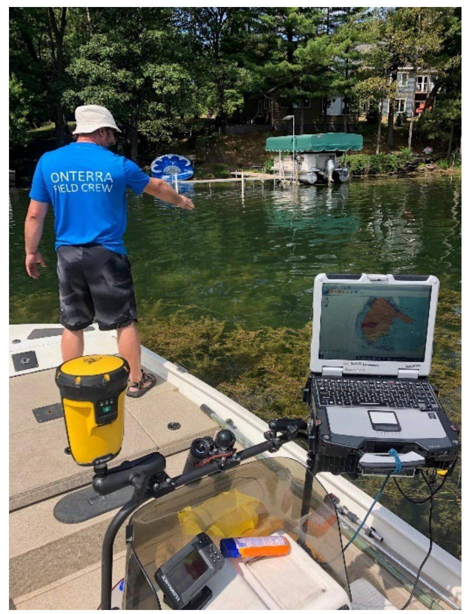
Because of their tendency to upset the natural balance of an aquatic ecosystem, exotic species are paid particular attention to during the aquatic plant surveys. Two exotics, curly-leaf pondweed and Eurasian watermilfoil are the primary targets of this extra attention.

Except for the emergent and floating-leaf community data discussed in Figure 3.4-12, all the aquatic plant data discussed so far was collected as part of point-intercept surveys. The subsequent materials will also incorporate data from AIS mapping surveys. Additional explanation about how these two surveys differ is discussed below.

The point-intercept survey provides a standardized way to gain quantitative information about a lake's aquatic plant population through visiting predetermined locations and using a rake sampler to identify all the plants at each location (Photograph 3.4-8). The point-intercept survey can be applied at various scales. Most commonly, the point-intercept survey is applied at the whole-lake scale to provide a lake-wide assessment of the overall plant community. More focused point-intercept surveys, called sub-sample point-intercept surveys, may be conducted over specific areas to monitor an active management strategy such as herbicide treatments or mechanical harvesting. These types of sub-sample point-intercept surveys have been conducted as part of the 2020 Foxtail Bay ProcellaCOR™ treatment.

Photograph 3.4-8. Point-intercept survey on a WI lake. Photo credit Onterra.

While the point-intercept survey is a valuable tool to understand the overall plant population of a lake, it does not offer a full account (census) of where a particular species exists in the lake. During the HWM mapping survey, the entire littoral area of the lake is surveyed through visual observations from the boat (Photograph 3.4-9). Field crews supplemented the visual survey by deploying a submersible camera along with periodically doing rake tows. The HWM population 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 were applied to AIS locations that were considered as *small plant colonies* (<40 feet in diameter), *clumps of plants*, or *single or few plants*.



Photograph 3.4-9. HWM mapping survey. Photo credit Onterra.

Overall, each survey has its strengths and weaknesses, which is why both are utilized in different ways as part of this project.

Curly-leaf Pondweed (Potamogeton crispus)

Photograph 3.4-10. Curly-leaf pondweed plants. Photo credit Onterra.

Curly-leaf pondweed (CLP; Photograph 3.4-10) was first documented in Silver Lake in 2004. Like our native pondweeds, CLP produces alternating leaves along a long, slender stem. The leaves are linear in shape with a blunt tip, and the margins are wavy and conspicuously serrated (saw-like). The plants are often brownish/green in color. Silver Lake has a number of native pondweed species, some of which are similar in appearance to and may be mistaken for CLP.

Curly-leaf pondweed's primary method of propagation is through the production of numerous asexual reproductive structures called turions. Once mature, these turions break free from the parent plant and may float for some time before settling and overwintering on the lake bottom. Once favorable growing conditions return (i.e., spring), new plants emerge and grow from these turions. Many of the turions produced by CLP begin to sprout in the fall and overwinter as small plants under the ice. Immediately following ice-out, these plants grow rapidly giving them a competitive advantage over native vegetation. Curly-leaf pondweed typically reaches its peak biomass by May to early-June, and following the production of turions, most of the CLP will naturally senesce (die back) by mid-July.

If the CLP population is large enough, the natural senescence and the resulting decaying of plant material can release sufficient nutrients into the water to cause mid-summer algal blooms (Leoni et al. 2016). In some lakes, CLP can reach growth levels which interfere with navigation and recreational activities. However, in other lakes, CLP appears to integrate itself into the plant community and does not grow to levels which inhibit recreation or have apparent negative impacts to the lake's ecology. Because CLP naturally senesces in early summer, surveys are completed early in the growing season in an effort to capture the full extent of the population.

Numerous early-season surveys have been conducted on Silver Lake and have documented the CLP population as being present, widespread, and very low in density. The largest population of CLP in recent years was mapped during June 2018. The 2018 survey found the CLP population in Silver Lake was distributed throughout the lake with a localized *highly scattered* colony in Fox Tail Bay (Figure 3.4-13). Other locations of *clumps of plants*, and *single or few plants* were also found throughout the lake.

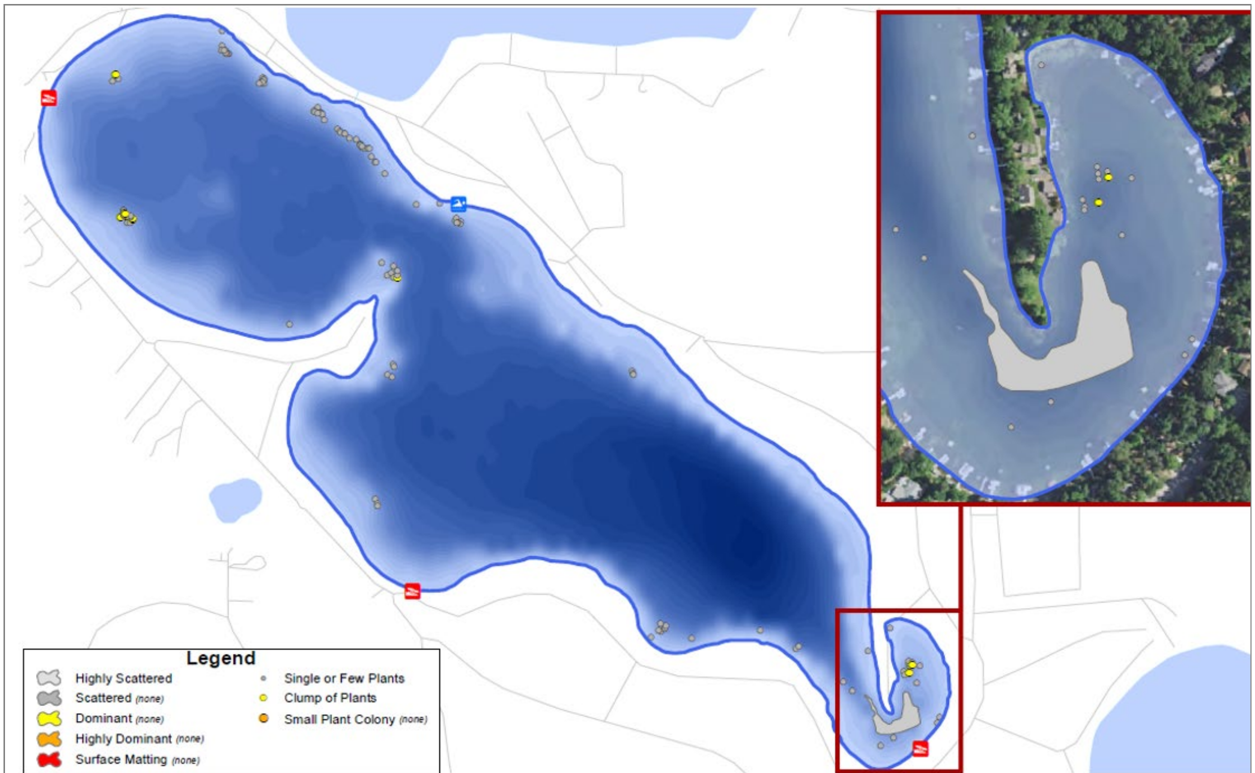


Figure 3.4-13. June 2018 Early-Season CLP Mapping Survey Results.

Curly-leaf Pondweed Management

The theoretical goal of CLP population management is to kill the plants each year before they are able to produce and deposit new turions. Not all of the turions produced each year sprout new plants the following year; many lie dormant in the sediment to sprout in subsequent years. This results in the creation of a sediment turion bank or reserve. Normally, a control strategy for an established CLP population includes multiple years of herbicide application of the same area to deplete the existing turion bank within the sediment. An example of this type of strategy would be through the annual application of the endothall for five or more consecutive years targeting the same areas of the lake. In instances where a large turion base may have already built up because of a long-term presence in the system, lake managers and regulators question whether the repetitive annual herbicide strategies may be imparting more strain on the environment than the existence of the invasive species.

Because CLP has been present in Silver Lake for nearly 20 years, the population is considered established within the lake. It is possible that the CLP population may not expand its footprint beyond what has already been observed in the lake in the past. It should be expected that the CLP population will be variable from year to year in Silver Lake as environmental variables such as snow depth, ice cover, and water temperatures, may or may not be favorable for turion germination in any given year.

Eurasian watermilfoil (Myriophyllum spicatum)

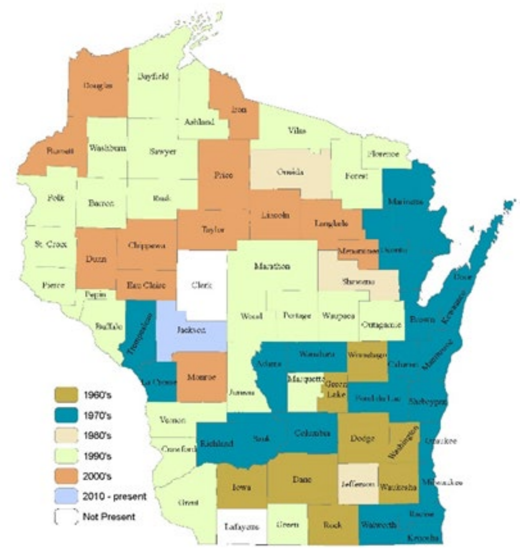


Figure 3.4-14. Spread of Eurasian watermilfoil within WI counties. WDNR Data 2022 mapped by Onterra.

Eurasian watermilfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.4-14). 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. However, in some lakes, EWM appears to integrate itself within the community without becoming a nuisance or having a measurable impact to the ecological function of the lake.

The non-native plant that is of primary concern in Silver Lake is Eurasian watermilfoil (EWM, Photograph 3.4-11). Genetic analysis confirms that the invasive milfoil population is comprised of both EWM and hybrid water milfoil (*M. spicatum x sibiricum*, HWM). Subsequent discussion using "HWM" will represent the collective invasive milfoil population of Silver Lake unless specifically referenced otherwise.

Photograph 3.4-11. Surface matting hybrid watermilfoil colony in Silver Lake. Photo credit Onterra.

EWM Research: WDNR Long-Term EWM Trends Monitoring

Starting in 2005, WDNR Science Services began conducting annual point-intercept aquatic plant surveys on a set of 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.

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). The data are clearest for unmanaged lakes in the Northern Lakes and Forests Ecoregion (NLF) and the North Central Hardwood Forests Ecoregion (NCHF) (Figure 3.4-15).

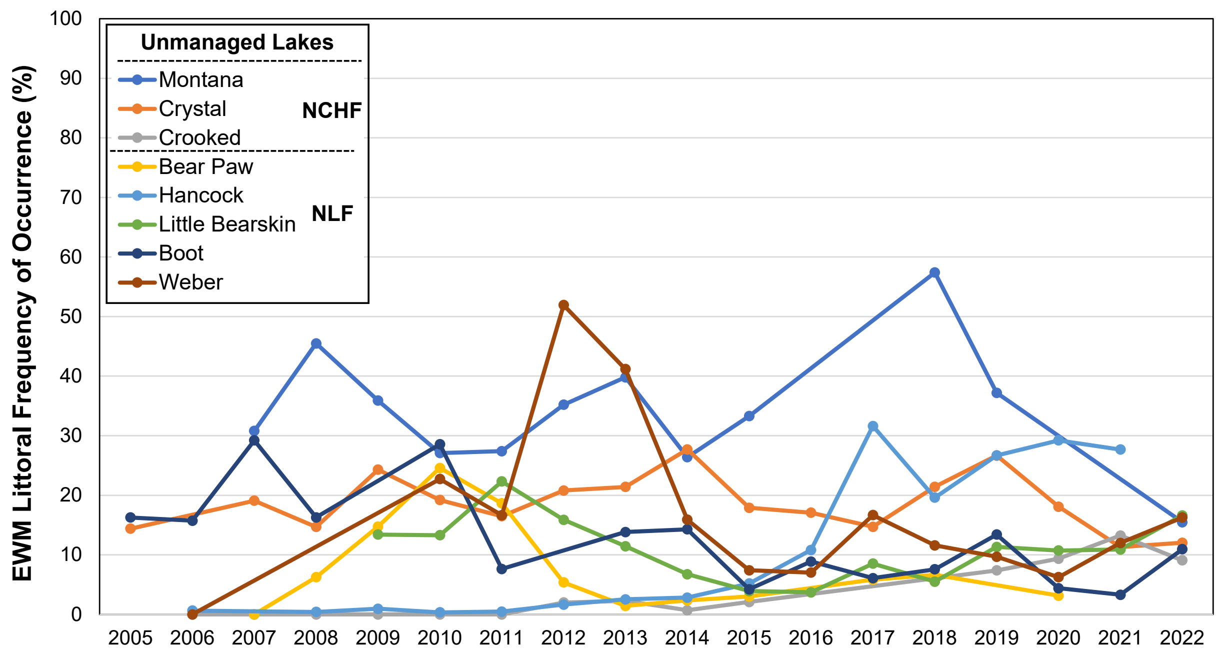


Figure 3.4-15. Littoral frequency of occurrence of EWM in the NLF and NCHF Ecoregions without management. Data provided by and used with permission from WDNR.

The results of the study clearly indicate that EWM populations in unmanaged lakes can fluctuate greatly between years (Figure 3.4-15). Following initial infestation, EWM expansion was rapid on some lakes, but overall was variable and unpredictable (Nault 2016). On some lakes, the EWM populations reached a relatively stable equilibrium whereas other lakes had more moderate year-to-year variation. Regional climatic factors also seem to be a driver in EWM populations, as many EWM populations declined in 2015 even though the lakes were at vastly different points in time following initial detection within the lake. 2019 also experienced record rainfall which may have had an impact on the EWM population indirectly through a decrease in water clarity.

HWM population of Silver Lake

Whole-lake point-intercept surveys have been completed almost every year since 2012 (Figure 3.4-16). Targeted herbicide treatments have occurred over this timeframe, and will be subsequently discussed in more length. The figure below highlights the two whole-lake treatments that occurred in the spring of 2014 (triclopyr) and the entire growing season of 2016 (fluridone).

The HWM population had been maintained at a relatively low level during the course of 2017-2021 as the SLMD enacted an integrated pest management strategy (coordinated hand harvesting and/or spot herbicide treatment) following the 2016 whole-lake fluridone treatment. The occurrence increased to 13.6% in 2022 representing a valid increase in occurrence since 2021, and the highest occurrence since prior to the fluridone treatment.

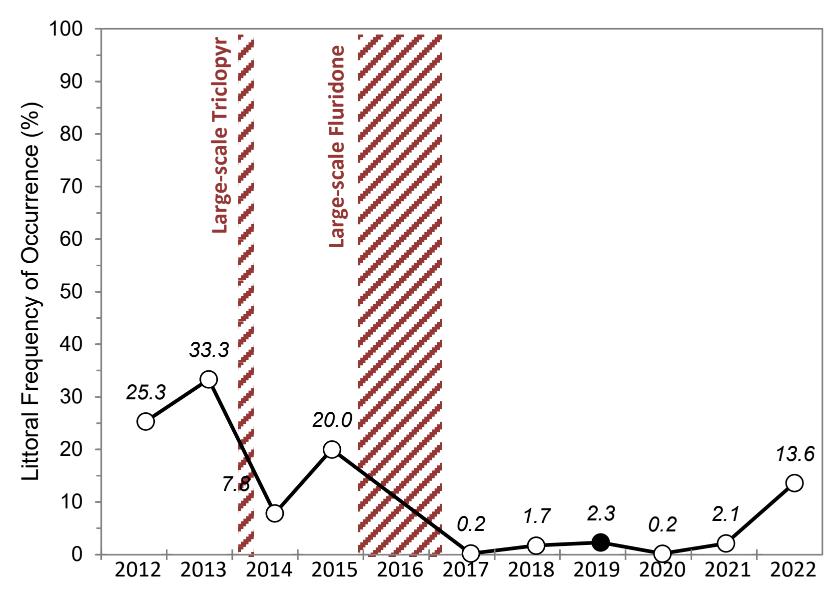


Figure 3.4-16. Littoral occurrence of HWM in Silver Lake. Created using data from whole-lake point-intercept surveys.

Onterra was first hired to work on Silver Lake in 2015. During that year, the first late-season EWM mapping survey was conducted. These surveys have been completed annually up until present (Figure 3.3-14). Please note that this figure represents only the acreage of mapped HWM polygons, not HWM mapped with point-based methodologies (*Single or Few Plants, Clumps of Plants,* or *Small Plant Colonies*). Said another way, HWM marked with point-based mapping methods do not contribute to colonized acreage as shown on Figure 3.3-20. Map 7 shows the entire HWM footprint over this period, including the point-based HWM occurrences.

In an effort to increase the flow of information between lake stakeholders and project planners, the SLMD has piloted an interactive web map application for the system, allowing users to see the late-season HWM mapping survey and management areas as they relate to their property or favorite recreation and fishing spots. Various layers can be turned on and off, and some layers can be selected and a pop-up window will provide additional information. This platform allows a better understanding of the HWM population dynamics and management strategies over time. To directly access this interactive map:

https://onterra.maps.arcgis.com/apps/View/index.html?appid=68c272c7817644e1a76f4df6fb2872d0

The mapped HWM population was relatively high in 2015, the year after a relatively unsuccessful whole-lake triclopyr treatment occurred (Map 8). A whole-lake fluridone treatment started in spring of 2016, maintaining detectable herbicide concentrations in the lake for over a year after the initial treatment through a series of subsequent "bump" treatments. No colonized HWM was detected during 2016 or 2017, although point-based occurrences started to reappear in Foxtail Bay in 2017.

From 2017-2022, HWM hand-harvesting (including DASH) had begun and colonized acreage of HWM remained fairly low at about 7.8 acres in 2019. A spot treatment of ProcellaCOR™ in Fox Tail Bay occurred in 2020 which impacted the HWM throughout the southern basin of the lake (Map 8). The HWM began to rebound in 2021 and has increased from 13.7 to 48.8 acres (2022) despite annual hand-harvesting (Map 9, Figure 3.4-17).

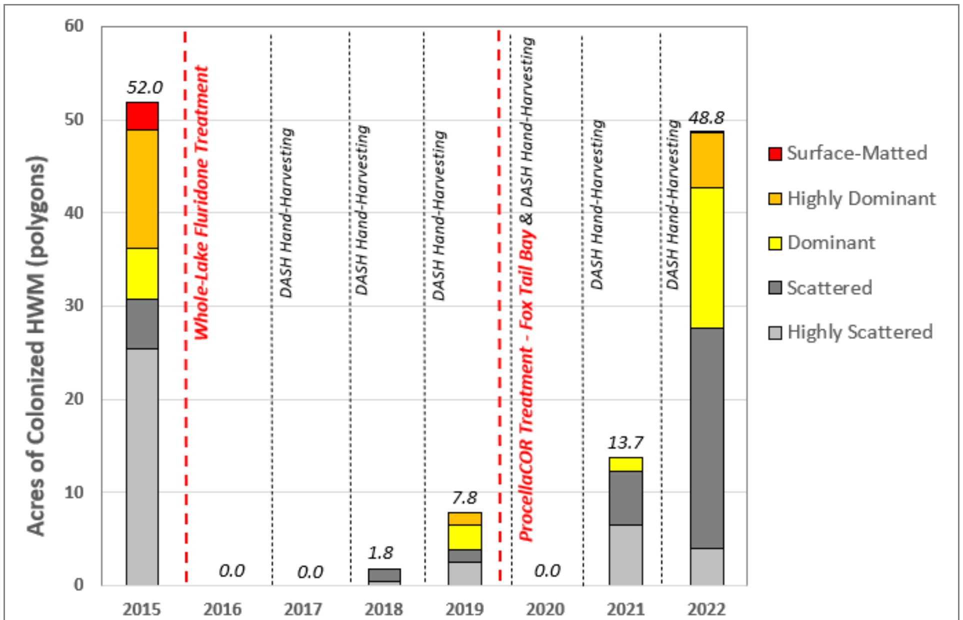


Figure 3.4-17. Acreage of colonized HWM in Silver Lake from 2015-2022. Created using data from Onterra late-season AIS mapping surveys.

Silver Lake Historic HWM Management

The term *Best Management Practice (BMP)* is often used in environmental management fields to represent the management option that is currently supported by that latest science and policy. When used in an action plan, the term can be thought of as a placeholder with anticipation of having an evolving definition over time. During the early days of management on the system, the BMP for managing EWM was through 2,4-D 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 to cause mortality as the herbicide dissipates out of the spots rapidly.

Table 3.4-3. Historical HWM Herbicide Treatments on Silver Lake. Data complied through available WDNR and applicator records.

	Date	Acres	Herbicide	Active Ingredient	Amount	Rate	Notes
2003	5/21/2003	5.0	Navigate	Granular 2,4-D	675 lbs	135 lb/ac	
	9/3/2003	13.0	Navigate	Granular 2,4-D	1,713 lbs	131.8 lb/ac	
2004	5/18/2004	9.0	Navigate	Granular 2,4-D	1,200 lbs	133 lb/ac	
	8/9/2004	0.1	Navigate	Granular 2,4-D	5.1 lbs	110 lb/ac	Private, single pier
	9/13/2004	15.7	Navigate	Granular 2,4-D	2,350 lbs	150 lb/ac	
	11/4/2004	12.0	Navigate	Granular 2,4-D	1,950 lbs	162 lb/ac	
2005	6/1/2005	16.2	Navigate	Granular 2,4-D	3,250 lbs	200 lb/ac	
	10/1/2005	9.4	Navigate	Granular 2,4-D	1,594 lbs	170 lb/ac	
2006	5/23/2006	16.0	Navigate	Granular 2,4-D	3,150 lbs	197 lb/ac	
	6/1/2006	5.0	Navigate	Granular 2,4-D	1,000 lbs	200 lb/ac	
	10/20/2006	3.9	Navigate	Granular 2,4-D	600 lbs	150 lb/ac	
	?/?/2008	20.0	Navigate	Granular 2,4-D	4,629 lbs	200 lb/ac	
2009	6/4/2009	19.4	Navigate	Granular 2,4-D	3,485 lbs	180 lb/ac	
	10/1/2009	2.3	Navigate	Granular 2,4-D	350 lbs	152 lb/ac	
	10/27/2009	7.5	Navigate	Granular 2,4-D	1,500 lbs	200 lb/ac	
2010	7/14/2010	8.2	Navigate	Granular 2,4-D	1,550 lbs	189 lb/ac	
	9/29/2010	6.9	DMA-4	Liquid 2,4-D	105 gal	15.2 gal/ac	Foxtail Bay
2011	8/18/2011	9.9	Navigate	Granular 2,4-D	1,980 lbs	200 lb/ac	
	9/13/2011	10.0	Navigate	Granular 2,4-D	2,000 lbs	200 lb/ac	
	10/3/2011	13.5	Navigate	Granular 2,4-D	2,650 lbs	200 lb/ac	
2012	5/31/2012	24.8	Navigate	Granular 2,4-D	4,950 lbs	200 lb/ac	
	5/31/2012	3.5	Navitrol	Liquid Triclopyr	50 gal	1.5 ppm	
	6/4/2012	15.3	Navigate	Granular 2,4-D	3,050 lbs	200 lb/ac	
	8/1/2012	5.2	Navitrol DPF	Granular Triclopyr	1,100 lbs	2.0 ppm	
	6/4/2013	8.9	Renovate OTF	Granular Triclopyr	4,320 lbs	2.5 ppm	
	6/11/2014	86.0	Renovate OTF	Granular Triclopyr	2,4280 lbs	200 ppb ae	Whole-lake treatment
	7/27/2015	2.0	Captain/Tribune	Copper/Diquat	1 gal /4 gal	1.0 ppm /1.5 ppm	Nusiance nav lanes
2016	5/26/2016	86.4	Sonar One	Fluridone	942 lbs	4 ppb	Whole-lake treatment: Initial
	7/21/2016	86.4	Sonar One	Fluridone	656 lbs	2 ppb	Whole-lake treatment: Bump 1
	9/1/2016	86.4	Sonar One	Fluridone	656 lbs	2 ppb	Whole-lake treatment: Bump 2
	6/8/2020	15.9	ProcellaCOR EC	Florpyrauxifen-Benzyl	434.4 PDU	3.5 PDU/acre-ft	Foxtail Bay

Year	Acres
2003	18.0
2004	36.8
2005	25.6
2006	24.9
2007	0.0
2008	20.0
2009	29.2
2010	15.1
2011	33.4
2012	48.8
2013	8.9
2014	86.0
2015	2.0
2016	259.2
2017	0.0
2018	0.0
2019	0.0
2020	15.9
2021	0.0
2022	0.0

Table 3.4-4. Consolidated Management Summary for Silver Lake. Data compiled by SLMD

Year	EWM/HWM Mgmt Method	Acres	Concentration/ cubic yds harvested	HWM % Littoral Zone	
2003	Navigate, Granular 2.4-D	18			
2005-2006	Navigate, Granular 2.4-D	25-36			
2007	No spot treatment				
2008-2011	Navigate, Granular 2.4-D	20-33			
2012	Navigate, Granular 2.4-D	48		**25.3** %	2012, treated 48 acres
	Navitrol, Liquid Triclopyr	3.5	1.5 ppm		
2013	Renovate, Granular Tricloypr	8.9	2.5 ppm	**33.3** %	
2014	Renovate, Granular Tricloypr	260	2.5 ppm	7.0 %	Whole Lake treatment
2015	Captain/Tribune	2	1.5 ppm	20.7 %	Spot Navigation lane
2016	Sonar One/Fluridone	260	4 ppb		Whole Lake treatment
7/21/2016	Bump treatment		2 ppb		Fluridone present
9/1/2016	Bump tratement	Dive Time	2 ppb		for 407 days
2017	Diver Assisted Suction Harvesting	40 hrs	1400 plants	0.2 %	
2018	DASH	78	23 cu yds	1.7 %	
2019	DASH, suspend within Fox Tail Bay	213	46 cu yds	2.3 %	
2020	DASH	172	20 cu yds	0.2 %	
2020	ProcellaCOR EC	17	3.5 pdu		Fox Tail Bay
2021	DASH	184	104 cu yds	2.1 %	
2022	DASH	276	200 cu yds	13.6 %	

The SLMD conducted spot-treatments directed to control HWM from 2003 to 2013 (Table 3.4-3, Table 3.4-4). Almost all of these treatments were conducted with 2,4-D ester in the granular form. Emerging science demonstrated that liquid treatments provided more consistent results at a fraction of the cost of granular products, ester forms of 2,4-D were more toxic to aquatic life, larger application areas appeared to retain herbicide concentrations and exposure times better, and attention needed to be paid to the addition of individual spot treatments that may cumulatively function as a whole-lake treatment.

From an ecological perspective, whole-lake treatments are those where the herbicide may be applied to specific sites, but when the herbicide dissipates from where it was applied and reaches equilibrium within the entire mixing volume of water (of the 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 treated volume. A recent article by (Nault et al. 2018) investigated 28 large-scale herbicide treatments in Wisconsin and found that "herbicide dissipation from the treatment sites into surrounding untreated waters was rapid (within 1 day) and lake-wide low-concentration equilibriums were reached within the first few days after application."

The 2014 Aquatic Plant Management (APM) Plan recommended the SLMD initiate a whole-lake herbicide treatment targeting HWM in Silver Lake. Based on discussion with industry professionals and following herbicide challenge testing (SePRO, unpublished), two herbicide use patterns were discussed within the APM Plan: liquid fluridone and combination treatment of 2,4-D and endothall. Both of these strategies were not commonly used in Wisconsin at this time, so the use of an additional herbicide, granular triclopyr, was also entertained during discussions that occurred in late-winter of 2013/14 between Stantec, SLMD, and WDNR. Ultimately, a whole-lake granular triclopyr (Renovate OTF) treatment occurred in early-June 2014 targeting 180-200 ppb acid equivalent (ae) lake-wide.

Triclopyr concentrations fell short of achieving target levels, with the following hypotheses given: uneven lake-wide mixing, expansion of mixing zone (i.e. epilimnion) following weather events, inaccurate bathymetric data which calculations were based off, herbicide granules releasing below epilimnion, and granules releasing into sediment pore-water.

Silver Lake riparian property owners have voiced increased frustration over the 2014 treatment results and the overall historic lack of success controlling HWM within the lake. In response, the SLMD contracted with Onterra, LLC during May 2015 to provide the technical directions as it initiates monitoring and controlling HWM on Silver Lake, including their wish to implement a whole-lake herbicide treatment strategy during spring of 2016. Onterra developed a preliminary three-year control and monitoring strategy in which a whole-lake herbicide treatment would occur in year two of the project. Three herbicidep use patterns were investigated for applicability on Silver Lake in 2016: combination of liquid 2,4-D/endothall, liquid fluridone, and pelletized fluridone. Ultimately, the decisions was made to move forward with a pelletized fluridone to target HWM in Silver Lake in 2016.

Fluridone is a systematic herbicide that disrupts photosynthetic pathways (carotenoid synthesis inhibitor). The herbicide degrades via photolysis (some microbial degradation may also occur) and requires long exposure times (>90 days) to cause mortality to HWM. Herbicide concentrations within the lake are kept at target levels by periodically adding additional herbicide ("bump treatment") over the course of the summer based upon herbicide concentration monitoring results. While liquid fluridone treatments result in a high initial concentration that tapers off over time as the herbicide degrades, pelletized fluridone treatments gradually reach peak concentrations over time (extended release) and result in a lower, sustained lake-wide herbicide concentration. This use-pattern of fluridone appears to demonstrate increased selectivity towards native plants in some field trials.

For Silver Lake, SePRO recommended a 4 ppb initial treatment, with an understanding that the measured concentrations within the lake would be approximately 2-3 ppb because of the extended release rate, herbicide degradation, and plant uptake. Once measured herbicide concentrations from the lake fall below 2 ppb, additional bump treatments would occur to keep the concentration between 2-3 ppb. The water levels at the time of the treatment planning were too low for water exchange with Irogami Lake to be a factor in herbicide dissipation. Ultimately 3 applications occurred in 2016, with concentrations being largely maintained between 1.5-2.0 ppb until ice-on occurred in mid-December. July 7, 2017 herbicide concentration sample (407 days after initial application) confirmed that fluridone was still present within the lake, but only slightly above the detection levels. More information on the planning, design, implementation, and post treatment monitoring of this treatment can be found in the *[Big] Silver 2017 HWM Monitoring & Management Report*.

Table 3.4-5. Silver Lake, 2017-2022 Hand Harvest/ DASH Summary.

Year	Company	Dive Time (hrs)	EWM Removed (cubic yards)
2017	DASH, LLC	38.95	1,300+ plants
2018	APM, LLC	78.49	23.0
2019	APM, LLC	212.81	46.2
2020	APM, LLC	171.50	19.9
2021	APM, LLC	183.50	103.5
2022	APM, LLC	275.90	217.2
Totals		961.15	409.8

The SLMD contracted with professional hand-harvesting firms from 2017 to 2022 to provide manual removal harvesting services that have included the use of Diver Assisted Suction Harvesting (DASH). Overall, the hand-harvesting actions have resulted in over 400 cubic yards of HWM removed. Aquatic Plant Management LLC (APM) divers have noted Silver Lake's sandy substrate makes it easy for harvesters to target and extract the root of the HWM plant without clouding their vision underwater.

As discussed above, the 2016 fluridone treatment was highly effective at reducing the HWM population, with modest but anticipated impacts to the native plant community. Figure 3.4-18 shows the level of control and longevity of 8 pelletized fluridone treatments conducted during this timeframe. Except for the unsuccessful treatment on South Twin Lake, Vilas County, all treatments had invasive watermilfoil populations reduced to zero during the year after treatment. Silver Lake has had the longest results in this dataset, primarily thought to be the result of the follow-up manual removal program.

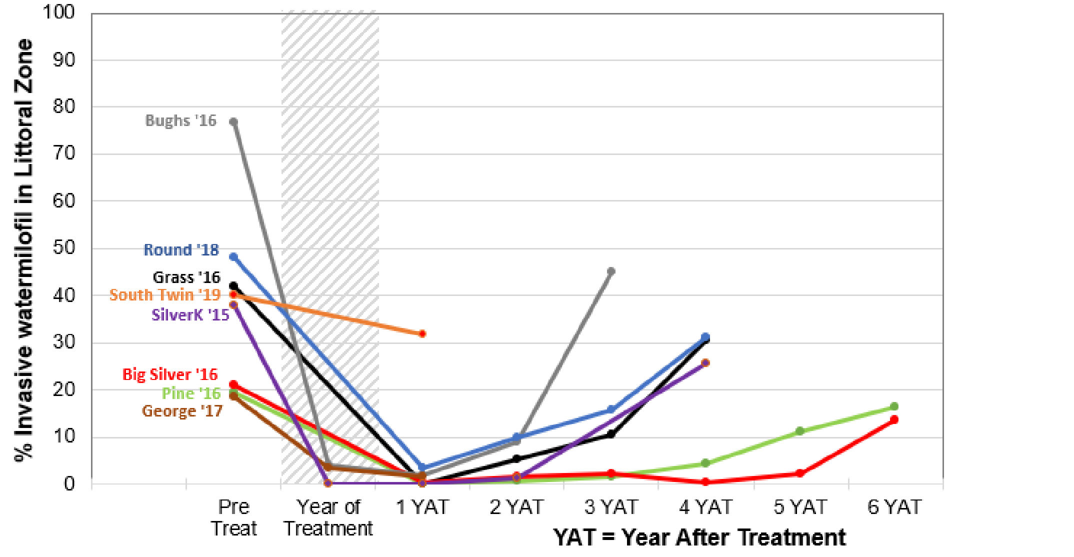


Figure 3.4-18. EWM/HWM Populations following whole-lake pelletized fluridone treatments. Data from Onterra, except Bughs, George, and SilverK (Kenosha) from Wisconsin Lake & Pond Resource.

Water levels on Silver Lake increased by at least 3 feet between the late-summers of 2015 and 2017, during the whole-lake fluridone treatment (Figure 3.4-19). The increased water depth of approximately 3 would make it much harder for HWM to survive in that footprint. This increased environmental stress during an active herbicide treatment period likely increased the effectiveness of this treatment. Said another way, a future treatment without this environmental factor may not be as effective.

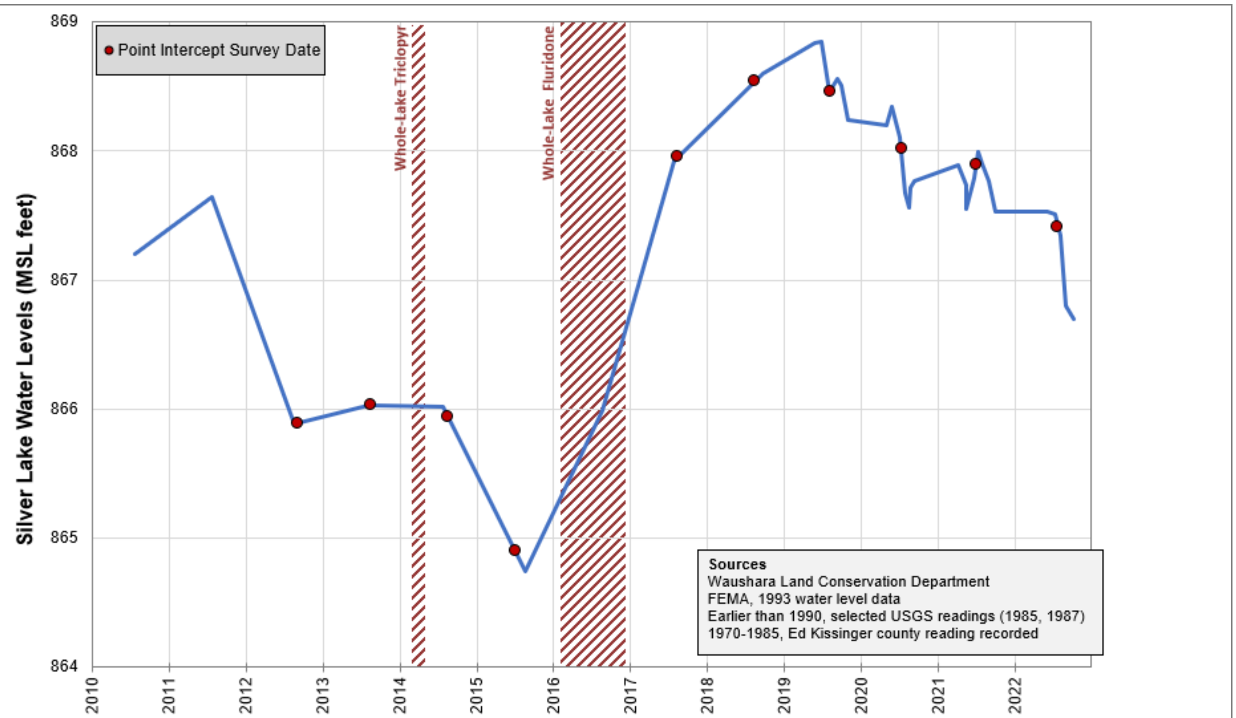


Figure 3.4-19. Silver Lake Water Levels.

Future HWM Management Philosophy

During the Planning Committee meetings held as part of this project, three broad hybrid watermilfoil management goals will be discussed including a generic potential action plan to help reach each of the goals (Figure 3.4-20). Conversation regarding risk assessment of the various management actions will also be discussed. Extracted relevant chapters from the WDNR's *APM Strategic Analysis Document* are provided to serve as an objective baseline for the SLMD to weigh the benefits of the management strategy with the collateral impacts each management action may have on the Silver Lake ecosystem. These chapters are included as Appendix D. The Planning Committee also reviewed these management perspectives in the context of perceived riparian stakeholder support, which is discussed in the subsequent sub-section.

1. **No Coordinated Active Management**
   (Let Nature Take its Course)
   - Focus on education of manual removal methods for property owners
   - Lake organization does not oppose contracted efforts, but does not organize or pay for them
2. **Minimize navigation and recreation impediment**
   (Nuisance Control)
   - Hand-harvesting alone is not able to accomplish this goal during high populations of EWM, herbicides and/or mechanical harvester would be required
3. **Reduce HWM Population on a lake-wide level**
   (Lake-Wide Population Management)
   - Would likely rely on herbicide treatment strategies (risk assessment)
   - Will not eradicate HWM
   - Set triggers (thresholds) of implementation and tolerance

Figure 3.4-20. Potential HWM Management Perspectives

<u>1. Let Nature Take its Course:</u> In some instances, the EWM/HWM population of a lake may plateau or reduce without conducting active management, as shown in the WDNR Long-Term EWM Trends Monitoring Research Project on Figure 3.4-15. Some lake groups decide to periodically monitor the EWM population, typically through a semi-annual point-intercept survey, but do not coordinate active management (e.g., hand-harvesting or herbicide treatments). This requires that the riparians tolerate the conditions caused by the EWM, acknowledging that some years may be problematic to recreation, navigation, and aesthetics. Individual riparians may choose to hand-remove the EWM within their recreational footprint, but most often the lake group chooses not to assist financially or with securing permits (only necessary if Diver Assisted Suction Harvest [DASH] is used). In some instances, the lake group may select this management goal, but also set an EWM population threshold or management *trigger* where they would revisit their management strategy if the population reached that level. Said another way, the lake group would let nature take its course up until populations reached a certain lake-wide level or site-specific density threshold. At that time, the lake group would investigate whether active management measures may be justified.

<u>2. Nuisance Control:</u> The concept of ecosystem services is that the natural world provides a multitude of services to humans, such as the production of food and water (provisioning), control of climate and disease (regulating), nutrient cycles and pollination (supporting), and spiritual and recreational benefits (cultural). Some lake groups acknowledge that the most pressing issues with the EWM population on their lake is the reduced recreation, navigation, and aesthetics compared to before EWM became established in their lake. Particularly on lakes with large EWM populations that may be impractical or unpopular to target on a lake-wide basis, the lake group would coordinate (secure permits and financially support the effort) a strategy to improve these cultural ecosystem services.

There has been a change in preferred strategy amongst many lake managers and regulators when it comes to established EWM population in recent years. Instead of chasing the entire EWM population with management, perhaps focusing on the areas that are causing the largest impacts can be more economical and cause less ecological stress. Mechanical harvesting and herbicide spot treatments are most typically employed to reach nuisance management goals, although hand-harvesting/DASH is sometimes employed to target small footprints. The SLMD has taken steps to align for managing HWM with a nuisance relief strategy in 2023 using both contracted mechanical harvesting and DASH manual removal.

3. Lake-Wide Population Management: Some believe that there is an intrinsic responsibility to correct for changes in the environment that are caused by humans. For lakes with HWM populations, that may mean to manage the HWM population at a reduced level with the perceived goal to allow the lake to function as it had prior to HWM establishment. Due to the inevitable collateral impacts from most forms of EWM management, lake managers and natural resource regulators question whether that is an achievable goal.

The repeated need for exposing the same areas of a lake to herbicides as is required when engaged in an annual spot treatment program has gone out of favor with some lake managers due to concerns over the non-target impacts that can accompany this type of strategy. In recent years, lake managers have sought actions that achieve multiyear EWM population suppression, such as whole-lake treatments. The EWM population reductions are more commensurate with the financial costs and risks of the treatment. For many lakes, lake-wide management is not ecologically and/or financially feasible. Sometimes this is because the system is too large or the EWM rebounds too quickly following management. The SLMD has historically taken a lake-wide population management approach, attempting to manage for suppressed EWM/HWM.

Herbicide Resistance

While understood in terrestrial herbicide applications for years, *herbicide resistance* (sometimes referred to as tolerance evolution) is an emerging topic amongst aquatic herbicide applicators, lake management planners, regulators, and researchers. Herbicide resistance is when a population of a given species develops reduced susceptibility to an herbicide over time, such that an herbicide use pattern that once was effective no longer produces the same level of effect. This occurs in a population when some of the targeted plants have an innate tolerance to the herbicide and some do not. Following an herbicide treatment, the more tolerant strains will rebound whereas the more sensitive strains will be controlled. Thus, the plants that re-populate the lake will be those that are more tolerant to that herbicide resulting in a more tolerant population over time.

If genetic variation in the target population exists, particularly the presence of hybrid watermilfoils, repetitive treatments with the same herbicide may cause a shift towards increased herbicide tolerance in the population. Rotating herbicide use-patterns can help avoid population-level herbicide tolerance evolution from occurring.

Stakeholder Survey Responses to Hybrid Watermilfoil Management

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. The return rate of the 2022 survey was 68%. Because the response rate was over 60%, the survey results can be understood in the context of the overall population (Silver Lake Management District) sampled.

Stakeholders were asked if they believed HWM was present in or immediately around Silver Lake (Question 25). Of the 187 respondents who answered this question, 92% percent of those respondents indicated that HWM is present in Silver Lake. SLMD stakeholders were then asked about their level of support or opposition for the past use of the aquatic herbicide, Fluridone, to manage HWM in 2016 in Silver Lake (Figure 3.4-21). This question was also filtered by stakeholders who have lived on the lake 6 years or more (Question 2).

Question 27: In 2016, a whole-lake Fluridone herbicide treatment was conducted on Silver Lake. What was your level of support or opposition for the use of aquatic herbicides to treat Eurasian watermilfoil in 2016?

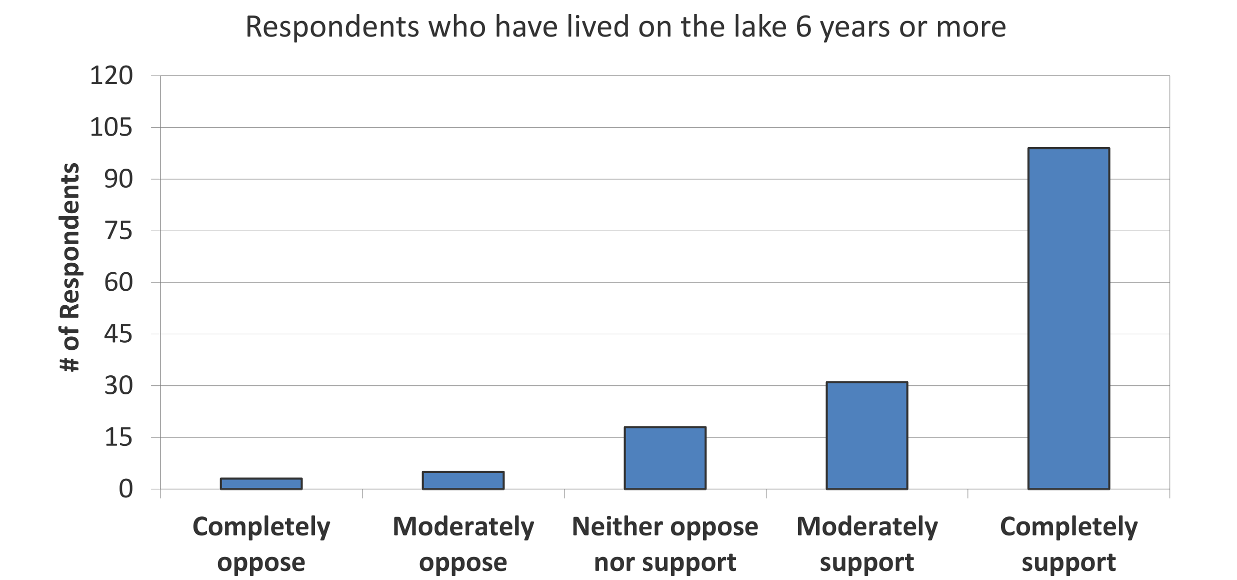


Figure 3.4-21. Select survey responses from the SLMD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

In 2022, SLMD stakeholders were asked about their level of support or opposition in the past for using hand-harvesting and DASH methodologies to manage HWM in Silver Lake (Figure 3.4-22). This strategy has been used on the lake since 2017 (following the Fluridone treatment).

Question 28: Since the 2016 whole-lake treatment, hand-harvesting (includes DASH) at a high amount of effort has been used to preserve the EWM reductions on Silver Lake. What was your level of support or opposition for the use of hand-harvesting to manage EWM since 2016?

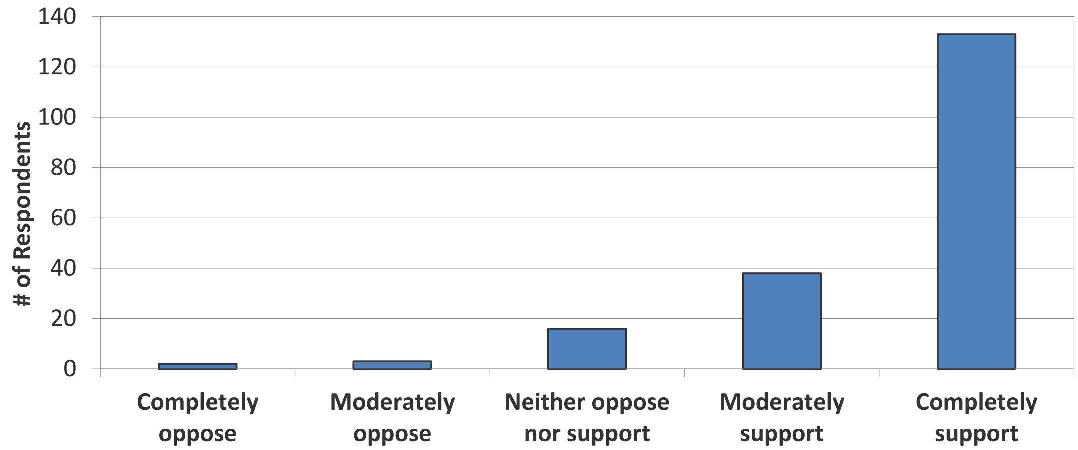


Figure 3.4-22. Select survey responses from the SLMD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Stakeholder were asked what their level of support or opposition was for the future use of various management techniques to target HWM in Silver Lake. Overall, herbicide treatments and hand-harvesting with DASH were highly supported (Figure 3.4-23). In regards to herbicide, the stakeholders who selected *not supportive* or *somewhat unsupportive* indicated their reasons were *potential impacts to human health, potential impacts to native (non-plant) species (fish, insects, etc.),* and *potential cost of technique was too high.* In regards to mechanical harvesting, the stakeholder who selected *not supportive* or *somewhat unsupportive* indicated their primary reason was *ineffectiveness of technique strategy.*

Question 30: As the Eurasian watermilfoil population rebounds from previous management activities, the Silver Lake Management District will begin assessing future techniques for the EWM population. What is your level of support for the future use of the following Eurasian watermilfoil management techniques in Silver Lake?

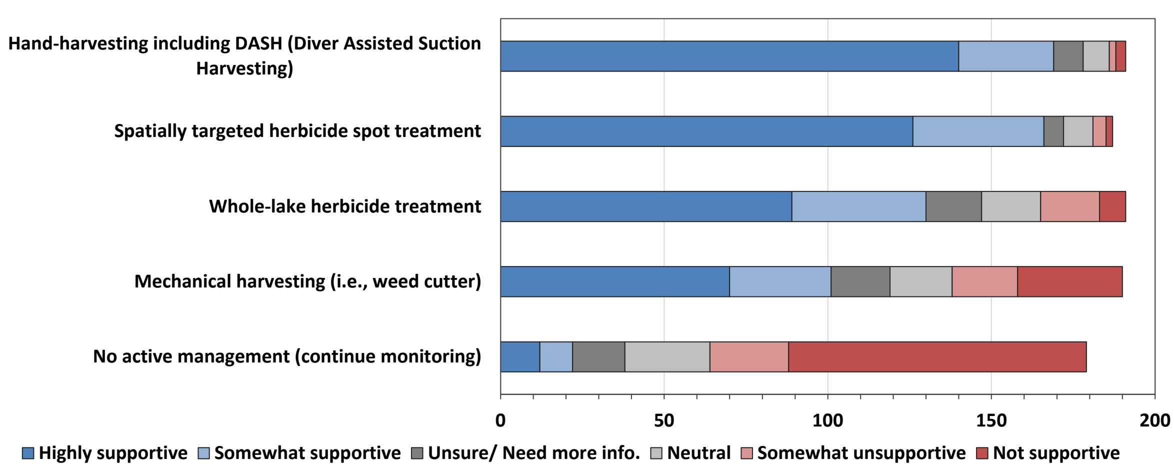


Figure 3.4-23. Select survey responses from the SLMD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Pale-yellow Iris (Iris pseudacorus)

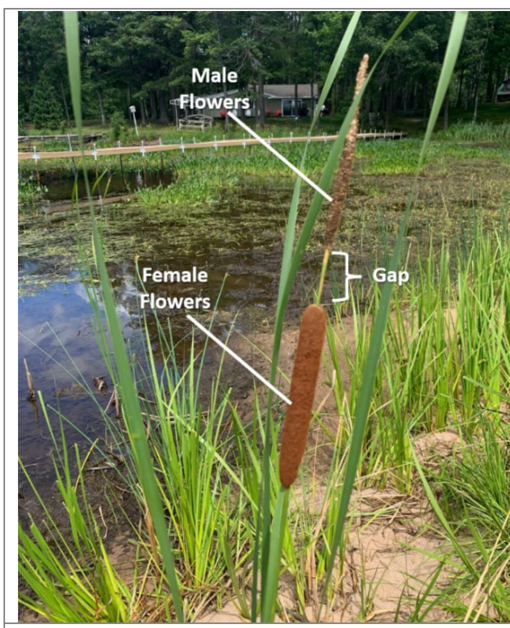
Pale-yellow iris was located at several locations within Foxtail Bay (Map 6). Pale yellow iris (*Iris pseudacorus*) is a large, showy iris with bright yellow flowers (Photograph 3.4-12). Native to Europe and Asia, this species was sold commercially in the United States for ornamental use and has since escaped into Wisconsin's wetland areas forming large monotypic colonies and displacing valuable native wetland species.

Photograph 3.4-12. The non-native wetland plant, pale-yellow iris. Clump of the non-native pale-yellow iris mixed with the native blue-flag iris (left) and large, contiguous colony of pale-yellow iris on the shores of Silver Thoroughfare (right). Photo credit Onterra.

Pale-yellow iris is typically in flower during the second half of June. The foliage of pale-yellow iris and northern blue flag iris (valuable native species) is too similar to make a definitive identification based off of this alone. Positive ID really needs to come from the flowers or the seed pods, which come after the flower is pollinated. Control of pale-yellow iris includes digging and removing the entire plant, cutting leaves below the water's surface, cutting flowers before they can go to seed, and herbicide applications for larger colonies.

Narrow-leaf Cattail (Typha angustifolia)

Two species of cattail can be found in Wisconsin, broad-leaved cattail (*Typha latifolia*) and narrow-leaved cattail (*Typha angustifolia*). Broad-leaved cattail is considered to be indigenous to North America while narrow-leaved cattail is believed to have been introduced from Europe and is considered to be ecologically invasive. While there are certain characteristics that differentiate these two species, hybridization between them (*T. x glauca*) is believed to be common, making positive identification without DNA analysis difficult (Photograph 3.4-13). Both species have prevalent throughout Waushara County. During the 2022 community mapping survey, several areas of cattail were observed in Foxtail Bay (Map 6). However, these plants lacked fully developed fruits like shown in the picture, therefore positive identification was unable to be made.



Photograph 3.4-13. Cattail identification aid. Narrow-leaved cattail shown, as there is a defined gap between male and female flowers. Broad-leaved cattail would have no gap between male and female flowers. Photo credit Onterra.

3.5 Aquatic Invasive Species in Silver Lake

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

Table 3.5-1. AIS present within Silver Lake

Type	Common name	Scientific name	Location within the report
Plants	Hybrid watermilfoil	*Myriophyllum sibiricum X M. spicatum*	Section 3.4 – Aquatic Plants
	Curly-Leaf Pondweed	*Potamogeton crispus*	Section 3.4 – Aquatic Plants
Invertebrates	Zebra mussel	*Dreissena polymorpha*	Section 3.6 – Aquatic Invasive Species
	Banded Mystery Snail	*Vivaparus georgianus*	Section 3.6 – Aquatic Invasive Species

Figure 3.5-2 displays the aquatic invasive species that Silver Lake stakeholder survey respondents believe are in Silver Lake. Only the species known to be present in Silver Lake 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 present within their lake, 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

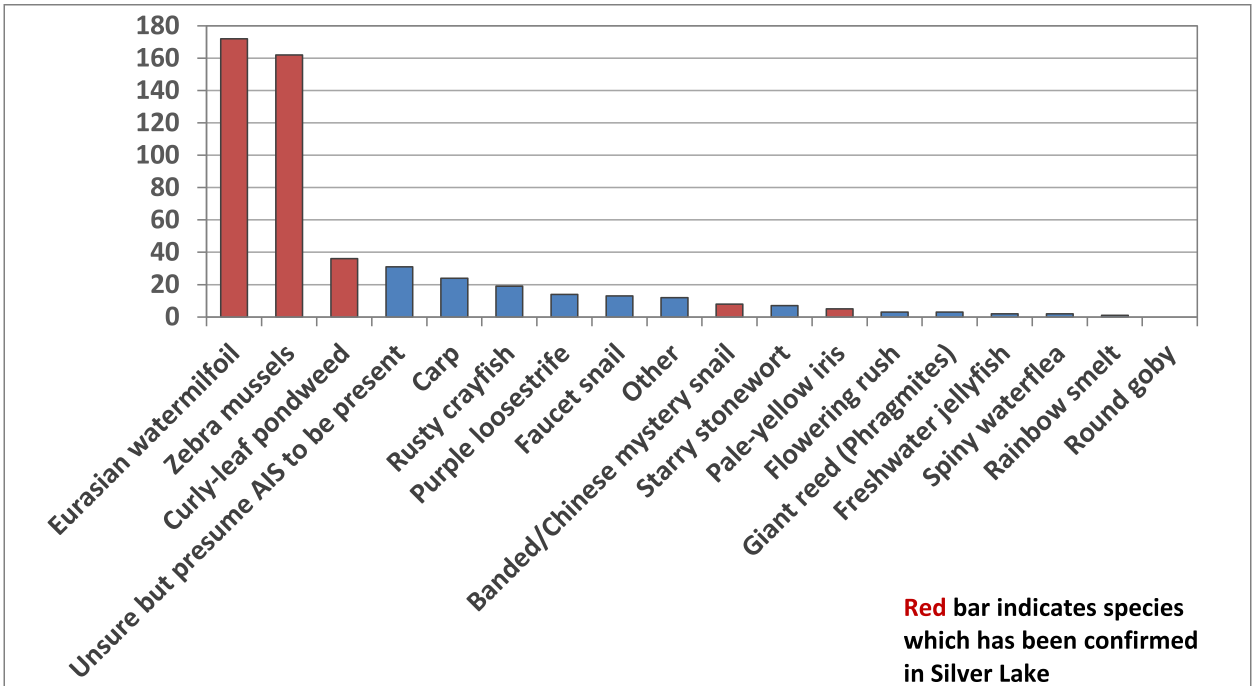


Figure 3.5-2. Stakeholder survey response Question #25. Which aquatic invasive species do you believe are present in or immediately around Silver Lake?

Mystery snails

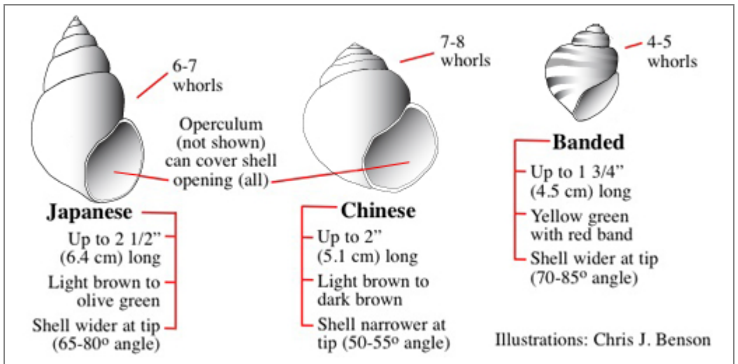


Figure 3.5-1. Identification of non-native mystery snails. Courtesy of Minnesota Sea Grant: (http://www.seagrant.umn.edu/ais/mysterysnail).

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 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). According to WDNR records, Silver Lake contains banded mystery snails. That being said, most lakes contain mixed populations of banded and Chinese mystery snails and it is likely that is also the case for Silver Lake.

Zebra mussels

Photograph 3.5-1. Zebra mussels attached to a large native mussel species. Photo credit: Onterra.

Zebra mussels (*Dreissena polymorpha*) are a small bottom dwelling mussel, 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.

Zebra mussels are reported as being first detected in Silver Lake in 2006. As discussed in the water quality section, zebra mussels can have large impacts on water quality. They can also have direct negative impacts on other mussel species (Photograph 3.5-1).

Silver Lake Prevention & Containment

Silver is an extremely popular regional destination by recreationists and anglers, making the lake vulnerable to new infestations of exotic species. The intent of a watercraft inspection program is not only be to prevent additional invasive species from entering the system through its public access locations, but also to prevent the infestation of other waterways with invasive species that originated in the system. The goal is typically to cover the landings 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 SLMD utilizes WDNR grant funding to sponsor watercraft inspections through the WDNR's Clean Boats Clean Waters (CBCW) program at the highway 21/73 landing on the northwest side of the lake. The SLMD has funded over 200 hours of inspections since 2015, with the exception of 2021 (Table 3.5-2). The SLMD partners with Gold Sands Resource Conservation & Development Council, Inc. to interview, hire, and maintain payroll and insurance for the seasonal staff.

Table 3.5-2. Watercraft inspections conducted on Silver Lake 2015-2020. Data from WDNR, SWIMS.

Silver Lake -- Access Off State Hwy 21								
	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Boats Inspected	419	385	313	176	211	562	206	431
Hours Spent	228	200	200	200	121	207	89	211
Boats Inspected/Hrs Spent	0.54	0.52	0.64	1.14	0.57	0.37	0.43	0.49

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 Silver Lake. 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 Adam Nickel (WDNR 2023).

Silver 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 Silver Lake 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.

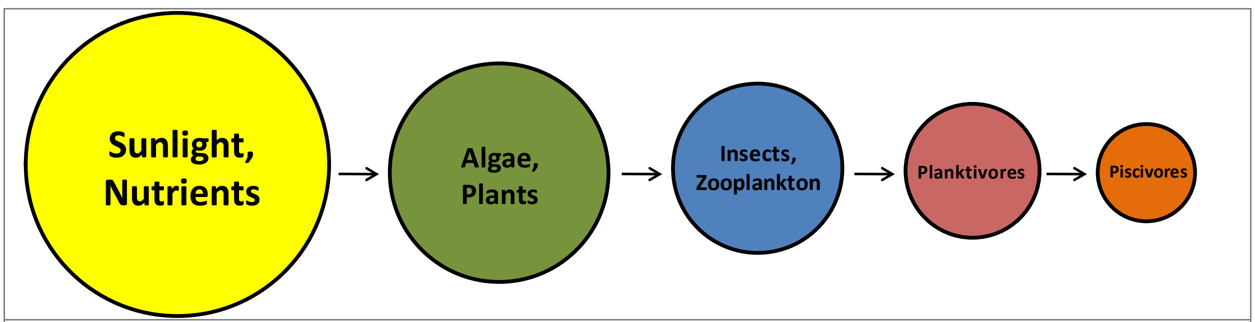


Figure 3.6-1. Aquatic food chain. Adapted from (Carpenter et al. 1985)

As discussed in the Water Quality section, Silver 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 Silver 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 shows the popular game fish present in the system. This is not an exhaustive list of fish species present in the lake.

Table 3.6-1. Gamefish present in Silver Lake with corresponding biological information (Becker 1983).

Common Name (*Scientific Name*)	Max Age (yrs)	Spawning Period	Spawning Habitat Requirements	Food Source
Black Crappie *(Pomoxis nigromaculatus)*	7	May - June	Near Chara or other vegetation, over sand or fine gravel	Fish, cladocera, insect larvae, other invertebrates
Bluegill *(Lepomis macrochirus)*	11	Late May - Early August	Shallow water with sand or gravel bottom	Fish, crayfish, aquatic insects and other invertebrates
Largemouth Bass *(Micropterus salmoides)*	13	Late April - Early July	Shallow, quiet bays with emergent vegetation	Fish, amphipods, algae, crayfish and other invertebrates
Northern Pike *(Esox lucius)*	25	Late March - Early April	Shallow, flooded marshes with emergent vegetation with fine leaves	Fish including other pike, crayfish, small mammals, water fowl, frogs
Pumpkinseed (Lepomis gibbosus)	12	Early May - August	Shallow warm bays 0.3 - 0.8 m, with sand or gravel bottom	Crustaceans, rotifers, mollusks, flatworms, insect larvae (terrestrial and aquatic)
Walleye *(Sander vitreus)*	18	Mid April - Early May	Rocky, wavewashed shallows, inlet streams on gravel bottoms	Fish, fly and other insect larvae, crayfish
Yellow Perch *(Perca flavescens)*	13	April - Early May	Sheltered areas, emergent and submergent veg	Small fish, aquatic invertebrates

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. Fisheries survey techniques. Fyke net positioned in the littoral zone of a Wisconsin Lake (left) and an electroshocking boat (right).

Fish Stocking

Photograph 3.6-2. Muskellunge 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.

Overall, Silver Lake has not received stocking from the DNR since 2011 (Table 3.6-2). Many walleye stocking efforts have been conducted dating back to the 1930s in efforts to establish a population, however lacking of spawning habitat has made natural recruitment unattainable. Several northern pike stocking events have also occurred, but none since 1993 (Table 3.6-3).

Table 3.6-2. Stocking data available for walleye in Silver Lake (1972-2011).

Year	Age Class	# Fish Stocked	Avg Fish Length (in)
2011	LARGE FINGERLING	1,497	6.0
2008	LARGE FINGERLING	1,500	7.0
2006	LARGE FINGERLING	1,500	6.5
2003	LARGE FINGERLING	480	4.6
2002	YEARLING	750	7.2
1997	SMALL FINGERLING	34,400	1.7
1996	FINGERLING	1,743	5.6
1994	LARGE FINGERLING	1,500	7.9
1989	FINGERLING	7,000	3.0
1987	FINGERLING	42,000	5.0
1986	FINGERLING	1,950	4.0
1984	FINGERLING	2,425	4.0
1975	ADULT	150	
1972	YEARLING	531	9.0

Table 3.6-3. Stocking data available for northern pike in Silver Lake (1982-1993).

Year	Age Class	# Fish Stocked	Avg Fish Length
1993	FINGERLING	1,725	8.6
1992	FINGERLING	1,720	8.0
1991	FINGERLING	1,173	7.0
1985	FINGERLING	1,750	9.0
1983	FINGERLING	1,795	9.0
1982	FINGERLING	2,000	9.0

Fishing Activity

Based on data collected from the stakeholder survey (Appendix B), fishing (open-water and ice) was the fifth-most important reason for owning property on or near Silver Lake (Question #5). Nearly 70% of respondents have fished in Silver Lake in the last three years. Figure 3.6-2 displays the fish that Silver Lake stakeholders enjoy catching the most, with bluegill/sunfish and largemouth bass being the most popular. Approximately 78% of these same respondents believed that the quality of fishing on the lake was either fair, good, or excellent (Figure 3.6-3). Approximately 44% of respondents who fish Silver Lake believe the quality of fishing has remained the same since they first started to fish the lake and 51% believe it has gotten somewhat or much worse (Figure 3.6-4).

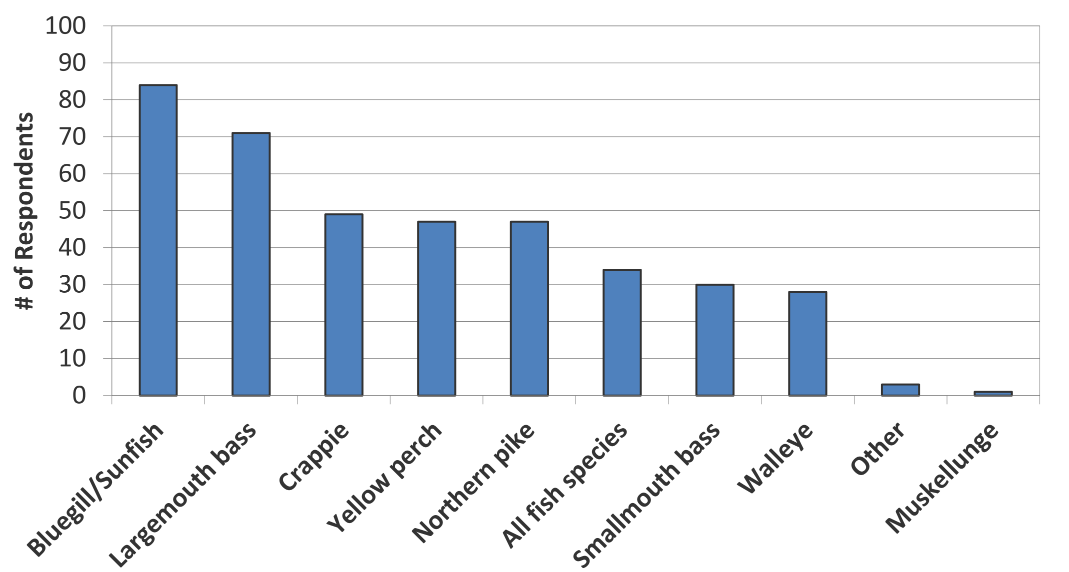


Figure 3.6-2. Stakeholder survey response Question #8. What species of fish do you like to catch on Silver Lake?

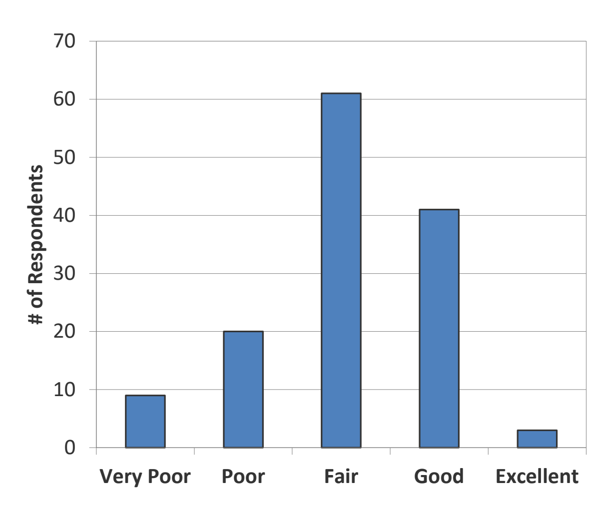


Figure 3.6-3. Stakeholder survey response Question #9. How would you describe the current quality of fishing on Silver Lake?

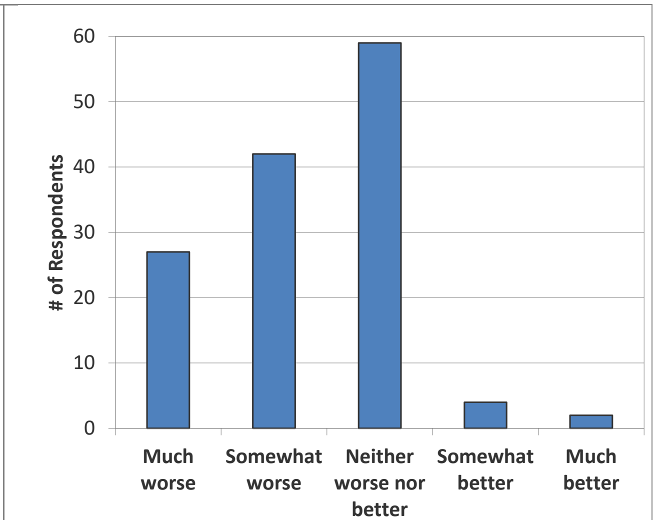


Figure 3.6-4. Stakeholder survey response Question #10. How has the quality of fishing changed on Silver Lake since you started fishing the lake?

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 (Niebur 2015). For example, if a CPUE is in the 90th percentile, it is higher than 90% of the other CPUEs in the state (Niebur 2015).

In 2021, the Wisconsin DNR conducted two separate surveys on Silver Lake to fully assess the fishery. In late march, crews deployed fyke nets in various areas around the lake to target walleye and northern pike, as well as certain panfish species. Any walleye encountered were given a fin clip to help determine any recaptured fish. On June 1st, a crew then returned to Silver Lake to conduct an electrofishing survey aimed at capturing bass and panfish as they come to the shallows to spawn. The crew surveyed 4.6 miles (one lap around the lake) in total. Data compiled from both surveys was put into a single report that can be found in Appendix E.

Gamefish

The gamefish present on Silver Lake represent different population dynamics depending on the species. The predominant gamefish species in Silver Lake is the largemouth bass, which is the most-targeted gamefish species by stakeholders according to the results of the stakeholder survey.

Largemouth bass are found in high densities in Silver Lake. Results from the 2021 survey show largemouth bass were sampled at a density of 45.7 fish per mile of shoreline, which ranks in the 87th percentile for the state of Wisconsin. Additionally, bass over 14 inches were sampled at a rate of almost 14 fish per mile of shoreline, ranking in the 92nd percentile for the state. Based on the high numbers and quality of fish, Silver Lake continues to be one of the best largemouth bass lakes in Waushara County. A full review of the 2021 survey results for largemouth bass can be found in Appendix E.

Northern Pike are found in moderate densities in Silver Lake. Northern Pike captured in fyke nets were marked with a fin clip and any recaptured fish were recorded. The results from the mark-recapture efforts calculated a population estimate of 1.6 pike per acre. While densities were slightly below the state average, biologists indicated that due to the timing of the survey, Silver Lake's morphology, and elevated water levels, some of the larger pike may have been located in Irogami Lake because of more suitable spawning habitat. Silver Lake has the potential to produce quality northern pike populations, however protecting and enhancing emergent plant shorelines areas is critical for spawning and then young-of-year fish. Onterra completed community mapping survey in 2022 to account for any emergent and floating-leaf species, these results can be found in Map 6. A full review of the 2021 WDNR fishery survey results for northern pike can be found in Appendix E.

Walleyes are found in Silver Lake at low densities, despite historical stocking data from both the DNR and the public. During the 2021 survey, only eight walleyes were sampled. Silver Lake does not have suitable walleye habitat, and natural reproduction is very rare in this lake. The last known stocking of walleye in Silver Lake was in 2011, and two fish from this stocking effort were captured in the 2021 survey. Both of these fish measured 24 inches. Additionally, a 27-inch fish was also captured during the survey.

Panfish

Bluegill, pumpkinseed (sunfish), and black crappies were the most common panfish encountered during the 2021 WDNR fisheries survey (Appendix E). The results for the stakeholder survey show anglers prefer to target bluegill and sunfish more than any other fish species in Silver Lake (Figure 3.6-2).

Bluegill are the most abundant panfish on Silver Lake. Results from the 2021 survey show that 830 bluegills were captured during fyke net and electrofishing efforts. Overall abundance ratings were high, ranking in the 93rd percentile and multiple fish over 9 inches were measured.

Pumpkinseed densities were also high, with fish up to 8 inches recorded. A full review of the 2021 survey results for bluegills and pumpkinseeds can be found in Appendix E.

Black crappie were commonly captured during the 2021 survey, but not as frequently as bluegill/pumpkinseed. Crappie typically experience a boom/bust cycle when spawning, so populations can vary from year to year. Biologists noted a strong 2019 class of fish, resulting in a high number of 4-6 inch fish that should provide good angling opportunities in the near future. Crappie growth rates in Silver Lake appear to fair to good, as some individuals reached 10 inches within five years. A 12.5 inch was the largest crappie captured during the survey. A full review of the 2021 survey results for black crappie can be found in Appendix E.

Yellow perch, while present in Silver Lake, are found in low densities. Neither of the surveys conducted by the DNR 2021 specifically targeted perch, but any incidental catches were recorded and measured. The DNR recommends increasing woody habitat to help improve perch spawning habitat.

Silver Lake 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 2022, 77% of the substrate sampled in the littoral zone of Silver Lake were soft, organic sediments, 22% was composed of sand, and 1% were composed of rock.

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). DNR biologist noted a very limited amount of optimal fish habitat was observed along the shores of Silver Lake (Appendix E). Onterra crews did not note any woody habitat during the2022 shoreland survey. Lake owners are encouraged to promote native vegetation and woody habitat along their shorelines.

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.


Photograph 3.6-3. Examples of fish habitat structures. Fish sticks (left) and half-log structure (right). 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 et al. 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.

Fishing Regulations

Regulations for Silver Lake fish species as of March 2023 are displayed in Table 3.6-4.

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 3.6-4. WDNR fishing regulations for Silver Lake (As of March 2023).

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 7, 2022 to March 5, 2023
Muskellunge and hybrids	1	40"	May 7, 2022 to December 31, 2022
Northern pike	5	None	May 5, 2018 to March 3, 2019
Walleye, sauger, and hybrids	5	15"	May 7, 2022 to March 5, 2023
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

Based off of the results of the 2021 survey, Silver Lake's fishery appears to be healthy and within many of the management goals set by the DNR. Going forward, biologists aim to keep largemouth bass populations near current densities to help prevent panfish overabundance and to keep the quality bass fishery that currently exists. The current daily limit of two northern pike over 26 inches may soon be changed to match the special regulation in Irogami Lake, where no minimum size limit is present but fish between 25-35 inches may not be kept. Fish habitat improvements would be beneficial to supplement the lack of natural habitat currently around the lake's shoreline.

4.0 SUMMARY AND CONCLUSIONS

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

1) Collect general baseline data to increase the general understanding of the Silver Lake ecosystem.
2) Collect detailed information regarding invasive plant species within the lake, with the primary emphasis being on Eurasian watermilfoil/hybrid watermilfoil
3) Collect sociological information from Silver Lake stakeholders regarding their use of the lake and their thoughts pertaining to the past and current condition of the lake and its management.

The three objectives were fulfilled during the project and have led to a good understanding of the Silver Lake ecosystem, the folks that care about the lakes, and what needs to be completed to protect and enhance them.

Silver Lake is considered a deep seepage lake even though it sometimes exchanges water with Irogami Lake, and sometimes stratifies during the summer (polymictic). The water quality analysis presented in this report concentrated on the trophic parameters: total phosphorus, chlorophyll-*a*, and Secchi disk depth. All three of these parameters suggest Silver Lake's water quality is in *excellent* condition. These studies also suggest that the lake experiences internal nutrient loading, a phenomenon that periodically allows deep water phosphorus to be mixed into warm summer surface waters which could cause free-floating algae blooms. While not a particularly large issue at the current time, future investigations will help understand the magnitude of this phosphorus source.

Sometimes Silver Lake also experiences filamentous algae blooms. Unlike the free-floating algae that give water a green appearance, these larger and connected algae can form unsightly and malodorous surface mats. As discussed in the water quality section (3.1), zebra mussels exacerbate filamentous algae production by filtering nutrients out of the water column and depositing on the lake bed where filamentous algae begin to grow. Zebra mussels also clear up the water column, allowing for increased light penetration to deeper parts of the lake increasing potential surface area for filamentous growth. It is common for lakes with zebra mussels to have increased filamentous algae issues.

This project largely relied on the efforts of previous studies to characterize the surficial watershed or drainage area of Silver Lake. These data indicate that there is a fair amount of development in the watershed and along the shorelines, which can increase nutrients and pollutant loads to the lake. Agriculture in the form of row crops deliver the largest source of nutrients to the lake, followed by pasture/grass. It is incredibly important for the long-term health of Silver Lake to ensure the valuable adjacent wetland complexes are in healthy and functioning order, as they act as a nutrient buffer between areas of agriculture and the lake.

While Silver Lake's water quality is currently in the *excellent* category, the biggest threat to it is the intense level of development around the lake. Urbanized shorelines, those with manicured grass and minimal other vegetation provide little to no filtering of the water as it runs off those shoreland properties. Further, those areas provide basically no fish or wildlife habitat in the most important area of a lake ecosystem. The buffering capacity and habitat value of those areas can be partially recovered through shoreland restorations utilizing the appropriate native vegetation for Silver Lake's region of the state. While it is often difficult for shoreland property owners to accept the fact that their nicely kept lawn truly impacts the lake in a very negative way, it is often even more difficult to convince them that the property should be restored for the good of the lake. Restoring the natural aesthetic of the Silver Lake shoreline is undoubtably the best lake stewardship activity that can be conducted for the system. The WDNR's Healthy Lakes & Rivers Grant program provides easy access to fund shoreland restoration activities for property owners.

Due to high clarity, a large portion of Silver Lake can support aquatic plants. The plant growing zone, or littoral zone, of Silver Lake extends to just over 30 feet in most years. The most abundant plants in Silver Lake are not actually true plants, but macro-algae called muskgrasses and stoneworts. Collectively called charophytes, these species typically proliferate in clear, high-calcium lakes such as those found in Silver Lake. These macro-algae are important for sediment stabilization, which is extremely important to help minimize the impacts from high amounts of recreation that periodically occur on the system. A non-native charophyte, starry stonewort has been located in a dozen or so lakes in WI, mostly on marly lakes like Silver Lake. To date, there have not been any effective chemical or manual removal management strategies for starry stonewort. Preventing this species from getting into Silver Lake and becoming established is of top priority.

Non-rooted plants like coontail and common waterweed are also dominant species in Silver Lake, moving around the lake and becoming entangled on standing vegetation. Growing out of the sandy areas of the lake is wild celery, one of the most beneficial food sources for migrating waterfowl. Over a dozen different pondweeds can be found in Silver Lake, with flat-stem pondweed being the most abundant during the most recent investigation. Although herbicide management of EWM/HWM has caused reductions on some of these species, the overall health of the aquatic plant community is strong, ranking higher than many lakes in the region and throughout the state.

The SLMD, in conjunction within WDNR grants, have invested a large amount of money managing the EWM/HWM population of Silver Lake primarily with herbicides but also incorporating strategic manual-removal operations in recent years to preserve the gains made from the herbicide treatments. The herbicide strategies employed during this time period were considered the *Best Management Practices (BMPs*) of the time. However, some of these management actions have gone out of favor as new research and information has become available.

As a part of this management planning project, the SLMD has been educated on the updated BMPs of managing EWM/HWM. This includes using newer herbicides that are more protective of the important native plant community and can be used at the whole-lake scale at a much shorter exposure time than other herbicides. The SLMD also piloted a mechanical harvesting program in 2023, where a weed cutter would be used to help partially restore navigation and recreational use of the lake. The SLMD has outlined criteria for when different types of management actions would be considered for Silver Lake that attempts to balance the health of the ecosystem and riparian enjoyment and aesthetics.

Through the process of this lake management planning effort, the SLMD has learned much about their system, both in terms of its positive and negative attributes. The SLMD continues to be tasked with properly maintaining and caring for this resource. It is particularly important to protect high quality aspects of the Silver Lake ecosystem.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the Silver Lake Management District Planning Committee and ecologist/planners from Onterra. It represents the path the Silver Lake Management 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 Silver 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: Ensure the SLMD has a Functioning and Up-to-Date Management Plan

Management Action:	Periodically update lake management plan
Timeframe:	Periodic
Facilitator:	Board of Commissioners
Description:	The term *Best Management Practice (BMP)* is often used in environmental management fields to represent the management option that is currently supported by that latest science and policy. When used in an action plan, the term can be thought of as a placeholder with anticipation of having an evolving definition over time. ***Comprehensive Management Plan*** The WDNR recommends *Comprehensive Lake Management Plans* generally get updated every 10 years. Implementation projects require a completion data of “no more than 10 years prior to the year in which an implementation grant application is submitted. The department may determine a longer lifespan is appropriate if the applicant can demonstrate a plan has been actively implemented and updated during its lifespan.” This allows a review of the available data from the lake, as well as to consider changing BMPs for water quality, watershed, and shoreland management. The *Comprehensive Lake Management Plan* presented here will be updated by 2033 or if prompted by a specific rationale such as the need to investigate a specific water quality parameter. ***Aquatic Plant Management Plan*** BMPs for aquatic plant management change rapidly, as new information about effectiveness, non-target impacts, and risk assessment emerges. To be eligible to apply for grants that provide cost share for AIS control and monitoring, “a current plan has a completion date of no more than 5 years prior to submittal of the recommendation for approval. The department may determine that a longer lifespan is appropriate for a given management plan if the applicant can demonstrate it has been actively implemented and updated during its lifespan.

	However, a [whole-lake] point-intercept survey of the aquatic plant community conducted within 5 years of the year an applicant applies for a grant is required." It is important to work with the regional WDNR Lakes Biologist to understand what is required at this time, as it is more subjective in comparison to the requirements of a *Comprehensive Lake Management Plan* as it relates to the specific management actions being considered. The SLMD conducted an official update to their aquatic plant management plan as part of this project. In roughly 2028, the SLMD would update the aquatic plant-related aspects of this plan to produce a focused *Aquatic Plant Management (APM) Plan.* ***<u>Annual Control & Monitoring Plan</u>*** It is important to note that the management plan provides a framework to guide the management action, but does not include the specific control plan for a given year. If the action being considered does not fall within the framework of the overall management plan, it is likely that an updated plan is needed regardless of its relative age. A written control and monitoring plan, consistent with the *Management Plan*, would be produced typically January-March prior its implementation. The control plan is useful for WDNR and other regulators when considering approval of the action, as well as to convey the control plan to SLMD members for their understanding.
Action Steps:	
	See description above.

<u>Management Action:</u>	Conduct periodic riparian stakeholder surveys
Timeframe:	Periodic: every 5 years, corresponding with management plan updates
Facilitator:	Board of Commissioners
Description:	Formal riparian stakeholder user surveys have been performed by the association in 2014 and 2022. Approximately once every 5-6 years, potentially at the time of a Plan update or prior to a large management effort, an updated stakeholder survey would be distributed to the SLMD members. Periodically conducting an anonymous stakeholder survey would gather comments and opinions from lake stakeholders to gain important information regarding their understanding of the lake and thoughts on how it should be managed. This information would be critical to the development of a realistic plan by supplying an indication of the needs of the stakeholders and their perspective on the management of the lake. The stakeholder survey could partially replicate the design and administration methodology conducted during 2021, with modified or additional questions as appropriate. The survey would again need to receive approval from a WDNR Research Social Scientist, particularly if WDNR grant funds are used to offset the cost of the effort.

Management Goal 2: Increase the SLMD's Capacity to Communicate with Lake Stakeholders and Facilitate Partnerships with Other Management Entities

Management Action:	Give consideration to the creation of an *Education Committee*
Timeframe:	Ambition to discuss in progress
Facilitator:	SLMD Board of Commissioners
Description:	By demonstrating a clear mission, the *Education Committee* would be responsible for marketing and public relations, educating its constituents, and overall increasing the SLMD's capacity to influence Silver Lake. The *Education Committee* would be the facilitator for a number of management actions outlined below. The *Education Committee* would deliver an oral report at the district's annual meeting of the previous year's accomplishments and the direction being considered for the following year. This committee would be comprised of 2-3 individuals, with at least one member being on the SLMD board of directors.
Action Steps:	
	See description above.

Management Action:	Bolster the SLMD, its communication abilities and pursue additional communication avenues
Timeframe:	Continuation of current effort
Facilitator:	Education Committee
Description:	Education represents an effective tool to address many lake issues. The SLMD aims to send out regularly distributed newsletters (at least once per year) and maintain an updated website, as the SLMD currently uses the Town of Marion's site for hosting content (https://townshipofmarion.com/lake-districts/silver-lake/). The webpage can become a useful repository for district information; including meeting minutes and announcement, general district information, and educational materials. However, it requires that the interested individual check back for updates periodically; therefore, it is not reliable for disseminating information quickly. The SLMD will consider supplemental educational forums, such as an email list or social media presence.

Management Action:	Routinely educate and communicate with all lake stakeholders
Timeframe:	Continuation of current effort

Facilitator:	Education Committee
Description:	The SLMD will make the education of lake-related issues a priority. One of the first tasks would be to disseminate the information contained within this *Comprehensive Management Plan*, allowing it to be better understood by association members. To accomplish this task, a committee plans to highlight key topics from the plan and share educational materials on the subjects over time. The SLMD believes that creating smaller modules of information and spreading out the delivery over time will be an effective educational initiative. As a part of the planning process, the SLMD identified key topics which they believe the association members would appreciate additional educational opportunities. These may include educational materials, awareness events, and demonstrations for lake users as well as activities which solicit local and state government support. The SLMD is also considering making an educational pamphlet or brochure with select important information on boating safety and lake stewardship. The goal is to make these educational pieces available at the public access points, watercraft rental operations, and local resorts and hotels. *Example Educational Topics* • Importance of natural landscapes and native aquatic plants • Aquatic invasive species identification • Shoreline habitat restoration and protection • Shoreline erosion and impacts of boating practices (e.g. watercraft speed, proximity to shore, wake boats) • Boating safety (promote existing guidelines, create courtesy code) • Fishing regulations and overfishing • Bolstering fish habitat • Promotion of Waushara County Land Conservation Field Days & Wautoma Schools AIS Tour

Management Action:	Continue SLMD's involvement with other entities that have responsibilities in managing Silver Lake
Timeframe:	Continuation of current efforts
Facilitator:	Education Committee
Description:	The purpose of the SLMD is to maintain, protect, and improve the quality of lakes for the landowners and those that use the lake for recreation purposes. 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 SLMD actively engage with all management entities to enhance the association's 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 following table.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Town of Marion	Clerk (920.566.2818) townofmarion@outlook.com	Silver Lake falls within the Town.	Keep up to date on Town activities. As needed. (townshipofmarion.com)	Aspects that involve the township government such as ordinances, building and zoning, and funding opportunities
Golden Sands RC&D	Amy Thorstenson (715-346-1264) amy.thorstenson@goldensandsrcd.org	Nonprofit promoting healthy lakes & watersheds	Annually and as opportunities arise.	Provides assistance implementing the CBCW program
Waushara County Land Conservation Department.	Conservationist Ed Hernandez (920.787.0453 ext 472) Ed.Hernandez@co.waushara.wi.us	Oversees conservation efforts for land and water projects.	As opportunities arise.	Provide assistance with shoreland restorations and habitat improvements. Assist in connecting/networking SLMD with other lake orgs.
Wisconsin Lakes	General staff (800.542.5253)	Education, networking and assistance.	As needed. (wisconsinlakes.org)	Reps can assist on education and outreach materials
Wisconsin Department of Natural Resources	Fisheries Biologist: Adam Nickel (920.647.6571) Adam.Nickel@wisconsin.gov	Manages the fishery of the system.	Once a year, or more as issues arise.	Stocking, surveys, volunteer opportunities for improving fishery.
	Lakes Coordinator Ted Johnson (715.365.8937) TedM.Johnson@wisconsin.gov	Oversees management plans, grants, all lake activities.	Once a year, or more as necessary.	Information on updating a lake management plans, submitting grants & permits, and to seek advice on other lake issues.
	Conservation Warden Ben Mott (920.896.3383)	Oversees regulations handed down by the state.	As needed. May contact WDNR Tip Line (1.800.847.9367) as needed also.	Suspected violations, including fishing, boating safety, ordinance violations, etc.
	Citizens Lake Monitoring Network contact Sandra Wickman (715.365.8951)	CLMN training and assistance.	Twice a year or more as needed.	Training, planning of monitoring and reporting of data.

Management Action:	Participate in annual Wisconsin Lakes and Rivers Convention
Timeframe:	Annually
Facilitator:	Education Committee
Description:	Wisconsin is unique in that there is a long-standing partnership between a governmental body, a citizen-based lake lobbying and protection association, and the state's primary educational outreach program. That unique group is the Wisconsin Lakes Partnership and its three members, the Wisconsin Dept. of Natural Resources, Wisconsin Lakes, and the UW-Extension Lakes Program, facilitate many lake-related events throughout the state. The

	primary event is the Wisconsin Lakes Partnership Convention held each spring in Stevens Point. This is the largest citizen-based lakes conference in the nation and is specifically suited to the needs of lake associations and associations. It is an exceptional opportunity for lake group members to learn about lake management and monitoring; network with other lake groups, agency staff, and lake management contractors; and learn how to effectively operate a lake association/association. The SLMD will encourage an SLMD board member to annually attend the convention. Following the attendance of the convention, the representative will report specifics to the board of directors regarding topics that may be applicable to the management of Silver Lake and operations of the SLMD. The attendees will also create a summary in the form of a newsletter article and if appropriate, update the association membership at the annual meeting. There is more information about it at: wisconsinlakes.org.

Management Goal 3: Maintain Current Water Quality Conditions

Management Action:	Monitor water quality of Silver Lake through WDNR Citizens Lake Monitoring Network.
Timeframe:	Continuation of current effort.
Facilitator:	Board of Commissioners – Terry Liska is current CLMN 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. Volunteer water quality monitoring would continue annually by SLMD riparians through the Citizen Lake Monitoring Network (CLMN). The CLMN is a WDNR program in which volunteers are trained to collect water quality information on their lake. The SLMD currently monitor water quality under the advanced CLMN program. This includes collecting Secchi disk transparency, as well as sending in water chemistry samples (chlorophyll-*a*, and total phosphorus) to the Wisconsin State Laboratory of Hygiene (WSLH) for analysis. The samples are collected three times during the summer and once during the spring (turnover). It is important to note that as a part of this program, the data collected are automatically added to the WDNR database and available through their Surface Water Integrated Monitoring System (SWIMS). As a part of this management planning process, it has been determined that internal nutrient loading may be occurring and the lake may be polymictic in some years. In order to better understand the magnitude of impact of this phenomenon, the

	SLMD will again collect hypolimnetic phosphorus concentrations at the time of its next Plan update. In addition, the SLMD will continue to conduct temperature and dissolved oxygen profiles in conjunction with the CLMN monitoring schedule as often as possible. Investigations into the dissolved oxygen data collected in recent years on Silver Lake suggest that the probe may be broken or require calibration. If a new probe is required, the WDNR recommends: YSI ProSolo ODO – Optical Dissolved Oxygen Meter. WDNR grant opportunities are available for this type of sampling equipment purchase. It also must be noted that the CLMN program may be changing in the near future. One possible change is that lake groups will only be allowed free water testing for a period of 3 years in a row once every decade. If that change occurs, the SLMD would like to continue this monitoring every year, but paying the laboratory analysis costs in years when the WDNR will not cover.

Management Goal 4: Monitor Aquatic Vegetation on Silver Lake

Management Action:	Give consideration to the creation of an *AIS Committee*
Timeframe:	Ambition to discuss in progress
Facilitator:	SLMD Board of Commissioners – Mark Magnusson
Description:	The SLMD would like to formally create standing committees to ensure duties are properly divided amongst district officers and interested SLMD members. The *AIS Committee* would be charged with AIS management, Clean Boats Clean Waters watercraft inspections, future AIS aquatic plant and animal (e.g., rusty crayfish, zebra-mussel) monitoring activities. The *AIS Committee* would also deal with funding, cost analysis, risk assessment, treatment strategy, and data review. This committee would be comprised of 2-4 individuals, with at least one member being on the SLMD board of directors.
Action Steps:	
	See description above.

Management Action:	Periodically monitor the Eurasian watermilfoil population
Timeframe:	Periodic: annually; Timing: during latter part of growing season
Facilitator:	AIS Committee
Description:	As the name implies, the Late-Season EWM Mapping Survey is a professionally contracted survey completed towards the end of the growing season when the plant is at its anticipated peak growth stage, allowing for a true assessment of the amount

	of this exotic within the lake. For the Silver Lake, this survey would likely take place in mid-August to the end of September, dependent on the growing conditions of the particular year. This survey would include a complete or focused meander survey of the system's littoral zone by professional ecologists and mapping using GPS technology (sub-meter accuracy is preferred). Late Season EWM Mapping Surveys have been conducted annually for over a decade, with modified methodology being used in 2015 upon the initial hiring of Onterra. These data allow lake stakeholders to understand annual EWM populations in response to natural variation and directed management activities. Depending on the EWM population and the responding management of a given year, consideration would be given to also conducting an Early-Season EWM Mapping Survey. Early-Season EWM Mapping Surveys have been used by the SLMD to detect and prioritize that growing season's hand-harvesting strategy. When EWM populations are higher, the utility of this survey declines and reliance of the previous years' Late-Season EWM Mapping Survey suffices. The SLMD has adopted the use of the ArcGIS Online platform to house spatial information related to past and current HWM populations and management activities on Silver Lake. The SLMD feels this tool provides value to convey a better understanding of the HWM management activities occurring on the system as well as take a more proactive role in developing future EWM management strategies. *https://onterra.maps.arcgis.com/apps/View/index.html?appid=68c272c7817644e1a76f4df6fb2872d0*

Management Action:	Periodically monitor the curly-leaf pondweed population
Timeframe:	Periodic: once every 5 years; Timing: mid-June
Facilitator:	AIS Committee
Description:	As discussed in the Aquatic Plant Section (3.4), CLP was first discovered in Silver Lake during 2004. Since that time, the CLP population remains small and variable. This invasive species can cause great ecological and recreational impacts on some lake. But in other lakes like Silver Lake, the CLP population remains low and does not cause these impacts. The SLMD intends to periosdically check-in on the CLP population, but has not management intentions at this time. Approximately once every 5 years, coinciding with a *Plan* update, the SLMD would coordinate an Early-Season CLP Mapping survey.

Management Action:	Coordinate periodic point-intercept aquatic plant surveys
Timeframe:	Periodic: annual is preferred; Timing: during July-August
Facilitator:	AIS Committee
Description:	The point-intercept aquatic plant monitoring methodology as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) has been used on the Silver Lake System approximately annually since 2012. This survey provides quantitative population estimates for all aquatic plant species within the lake and is designed to allow comparisons with past surveys in Silver Lake as well as to other waterbodies throughout the state. At each point-intercept location within the *littoral zone,* information regarding the depth, substrate type (soft sediment, sand, or rock), and the plant species sampled along with their relative abundance (rake fullness) on the sampling rake is recorded. The SLMD will ensure the point-intercept surveys is conducted at least once every five years, but aims to complete this quantitative survey of its aquatic vegetation annually. If the SLMD is considering large-scale aquatic plant management, such as a whole-lake herbicide treatment, point-intercept surveys would occur the *year prior to treatment*, *year of treatment*, and *year after treatment* to help understand intended and unintended impacts from this management action.

Management Action:	Consider periodic community mapping (floating-leaf and emergent) surveys
Timeframe:	Periodic: every 5 years or when prompted
Facilitator:	AIS Committee
Description:	This survey would delineate the margins of floating-leaf (e.g., water lilies) and emergent (e.g., cattails, bulrushes) plant species using GPS technology (preferably sub-meter accuracy) as well as document the primary species present within each community. 2022 was the first time this survey has been conducted on Silver Lake, with very minimal amounts of these habitats being present in the lake. While many lakes to choose to conduct this survey every 10 years, the low amount of floating-leaf and emergent plant communities justifies a more frequent investigation. The SLMD is going to continue to educate its membership about the importance of these species, possibly even attempting bullrush restoration.

Management Goal 5: Prevent Establishment of New Aquatic Invasive Species

Management Action:	Monitor Silver Lake entry points for aquatic invasive species
Timeframe:	Ongoing
Facilitator:	AIS Committee – Bill Herbert
Description:	The intent of this program is not only be to prevent additional invasive species from entering the Silver Lake through its public access locations, but also to prevent the infestation of other waterways with invasive species that originated in Silver Lake. The SLMD is most concerned about new strains of EWM/HWM entering into the lake, as well as a relatively new arrival to Wisconsin – Starry Stonewort. Starry stonewort (SSW) is a non-native macro-algae that superficially looks like other charophyte species abundant in Silver Lake such as muskgrasses and stoneworts. SSW is typically found in marl lakes such as Silver. The SLMD utilizes WDNR grant funding to sponsor watercraft inspections through the WDNR's Clean Boats Clean Waters (CBCW) program at the highway 21/73 landing on the northwest side of the lake. The SLMD has maintained a goal of 200 hours of inspections since 2015. The SLMD partners with Golden Sands Resource Conservation & Development Council, Inc. to interview, hire, and maintain payroll and insurance for the seasonal staff. The SLMD will continue to seek cost share assistance through the WDNR's streamline Clean Boats Clean Waters (CBCW) program: https://dnr.wisconsin.gov/sites/default/files/topic/Aid/grants/surfacewater/CF0002.pdf#page=22

Management Action:	Investigate supplemental aquatic invasive species prevention and containment methods.
Timeframe:	Ongoing
Facilitator:	AIS Committee
Description:	Silver is an extremely popular regional destination by recreationists and anglers, making the lake vulnerable to new infestations of exotic species. In addition to its watercraft inspection program, the SLMD would like to investigate supplemental prevention steps it can take to project Silver Lake from new aquatic invasive species. The SLMD will strive to have updated signage at all landings promoting CBCW messaging. They will also consider supplemental prevention efforts as described below.

	Supplemental prevention efforts such as decontamination stations (e.g., pressure washer), water-less cleaning stations (e.g. CD3 systems), and remote video surveillance (e.g., I-Lids™) have been taken on a few waterbodies throughout the state. The SLMD will research these options and determine applicability for Silver Lake.

Management Goal 6: Actively manage EWM to keep the population from negatively impacting recreation, navigation, and aesthetics

Management Action:	Conduct Integrated Pest Management Program towards HWM
Timeframe:	Ongoing
Facilitator:	AIS Committee
Description:	The objective of this action will be to minimize the periodic nuisance conditions that EWM causes on Silver Lake by restoring navigation, recreation, and aesthetics. In order to reach this objective, the SLMD has developed a multi-pronged approach as part of this Integrated Pest Management (IPM) Program. Each management technique described below is discussed in regards to site selection and corresponding monitoring strategy. The following bullets are a general guide to the IPM Program: • ***Herbicide Treatment*** Due to the size and shape of Silver Lake, all herbicide treatments targeting HWM would be intentionally designed as whole-lake or whole-basin treatments. If HWM reached the predefined trigger within the lake, discussion of herbicide treatment would occur, including extensive risk assessment. • ***Manual Removal*** using traditional hand-harvesting or with DASH would be used to target scale-appropriate HWM occurrences. This typically would occur in the years after herbicide treatment to maintain the gains made from that effort. • ***Mechanical Harvesting*** would be implemented when HWM occurrences are too large or dense to be targeted within manual removal methods, and prior to implementing an herbicide treatment. The first trial mechanical harvesting operation will occur in 2023. The WDNR has indicated they support the least impactful method that is feasible to alleviate an aquatic plant issue, being interpreted by many as favoring mechanical harvesting over herbicide treatment. 1. **Herbicide Treatment** Purposeful whole-lake herbicide treatments were conducted on Silver Lake in 2014 (triclopyr) and 2016 (fluridone). Past spot herbicide spot treatments, including one conducted in 2020 (ProcellaCOR), likely resulted in basin-wide concentrations to impact HWM not just where applied (Foxtail Bay), but also in the southern basin. As discussed within the

Aquatic Plant Section (3.4), the past treatments had an impact on species frequency and plant diversity. That being said, approximately 68% of Silver Lake riparian stakeholder survey respondents indicated support (pooled completely support and moderately support) for future whole-lake herbicide treatment (Appendix B, Question #30).

When the littoral frequency of HWM, according to the point-intercept survey, approaches 20% (trigger), the SLMD would give consideration to investigating the applicability of a whole-lake management strategy. The HWM population of Silver Lake in 2012-2013, before the first whole-lake triclopyr treatment, was 25.3% and 33.3%, respectively. The SLMD understands what the condition of Silver Lake was at that time, with navigation and recreation greatly impaired. Following the 2016 fluridone treatment, the HWM population remained below 2.5% until 2022, when the HWM population increased to 13.6%.

At the time of this writing, the SLMD largely considered the following herbicide treatment strategies. The SLMD will continue to investigate the applicability of these strategies, modified use-patterns of these herbicides, and new herbicides as it relates to future whole-lake HWM management of Silver Lake

- *Fluridone (Sonar®)* is often used when targeting difficult invasive milfoil populations, particularly HWM populations that have not been effectively controlled by prior applications of auxins (2,4-D or Triclopyr) or auxin/endothall combinations. Fluridone has a checkered history in Wisconsin as prior treatments have been particularly impactful to native plant communities. While native plant declines were observed during the 2016 fluridone treatment on Silver Lake, they were relatively modest and anticipated. While the 2016 fluridone treatment on Silver Lake was one of the most effective employed in WI, this treatment was accompanied by a 3-foot water level increase that likely aided in its success. Onterra maintains concern that a future fluridone treatment without this environmental factor may not be as effective. This treatment was also the longest active herbicide treatment documented in WI, holding concentrations for over 400 days. It is unlikely that public and regulatory support for such a long exposure time would occur in the future.
- *Florpyrauxifen-benzyl (ProcellaCOR™)* is in a new class of synthetic auxin mimic herbicides (arylpicolinates) with short concentration and exposure time (CET) requirements compared to other systemic herbicides. The active ingredient of ProcellaCOR™, florpyrauxifen-benzyl, is primarily degraded by photolysis (light exposure), with some microbial degradation. The active ingredient is relatively short-lived in the environment, with half-lives of 4-6 days in aerobic environments and 2 days in anerobic environments (WSDE 2017). The primary breakdown product of florpyrauxifen-benzyl is florpyrauxifen acid. Florpyrauxifen acid has been shown to persist in the lake longer than the active ingredient.

This chemical metabolite is reported to have activity as an herbicide on aquatic plants, albeit to a lower degree than the active ingredient. It is unclear at this time the exact role that the acid metabolite may play in contributing to EWM reductions, particularly in areas not located directly within the herbicide application area. Native plant impacts from ProcellaCOR™ are anticipated to be less and more specific to susceptibly species than fluridone treatments. The 2020 ProcellaCOR™ treatment of Foxtail Bay resulted in lowered EWM for 2-3 years after treatment.

If the SLMD decides to pursue future herbicide management towards EWM, the following set of bullet points would occur:

- Early consultation with WDNR would occur.
- The preceding annual *HWM Control & Monitoring Report* would outline the precise control and monitoring strategy. This would include applying herbicide over the target species with attention to whole-lake epilimnetic target concentrations.
- Give consideration to pretreatment invasive watermilfoil genetic testing (i.e., fingerprinting)
- HWM efficacy would occur by comparing annual late-summer EWM mapping surveys and point-intercept surveys. Specifically, these would be conducted during the *year prior to treatment*, *year of treatment*, and *year after treatment*.
- Herbicide concentration monitoring would occur surrounding the treatment.
- An herbicide applicator firm would be selected in late-winter and a permit application would be applied to the WDNR as early in the calendar year as possible, allowing interested parties sufficient time to review the control plan outlined within the annual report as well as review the permit application.
- Unless specified otherwise by the manufacturer of the herbicide, an early-season use-pattern would likely occur. This would consist of the herbicide treatment occurring towards the beginning of the growing season (typically in early-June), active growth tissue is confirmed on the target plants, and is after sensitive fish species of concern have outgrown their vulnerable life stage. A focused pretreatment survey would take place approximately a week or so prior to treatment. This site visit would evaluate the growth stage of the HWM (and native plants) as well as to confirm the proposed treatment area extents and water depths. This information would be used to finalize the permit, potentially with adjustments and dictate approximate ideal treatment timing. Additional aspects of the treatment may also be investigated, depending on the use pattern being considered, such as the role of stratification.

2. **Manual Removal (includes DASH)** The objective of this action will be to target low-density areas of the lake with hand-harvesting, including Diver-Assisted Suction Harvest (DASH) techniques, to maintain a low HWM population in these areas. The proactive EWM management strategy that has occurred in Silver Lake following the HWM rebound after the 2016 whole-lake fluridone treatment, with large success. The SLMD would like to continue a proactive management approach to HWM to keep the population low within the lake, preferably with non-herbicide control options. As areas become too large or dense to be feasibly or financially practical to target with this management tool, they will be considered for other strategies.

   Contracted hand-harvesting operations with DASH would adhere to the following bullet points in addition to WDNR permit conditions:

   - During the winter following a late-season HWM mapping survey, a hand-harvesting strategy would be developed. The management and monitoring strategy would be formally outlined in an annual report that would be made available to the SLMD and WDNR. Areas appliable for manual removal include HWM mapped with point-based methods as well as low-density and smaller areas of HWM mapped with polygon.
   - The SLMD may choose to conduct a supplemental Early-Season EWM Mapping Survey in June to further assist with prioritization of the manual, removal strategy.
   - If a Diver Assisted Suction Harvest (DASH) component is utilized, the SLMD and contracted firm would be responsible for the WDNR permit procedures. The contracted firm would be guided with GPS data from the consultant and would track their efforts (when, where, time spent, quantity removed) for post assessments.
   - The hand-harvesting would occur from approximately mid-June to mid-September, but could be slightly extend earlier or later if climactic conditions allow. Generally conducting hand-harvesting earlier or later in the year can reduce the effectiveness of the strategy, as plants are more brittle and extraction of the roots more difficult.
   - A Late-Summer HWM Mapping Survey would take place following the hand-harvesting and be compared to the previous year for assessment. Hand-removal sites will be deemed successful if the level of HWM within the hand-removal areas were at least maintained to pretreatment levels.

3. **Mechanical Harvesting** When HWM populations exceed levels applicable to hand-harvesting but before herbicide treatments are implemented, the SLMD would consider contracting a mechanical harvesting firm to restore navigation and recreational access in these areas. If herbicide treatments become unsupported by the SLMD or WDNR, this tool may play a greater role in HWM management on Silver Lake.

   Mechanical harvesting operations would have the following guidelines:

   - Harvesting locations are limited to areas on the permit map.

- The harvester would not be permitted in waters less than 3-feet to minimize sediment disturbance.
- Cut no more than half the water depth.
- Harvesting operations shall not disturb spawning or nesting fish. Harvesting shall be done in a manner to minimize accidental capture of fish. An attempt would be made to return all gamefish, panfish, amphibians, and turtles to the water immediately.
- Submerged plants, specifically HWM, are the target for this permit. Removal of emergent (e.g. bulrushes) and floating-leaf (e.g. water lilies) species needs to be avoided because of their ecological value and niche occupation.
- A reasonable effort must be made to capture all aquatic plant fragments during operation. The WDNR may consider allowing "floaters" to be picked up even if they occur outside the areas delineated on the permit map.
- Reports summarizing harvesting activities shall be given to the WDNR by November 30, each harvesting season. The report shall include a map showing the areas harvested, the total amount of plant material removed from each site, and amount of effort (time) spent at each site. The report shall also include a summary of the composition and quantity of plants removed by species (rough percent of each species from each operation).

2023 HWM Nuisance Management Plan:

In order to ensure navigability around the lake, the SLMD has contracted for mechanical harvesting operations during 2023. Initial iterations of the harvesting plan included the creation of spokes or lanes through dense HWM colonies that would be placed out from riparian docks. Parallel to shore cuts were also included in earlier drafts of the harvesting plan. After continued conversations, the SLMD settled on a harvesting strategy that would include harvesting nearly all HWM colonies that were mapped as dominant or greater during the most recent mapping survey (Map 10). In addition, perpendicular navigation lanes will be cut at high traffic locations (Hwy 21/73 boat landing and Marion patrol boat dock, Silvercryst dock, Silvercryst beach bar, and the Hwy 73 boat landing). The SLMD intends to cut all harvesting sites twice during the summer.

Long-Term HWM Population Control Plan:

SLMD intends to apply for a WDNR permit in spring 2024 for a whole-lake herbicide treatment targeting HWM. Due to excellent results obtained on other lakes, ProcellaCOR™ EC is the herbicide the district plans to utilize. Onterra will calculate the application rates required to target all HWM colonies in the lake with direct application, reaching meaningful concentrations when uniformly mixed within the entire lake (epilimnetic). The 2023 DASH and mechanical harvesting map will also be updated with the results of the August 2023 Point Intercept Survey (PIS) and the late season EWM Mapping survey. The district's post treatment strategy will remain the same in subsequent years. DASH, hand-harvesting, and

	mechanical harvesting will be utilized yearly with the goal to maintain HWM under 10% of the plant littoral zone. The district is hopeful they can have another 6-year period before additional whole-lake herbicide treatment is considered to control HWM.

Management Goal 7: Promote Lake Stewardship and Conservation Ethics to SLMD Members and Silver Lake Riparians

Management Action:	Facilitate connecting riparians with Healthy Lakes & River Grants
Timeframe:	Ongoing
Facilitator:	Education Committee
Description:	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, now called the Healthy Lakes and Rivers Grant 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. The cost share allows $1,000 per practice, up to $25,000 per annual grant application. More details and resources for the program can be found at: *https://healthylakeswi.com* • Rain Garden • Rock Infiltration • Diversion • Native Plantings • Fish Sticks The SLMD will continue to focus specific education on the importance of shoreland condition and the resources that are available (planning and funding). Partial funding for shoreland restoration activities is available through the WDNR Healthy Lakes Initiative but needs to be applied for by a qualified lake group such as the SLMD, not an individual riparian. The SLMD would assist with the grant application, but all direct and indirect costs would be the responsibility of the benefiting riparian. On larger waterbodies like Silver Lake, particularly in years of high water levels, erosion and ice shoves can be extremely damaging to valuable shoreline properties. They also have impacted past shoreland restoration attempts. Therefore, circumstances arise where shoreland modifications to protect property are warranted. The WDNR favors properly implemented rip-rap/rock to satisfy this need. In addition. the SLMD encourages shoreland buffers be added above the shoreline modification practice.

	Understanding Silver Lake is highly developed with narrow individual frontage, it is unlikely that SLMD riparians would institute fish sticks or in-lake plantings. Based upon input from the WDNR fisheries biologist, these practices would be extremely helpful in addressing some of the fisheries concerns on the system. Therefore, the SLMD would consider these activities or variations of these activities on undeveloped properties such as those owned by the Town of Marion.

Management Action:	Continue to investigate feasibility of controlling high water events on Silver Lake
Timeframe:	Continuation of Current Effort
Facilitator:	Board of Commissioners
Description:	When water levels are above full pool (>867.61 NGVD29), water exchange occurs with Irogami Lake via a culvert under State Hwy 21. In 1993, FEMA created an emergency high-water weir from Irogami Lake to a marsh complex that leads to Bruce Creek. A culvert under 20th Street further assisted with surface connection of Irogami Lake to the recently impounded Alpine Lake (in 1970). These water control devices restore water levels to promote functioning sewerage district as well as flooding of personal properties. While this culvert assists Irogami deal with these issues, it does not always minimize issues with high water on Silver Lake. The SLMD will continue to investigate realistic options to keep the water level of Silver Lake from flooding properties and exacerbating shoreland erosion. At this time, the SLMD continues to work with Waushara County Zoning, WI Department of Transportation, WDNR, and the Town of Marion to explore solutions. At this time, the water control strategy with the greatest potential is creating weir connecting Silver Lake to Bruce/ Creek and circumventing Irogaimi.

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A

APPENDIX A

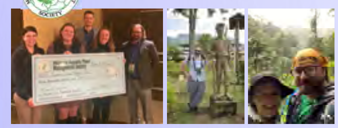
Public Participation Materials

Management Planning Meeting I Presentation Materials

Management Planning Meeting II Presentation Materials

Onterra, LLC

- Founded in 2005, HQ in De Pere, WI
- Staff
  - Three full-time ecologists
  - One part-time paleoecologist
  - Four full-time field technicians
  - Five summer interns
- Services
  - Science and planning
- Philosophy
  - Promote realistic planning
  - Assist, not direct



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Why Create a Lake Management Plan?

- Preserve/restore ecological function
- To create a better understanding of lake's positive and negative attributes.
- To discover ways to minimize the negative attributes and maximize the positive attributes.
- Snapshot of lake's current status or health.
- Foster realistic expectations and dispel any misconceptions.

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Management Planning Project Overview

- Foster holistic understanding of ecosystem
- Collect & analyze data
  - Technical & sociological
- Construct long-term & useable plan
  - Living plan subject to revision over time
- Onterra's role is to provide technical direction
  - Not really recommendations

Management Plan and Grants

- WDNR recommends *Comprehensive Lake Management Plans* generally get updated every 10 years
  - Primarily for grants/permits related to water quality improvements (implementation grants)
- WDNR recommends lakes conducting active management update aspects of the plan every 5 years (*APM Plan*)
  - Primarily for grants/permits related to aquatic plant management (AIS control grants, NR107, NR109)
  - Whole-lake PI survey needs to be within 5 years
  - Management action in AIS Grant needs to be supported by Plan

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Management Planning Project Overview

Collect and compile information

Includes both environmental & sociological
Historical & current information
Past management actions

Planning Meeting I
Data Sections

Create a realistic and implementable management plan

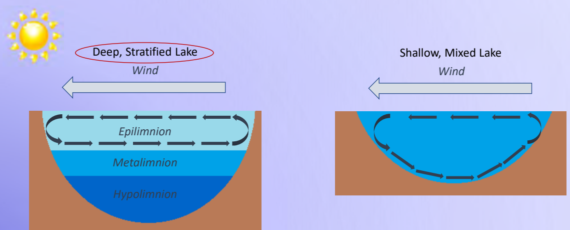
Challenges facing lakes and lake groups
Create goals that will address challenges
Develop actions that will meet goals
Assign timeframes & facilitators

Planning Meeting II
Implementation Plan

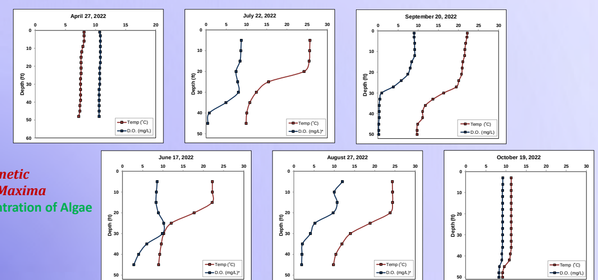
Comprehensive Management Plan Outline

- 1.0 Introduction
- 2.0 Stakeholder Participation
- 3.0 Study Results
  - 3.1 Water Quality
  - 3.2 Watershed
  - 3.3 Shoreland Condition
  - 3.4 Aquatic Plants
  - 3.5 AIS
  - 3.6 Fishery Data Integration
- 4.0 Summary & Conclusions
- 5.0 Implementation Plan
- 6.0 Methods
- 7.0 Literature Cited

Wisconsin Lakes Classification



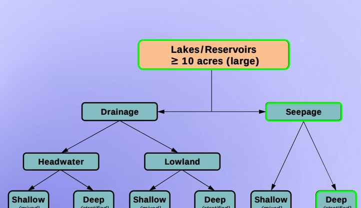
Stratification



Metalimnetic Oxygen Maxima
- Concentration of Algae

Natural Community Types

Categorization of lakes with similar features that influence water quality



Ecoregions

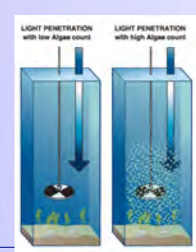
An area containing similar geology, physiography, hydrology, climate, and soils. As well as common terrestrial and aquatic fauna.

Introduction to Lake Water Quality

Phosphorus
Naturally occurring & essential for all life
Regulates phytoplankton biomass in **most** WI lakes
Most often 'limiting plant nutrient' (shortest supply)
Human activity often increases P delivery to lakes

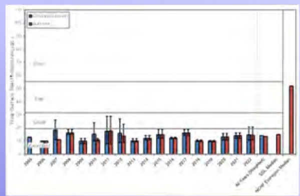
Chlorophyll-*a*
Pigment used in photosynthesis
Used as surrogate for phytoplankton biomass

Secchi Disk Transparency
Measure of water clarity
Measured using a Secchi disk



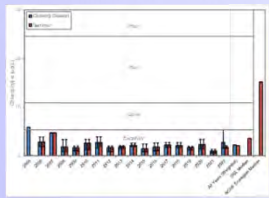
Silver Lake Water Quality

Near-Surface Total Phosphorus



- *Excellent* for Deep Seepage Lakes
- Similar to Ecoregion Median

Chlorophyll-a



- *Excellent* for Deep Seepage Lakes
- Slightly lower than the Ecoregion Median

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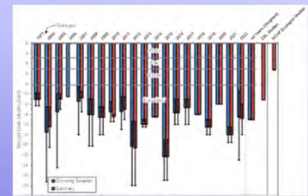
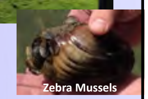
Silver Lake Water Quality

Secchi Disk Transparency



- *Excellent* for Deep Seepage Lakes
- Much lower (clearer) than the Ecoregion Median
- Minimally impacted by tannins

Filamentous Algae



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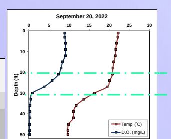
Silver Lake Water Quality
Internal Phosphorus Loading

Depth Feet	Total Phos. µg/L	Thermal Layer
3	15.0	Epilimnion
12	14.8	
24	17.6	Metalimnion
30	17.6	Hypolimnion
36	45.7	
42	154.0	
45	344.0	
48	495.0	



What is internal loading?

- Iron binds P with oxygen in oxygenated waters
- Iron releases P when no oxygen is present (anoxic)
- P is then made available to algae following turnover event
- Cyanobacteria (Oscillatoria) can access P, N, & ferrous Iron from hypo when stratified

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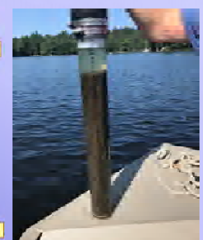
Silver Lake Paleocology



Sediment core

Top-Bottom Sediment Core Results (2012)

- Some, but minimal difference in top vs bottom phosphorus concentrations
- Significant changes in habitat, with greater expanse of aquatic plants and filamentous algae.

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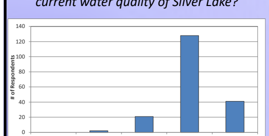
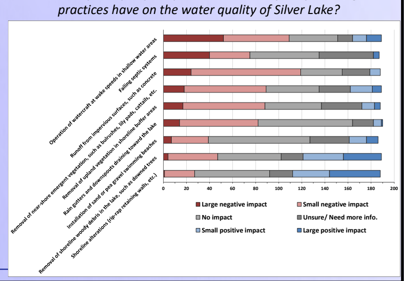
Stakeholder Perceptions of Water Quality

68% Response Rate

How would you describe the overall current water quality of Silver Lake?



What impact, if any, do you believe each of the following practices have on the water quality of Silver Lake?



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Watershed

Geographic area within which all water drains to a common point

Current Project

- Because of good water quality and no large negative trends, project component would be minimal
- Update UWSP's assessment with more current land cover information

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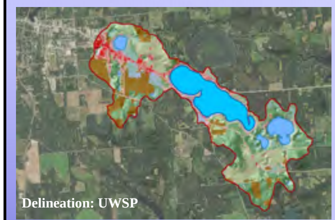
Silver Lake Watershed



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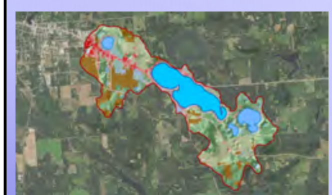
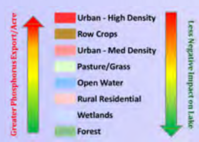
Silver Lake Watershed



Delineation: UWSP
Landcover: NLCD, 2019

~2,543 acres (4 mi^2)
WS:LA = 6:1

- Groundwater is important
- Wetland nutrient seeps
- Influence of sanitary districts
- Overlap with municipal storm water



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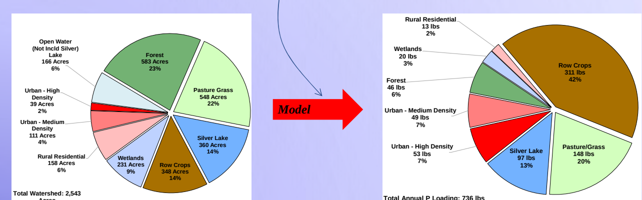
Watershed Modeling

Sanitary District



Model relatively accurately predicts phosphorus load

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Shoreland Assessment

- Shoreland area is important for buffering runoff and provides valuable habitat for aquatic and terrestrial wildlife.
- EPA National Lakes Assessment results indicate shoreland development has greatest negative impact to health of our nation's lakes.
- WDNR Healthy Lakes Grant Program

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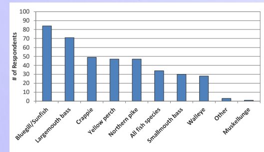
Stakeholder Perceptions of Fisheries

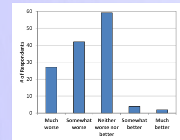
68% Response Rate

What species of fish do you like to catch on Silver Lake?



How would you describe the current quality of fishing on Silver Lake?

How has the quality of fishing changed on Silver Lake since you started fishing the lake?



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Fisheries Data – 2021 Comprehensive Study

Largemouth Bass	High Density, Good size structure	Keep populations up to prevent panfish overabundance
Northern Pike	About average population, goal to increase	Enhance emergent plant shorelines for spawning
Walleye	Present, but not managed for	Not suitable habitat
Bluegill & Pumpkinseed	High abundance and good size structure	
Black Crappie	Common, w/ fair>good size structure	
Yellow Perch	Very low density	Need more woody habitat

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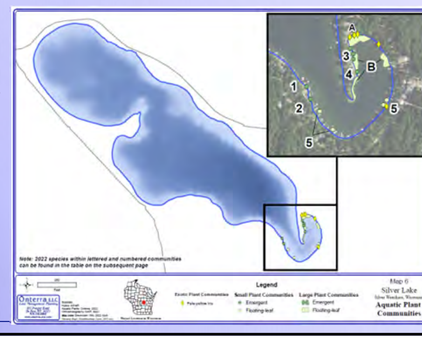
Fisheries Habitat

- Few white-water lilies
- Minimal shoreline emergent
  - Cattail spp.
  - Rushes
- No woody habitat documented



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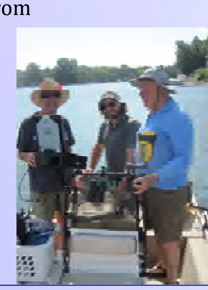
Aquatic Plant Surveys

- Determine changes in plant community from past surveys
- Assess both native and non-native populations
- Numerous surveys used in assessment
  - ~~Early-Season AIS Survey (CLP, PYI)~~
  - Whole-Lake Point-Intercept Surveys
  - Late-Season AIS Survey (EWM)
  - Emergent/Floating-Leaf Community Mapping Survey (PL)



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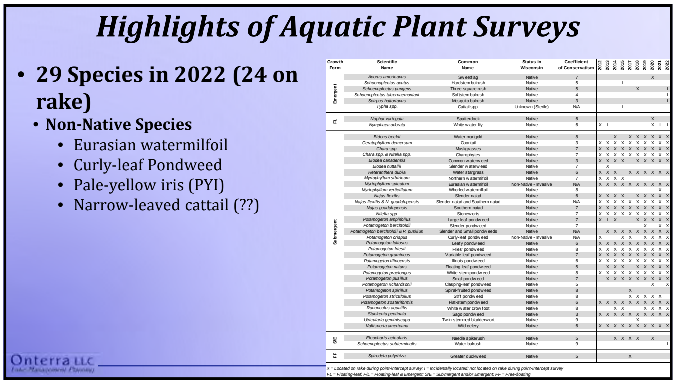
Highlights of Aquatic Plant Surveys
• 29 Species in 2022 (24 on rake)
• Non-Native Species
• Eurasian watermilfoil
• Curly-leaf Pondweed
• Pale-yellow iris (PYI)
• Narrow-leaved cattail (??)
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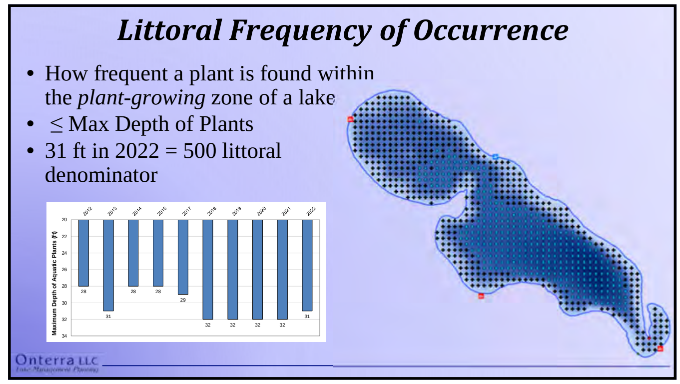
Littoral Frequency of Occurrence
• How frequent a plant is found within the plant-growing zone of a lake
• ≤ Max Depth of Plants
• 31 ft in 2022 = 500 littoral denominator
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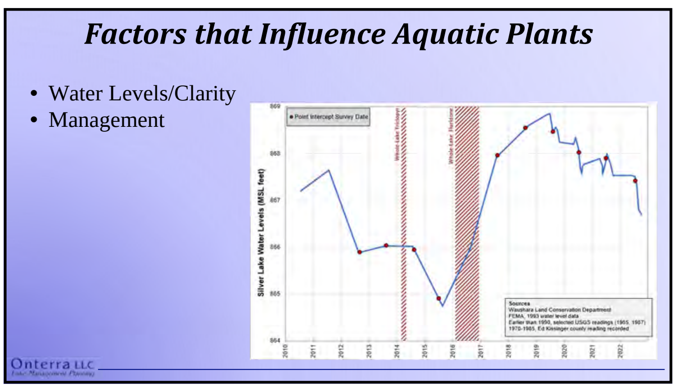
Factors that Influence Aquatic Plants
• Water Levels/Clarity
• Management
Silver Lake Water Levels (MSL feet)
Point Intercept Survey Date
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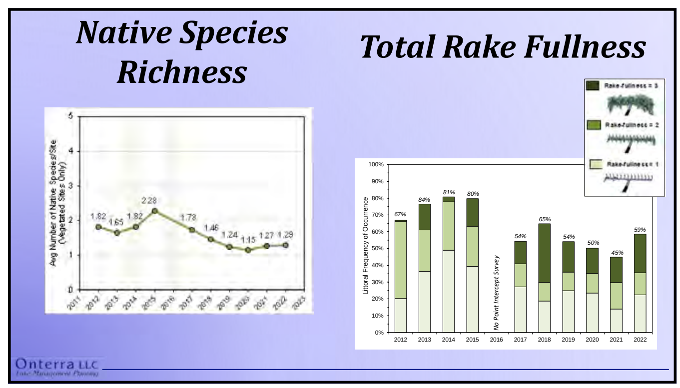
Native Species Richness
Total Rake Fullness
1.82
1.65
1.82
2.28
1.73
1.46
1.24
1.15
1.27
1.29
67%
84%
81%
80%
65%
54%
54%
50%
45%
59%
No Point Intercept Survey
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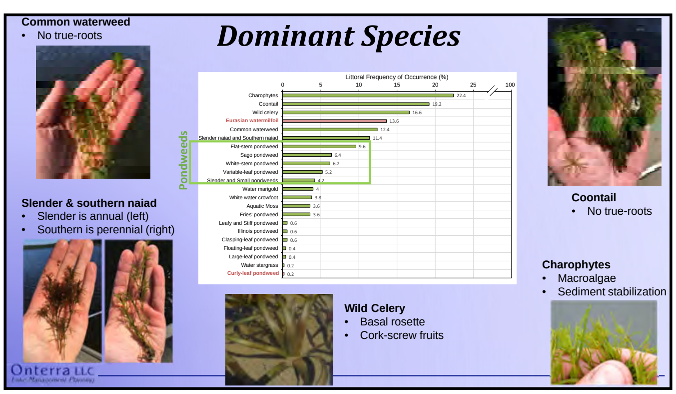
Common waterweed
• No true-roots
Dominant Species
Littoral Frequency of Occurrence (%)
Pondweeds
Slender & southern naiad
• Slender is annual (left)
• Southern is perennial (right)
Coontail
• No true-roots
Charophytes
• Macroalgae
• Sediment stabilization
Wild Celery
• Basal rosette
• Cork-screw fruits
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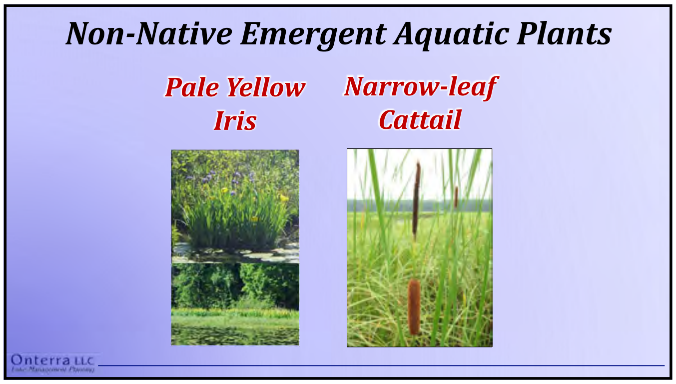
3.4 Aquatic Invasive Species


Non-Native Emergent Aquatic Plants
Pale Yellow Iris
Narrow-leaf Cattail
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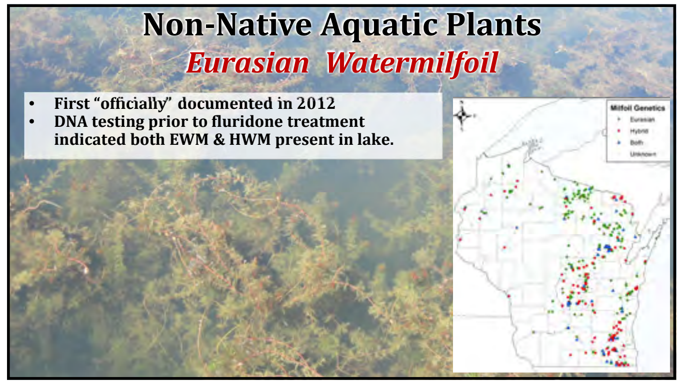
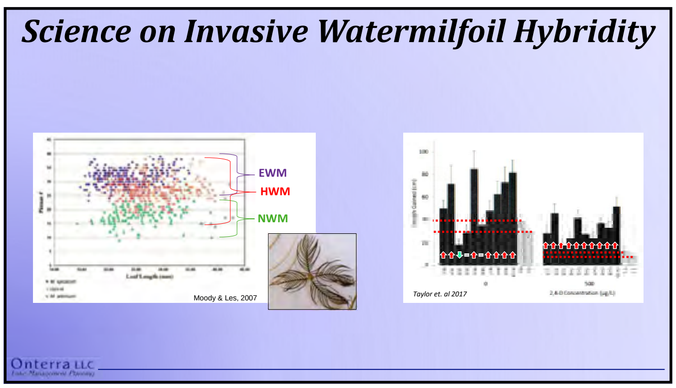

Non-Native Aquatic Plants
Eurasian Watermilfoil
• First "officially" documented in 2012
• DNA testing prior to fluridone treatment indicated both EWM & HWM present in lake.
Milfoil Genetics


Science on Invasive Watermilfoil Hybridity
EWM
HWM
NWM
Moody & Les, 2007
Taylor et. al 2017
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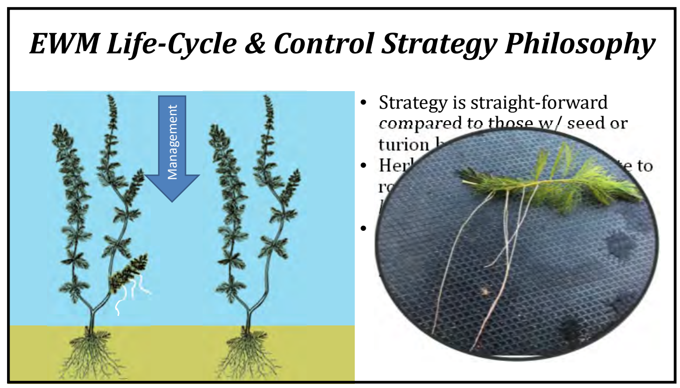
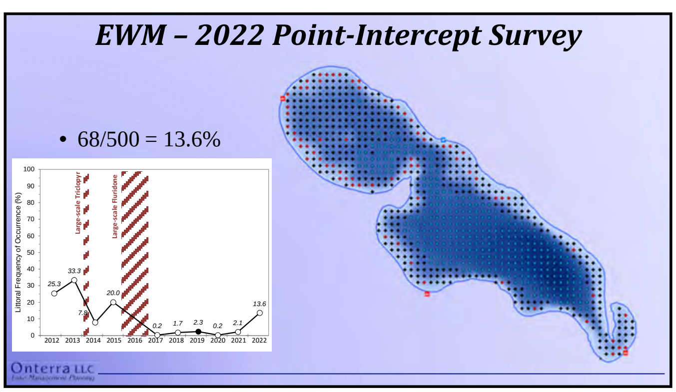

EWM Life-Cycle & Control Strategy Philosophy
Management
• Strategy is straight-forward compared to those w/ seed or turion


EWM – 2022 Point-Intercept Survey
• 68/500 = 13.6%
Littoral Frequency of Occurrence (%)
Large-scale Triclopyr
Large-scale Fluridone
25.3
33.3
7.9
20.0
0.2
1.7
2.3
0.2
2.1
13.6
2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022
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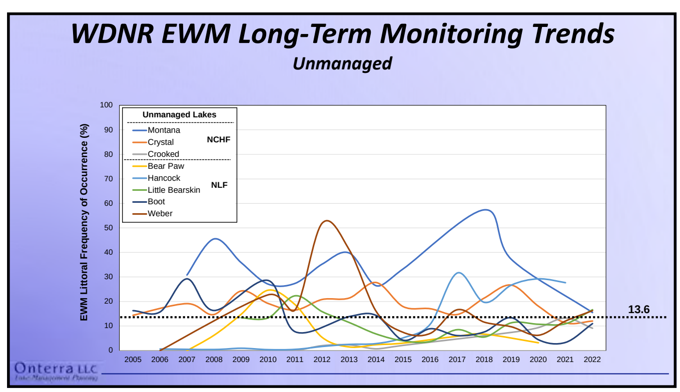
WDNR EWM Long-Term Monitoring Trends
Unmanaged
EWM Littoral Frequency of Occurrence (%)
Unmanaged Lakes
Montana
Crystal
Crooked
NCHF
Bear Paw
Hancock
Little Bearskin
Boot
Weber
NLF
13.6
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022
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Types of Aquatic Plant Surveys

Quantitative
- Point-Intercept Survey
  - Numeric & systematic
  - Applied at various scales

Qualitative
- EWM Mapping Surveys
  - Fine-scale location accuracy
  - Subjective designations



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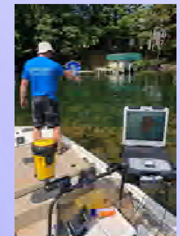
Professional AIS Mapping


Point-Based Mapping
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony

Polygon-Based Mapping
- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting

True Colonies

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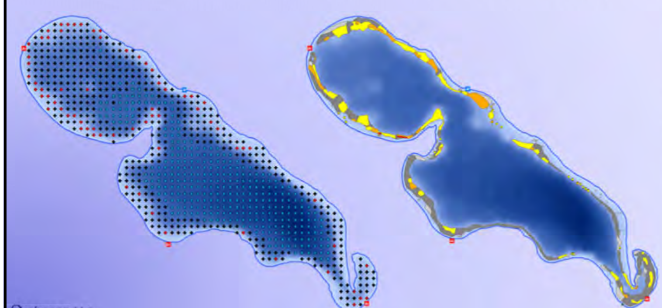
2022 EWM Surveys



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2015-2020 EWM Mapping Surveys

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2021-2022 EWM Mapping Surveys


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Best Management Practices (BMPs)

- **A "placeholder" term to represent the management option that is currently supported by that latest science and policy**
- **Definition evolves over time**
  - Pre 2010 - small spot treatments with granular products
  - Early 2010s - larger spot treatments with liquid products
  - Mid 2010s – whole-lake treatments (2,4-D & fluridone 2.0), spot treatments with herbicide combos, hand-harvesting/DASH
  - Current– whole-lake/basin approaches, nuisance maintenance vs population management, mechanical harvesting, increasing human tolerance, new herbicides

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EWM/HWM Management Perspectives

1. **No Coordinated Active Management (Let Nature Take its Course)**
   - Focus on education of manual removal by property owners
   - District does not oppose contracted efforts, but does not organize or pay for them
2. **Reduce AIS Population on a lake-wide level (Population Management)**
   - Would likely rely on herbicide treatment (risk assessment)
   - Will not "eradicate" HWM
   - Set triggers (thresholds) of implementation and tolerance
3. **Minimize navigation and recreation impediment (Nuisance Control)**
   - Hand-harvesting alone is not able to accomplish this goal during high populations of EWM, herbicides and/or mechanical harvester would be required

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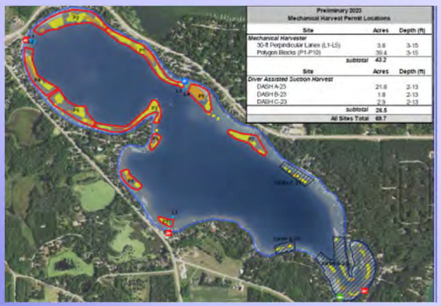
#3: Maintain Navigation, Recreation, Aesthetics



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Herbicide Treatment on Loon Lake

- Tracer Dye (Rhodamine WT)
- ~24 acres of 305 acre lake (7.8%)

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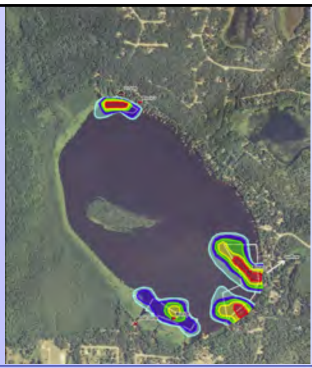
1 HAT

75-100%
50-75%
25-50%
10-25%
5-10%



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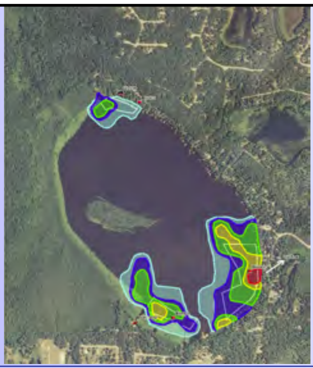
2.5 HAT

75-100%
50-75%
25-50%
10-25%
5-10%



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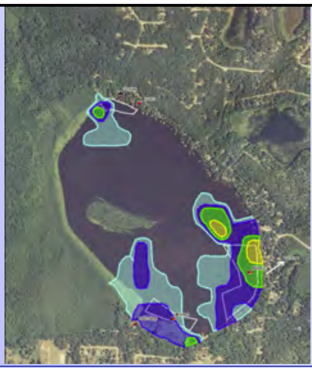
4 HAT

75-100%
50-75%
25-50%
10-25%
5-10%



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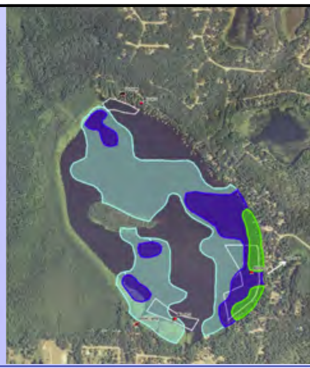
6 HAT

75-100%
50-75%
25-50%
10-25%
5-10%

2,4-D CET needed for EWM control based upon published studies:
- sustained 4.0 ppm for 12 hours
- sustained 2.0 ppm for 24 hours
- 0.1-0.3 ppm for 6 weeks+ (whole-lake)



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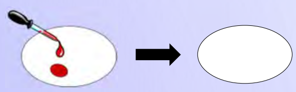
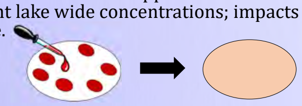
Ecological Definitions of Herbicide Treatment

Spot Treatment: Herbicide applied at a scale where dissipation will not result in significant lake wide concentrations; impacts are anticipated to be localized to in/around application area.



Whole-Lake (basin-wide) Treatment: Herbicide applied at a scale where dissipation will result in significant lake wide concentrations; impacts are anticipated to be on a lake wide scale.



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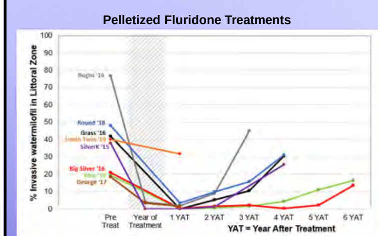
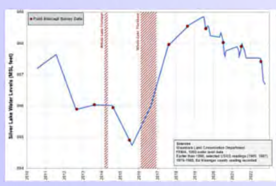
#2: Lake-Wide HWM "Control"





Year	Company	Dive Time (hrs)	EWM Removed (cubic yards)
2017	DASH, LLC	38.95	1,300+ plants
2018	APM, LLC	78.49	23.0
2019	APM, LLC	212.81	46.2
2020	APM, LLC	171.50	19.9
2021	APM, LLC	183.50	103.5
2022	APM, LLC	275.90	217.2
Totals		961.15	409.8

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#2: Lake-Wide HWM "Control"

Primary Whole-Lake Herbicide Options

- **Fluridone –** inhibits plant-specific enzyme (carotene) which protects chlorophyll from UV (sun) damage – breakdown from photolysis; requires "bumps" to sustain full growing season
  - Worked in 2016, but results complicated by water levels
  - Native plant selectivity is moderate
  - Herbicide resistance?
  - Active ingredient present for a year
- **Florpyrauxifen-benzyl –** absorbed by plant tissue; inhibits plant growth and cell division (auxin hormone mimic) – many breakdown pathways, some with herbicidal properties
  - Different binding affinity than other auxins
  - Native plant selectivity is high
  - Minimal history of use (2020 spot results)
  - Active ingredient present for a week, acid metabolite for month(s)

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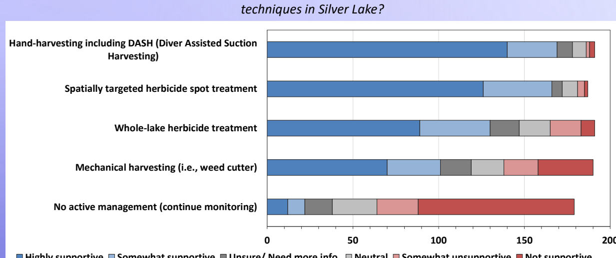
Stakeholder Perceptions of EWM Management

68% Response Rate

What is your level of support for the future use of the following Eurasian watermilfoil management techniques in Silver Lake?



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4.0 Conclusions

Water Quality
- Overall "excellent" for Deep Seepage Lake
- Metalimnetic oxygen maxima, internal nutrient loading, and zebra mussels influences are present
- Paleocore suggests similar nutrient composition to pre-European settlement, but shoreline zone habitat is different

Watershed
- Moderately small watershed, with complicated components

Shoreland Condition
- Highly developed, any addition of healthy shoreline practices would be beneficial, especially from fisheries habitat perspective

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4.0 Conclusions

Aquatic Plants

- Fairly healthy and stable aquatic plant community
- Largest changes occurred in 2016 (fluridone & water level increase)
- HWM population increasing; long term strategy development required
- Likely ideal habitat for starry stonewort, a relatively recent AIS to WI

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Implementation Plan Development

Goal
- Reflects big picture
- Can be ambitious, but attainable

Action
- Step to meet goal
- Measurable outcome
- Timeframe
- Facilitator

- Management goals are statements, were as management actions are detaile.

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Planning Meeting II

Primary Objective: Create implementation plan framework

Steps to Achieve Objective:

1. Discuss challenges facing lakes and lake groups
2. Convert challenges to management goals
3. Create management actions to meet management goals
4. Determine timeframes and facilitators to carry out actions

Assignment for Planning Meeting II

1. Create list of challenges facing lake and lake group (keep to yourself)
2. Review stakeholder survey results
3. Send potential report section edits and questions to Onterra

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Thank You

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Lake Management Planning

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Lake-Wide HWM "Control"

Primary Whole-Lake Herbicide Options

- **Fluridone –** inhibits plant-specific enzyme (carotene) which protects chlorophyll from UV (sun) damage – breakdown from photolysis; requires "bumps" to sustain full growing season
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  - Minimal history of use (2020 spot results)
  - Active ingredient present for a week, acid metabolite for month(s)

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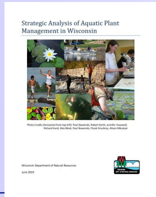
Fluridone

- Sold as liquid or pelletized formulation, primarily by SePRO as Sonar™
- Inhibits plant-specific enzyme (carotene) which protects chlorophyll from UV (sun) damage - bleaching
- Purposefully long environmental fate of active ingredient (mainly photolysis)
- Requires long exposure times (≥ 90 days, but have had exposures of >400 days) sustained through "bump" treatments
- Checkered past in WI due to non-target plant impacts
- *Slightly* to *moderately toxic* to freshwater fish and invertebrates. *Practically nontoxic* to birds or small mammals.



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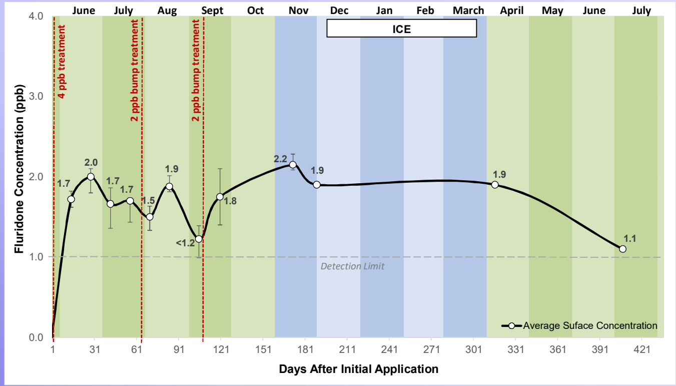
Silver Lake Fluridone Treatment



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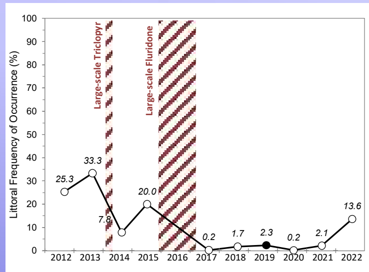
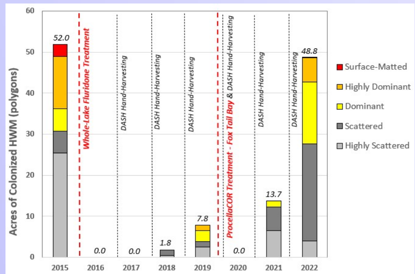
Silver Lake Fluridone Treatment





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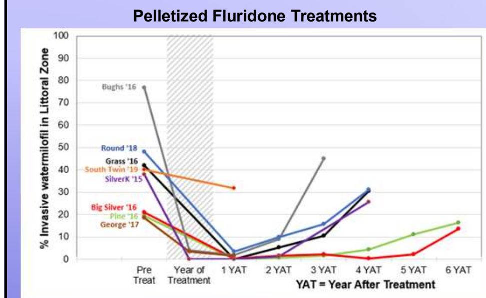
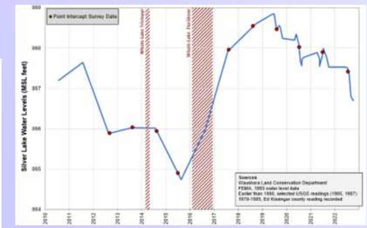
Silver Lake Fluridone Treatment





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Totals		961.15	409.8

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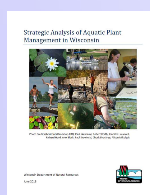
Florpyrauxifen-benzyl (ProcellaCOR™)

- New class of synthetic auxin hormone mimics
  - Much different binding affinity than other auxins
  - Use at PPB rate vs PPM
- Shorter contact exposure time (CET) requirement
- Short environmental fate of active ingredient (mainly photolysis)
- Acid metabolite has activity as an herbicide (longer environmental fate)
- Detailed information on field applications is limited (first in 2019 in WI)
  - Onterra may have the largest field monitoring database
- *Practically nontoxic* to freshwater fish and invertebrates, birds, bees, reptiles, amphibians and mammals



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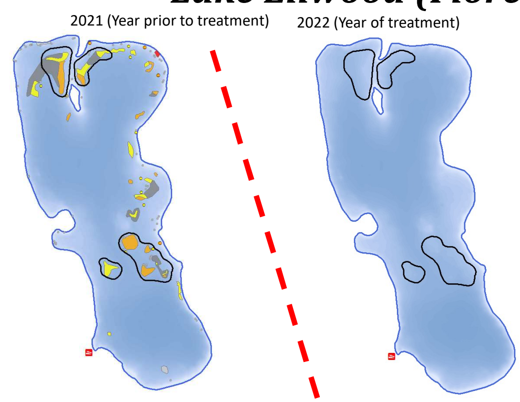
HWM

Lake Ellwood (Florence Co.)



Application Area Total: 11.7 acres
Application Rate: 4.0 PDU
Lake-wide (131.5 acres)
Epilimnetic Calculation: 0.61 ppb

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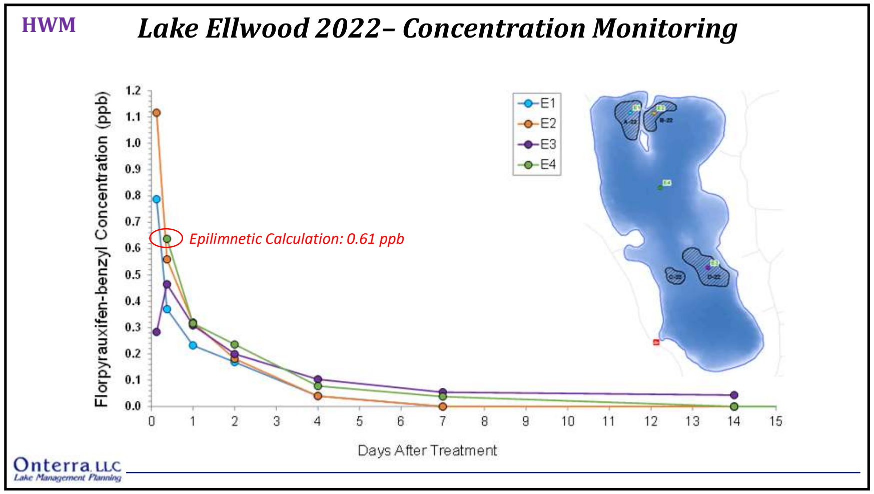
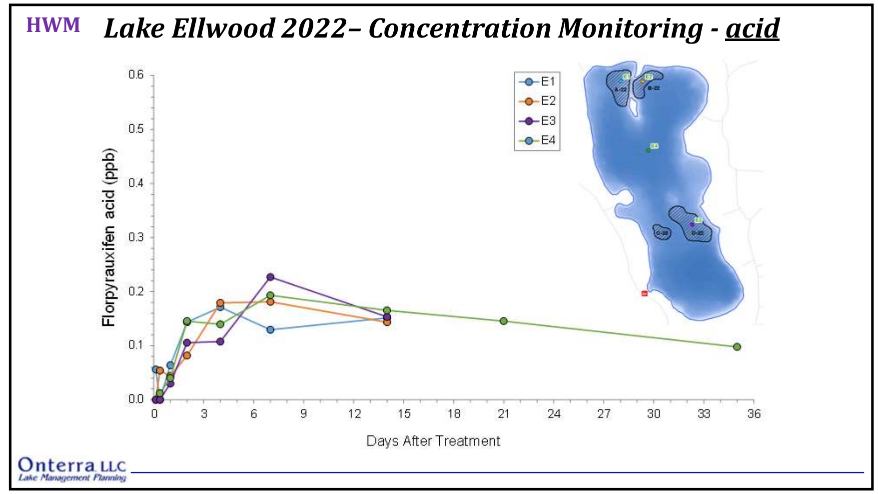
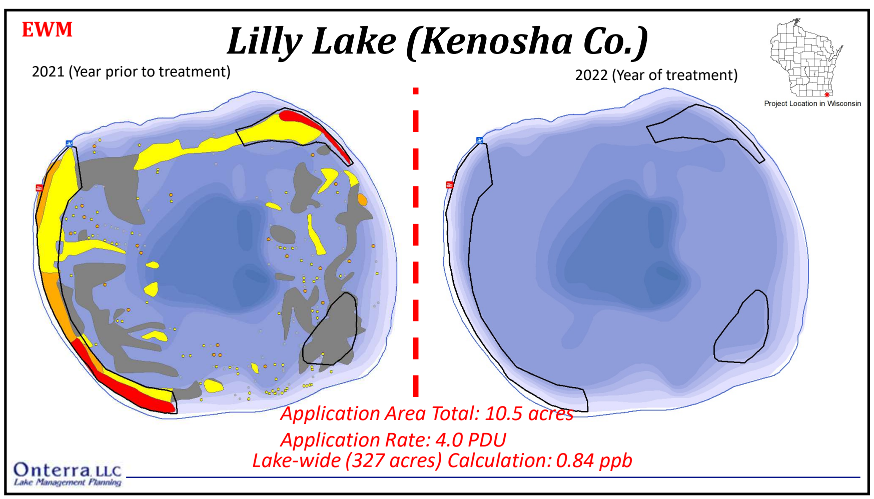
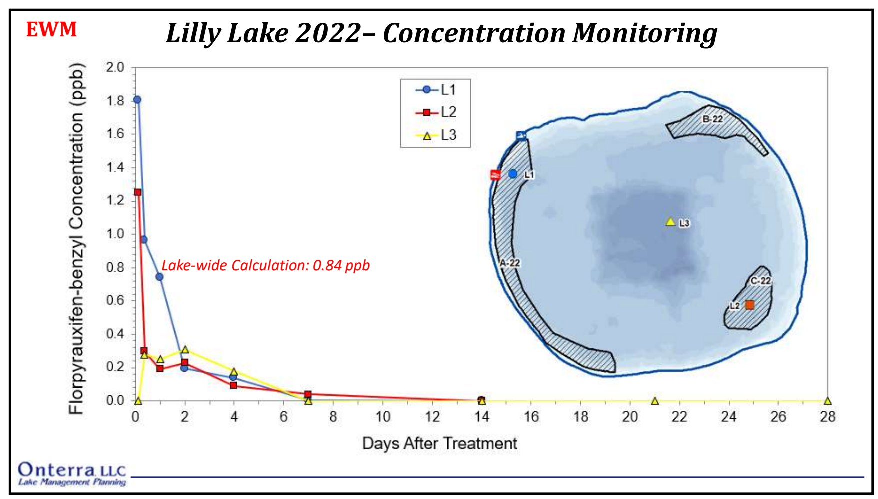
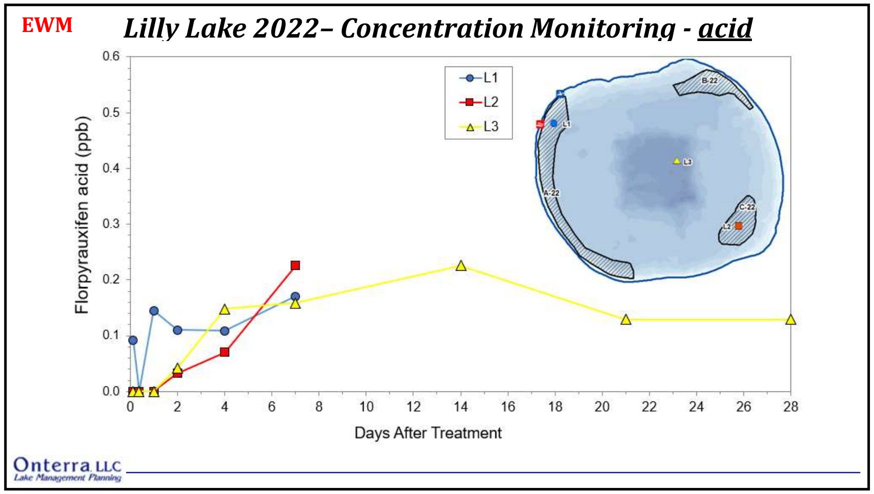
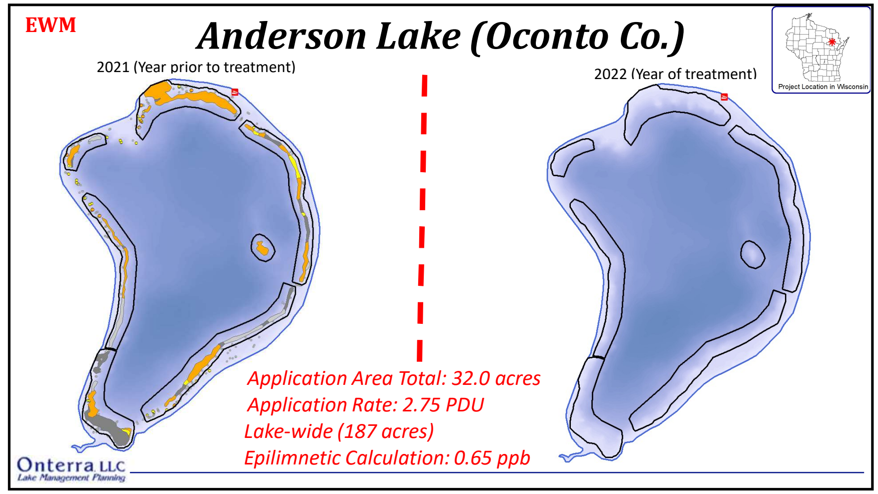

HWM
Lake Ellwood 2022– Concentration Monitoring
Florpyrauxifen-benzyl Concentration (ppb)
Days After Treatment
E1
E2
E3
E4
Epilimnetic Calculation: 0.61 ppb
Onterra LLC
Lake Management Planning


HWM
Lake Ellwood 2022– Concentration Monitoring - acid
Florpyrauxifen acid (ppb)
Days After Treatment
E1
E2
E3
E4
Onterra LLC
Lake Management Planning


EWM
Lilly Lake (Kenosha Co.)
2021 (Year prior to treatment)
2022 (Year of treatment)
Project Location in Wisconsin
Application Area Total: 10.5 acres
Application Rate: 4.0 PDU
Lake-wide (327 acres) Calculation: 0.84 ppb
Onterra LLC
Lake Management Planning


EWM
Lilly Lake 2022– Concentration Monitoring
Florpyrauxifen-benzyl Concentration (ppb)
Days After Treatment
L1
L2
L3
Lake-wide Calculation: 0.84 ppb
A-22
B-22
C-22
Onterra LLC
Lake Management Planning


EWM
Lilly Lake 2022– Concentration Monitoring - acid
Florpyrauxifen acid (ppb)
Days After Treatment
L1
L2
L3
Onterra LLC
Lake Management Planning


EWM
Anderson Lake (Oconto Co.)
2021 (Year prior to treatment)
2022 (Year of treatment)
Application Area Total: 32.0 acres
Application Rate: 2.75 PDU
Lake-wide (187 acres)
Epilimnetic Calculation: 0.65 ppb
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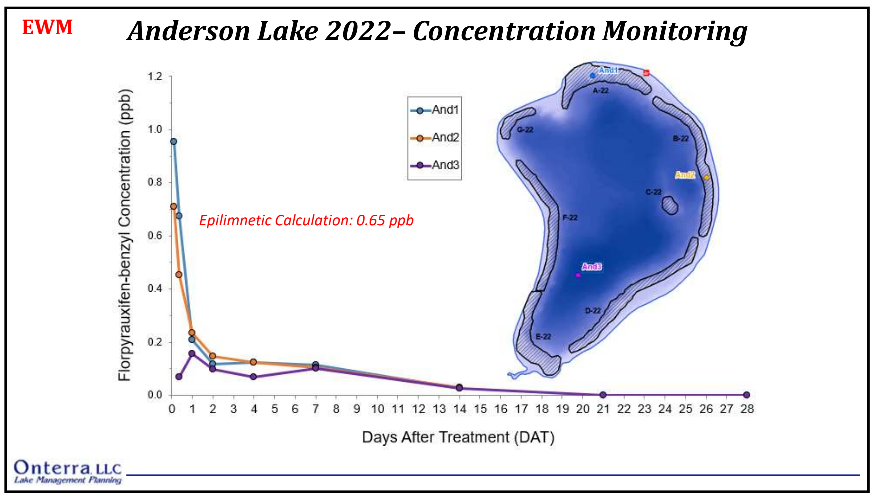
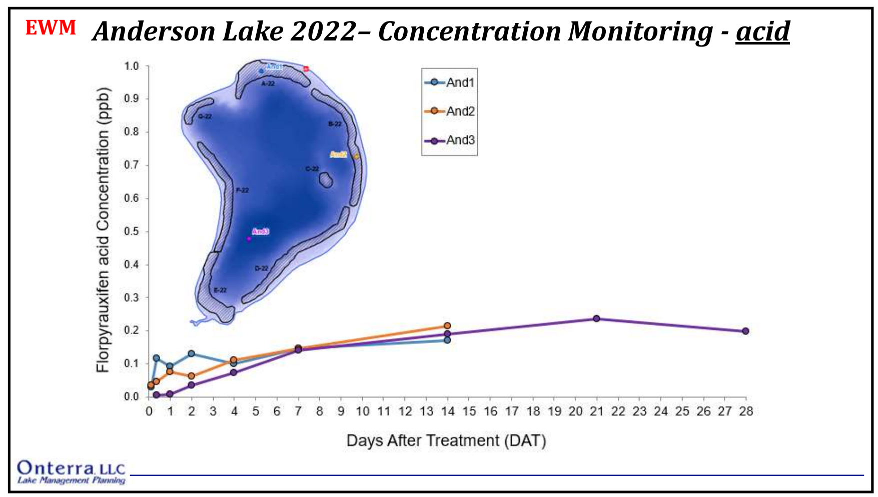
Lake Management Planning


EWM
Anderson Lake 2022– Concentration Monitoring
Florpyrauxifen-benzyl Concentration (ppb)
Days After Treatment (DAT)
And1
And2
And3
Epilimnetic Calculation: 0.65 ppb
Onterra LLC
Lake Management Planning


EWM
Anderson Lake 2022– Concentration Monitoring - acid
Florpyrauxifen acid Concentration (ppb)
Days After Treatment (DAT)
And1
And2
And3
Onterra LLC
Lake Management Planning

Native Plant Susceptibility Table

Fluridone on Silver	ProcellaCOR	Species	Littoral Frequency of Occurrence (%)
-	-	Charophytes	22.4
↓	↓	Coontail	19.2
-	-	Wild celery	16.6
↓	↓	Eurasian watermilfoil	13.6
↓	↑	Common waterweed	12.4
-	-	Flat-stem pondweed	9.6
↓	-	Southern naiad	7.8
-	-	Sago pondweed	6.4
↓	↑	White-stem pondweed	6.2
↓	-	Variable-leaf pondweed	5.2
↓	-	Slender naiad	4.4
-	-	Slender and Small pondweeds	4.2
↓	↓	Water marigold	4
↓	↓	White water crowfoot	3.8
↓	-	Fries' pondweed	3.6

Silver Lake 2022

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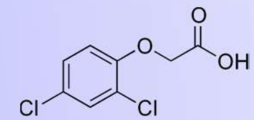
2.4-D Impacts on Fish Early Life Stages

- DeQuattro and Karasov 2016 demonstrated statistically valid reduction in fathead minnow larval survivability when 2,4-D is exposed to embryo (eggs) and larval (hatched). Also demonstrated sub-lethal endocrine disruption impacts (tubercles).
- Dehnert et. al 2018 indicates the first 14 days post hatch (dph) is the most critical period for fathead minnow.
- Dehnert et. al 2021 investigated multiple gamefish species, exposing to 30 dph to conform with EPA's definition of "chronic"



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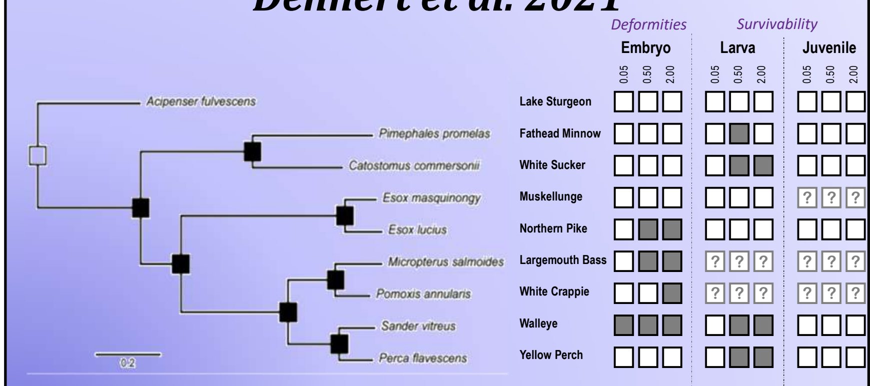
Dehnert et al. 2021



Onterra LLC
Lake Management Planning

Implementation Plan Development

Goal
- Reflects big picture
- Can be ambitious, but attainable

Action
- Step to meet goal
- Measurable outcome
- Timeframe
- Facilitator

- Management goals are statements, were as management actions are detaile.

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Challenges Discussion

- Aquatic plants
  - Monitoring
    - Strategy & Frequency
  - Management
    - HWM, CLP, Emergent AIS
    - Implementation Triggers
    - Monitoring framework
  - Prevention & Containment
    - CBCW
      - Inspection/awareness
    - Supplemental Programs
      - Cleaning/surveillance

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Challenges Discussion

- Water quality
  - Zebra mussels & Filamentous algae
  - Internal nutrient & metalimnetic oxygen maxima
  - CLMN Advanced (temp & DO)
- Watershed
  - Sanitary districts
  - Point-source influence (Irogami)
- Shorelands & Nearshore
  - Importance of nearshore areas
  - Healthy Lakes Grants
  - Role of shoreland modifications
  - Increase emergent vegetation & woody habitat for fish

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Challenges Discussion

- Fisheries
  - Habitat (Fish sticks/cribs, shoreland vegetation)
  - Stocking
  - Emphasize district capacity
- Organizational capacity
  - Communication abilities
- Education & Stewardship
  - Examples
- Recreation
  - Watercraft safety/guidelines/courtesy code
  - Highwater & boating

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Thank You

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B

APPENDIX B

Riparian Stakeholder Survey Response Charts & Comments

Silver Lake - Anonymous Property Owner Survey

Surveys Distributed: *290*
Surveys Returned: *196*
Response Rate: *68%*

DRAFT

Silver Lake Property

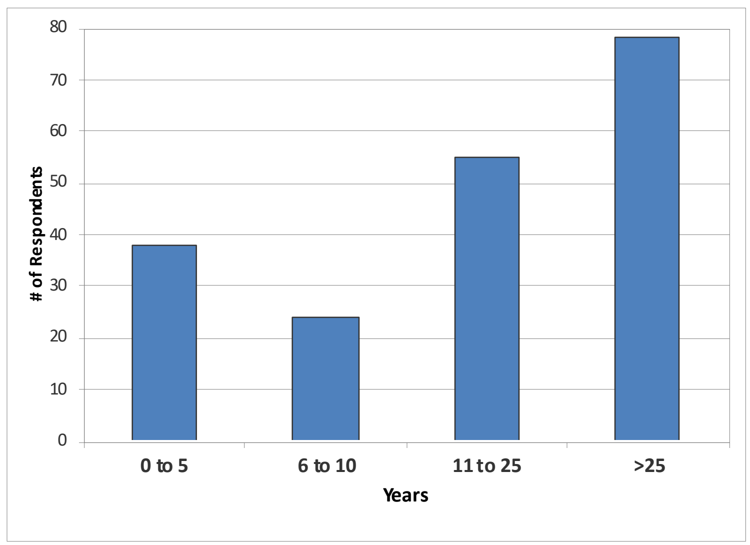
1. Do you currently use your property as a rental property?

Answer Options	Response Percent	Response Count
Yes	6.7%	13
No	93.3%	182
	answered question	**195**
	skipped question	**1**

2. How many years have you owned or rented your property on or near Silver Lake?

Answer Options	Response Count
	195
answered question	**195**
skipped question	**1**

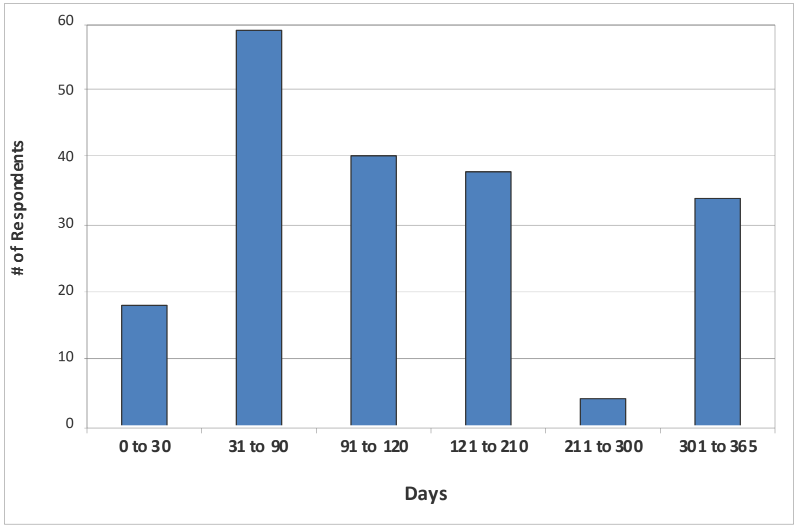
Category (# of years)	Responses	% Response
0 to 5	**38**	**19%**
6 to 10	**24**	**12%**
11 to 25	**55**	**28%**
>25	**78**	**40%**



3. Considering the past three years, how many days each year is your property used by you or others?

	Response Count
answered question	193
skipped question	3

Category (# of days)	Responses	%
0 to 30	18	9%
31 to 90	59	31%
91 to 120	40	21%
121 to 210	38	20%
211 to 300	4	2%
301 to 365	34	18%

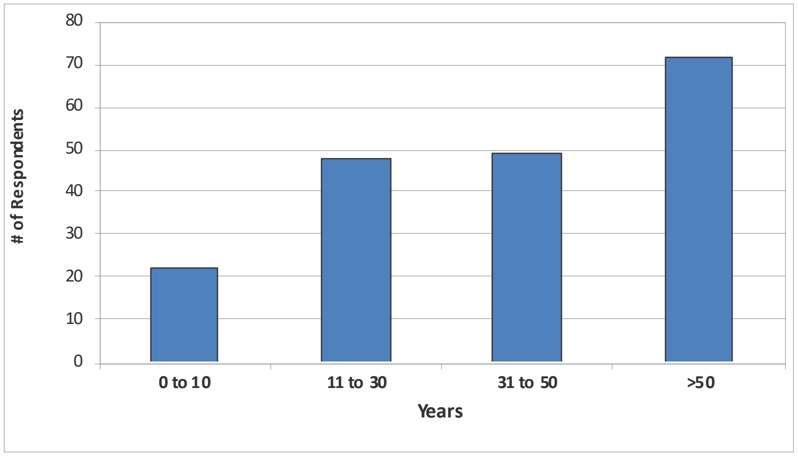


Recreational Activity on Silver Lake

4. How many years ago did you first visit Silver Lake?

Answer Options	Response Count
answered question	191
skipped question	5

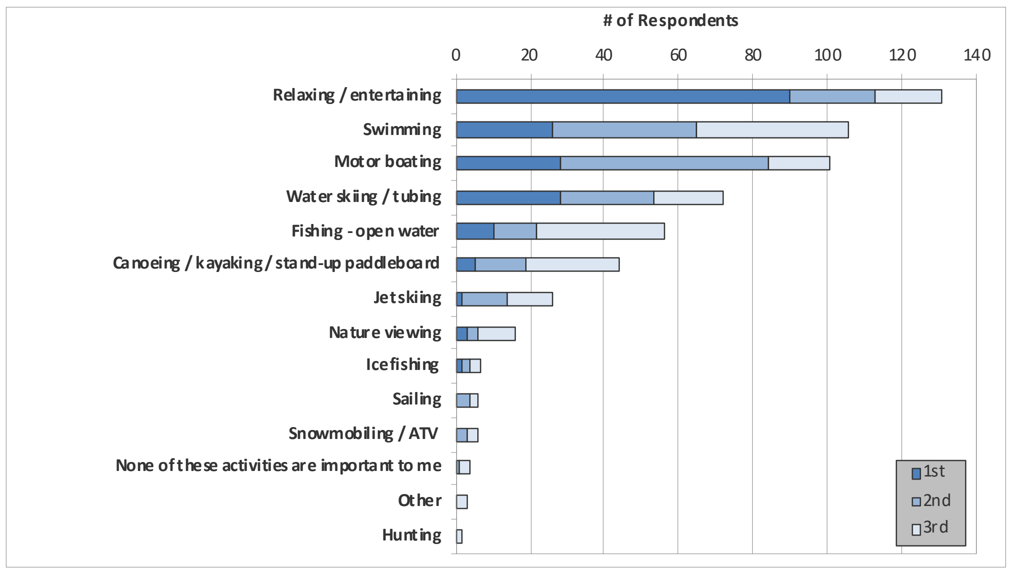
Category (# of years)	Response Percent	Response Count
0 to 10	12%	22
11 to 30	25%	48
31 to 50	26%	49
>50	38%	72



5. Please rank up to three activities that are important reasons for owning your property on or near Silver Lake, with the 1st being most important.

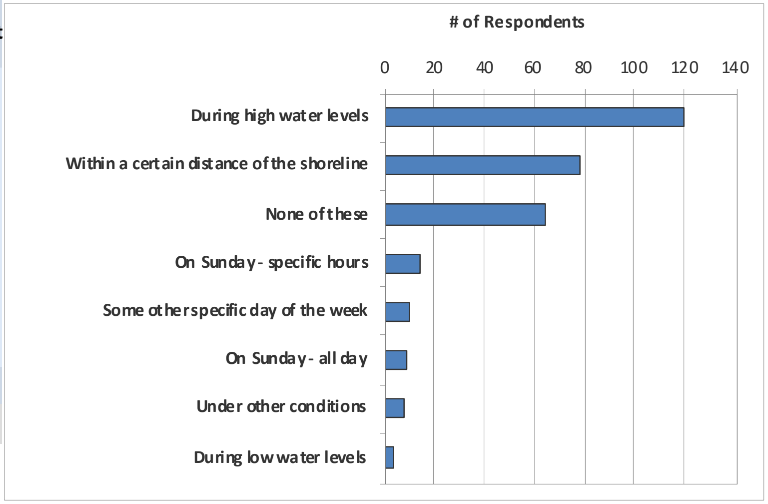
Answer Options	1st	2nd	3rd	Rating Average	Response Count
Relaxing / entertaining	90	23	18	1.45	131
Swimming	26	39	41	2.14	106
Motor boating	28	56	17	1.89	101
Water skiing / tubing	28	25	19	1.88	72
Fishing - open water	10	12	34	2.43	56
Canoeing / kayaking / stand-up paddleboard	5	14	25	2.45	44
Jet skiing	2	12	12	2.38	26
Nature viewing	3	3	10	2.44	16
Ice fishing	2	2	3	2.14	7
Sailing	0	4	2	2.33	6
Snowmobiling / ATV	0	3	3	2.5	6
None of these activities are important to me	0	1	3	2.75	4
Other	0	0	3	3	3
Hunting	0	0	2	3	2
				answered question	**195**
				skipped question	**1**

Number	"Other" responses
1	wakesurfing/wakeboarding is high on the list
2	It is my residence
3	Unfortunately, lake is not pristine like it used to be. Lots of crazy boaters. Unsupervised kids racing motor boats. Perhaps unauthorized renters.
4	Being with family at the lake
5	Investment



6. Currently on Silver Lake, slow-no-wake restrictions limit boating speeds during the evening and overnight hours and along certain shoreline areas. Considering this, when, if at all, would you suggest additional slow-no-wake restrictions?

Answer Options	Response Percent	Response Count
During high water levels	62.5%	120
Within a certain distance of the shoreline	40.6%	78
None of these; I don't believe additional restrictions are needed	33.9%	65
On Sunday - specific hours	7.8%	15
Some other specific day of the week	5.2%	10
On Sunday - all day	4.7%	9
Under other conditions	4.2%	8
During low water levels	2.1%	4
	answered question	**192**
	skipped question	**4**

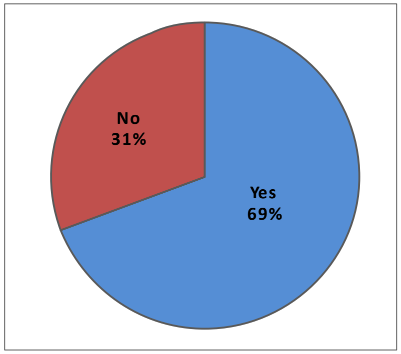


Number	"Other" responses
1	No wake after 4 pm on Sundays
2	Before 9:00AM
3	until noon and after 5pm
4	10-6 every day
5	After 3:00 p.m.
6	where the lake pinches - we need wake boats to stay away from the shorelines. THis is getting crazy! That is the number one area the sheriff needs to ticket people for
7	Keep fishing boats away from piers and swimming areas at all times.
8	No wake area pushed farther out away from Fox Tail Bay
9	All others are fine
10	Extend nowake out further from foxtail, no wake every day before noon and after6pmnoon
11	No wake 7:00pm-9:00 am everyday
12	No wake before 10am daily.
13	Before 10:00am and after 4:00pm
14	“High water” being when water is up against property sea walls!
15	would like the the no wake to start later in the mornings so fisherman and kayaking can enjoy without waves
16	Slow no wake for PWCs should end when water skiing end.
17	Saturday & Sunday I'd recommend large wake making boating hours between 9 and 5 only. Outside those hours is more ideal for pontoon rides swimming, kayaking, paddle boards etc.
18	Saturday and Sunday no wake before 10 am and after 5 pm

19	before 10am and after 8pm all weekend
20	SATURDAYS&SUNDAYS AT TIMES
21	My windows are kept open at night during the summer; unbelievable the noisy boaters with music cranked up to the highest level and what appears to be drunk passengers at all hours of the night. Not only is it dangerous but it's hard to sleep when that is occurring at 11pm and later!
22	When shoreline erosion is taking place due to high wave action
23	During weekends when towing isn't allowed
24	Not before 10am & after 8:00pm
25	only during extreme high water levels
26	Wave runners should follow same regulations as boats, including mornings and after sunset every day.
27	4 pm to sunset
28	No wake after 6 PM daily
29	Every day of the week (Sun-Sat) 6pm-10am (evening and overnight)
30	Weekend evenings like the skiing hours.
31	when water levels are super high
32	Boat should have the same wake limits as jet skis and restrict use of wakeboarding during high water times. It has destroyed our shoreline with use @ the high water and we all know I ame not the only one. Stop wak on lake after 3:00 pm on sunday
33	no wake after 6pm M-F....
34	Saturday no wake
35	Monday or Tuesday or Wednesday
36	sat and sun after 5pm
37	I would support restrictions on motorboat and personal watercraft speeds during the same periods when water skiing and tubing are currently limited.
38	No wake hours should include all boats not just water skiing the signs are so confusing no one knows what to do
39	as many days as possible after 6 pm
40	Police water patrol should be defunded. No need

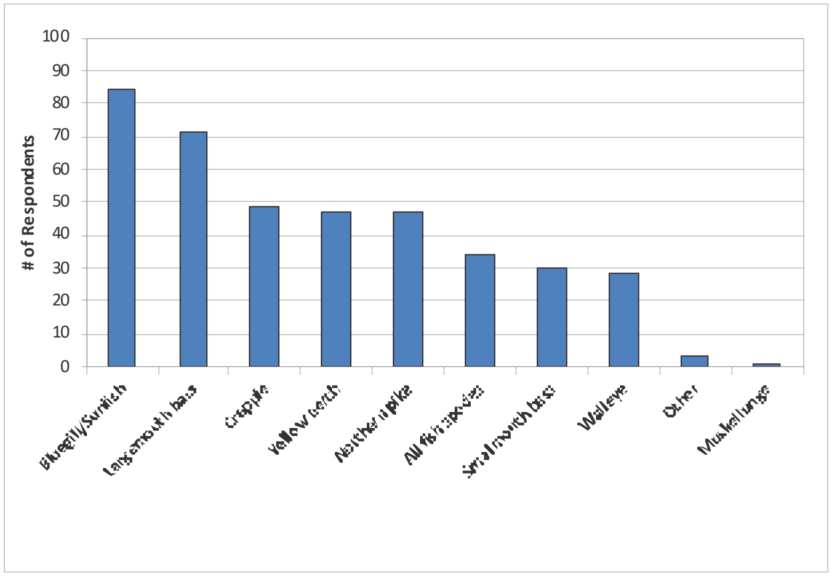
7. Have you personally fished on Silver Lake in the past three years?

Answer Options	Response Percent	Response Count
Yes	69.2%	135
No	30.8%	60
	answered question	**195**
	skipped question	**1**



8. What species of fish do you try to catch on Silver Lake?

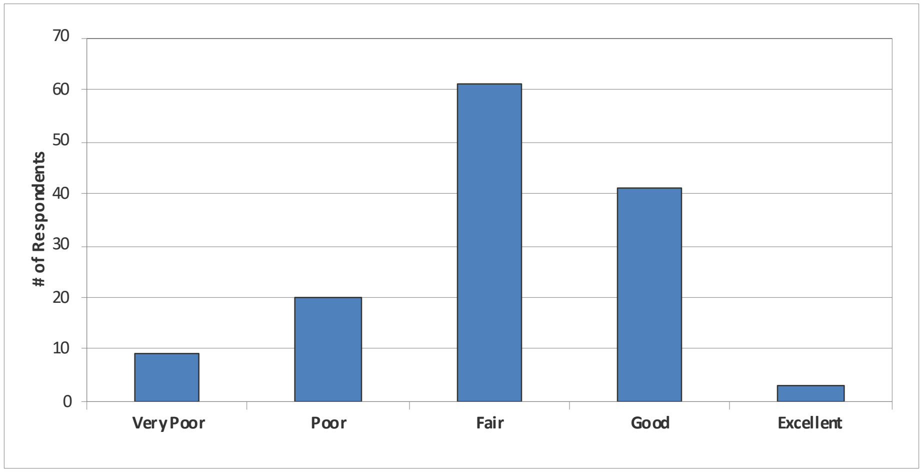
Answer Options	Response Percent	Response Count
Bluegill/Sunfish	62.2%	84
Largemouth bass	52.6%	71
Crappie	36.3%	49
Yellow perch	34.8%	47
Northern pike	34.8%	47
All fish species	25.2%	34
Smallmouth bass	22.2%	30
Walleye	20.7%	28
Other	2.2%	3
Muskellunge	0.7%	1
	answered question	**135**
	skipped question	**61**



Number	"Other" responses
1	Northern
2	whatever takes my bait
3	Very poor fish population esp walleye & panfish

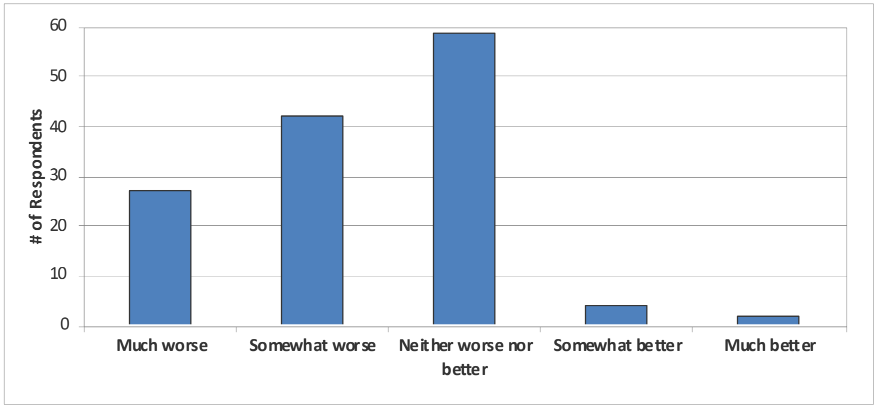
9. How would you describe the current quality of fishing on Silver Lake?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	9	20	61	41	3	134
					answered question	**134**
					skipped question	**62**



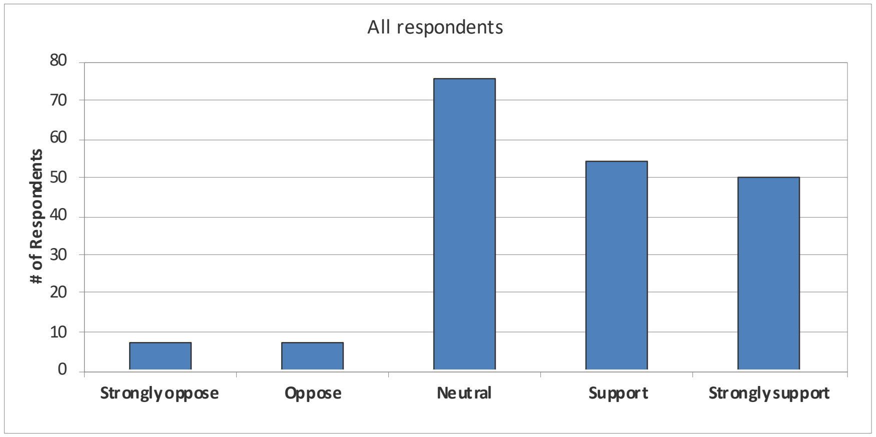
10. How has the quality of fishing changed on Silver Lake since you have started fishing the lake?

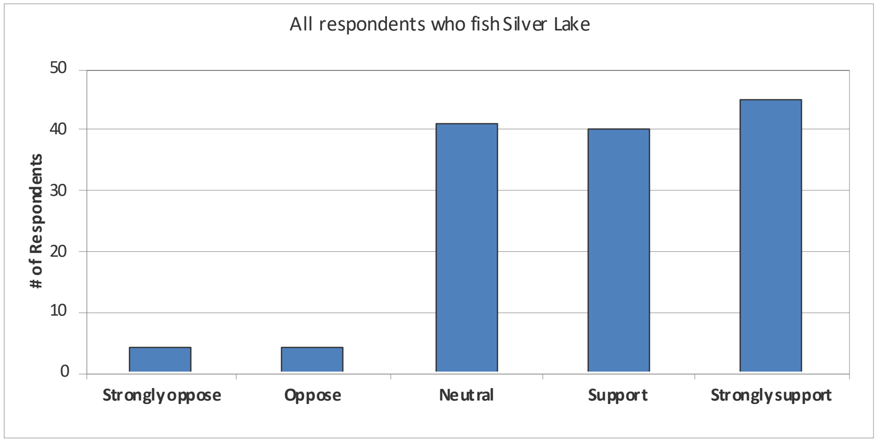
Answer Options	Much worse	Somewhat worse	Neither worse nor better	Somewhat better	Much better	Response Count
	27	42	59	4	2	134
					answered question	134
					skipped question	62



11. Based on the 2016 management plan, Silver Lake harbors a low population of walleye and consists of entirely stocked fish with no natural reproduction. Before we spend additional time and money, we would like to know your level of support or opposition in pursuing walleye stocking efforts on Silver Lake?

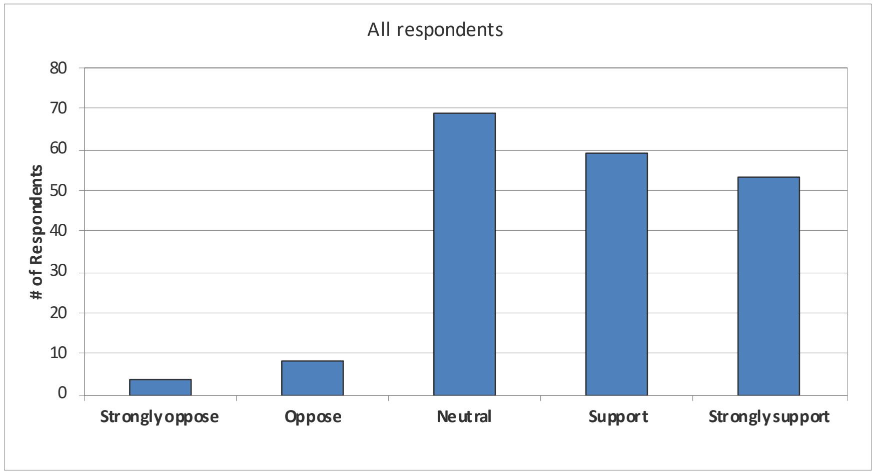
Answer Options	Strongly oppose	Oppose	Neutral	Support	Strongly support	Response Count
All respondents	7	7	76	54	50	194
All respondents who fish Silver Lake (Q7)	4	4	41	40	45	134
					answered question	**194**
					skipped question	**2**

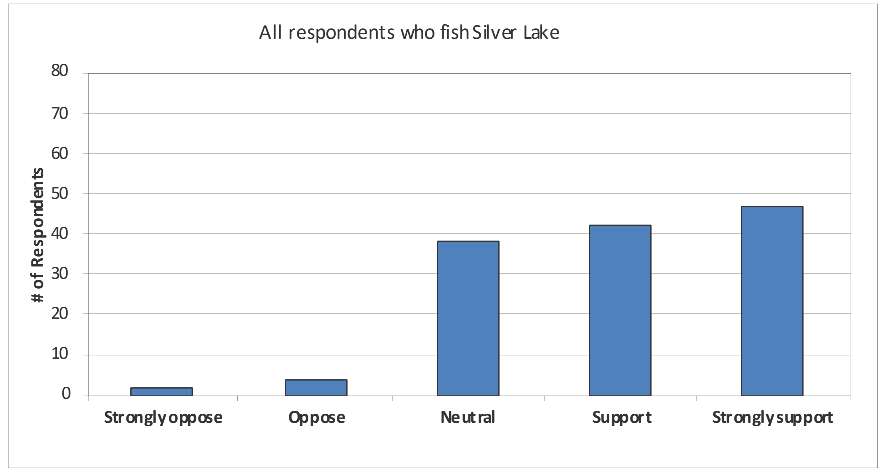




12. Adding or improving existing walleye spawning habitat could increase the likelihood of walleye naturally reproducing in Silver Lake. Before we spend additional time and money, we would like to know your level of support or opposition to increasing walleye spawning habitat on Silver Lake?

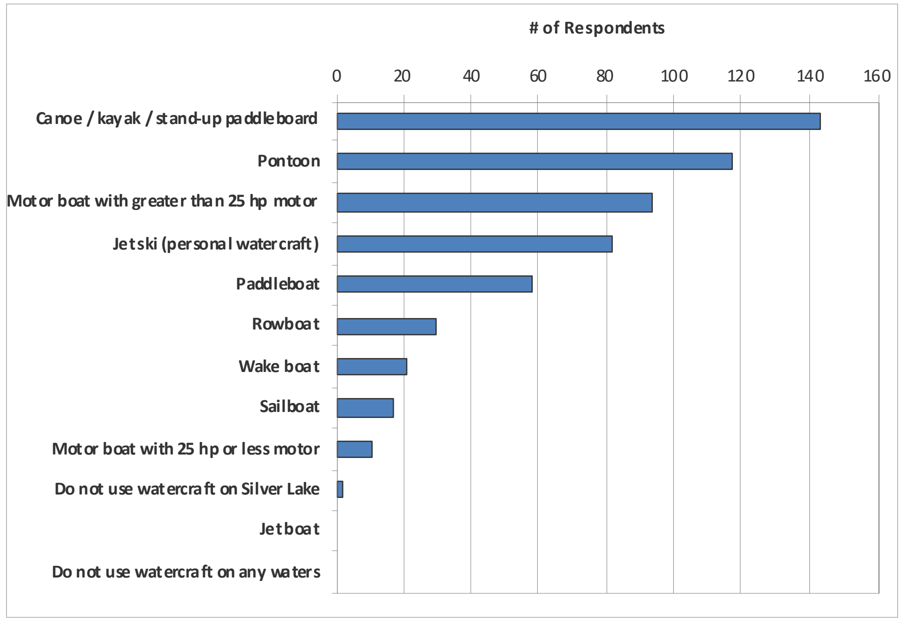
Answer Options	Strongly oppose	Oppose	Neutral	Support	Strongly support	Response Count
All respondents	4	8	69	59	53	193
All respondetnts who fish Silver Lake (Q7)	2	4	38	42	47	133
					answered question	**193**
					skipped question	**3**





13. What types of watercraft do you currently use on Silver Lake?

Answer Options	Response Percent	Response Count
Canoe / kayak / stand-up paddleboard	73.7%	143
Pontoon	60.3%	117
Motor boat with greater than 25 hp motor	48.5%	94
Jet ski (personal watercraft)	42.3%	82
Paddleboat	29.9%	58
Rowboat	15.5%	30
Wake boat	10.8%	21
Sailboat	8.8%	17
Motor boat with 25 hp or less motor	5.7%	11
Do not use watercraft on Silver Lake	1.0%	2
Jet boat	0.0%	0
Do not use watercraft on any waters	0.0%	0
	answered question	**194**
	skipped question	**2**

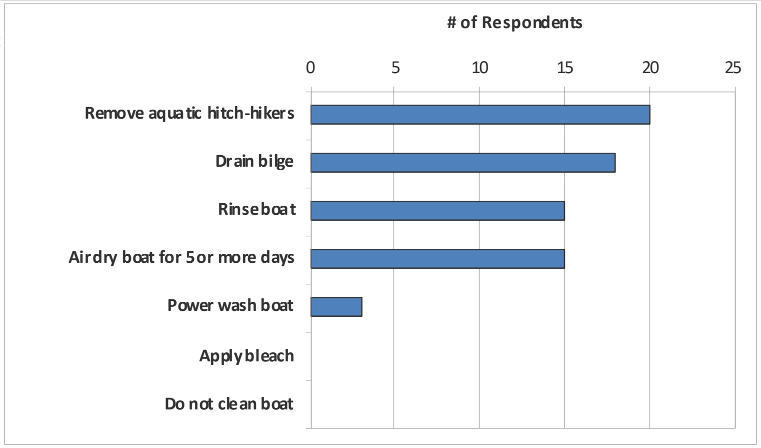


14. Do you use your watercraft on waters other than Silver Lake?

Answer Options	Response Percent	Response Count
Yes	11.9%	23
No	88.1%	171
	answered question	**194**
	skipped question	**2**

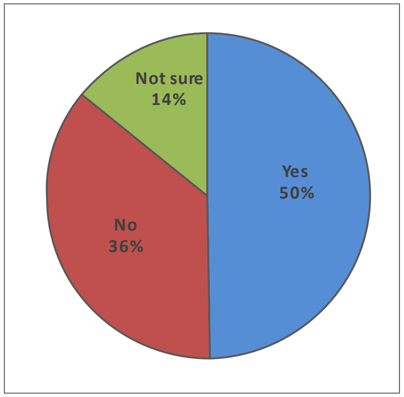
15. What is your typical cleaning routine after using your watercraft on waters other than Silver Lake?

Answer Options	Response Percent	Response Count
Remove aquatic hitch-hikers (ex. - plant material, clams, mussels)	87.0%	20
Drain bilge	78.3%	18
Rinse boat	65.2%	15
Air dry boat for 5 or more days	65.2%	15
Power wash boat	13.0%	3
Apply bleach	0.0%	0
Do not clean boat	0.0%	0
	answered question	**23**
	skipped question	**173**



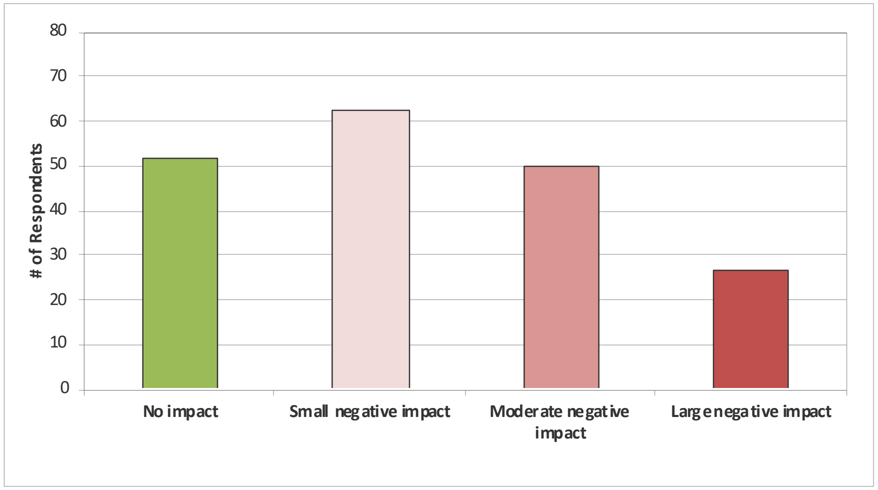
16. Do you feel that current slow-no-wake restrictions are adequately enforced on Silver Lake?

Answer Options	Response Percent	Response Count
Yes	49.7%	95
No	36.1%	69
Not sure	14.1%	27
	answered question	**191**
	skipped question	**5**



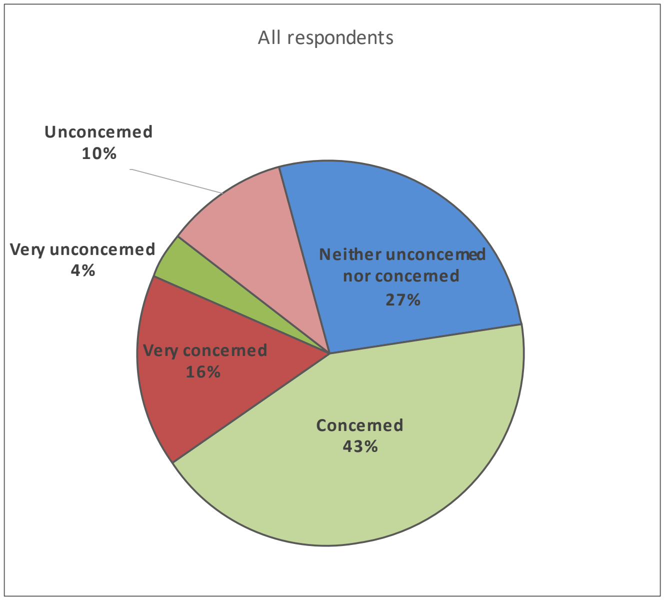
17. To what extent, if any, do you feel the volume of summer boat traffic negatively affects your enjoyment of the lake?

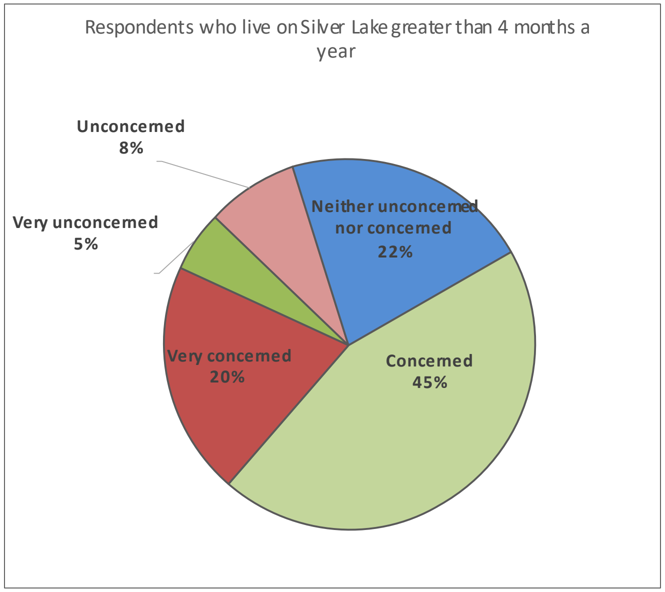
Answer Options	No impact	Small negative impact	Moderate negative impact	Large negative impact	Response Count
	52	63	50	27	192
				answered question	**192**
				skipped question	**4**



18. How concerned or unconcerned do you feel about watercraft safety during busy days on Silver Lake?

Answer Options	Very unconcerned	Unconcerned	Neither unconcerned nor concerned	Concerned	Very concerned	Response Count
All respondents	7	20	51	82	31	191
Respondents who live on Silver Lake >4 months a year (Q2)	4	6	16	33	15	74
					answered question	**191**
					skipped question	**5**

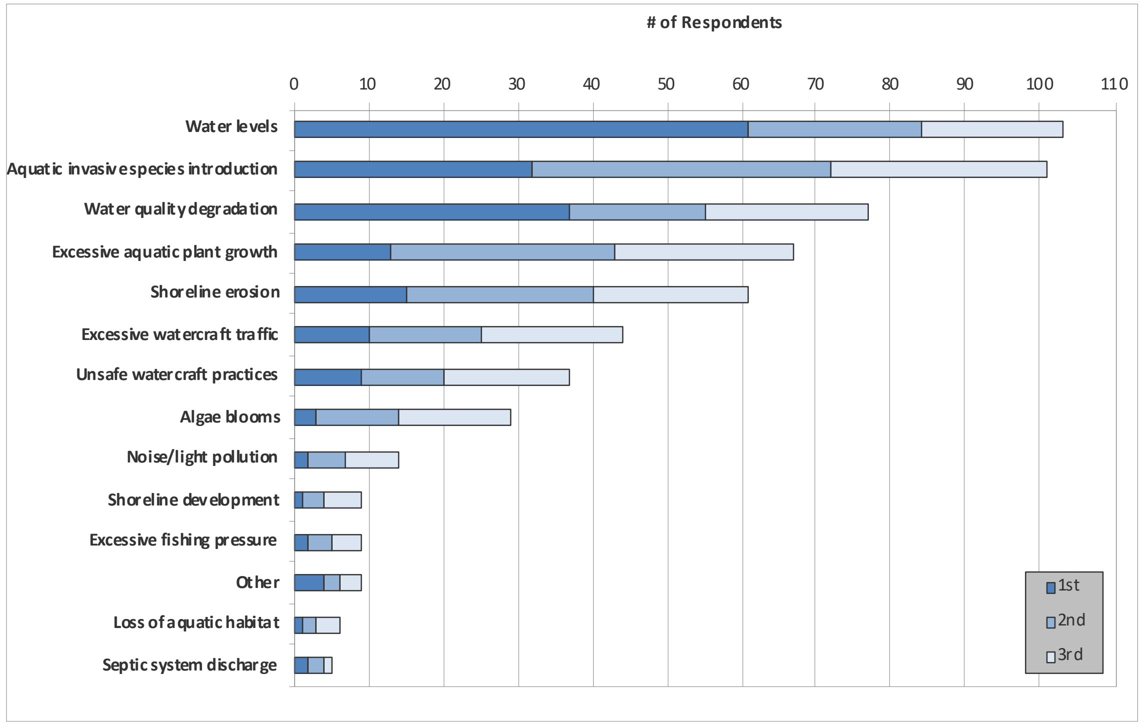




Silver Lake Current and Historic Condition, Health and Management

19. From the list below, please rank your top three concerns regarding Silver Lake, with 1 being your greatest concern.

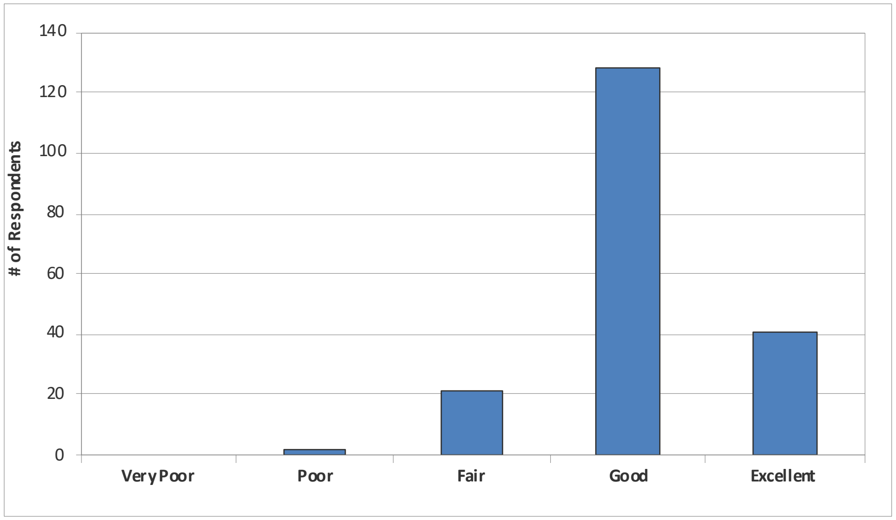
Answer Options	1st	2nd	3rd	Response Count
Water levels	61	23	19	103
Aquatic invasive species introduction	32	40	29	101
Water quality degradation	37	18	22	77
Excessive aquatic plant growth	13	30	24	67
Shoreline erosion	15	25	21	61
Excessive watercraft traffic	10	15	19	44
Unsafe watercraft practices	9	11	17	37
Algae blooms	3	11	15	29
Noise/light pollution	2	5	7	14
Shoreline development	1	3	5	9
Excessive fishing pressure	2	3	4	9
Other	4	2	3	9
Loss of aquatic habitat	1	2	3	6
Septic system discharge	2	2	1	5
			answered question	**192**
			skipped question	**4**



Number	"Other" responses
1	Too high of speed limit on Hwy 73
2	muskrat damage to shoreline
3	Bubbling systems not allowing lake to freeze near shoreline!
4	I rank all three equally important; Did they change the rules about renting property? I thought your property had to be zones for rental before you could rent? I know decades ago when I rented that was the rule and I had to have my property inspected by health officials. I have a feeling that is a big part of the problem coupled with motor boats that are really too big and engines too powerful for the size of Silver Lake. They belong on much larger lakes unless someone enforces the use.
5	waves from wake boats
6	TOO MANY BOATS ON THE LAKE FROM NON RESIDENTS. THERE CAN BE 20 PLUS BOATS ON THE LAKE DURING THE DAY THAT THE RESIDENTS OF THE LAKE ARE UNABLE TO ENJOY THE LAKE SAFELY. I PROPOSE INCREASING THE COST OF PEOPLE LAUNCHING A BOAT OF THE LAKE TO HELP OFFSET THE COST OF KEEPING THE LAKE STOCK WITH FISH AND ALSO KEEPING UP WITH MAINTAINING THE QUALITY OF THE LAKE. I BELIVE WE SHOULD CHARGE $20 A DAY TO LAUNCH A BOAT ON SILVER LAKE WITH NO SEASONAL PASS.
7	Too big size of boats-wake boats
8	Excessive and unsafe watercraft activity on weekends and holidays
9	properties being rented to non-owners without renters knowing or abiding by the rules.
10	Silver lake is TOO SMALL FOR WAKE BOATS OUR SHORELINE IS BEING DESTROYED
11	Fertilizing lawns

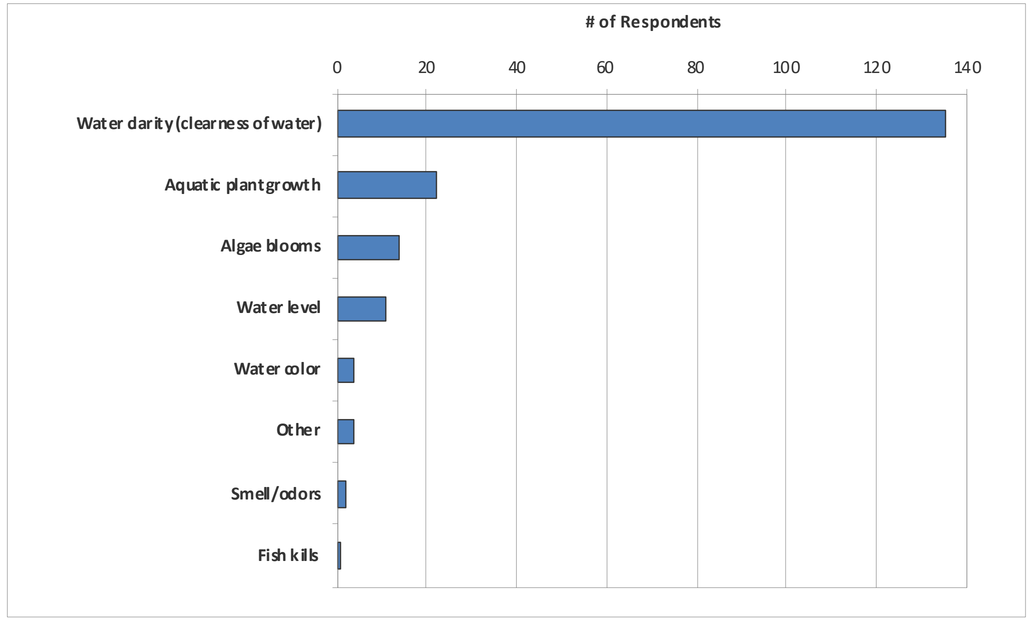
20. How would you describe the overall current water quality of Silver Lake?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	0	2	21	128	41	192
					answered question	**192**
					skipped question	**4**



21. Which of the following would you say is the single most important aspect when considering water quality?

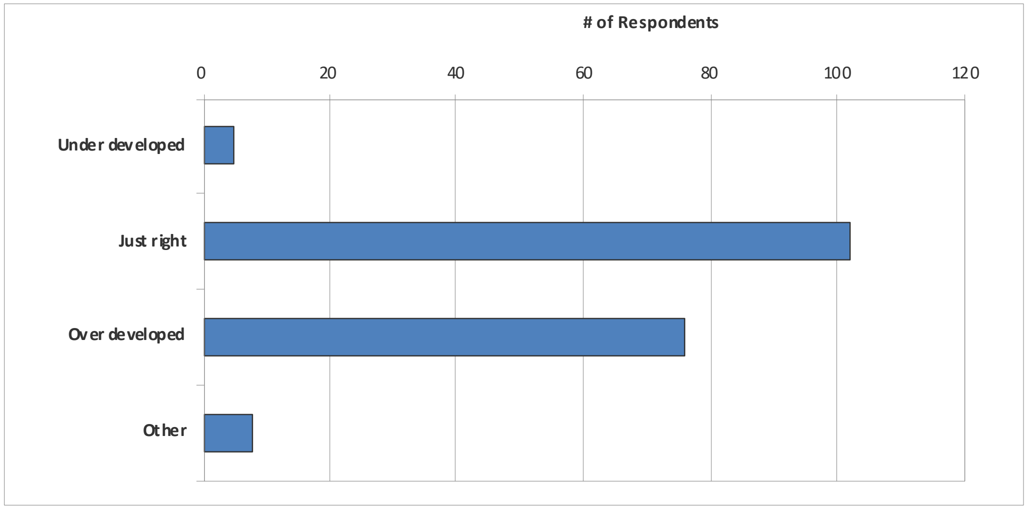
Answer Options	Response Percent	Response Count
Water clarity (clearness of water)	70.0%	135
Aquatic plant growth	11.4%	22
Algae blooms	7.3%	14
Water level	5.7%	11
Water color	2.1%	4
Other	2.1%	4
Smell/odors	1.0%	2
Fish kills	0.5%	1
answered question		**193**
skipped question		**3**



Number	"Other" responses
1	pollutants in water like ag runoff or sewage
2	concerned about zebra mussel invasion
3	Agents which are harmful to humans
4	The answer to this question should be....A HEALTHY WATER BASED ON CURRENT SCIENCE!

22. Which of the following descriptions do you believe most accurately describes the development (residential and commercial) of the Silver Lake shoreline?

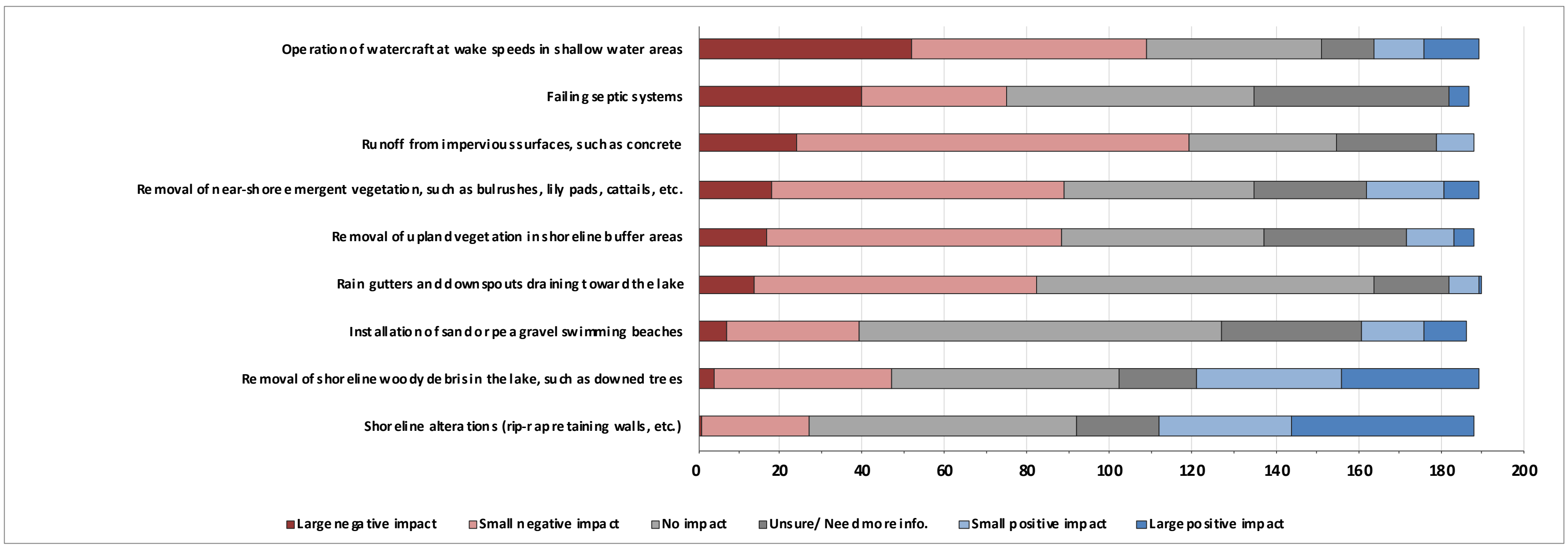
Answer Options	Response Percent	Response Count
Under developed	2.6%	5
Just right	53.4%	102
Over developed	39.8%	76
Other	4.2%	8
answered question		**191**
skipped question		**5**



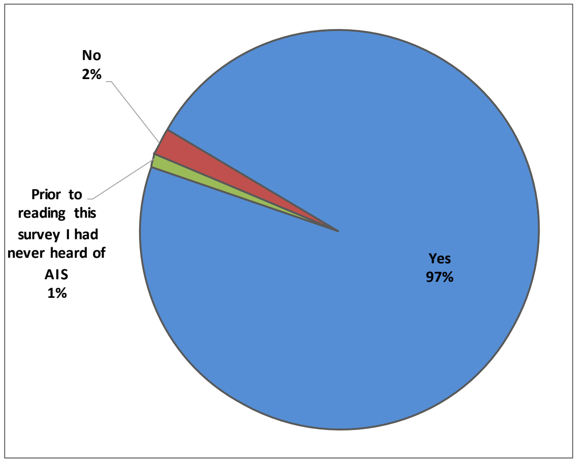
Number	"Other" responses
1	some newer homes are too big
2	perfect - would be great to have a place to get gas or another restaurant
3	Currently at its maximum development. No more.
4	We've all had to do shoreline protection to protect our properties from high water mark. We really need to be looking at the situation with the weir on Lake Alpine. How can 1 person hold hostage the water level on the entirety of Silver Lake? There's an underlying problem with the persistent high water level of Silver Lake that does not appear to be related to waterfall and likely more related to various rerouting of bodies of water.
5	Typical
6	Efforts should be made to have property owners clean up their shoreline, i.e., old boats, unused piers.
7	It's fine. Property owners should have the right to develop their property in accordance with DNR statues
8	no response

23. Using the following scale, what impact, if any, do you believe each of the following practices have on the water quality of Silver Lake?

Answer Options	Large negative impact	Small negative impact	No impact	Small positive impact	Large positive impact	Unsure/ Need more info.	Response Count
Shoreline alterations (rip-rap retaining walls, etc.)	1	26	65	32	44	20	188
Removal of shoreline woody debris in the lake, such as downed trees	4	43	55	35	33	19	189
Installation of sand or pea gravel swimming beaches	7	32	88	15	10	34	186
Rain gutters and downspouts draining toward the lake	14	68	82	7	1	18	190
Removal of upland vegetation in shoreline buffer areas	17	71	49	11	5	35	188
Removal of near-shore emergent vegetation, such as bulrushes, lily pads, cattails, etc.	18	71	46	19	8	27	189
Runoff from impervious surfaces, such as concrete	24	95	36	9	0	24	188
Failing septic systems	40	35	60	0	5	47	187
Operation of watercraft at wake speeds in shallow water areas	52	57	42	12	13	13	189
						answered question	**193**
						skipped question	**3**



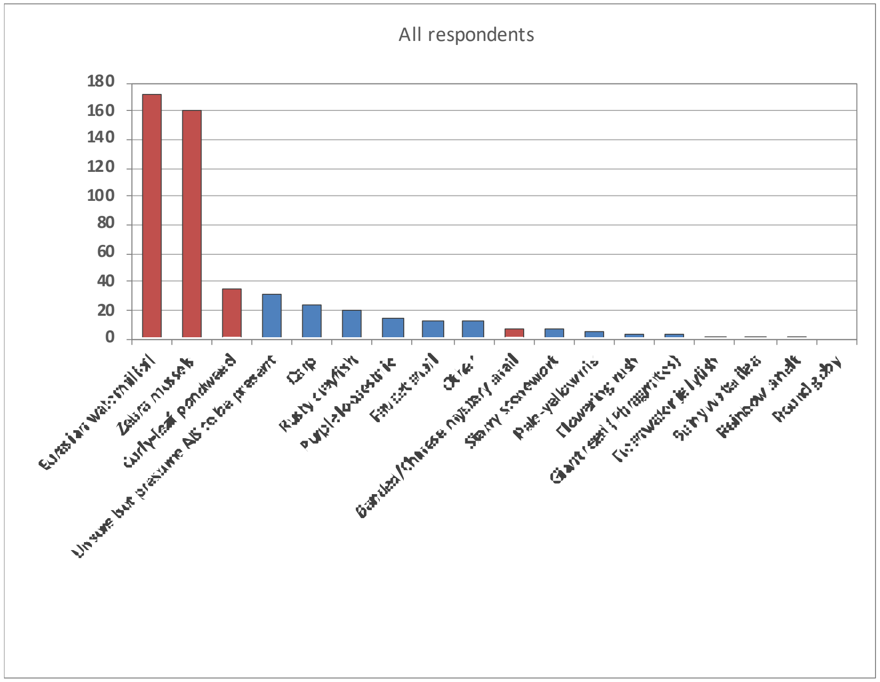
24. Do you believe aquatic invasive species are present within Silver Lake?		
Answer Options	**Response Percent**	**Response Count**
Yes	96.9%	186
Prior to reading this survey I had never heard of AIS	1.0%	2
No	2.1%	4
answered question		**192**
skipped question		**4**

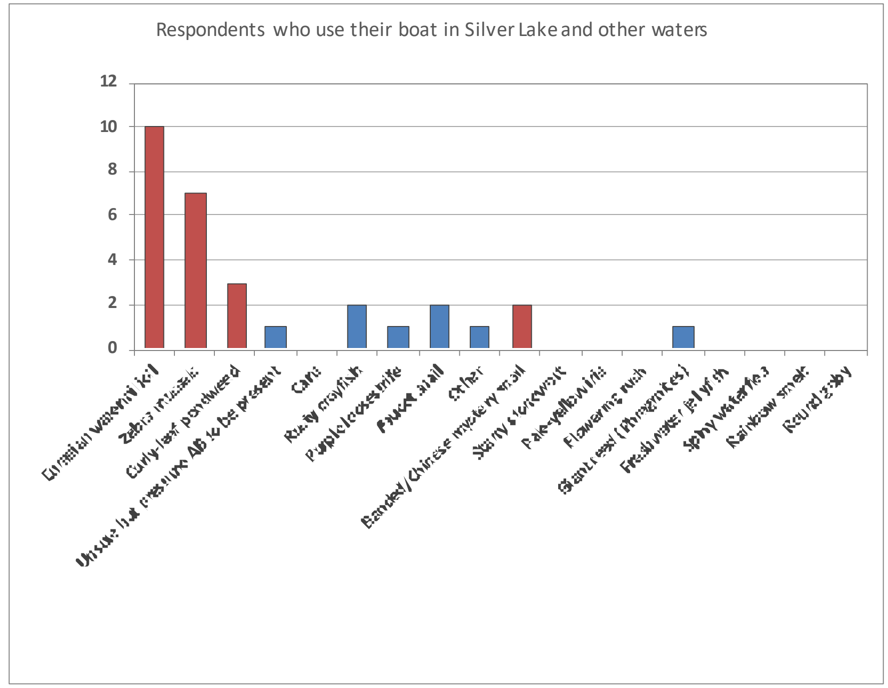


25. Which aquatic invasive species do you believe are present in or immediately around Silver Lake?

Answer Options	Response Percent	Response Count	Response Count of respondents who use boats on Silver Lake and other waters
Eurasian watermilfoil	92.0%	172	10
Zebra mussels	86.6%	162	7
Curly-leaf pondweed	19.3%	36	3
Unsure but presume AIS to be present	16.6%	31	1
Carp	12.8%	24	0
Rusty crayfish	10.2%	19	2
Purple loosestrife	7.5%	14	1
Faucet snail	7.0%	13	2
Other	6.4%	12	1
Banded/Chinese mystery snail	4.3%	8	2
Starry stonewort	3.7%	7	0
Pale-yellow iris	2.7%	5	0
Flowering rush	1.6%	3	0
Giant reed (Phragmites)	1.6%	3	1
Freshwater jellyfish	1.1%	2	0
Spiny waterflea	1.1%	2	0
Rainbow smelt	0.5%	1	0
Round goby	0.0%	0	0
	answered question	**187**	**10**
	skipped question	**9**	

Number	"Other" responses
1	non homeowner renters
2	snails, but don't know type
3	Japanese Knotweed
4	Cecaria (swimmer's itch)
5	Do not know about the rest.
6	My pending retirement will allow me to focus more on the answers to your question.
7	this is absurd - keep this looks like a DNR survey
8	Muskrats too many from west end of lake connected to marshland
9	Probably others but I'm not educated enough to know
10	Snails, not sure what they are called. Sharp edged shells forming on the riprap.
11	believe there are others. these are known to me
12	Ask the experts we have been paying!!



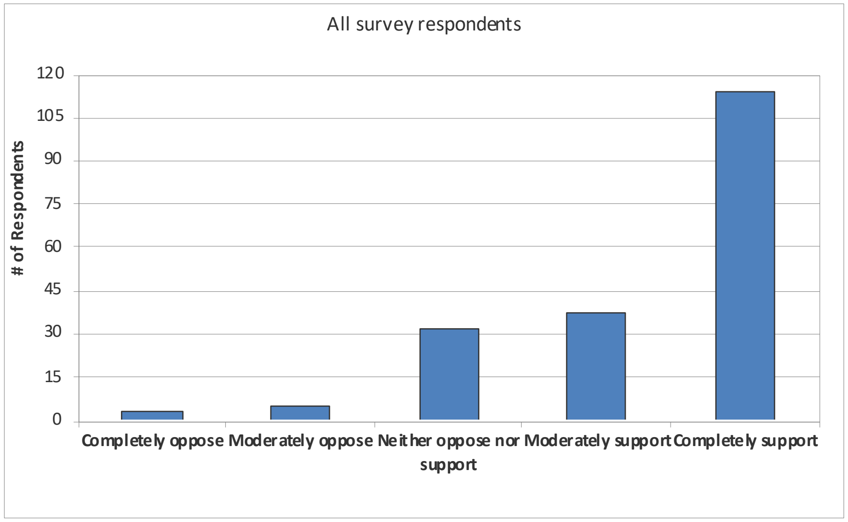


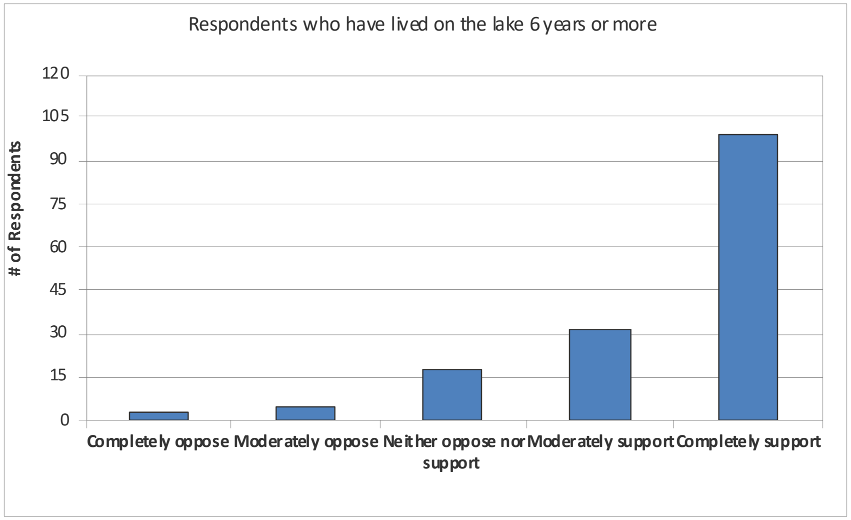
26. Before the present year, aquatic herbicides have been used to manage Eurasian watermilfoil on Silver Lake. Professional monitoring of the aquatic plant community has also occurred during this time. Prior to reading this information, did you know that aquatic herbicides were being applied in Silver Lake to manage Eurasian watermilfoil?

Answer Options	Response Percent	Response Count
Yes	91.7%	177
I think so but can't say for certain	5.2%	10
No	3.1%	6
	answered question	**193**
	skipped question	**3**

27. In 2016, a whole-lake Fluridone herbicide treatment was conducted on Silver Lake. What was your level of support or opposition for the use of aquatic herbicides to treat Eurasian watermilfoil in 2016?

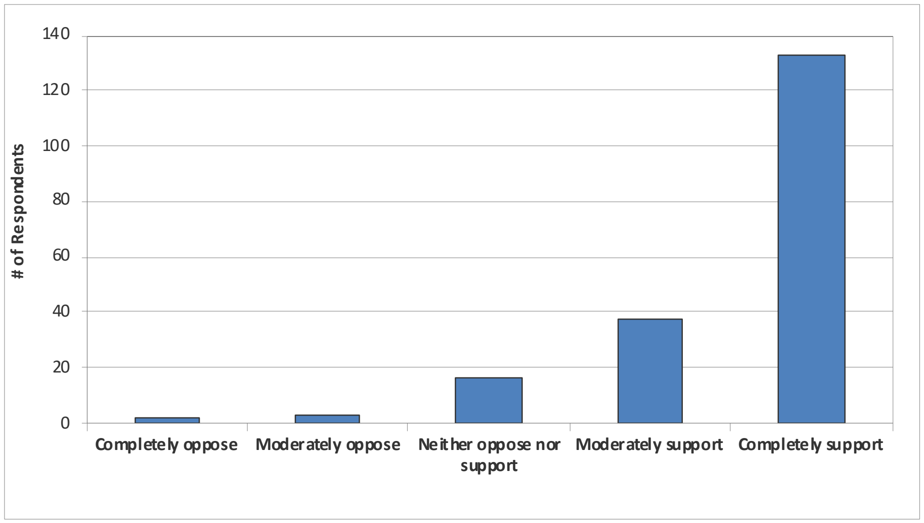
Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Rating Average	Response Count
(All survey respondents)	3	5	32	37	114	4.33	191
Respondents who lived on lake >6 years	3	5	18	31	99	4.4	156
						answered question	191
						skipped question	5





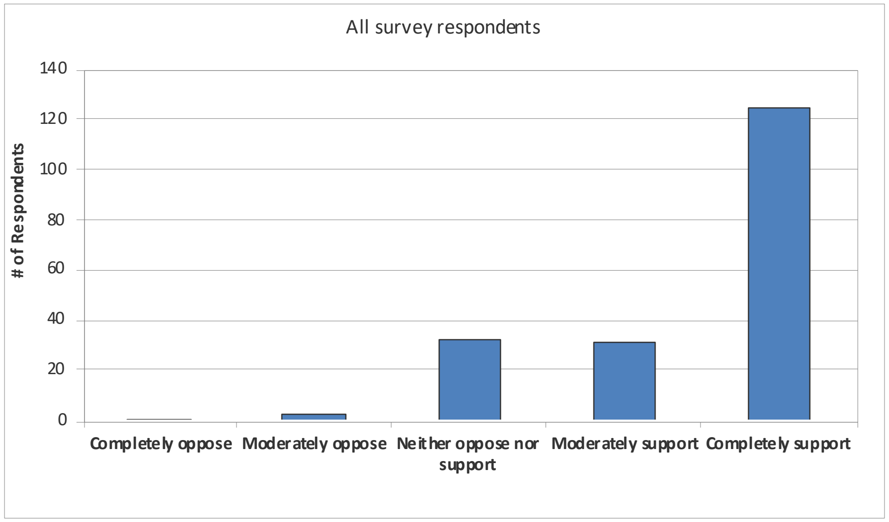
28. Since the 2016 whole-lake treatment, hand-harvesting (includes DASH) at a high amount of effort has been used to preserve the EWM reductions on Silver Lake. What was your level of support or opposition for the use of hand-harvesting with DASH to manage Eurasian watermilfoil since 2016?

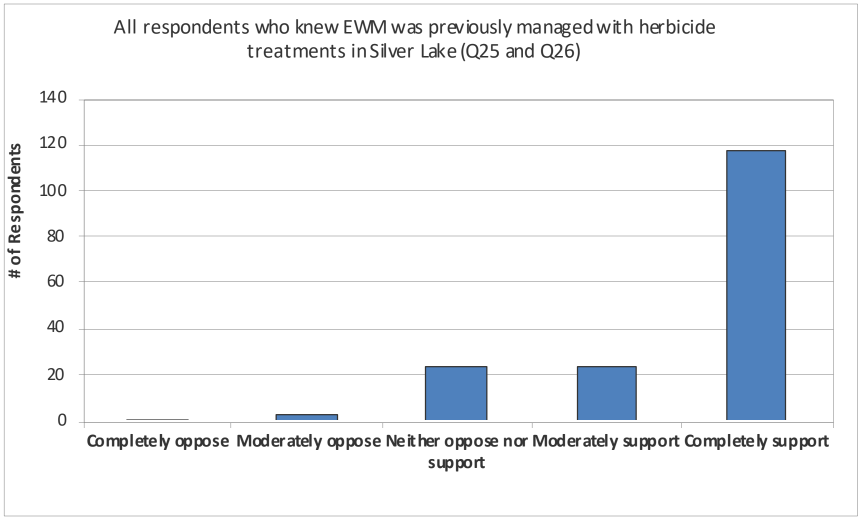
Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Rating Average	Response Count
	2	3	16	38	133	4.55	192
						answered question	**192**
						skipped question	**4**



29. In 2020, a spatially targeted ProcellaCOR herbicide treatment was conducted within Fox Tail Bay of Silver Lake. What was your level of support or opposition for the use of aquatic herbicides to treat Eurasian watermilfoil in Fox Tail Bay in 2020?

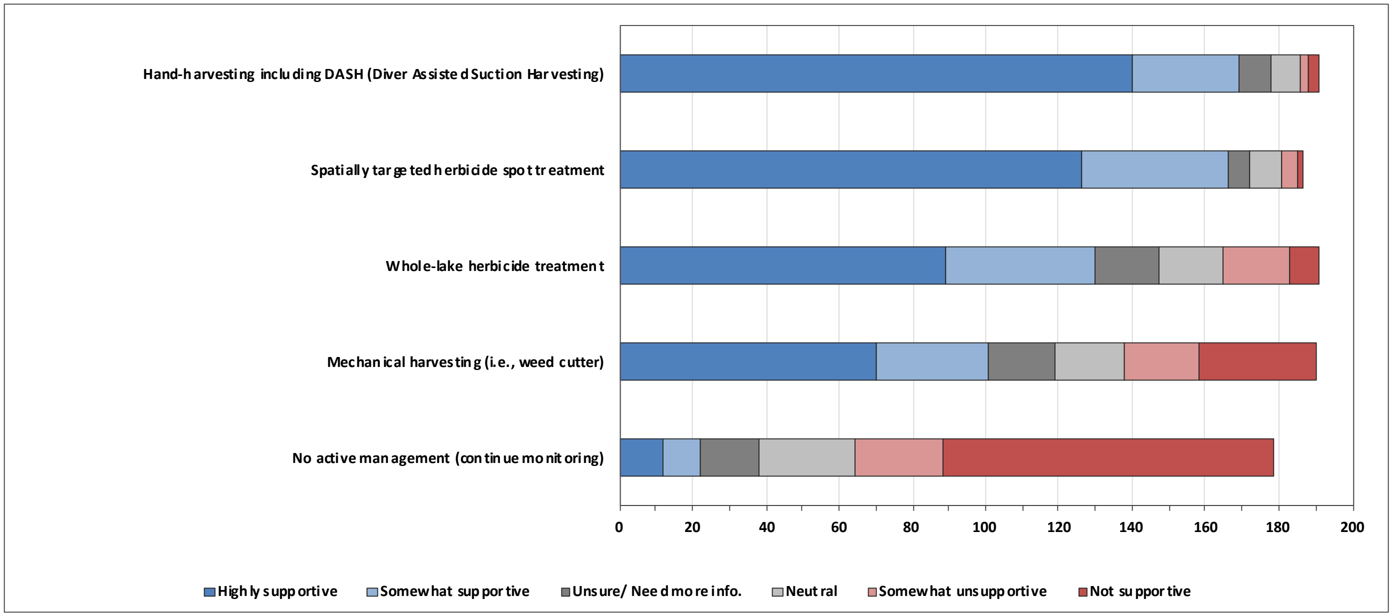
Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Rating Average	Response Count
All survey respondents	1	3	32	31	125	4.55	192
All respondents who knew EWM was previously managed with herbicide treatments in Silver Lake (Q25 and Q26)	1	3	24	23	117	4.5	168
						answered question	**192**
						skipped question	**4**





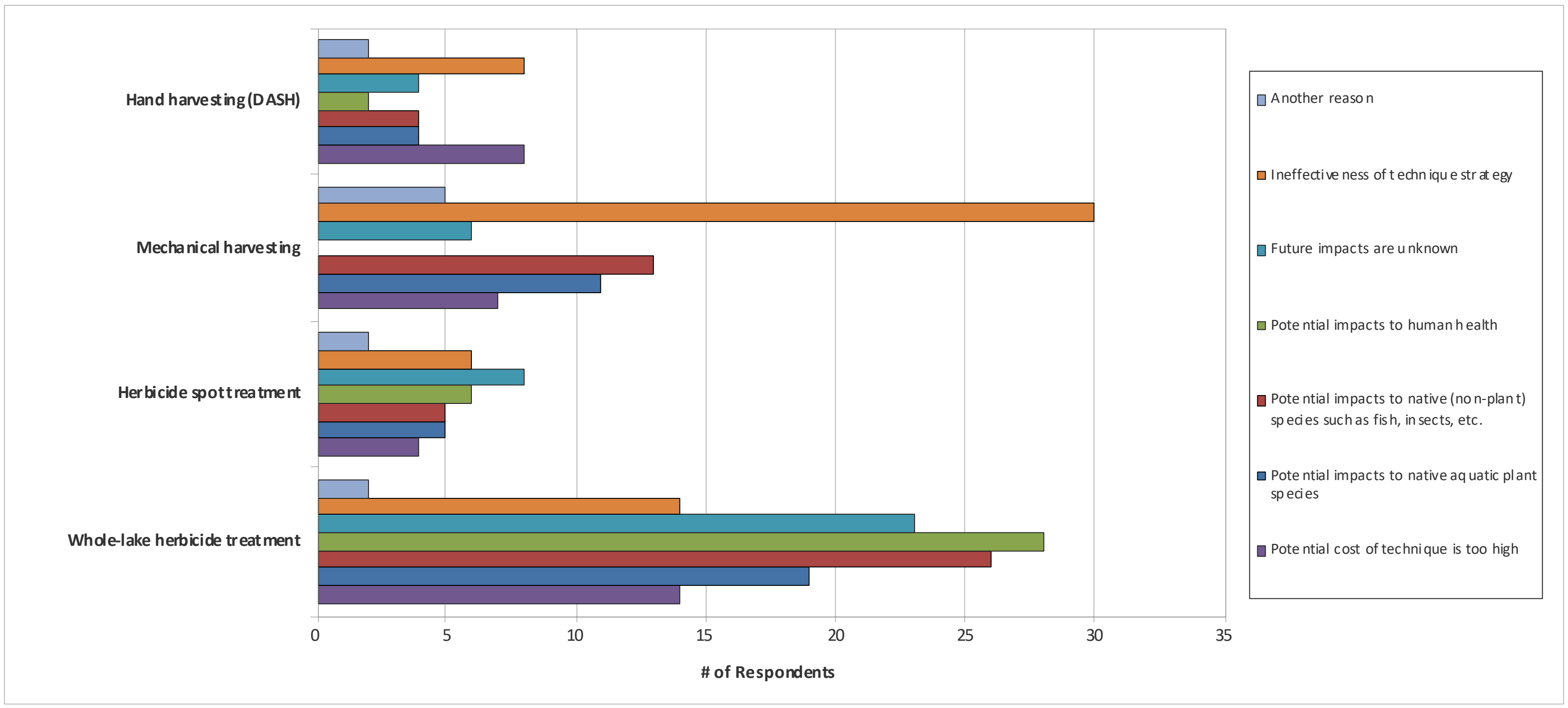
30. As the Eurasian watermilfoil population rebounds from previous management activities, the Silver Lake Management District will begin assessing future techniques for the EWM population. What is your level of support for the future use of the following Eurasian watermilfoil management techniques in Silver Lake?

Answer Options	Not supportive	Somewhat unsupportive	Neutral	Somewhat supportive	Highly supportive	Unsure/ Need more info.	Response Count
No active management (continue monitoring)	91	24	26	10	12	16	179
Mechanical harvesting (i.e., weed cutter)	32	20	19	31	70	18	190
Whole-lake herbicide treatment	8	18	18	41	89	17	191
Spatially targeted herbicide spot treatment	2	4	9	40	126	6	187
Hand-harvesting including DASH (Diver Assisted Suction Harvesting)	3	2	8	29	140	9	191
						answered question	**193**
						skipped question	**3**



31. If you answered "Not supportive" or "Somewhat unsupportive" for Question #30, what is the reason or reasons you oppose the future use of the management techniques to target EWM in Silver Lake?

Answer Options	Whole-lake herbicide treatment	Herbicide spot treatment	Mechanical harvesting	Hand harvesting (DASH)	Response Count
Potential cost of technique is too high	14	4	7	8	26
Potential impacts to native aquatic plant species	19	5	11	4	34
Potential impacts to native (non-plant) species such as fish, insects, etc.	26	5	13	4	39
Potential impacts to human health	28	6	0	2	34
Future impacts are unknown	23	8	6	4	34
Ineffectiveness of technique strategy	14	6	30	8	52
Another reason	2	2	5	2	10
No concerns	27	30	23	34	55
				answered question	**93**
				skipped question	

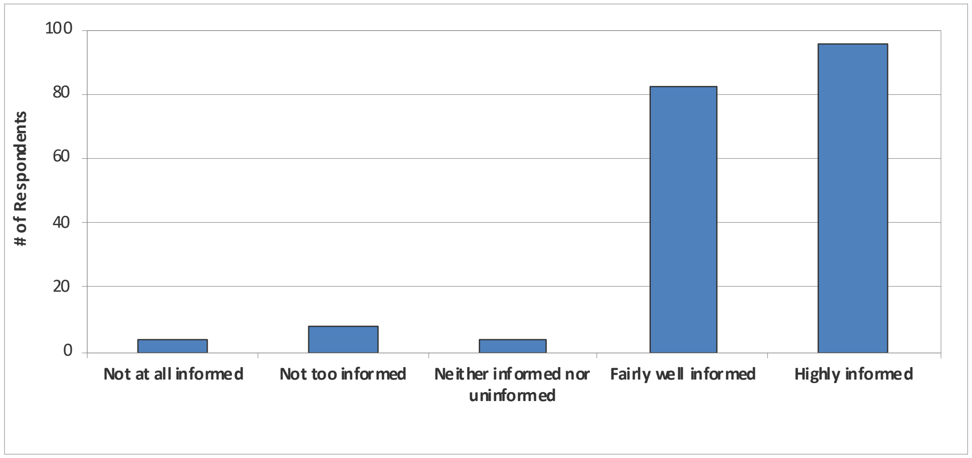


Number	"Other" responses
1	We have a huge weed problem besides the millfoil on our side of the lake. A mechanical cutter and pick up of weeds needs to be done. Sometimes I spend the whole weekend picking up massive amounts of weeds. Come the next weekend and they are they all over again!!
2	FLOATING WEEDS ACROSS THE LAKE
3	raise fee for boat launch. Stop Herbicide poison
4	Very confusing question as I am not supportive of doing nothing.
5	Cost and storage of weedcutter
6	Didn't even see the signs last time and kids were swimming
7	Oddly worded question since the item I am not supportive of is "no active management"
8	I am not supportive of "no active management".
9	I am fully supportive of our current management practices
10	this question and answer options dont make sense. not sure answers are correct
11	Stimulates growth
12	I support active and aggressive management. Do not support doing nothing.
13	not effective
14	The only thing I don't support is doing nothing to combat it
15	Plants that were harvested could be left floating on the lake that either be sucked into a watercraft or land on the shore for a property owner to remove.
16	Not sufficient growth to warrant mechanical harvesting. Also, must continue active management!

Silver Lake Management District (SLMD)

32. How informed has (or had) the SLMD kept you regarding issues with Silver Lake and its management?

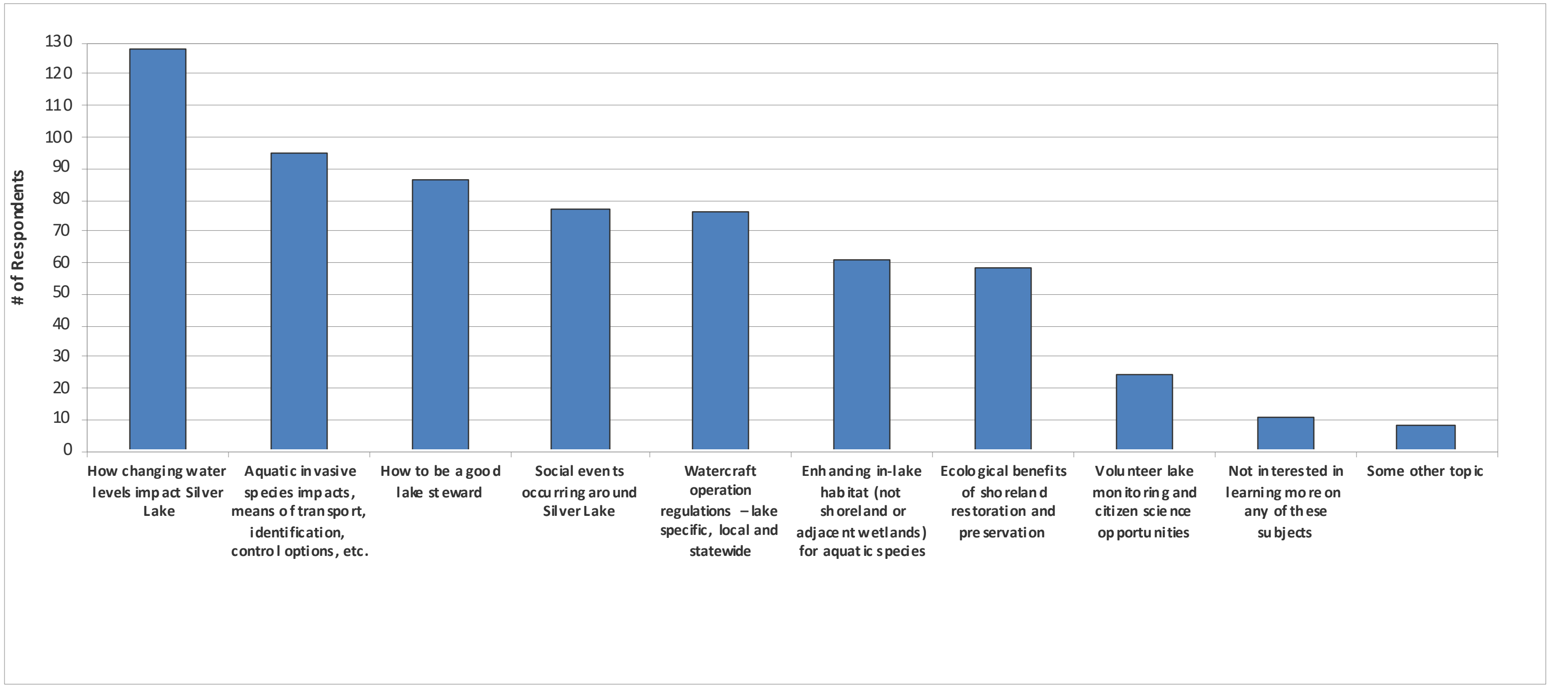
Answer Options	Not at all informed	Not too informed	Neither informed nor uninformed	Fairly well informed	Highly informed	Response Count
	4	8	4	82	95	193
					answered question	**193**
					skipped question	**3**



33. Property Owner education is an important component of every lake management planning effort. Which of these subjects would you like to learn more about?

Answer Options	Response Percent	Response Count
How changing water levels impact Silver Lake	67.7%	128
Aquatic invasive species impacts, means of transport, identification, control options, etc.	50.3%	95
How to be a good lake steward	45.5%	86
Social events occurring around Silver Lake	40.7%	77
Watercraft operation regulations – lake specific, local and statewide	40.2%	76
Enhancing in-lake habitat (not shoreland or adjacent wetlands) for aquatic species	32.3%	61
Ecological benefits of shoreland restoration and preservation	30.7%	58
Volunteer lake monitoring and citizen science opportunities	12.7%	24
Not interested in learning more on any of these subjects	5.8%	11
Some other topic	4.2%	8
	answered question	**189**
	skipped question	**7**

Number	"Some other topic" responses
1	schedule of treatment and H20 quality correction actions
2	I think the police overly enforce regulations. Warning tickets should be used first and then ticket the person if they don't abide by the rules.
3	Suggestions for improving boating safety on Silver Lake. For example: Mandating orange flags to be shown for skiers or tubers in the water before and after active skiing/tubing.
4	totally appreciate any high quality information on all of these topics. I have been impressed with the skill and knowledge level of several people on the Silver Lake Association.
5	I have a significant investment in Silver Lake and always welcome information that keeps me updated on things that impact the lake.
6	Walleye habitat improvement, stocking, and ultimately natural reproduction
7	Our Board has been doing a very good job. I hope we can keep this level of management in place.
8	Next steps to lower water level and why does Lake Irogami control the flow of water. Find options to be lower water levels and do it, stop talking


130
120
110
100
90
80
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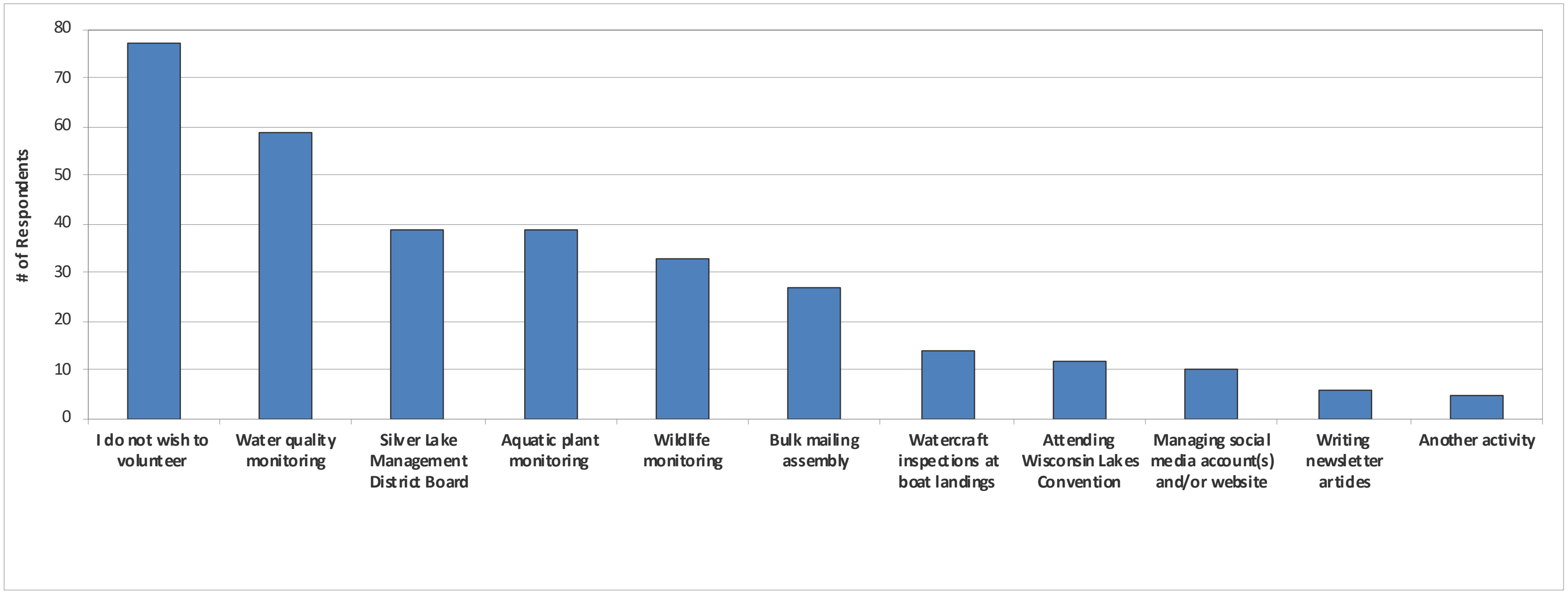
# of Respondents
How changing water levels impact Silver Lake
Aquatic invasive species impacts, means of transport, identification, control options, etc.
How to be a good lake steward
Social events occurring around Silver Lake
Watercraft operation regulations – lake specific, local and statewide
Enhancing in-lake habitat (not shoreland or adjacent wetlands) for aquatic species
Ecological benefits of shoreland restoration and preservation
Volunteer lake monitoring and citizen science opportunities
Not interested in learning more on any of these subjects
Some other topic

34. The effective management of Silver Lake will require the cooperative efforts of numerous volunteers. Please select the activities you would be willing to participate in if the Silver Lake Management District requires additional assistance.

Answer Options	Response Percent	Response Count
I do not wish to volunteer	41.9%	77
Water quality monitoring	32.1%	59
Silver Lake Management District Board	21.2%	39
Aquatic plant monitoring	21.2%	39
Wildlife monitoring	17.9%	33
Bulk mailing assembly	14.7%	27
Watercraft inspections at boat landings	7.6%	14
Attending Wisconsin Lakes Convention	6.5%	12
Managing social media account(s) and/or website	5.4%	10
Writing newsletter articles	3.3%	6
Another activity	2.7%	5
	answered question	**184**
	skipped question	**12**

Number	"Another activity" responses
1	AIS Education Day
2	The summer of 2022 I'll have to focus on various family matters, but since I am retiring, I may be able to volunteer in 2023. I doubt if I will be spending entire summers on Silver Lake, so they may impact my ability to do certain tasks effectively.
3	I would be willing to volunteer but need more info on what each of these involve
4	fish stocking and crib program
5	not sure, but would be willing to help when able to



35. Please feel free to provide written comments concerning Silver Lake, its current and/or historic condition and its management.

Answer Options	Response Count
	100
answered question	**100**
skipped question	**96**

Number	Response Text
1	thank you for asking and listening
2	Thanks
3	Ed is doing a great job of communicating to all of us
4	High water levels are a threat. We need to improve the balance between Silver and Irogami.
5	I am pleased with the level of concern for a healthy lake and the efforts of individuals to ensure it.
6	Silver Lake is one of the clearest and cleanest lakes I know and it is important to keep it that way.
7	I feel that the lake has been managed effectively, and the largest concern for me is the milfoil issue. hopefully a more effective treatment can be found to control this species. Same issue and hope for the future in regards to the zebra mussel population.
8	We think you are doing a good job at keeping the water free from the milfoil.
9	Thank you for doing this
10	The lake (water and lakebed quality, fish population) has seriously degraded under the pressure of excessive rentals, daily boaters, high water levels and unrestricted use of lawn fertilizers. The high water level is contributing to the water degradation why isn't anything done? Lawn Fertilizer use is prohibited within the shoreline but is unenforced causing algae blooms. Homeowners are paying 300 per tax id while the recreation industry profits at the expense of the lake and property owners. There should be a cottage/room rental and daily boat launch fee/tax to offset the residents tax burden. It is inequitable for one family to owe $600 to SMD for adjoining unimproved lots which are for personal seasonal single family use while rentals and resorts pay far less comparatively for far more use year round. Herbicides are not a solution. Totally opposed. The long term health effects are unknown and the beneficial plants, fish etc were visibly damaged. The lakebed was scorched following treatment. Methods to notify landowners of any and all treatment schedules must be improved. Posted signs aren't enough. Rental properties are out of control. VRBO: sleeps 23, pets ok in a 3 bed cottage bring 4 boats, 50 people (revolving door) 2 or 3 dogs and 4 boats from who knows where for the weekend. Not good for anyone or anything. It's a serious problem for many of us who just want to sleep at night and enjoy the lake and the property we pay for.
11	I think the board has done a great job overall and should be commended for their efforts. I hope that we start stocking walleye again and continue stocking other fish as well. I don't like the idea of whole lake chemical treatment but I do think we should continue spending money on hand harvesting and spot treatments so we hopefully avoid having to use chemicals on the entirety of the lake.
12	We have been pleased with the SLMD.
13	Our concern is with wakeboats! The waves they create and how close they drive to the shoreline is critical. They need to stay away from the shorelines. Can we add signage at the boat landings and ask the sheriff to enforce!

14	Management is doing a wonderful job in communicating the news and issues. Our lake brings in out of town boaters and guests that boost the local economy. Although I DO NOT rent my home, I support intermittent rental (to a degree) on the lake. I feel that water sports like surfing, tubing, skiing and PWC are a must have on our lake. I am open to restricting the # of non-resident boats allowed on the lake on weekends. Also, I feel that there should be a maximum boat length that should not be allowed to use our lake.
15	I have been a long time visitor to this other Wisconsin Lakes and lived on Lake Nippissing in Ontario for 20 years. I have observed that if the public Launch ramps are monitored and a fee is imposed to use the lake for day trippers, there is a striking reduction in the transfer of invasive species, a reduction in the overfishing stress on the lake and a reduction of recreational activity stresses implied to the lake. The owners on the lake are usually granted launch privileges. The revenue from the launch ramps are used to pay for the monitoring staff and launch ramp maintenance. Over the last 10 years we have been at Silver Lake, we have noticed a significant increase in day trippers and their disregard for lake etiquette and safety. As a general rule, Silver Lake owners have great respect and understanding of the rules and etiquette on our lake. At other lakes I'm familiar with, launch ramp attendants and the imposing of fees will solve some of these issues.
16	Property owners that over rent. They need to get the RULES to their tenants! If the tenants continue to violate the rules, then hold the landlord responsible. After their 3-4th violation suspend them from renting for a period of time. I have seen this being a bigger problem each year.
17	We sincerely appreciate all the efforts of the Silver Lake Mgmt team. Their hard work has greatly benefitted the Lake.
18	We feel that those involved with managing the Lake Protection District have done an admirable job! We thank all involved-especially Resident Ed Kissinger!
19	we appreciate the yearly letters with updates on the condition of the lake and any activities that have taken place to maintain the lake health/care
20	Really appreciate all the efforts of the volunteers including Ed Kissinger and all SLMD board members. Thank you!!
21	The Lake Management board has been doing an excellent job informing the owners of challenges facing the lake and doing a great job finding solutions to these problems.
22	main concern is highwater levels, excessive large boat activity, and lack of enforcement of no wake close to shoreline.
23	Please set some no wake hours such that the lake is calm for some portion of summer daylight hours- I.e. wake hours 9:00am-6:00 pm. Limit surf/wake boats.
24	Do not like bubbling systems to keep water from freezing near the shoreline preventing access to the lake in the wintertime for fishing, skating, and snowmobiling.
25	Thank you for the survey.
26	I believe lake management is going quite well. However, I also feel it would be prudent to look for opportunities to improve.
27	Wave runners/jet skis seem to be the largest rule breakers of no wake zones and distance between other watercraft and especially water skiers. I feel that it should be mandatory for landlords/VRBO to present each renter with some sort of approved Silver Lake rules pamphlet. Renters that I have encountered break, no wake times, no wake areas (mainly Fox Tail bay) and towing after hours. Very concerned about how many VRBO's are going to be allowed on Silver Lake. I'd propose a $100(?) per night Silver Lake Improvement tax on all VRBO's. Most hotels and tourist cities charge extra taxes and fees above the normal state tax, why can't we?
28	Lake Association does a great job!
29	We do want to thank all the Silver Lake volunteer efforts.
30	I believe that the high level of rental properties on SL is having a very negative impact on the lake. All rental properties need to pay a higher $ support to keep the lake quality positive.
31	We applaud the people working for the ;property owners.
32	Let's keep this lake great and the best in Waushara cty!
33	I think we need to ban wake boats on Silver Lake. The water level is high and the waves are destroying our shoreline.
34	The SLMD board is doing a great job and I appreciate all they do to maintain the quality of Silver Lake. The current rental situation is getting overwhelming and is negatively impacting my life as a full-time resident on the lake.
35	It's a Great Lake, very fun for our family and young kids. Our most important items are keeping the lake clean, removing invasives like zebra mussels and milfoil, and lets get more walleye stocked and habitat improved! Thanks for putting together this survey! :)
36	The high water levels have been very frustrating, the Wier at Irogami Lake must always be open and flowing at its max potential. We also must look at other water level controls beyond the Irogomi Wier, that will only control the lake level up to a point, level of the drainage pipe under 21 connecting both lakes together. I support other means to control water levels.
37	wish there was a way to get the water level down

38	Very upsetting you can't lower the water level the past several years.
39	Need to consider the number of drop-ins to the lake especially weekends. DASH is a waste as it leaves the root and regrows. Wake Boats cause erosion and difficulty for fisher boats as well as stirring up the bottom. May have to look at restrictions on them?
40	The constant police monitoring of the lake is very excessive. I'd recommend a boating hour time frame on weekends of 9 to 5 so that fishing and other lake activities are more easily enjoyed. Limiting the number of non owner boats that can be launched on weekends would be ideal to keep the lake from being too busy.
41	I am pleased & impressed with the SLMD Board & its ongoing efforts to protect & enhance Silver Lake.
42	The members of the board are doing an excellent job!
43	We want to express our gratitude for our SLMD Board.
44	Thank you
45	Silver Lake is a special lake for many reasons. Our size i both a strength and weakness depending on the topic. I'd like to see more options for on water commercial options (more bars, restaurants, public sandy beaches for kids & families). I really like that their is usually a patrol officer on the lake during high season/usage. I think more can be done for safety for people in the water per my comments earlier on orange flags for people in the water. As a boat driver on a small lake it is very difficult especially while pulling skiers / tubers to see people in the water. Some use of an orange flag would be helpful to know when people recently fell in the water while skiing or are preparing to start the activity. Thank you for doing this survey, very helpful.
46	Lake level has been too high for too long.
47	TOO MUCH BOAT/JET SKI TRAFFIC ON WEEKENDS
48	I'm very concerned about persistent high water level, poor water quality compared to 20 years ago (perhaps we need better monitoring of visiting boaters), loud and fast boaters well past 10pm at night and sometimes during slow-wake time frames, and possibly folks renting properties when they have no rental license to do so. I've seen properties with huge numbers of people in a relatively small cottage and those people are different every week. Sure hope if there is illegal renting going on the Association is charging incredibly high penalty fees to them. The Lake Association could use the $$$ and it might be a deterrent. I don't understand how folks could be renting their properties without the proper licenses??? And, I can't believe that these licenses have been granted. And, what about camping trailers sitting (permanently or for prolonged time frames) on lake properties? I thought that was not allowed. I'm pretty flexible on a lot of things but don't like to see this beautiful and once pristine lake being destroyed.
49	Still dealing with the high water levels and would would like to see a more permeant solution to decrease the water level. We are concerned about the number of rentals and how many people are in the properties and behavior (loud music, unsafe boating, too many people). Thank you for all your work
50	Ed Kissinger is a great asset to our lake management. I hope we have good succession.
51	Law enforcement on Silver Lake is predictable. All one has to do is look at the boat launch to see if the boat is on the lake. Silver Lake needs law enforcement in the evening hours, especially on weekends Memorial Day wkd thru Labor Day wkd.
52	Thanks SLMD for all your concerns and hard work!
53	Would like to see water level lower and have more beach
54	we feel that the silver lake board has done an outstanding job
55	Wave runners should observe the same rules on mornings and after sunset as boats. Idling slowly is fine but they create a noise factor otherwise. They are tearing up the lake at 7 a.m. on a Sunday morning!
56	Better fishing hours. Water skiing hours should be 10-6 7 days a week. Give the fishermen a break.
57	During the period of "high water", wake boarding should be banned until the lake recedes to the ordinary high water mark.Boating should be done in rotation of "clockwise manner".
58	Need better panfish and walleye fishing- Thanks you

59	I feel the police enforcement on the lake is overdone and borders on intimidation. I frequently see the police boat on the water when there are hardly any boats on the water. People pulled over for minor infractions. What point are they trying to make? I'm all for safety on the lake but I'm not aware of any body of water of Silver Lake's size that has police enforcement to the level we do. It's unnecessary.
60	For decades, the SLMD and supporting agencies have done an outstanding job of managing the water clarity and quality of Silver Lake, and being good stewards of our natural resources, with special acknowledgement of monitoring and controlling AIS. Keep up the great work!
61	Slow no lake at any water level is a mistake, So no wake affects property values, local businesses. Water levels were higher in 1992 and there was not slow no wake
62	We commend the SLMD for keeping owners informed
63	Please continue to work hard to maintain the flood controls and communicate the challenges associated with water levels during abnormally high elevation times. I have not seen a clear description of how the Silver and Irogami high levels are controlled by some mysterious weir.
64	I am concerned about new water sport activities impacting the quality and overall enjoyment of the lake. Currently the new water sports adversely impacting shoreline erosion include wake boarding and wake surfing. Both of these new sports create artificially high waves that erode the shoreline. Our lake is too long and narrow for these artificially high waves to dissipate before reaching the shore and cause irreparable and extremely costly damage to individual properties. It is very hard to quantify that loss other than the tens of thousands of dollars homeowners have had to spend to combat the damage. Like wise the damage is difficult to attribute to any one boat for two reasons: 1. It is an accumulative effect, not just one boat one time. 2. there has been an increase of unidentifiable boats on the lake....boats with no registration number on the hull.
65	My concern as an owner is more about the increasing VRBO and AirBNB rentals and the regulations regarding numbers and noise, and increased boaters who don't know the lake rules.
66	Board is doing a great job - much appreciated. Lake level, high volume rentals, no-wake hours and water quality are important to me, and these are all on the radar. Thank you
67	I feel that we have a great board that takes good care of our lake. Not an easy job by any means. Also they all seem very knowledgeable about how to keep our lake a great place to own and enjoy! Thanks to all of you!
68	Very concerned about fishing quality. Seems to have gotten way worse. I remember as a kid that you couldn't get a ice fishing shack on the lake as it was a great perch lake. Very concerned about rental properties and renters not following lake watercraft rules causing undue danger on the lake. I feel the board is doing a great job monitoring, educating, reacting and guiding lake matters. Thank you.
69	Is there anyway to limit the number of boats that can be put on to the lake for daily use to lower the amount of weekend traffic. Could we reduce the number of landings and increase launch fees for non residence?
70	Thank you for the efforts of many to make Silver Lake an enjoyable location for family cottage owners.
71	We love Silver Lake and appreciate the time and effort of the Board. However, the high lake level is still a concern to us and has costed us more than $30,000 to date.
72	When we first bought our cottage in 2010, the water was crystal clear, the sand floor was pretty pristine. Not the same now.
73	I do believe the shoreline must be protected during these hi-water times even if it means shutting down the lake as far as wakes. The damage around the lake over the past 5 years has been huge from my observations and I really do not care if the visitors cannot attempt to splash all the water out of the lake. I have not heard of any rentals offering to help restore shoreline damage or costs associated with it. I would support no use of wakeboarding until the high water mark reduction is met. The boats are still able to be used just not in the fashion. I would have thought by now we might have seen some kind of water reduction but every year it seems to be the same or worse and more shoreline repairs needed thru the summer. The info I have been told about water levels is that we could be possibly stuck with them. I know the chamber and rentals would tell us not to be hasty in our answers but they are not in it for true and total costs. I would also hope the boating regs would become somewhat more enforced they are kinda easy going compared with other lakes thru out wisconsin but the difference being a DNR agent or sheriff not trained as well or at all, please train them. Thank You
74	Thank you to the many people who work to keep Silver Lake in the best possible condition.
75	I think the SLMD board members are doing an excellent job in seeking best practices in the management of Silver Lake.
76	love being on this lake. PWC hours of no wake NEED TO CHANGE
77	Please stock our lake with fish

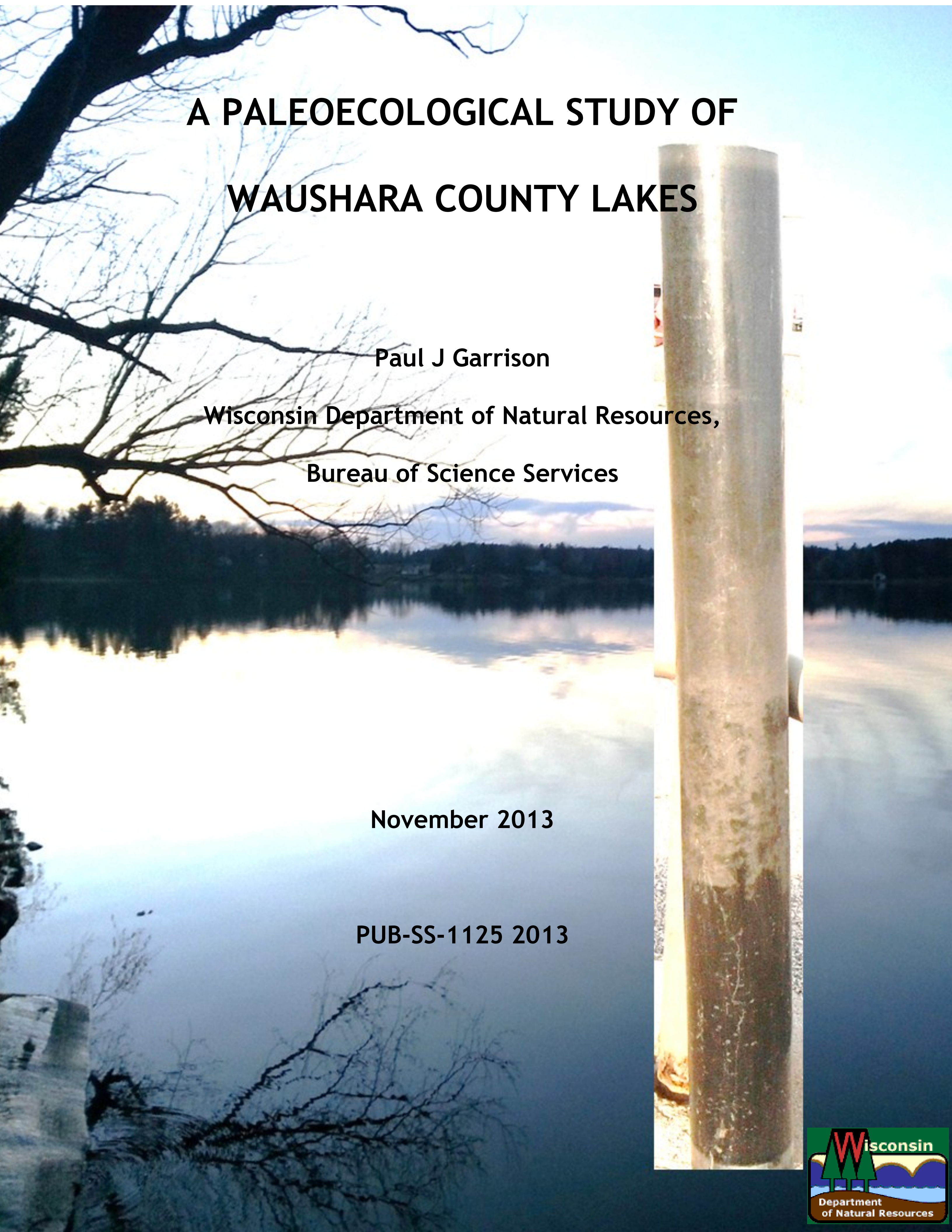
78	We appreciate the work of the board! The lake is getting too busy with boat traffic and the high water levels great concern to us as owners. The lake over the years is being ruined by too much, too fast boat traffic and jet ski's. There should be a fee for non owners to boat on the lake or other limitations. Water level needs to be lowered. Thanks!
79	We are only summer people. I feel those who live year round should have a bigger say in the management. I really do want information for everyone.
80	We agree with current water ski restrictions but feel it should either be applicable to all water activities, i.e. tubing, wave runners and also fisherman. If it is no wake before 1000 on weekends and holidays, it should be for ALL water craft or none and just make it sun up to sun down on all days.
81	Management has done a terrific job in maintaining Sliver Lake quality for many years
82	Let's get rid of the high water.
83	I think we need to focus also on stocking and maintaining the fishing sport on the lake
84	I appreciate the efforts that are taking place to protect the lake and keep it healthy and available for our enjoyment. I do worry about the increased number of rental units on the lake and the impact of a large number of non-owners using or mis-using the lake.
85	Limited on time spent at the lake so I don't support expanding restrictions on boating hours
86	too many homes with manicured lawns that need fertilizer and weed killer that poison the water. too many wake boats producing large waves. also we need no wake after 5 on saturday and sunday
87	Current group of volunteers are doing a great service to all of us State of Wisconsin, waushara county, or whoever has the authority needs to recognize that there is a place on Wisconsin lakes for Wakeboats……and it is not on small acreage lakes like Silver. Nor is Silver lake capable of handling boat speeds in excess of that for enjoying water skiing, tubing, etc. 50 mph?? law enforcement seems to be getting more petty each year….ie a neighbor ticked for creating a wake with pontoon boat going about 5-8 mph too close to shore!?
88	Management has been exemplary.
89	My family has owned property on Silver Lake since 1955. In some ways the lake has degraded since then and in others it has improved. Boat traffic has increased a little, but the increase in size and speed of many of the boats has a much greater negative effect. Water quality is different than it used to be, but I can't say that it's worse. Bass fishing is better now, but pan fish don't appear to be as abundant. The water level is high now, but I've seen it just as bad and I've also seen it too low. The levels we're seeing now would be tolerable if part of a normal cycle, but I'm concerned that they might be due to climate change and therefore long term
90	No wake enforcement in Fox Tail Bay is not effective and timely. Violations are numerous and occur after posted hours of enforcement. Fishermen frequently but many others as well.
91	As a owner on the lake I appreciate the efforts of all of the volunteers who make out lake one of the best in Waushara County.
92	We need to develop a permanent solution to controlling lake level. I was disappointed this was not a larger part of the survey.
93	We feel the management of the lake has been done very well during the years we have been property owners. As more properties have become rentals, people on the lake and boat traffic have both increased.
94	all efforts are appreciated
95	Wake surfing boats are a nuisance. Water skiing and wake boarding okay. The wake surfing boats make huge waves and play loud music, but understand, impossible to regulate, since I still want water skiing, tubing, wake boarding allowed.

96	Thank you for protecting our lake from weeds and invasive species. One of the best attributes and selling points of the lake is its water clarity and lack of surface weeds for boating and skiing. A reminder that we cannot pretend like the lake is an "up north" quiet secluded get away. Our home values depend on the lake being extremely accommodating to boating and recreation, that is the top selling feature and draw. Sandwiched between two busy and major highways means we cannot magically turn this into a quiet fishing mecca, the emphasis needs to remain on recreation. Thanks to the management district and the board for all the thankless things you do and hours you put in for our beautiful lake. The number one threat to our lake home values remains high water levels, we need to continue to push continuously on the DNR to allow us to find other ways to draw down the water level. "No one" wants this lake to ever be no wake again, this is the best recreational lake in the county by far and the reason most of us bought on the lake.
97	It would be nice to have a visual buffer around the lake of how close boat can get to the shore
98	FIX THE WATER LEVEL
99	I have expressed my concern about water patrol enforcement of certain rules. I personally have seen numerous violations of after hours skiing and speed. This could use a significant review as to possibly staggering the hours the patrol is on the lake. Considering the amount of use the lake gets and has gotten over the years, I feel it is a very safe lake.
100	Thanks for sending out this survey.

C

APPENDIX C

Paleoecological Study of Waushara County Lakes - WDNR



A PALEOECOLOGICAL STUDY OF WAUSHARA COUNTY LAKES

Paul J Garrison

Wisconsin Department of Natural Resources,

Bureau of Science Services

November 2013

PUB-SS-1125 2013

Wisconsin Department of Natural Resources

Introduction

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. Questions often asked are if the condition of the lake has changed, when did this occur, what were the causes, and what were the historical condition of the lake? 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 diatom frustules, cell walls of certain algal species, and subfossils from aquatic plants. 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. Using the fossil remains found in the sediment, one can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

A relatively inexpensive means of comparing present day conditions with pre-settlement conditions is top/bottom sediment cores. While a full core, which is assumed to cover a time period of European settlement, is collected, only the top and bottom sections are analyzed. It is assumed that the top section was deposited during the last 2-3 years. The bottom section is assumed to have been deposited prior to the arrival of Europeans during the latter part of the nineteenth century.

This report will examine eight lakes of Waushara County (Table 1, Figure 1) that have potentially been impacted by anthropogenic activities. The most common potential change in the lakes is eutrophication through the introduction of excess nutrients to the lakes. Originally seven lakes were selected but during 2012, Deer Lake was sampled as part of the U.S. EPA National Lake Assessment (http://water.epa.gov/type/lakes/lakessurvey_index.cfm).

A single sediment core was collected from the deep area of the lake (Table 1) generally using a piston corer during November 2012. This corer has an inside diameter of 8.8 cm. The total length of the cores was between 90 and 100 cm. Long and Pine lakes were cored with a gravity corer with a plastic tube with an inside diameter of 6.8 cm. This resulted in a shorter core length but long enough to reach sediments deposited at least 150 years ago. The cores were sectioned into 1 cm intervals for the top 40 cm and then at 2 cm to the bottom of the core. For this study usually the top section and a section very near the bottom of the core were examined for the diatom community composition. It is expected that the bottom sample was deposited at least 150 years ago and represent pre-settlement conditions in the lake. For Pleasant and Long lakes an intermediate section was examined. Deer Lake was sampled as part of another study. A gravity corer was used and the core was sectioned into 1 cm intervals throughout the core. The core collected was not as long (44 cm) as the other cores but it should have been deep enough to reach pre-settlement conditions.

Diatoms are a type of algae which possess siliceous cell walls and are usually abundant, diverse, and well preserved in sediments. They are especially useful for reconstructing past lake conditions as they are ecologically diverse and their ecological optima and tolerances can be quantified. Samples for diatom analysis were cleaned with hydrogen peroxide and potassium dichromate (van der Werff 1956). Cover slips on which a portion of the diatom suspension was dried were mounted on microscope slides with Naphrax®. Specimens were identified and counted under oil immersion objective (1000X) until at least 500 valves had been encountered. Diatoms were identified to species level whenever possible using references which included Patrick and Reimer (1966, 1975), Krammer and Lange-

Table 1. Lake Morphometry, hydrologic type and sampling location of the study lakes.

	Hydrologic Type	Location	Area (ha)	Maximum Depth (m)
Big Silver	Seepage	44.05320° 89.23025°	139	13.7
Deer	Seepage	44. 04256° 89.21638°	6	4.3
Huron	Seepage	44.19461° 89.41721°	16	14.0
Long	Seepage	44.21535° 89.12636°	110	21.6
Pine	Seepage	44.12920° 89.51069°	38	6.4
Pleasant	Seepage	43.9847989.55374°	51	9.1
Round	Seepage	44.16072° 89.16146°	26	5.8
Wilson	Seepage	44.17465° 89.17552°	12	3.7

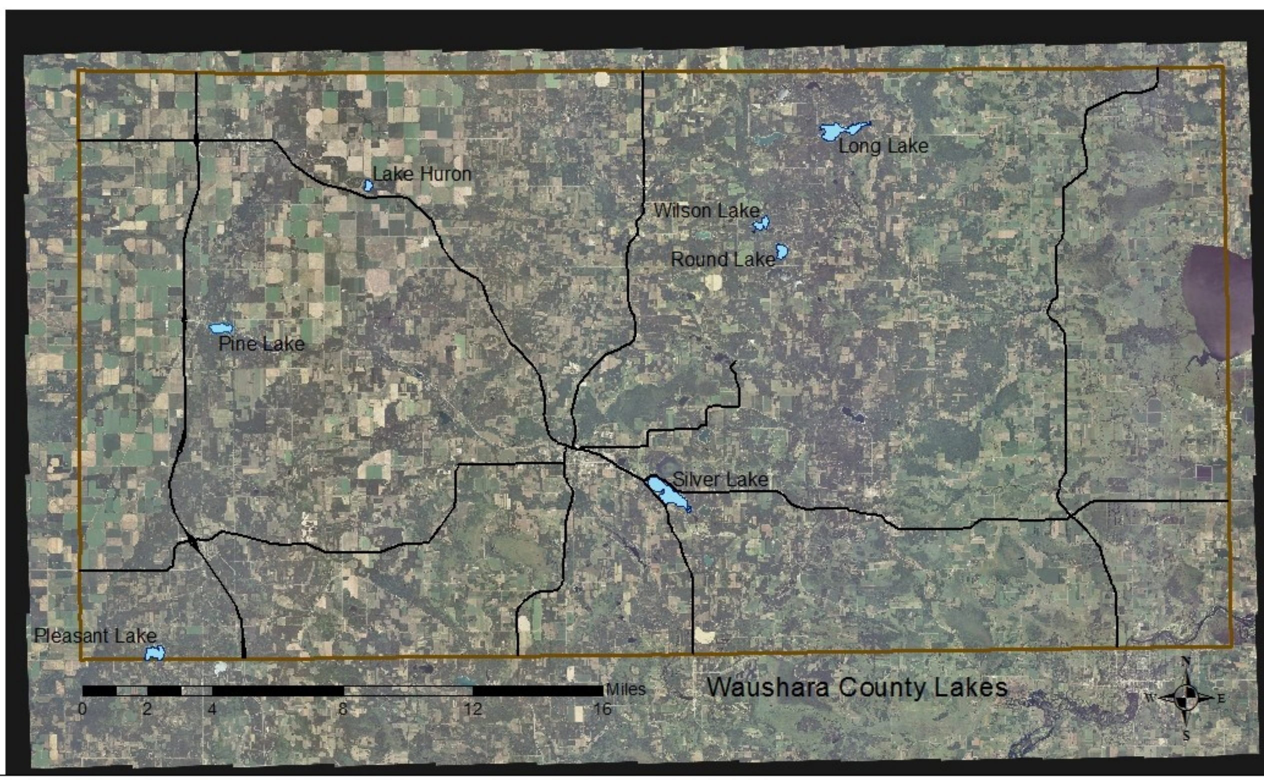


Figure 1. Map of Waushara County showing the study lakes. Deer Lake is not shown on this map as it was sampled as part of another study.

Bertalot (1986, 1988, 1991a,b), Camburn and Charles (2000), Krammer (2000), Lange-Bertalot (2001), and Siver et al. (2005) as well as primary species literature.

Results and Discussion

Aquatic organisms are good indicators of water chemistry because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short lived so the community composition responds rapidly to changing environmental conditions. One of the most useful organisms for paleolimnological analysis is diatoms. They are a type of alga which possess siliceous cell walls and are usually abundant, diverse, and well preserved in sediments. They are especially useful as they are ecologically diverse and their ecological optima and tolerances can be quantified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. They also live under a variety of habitats, which enables us to reconstruct changes in nutrient levels in the open water as well as changes in benthic environments such as aquatic plant communities. Figure 2 shows photographs of diatom species that were common in the sediment cores.

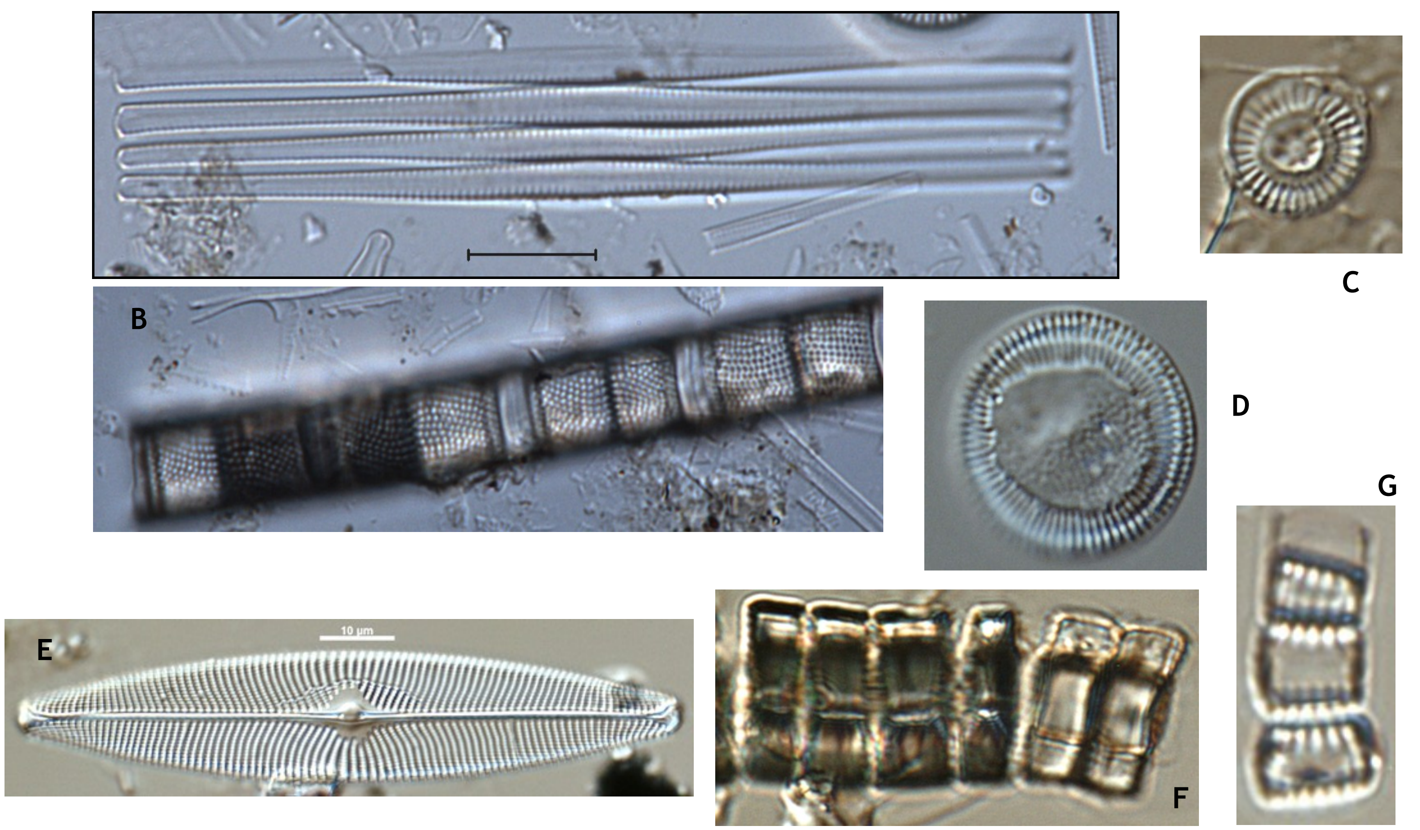


Figure 2. Photomicrographs of the common diatoms found in the sediment cores. The first four diatoms (A) *Fragilaria crotonensis,* (B) *Aulacoseira ambigua*, (C) *Discotella stelligera, and (D) Cyclotella michiganiana* typically are found in open water environments. *Staurosira construens* ((F) and *Staurosira construens* var. *venter (G)* is commonly found attached to substrates such as aquatic plants, other filamentous algae or grow on the sediments and are often associated with higher nutrient concentrations. *Navicula vulpina* (E) grows on aquatic plants and is usually found in low nutrient environments.

All of the lakes are seepage lakes, meaning they have no surface inlets or outlets. These types of lakes generally have lower nutrient concentrations. Water chemistry samples collected and analyzed during the last few years found that these lakes would be classified as mesotrophic based upon their summer phosphorus levels (Table 2). Long (Saxeville) had the lowest phosphorus and chlorophyll concentrations as well as the best water clarity. These levels put this lake

Table 2. Summary of selected water chemical variables from the study lakes. Samples were collected and analyzed by the UW-Stevens Point during the period 2010-12. Secchi disk transparency, phosphorus and chlorophyll are mean values for the summer period while the other variables were sampled less frequently.

	Secchi (m)	Alkalinity (mg L^{-1})	Color (PTU)	pH	Total P (µg L-1)	Total N (µg L^{-1})	Chlorophyll *a* (µg L^{-1})	Chloride (mg L^{-1})
Big Silver	5.3	128	8	8.1	18	700	2.1	12.7
Deer*	2.8	131	10	8.1	18	720	4.5	11.1
Huron	4.0	158	14	8.2	10	1402	1.8	8.5
Long	5.3	134	9	8.2	9	730	1.4	1.7
Pine	3.8	142	26	8.3	16	1088	2.8	5.1
Pleasant	3.0	136	10	8.5	18	858	3.6	1.6
Round	3.4	63	13	7.8	14	780	2.7	1.2
Wilson	2.0	130	29	8.0	19	1270	4.2	14.3

*Only a single sample was collected in July 2012

on the border with oligotrophic. All of these lakes have moderate to high alkalinity values and pH levels are around 8.0. Big Silver, Deer, and Wilson lakes have higher chloride levels, probably the result of the application of salt for ice and snow removal on roadways.

Big Silver Lake

The diatom community at the bottom of the core was dominated by planktonic taxa (Figure 3) which are a type of diatom that are found in the floating in open water. This is not surprising as the lake is relatively deep and of moderate size. The dominant taxa, *Aulacoseira ambigua*, pictured in Figure 1B, is a common diatom in many Upper Midwest lakes. This diatom can exist in a range of phosphorus levels but usually dominate under moderate to low concentrations. At the top of the core the dominant taxa shift to diatoms that grow attached to substrates, e.g. submerged aquatic plants and filamentous soft bodied algae. The taxa richness and diversity are greater in the top sample (Table 3) which supports the suggestion of more macrophytes. With the increase in abundance of macrophytes there are more niches for the diatoms to grow. This increase in diversity with increased nutrients is known as intermediate disturbance hypothesis. This hypothesis suggests that moderate disturbances result in a more diverse community because increased productivity results in more habitats. If the disturbance becomes great enough then richness and diversity decline. The increased richness and diversity is very common in lakes in northern WI that have moderate shoreland development but the watersheds are otherwise forested. This shift suggests that at the present time there are more macrophytes then prior to settlement. This shift also suggests there has been an increase in phosphorus concentrations in recent decades. The increase in phosphorus levels is probably not large or there would a greater shift in planktonic species to eutrophic taxa.

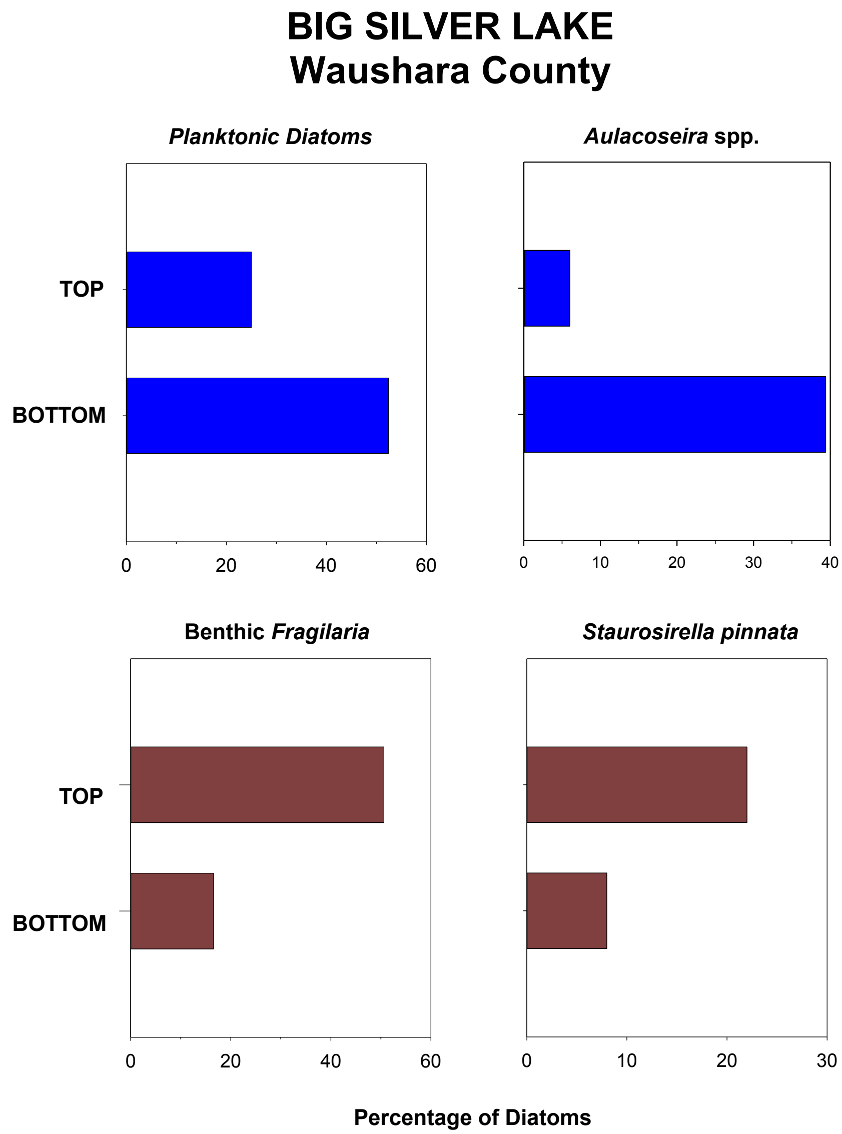


Figure 3. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Big Silver Lake.

Deer Lake

There were almost no planktonic species in either the top or bottom sample in this lake. This reflects the fact that this is a relatively shallow lake and the diatom community is associated with submerged aquatic plants and filamentous algae. The bottom sample is dominated by benthic taxa that indicate low nutrient levels, e.g. Navicula vulpina (Figure 1E), *N. aurora*, and *N. wildii (Lange-Bertalot 2001)* (Figure 4). The diatoms indicate that submerged aquatic plants were common but they were not very dense and phosphorus concentrations in the water were low. In the top sample there were none of these large *Navicula* but instead most of the community was composed of benthic *Fragilaria*. This indicates that nutrient levels have increased to the point where filamentous soft bodied algae are present and the diatoms grow attached to these algae. The degradation of the lake is further suggested by the large decline in species richness (55 to 19) and accompanying decline in diversity (3.23 to 1.03) (Table 3).

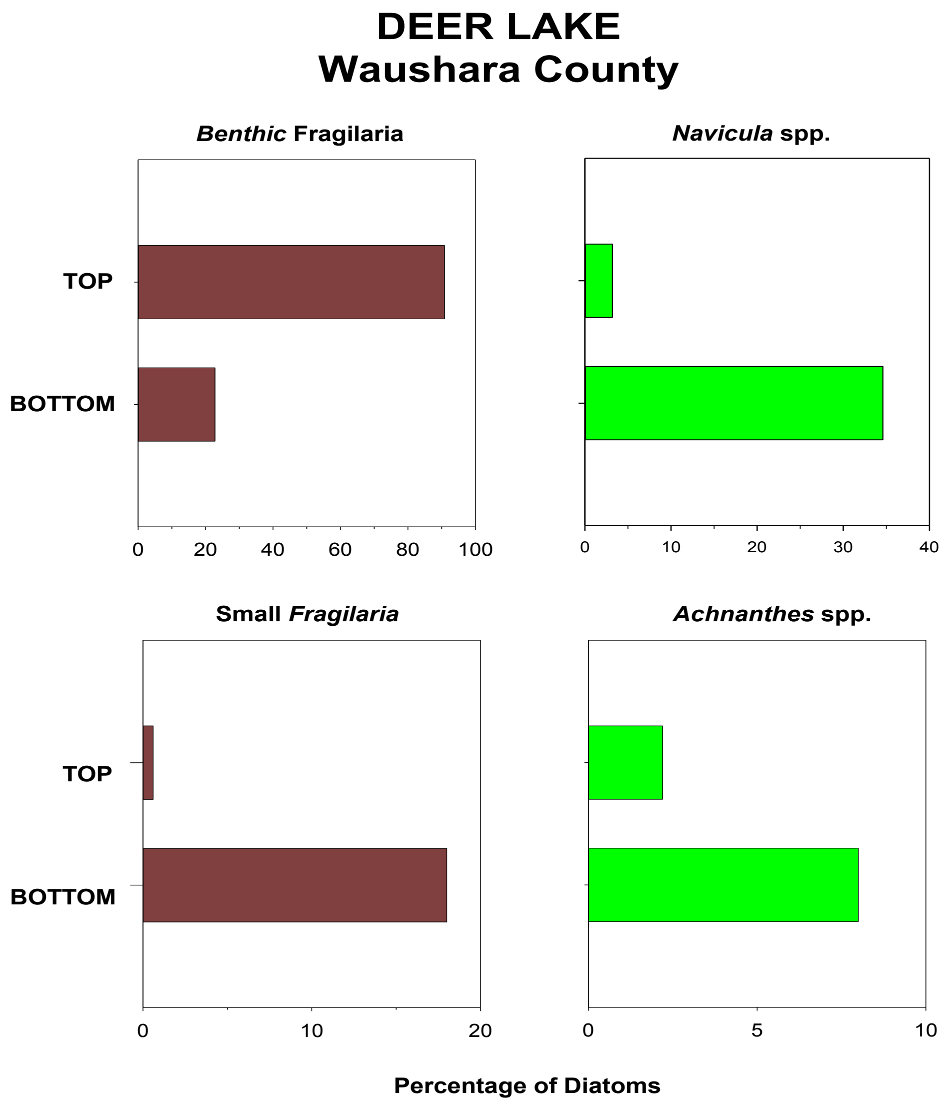


Figure 4. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Deer Lake.

Huron Lake

Similar to Big Silver Lake, the diatom community is dominated by planktonic diatoms in the bottom sample (Figure 5). As with Big Silver, the dominant diatom is *A. ambigua*. Unlike Big Silver, at the top of the core planktonic diatoms still dominate the diatom community. There is a shift in the dominant taxa from *A. ambigua* to *Cyclotella michiganiana* and *Discotella stelligera*. *C. michiganiana* grows in the metalimnion and thus needs good water clarity. In the top sample *Cyclotella comensis* was found at a moderate abundance. This diatom is an invasive from northern Europe. It was first detected in North America in the 1950s (Stormer 1993, 1998). This diatom has been found in sediments deposited since 1950 in the Great Lakes (Stoermer et al. 1985; 1990; 1993) as well as inland lakes in northern lower Michigan (Fritz et al. 1993; Wolin and Stoermer 2005) and northern Wisconsin (Garrison 2005a,b; Garrison 2013). The diatom *C. comensis* typically is found growing in the open water in the middle part of the water column. This means that this taxa is found in lakes with good water clarity but elevated nutrient levels in the deeper waters. Studies indicate that this diatom responds to increased phosphorus and nitrogen levels (Schelske et al. 1972; Wolin and Stoermer 2005).

Table 3. Taxa richness and diversity for the study lakes.

Lake		Richness	Diversity
Big Silver	Top	63	2.95
	Bottom	43	2.46
Deer	Top	19	1.03
	Bottom	55	3.23
Huron	Top	48	2.97
	Bottom	32	1.69
Long (Saxeville)	Top	20	0.97
	Middle	56	2.60
	Bottom	34	1.98
Pine (Hancock)	Top	16	1.69
	Bottom	29	2.08
Pleasant	Top	14	1.33
	Middle	28	2.03
	Bottom	21	1.77
Round	Top	23	1.57
	Bottom	61	2.87
Wilson	Top	37	1.99
	Bottom	28	1.74

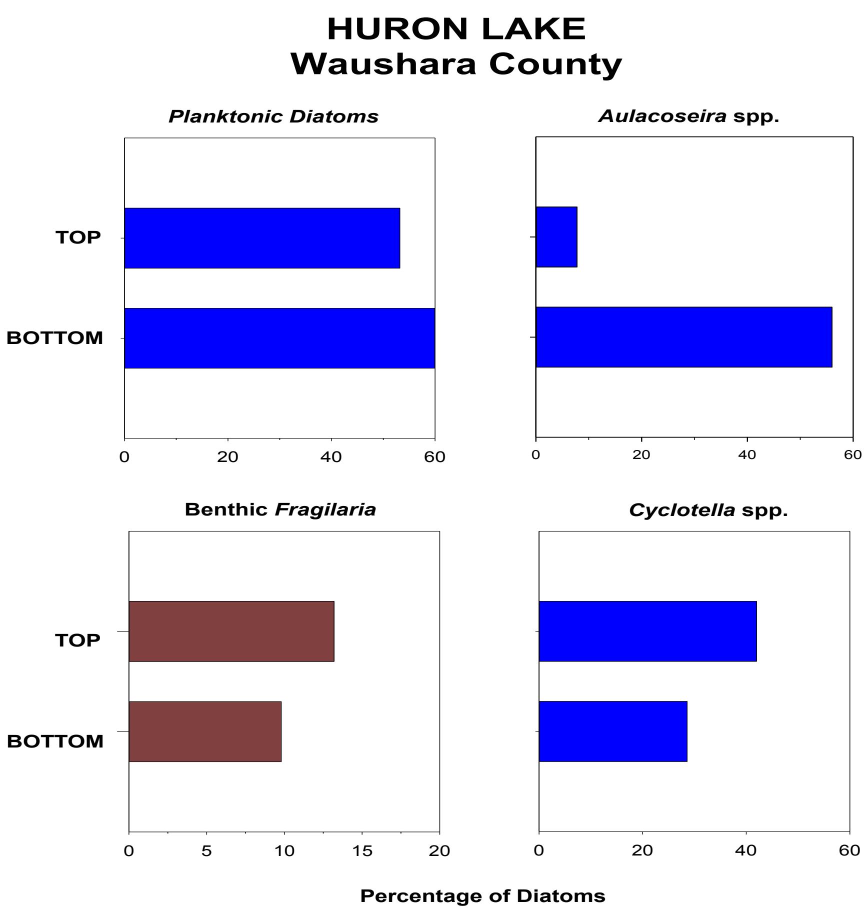


Figure 5. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Huron Lake. *Cyclotella* spp. includes *Cyclotella* and *Discotella* species.

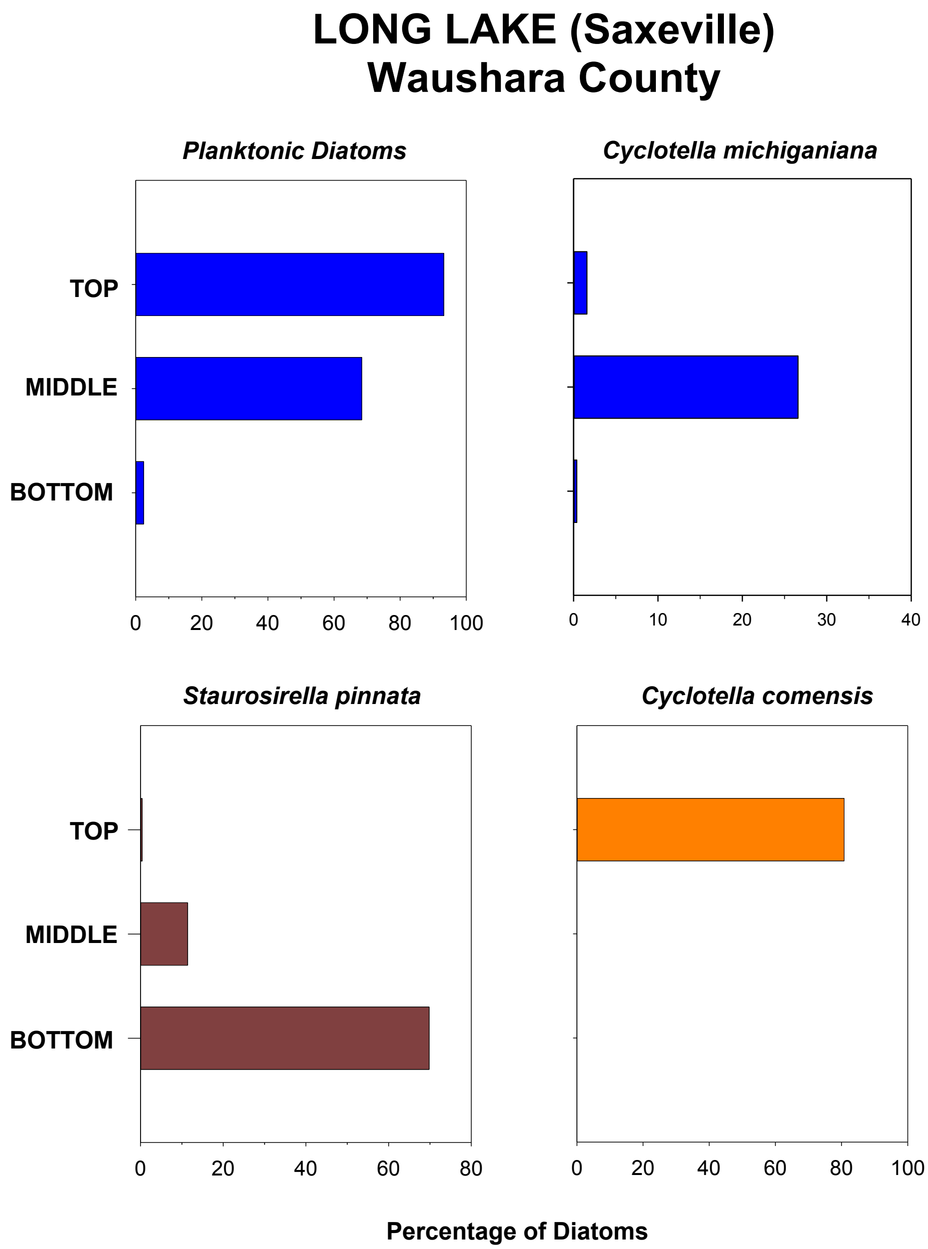


Figure 6. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Long Lake. Three depths were analyzed in this core because the high dominance of *C. comensis* in the top sample made it difficult to fully understand the historical changes in this lake.

There are a few more benthic *Fragilaria* in the top sample which suggests there may have been a small increase in submerged aquatic plants and filamentous algae but it is much smaller than in Big Silver. This is indicated by a small increase in taxa richness and diversity (Table 3). Phosphorus concentrations probably have increased only a small amount.

Long Lake

Even though Long Lake is a large, deep lake, the bottom sample is dominated by the benthic diatom *Staurosirella pinnata* (Figure 6). This often is associated with filamentous algae and is an indicator of higher phosphorus levels. This diatom is also known to grow on bottom sediments and has been found two southeastern WI marl lakes at sediment depths prior to European settlement (Garrison and Wakeman 2000). It was hypothesized that in these types of lake, very clear water allows light to reach a significant part of the bottom sediments allowing this diatom dominates the community.

The dominant diatom in the top sample was *C. comensis*, the invasive diatom found in Huron Lake. Unlike Huron Lake, this diatom was found in very high numbers in Long Lake. In order to gain a better understanding of changes that occurred in the lake prior to the abundance of C. comensis, a sample in the upper middle part of the core was examined. In this section the dominant diatoms were planktonic taxa. By this time nutrients had increased enough that water clarity had declined and the planktonic diatom, *C. michiganiana* ,was an important part of the community. Since this diatom grows in the mid-level of the water column, water clarity was good at this time. This change in the diatom community from *S. pinnata* to *C. michiganiana* was also observed in the southeastern WI marl lakes mentioned earlier (Garrison and Wakeman 2000).

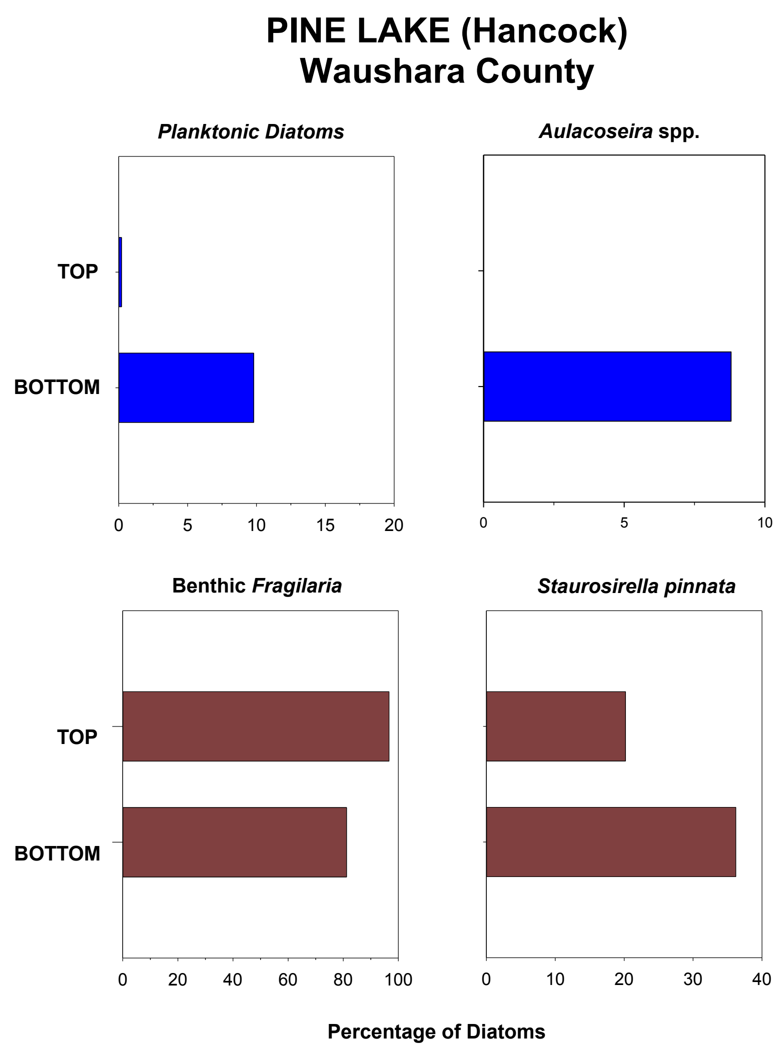


Figure 7. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Pine Lake.

Taxa richness and diversity are highest in the middle section compared with the top and bottom which is consistent with the intermediate disturbance hypothesis. The low diversity at the top is common when an ecosystem is heavily impacted by an invasive species.

Pine Lake

Similar to Deer Lake, the bottom and top samples of Pine Lake are dominated by benthic diatoms (Figure 7). There are a few planktonic diatoms in the bottom sample unlike Deer Lake which reflects the slightly deeper maximum depth of Pine Lake. The dominant diatoms in the bottom sample are benthic *Fragilaria* which often are associated with submerged aquatic plants and filamentous soft bodied algae. Even though an important species is *S. pinnata* the abundance of other benthic *Fragilaria* suggests that historically there were abundant macrophytes. In the top sample there were almost no planktonic diatoms indicating higher nutrients concentrations at the present time. The reduction in taxa richness and diversity (Table 3) also indicates an increase in nutrients.

Pleasant Lake

Even though Pleasant Lake is relatively deep, the dominant diatoms were benthic taxa (Figure 8). There were slightly more planktonic taxa in the bottom sample but there is little change between the top and bottom samples. Because of the possibility that the dominance of small *Fragilaria* at the bottom of the core might have indicated excellent water clarity, an upper middle sample was examined. The community was similar in both samples. While it is possible that the dominance of small *Fragilaria* in the middle sample also signals excellent water quality, I think it is more likely that the diatom community has not changed much in the last 150 years because the lake's ecosystem has not significantly changed. The lowest taxa richness and diversity is at the top of the core and this suggests that phosphorus levels may have increased slightly.

Round Lake

In the bottom sample the dominant diatoms were benthic taxa but there were also a significant amount of planktonic diatoms (Figure 9). The most common planktonic taxa was *A. ambigua* which was present historically in most of the other lakes. The bottom sample also had some *N. vulpina* which are found growing on submerged aquatic vegetation when phosphorus concentrations are low. The taxa richness and diversity are also higher in the bottom sample (Table 3) suggesting that there was a rich macrophyte community and nutrient levels were low. In the top sample there were almost no planktonic taxa and the community was dominated by benthic *Fragilaria*. This suggests that nutrient levels have increased and while macrophytes are still common, there is a greater abundance of soft bodied filamentous algae. The taxa richness in the top sample is almost one third that in the bottom sample indicating that the lake's ecosystem has degraded.

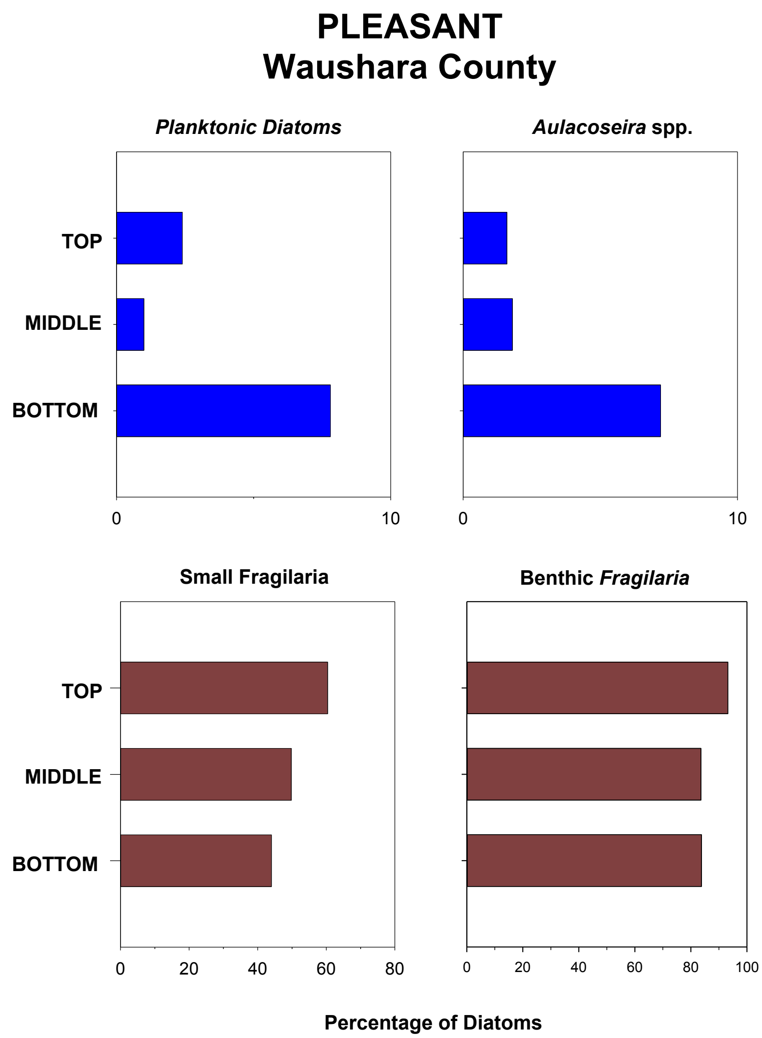


Figure 8. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Pleasant Lake.

Wilson Lake

The dominant diatoms in the bottom and top of the core are benthic taxa (Figure 10). This reflects the relative shallow depth of the lake. Historically the dominant taxa are benthic *Fragilaria* which suggests that the historical phosphorus were higher compared with Deer and Round lakes. The bottom sample of Wilson Lake does not contain any of the large *Navicula* found in Deer and Round lakes which further suggests higher nutrient levels. The higher nutrients indicated at the bottom of the core may be because the lake is shallower than Deer and Round lakes. Similar to Pleasant Lake, the diatom community suggests that there has been little change in Wilson Lake during the last 150 years.

Data Analysis

In order to better understand how much the lakes have changed from historical times, a multivariate statistical analysis, detrended correspondence analysis (DCA), was performed on the diatom communities in the top and bottom samples of the study lakes (CANOCO 4.5 software, ter Braak and Smilauer 2002). The greater the separation between the bottom and top samples, the more the lake is different at the present time compared with its historical ecosystem.

ROUND LAKE
Waushara County

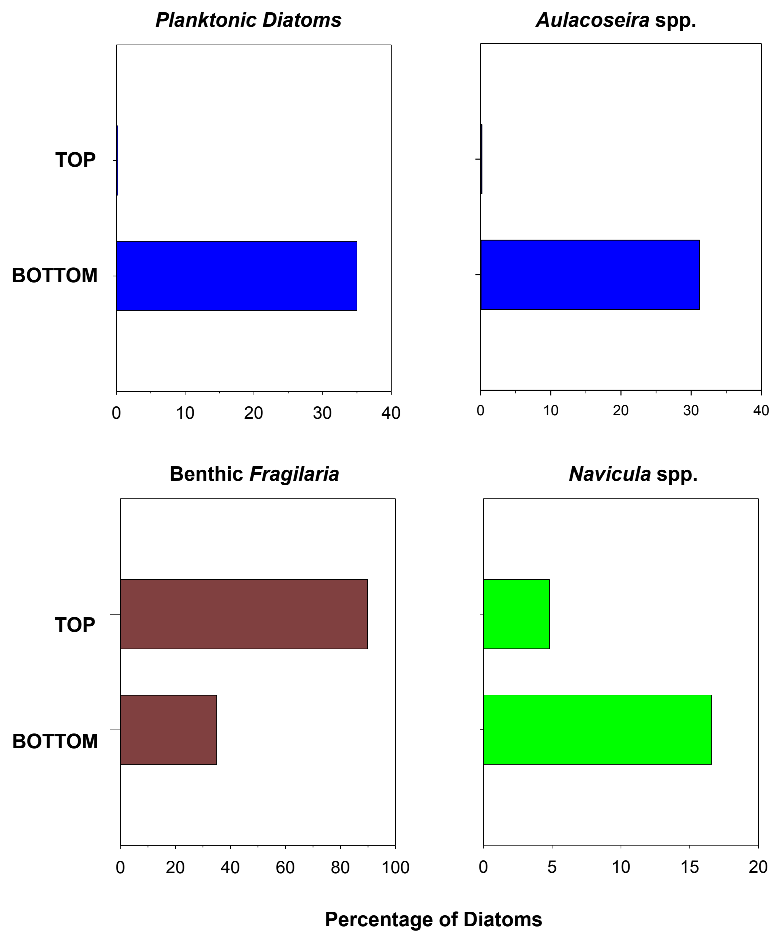


Figure 9. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Round Lake.

The lakes that showed the greatest change are Deer and Long lakes (Figure 11). The lakes with the least change in the diatom community were Pleasant and Wilson lakes. With this analysis it is not possible to know for sure what environmental conditions are most influencing the shift in the placement of the samples on the graph but we can hypothesize what the main factors are. It is not clear what the horizontal axis indicates but most of the shift is in the direction of the vertical axis. The vertical axis probably indicates increasing amounts of benthic filamentous algae and increased macrophyte growth which is associated with increased phosphorus concentrations. A shift from bottom to top, e.g. Deer, indicates an increase in plants and filamentous soft bodied algae. The remainder of the lakes show some change from the bottom to the top but on a smaller scale than Long or Deer lakes.

Weighted averaging calibration and reconstruction (Birks et al., 1990) were used to infer historical water column total phosphorus (TP) in the sediment core. A training set was developed from 52 Wisconsin lakes. The 52 lakes training set is based on lakes with total phosphorus values from 3 to 30 µg L^{-1}. Training set species and environmental data were analyzed using weighted average regression software (C2; Juggins 2003) to calculate TP optima for 128 taxa in the training set. The resulting transfer functions (bootstrapped 999 cycles $r^2 = 0.79$, $P < 0.05$) were subsequently applied with weighted averaging calibration to the fossil diatom assemblages (Birks et al., 1990, Juggins, 2003). Initial TP esti-

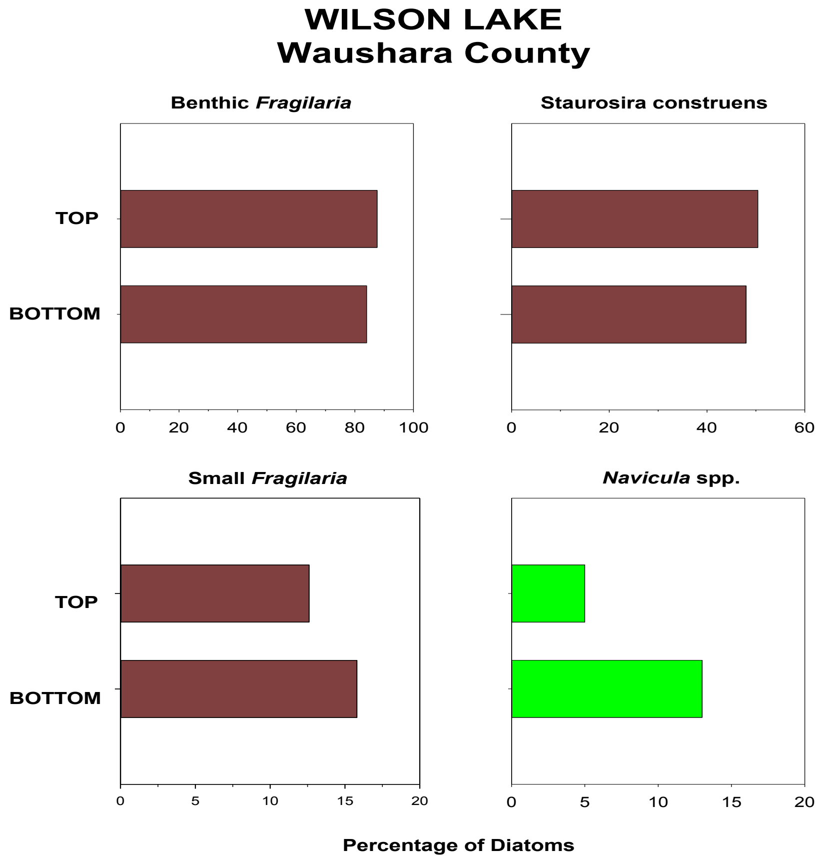


Figure 10. Changes in abundance of important diatoms found at the top and bottom of the sediment core in Wilson Lake.

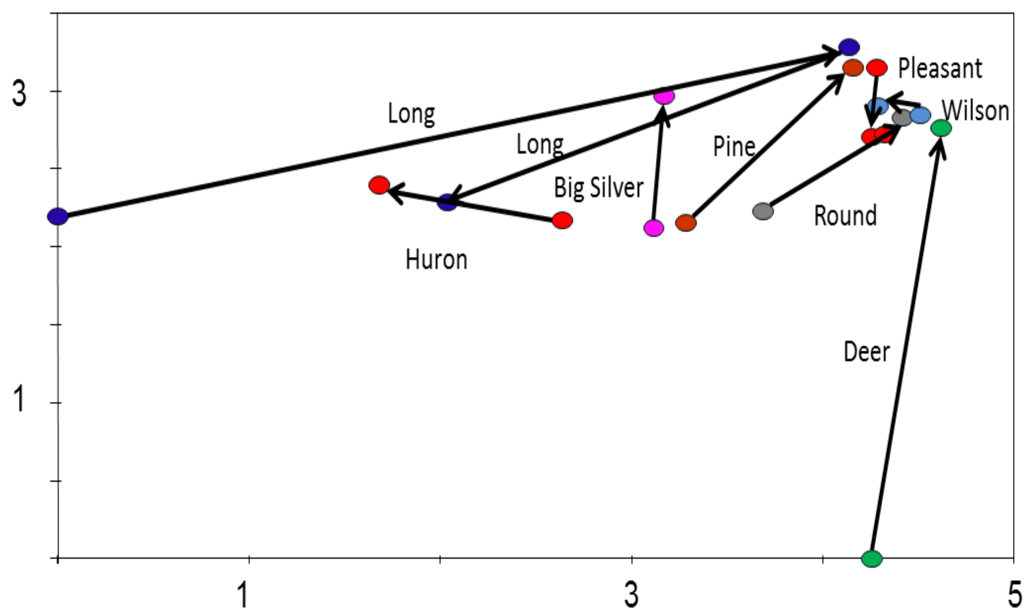


Figure 11. Discriminant correspondence analysis (DCA) for the diatom communities in the study lakes. The further apart the samples are the more dissimilar they are. Deer and Long lakes are the most different between the top and bottom samples while Pleasant and Wilson lakes show little change over time.

mates from weighted averaging regression were corrected using inverse deshrinking. Bootstrapped error estimates are based on initial log transformed data with the TP log error being 0.1407.

The results of the weighted averaging modeling accurately predicted the present day phosphorus concentrations in all of the lakes. The historical inferred phosphorus concentrations are similar for all the lakes ranging from 12-16 µg L^{-1} (Table 4). These concentrations are the same as most other seepage lakes in Wisconsin (Garrison et al. 2008). Most the lakes have experienced little on no increase in phosphorus concentrations. The lakes with the greatest increase in phosphorus are Deer and Pine lakes. These lakes have experienced an increase of 4-5 µg L^{-1}. Although the model appeared to work well for Long Lake, predicting a modern concentration of 8 µg L^{-1} which is nearly the same as the measured value of 9 µg L^{-1} (Table 2), the presence of the invasive diatom *C. comensis* may adversely affect the modeling results. It is unlikely that the phosphorus levels at the present time are lower than historical values. It is more likely that the historical phosphorus concentration was probably around 6-7 µg L^{-1} and phosphorus levels have increased around 2-3 µg L^{-1}. Estimating an accurate historical phosphorus concentration is complicated by the dominance of the benthic diatom *S. pinnata*. While this often is found under higher phosphorus levels, it is likely that in this lake it signals very good water clarity and low phosphorus concentrations.

Table 4. Diatom inferred summer mean phosphorus concentrations.

Lake		**Summer Phosphorus (µg L^{-1})**
Big Silver	Top	14
	Bottom	13
Deer	Top	17
	Bottom	13
Huron	Top	13
	Bottom	14
Long (Saxeville)	Top	8
	Middle	14
	Bottom	12
Pine (Hancock)	Top	20
	Bottom	15
Pleasant	Top	14
	Middle	13
	Bottom	14
Round	Top	14
	Bottom	15
Wilson	Top	16
	Bottom	16

Although phosphorus concentrations have increased a small amount or not at all in these lakes, there have been significant changes in the habitat of the lakes. Most of the lakes have more submerged aquatic plants and a greater expanse of filamentous soft bodied algae. This is especially true for Deer Lake. Long Lake has also experienced a decline in water clarity although phosphorus concentrations have only increased about 2 μg L^{-1}. Numerous other paleolimnological studies on lakes in northern WI have shown that lakes with shoreland development have experienced little change in phosphorus but significant changes in habitat. Borman (2007) found that in northwestern Wisconsin the macrophyte community often changed in seepage lakes, from one dominated by low growing plants to a community dominated by larger macrophytes, as a result of shoreline development. The structure of the macrophyte community changes because the increased runoff of sediment during construction on the shoreline enables the establishment of the larger plants. With the larger plants there is much more surface area available on which diatoms and other periphytic algae are able to grow. This appears to have occurred in many of the lakes in this study. With the increase in aquatic plants there is more surface area for attached algae to grow. While macrophytes obtain most of their phosphorus from sediments the attached algae obtain most of their nutrients from the water column. Consequently there is little increase in measured phosphorus levels because it is incorporated into the algae.

Summary

The lake that that experienced the greatest change from presettlement conditions was Deer Lake. This lake transitioned from a low nutrient with moderate submerged aquatic vegetation to a present day system where plants are much more abundant and there is a fair amount of filamentous soft bodied algae. The present day diatom community in Long Lake is dominated by the invasive diatom *Cyclotella comensis* which is native to northern Europe. This diatom was also found in Huron Lake but in much lower abundance. Only Deer and Pine (Hancock) lakes have experienced significant increased concentrations of phosphorus during the last 150 years. The historical phosphorus concentration in these lakes ranged from 12 to 16 μg L^{-1} which is similar to many other seepage lakes in Wisconsin.

Nearly all of the lakes have experienced a significant change in habitat with shoreland development. Many other lakes in central and northern Wisconsin have seen similar impacts from shoreland development. Although this study is not designed to document degradation of habitat on shore that other studies have found is common, this study does show that with development there often is increased growth of macrophytes and filamentous algae. The periphyton attached to these communities acts as a buffer to inputs of nutrients from shoreland runoff by incorporating nutrients into their plant tissues. Other studies in Wisconsin have shown that if nutrient runoff increases sufficiently, this buffer is overwhelmed and increased phosphorus levels occur in the open water of the lake (Garrison and Wakeman 2000). These Waushara County lakes are typical of many Wisconsin seepage lakes with shoreland development in that they have experienced limited increased concentrations of phosphorus but large changes in habitat during the last century.

Acknowledgments

Large kudos go to the field crew of Caitlin Carson, Brint Schwerbel, and Chris Noll who collected the cores, often under adverse weather conditions. Temperatures were near freezing and they even needed to break through the ice on one lake. Thanks for the long days and hard work. Funding was provided by the Wisconsin Department of Natural Resources.

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D

APPENDIX D

Strategic Analysis of Aquatic Plant Management in Wisconsin (June 2019).

Extracted Supplemental Chapters:

3.3 (Herbicide Treatment)
3.4 (Physical Removal)
3.5 (Biological Control)

In 2016-2019, the WDNR conducted a Strategy Analysis of Aquatic Plant Management in Wisconsin, which will serve as a reference document to mold future policies and approaches. The strategy the WDNR is following is outlined on the WDNR's APM Strategic Analysis Webpage:

https://dnr.wi.gov/topic/eia/apmsa.html

Below is a table of contents for the extracted materials for use in risk assessment of the discussed management tools within this project. Please refer to the WDNR's full text document cited above for Literature Cited.

Extracted Table of Contents

S.3.3. Herbicide Treatment

Herbicides are the most commonly employed method for controlling aquatic plants in Wisconsin. They are extremely useful tools for accomplishing aquatic plant management (APM) goals, like controlling invasive species, providing waterbody access, and ecosystem restoration. This Chapter includes basic information about herbicides and herbicide formulations, how herbicides are assessed for ecological and human health risks and registered for use, and some important considerations for the use of herbicides in aquatic environments.

A pesticide is a substance used to either directly kill pests or to prevent or reduce pest damage; herbicides are pesticides that are used to kill plants. Only a certain component of a pesticide product is intended to have pesticidal effects and this is called the active ingredient. The active ingredient is listed near the top of the first page on an herbicide product label. Any product claiming to have pesticidal properties must be registered with the U.S. EPA and regulated as a pesticide.

Inert ingredients often make up the majority of a pesticide formulation and are not intended to have pesticidal activity, although they may enhance the pesticidal activity of the active ingredient. These ingredients, such as carriers and solvents, are often added to the active ingredient by manufacturers, or by an herbicide applicator during use, in order to allow mixing of the active ingredient into water, make it more chemically stable, or aid in storage and transport. Manufacturers are not required to identify the specific inert ingredients on the pesticide label. In addition to inert ingredients included in manufactured pesticide formulations, adjuvants are inert ingredient products that may be added to pesticide formulations before they are applied to modify the properties or enhance pesticide performance. Adjuvants are typically not intended to have pesticidal properties and are not regulated as pesticides under the Federal Insecticide, Fungicide and Rodenticide Act. However, research has shown that inert ingredients can increase the efficacy and toxicity of pesticides especially if the appropriate label uses aren't followed (Mesnage et al. 2013; Defarge et al. 2016).

The combination of active ingredients and inert ingredients is what makes up a pesticide formulation. There are often many formulations of each active ingredient and pesticide manufacturers typically give a unique product or trade name to each specific formulation of an active ingredient. For instance, "Sculpin G" is a solid, granular 2,4-D amine product, while "DMA IV" is a liquid amine 2,4-D product, and the inert ingredients in these formulations are different, but both have the same active ingredient. Care should always be taken to read the herbicide product label as this will give information about which pests and ecosystems the product is allowed to be used for. Some formulations (i.e., non-aquatic formulations of glyphosate such as "Roundup") are not allowed for aquatic use and could lead to environmental degradation even if used on shorelines near the water. There are some studies which indicate that the combination of two chemicals (e.g., 2,4-D and endothall) applied together produces synergistic efficacy results that are greater than if each product was applied alone (Skogerboe et al. 2012). Conversely, there are studies which indicate the combination of two chemicals (i.e. diquat and penxosulam) which result in an antagonistic response between the herbicides, and resulted in reduced efficacy than when applying penoxsulam alone (Wersal and Madsen 2010b).

The U.S. EPA is responsible for registering pesticide products before they may be sold. In order to have their product registered, pesticide manufacturers must submit toxicity test data to the EPA that shows that the intended pesticide use(s) will not create unreasonable risks. “Unreasonable” in this context means that the risks of use outweigh the potential benefits. Once registered, the EPA must re-evaluate each pesticide and new information related to its use every 15 years. The current cycle of registration review will end in 2022, with a new cycle and review schedule starting then. In addition, EPA may decide to only register certain uses of any given pesticide product and can also require that only trained personnel can apply a pesticide before the risks outweigh the benefits. Products requiring training before application are called Restricted Use Pesticides.

As part of their risk assessments, EPA reviews information related to pesticide toxicity. Following laboratory testing, ecotoxicity rankings are given for different organismal groups based on the dosage that would cause harmful ecological effects (e.g., death, reduction in growth, reproductive impairment, and others). For example, the ecotoxicity ranking for 2,4-D ranges from “practically non-toxic” to “slightly toxic” for freshwater invertebrates, meaning tests have shown that doses of >100 ppm and 10-100 ppm are needed to cause 50% mortality or immobilization in the test population, respectively. Different dose ranges and indicators of “harm” are used to assess toxicity depending on the organisms being tested. More information can be found on the EPA’s website.

Beyond selecting herbicide formulations approved for use in aquatic environments, there are additional factors to consider supporting appropriate and effective herbicide use in those environments. Herbicide treatments are often used in terrestrial restorations, so they are also often requested in the management and restoration of aquatic plant communities. However, unlike applications in a terrestrial environment, the fluid environment of freshwater systems presents a set of unique challenges. Some general best practices for addressing challenges associated with herbicide dilution, migration, persistence, and non-target impacts are described in Chapter 7.4. More detailed documentation of these challenges is described below and in discussions on individual herbicides in Supplemental Chapter S.3.3 (Herbicide Treatment).

As described in Chapter 7.4, when herbicide is applied to waters, it can quickly migrate offsite and dilute to below the target concentrations needed to provide control (Hoeppel and Westerdal 1983; Madsen et al. 2015; Nault et al. 2015). Successful plant control with herbicide is dependent on concentration exposure time (CET) relationships. In order to examine actual observed CET relationships following herbicide applications in Wisconsin lakes, a study of herbicide CET and Eurasian watermilfoil (*Myriophyllum spicatum*) control efficacy was conducted on 98 small-scale (0.1-10 acres) 2,4-D treatment areas across 22 lakes. In the vast majority of cases, initial observed 2,4-D concentrations within treatment areas were far below the applied target concentration, and then dropped below detectable limits within a few hours after treatment (Nault et al. 2015). These results indicate the rapid dissipation of herbicide off of the small treatment areas resulted in water column concentrations which were much lower than those recommended by previous laboratory CET studies for effective Eurasian watermilfoil control. Concentrations in protected treatment areas (e.g., bays, channels) were initially higher than those in areas more exposed to wind and waves, although concentrations quickly dissipated to below detectable limits within hours after treatment regardless of spatial location. Beyond confining small-scale treatments to protected areas, utilizing or integrating faster-acting herbicides with shorter CET requirements may also help to compensate for reductions in plant control due to dissipation (Madsen et al. 2015). The use of chemical curtains or adjuvants (weighting or sticking agents) may also help to maintain adequate CET, however more research is needed in this area.

This rapid dissipation of herbicide off of treatment areas is important for resource managers to consider in planning, as treating numerous targeted areas at a ‘localized’ scale may actually result in low-concentrations capable of having lakewide impacts as the herbicide dissipates off of the individual treatment sites. In general, if the percentage of treated areas to overall lake surface area is >5% and targeted areas are treated at relatively high 2,4-D concentrations (e.g., 2.0-4.0 ppm), then anticipated lakewide concentrations after dissipation should be calculated to determine the likelihood of lakewide effects (Nault et al. 2018).

Aquatic-use herbicides are commercially available in both liquid and granular forms. Successful target species control has been reported with both granular and liquid formulations. While there has been a commonly held belief that granular products are able to ‘hold’ the herbicide on site for longer periods of time, actual field comparisons between granular and liquid 2,4-D forms revealed that they dissipated similarly when applied at small-scale sites (Nault et al. 2015). In fact, liquid 2,4-D had higher initial observed water column concentrations than the granular form, but in the majority of cases concentrations of both forms decreased rapidly to below detection limits within several hours after treatment Nault et al. 2015). Likewise, according to United Phosphorus, Inc. (UPI), the sole manufacturer of endothall, the granular formulation of endothall does not hold the product in a specific area significantly longer than the liquid form (Jacob Meganck [UPI], *personal communication*).

In addition, the stratification of water and the formation of a thermal density gradient can confine the majority of applied herbicides in the upper, warmer water layer of deep lakes. In some instances, the entire lake water volume is used to calculate how much active ingredient should be applied to achieve a specific lakewide target concentration. However, if the volume of the entire lake is used to calculate application rates for stratified lakes, but the chemical only readily mixes into the upper water layer, the achieved lakewide concentration is likely to be much higher than the target concentration, potentially resulting in unanticipated adverse ecological impacts.

Because herbicides cannot be applied directly to specific submersed target plants, the dissipation of herbicide over the treatment area can lead to direct contact with non-target plants and animals. No herbicide is completely selective (i.e., effective specifically on only a single target species). Some plant species may be more susceptible to a given herbicide than others, highlighting the importance of choosing the appropriate herbicide, or other non-chemical management approach, to minimize potential non-target effects of treatment. There are many herbicides and plant species for which the CET relationship that would negatively affect the plant is unknown. This is particularly important in the case of rare, special concern, or threatened and endangered species. Additionally, loss of habitat following any herbicide treatment or other management technique may cause indirect reductions in populations of invertebrates or other organisms. Some organisms will only recolonize the managed areas as aquatic plants become re-established.

Below are reviews for the most commonly used herbicides for APM in Wisconsin. Much of the information here was pulled directly from DNR's APM factsheets (http://dnr.wi.gov/lakes/plants/factsheets/), which were compiled in 2012 using U.S. EPA herbicide product labels, U.S. Army Corps of Engineers reports, and communications with natural resource agencies in other northern, lake-rich states. These have been supplemented with more recent information from primary research publications.

Each pesticide has at least one mode of action which is the specific mechanism by which the active ingredient exerts a toxic effect. For example, some herbicides inhibit production of the pigments needed for photosynthesis while others mimic plant growth hormones and cause uncontrolled and unsustainable growth. Herbicides are often classified as either systemic or contact in mode of action, although some herbicides are able to function under various modes of action depending on environmental variables such as water temperature. Systemic pesticides are those that are absorbed by organisms and can be moved or translocated within the organism. Contact pesticides are those that exert toxic effects on the part(s) of an organism that they come in contact with. The amount of exposure time needed to kill an organism is based on the specific mode of action and the concentration of any given pesticide. In the descriptions below herbicides are generally categorized into which environment (above or below water) they are primarily used and a relative assessment of how quickly they impact plants. Herbicides can be applied in many ways. In lakes, they are usually applied to the water's surface (or below the water's surface) through controlled release by equipment including spreaders, sprayers, and underwater hoses. In wetland environments, spraying by helicopter, backpack sprayer, or application by cut-stem dabbing, wicking, injection, or basal bark application are also used.

S.3.3.1. Submersed or Floating, Relatively Fast-Acting Herbicides

Diquat

Registration and Formulations

Diquat (or diquat dibromide) initially received Federal registration for control of submersed and floating aquatic plants in 1962. It was initially registered with the U.S. EPA in 1986, evaluated for reregistration in 1995, and is currently under registration review. A registration review decision was expected in 2015 but has not been released (EPA Diquat Plan 2011). The active ingredient is 6,7-dihydrodipyrido[1,2-α:2',1'-c] pyrazinediium dibromide, and is commercially sold as liquid formulations for aquatic use.

Mode of Action and Degradation

Diquat is a fast-acting herbicide that works through contact with plant foliage by disrupting electron flow in photosystem I of the photosynthetic reaction, ultimately causing the destruction of cell membranes (Hess 2000; WSSA 2007). Plant tissues in contact with diquat become impacted within several hours after application, and within one to three days the plant tissue will become necrotic. Diquat is considered a non-selective herbicide and will rapidly kill a wide variety of plants on contact. Because diquat is a fast-acting herbicide, it is oftentimes used for managing plants growing in areas where water exchange is anticipated to limit herbicide exposure times, such as small-scale treatments.

Due to rapid vegetation decomposition after treatment, only partial treatments of a waterbody should be conducted to minimize dissolved oxygen depletion and associated negative impacts on fish and other aquatic organisms. Untreated areas can be treated with diquat 14 days after the first application.

Diquat is strongly attracted to silt and clay particles in the water and may not be very effective under highly turbid water conditions or where plants are covered with silt (Clayton and Matheson 2010).

The half-life of diquat in water generally ranges from a few hours to two days depending on water quality and other environmental conditions. Diquat has been detected in the water column from less than a day up towards 38 DAT, and remains in the water column longer when treating waterbodies with sandy sediments with lower organic matter and clay content (Coats et al. 1964; Grzenda et al. 1966; Yeo 1967; Sewell et al. 1970; Langeland and Warner 1986; Langeland et al. 1994; Poovey and Getsinger 2002; Parsons et al. 2007; Gorzerino et al. 2009; Robb et al. 2014). One study reported that diquat is chemically stable within a pH range of 3 to 8 (Florêncio et al. 2004). Due to the tendency of diquat to be rapidly adsorbed to suspended clays and particulates, long exposure periods are oftentimes not possible to achieve in the field. Studies conducted by Wersal et al. (2010a) did not observe differences in target species efficacy between daytime versus night-time applications of diquat. While large-scale diquat treatments are typically not implemented, a study by Parsons et al. (2007), observed declines in both dissolved oxygen and water clarity following the herbicide treatment.

Diquat binds indefinitely to organic matter, allowing it to accumulate and persist in the sediments over time (Frank and Comes 1967; Simsiman and Chesters 1976). It has been reported to have a very long-lived half-life (1000 days) in sediment because of extremely tight soil sorption, as well as an extremely low rate of degradation after association with sediment (Wauchope et al. 1992; Peterson et al. 1994). Both photolysis and microbial degradation are thought to play minor roles in degradation (Smith and Grove 1969; Emmett 2002). Diquat is not known to leach into groundwater due to its very high affinity to bind to soils.

One study reported that combinations of diquat and penoxsulam resulted in an antagonistic response between the herbicides when applied to water hyacinth (*Eichhornia crassipes*) and resulted in reduced efficacy than when applying penoxsulam alone. The antagonistic response is likely due to the rapid cell destruction by diquat that limits the translocation and efficacy of the slower acting enzyme inhibiting herbicides (Wersal and Madsen 2010b).
Toxicology

There are no restrictions on swimming or eating fish from waterbodies treated with diquat. Depending on the concentration applied, there is a 1-3 day waiting period after treatment for drinking water. However, in one study, diquat persisted in the water at levels above the EPA drinking water standard for at least 3 DAT, suggesting that the current 3-day drinking water restriction may not be sufficient under all application scenarios (Parsons et al. 2007). Water treated with diquat should not be used for pet or livestock drinking water for one day following treatment. The irrigation restriction for food crops is five days, and for ornamental plants or lawn/turf, it varies from one to three days depending on the concentration used. A study by Mudge et al. (2007)

on the effects of diquat on five popular ornamental plant species (begonia, dianthus, impatiens, petunia, and snapdragon) found minimal risks associated with irrigating these species with water treated with diquat up to the maximum use rate of 0.37 ppm.

Ethylene dibromide (EDB) is a trace contaminant in diquat products which originates from the manufacturing process. EDB is a documented carcinogen, and the EPA has evaluated the health risk of its presence in formulated diquat products. The maximum level of EDB in diquat dibromide is 0.01 ppm (10 ppb). EBD degrades over time, and it does not persist as an impurity.

Diquat does not have any apparent short-term effects on most aquatic organisms that have been tested at label application rates (EPA Diquat RED 1995). Diquat is not known to bioconcentrate in fish tissues. A study using field scenarios and well as computer modelling to examine the potential ecological risks posed by diquat determined that diquat poses a minimal ecological impact to benthic invertebrates and fish (Campbell et al. 2000). Laboratory studies indicate that walleye (*Sander vitreus*) are more sensitive to diquat than some other fish species, such as smallmouth bass (*Micropterus dolomieu),* largemouth bass (*Micropterus salmoides*), and bluegills (*Lepomis macrochirus*), with individuals becoming less sensitive with age (Gilderhus 1967; Paul et al. 1994; Shaw and Hamer 1995). Maximum application rates were lowered in response to these studies, such that applying diquat at recommended label rates is not expected to result in toxic effects on fish (EPA Diquat RED 1995). Sublethal effects such as respiratory stress or reduced swimming capacity have been observed in studies where certain fish species (e.g., yellow perch (*Perca flavescens*), rainbow trout (*Oncorhynchus mykiss*), and fathead minnows (*Pimephales promelas*)) have been exposed to diquat concentrations (Bimber et al. 1976; Dodson and Mayfield 1979; de Peyster and Long 1993). Another study showed no observable effects on eastern spiny softshell turtles (*Apalone spinifera spinifera*; Paul and Simonin 2007). Reduced size and pigmentation or increased mortality have been shown in some amphibians but at above recommended label rates (Anderson and Prahlad 1976; Bimber and Mitchell 1978; Dial and Bauer-Dial 1987). Toxicity data on invertebrates are scarce and diquat is considered not toxic to most of them. While diquat is not highly toxic to most invertebrates, significant mortality has been observed in some species at concentrations below the maximum label use rate for diquat, such as the amphipod *Hyalella azteca* (Wilson and Bond 1969; Williams et al. 1984), water fleas (*Daphnia* spp.). Reductions in habitat following treatment may also contribute to reductions of *Hyalella azteca*. For more information, a thorough risk assessment for diquat was compiled by the Washington State Department of Ecology Water Quality Program (WSDE 2002). Available toxicity data for fish, invertebrates, and aquatic plants is summarized in tabular format by Campbell et al. (2000).

Species Susceptibility

Diquat has been shown to control a variety of invasive submerged and floating aquatic plants, including Eurasian watermilfoil (*Myriophyllum spicatum*), curly-leaf pondweed (*Potamogeton crispus*), parrot feather (*Myriophyllum aquaticum*), Brazilian waterweed (*Egeria densa*), water hyacinth, water lettuce (*Pistia stratiotes*), flowering rush (*Butomus umbellatus*), and giant salvinia (*Salvinia molesta*; Netherland et al. 2000; Nelson et al. 2001; Poovey et al. 2002; Langeland et al. 2002; Skogerboe et al. 2006; Martins et al. 2007, 2008; Wersal et al. 2010a; Wersal and Madsen 2010a; Wersal and Madsen 2012; Poovey et al. 2012; Madsen et al. 2016). Studies conducted on the use of diquat for hydrilla (*Hydrilla verticillata*) and fanwort (*Cabomba caroliniana*) control have resulted in mixed reports of efficacy (Van et al. 1987; Langeland et al. 2002; Glomski et al. 2005; Skogerboe et al. 2006; Bultemeier et al. 2009; Turnage et al. 2015). Non-native phragmites (*Phragmites australis* subsp. *australis*) has been shown to not be significantly reduced by diquat (Cheshier et al. 2012).

Skogerboe et al. 2006 reported on the efficacy of diquat (0.185 and 0.37 ppm) under flow-through conditions (observed half-lives of 2.5 and 4.5 hours, respectively). All diquat treatments reduced Eurasian watermilfoil biomass by 97 to 100% compared to the untreated reference, indicating that this species is highly susceptible to diquat. Netherland et al. (2000) examined the role of various water temperatures (10, 12.5, 15, 20, and 25°C) on the efficacy of diquat applications for controlling curly-leaf pondweed. Diquat was applied at rates of 0.16-0.50 ppm, with exposure times of 9-12 hours. Diquat efficacy on curly-leaf pondweed was inhibited as water temperature decreased, although treatments at all temperatures were observed to significantly reduce biomass and turion formation. While the most efficacious curly-leaf pondweed treatments were conducted at 25°C, waiting until water warms to this temperature limits the potential for reducing turion production. Diquat applied at 0.37 ppm (with a 6 to 12-hour exposure time) or at 0.19 ppm (with a 72-hour exposure time) was effective at reducing biomass of flowering rush (Poovey et al. 2012; Madsen et al. 2016).

Native species that have been shown to be affected by diquat include: American lotus (*Nelumbo lutea*), common bladderwort (*Utricularia vulgaris*), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), needle spikerush (*Eleocharis acicularis*), Illinois pondweed (*Potamogeton illinoensis*), leafy pondweed (*P. foliosus*), clasping-leaf pondweed (*P. richardsonii*), fern pondweed (*P. robbinsii*), sago pondweed (*Stuckenia pectinata*), and slender naiad (*Najas flexilis*) (Hofstra et al. 2001; Glomski et al. 2005; Skogerboe et al. 2006; Mudge 2013; Bugbee et al. 2015; Turnage et al. 2015). Diquat is particularly toxic to duckweeds (*Landoltia punctata* and *Lemna* spp.), although certain populations of dotted duckweed (*Landoltia punctata*) have developed resistance of diquat in waterbodies with a long history (20-30 years) of repeated diquat treatments (Peterson et al. 1997; Koschnick et al. 2006). Variable effects have been observed for water celery (*Vallisneria americana*), long-leaf pondweed (*Potamogeton nodosus*), and variable-leaf watermilfoil (*Myriophyllum heterophyllum*; Skogerboe et al. 2006; Glomski and Netherland 2007; Mudge 2013).

Flumioxazin

Registration and Formulations

Flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione) was registered with the U.S. EPA for agricultural use in 2001 and registered for aquatic use in 2010. The first registration review of flumioxazin is expected to be completed in 2017 (EPA Flumioxazin Plan 2011). Granular and liquid formulations are available for aquatic use.

Mode of Action and Degradation

The mode of action of flumioxazin is through disruption of the cell membrane by inhibiting protoporphyrinogen oxidase which blocks production of heme and chlorophyll. The efficacy of this mode of action is dependent on both light intensity and water pH (Mudge et al. 2012a; Mudge and Haller 2010; Mudge et al. 2010), with herbicide degradation increasing with pH and efficacy decreasing as light intensity declines.

Flumioxazin is broken down by water (hydrolysis), light (photolysis) and microbes. The half-life ranges from approximately 4 days at pH 5 to 18 minutes at pH 9 (EPA Flumioxazin 2003). In the majority of Wisconsin lakes half-life should be less than 1 day.

Flumioxazin degrades into APF (6-amino-7-fluro-4-(2-propynyl)-1,4,-benzoxazin-3(2H)-one) and THPA (3,4,5,6-tetrahydrophthalic acid). Flumioxazin has a low potential to leach into groundwater due to the very quick hydrolysis and photolysis. APF and THPA have a high potential to leach through soil and could be persistent.

Toxicology

Tests on warm and cold-water fishes indicate that flumioxazin is "slightly to moderately toxic" to fish on an acute basis, with possible effects on larval growth below the maximum label rate of 0.4 ppm (400 ppb). Flumioxazin is moderately to highly toxic to aquatic invertebrates, with possible impacts below the maximum label rate. The potential for bioaccumulation is low since degradation in water is so rapid. The metabolites APF and THPA have not been assessed for toxicity or bioaccumulation.

The risk of acute exposure is primarily to chemical applicators. Concentrated flumioxazin doesn't pose an inhalation risk but can cause skin and eye irritation. Recreational water users would not be exposed to concentrated flumioxazin.

Acute exposure studies show that flumioxazin is "practically non-toxic" to birds and small mammals. Chronic exposure studies indicate that flumioxazin is non-carcinogenic. However, flumioxazin may be an endocrine disrupting compound in mammals (EPA Flumioxazin 2003), as some studies on small mammals did show effects on reproduction and larval development, including reduced offspring viability, cardiac and skeletal malformations, and anemia. It does not bioaccumulate in mammals, with the majority excreted in a week.

Species Susceptibility

The maximum target concentration of flumioxazin is 0.4 ppm (400 ppb). At least one study has shown that flumioxazin (at or below the maximum label rate) will control the invasive species fanwort (*Cabomba caroliniana*), hydrilla (*Hydrilla verticillata*), Japanese stiltgrass (*Microstegium vimineum*), Eurasian watermilfoil (*Myriophyllum spicatum*), water lettuce (*Pistia stratiotes*), curly-leaf pondweed (*Potamogeton crispus*), and giant salvinia (*Salvinia molesta*), while water hyacinth (*Eichhornia crassipes*) and water pennyworts (*Hydrocotyle* spp.) do not show significant impacts (Bultemeier et al. 2009; Glomski and Netherland 2013a; Glomski and Netherland 2013b; Mudge 2013; Mudge and Netherland 2014; Mudge and Haller 2012; Mudge and Haller 2010). Flowering rush (*Butomus umbellatus*; submersed form) showed mixed success in herbicide trials

(Poovey et al. 2012; Poovey et al. 2013). Native species that were significantly impacted (in at least one study) include coontail (*Ceratophyllum demersum*), water stargrass (*Heteranthera dubia*), variable-leaf watermilfoil (*Myriophyllum heterophyllum*), America lotus (*Nelumbo lutea*), pond-lilies (*Nuphar* spp.), white waterlily (*Nymphaea odorata*), white water crowfoot (*Ranunculus aquatilis*), and broadleaf cattail (*Typha latifolia*), while common waterweed (*Elodea canadensis*), squarestem spikerush (*Eleocharis quadrangulate*), horsetail (*Equisetum hyemale*), southern naiad (*Najas guadalupensis*), pickerelweed (*Pontederia cordata*), Illinois pondweed (*Potamogeton illinoensis*), long-leaf pondweed (*P. nodosus*), broadleaf arrowhead (*Sagittaria latifolia*), hardstem bulrush (*Schoenoplectus acutus*), common three-square bulrush (*S. pungens*), softstem bulrush (*S. tabernaemontani*), sago pondweed (*Stuckenia pectinata*), and water celery (*Vallisneria americana*) were not impacted relative to controls. Other species are likely to be susceptible, for which the effects of flumioxazin have not yet been evaluated.

Carfentrazone-ethyl

Registration and Formulations

Carfentrazone-ethyl is a contact herbicide that was registered with the EPA in 1998. The active ingredient is ethyl 2-chloro-3-[2 -chloro-4-fluoro-5-[4 -(difluoromethyl)-4,5-diydro-3-methyl-5-oxo-1H-1,2,4-trizol-1-yl)phenyl]propanoate. A liquid formulation of carfentrazone-ethyl is commercially sold for aquatic use.

Mode of Action and Degradation

Carfentrazone-ethyl controls plants through the process of membrane disruption which is initiated by the inhibition of the enzyme protoporphyrinogen oxidase, which interferes with the chlorophyll biosynthetic pathway. The herbicide is absorbed through the foliage of plants, with injury symptoms viable within a few hours after application, and necrosis and death observed in subsequent weeks.

Carfentrazone-ethyl breaks down rapidly in the environment, while its degradates are persistent in aquatic and terrestrial environments. The herbicide primarily degrades via chemical hydrolysis to carfentrazone-chloropropionic acid, which is then further degraded to carfentrazone -cinnamic, -propionic, -benzoic and 3-(hydroxymethyl)-carfentrazone-benzoic acids. Studies have shown that degradation of carfentrazone-ethyl applied to water (pH = 7-9) has a half-life range of 3.4-131 hours, with longer half-lives (>830 hours) documented in waters with lower pH (pH = 5). Extremes in environmental conditions such as temperature and pH may affect the activity of the herbicide, with herbicide symptoms being accelerated under warm conditions.

While low levels of chemical residue may occur in surface and groundwater, risk concerns to non-target organisms are not expected. If applied into water, carfentrazone-ethyl is expected to adsorb to suspended solids and sediment.

Toxicology

There is no restriction on the use of treated water for recreation (e.g., fishing and swimming). Carfentrazone-ethyl should not be applied directly to water within ¼ mile of an active potable water intake. If applied around or within potable water intakes, intakes must be turned off prior to application and remain turned off for a minimum of 24 hours following application; the intake may be turned on prior to 24 hours only if the carfentrazone-ethyl and major degradate level is determined by laboratory analysis to be below 200 ppb. Do not use water treated with carfentrazone-ethyl for irrigation in commercial nurseries or greenhouses. In scenarios where the herbicide is applied to 20% or more of the surface area, treated water should not be used for irrigation of crops until 14 days after treatment, or until the carfentrazone-ethyl and major degradate level is determined by analysis to be below 5 ppb.

In scenarios where the herbicide is applied as a spot treatment to less than 20% of the waterbody surface area, treated water may be used for irrigation by commercial turf farms and on residential turf and ornamentals without restriction. If more than 20% of the waterbody surface area is treated, water should not be used for irrigation of turf or ornamentals until 14 days after treatment, or until the carfentrazone-ethyl and major degradate level is determined by analysis to be below 5 ppb.

Carfentrazone-ethyl is listed as very toxic to certain species of algae and listed as moderately toxic to fish and aquatic animals. Treatment of dense plants beds may result in dissolved oxygen declines from plant decomposition which may lead to fish suffocation or death. To minimize impacts, applications of this herbicide should treat up to a maximum of half of the waterbody at a time and wait a minimum of 14 days before retreatment or treatment of the remaining half of the waterbody. Carfentrazone-ethyl is considered to be practically non-toxic to birds on an acute and sub-acute basis.

Carfentrazone-ethyl is harmful if swallowed and can be absorbed through the skin or inhaled. Those who mix or apply the herbicide need to protect their skin and eyes from contact with the herbicide to minimize irritation and avoid breathing the spray mist. Carfentrazone-ethyl is not carcinogenic, neurotoxic, or mutagenic and is not a developmental or reproductive toxicant.

Species Susceptibility

Carfentrazone-ethyl is used for the control of floating and emergent aquatic plants such as duckweeds (*Lemna* spp.), watermeals (*Wolffia* spp.), water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and salvinia (*Salvinia* spp.). Carfentrazone-ethyl can also be used to control submersed plants such as Eurasian watermilfoil (*Myriophyllum spicatum*).

S.3.3.2. Submersed, Relatively Slow-Acting Herbicides

2,4-D

Registration and Formulations

2,4-D is an herbicide that is widely used as a household weed-killer, agricultural herbicide, and aquatic herbicide. It has been in use since 1946 and was registered with the U.S. EPA in 1986 and evaluated and reregistered in 2005. It is currently being evaluated for reregistration, and the estimated registration review decision date was in 2017 (EPA 2,4-D Plan 2013). The active ingredient is 2,4-dichloro-phenoxyacetic acid. There are two types of 2,4-D used as aquatic herbicides: dimethyl amine salt (DMA) and butoxyethyl ester (BEE). The ester formulations are toxic to fish and some important invertebrates such as water fleas (*Daphnia* spp.) and midges at application rates. 2,4-D is commercially sold as a liquid amine as well as ester and amine granular products for control of submerged, emergent, and floating-leaf vegetation. Only 2,4-D products labeled for use in aquatic environments may be used to control aquatic plants.

Mode of Action and Degradation

Although the exact mode of action of 2,4-D is not fully understood, the herbicide is traditionally believed to target broad-leaf dicotyledon species with minimal effects generally observed on numerous monocotyledon species, especially in terrestrial applications (WSSA 2007). 2,4-D is a systemic herbicide which affects plant cell growth and division. Upon application, it mimics the natural plant hormone auxin, resulting in bending and twisting of stems and petioles followed by growth inhibition, chlorosis (reduced coloration) at growing points, and necrosis or death of sensitive species (WSSA 2007). Following treatment, 2,4-D is taken up by the plant and translocated through the roots, stems and leaves, and plants begin to die within one to two weeks after application, but can take several weeks to decompose. The total length of target plant roots can be an important in determining the response of an aquatic plant to 2,4-D (Belgers et al. 2007). Treatments should be made when plants are growing. After treatment, the 2,4-D concentration in the water is reduced primarily through microbial activity, off-site movement by water, or adsorption to small particles in silty water.

Previous studies have indicated that 2,4-D degradation in water is highly variable depending on numerous factors such as microbial presence, temperature, nutrients, light, oxygen, organic content of substrate, pH, and whether or not the water has been previously exposed to 2,4-D or other phenoxyacetic acids (Howard et al. 1991). Once in contact with water, both the ester and amine formulations dissociate to the acid form of 2,4-D, with a faster dissociation to the acid form under more alkaline conditions. 2,4-D degradation products include 1,2,4-benzenetriol, 2,4-dichlorophenol, 2,4-dichloroanisole, chlorohydroquinone (CHQ), 4-chlorophenol, and volatile organics.

The half-life of 2,4-D has a wide range depending on water conditions. Half-lives have been reported to range from 12.9 to 40 days, while in anaerobic lab conditions the half-life has been measured at 333 days (EPA RED 2,4-D 2005). In large-scale low-concentration 2,4-D treatments monitored across numerous Wisconsin lakes, estimated half-lives ranged from 4-76 days, and the rate of herbicide degradation was generally observed to be slower in oligotrophic seepage lakes. Of these large-scale 2,4-D treatments, the threshold for irrigation of plants which are not labeled for direct treatment with 2,4-D (<0.1 ppm (100 ppb) by 21 DAT) was exceeded the majority of the treatments (Nault et al. 2018). Previous historical use of 2,4-D may also be an important variable to consider, as microbial communities which are responsible for the breakdown of 2,4-D may potentially exhibit changes in community composition over time with repeated use (de Lipthay et al. 2003; Macur et al. 2007). Additional detailed information on the environmental fate of 2,4-D is compiled by Walters 1999.

There have been some preliminary investigations into the concentration of primarily granular 2,4-D in water-saturated sediments, or pore-water. Initial results suggest the concentration of 2,4-D in the pore-water varies widely from site to site following a chemical treatment, although in some locations the concentration in the pore-water was observed to be 2-3 times greater than the application rate (Jim Kreitlow [DNR], *personal communication*). Further research and additional studies are needed to assess the implications of this finding for target species control and non-target impacts on a variety of organisms.

<u>Toxicology</u>

There are no restrictions on eating fish from treated waterbodies, human drinking water, or pet/livestock drinking water. Based upon 2,4-D ester (BEE) product labels, there is a 24-hour waiting period after treatment for swimming. Before treated water can be used for irrigation, the concentration must be below 0.1 ppm (100 ppb), or at least 21 days must pass. Adverse health effects can be produced by acute and chronic exposure to 2,4-D. Those who mix or apply 2,4-D need to protect their skin and eyes from contact with 2,4-D products to minimize irritation and avoid inhaling the spray. In its consideration of exposure risks, the EPA believes no significant risks will occur to recreational users of water treated with 2,4-D.

There are differences in toxicity of 2,4-D depending on whether the formulation is an amine (DMA) or ester (BEE), with the BEE formulation shown to be more toxic in aquatic environments. BEE formulations are considered toxic to fish and invertebrates such as water fleas and midges at operational application rates. DMA formulations are not considered toxic to fish or invertebrates at operational application rates. Available data indicate 2,4-D does not accumulate at significant levels in the tissues of fish. Although fish exposed to 2,4-D may take up very small amounts of its breakdown products to then be metabolized, the vast majority of these products are rapidly excreted in urine (Ghassemi et al. 1981).

On an acute basis, EPA assessment considers 2,4-D to be “practically non-toxic” to honeybees and tadpoles. Dietary tests (substance administered in the diet for five consecutive days) have shown 2,4-D to be “practically non-toxic” to birds, with some species being more sensitive than others (when 2,4-D was orally and directly administered to birds by capsule or gavage, the substance was “moderately toxic” to some species). For freshwater invertebrates, EPA considers 2,4-D amine to be “practically non-toxic” to “slightly toxic” (EPA RED 2,4-D 2005). Field studies on the potential impact of 2,4-D on benthic macroinvertebrate communities have generally not observed significant changes, although at least one study conducted in Wisconsin observed negative correlations in macroinvertebrate richness and abundance following treatment, and further studies are likely warranted (Stephenson and Mackie 1986; Siemering et al. 2008; Harrahy et al. 2014). Additionally, sublethal effects such as mouthpart deformities and change in sex ratio have been observed in the midge *Chironomus riparius* (Park et al. 2010).

While there is some published literature available looking at short-term acute exposure of various aquatic organisms to 2,4-D, there is limited literature is available on the effects of low-concentration chronic exposure to commercially available 2,4-D formulations (EPA RED 2,4-D 2005). The department recently funded several projects related to increasing our understanding of the potential impacts of chronic exposure to low-concentrations of 2,4-D through AIS research and development grants. One of these studies observed that fathead minnows (*Pimephales promelas*) exposed under laboratory conditions for 28 days to 0.05 ppm (50 ppb) of two different commercial formulations of 2,4-D (DMA® 4 IVM and Weedestroy® AM40) had decreases in larval survival and tubercle presence in males, suggesting that these formulations may exert some degree of chronic toxicity or endocrine-disruption which has not been previously observed when testing pure compound 2,4-D (DeQuattro and Karasov 2016). However, another follow-up study determined that fathead minnow larval survival (30 days post hatch) was decreased following exposure of eggs and larvae to pure 2,4-D, as well as to the two commercial formulations (DMA® 4 IVM and Weedestroy® AM40), and also identified a critical window of exposure for effects on survival to the period between fertilization and 14 days post hatch (Dehnert et al. 2018).

Another related follow-up laboratory study is currently being conducted to examine the effects of 2,4-D exposure on embryos and larvae of several Wisconsin native fish species. Preliminary results indicate that negative impacts of embryo survival were observed for 4 of the 9 native species tested (e.g., walleye, northern pike, white crappie, and largemouth bass), and negative impacts of larval survival were observed for 4 of 7 natives species tested (e.g., walleye, yellow perch, fathead minnows, and white suckers; Dehnert and Karasov, *in progress*).

A controlled field study was conducted on six northern Wisconsin lakes to understand the potential impacts of early season large-scale, low-dose 2,4-D on fish and zooplankton (Rydell et al. 2018). Three lakes were treated with early season low-dose liquid 2,4-D (lakewide epilimnetic target rate: 0.3 ppm (300 ppb)), while the other three lakes served as reference without treatment. Zooplankton densities were similar within lakes during the pre-treatment year and year of treatment, but different trends in several zooplankton species were observed in treatment lakes during the year following treatment. Peak abundance of larval yellow perch (*Perca flavescens*) was lower in the year following treatment, and while this finding was not statistically significant, decreased larval yellow perch abundance was not observed in reference lakes. The observed declines in larval yellow perch abundance and changes in zooplankton trends within treatment lakes in the year after treatment may be a result of changes in aquatic plant communities and not a direct effect of treatment. No significant effect was observed on peak abundance of larval largemouth bass (*Micropterus salmoides*), minnows, black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), or juvenile yellow perch. Larval black crappie showed no detectable response in growth or feeding success. Net pen trials for juvenile bluegill indicated no significant difference in survival between treatment and reference trials, indicating that no direct mortality was associated with the herbicide treatments. Detection of the level of larval fish mortality found in the lab studies would not have been possible in the field study given large variability in larval fish abundance among lakes and over time.

Concerns have been raised about exposure to 2,4-D and elevated cancer risk. Some epidemiological studies have found associations between 2,4-D and increased risk of non-Hodgkin lymphoma in high exposure populations, while other studies have shown that increased cancer risk may be caused by other factors (Hoar et al. 1986; Hardell and Eriksson 1999; Goodman et al. 2015). The EPA determined in 2005 that there is not sufficient evidence to classify 2,4-D as a human carcinogen (EPA RED 2,4-D 2005).

Another chronic health concern with 2,4-D is the potential for endocrine disruption. There is some evidence that 2,4-D may have effects on reproductive development, though other studies suggest the findings may have had other causes (Garry et al. 1996; Coady et al. 2013; Goldner et al. 2013; Neal et al. 2017). The extent and implications of this are not clear and it is an area of ongoing research.

Detailed literature reviews of 2,4-D toxicology have been compiled by Garabrant and Philbert (2002), Jervais et al. (2008), and Burns and Swaen (2012).

Species Susceptibility

With appropriate concentration and exposure, 2,4-D is capable of reducing abundance of the invasive plant species Eurasian watermilfoil (*Myriophyllum spicatum*), parrot feather (*M. aquaticum*), water chestnut (*Trapa natans*), water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*; Elliston and Steward 1972; Westerdahl et al. 1983; Green and Westerdahl 1990; Helsel et al. 1996, Poovey and Getsinger 2007; Wersal et al. 2010b; Cason and Roost 2011; Robles et al. 2011; Mudge and Netherland 2014). Perennial pepperweed (*Lepidium latifolium)* and fanwort (*Cabomba caroliniana*) have been shown to be somewhat tolerant of 2,4-D (Bultemeier et al. 2009; Whitcraft and Grewell 2012).

Efficacy and selectivity of 2,4-D is a function of concentration and exposure time (CET) relationships, and rates of 0.5-2.0 ppm coupled with exposure times ranging from 12 to 72 hours have been effective at achieving Eurasian watermilfoil control under laboratory settings (Green and Westerdahl 1990). In addition, long exposure times (>14 days) to low-concentrations of 2,4-D (0.1-0.25 ppm) have also been documented to achieve milfoil control (Hall et al. 1982; Glomski and Netherland 2010).

According to product labels, desirable native species that may be affected include native milfoils (*Myriophyllum* spp.), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), naiads (*Najas* spp.), waterlilies (*Nymphaea* spp. and *Nuphar* spp.), bladderworts (*Utricularia* spp.), and duckweeds (*Lemna* spp.). While it may affect softstem bulrush (*Schoenoplectus tabernaemontani*), other species such as American bulrush (*Schoenoplectus americanus*) and muskgrasses (*Chara* spp.) have been shown to be somewhat tolerant of 2,4-D (Miller and Trout 1985; Glomski et al. 2009; Nault et al. 2014; Nault et al. 2018).

In large-scale, low-dose (0.073-0.5 ppm) 2,4-D treatments evaluated by Nault et al. (2018), milfoil exhibited statistically significant lakewide decreases in posttreatment frequency across 23 of the 28 (82%) of the treatments monitored. In lakes where year of treatment milfoil control was achieved, the longevity of control ranged from 2–8 years. However, it is important to note that milfoil was not 'eradicated' from any of these lakes and is still present even in those lakes which have sustained very low frequencies over time. While good year of treatment control was achieved in all lakes with pure Eurasian watermilfoil populations, significantly reduced control was observed in the majority of lakes with hybrid watermilfoil (*Myriophyllum spicatum* x *sibiricum*) populations. Eurasian watermilfoil control was correlated with the mean concentration of 2,4-D measured during the first two weeks of treatment, with increasing lakewide concentrations resulting in increased Eurasian watermilfoil control. In contrast, there was no significant relationship observed between Eurasian watermilfoil control and mean concentration of 2,4-D. In lakes where good (>60%) year of treatment control of hybrid watermilfoil was achieved, 2,4-D degradation was slow, and measured lakewide concentrations were sustained at >0.1 ppm (>100 ppb) for longer than 31 days. In addition to reduced year of treatment efficacy, the longevity of control was generally shorter in lakes that contained hybrid watermilfoil versus Eurasian watermilfoil, suggesting that hybrid watermilfoil may have the ability to rebound quicker after large-scale treatments than pure Eurasian watermilfoil populations. However, it is important to keep in mind that hybrid watermilfoil is broad term for multiple different strains, and variation in herbicide response and growth between specific genotypes of hybrid watermilfoil has been documented (Taylor et al. 2017).

In addition, the study by Nault et al. (2018) documented several native monocotyledon and dicotyledon species that exhibited significant declines posttreatment. Specifically, northern watermilfoil (*Myriophyllum sibiricum*), slender naiad (*Najas flexilis*), water marigold (*Bidens beckii*), and several thin-leaved pondweeds (*Potamogeton pusillus*, *P. strictifolius*, *P. friesii* and *P. foliosus*) showed highly significant declines in the majority of the lakes monitored. In addition, variable/Illinois pondweed (*P. gramineus*/*P. illinoensis*), flat-stem pondweed (*P. zosteriformis*), fern pondweed (*P. robbinsii*), and sago pondweed (*Stuckenia pectinata*) also declined in many lakes. Ribbon-leaf pondweed (*P. epihydrus*) and water stargrass (*Heteranthera dubia*) declined in the lakes where they were found. Mixed effects of treatment were observed with water celery (*Vallisneria americana*) and southern naiad (*Najas guadalupensis*), with some lakes showing significant declines posttreatment and other lakes showing increases.

Since milfoil hybridity is a relatively new documented phenomenon (Moody and Les 2002), many of the early lab studies examining CET for milfoil control did not determine if they were examining pure Eurasian watermilfoil or hybrid watermilfoil (*M. spicatum* x *sibiricum*) strains. More recent laboratory and mesocosm studies have shown that certain strains of hybrid watermilfoil exhibit more aggressive growth and are less affected by 2,4-D (Glomski and Netherland 2010; LaRue et al. 2013; Netherland and Willey 2017; Taylor et al. 2017), while other studies have not seen differences in overall growth patterns or treatment efficacy when compared to pure Eurasian watermilfoil (Poovey et al. 2007). Differences between Eurasian and hybrid watermilfoil control following 2,4-D applications have also been documented in the field, with lower efficacy and shorter longevity of hybrid watermilfoil control when compared to pure Eurasian watermilfoil populations (Nault et al. 2018). Field studies conducted in the Menominee River Drainage in northeastern Wisconsin and upper peninsula of Michigan observed hybrid milfoil genotypes more frequently in lakes that had previous 2,4-D treatments, suggesting possible selection of more tolerant hybrid strains over time (LaRue 2012).

Fluridone

Registration and Formulations

Fluridone is an aquatic herbicide that was initially registered with the U.S. EPA in 1986. It is currently being evaluated for reregistration. The estimated registration review decision date was in 2014 (EPA Fluridone Plan 2010). The active ingredient is (1-methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone). Fluridone is available in both liquid and slow-release granular formulations.

Mode of Action and Degradation

Fluridone's mode of action is to reduce a plant's ability to protect itself from sun damage. The herbicide prevents the plant from making a protective pigment and as a result, sunlight causes the plant's chlorophyll to break down. Treated plants will turn white or pink at the growing tips a week after exposure and will begin to die one to two months after treatment (Madsen et al. 2002). Therefore, fluridone is only effective if plants are actively growing at the time of treatment. Effective use of fluridone requires low, sustained concentrations and a relatively long contact time (e.g., 45-90 days). Due to this requirement, fluridone is usually applied to an entire waterbody or basin. Some success has been demonstrated when additional follow-up 'bump' treatments are used to maintain the low concentrations over a long enough period of time to produce control. Fluridone has also been applied to riverine systems using a drip system to maintain adequate CET.

Following treatment, the amount of fluridone in the water is reduced through dilution and water movement, uptake by plants, adsorption to the sediments, and via breakdown caused by light and microbes. Fluridone is primarily degraded through photolysis (Saunders and Mosier 1983), while depth, water clarity and light penetration can influence degradation rates (Mossler et al. 1989; West et al. 1983). There are two major degradation products from fluridone: n-methyl formamide (NMF) and 3-trifluoromethyl benzoic acid.

The half-life of fluridone can be as short as several hours, or hundreds of days, depending on conditions (West et al. 1979; West et al. 1983; Langeland and Warner 1986; Fox et al. 1991, 1996; Jacob et al. 2016). Preliminary work on a seepage lake in Waushara County, WI detected fluridone in the water nearly 400 days following an initial application that was then augmented to maintain concentrations via a 'bump' treatment at 60 and 100 days later (Onterra 2017a). Light exposure is influential in controlling degradation rate, with a half-life ranging from 15 to 36 hours when exposed to the full spectrum of natural sunlight (Mossler et al. 1989). As light wavelength increases, the half-life increases too, indicating that season and timing may affect fluridone persistence. Fluridone half-life has been shown to be only slightly dependent on fluridone concentration, oxygen concentration, and pH (Saunders and Mosier 1983). One study found that the half-life of fluridone in water was slightly lower when the herbicide was applied to the surface of the water as opposed to a sub-surface application, suggesting that degradation may also be affected by mode of application (West and Parka 1981).

The persistence of herbicide in the sediment has been reported to be much longer than in the overlying water column, with studies showing persistence ranges from 3 months to a year in

sediments (Muir et al. 1980; Muir and Grift 1982; West et al. 1983). Persistence in soil is influenced by soil chemistry (Shea and Weber 1983; Mossler et al. 1993). Fluridone concentrations measured in sediments reach a maximum in one to four weeks after treatment and decline in four months to a year depending on environmental conditions. Fluridone adsorbs to clay and soils with high organic matter, especially in pellet form, and can reduce the concentration of fluridone in the water. Adsorption to the sediments is reversible; fluridone gradually dissipates back into the water where it is subject to chemical breakdown.
Some studies have shown variable release time of the herbicide among different granular fluridone products (Mossler et al. 1993; Koschnick et al. 2003; Bultemeier and Haller 2015). In addition, pelletized formulations may be more effective in sandy hydrosoils, while aqueous suspension formulations may be more appropriate for areas with high amounts of clay or organic matter (Mossler et al. 1993)

Toxicology

Fluridone does not appear to have short-term or long-term effects on fish at approved application rates, but fish exposed to water treated with fluridone do absorb fluridone into their tissues. However, fluridone has demonstrated a very low potential for bioconcentration in fish, zooplankton, and aquatic plants (McCowen et al. 1979; West et al. 1979; Muir et al. 1980; Paul et al. 1994). Fluridone concentrations in fish decrease as the herbicide disappears from the water. Studies on the effects of fluridone on aquatic invertebrates (e.g., midge and water flea) have shown increased mortality at label application rates (Hamelink et al. 1986; Yi et al. 2011). Studies on birds indicate that fluridone would not pose an acute or chronic risk to birds. In addition, no treatment related effects were noted in mice, rats, and dogs exposed to dietary doses. No studies have been published on amphibians or reptiles. There are no restrictions on swimming, eating fish from treated waterbodies, human drinking water or pet/livestock drinking water. Depending on the type of waterbody treated and the type of plant being watered, irrigation restrictions may apply for up to 30 days. There is some evidence that the fluridone degradation product NMF causes birth defects, though NMF has only been detected in the lab and not following actual fluridone treatments in the field, including those at maximum label rate (Osborne et al. 1989; West et al. 1990).

Species Susceptibility

Because fluridone treatments are often applied at a lakewide scale and many plant species are susceptible to fluridone, careful consideration should be given to potential non-target impacts and changes in water quality in response to treatment. Sustained native plant species declines and reductions in water clarity have been observed following fluridone treatments in field applications (O'Dell et al. 1995; Valley et al. 2006; Wagner et al. 2007; Parsons et al. 2009). However, reductions in water clarity are not always observed and can be avoided (Crowell et al. 2006). Additionally, the selective activity of fluridone is primarily rate-dependent based on analysis of pigments in nine aquatic plant species (Sprecher et al. 1998b).

Fluridone is most often used for control of invasive species such as Eurasian and hybrid watermilfoil (*Myriophyllum spicatum* x *sibiricum*), Brazilian waterweed (*Egeria densa*), and hydrilla (*Hydrilla verticillata*; Schmitz et al. 1987; MacDonald et al. 1993; Netherland et al. 1993;

Netherland and Getsinger 1995a, 1995b; Cockreham and Netherland 2000; Hofstra and Clayton 2001; Madsen et al. 2002; Netherland 2015). However, fluridone tolerance has been observed in some hydrilla and hybrid watermilfoil populations (Michel et al. 2004; Arias et al. 2005; Puri et al. 2006; Slade et al. 2007; Berger et al. 2012, 2015; Thum et al. 2012; Benoit and Les 2013; Netherland and Jones 2015). Fluridone has also been shown to affect flowering rush (*Butomus umbellatus*), fanwort (*Cabomba caroliniana*), buttercups (*Ranunculus* spp.), long-leaf pondweed (*Potamogeton nodosus*), Illinois pondweed (*P. illinoensis*), leafy pondweed (*P. foliosus*), flat-stem pondweed (*P. zosteriformis*), sago pondweed (*Stuckenia pectinata*), oxygen-weed (*Lagarosiphon major*), northern watermilfoil (*Myriophyllum sibiricum*), variable-leaf watermilfoil (*M. heterophyllum*), curly-leaf pondweed (*Potamogeton crispus*), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), southern naiad (*Najas guadalupensis*), slender naiad (*N. flexilis*), white waterlily (*Nymphaea odorata*), water marigold (*Bidens beckii*), duckweed (*Lemna* spp.), and watermeal (*Wolffia columbiana*) (Wells et al. 1986; Kay 1991; Farone and McNabb 1993; Netherland et al. 1997; Koschnick et al. 2003; Crowell et al. 2006; Wagner et al. 2007; Parsons et al. 2009; Cheshier et al. 2011; Madsen et al. 2016). Muskgrasses (*Chara* spp.), water celery (*Vallisneria americana*), cattails (*Typha* spp.), and willows (*Salix* spp.) have been shown to be somewhat tolerant of fluridone (Farone and McNabb 1993; Poovey et al. 2004; Crowell et al. 2006).

Large-scale fluridone treatments that targeted Eurasian and hybrid watermilfoils have been conducted in several Wisconsin lakes. Recently, five of these waterbodies treated with low-dose fluridone (2-4 ppb) have been tracked over time to understand herbicide dissipation and degradation patterns, as well as the efficacy, selectivity, and longevity of these treatments. These field trials resulted in a pre- vs. post-treatment decrease in the number of vegetated littoral zone sampling sites, with a 9-26% decrease observed following treatment (an average decrease in vegetated littoral zone sites of 17.4% across waterbodies). In four of the five waterbodies, substantial decreases in plant biomass (≥10% reductions in average total rake fullness) was documented at sites where plants occurred in both the year of and year after treatment. Good milfoil control was achieved, and long-term monitoring is ongoing to understand the longevity of target species control over time. However, non-target native plant populations were also observed to be negatively impacted in conjunction with these treatments, and long-term monitoring is ongoing to understand their recovery over time. Exposure times in the five waterbodies monitored were found to range from 320 to 539 days before falling below detectable limits. Data from these recent projects is currently being compiled and a compressive analysis and report is anticipated in the near future.

Endothall

Registration and Formulations

Endothall was registered with the U.S. EPA for aquatic use in 1960 and reregistered in 2005 (Menninger 2012). Endothall is the common name of the active ingredient endothal acid (7-oxabicyclo[2,2,1] heptane-2,3-dicarboxylic acid). Granular and liquid formulations are currently registered by EPA and DATCP. Endothall products are used to control a wide range of terrestrial and aquatic plants. Two types of endothall are available: dipotassium salt and dimethylalkylamine salt (“mono-N,N-dimethylalkylamine salt” or “monoamine salt”). The dimethylalkylamine salt form is toxic to fish and other aquatic organisms and is faster-acting than the dipotassium salt form.

Mode of Action and Degradation

Endothall is considered a contact herbicide that inhibits respiration, prevents the production of proteins and lipids, and disrupts the cellular membrane in plants (MacDonald et al. 1993; MacDonald et al. 2001; EPA RED Endothall 2005; Bajsa et al. 2012). Although typical rates of endothall application inhibit plant respiration, higher concentrations have been shown to increase respiration (MacDonald et al. 2001). The mode of action of endothall is unlike any other commercial herbicide. For effective control, endothall should be applied when plants are actively growing, and plants begin to weaken and die within a few days after application.

Uptake of endothall is increased at higher water temperatures and higher amounts of light (Haller and Sutton 1973). Netherland et al. (2000) found that while biomass reduction of curly-leaf pondweed (*Potamogeton crispus*) was greater at higher water temperature, reductions of turion production were much greater when curly-leaf pondweed was treated a lower water temperature (18 °C vs 25 °C).

Degradation of endothall is primarily microbial (Sikka and Saxena 1973) and half-life of the dipotassium salt formulations is between 4 to 10 days (Reinert and Rodgers 1987; Reynolds 1992), although dissipation due to water movement may significantly shorten the effective half-life in some treatment scenarios. Half of the active ingredient from granular endothall formulations has been shown to be released within 1-5 hours under conditions that included water movement (Reinert et al. 1985; Bultemeier and Haller 2015). Endothall is highly water soluble and does not readily adsorb to sediments or lipids (Sprecher et al. 2002; Reinert and Rodgers 1984). Degradation from sunlight or hydrolysis is very low (Sprecher et al. 2002). The degradation rate of endothall has been shown to increase with increasing water temperature (UPI, *unpublished data*). The degradation rate is also highly variable across aquatic systems and is much slower under anaerobic conditions (Simsiman and Chesters 1975). Relative to other herbicides, endothall is unique in that is comprised of carbon, hydrogen, and oxygen with the addition of potassium and nitrogen in the dipotassium and dimethylalkylamine formulations, respectively. This allows for complete breakdown of the herbicide without additional intermediate breakdown products (Sprecher et al. 2002).

Toxicology

All endothall products have a drinking water standard of 0.1 ppm and cannot be applied within 600 feet of a potable water intake. Use restrictions for dimethylalkylamine salt formulations have additional irrigation and aquatic life restrictions.

Dipotassium salt formulations

At recommended rates, the dipotassium salt formulations appear to have few short-term behavioral or reproductive effects on bluegill (*Lepomis macrochirus*) or largemouth bass (*Micropterus salmoides;* Serns 1977; Bettolli and Clark 1992; Maceina et al. 2008). Bioaccumulation of dipotassium salt formulations by fish from water treated with the herbicide is unlikely, with studies showing less than 1% of endothall being taken up by bluegill (Sikka et al. 1975; Serns 1977). In addition, studies have shown the dipotassium salt formulation induces no significant adverse effects on aquatic invertebrates when used at label application rates (Serns 1975; Williams et al. 1984). A freshwater mussel species was found to be more sensitive to dipotassium salt endothall than other invertebrate species tested, but significant acute toxicity was still only found at concentrations well above the maximum label rate. However, as with other plant control approaches, some aquatic plant-dwelling populations of aquatic organisms may be adversely affected by application of endothall formulations due to habitat loss.

During EPA reregistration of endothall in 2005, it was required that product labels state that lower rates of endothall should be used when treating large areas, "such as coves where reduced water movement will not result in rapid dilution of the herbicide from the target treatment area or when treating entire lakes or ponds."

Dimethylalkylamine salt formulations

In contrast to the respective low to slight toxicity of the dipotassium salt formulations to fish and aquatic invertebrates, laboratory studies have shown the dimethylalkylamine formulations are toxic to fish and macroinvertebrates at concentrations above 0.3 ppm. In particular, the liquid formulation will readily kill fish present in a treatment site. Product labels for the dimethylalkylamine salt formulations recommend no treatment where fish are an important resource.

The dimethylalkylamine formulations are more active on aquatic plants than the dipotassium formulations, but also are 2-3 orders of magnitude more toxic to non-target aquatic organisms (EPA RED Endothall 2005; Keckemet 1969). The 2005 reregistration decision document limits aquatic use of the dimethylalkylamine formulations to algae, Indian swampweed (*Hygrophila polysperma*), water celery (*Vallisneria americana*), hydrilla (*Hydrilla verticillata*), fanwort (*Cabomba caroliniana*), bur reed (*Sparganium* sp.), common waterweed (*Elodea canadensis*), and Brazilian waterweed (*Egeria densa*). Coontail (*Ceratophyllum demersum*), watermilfoils (*Myriophyllum* spp.), naiads (*Najas* spp.), pondweeds (*Potamogeton* spp.), water stargrass (*Heteranthera dubia*), and horned pondweed (*Zannichellia palustris*) were to be removed from product labels (EPA RED Endothall 2005).

<u>Species Susceptibility</u>

According to the herbicide label, the maximum target concentration of endothall is 5000 ppb (5.0 ppm) acid equivalent (ae). Endothall is used to control a wide range of submersed species, including non-native species such as curly-leaf pondweed and Eurasian watermilfoil (*Myriophyllum spicatum*). The effects of the different formulations of endothall on various species of aquatic plants are discussed below.

Dipotassium salt formulations

At least one mesocosm or lab study has shown that endothall (at or below the maximum label rate) will control the invasive species hydrilla (Netherland et al. 1991; Wells and Clayton 1993; Hofstra and Clayton 2001; Pennington et al. 2001; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Netherland and Haller 2006; Poovey and Getsinger 2010), oxygen-weed (*Lagarosiphon major*; Wells and Clayton 1993; Hofstra and Clayton 2001), Eurasian watermilfoil (Netherland et al. 1991; Skogerboe and Getsinger 2002; Mudge and Theel 2011), water lettuce (*Pistia stratiotes*; Conant et al. 1998), curly-leaf pondweed (Yeo 1970), and giant salvinia (*Salvinia molesta*; Nelson et al. 2001). Wersal and Madsen (2010a) found that parrot feather (*Myriophyllum aquaticum*) control with endothall was less than 40% even with two days of exposure time at the maximum label rate. Endothall was shown to control the shoots of flowering rush (*Butomus umbellatus*), but control of the roots was variable (Poovey et al. 2012; Poovey et al. 2013). One study found that endothall did not significantly affect photosynthesis in fanwort with 6 days of exposure at 2.12 ppm ae (2120 ppb ae; Bultemeier et al. 2009). Large-scale, low-dose endothall treatments were found to reduce curly-leaf pondweed frequency, biomass, and turion production substantially in Minnesota lakes, particularly in the first 2-3 years of treatments (Johnson et al. 2012).

Native species that were significantly impacted (at or below the maximum endothall label rate in at least one mesocosm or lab study) include coontail (Yeo 1970; Hofstra and Clayton 2001; Hofstra et al. 2001; Skogerboe and Getsinger 2002; Wells and Clayton 1993; Mudge 2013), southern naiad (*Najas guadalupensis*; Yeo 1970; Skogerboe and Getsinger 2001), white waterlily (*Nymphaea odorata*; Skogerboe and Getsinger 2001), leafy pondweed (*Potamogeton foliosus*; Yeo 1970), Illinois pondweed (*Potamogeton illinoensis*; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Skogerboe and Getsinger 2002; Mudge 2013), long-leaf pondweed (*Potamogeton nodosus*; Yeo 1970; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Mudge 2013), small pondweed (*P. pusillus*; Yeo 1970), broadleaf arrowhead (*Sagittaria latifolia*; Skogerboe and Getsinger 2001), sago pondweed (*Stuckenia pectinata*; Yeo 1970; Sprecher et al. 1998a; Skogerboe and Getsinger 2002; Slade et al. 2008), water celery (*Vallisneria americana*; Skogerboe and Getsinger 2001; Skogerboe and Getsinger 2002; Shearer and Nelson 2002; Mudge 2013), and horned pondweed (Yeo 1970; Gyselinck and Courter 2015).

Species which were not significantly impacted or which recovered quickly include watershield (*Brasenia schreberi*; Skogerboe and Getsinger 2001), muskgrasses (*Chara* spp.; Yeo 1970; Wells and Clayton 1993; Hofstra and Clayton 2001), common waterweed (Yeo 1970; Wells and Clayton 1993; Skogerboe and Getsinger 2002), water stargrass (Skogerboe and Getsinger 2001), water net (*Hydrodictyon reticulatum*; Wells and Clayton 1993), the freshwater macroalgae *Nitella clavata* (Yeo 1970), yellow pond-lily (*Nuphar advena*; Skogerboe and Getsinger 2002), swamp smartweed (*Polygonum hydropiperoides*; Skogerboe and Getsinger 2002), pickerelweed (*Pontederia cordata*; Skogerboe and Getsinger 2001), softstem bulrush (*Schoenoplectus tabernaemontani*; Skogerboe and Getsinger 2001), and broadleaf cattail (*Typha latifolia*; Skogerboe and Getsinger 2002).

Field trials mirror the species susceptibility above and in addition show that endothall also can impact several high-value pondweed species (*Potamogeton* spp.), including large-leaf pondweed (*P. amplifolius*; Parsons et al. 2004), fern pondweed (*P. robbinsii*; Onterra 2015; Onterra 2018), white-stem pondweed (*P. praelongus*; Onterra 2018), small pondweed (Big Chetac Chain Lake Association 2016; Onterra 2018), clasping-leaf pondweed (*P. richardsonii*; Onterra 2018), and flat-stem pondweed (*P. zosteriformis*; Onterra 2017b).

Dimethylalkylamine salt formulations

The dimethylalkylamine formulations are more active on aquatic plants than the dipotassium formulations (EPA RED Endothall 2005; Keckemet 1969). At least one mesocosm study has shown that dimethylalkylamine formulation of endothall (at or below the maximum label rate) will control the invasive species fanwort (Hunt et al. 2015) and the native species common waterweed (Mudge et al. 2015), while others have shown that the dipotassium formulation does not control these species well.

Imazamox

Registration and Formulations

Imazamox is the common name of the active ingredient ammonium salt of imazamox (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-(methoxymethl)-3-pyridinecarboxylic acid. It was registered with U.S. EPA in 2008 and is currently under registration review with an estimated registration decision between 2019 and 2020 (EPA Imazamox Plan 2014). In aquatic environments, a liquid formulation is typically applied to submerged vegetation by broadcast spray or underwater hose application and to emergent or floating leaf vegetation by broadcast spray or foliar application. There is also a granular formulation.

Mode of Action and Degradation

Imazamox is a systemic herbicide that moves throughout the plant tissue and prevents plants from producing a necessary enzyme, acetolactate synthase (ALS), which is not found in animals. Susceptible plants will stop growing soon after treatment, but plant death and decomposition will occur over several weeks (Mudge and Netherland 2014). If used as a post-emergence herbicide, imazamox should be applied to plants that are actively growing. Resistance to ALS-inhibiting herbicides has appeared in weeds at a higher rate than other herbicide types in terrestrial environments (Tranel and Wright 2002).

Dissipation studies in lakes indicate a half-life ranging from 4 to 49 days with an average of 17 days. Herbicide breakdown does not occur readily in deep, poorly-oxygenated water where there is no light. In this part of a lake, imazamox will tend to bind to sediments rather than breaking down, with a half-life of approximately 2 years. Once in soil, leaching to groundwater is believed to be very limited. The breakdown products of imazamox are nicotinic acid and di- and tricarboxylic acids. It has been suggested that photolytic break down of imazamox is faster than other herbicides, reducing exposure times. However, short-term imazamox exposures have also been associated with extended regrowth times relative to other herbicides (Netherland 2011).

Toxicology

Treated water may be used immediately following application for fishing, swimming, cooking, bathing, and watering livestock. If water is to be used as potable water or for irrigation, the tolerance is 0.05 ppm (50 ppb), and a 24-hour irrigation restriction may apply depending on the waterbody. None of the breakdown products are herbicidal nor suggest concerns for aquatic organisms or human health.

Most concerns about adverse effects on human health involve applicator exposure. Concentrated imazamox can cause eye and skin irritation and is harmful if inhaled. Applicators should minimize exposure by wearing long-sleeved shirts and pants, rubber gloves, and shoes and socks.

Honeybees are affected at application rates so drift during application should be minimized. Laboratory tests using rainbow trout (*Oncorhynchus mykiss*), bluegill (*Lepomis macrochirus*), and water fleas (*Daphnia magna*) indicate that imazamox is not toxic to these species at label application rates.

Imazamox is rated "practically non-toxic" to fish and aquatic invertebrates and does not bioaccumulate in fish. Additional studies on birds indicate toxicity only at dosages that exceed approved application rates.

In chronic tests, imazamox was not shown to cause tumors, birth defects or reproductive toxicity in test animals. Most studies show no evidence of mutagenicity. Imazamox is not metabolized and was excreted by mammals tested. Based on its low acute toxicity to mammals, and its rapid disappearance from the water column due to light and microbial degradation and binding to soil, imazamox is not considered to pose a risk to recreational water users.

<u>Species Susceptibility</u>

In Wisconsin, imazamox is used for treating non-native emergent vegetation such as non-native phragmites (*Phragmites australis* subsp. *australis*) and flowering rush (*Butomus umbellatus*). Imazamox may also be used to treat the invasive curly-leaf pondweed (*Potamogeton crispus*). Desirable native species that may be affected could include other pondweed species (long-leaf pondweed (*P. nodosus*), flat-stem pondweed (*P. zosteriformis*), leafy pondweed (*P. foliosus*), Illinois pondweed (*P. illinoensis*), small pondweed (*P. pusillus*), variable-leaf pondweed (*P. gramineus*), water-thread pondweed (*P. diversifolius*), perfoliate pondweed (*P. perfoliatus*), large-leaf pondweed (*P. amplifolius*), watershield (*Brasenia schreberi*), and some bladderworts (*Utricularia* spp.). Higher rates of imazamox will control Eurasian watermilfoil (*Myriophyllum spicatum*) but would also have greater non-target impacts on native plants. Imazamox can also be used during a drawdown to prevent plant regrowth and on emergent vegetation.

At low concentrations, imazamox can cause growth regulation rather than mortality in some plant species. This has been shown for non-native phragmites and hydrilla (*Hydrilla verticillata*; Netherland 2011; Cheshier et al. 2012; Theel et al. 2012). In the case of hydrilla, some have suggested that this effect could be used to maintain habitat complexity while providing some target species control (Theel et al. 2012). Imazamox can reduce biomass of non-native phragmites though some studies found regrowth to occur, suggesting a combination of imazapyr and glyphosate to be more effective (Cheshier et al. 2012; Knezevic et al. 2013).

Some level of control of imazamox has also been reported for water hyacinth (*Eichhornia crassipes*), parrot feather (*Myriophyllum aquaticum*), Japanese stiltgrass (*Microstegium* *vimineum*), water lettuce (*Pistia stratiotes*), and southern cattail (*Typha domingensis*; Emerine et al. 2010; de Campos et al. 2012; Rodgers and Black 2012; Hall et al. 2014; Mudge and Netherland 2014). Imazamox was observed to have greater efficacy in controlling floating plants than emergents in a study of six aquatic plant species, including water hyacinth, water lettuce, parrot feather, and giant salvinia (*Salvinia molesta*; Emerine et al. 2010). Non-target effects have been observed for softstem bulrush (*Schoenoplectus tabernaemontani*), pickerelweed (*Pontederia cordata*), and the native pondweeds long-leaf pondweed, Illinois pondweed, and coontail (*Ceratophyllum demersum*; Koschnick et al. 2007; Mudge 2013). Giant salvinia, white waterlily (*Nymphaea odorata*), bog smartweed (*Polygonum setaceum*), giant bulrush (*Schoenoplectus californicus*), water celery (*Vallisneria americana*; though the root biomass of wide-leaf *Vallisneria* may be reduced), and several algal species have been found by multiple studies to be unaffected by imazamox (Netherland et al. 2009; Emerine et al. 2010; Rodgers and Black 2012; Mudge 2013; Mudge and Netherland 2014). Other species are likely to be susceptible, for which the effects of imazamox have not yet been evaluated.

Florpyrauxifen-benzyl

Registration and Formulations

Florpyrauxifen-benzyl is a relatively new herbicide, which was first registered with the U.S. EPA in September 2017. The active ingredient is 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester, also identified as florpyrauxifen-benzyl. Florpyrauxifen-benzyl is used for submerged, floating, and emergent aquatic plant control (e.g., ProcellaCORTM) in slow-moving and quiescent waters, as well as for broad spectrum weed control in rice (*Oryza sativa*) culture systems and other crops (e.g., RinskorTM).

Mode of Action and Degradation

Florpyrauxifen-benzyl is a member of a new class of synthetic auxins, the arylpicolinates, that differ in binding affinity compared to other currently registered synthetic auxins such as 2,4-D and triclopyr (Bell et al. 2015). Florpyrauxifen-benzyl is a systemic herbicide (Heilman et al. 2017).

Laboratory studies and preliminary field dissipation studies indicate that florpyrauxifen-benzyl in water is subject to rapid photolysis (Heilman et al. 2017). In addition, the herbicide can also convert partially via hydrolysis to an acid form at high pH (>9) and higher water temperatures (>25°C), and microbial activity in the water and sediment can also enhance degradation (Heilman et al. 2017). The acid form is noted to have reduced herbicidal activity (Netherland and Richardson 2016; Richardson et al. 2016). Under growth chamber conditions, water samples at 1 DAT found that 44-59% of the applied herbicide had converted to acid form, while sampling at 7 and 14 DAT indicated that all the herbicide had converted to acid form (Netherland and Richardson 2016). The herbicide is short-lived, with half-lives ranging from 4 to 6 days in aerobic aquatic environments, and 2 days in anaerobic aquatic environments (WSDE 2017). Degradation in surface water is accelerated when exposed to sunlight, with a reported photolytic half-life in laboratory testing of 0.07 days (WSDE 2017).

There is some anecdotal evidence that initial water temperature and/or pH may impact the efficacy of florpyrauxifen-benzyl (Beets and Netherland 2018). Florpyrauxifen-benzyl has a high soil adsorption coefficient (KOC) and low volatility, which allows for rapid plant uptake resulting in short exposure time requirements (Heilman et al. 2017). Florpyrauxifen-benzyl degrades quickly (2-15 days) in soil and sediment (Netherland et al. 2016). Few studies have yet been completed for groundwater, but based on known environmental properties, florpyrauxifen-benzyl is not expected to be associated with potential environmental impacts in groundwater (WSDE 2017).

Toxicology

No adverse human health effects were observed in toxicological studies submitted for EPA herbicide registration, regardless of the route of exposure (Heilman et al. 2017). There are no drinking water or recreational use restrictions, including swimming and fishing. There are no restrictions on irrigating turf, and a short waiting period (dependent on application rate) for other non-agricultural irrigation purposes.

Florpyrauxifen-benzyl showed a good environmental profile for use in water, and is “practically non-toxic” to birds, bees, reptiles, amphibians, and mammals (Heilman et al. 2017). No ecotoxicological effects were observed on freshwater mussel or juvenile chinook salmon (Heilman et al. 2017). Florpyrauxifen-benzyl will temporarily bioaccumulate in freshwater organisms but is rapidly depurated and/or metabolized within 1 to 3 days after exposure to high (>150 ppb) concentrations (WSDE 2017).

An LC50 value indicates the concentration of a chemical required to kill 50% of a test population of organisms. LC50 values are commonly used to describe the toxicity of a substance. Label recommendations for milfoils do not exceed 9.65 ppb and the maximum label rate for an acre-foot of water is 48.25 ppb. Acute toxicity results using rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*), and sheepshead minnows (*Cyprinodon variegatus variegatus*) indicated LC50 values of greater than 49 ppb, 41 ppb, and 40 ppb, respectively when exposed to the technical grade active ingredient (WSDE 2017). An LC50 value of greater than 1,900 ppb was reported for common carp (*Cyprinus carpio*) exposed to the ProcellaCOR end-use formulation (WSDE 2017).

Acute toxicity results for the technical grade active ingredient using water flea (*Daphnia magna*) and midge (*Chironomus* sp.) indicated LC50 values of greater than 62 ppb and 60 ppb, respectively (WSDE 2017). Comparable acute ecotoxicity testing performed on *D. magna* using the ProcellaCOR end-use formulation indicated an LC50 value of greater than 8 ppm (80,000 ppb; WSDE 2017).

The ecotoxicological no observed effect concentration (NOEC) for various organisms as reported by Netherland et al. (2016) are: fish (>515 ppb ai), water flea (*Daphnia* spp.; >21440 ppb ai), freshwater mussels (>1023 ppb ai), saltwater mysid (>362 ppb ai), saltwater oyster (>289 ppb ai), and green algae (>480 ppb ai). Additional details on currently available ecotoxicological information is compiled by WSDE (2017).

Species Susceptibility

Florpyrauxifen-benzyl is a labeled for control of invasive watermilfoils (e.g., Eurasian watermilfoil (*Myriophyllum spicatum*), hybrid watermilfoil (*M. spicatum* x *sibiricum*), parrot feather (*M. aquaticum*)), hydrilla (*Hydrilla verticillata*), and other non-native floating plants such as floating hearts (*Nymphoides* spp.), water hyacinth (*Eichhornia crassipes*), and water chestnut (*Trapa natans*; Netherland and Richardson 2016; Richardson et al. 2016). Natives species listed on the product label as susceptible to florpyrauxifen-benzyl include coontail (*Ceratophyllum demersum*; Heilman et al. 2017), watershield (*Brasenia schreberi*), and American lotus (*Nelumbo lutea*). In laboratory settings, pickerelweed (*Pontederia cordata*) vegetation has also been shown to be affected (Beets and Netherland 2018).

Based on available data, florpyrauxifen-benzyl appears to show few impacts to native aquatic plants such as aquatic grasses, bulrush (*Schoenoplectus* spp.), cattail (*Typha* spp.), pondweeds (*Potamogeton* spp.), naiads (*Najas* spp.), and water celery (*Vallisneria americana*; WSDE 2017). Laboratory and mesocosm studies also found water marigold (*Bidens beckii*), white waterlily (*Nymphaea odorata*), common waterweed (*Elodea canadensis*), water stargrass (*Heteranthera dubia*), long-leaf pondweed (*Potamogeton nodosus*), and Illinois pondweed (*P. illinoensis*) to be relatively less sensitive to florpyrauxifen-benzyl than labeled species (Netherland et al. 2016; Netherland and Richardson 2016). Non-native fanwort (*Cabomba caroliniana*) was also found to be tolerant in laboratory study (Richardson et al. 2016).

Since florpyrauxifen-benzyl is a relatively new approved herbicide, detailed information on field applications is very limited. Trials in small waterbodies have shown control of parrot feather (*Myriophyllum aquaticum*), variable-leaf watermilfoil (*M. heterophyllum*), and yellow floating heart (*Nymphoides peltata*; Heilman et al. 2017).

S.3.3.3. Emergent and Wetland Herbicides

Glyphosate

Registration and Formulations

Glyphosate is a commonly used herbicide that is utilized in both aquatic and terrestrial sites. It was first registered for use in 1974. EPA is currently re-evaluating glyphosate and the registration decision was expected in 2014 (EPA Glyphosate Plan 2009). The use of glyphosate-based herbicides in aquatic environments that are not approved for aquatic use is very unsafe and is a violation of federal and state pesticide laws. Different formulations of glyphosate are available, including isopropylamine salt of glyphosate and potassium glyphosate.

Glyphosate is effective only on plants that grow above the water and needs to be applied to plants that are actively growing. It will not be effective on plants that are submerged or have most of their foliage underwater, nor will it control regrowth from seed.

Mode of Action and Degradation

Glyphosate is a systemic herbicide that moves throughout the plant tissue and works by inhibiting an important enzyme needed for multiple plant processes, including growth. Following treatment, plants will gradually wilt, appear yellow, and will die in approximately 2 to 7 days. It may take up to 30 days for these effects to become apparent for woody species.

Application should be avoided when heavy rain is predicted within 6 hours. To avoid drift, application is not recommended when winds exceed 5 mph. In addition, excessive speed or pressure during application may allow spray to drift and must be avoided. Effectiveness of glyphosate treatments may be reduced if applied when plants are growing poorly, such as due to drought stress, disease, or insect damage. A surfactant approved for aquatic sites must be mixed with glyphosate before application.

In water, the concentration of glyphosate is reduced through dispersal by water movement, binding to the sediments, and break-down by microorganisms. The half-life of glyphosate is between 3 and 133 days, depending on water conditions. Glyphosate disperses rapidly in water so dilution occurs quickly, thus moving water will decrease concentration, but not half-life. The primary breakdown product of glyphosate is aminomethylphosphonic acid (AMPA), which is also degraded by microbes in water and soil.

Toxicology

Most aquatic forms of glyphosate have no restrictions on swimming or eating fish from treated waterbodies. However, potable water intakes within ½ mile of application must be turned off for 48 hours after treatment. Different formulations and products containing glyphosate may vary in post-treatment water use restrictions.

Most glyphosate-related health concerns for humans involve applicator exposure, exposure through drift, and the surfactant exposure. Some adverse effects from direct contact with the herbicide include temporary symptoms of dermatitis, eye ailments, headaches, dizziness, and nausea. Protective clothing (goggles, a face shield, chemical resistant gloves, aprons, and footwear) should be worn by applicators to reduce exposure. Recently it has been demonstrated that terrestrial formulations of glyphosate can have toxic effects to human embryonic cells and linked to endocrine disruption (Benachour et al. 2007; Gasnier et al. 2009).

Laboratory testing indicates that glyphosate is toxic to carp (*Cyprinus* spp.), bluegills (*Lepomis macrochirus*), rainbow trout (*Oncorhynchus mykiss*), and water fleas (*Daphnia* spp.) only at dosages well above the label application rates. Similarly, it is rated "practically non-toxic" to other aquatic species tested. Studies by other researchers examining the effects of glyphosate on important food chain organisms such as midge larvae, mayfly nymphs, and scuds have demonstrated a wide margin of safety between application rates.

EPA data suggest that toxicological effects of the AMPA compound are similar to that of glyphosate itself. Glyphosate also contains a nitrosamine (n-nitroso-glyphosate) as a contaminant at levels of 0.1 ppm or less. Tests to determine the potential health risks of nitrosamines are not required by the EPA unless the level exceeds 1.0 ppm.

Species Susceptibility

Glyphosate is only effective on actively growing plants that grow above the water's surface. It can be used to control reed canary grass (*Phalaris arundinacea*), cattails (*Typha* spp.; Linz et al. 1992; Messersmith et al. 1992), purple loosestrife (*Lythrum salicaria*), phragmites (*Phragmites australis* subsp. *australis*; Back and Holomuzki 2008; True et al. 2010; Back et al. 2012; Cheshier et al. 2012), water hyacinth (*Eichhornia crassipes*; Lopez 1993; Jadhav et al. 2008), water lettuce (*Pistia stratiotes*; Mudge and Netherland 2014), water chestnut (*Trapa natans*; Rector et al. 2015), Japanese stiltgrass (*Microstegium vimineum*; Hall et al. 2014), giant reed (*Arundo donax*; Spencer 2014), and perennial pepperweed (*Lepidium latifolium*; Boyer and Burdick 2010). Glyphosate will also reduce abundance of white waterlily (*Nymphaea odorata*) and pond-lilies (*Nuphar* spp.; Riemer and Welker 1974). Purple loosestrife biocontrol beetle (*Galerucella calmariensis*) oviposition and survival have been shown not to be affected by integrated management with glyphosate. Studies have found pickerelweed (*Pontederia cordata*) and floating marsh pennywort (*Hydrocotyle ranunculoides*) to be somewhat tolerant to glyphosate (Newman and Dawson 1999; Gettys and Sutton 2004).

Imazapyr

Registration and Formulations

Imazapyr was registered with the U.S. EPA for aquatic use in 2003 and is currently under registration review. It was estimated to have a registration review decision in 2017 (EPA Imazapyr Plan 2014). The active ingredient is isopropylamine salt of imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid). Imazapyr is used for control of emergent and floating-leaf vegetation. It is not recommended for control of submersed vegetation.

Mode of Action and Degradation

Imazapyr is a systemic herbicide that moves throughout the plant tissue and prevents plants from producing a necessary enzyme, acetolactate synthase (ALS), which is not found in animals. Susceptible plants will stop growing soon after treatment and become reddish at the tips of the plant. Plant death and decomposition will occur gradually over several weeks to months. Imazapyr should be applied to plants that are actively growing. If applied to mature plants, a higher concentration of herbicide and a longer contact time will be required.

Imazapyr is broken down in the water by light and has a half-life ranging from three to five days. Three degradation products are created as imazapyr breaks down: pyridine hydroxy-dicarboxylic acid, pyridine dicarboxylic acid (quinolinic acid), and nicotinic acid. These degradates persist in water for approximately the same amount of time as imazapyr (half-lives of three to eight days). In soils imazapyr is broken down by microbes, rather than light, and persists with a half-life of one to five months (Boyer and Burdick 2010). Imazapyr doesn't bind to sediments, so leaching through soil into groundwater is likely.

Toxicology

There are no restrictions on recreational use of treated water, including swimming and eating fish from treated waterbodies. If application occurs within a ½ mile of a drinking water intake, then the intake must be shut off for 48 hours following treatment. There is a 120-day irrigation restriction for treated water, but irrigation can begin sooner if the concentration falls below 0.001 ppm (1 ppb). Imazapyr degradates are no more toxic than imazapyr itself and are excreted faster than imazapyr when ingested.

Concentrated imazapyr has low acute toxicity on the skin or if ingested but is harmful if inhaled and may cause irreversible damage if it gets in the eyes. Applicators should wear chemical-resistant gloves while handling, and persons not involved in application should avoid the treatment area during treatment. Chronic toxicity tests for imazapyr indicate that it is not carcinogenic, mutagenic, or neurotoxic. It also does not cause reproductive or developmental toxicity and is not a suspected endocrine disrupter.

Imazapyr is "practically non-toxic" to fish, invertebrates, birds and mammals. Studies have also shown imazapyr to be "practically non-toxic" to "slightly toxic" to tadpoles and juvenile frogs (Trumbo and Waligora 2009; Yahnke et al. 2013). Toxicity tests have not been published on reptiles. Imazapyr does not bioaccumulate in animal tissues.

Species Susceptibility

The imazapyr herbicide label is listed to control the invasive plants phragmites (*Phragmites australis* subsp. *australis*), purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phalaris arundinacea*), non-native cattails (*Typha* spp.) and Japanese knotweed (*Fallopia japonica*) in Wisconsin. Native species that are also controlled include cattails (*Typha* spp.), waterlilies (*Nymphaea* sp.), pickerelweed (*Pontederia cordata*), duckweeds (*Lemna* spp.), and arrowhead (*Sagittaria* spp.).

Studies have shown imazapyr to effectively control giant reed (*Arundo donax*), water hyacinth (*Eichhornia crassipes*), manyflower marsh-pennywort (*Hydrocotyle umbellata*); yellow iris (*Iris pseudacorus*), water lettuce (*Pistia stratiotes*), perennial pepperweed (*Lepidium latifolium*), Japanese stiltgrass (*Microstegium vimineum*), parrot feather (*Myriophyllum aquaticum*), and cattails (Boyer and Burdick 2010; True et al. 2010; Back et al. 2012; Cheshier et al. 2012; Whitcraft and Grewell 2012; Hall et al. 2014; Spencer 2014; Cruz et al. 2015; DiTomaso and Kyser 2016). Giant salvinia (*Salvinia molesta*) was found to be imazapyr-tolerant (Nelson et al. 2001).

S.3.3.4. Herbicides Used for Submersed and Emergent Plants

Triclopyr

Registration and Formulations

Triclopyr was initially registered with the U.S. EPA in 1979, reregistered in 1997, and is currently under review with an estimated registration review decision in 2019 (EPA Triclopyr Plan 2014). There are two forms of triclopyr used commercially as herbicides: the triethylamine salt (TEA) and the butoxyethyl ester (BEE). BEE formulations are considered highly toxic to aquatic organisms, with observed lethal effects on fish (Kreutzweiser et al. 1994) as well as avoidance behavior and growth impairment in amphibians (Wojtaszek et al. 2005). The active ingredient triethylamine salt (3,5,6-trichloro-2-pyridinyloxyacetic acid) is the formulation registered for use in aquatic systems. It is sold both in liquid and granular forms for control of submerged, emergent, and floating-leaf vegetation. There is also a liquid premixed formulation that contains triclopyr and 2,4-D, which when combined together are reported to have synergistic impacts. Only triclopyr products labeled for use in aquatic environments may be used to control aquatic plants.

Mode of Action and Degradation

Triclopyr is a systemic plant growth regulator that is believed to selectively act on broadleaf (dicot) and woody plants. Following treatment, triclopyr is taken up through the roots, stems and leaf tissues, plant growth becomes abnormal and twisted, and plants die within one to two weeks after application (Getsinger et al. 2000). Triclopyr is somewhat persistent and can move through soil, although only mobile enough to permeate top soil layers and likely not mobile enough to potentially contaminate groundwater (Lee et al. 1986; Morris et al. 1987; Stephenson et al. 1990).

Triclopyr is broken down rapidly by light (photolysis) and microbes, while hydrolysis is not a significant route of degradation. Triclopyr photodegrades and is further metabolized to carbon dioxide, water, and various organic acids by aquatic organisms (McCall and Gavit 1986). It has been hypothesized that the major mechanism for the removal of triclopyr from the aquatic environment is microbial degradation, though the role of photolysis likely remains important in near-surface and shallow waters (Petty et al. 2001). Degradation of triclopyr by microbial action is slowed in the absence of light (Petty et al. 2003). Triclopyr is very slowly degraded under anaerobic conditions, with a reported half-life (the time it takes for half of the active ingredient to degrade) of about 3.5 years (Laskowski and Bidlack 1984). Another study of triclopyr under aerobic aquatic conditions yielded a half-life of 4.7 months (Woodburn and Cranor 1987). The initial breakdown products of triclopyr are TCP (3,5,6-trichloro-2-pyridinol) and TMP (3,5,6-trichloro-2-methoxypridine).

Several studies reported triclopyr half-lives between 0.5-7.5 days (Woodburn et al. 1993; Getsinger et al. 2000; Petty et al. 2001; Petty et al. 2003). Two large-scale, low-dose treatments were reported to have longer triclopyr half-lives from 3.7-12.1 days (Netherland and Jones 2015). Triclopyr half-lives have been shown to range from 3.4 days in plants, 2.8-5.8 days in sediment, up to 11 days in fish tissue, and 11.5 days in crayfish (Woodburn et al. 1993; Getsinger et al. 2000; Petty et al. 2003). TMP and TCP may have longer half-lives than triclopyr, with higher levels in bottom-feeding fish and the inedible parts of fish (Getsinger et al. 2000).

Toxicology

Based upon the triclopyr herbicide label, there are no restrictions on swimming, eating fish from treated waterbodies, or pet/livestock drinking water use. Before treated water can be used for irrigation, the concentration must be below 0.001 ppm (1 ppb), or at least 120 days must pass. Treated water should not be used for drinking water until concentrations of triclopyr are less than

0.4 ppm (400 ppb). There is a least one case of direct human ingestion of triclopyr TEA which resulted in metabolic acidosis and coma with cardiovascular impairment (Kyong et al. 2010).

There are substantial differences in toxicity of BEE and TEA, with the BEE shown to be more toxic in aquatic settings. BEE formulations are considered highly toxic to aquatic organisms, with observed lethal effects on fish (Kreutzweiser et al. 1994) as well as avoidance behavior and growth impairment in amphibians (Wojtaszek et al. 2005). Triclopyr TEA is "practically non-toxic" to freshwater fish and invertebrates (Mayes et al. 1984; Gersich et al. 1984). It ranges from "practically non-toxic" to "slightly toxic" to birds (EPA Triclopyr RED 1998). TCP and TMP appear to be slightly more toxic to aquatic organisms than triclopyr; however, the peak concentration of these degradates is low following treatment and depurates from organisms readily, so that they are not believed to pose a concern to aquatic organisms.

Species susceptibility

Triclopyr has been used to control Eurasian watermilfoil (*Myriophyllum spicatum*) and hybrid watermilfoil (*M. spicatum* x *sibiricum*) at both small- and large-scales (Netherland and Getsinger 1992; Getsinger et al. 1997; Poovey et al. 2004; Poovey et al. 2007; Nelson and Shearer 2008; Heilman et al. 2009; Glomski and Netherland 2010; Netherland and Glomski 2014; Netherland and Jones 2015). Getsinger et al. (2000) found that peak triclopyr accumulation was higher in Eurasian watermilfoil than flat-stem pondweed (*Potamogeton zosteriformis*), indicating triclopyr's affinity for Eurasian watermilfoil as a target species.

According to product labels, triclopyr is capable of controlling or affecting many emergent woody plant species, purple loosestrife (*Lythrum salicaria*), phragmites (*Phragmites australis* subsp. *australis*), American lotus (*Nelumbo lutea*), milfoils (*Myriophyllum* spp.), and many others. Triclopyr application has resulted in reduced frequency of occurrence, reduced biomass, or growth regulation for the following species: common waterweed (*Elodea canadensis*), water stargrass (*Heteranthera dubia*), white waterlily (*Nymphaea odorata*), purple loosestrife, Eurasian watermilfoil, parrot feather (*Myriophyllum aquaticum*), variable-leaf watermilfoil (*M. heterophyllum*), watercress (*Nasturtium officinale*), phragmites, flat-stem pondweed (*Potamogeton zosteriformis*), clasping-leaf pondweed (*P. richardsonii*), stiff pondweed (*P. strictifolius*), variable-leaf pondweed (*P. gramineus*), white water crowfoot (*Ranunculus aquatilis*), sago pondweed (*Stuckenia pectinata*), softstem bulrush (*Schoenoplectus tabernaemontani*), hardstem bulrush (*S. acutus*), water chestnut (*Trapa natans*), duckweeds (*Lemna* spp.), and submerged flowering rush (*Butomus umbellatus*; Cowgill et al. 1989; Gabor et al. 1995; Sprecher and Stewart 1995; Getsinger et al. 2003; Poovey et al. 2004; Hofstra et al. 2006; Poovey and Getsinger 2007; Champion et al. 2008; Derr 2008; Glomski and Nelson 2008; Glomski et al. 2009; True et al. 2010; Cheshier et al. 2012; Netherland and Jones 2015; Madsen et al. 2015; Madsen et al. 2016). Wild rice (*Zizania palustris*) biomass and height has been shown to decrease significantly following triclopyr application at 2.5 mg/L. Declines were not significant at lower concentrations (0.75 mg/L), though seedlings were more sensitive than young or mature plants (Madsen et al. 2008). American bulrush (*Schoenoplectus americanus*), spatterdock (*Nuphar variegata*), fern pondweed (*Potamogeton robbinsii*), large-leaf pondweed (*P. amplifolius*), leafy pondweed (*P. foliosus*), white-stem pondweed (*P. praelongus*), long-leaf pondweed (*P. nodosus*), Illinois pondweed (*P. illinoensis*), and water celery (*Vallisneria americana*) can be somewhat tolerant of triclopyr applications depending on waterbody characteristics and application rates (Sprecher and Stewart 1995; Glomski et al. 2009; Wersal et al. 2010b; Netherland and Glomski 2014).

Netherland and Jones (2015) evaluated the impact of large-scale, low-dose (~0.1-0.3 ppm) granular triclopyr) applications for control of non-native watermilfoil on several bays of Lake Minnetonka, Minnesota. Near complete loss of milfoil in the treated bays was observed the year of treatment, with increased milfoil frequency reported the following season. However, despite the observed increase in frequency, milfoil biomass remained a minor component of bay-wide biomass (<2%). The number of points with native plants, mean native species per point, and native species richness in the bays were not reduced following treatment. However, reductions in frequency were seen amongst individual species, including northern watermilfoil (*Myriophyllum sibiricum*), water stargrass, common waterweed, and flat-stem pondweed.

Penoxsulam

Registration and Formulations

Penoxsulam (2-(2,2-difluoroethoxy)--6-(trifluoromethyl-N-(5,8-dimethoxy[1,2,4] triazolo[1,5-c]pyrimidin-2-yl))benzenesulfonamide), also referred to as DE-638, XDE-638, XR-638 is a post-emergence, acetolactate synthase (ALS) inhibiting herbicide. It was first registered for use by the U.S. EPA in 2009. It is liquid in formulation and used for large-scale control of submerged, emergent, and floating-leaf vegetation. Information presented here can be found in the EPA pesticide fact sheet (EPA Penoxsulam 2004).

Mode of Action and Degradation

Penoxsulam is a slow-acting herbicide that is absorbed by above- and below-ground plant tissue and translocated throughout the plant. Penoxsulam interferes with plant growth by inhibiting the AHAS/ALS enzyme which in turn inhibits the production of important amino acids (Tranel and Wright 2002). Plant injury or death usually occurs between 2 and 4 weeks following application.

Penoxsulam is highly mobile but not persistent in either aquatic or terrestrial settings. However, the degradation process is complex. Two degradation pathways have been identified that result in at least 13 degradation products that persist for far longer than the original chemical. Both microbial- and photo-degradation are likely important means by which the herbicide is removed from the environment (Monika et al. 2017). It is relatively stable in water alone without sunlight, which means it may persist in light-limited areas.

The half-life for penoxsulam is between 12 and 38 days. Penoxsulam must remain in contact with plants for around 60 days. Thus, supplemental applications following initial treatment may be required to maintain adequate concentration exposure time (CET). Due to the long CET requirement, penoxsulam is likely best suited to large-scale or whole-lake applications.

Toxicology

Penoxsulam is unlikely to be toxic to animals but may be "slightly toxic" to birds that consume it. Human health studies have not revealed evidence of acute or chronic toxicity, though some indication of endocrine disruption deserves further study. However, screening-level assessments of risk have not been conducted on the major degradates which may have unknown non-target effects. Penoxsulam itself is unlikely to bioaccumulate in fish.

Species Susceptibility

Penoxsulam is used to control monocot and dicot plant species in aquatic and terrestrial environments. The herbicide is often applied at low concentrations of 0.002-0.02 ppm (2-20 ppb), but as a result long exposure times are usually required for effective target species control (Cheshier et al. 2011; Mudge et al. 2012b). For aquatic plant management applications, penoxsulam is most commonly utilized for control of hydrilla (*Hydrilla verticillata*). It has also been used for control of giant salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*; Richardson and Gardner 2007; Mudge and Netherland 2014). However, the herbicide is only semi-selective; it has been implicated in injury to non-target emergent native species, including arrowheads (*Sagittaria* spp.) and spikerushes (*Eleocharis* spp.) and free-floating species like duckweed (Mudge and Netherland 2014; Cheshier et al. 2011). Penoxsulam can also be used to control milfoils such as Eurasian watermilfoil (*Myriophyllum spicatum*) and variable-leaf watermilfoil (*M. heterophyllum*; Glomski and Netherland 2008). Seedling emergence as well as vegetative vigor is impaired by penoxsulam in both dicots and monocots, so buffer zone and dissipation reduction strategies may be necessary to avoid non-target impacts (EPA Penoxsulam 2004).

When used to treat salvinia, the herbicide was found to have effects lasting through 10 weeks following treatment (Mudge et al. 2012b). The herbicide is effective at low doses, but while low-concentration applications of slow-acting herbicides like penoxsulam often result in temporary growth regulation and stunting, plants are likely to recover following treatment. Thus, complementary management strategies should be employed to discourage early regrowth (Mudge et al. 2012b). In particular, joint biological and herbicidal control with penoxsulam has shown good control of water hyacinth (Moran 2012). Alternately, a low concentration may be maintained over time by repeated low-dose applications. Studies show that maintaining a low concentration for at least 8-12 weeks provided excellent control of salvinia, and that a low dose followed by a high-dose application was even more efficacious (Mudge et al. 2012b).

S.3.4. Physical Removal Techniques

There are several management options which involve physical removal of aquatic plants, either by manual or mechanical means. Some of these include manual and mechanical cutting and hand-pulling or Diver-Assisted Suction Harvesting (DASH).

S.3.4.1. Manual and Mechanical Cutting

Manual and Mechanical Cutting

Manual and mechanical cutting involve slicing off a portion of the target plants and removing the cut portion from the waterbody. In addition to actively removing parts of the target plants, destruction of vegetative material may help prevent further plant growth by decreasing photosynthetic uptake, and preventing the formation of rhizomes, tubers, and other growth types (Dall Armellina et al. 1996a, 1996b; Fox et al. 2002). These approaches can be quick to allow recreational use of a waterbody but because the plant is still established and will continue to grow from where it was cut, it often serves to provide short-term relief (Bickel and Closs 2009; Crowell et al. 1994). A synthesis of numerous historical mechanical harvesting studies is compiled by Breck et al. 1979.

The amount of time for macrophytes to return to pre-cutting levels can vary between waterbodies and with the dominant plant species present (Kaenel et al. 1998). Some studies have suggested that annual or biannual cutting of Eurasian watermilfoil (*Myriophyllum spicatum*) may be needed, while others have shown biomass can remain low the year after cutting (Kimbel and Carpenter 1981; Painter 1988; Barton et al. 2013). Hydrilla (*Hydrilla verticillata*) has been shown to recover beyond pre-harvest levels within weeks in some cases (Serafy et al. 1994). In deeper waters, greater cutting depth may lead to increased persistence of vegetative control (Unmuth et al. 1998; Barton et al. 2013). Higher frequency of cutting, rather than the amount of plant that is cut, can result in larger reductions to propagules such as turions (Fox et al. 2002).

The timing of cutting operations, as for other management approaches, is important. For species dependent on vegetative propagules, control methods should be taken before the propagules are formed. However, for species with rhizomes, cutting too early in the season merely postpones growth while later-season cutting can better reduce plant abundance (Dall Armellina et al. 1996a, 1996b). Eurasian watermilfoil regrowth may be slower if cutting is conducted later in the summer (June or later). Cutting in the fall, rather than spring or summer, may result in the lowest amount of Eurasian watermilfoil regrowth the year after management (Kimbel and Carpenter 1981). However, managing early in the growing season may reduce non-target impacts to native plant populations when early-growing non-native plants are the dominant targets (Nichols and Shaw 1986). Depending on regrowth rate and management goals, multiple harvests per growing season may be necessary (Rawls 1975).

Vegetative fragments which are not collected after cutting can produce new localized populations, potentially leading to higher plant densities (Dall Armellina et al. 1996a). Eurasian watermilfoil and common waterweed (*Elodea canadensis*) biomass can be reduced by cutting (Abernethy et al. 1996), though Eurasian watermilfoil can maintain its growth rate following cutting by developing a more-densely branched form (Rawls 1975; Mony et al. 2011). Cutting and physical removal tend to be less expensive but require more effort than benthic barriers, so these approaches may be best used for small infestations or where non-native and native species inhabit the same stand (Bailey and Calhoun 2008).

Ecological Impacts of Manual and Mechanical Cutting

Plants accrue nutrients into their tissues, and thus plant removal may also remove nutrients from waterbodies (Boyd 1970), though this nutrient removal may not be significant among all lake types. Cutting and harvesting of aquatic plants can lead to declines in fish as well as beneficial zooplankton, macroinvertebrate, and native plant and mussel populations (Garner et al. 1996; Aldridge 2000; Torn et al. 2010; Barton et al. 2013). Many studies suggest leaving some vegetated areas undisturbed to reduce negative effects of cutting on fish and other aquatic organisms (Swales 1982; Garner et al. 1996; Unmuth et al. 1998; Aldridge 2000; Greer et al. 2012). Recovery of these populations to cutting in the long-term is understudied and poorly understood (Barton et al. 2013). Effects on water quality can be minimal but nutrient cycling may be affected in wetland systems (Dall Armellina et al. 1996a; Martin et al. 2003). Cutting can also increase algal production, and turbidity temporarily if sediments are disturbed (Wile 1978; Bailey and Calhoun 2008).

Some changes to macroinvertebrate community composition can occur as a result of cutting (Monahan and Caffrey 1996; Bickel and Closs 2009). Studies have also shown 12-85% reductions in macroinvertebrates following cutting operations in flowing systems (Dawson et al. 1991; Kaenel et al. 1998). Macroinvertebrate communities may not rebound to pre-management levels for 4-6 months and species dependent on aquatic plants as habitat (such as simuliids and chironomids) are likely to be most affected. Reserving cutting operations for summer, rather than spring, may reduce impacts to macroinvertebrate communities (Kaenel et al. 1998).

Mechanical harvesting can also incidentally remove fish and turtles inhabiting the vegetation and lead to shifts in aquatic plant community composition (Engel 1990; Booms 1999). Studies have shown mechanical harvesting can remove between 2%-32% of the fish community by fish number, with juvenile game fish and smaller species being the primary species removed (Haller et al. 1980; Mikol 1985). Haller et al. (1980) estimated a 32% reduction in the fish community at a value of $6000/hectare. However, fish numbers rebounded to similar levels as an unmanaged area within 43 days after harvesting in the Potomac River in Maryland (Serafy et al. 1994). In addition to direct impacts to fish populations, reductions in fish growth rates may correspond with declines in zooplankton populations in response to cutting (Garner et al. 1996).

S.3.4.2. Hand Pulling and Diver-Assisted Suction Harvesting

Hand-pulling and DASH involve removing rooted plants from the bottom sediment of the water body. The entire plant is removed and disposed of elsewhere. Hand-pulling can be done at shallower depths whereas DASH, in which SCUBA divers do the pulling, may be better suited for deeper aquatic plant beds. As a permit condition, DASH and hand-pulling may not result in lifting or removal of bottom sediment (i.e., dredging). Efforts should be made to preserve water clarity because turbid conditions reduce visibility for divers, slowing the removal process and making species identification difficult. When operated with the intent to distinguish between species and minimize disturbance to desirable vegetation, DASH can be selective and provide multi-year control (Boylen et al. 1996). One study found reduced cover of Eurasian watermilfoil both in the year of harvest and the following year, along with increased native plant diversity and reduced overall plant cover the year following DASH implementation (Eichler et al. 1993). However, hand harvesting or DASH may require a large time or economic investment for Eurasian watermilfoil and other aquatic vegetation control on a large-scale (Madsen et al. 1989; Kelting and Laxson 2010). Lake type, water clarity, sediment composition, underwater obstacles and presences of dense native plants, may slow DASH efforts or even prohibit the ability to utilized DASH. Costs of DASH per acre have been reported to typically range from approximately $5,060-8,100 (Cooke et al. 1993; Mattson et al. 2004). Additionally, physical removal of turions from sediments, when applicable, has been shown to greatly reduce plant abundance for multiple subsequent growing seasons (Caffrey and Monahan 2006), though this has not been implemented in Wisconsin due to the significant effort it requires.

Ecological Impacts of Hand-Pulling and DASH

Because divers are physically uprooting plants from the lake bed, hand removal may disturb benthic organisms. Additionally, DASH may also result in some accidental capture of fish and invertebrates, small amounts of sediment removal, or increased turbidity. It is possible that equipment modifications could help minimize some of these unintended effects. Because DASH is a relatively new management approach, less information is available about potential impacts than for some more established techniques like large-scale mechanical harvesting.

S.3.4.3. Benthic Barriers

Benthic barriers can be used to kill existing plants or prevent their growth from the outset. They are sometimes referred to as benthic mats, or screens, and involve placing some sort of covering over a plant bed, which provides a physical obstruction to plant growth and reduces light availability. They may be best used for dense, confined infestations or along shore or for providing boat lanes (Engel 1983; Payne et al. 1993; Bailey and Calhoun 2008). Reductions in abundance of live aquatic plants beneath the barrier may be seen within weeks (Payne et al. 1993; Carter et al. 1994). The target plant species, light availability, and sediment accumulation have been shown to influence the efficacy of benthic barriers for aquatic plant control. Effects on the target plants may be more rapid in finer sediments because anoxic conditions are reached more quickly due to higher sediment organic content and oxidization by bacteria (Carter et al. 1994). Benthic barriers may be more expensive but less time intensive than some of the physical removal approaches described above (Carter et al. 1994; Bailey and Calhoun 2008). Engel (1983) suggests that benthic barriers may be useful in situations where plants are growing too deep for other physical removal approaches or effective herbicide application. They may also improve plant control when used in combination with herbicide treatments to hold most of the herbicide to a given treatment area (Helsel et al. 1996).

There is some necessary upkeep associated with the use of benthic barriers. Some barriers can be difficult to re-use because of algae and plants that can grow on top of the barrier. Periodically removing sediment that accumulates on the barrier can help offset this (Engel 1983; Carter et al. 1994; Laitala et al. 2012). Some materials are made to be removed after the growing season, which may make cleaning and re-use easier (Engel 1983). Additionally, gases often accumulate beneath benthic barriers as a result of plant decay, which can cause them to rise off the bottom of the waterbody, requiring further maintenance (Engel 1983; Ussery et al. 1997; Bailey and Calhoun 2008). Eurasian watermilfoil (*Myriophyllum spicatum*) and other plant species have been shown to recolonize the managed area quickly following barrier removal (Eichler et al. 1995; Boylen et al. 1996), so this approach may require hand-pulling or other integrated approaches once the barrier is removed (Carter et al. 1994; Eichler et al. 1995; Bailey and Calhoun 2008). Some studies have observed low abundance of plants maintained for 1-2 months after barriers were removed (Engel 1983). Others found that combining 2,4-D treatments with benthic barriers could reduce Eurasian watermilfoil to a degree that helped native plants recolonize the target site (Helsel et al. 1996).

The material used to create benthic barriers can vary and include biodegradable jute matting, fiberglass screens, and woven polypropylene fibers (Mayer 1978; Perkins et al. 1980; Lewis et al. 1983; Hoffman et al. 2013). Some plants such as Eurasian watermilfoil and common waterweed (Elodea canadensis; Eichler et al. 1995) are able to growth through the mesh in woven barriers but this material can be effective in reducing growth on certain target plant species (Payne et al. 1993; Caffrey et al. 2010; Hoffman et al. 2013). Hofstra and Clayton (2012) suggested that less dense materials barriers may provide selective control of some species while allowing more tolerant species, such as some charophytes (*Chara* spp. and *Nitella* spp.), to grow through. More dense materials may prevent growth of a wider range of aquatic plants (Hofstra and Clayton 2012). Most materials must be well anchored to the bottom of the waterbody, which can be accomplished early in the growing season or by placing the barriers on ice before thawing of the waterbody (Engel 1983). Gas accumulation can occur in using both fibrous mesh and screen-type barriers (Engel 1983).

Eurasian watermilfoil and common waterweed have been found to be somewhat resistant to control by benthic barriers (Perkins et al. 1980; Engel 1983) while affected species include hydrilla (*Hydrilla verticillata*), curly-leaf pondweed (*Potamogeton crispus*), and coontails (*Ceratophyllum* spp.; Engel 1983; Payne et al. 1993; Carter et al. 1994). One study found that an 8-week barrier placement removed Eurasian watermilfoil while allowing native plant regrowth after the barrier was retrieved; while shorter durations were less effective in reducing Eurasian watermilfoil abundance and longer durations negatively impacted native plant regrowth (Laitala et al. 2012).

Ecological Impacts of Benthic Barriers

Macroinvertebrates will be negatively affected by benthic barriers while they are in place (Engel 1983) but have been shown to rebound to pre-management conditions shortly after removal of the barrier (Payne et al. 1993; Ussery et al. 1997). Benthic barriers may also affect spawning of some warm water fish species through direct disruption of spawning habitat (NYSFOLA 2009). Additionally, increased ammonium and decreased dissolved oxygen contents are often observed beneath benthic barriers (Carter et al. 1994; Ussery et al. 1997). These water chemistry considerations may partially explain decreases in macroinvertebrate populations (Engel 1983; Payne et al. 1993) and ammonium content is likely to increase with sediment organic content (Eakin 1992). Toxic methane gas has also been found to accumulate beneath benthic barriers (Gunnison and Barko 1992).

There may be some positive ecological aspects of benthic barriers. Barriers may reduce turbidity and nutrient release from sediments (Engel 1983). They may also provide channels that improve ease of fish foraging when other aquatic plant cover is present near the managed area. Fish may feed on the benthic organisms colonizing any sediment accumulating on top of the barrier (Payne et al. 1993). Payne et al. (1993) also suggest that, despite negative impacts in the managed area, the overall impact of benthic barriers is negligible since they typically are only utilized in small areas of the littoral zone. However, further research is needed on the effects of benthic barriers on fish and wildlife populations and their ability to rebound following barrier removal (Eichler et al. 1995).

S.3.4.4. Dredging

Dredging is a method that involves the removal of top layers of sediment and associated rooted plants, sediment-dwelling organisms, and sediment-bound nutrients. This approach is "non-selective" (USACE 2012), meaning that it offers limited control over what material is removed. In addition to being employed as an APM technique, dredging is often used to manage water flow, provide navigation channels, and reduce the chance of flooding (USACE 2012). Due to the expense of this method, APM via dredging is often an auxiliary effect of dredging performed for other purposes (Gettys et al. 2014). However, reduced sediment nutrient load and decreased light penetration due to greater depth post-dredging may result in multi-season reductions in plant biomass and density (Gettys et al. 2014).

Several studies discuss the utility of dredging for APM. Dredging may be effective in controlling species that propagate by rhizomes, by removing the rhizomes from the sediment before they have a chance to grow (Dall Armellina et al. 1996b). Additionally, invasive phragmites has been controlled in areas where dredging increases water depth to ≥ 5-6 feet; though movement of the equipment used in dredging activities has been implicated in expanding the range of invasive phragmites (Gettys et al. 2014). In streams, dredging resulted in a significant reduction in plant biomass (≥ 90%). However, recovery of plant populations reflected the timing of management actions relative to flowering: removal prior to flowering allowed for plant population recovery within the same growing season, while removal after flowering meant populations did not rebound until the next spring (Kaenel and Uehlinger 1999). Sediment testing for chemical residue levels high enough to be considered hazardous waste (from historically used sodium arsenite, copper, chromium, and other inorganic compounds) should be conducted before dredging, to avoid stirring of toxic material into the water column. The department routinely requires sediment analysis before dredging begins and destination approval of spoils to prevent impacts from sediment leachate outside of the disposal area. Planning and testing can be an extensive component to a dredging project.

<u>Ecological effects of Dredging</u>

Repeated dredging may result in plant communities consisting of populations of fast-growing species that are capable of rebounding quickly (Sand-Jensen et al. 2000). In experimental studies, faster growing invasive plant species with a higher tolerance for disturbance were able to better recover from simulated dredging than slower growing native plant species, suggesting that post-dredging plant communities may be comprised of undesirable invasives (Stiers et al. 2011).

Macroinvertebrate biomass has been shown to decrease up to 65% following dredging, particularly among species which use plants as habitat. Species that live deeper in sediments, or those that are highly mobile, were less affected. As macroinvertebrates are valuable components of aquatic ecosystems, it is recommended that plant removal activities consider impacts on macroinvertebrates (Kaenel and Uehlinger 1999). Dredging can also result in declines to native mussel populations (Aldridge 2000).

Impacts to fish and water quality parameters have also been observed. Dredging to remove aquatic plants significantly increased both dissolved oxygen levels and the number of fish species found inhabiting farm ponds (Mitsuo et al. 2014). This increase in fish abundance may have been due to extremely high pre-dredging density of aquatic plants, which can negatively influence fish foraging success. In another study, aquatic plant removal decreased the amplitude of daily oxygen fluctuations in streams. However, post-dredging changes in metabolism were short-lived, suggesting that algae may have taken over primary productivity (Kaenel et al. 2000). Finally, several studies have also documented or suggested a reduction in sediment phosphorous levels after dredging, which may in turn reduce nutrient availability for aquatic plant growth (Van der Does et al. 1992; Kleeberg and Kohl 1999; Meijer et al. 1999; Søndergaard et al. 2001; Zuccarini et al. 2011). However, consideration must be given to factors affecting whether goals are obtainable via dredging (e.g., internal or external phosphorus inputs, water retention time, sediment characteristics, etc.).

S.3.4.5. Drawdown

Water-level drawdown is another approach for aquatic plant control as well as aquatic plant restoration. Exposure of aquatic plant vegetation, seeds, and other reproductive structures may reduce plant abundance by freezing, drying, or consolidation of sediments. This management technique is not effective for control of all aquatic plant species. Due to potential ecological impacts, it is necessary to consider other factors such as: waterfowl habitat, fisheries enhancement, release of nutrients and solids downstream, and refill and sediment consolidation potential. Often drawdowns for aquatic plant control and/or restoration can be coordinated to time with dam repair or repair of shoreline structures. A review by Cooke (1980), suggests drawdown can provide at least short-term aquatic plant control (1-2 years) when the target species is vulnerable to drawdown and where sediment can be dewatered under rigorous heat or cold for 1-2 months. Costs can be relatively low when a structure for manipulating water level is in place (otherwise high capacity pumps must be used). Conversely, costs can be high to reimburse an owner for lost power generation if the water control structure produces hydro-electric power. The aesthetic and recreational value of a waterbody may be reduced during a drawdown, as large areas of sediment are exposed prior to revegetation. Bathymetry is also important to consider, as small decreases in water level may lead to drop-offs if a basin does not have a gradual slope (Cooke 1980). The downcutting of the stream to form a new channel can also release high amounts of solids and organic matter that can impair water quality downstream. For example, in July 2005, the Waupaca Millpond, Waupaca Co. had to conduct an emergency drawdown that resulted in the river downcutting a new channel. High suspended solid concentrations and BOD resulted in decreased water clarity, sedimentation and depressed dissolved oxygen levels. A similar case occurred in 2015 with the Amherst Mill Pond, Portage Co. during a drawdown at a rate of six inches per day (Scott Provost [WDNR], *personal communication*).

Because extreme heat or cold provide optimal conditions for aquatic plant control, drawdowns are typically conducted in the summer or winter. Because of Wisconsin’s cold winters, winter drawdown is likely to have several advantages when used for aquatic plant management, including avoiding many conflicts with recreational use, potential for cyanobacterial blooms, and terrestrial and emergent plant growth in sediments exposed by reduced water levels (ter Heerdt and Drost 1994; Bakker and Hilt 2016).

A synthesis of the abiotic and biotic responses to annual and novel winter water level drawdowns in littoral zones of lakes and reservoirs is summarized by Carmignani and Roy 2017. Climatic conditions also determine the capacity of a waterbody to support drawdown (Coops et al. 2003). Resources managers pursuing drawdown must carefully calculate the waterbody's water budget and the potential for increased cyanobacterial blooms in the future may reduce the number of suitable waterbodies (Callieri et al. 2014). Additionally, mild winters and groundwater seepage in some waterbodies may prevent dewatering, leading to reduced aquatic plant control (Cooke 1980). Complete freezing of sediment is more likely to control aquatic plants. Sediment exposure during warmer temperatures (>5° C) can also result in the additional benefit of oxidizing and compacting organic sediments (Scott Provost and Ted Johnson [DNR], *personal communication*). When drawdowns are conducted to improve migratory bird habitat, summer drawdowns prove to be more beneficial for species of shorebirds, as mudflats and shallow water are exposed to promote the production of and accessibility to invertebrates during late summer months that coincide with southward migration (Herwig and Gelvin-Innvaer 2015). Drawdowns conducted during mid-late summer can result in conditions that are favorable for cattails (*Typha* spp.) germination and expansion. However, cattails can be controlled if certain stressors are implemented in conjunction with a drawdown, such as cutting, burning or herbicide treatment during the peak of the growing season. The ideal situation is to cut cattail during a drawdown and flood over cut leaves when water is raised. However, this option is not always feasible due to soil conditions and equipment limitations.

<u>Ecological Impacts of Water-level Drawdown</u>

Artificial manipulation of water level is a major disturbance which can affect many ecological aspects of a waterbody. Because drawdown provides species-selective aquatic plant control, it can alter aquatic plant community composition and relative abundance and distribution of species (Boschilia et al. 2012; Keddy 2000). Sometimes this is the intent of the drawdown, which creates plant community characteristics that are desired for wildlife or fish habitat. Consecutive annual drawdowns may prevent the re-establishment of native aquatic plants or lead to reduced control of aquatic plant abundance as drawdown-tolerant species begin to dominate the community (Nichols 1975). Sediment exposure can also lead to colonization of emergent vegetation in the drawdown zone. In one study, four years of consecutive marsh drawdown led to dominance of invasive phragmites (*Phragmites australis subsp. australis*; ter Heerdt and Drost 1994). However, when drawdowns are conducted properly, it can provide a favorable response to native emergent plants for providing food and cover for migrating waterfowl in the fall. Population increases in emergent plant species such as bulrush (*Schoenoplectus* spp.), bur-reeds (*Sparganium* spp.), and wild rice (*Zizania palustris*) is often a goal of drawdowns, which provides a great food source for fish and wildlife, and provides important spawning and nesting habitat. Full or partial drawdowns that are conducted after wild rice production in the fall tend to favor early successional emergent germination such as wild rice and bulrush the following spring. Spring drawdowns are also possible for producing wild rice but must be done during a tight window following ice-out and slowly raised prior to the wild rice floating leaf stage.

Drawdown can also have various effects on ecosystem fauna. Drawdowns can influence the mortality, movement and behavior of native freshwater mussels (Newton et al. 2014). Although mussels can move with lowering water levels, they can be stranded and die if they are unable to move fast enough or get trapped behind logs or other obstacles (WDNR et al. 2006). Some mussels will burrow down into the mud or sand to find water but can desiccate if the water levels continue to lower (Watters et al. 2001). Maintaining a slow drawdown rate can allow mussels to respond and stranded individuals can be relocated to deeper water during the drawdown period to reduce mussel death (WDNR et al. 2006). Macroinvertebrate communities may experience reduced species diversity and abundance from changes to their environment due to drawdown and loss of habitat provided by aquatic plants (Wilcox and Meeker 1992; McEwen and Butler 2008). These effects may be reduced by considering benthic invertebrate phenology in determining optimal timing for drawdown release. Adequate moisture is required to support the emergence of many macroinvertebrate species and complete drawdown may also result in hardening of sediments which can trap some species (Coops et al. 2003). Reduced macroinvertebrate availability can have negative effects on waterfowl and game fish species which rely on macroinvertebrate food sources (Wilcox and Meeker 1992). Depending on the time of year, drawdown may also lead to decreased reproductive success of some waterfowl through nest loss, including common loon (*Gavia immer*) and red-necked grebe (*Podiceps grisegena*; Reiser 1998). However, drawdown may lead to increased production of annual plants and seed production, thereby increasing food availability for brooding and migrating waterfowl. Semi-aquatic mammals such as muskrats and beavers may also be adversely affected by water level drawdown (Smith and Peterson 1988, 1991). DNR Wildlife Management staff follow guidance to ensure drawdowns are timed with the seasons or temperature to minimize negative impacts to wildlife. Negative impacts to reptiles are possible during the spring if water is raised following a drawdown, as nests may be flooded. In the fall, negative impacts to reptiles and amphibians are possible if water is lowered when species are attempting to settle into sediments for hibernation. The impact may be reduced dissolved oxygen if they are below the water or freezing if the water is dropped below the point of hibernation (Herwig and Smith 2016a, 2016b). Surveying and relocation of stranded organisms may help to mitigate some of these impacts. In Wisconsin there are general provisions for conducting drawdowns for APM that are designed to mitigate or even eliminate potential negative impacts.

Water chemistry can also be affected by water level fluctuation. Beard (1973) describes a substantial algal bloom occurring the summer following a winter drawdown which provided successful aquatic plant control. Other studies reported reduced dissolved oxygen, severe cyanobacterial blooms with summer drawdown, or increased nutrient concentrations and reduced water clarity during summer drawdown for urban water supply (Cooke 1980; Geraldes and Boavida 2005; Bakker and Hilt 2016). Water clarity and trophic state may be improved when drawdown level is similar to a waterbody's natural water level regime (Christensen and Maki 2015).

Species Susceptibility to Water-level Drawdown

Not all plant species are susceptible to management by water level drawdown and some dry- or cold-tolerant species may benefit from it (Cooke 1980). Generally, plants and charophytes which reproduce primarily by seed benefit from drawdowns while those that reproduce vegetatively tend to be more negatively affected. Marsh vegetation can be dependent on water level fluctuation (Keddy and Reznicek 1986). Cooke (1980) provides a summary table of drawdown responses for 63 aquatic plant species. Watershield (Brasenia schreberi), fern pondweed (*Potamogeton robbinsii*), pond-lilies (*Nuphar* spp.) and watermilfoils (*Myriophyllum* spp.) tend to be controlled by drawdown. Increases in abundance associated with drawdown have often been seen for duckweed (*Lemna minor*), rice cutgrass (*Leersia oryzoides*) and slender naiad (*Najas flexilis*; Cooke 1980). One study showed drawdown reduced Eurasian watermilfoil (*Myriophyllum spicatum*) at shallow depths while another cautioned that Eurasian watermilfoil vegetative fragments may be able to grow even after complete desiccation (Siver et al. 1986; Evans et al. 2011). Similarly, a tank-simulated drawdown experiment suggested short-term summer drawdown may be effective in controlling monoecious hydrilla (*Hydrilla verticillata*; Poovey and Kay 1998). However, other studies have shown hydrilla fragments to be resistant to drying following drawdown (Doyle and Smart 2001; Silveira et al. 2009). A study on Brazilian waterweed (*Egeria densa*) showed that stems were no longer viable after 22 days of exposure due to drawdown (Dugdale et al. 2012).

Two examples of recent drawdowns in Wisconsin that were evaluated for their efficacy in controlling invasive aquatic plants occurred in Lac Sault Dore and Musser Lake, both in Price County, which were conducted in 2010 and 2013, respectively. Dam maintenance was the initial reason for these drawdowns, with the anticipated control of nuisance causing aquatic invasive species as a secondary benefit. Aquatic plant surveys showed that the drawdown in Lac Sault Dore resulted in a 99% relative reduction in the littoral cover of Eurasian watermilfoil when comparing pre- vs. post-drawdown frequencies. Native plant cover expanded following the drawdown and Eurasian watermilfoil cover has continued to remain low (82% relative reduction compared to pre-drawdown) as of 2017 (Onterra 2013). Lake-wide cover of curly-leaf pondweed in Musser Lake decreased following drawdown (63% relative reduction compared to pre-drawdown), and turion viability was also reduced. Reductions in native plant populations were observed, though population recovery could be seen in the second year following the drawdown (Onterra 2016). These examples of water-level drawdowns in Wisconsin show that they can be valuable approaches for aquatic invasive species control in some waterbodies. Water level reduction must be conducted such that a sufficient proportion of the area occupied by the target species is exposed. Numerous other single season winter drawdowns monitored in central Wisconsin by department staff show similar results (Scott Provost [DNR], *personal communication*). Careful timing and proper duration is needed to maximize control of target species and growth of favorable species.

S.3.5.Biological Control

Biological control refers to any method involving the use of one organism to control another. This method can be applied to both invasive and native plant populations, since all organisms experience growth limitation through various mechanisms (e.g., competition, parasitism, disease, predation) in their native communities. As such, when control of aquatic plants is desired it is possible that a growth limiting organism, such as a predator, exists and is suitable for this purpose.

Care must be taken to ensure that the chosen biological control method will effectively limit the target population and will not cause unintended negative effects on the ecosystem. The world is full of examples of biological control attempts gone wrong: for example, Asian lady beetles (*Harmonia axyridis*) have been introduced to control agricultural aphid pests. While the beetles have been successful in controlling aphid populations in some areas, they can also outcompete native lady beetles and be a nuisance to humans by amassing on buildings (Koch 2003). Additionally, a method of control that works in some Wisconsin lakes may not work in other parts of the state where differing water chemistry and/or biological communities may affect the success of the organism. The department recognizes the variation in control efficacy and well as potential unintentional effects of some organisms and is very cautious in allowing their use for control of aquatic plants.

Purple loosestrife beetles

The use of herbivorous insects to reduce populations of aquatic plants is another method of biocontrol. Several beetle species native to Eurasia (*Galerucella calmariensis*, *G. pusilla*, *Hylobius transversovittatus*, and *Nanophyes marmoratus*) have been well-studied and intentionally released in North America for their ability to suppress populations of the invasive wetland plant, purple loosestrife (*Lythrum salicaria*). These beetles only feed on loosestrife plants and therefore are not a threat to other wetland plant species (Kok et al. 1992; Blossey et al. 1994a, 1994b; Blossey and Schroeder 1995). The department implements a purple loosestrife biocontrol program, in which citizens rear and release beetles on purple loosestrife stands to reduce the plants' ability to overtake wetlands, lakeshores, and other riparian areas.

Beetle biocontrol can provide successful long-term control of purple loosestrife. The beetles feed on purple loosestrife foliage which in turn can reduce seed production (Katovich et al. 2001). This approach typically does not eradicate purple loosestrife but stresses loosestrife populations such that other plants are able to compete and coexist with them (Katovich et al. 1999). Depending on the composition of the plant community invaded by purple loosestrife and the presence of other non-native invasive species, further restoration efforts may be needed following biocontrol efforts to support the regrowth of beneficial native plants (McAvoy et al. 2016).

Several factors have been identified that may influence the efficacy of beetle biocontrol of purple loosestrife. Purple loosestrife beetles have for the most part been shown to be capable of successfully surviving and establishing in a variety of locations (Hight et al. 1995; McAvoy et al. 2002; Landis et al. 2003). The different species have different preferred temperatures for feeding and reproduction (McAvoy and Kok 1999; McAvoy and Kok 2004). In addition, one study suggests that the number of beetles introduced does not necessarily correlate with greater beetle colonization (Yeates et al. 2012). Disturbance, such as flooding and predation by other animals on the beetles, can also reduce desired effects on loosestrife populations (Nechols et al. 1996; Dech and Nosko 2002; Denoth and Myers 2005). Finally, one study suggests that the use of triclopyr amine for purple loosestrife control may be compatible with beetle biocontrol, although there may be negative effects on beetle egg-batch size or indirect effects if the beetle's food source is too greatly depleted (Lindgren et al. 1998). Some mosquito larvicides may harm purple loosestrife beetles (Lowe and Hershberger 2004).

Milfoil weevils

Similar to the use of beetles for biological control of purple loosestrife, the use of milfoil weevils (*Euhrychiopsis lecontei*) has been investigated in North America to control populations of non-native Eurasian and hybrid watermilfoils (*Myriophyllum spicatum* x *sibiricum*). This weevil species is native to North America and is often naturally present in waterbodies that contain native watermilfoils, such as northern watermilfoil (*M. sibiricum*). The weevils have the potential to damage Eurasian watermilfoil (*M. spicatum*) by feeding on stems and leaves and/or burrowing into stems. Weevils may reduce milfoil plant biomass, inhibit growth, and compromise buoyancy (Creed and Sheldon 1993; Creed and Sheldon 1995; Havel et al. 2017a). Damage caused to the milfoil tissue may then indirectly increase susceptibility to pathogens (Sheldon and Creed 1995).

In experiments, weevils have been shown to negatively impact Eurasian watermilfoil populations to varying degrees. Experiments by Creed and Sheldon (1994) found that plant weight was negatively affected when weevils were at densities of 1 and 2 larvae/tank, and Eurasian watermilfoil in untreated control tanks added more root biomass than those in tanks with weevils, suggesting that weevil larvae may interfere with the plant's ability to move nutrients. Similarly, experiments by Newman et al. (1996) found that weevils at densities of 6, 12, and 24 adults/tank caused significant decreases in Eurasian watermilfoil stem and root biomass, and that higher weevil densities generally produced more damage.

In natural communities, effects of weevils have been mixed, likely because waterbody characteristics may play a role in determining weevil effects on Eurasian watermilfoil populations in natural lakes. In a 56 ha (138 acre) pond in Vermont, weevil density was negatively associated with Eurasian watermilfoil biomass and distribution; Eurasian watermilfoil beds were reduced from 2.5 (6.2 acres) to 1 ha (2.5 acres) in one year, and biomass decreased by 4 to 30 times (Creed and Sheldon 1995). A survey of Wisconsin waterbodies conducted by Jester et al. (2000) revealed that most lakes containing Eurasian watermilfoil also contained weevils. Weevil abundance varied from functionally non-detectable to 2.5 weevils/stem and was positively associated with the presence of large, shallow Eurasian watermilfoil beds (compared to deep, completely submerged beds). There was no relationship between natural weevil abundance and Eurasian watermilfoil density between lakes. However, when the authors augmented natural weevil populations in plots in an attempt to achieve target densities of 1, 2, or 4/stem, they found that augmentation was associated with significant decreases in Eurasian watermilfoil biomass, stem density and length, and tips/stem (Jester et al. 2000). However, another more recent study conducted in several northern Wisconsin lakes found no effect of weevil stocking on Eurasian watermilfoil or native plant biomass (Havel et al. 2017a).

There are several factors to consider when determining whether weevils are an appropriate method of biocontrol. First, previous research has suggested that densities of at least 1.5 weevils per stem are required for control (Newman and Biesboer 2000). Adequate densities may not be achievable due to factors including natural population fluctuations, the amount of available milfoil biomass within a waterbody, the presence of insectivorous predators, such as bluegills (*Lepomis macrochirus*), and the availability of nearshore overwintering habitat (Thorstenson et al. 2013; Havel et al. 2017a). In addition, weevils fed and reproduce on native milfoil species and biocontrol efforts could potentially impact these species, although experiments conducted by Sheldon and Creed (2003) found that native milfoil weevil density was lower and weevils caused less damage than when they were found on Eurasian watermilfoil. Adult weevils spend their winters on land, so available habitat for adults must be present for a waterbody to sustain weevil populations (Reeves and Lorch 2011; Newman et al. 2001). Additionally, one study found that lakes with no Eurasian watermilfoil (despite the presence of other milfoil species) and lakes that had a recent history of herbicide treatment had lower weevil densities than similar, untreated lakes or lakes with Eurasian watermilfoil (Havel et al. 2017b).

Grass carp – not allowed in Wisconsin

The use of grass carp (*Ctenopharyngodon idella*) to control aquatic plants is not allowed in Wisconsin; they are a prohibited invasive species under ch. NR 40, Wis. Admin. Code, which makes it illegal to possess, transport, transfer, or introduce grass carp in Wisconsin.

Sterile (also known as triploid) grass carp have been used to control populations of aquatic plants with varying success (Pípalová 2002; Hanlon et al. 2000). Whether this method is effective depends on several factors. For instance, each individual fish must be tested to ensure sterility before stocking, which can be a time- and resource-consuming process. Since the sterile fish do not reproduce, it can be difficult to achieve the desired density in a given waterbody. In addition, grass carp, like many fish species, have dietary preferences for different plant species which must be considered (Pine and Anderson 1991). Further information summarizing the effects of stocking triploid grass carp can be found in Pípalová (2006), Dibble and Kovalenko (2009), and Bain (1993).

E

APPENDIX E

2021 Comprehensive Fish Survey Summary Report - WDNR

WISCONSIN DEPARTMENT OF NATURAL RESOURCES
2021 Comprehensive Fish Survey Summary Report

Silver Lake (WBIC 107900)

Waushara County

Introduction and Objectives

In 2021, the Wisconsin Department of Natural Resources conducted a comprehensive fish survey of Silver Lake in order to provide insight and direction for the future fisheries management of this lake. Comprehensive fish surveys include both spring fyke netting and spring electrofishing surveys. Primary sampling objectives of these surveys are to characterize species composition, relative abundance, and size structure. The following report is a brief summary of the activities conducted, general status of fish populations and future management options for Silver Lake.

Combined Acres: 328
Shoreline Miles: 4.6
Maximum Depth (feet): 50
Lake Type: Seepage
Public Access: 3 Public Boat Launch
Regulations: Statewide Default Regulations

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Survey Methods

- Silver Lake was sampled according to spring netting I (SNI), and spring electrofishing II (SEII) protocols as outlined in the statewide lake protocol. The primary objective of the spring fyke netting I survey is to count and measure adult Walleye, Northern Pike and panfish, as well as mark adult Walleyes to estimate Walleye abundance. The primary objective of the SNI survey is act as a recapture event to estimate walleye abundance. The primary objective of the SEII survey is to count and measure adult Largemouth Bass, Smallmouth Bass and panfish. Other species of fish may be sampled during each survey, but are considered by-catch as part of that survey.
- Spring fyke netting takes place shortly after ice out since the goal is to capture Walleye and Northern Pike as they begin to spawn. Fyke Nets were deployed in areas of the lake that contained spawning habitat or were likely travel areas for Northern Pike and Walleyes. All captured fish were identified to species and gamefish and panfish were measured for length. All newly captured Walleye were given a top caudal fin clip. All Walleye and Northern Pike were weighed and age structures (i.e. otoliths, fin rays and spines) were collected from a subsample of Northern Pike, Bluegill and Back Crappie for age and growth analysis.
- Spring electrofishing takes place after netting is complete and water temperatures warm to at least 55°F, just as Largemouth Bass and panfish move into shallow water to spawn. The entire shoreline was electroshocked as part of this survey. All fish captured were identified to species and gamefish and panfish were measured for length.
- Fish metrics used to describe fish populations include catch per unit effort, total abundance, proportional stock density, length frequency distribution and mean age at length.

FKYE NETTING SURVEY INFORMATION - SNI

Site Location	Survey Dates	Water Temperature (°F)	Target Species	Gear	Number of Nets	Net Nights
Silver Lake	3/25/2021 - 4/6/2021	40 - 49	Northern Pike and Walleye	Fyke Net	6	84

SPRING ELECTROFISHING II SURVEY INFORMATION

Site Location	Survey Date	Water Temperature (°F)	Target Species	Total Miles Shocked	Number of Stations	Gear	Number of Netters
Silver Lake	6/1/2021	67	Bass and Panfish	4.6	5	Boom shocker	2 (1 Shocking Boats)

Fish Metric Descriptions

Catch per unit effort (CPUE) is an index used to measure fish population relative abundance, which simply refers to the number of fish captured per unit of distance or time. For netting surveys, we typically quantify CPUE by the number and size of fish per net night. For electrofishing surveys, we typically quantify CPUE by the number and size of fish captured per mile of shoreline. CPUE indexes are compared to statewide data by percentiles and within lake trends. For example, if a CPUE is in the 90th percentile, it is higher than 90% of the other CPUEs in the state.

Total abundance is a metric that describes population size and is estimated by mark and recapture. In the fyke netting survey, all Northern Pike that were captured were examined for a partial caudal fin (i.e., tail fin) clip. If a partial fin clip was not observed, one was given and the fish was released. If a partial caudal fin clip was observed, it was noted on the data sheet and the fish was released. The number of fin clipped fish versus unmarked fish was kept track of daily and used to estimate the Northern Pike abundance in Silver Lake.

Proportional Stock Density (PSD) is an index used to describe size structure of fish populations. It is calculated by dividing the number of quality size fish by the number of stock size fish for a given species. PSD values between 40 - 60 generally describe a balanced fish population.

Length frequency distribution (LFD) is a graphical representation of the number or percentage of fish captured by half inch or one inch size intervals. Smaller fish (or younger age classes) may not always be represented in the length frequency due to different habitat usage or sampling gear limitations.

Mean Age at Length is an index used to assess fish growth. Calcified structures (e.g., otoliths, spines, or scales) are collected from a specified length bin of interest (e.g., 7.0-7.5 inches for Bluegill). Mean age is compared to statewide data by percentile with growth characterized by the following benchmarks: slow (<33rd percentile); moderate (33rd to 66th percentile); and fast (>66th percentile).

WISCONSIN DEPT. OF NATURAL RESOURCES

Silver Lake (WBIC 107900)

Gamefish Summary

Waushara County

Northern Pike

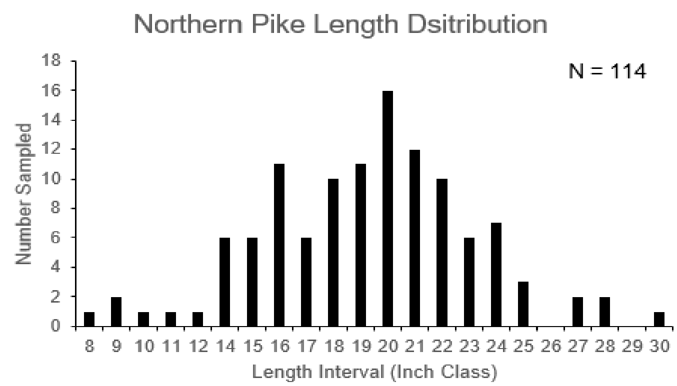
- Fyke netting is the preferred sampling gear for Northern Pike. All results presented for Northern Pike are from spring fyke netting surveys.

2021 NORTHERN PIKE SIZE STRUCTURE METRICS								
Total Number Measured	Average Length (inches)	Length Range (inches)	Stock and Quality Size (inches)	Stock Number	Quality Number	PSD	Percentile Rank	Size Rating
114	19.7	8.9 - 30.6	14.0 and 21.0	109	43	39	45th	Moderate

NORTHERN PIKE RELATIVE ABUNDANCE (CPUE = NUMBER PER NET NIGHT)					
2021 Total Sampled	2015	2021	Historical Median	2021 Statewide Percentile Rank	2021 Abundance Rating
114	1.0	1.6	1.3	48th	Moderate

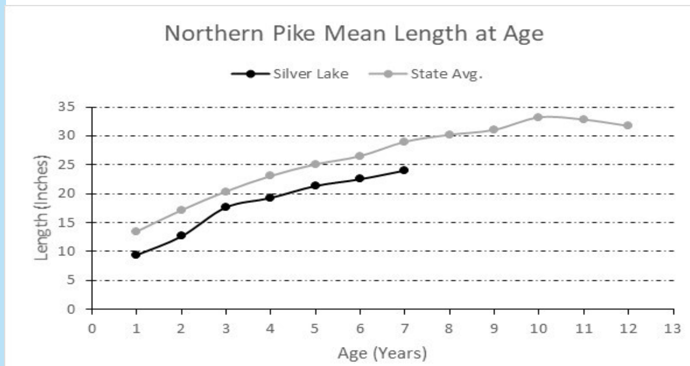
NORTHERN PIKE SIZE STRUCTURE (PSD) TRENDS		
PSD by Year		Historical Median
2015	2021	
26	39	32.5

NORTHERN PIKE ADULT ABUNDANCE (POPULATION ESTIMATE)					
Marked	Captured	Recaptures	Population Estimate (95% CI)	Number per Acre	Abundance Rating
110	134	19	348.2 (231.7 - 699.9)	1.1	Moderate



Northern Pike Summary

- Silver Lake supports a moderate density Northern Pike population, with catch rates being 1.6 per net night in the 2021 fyke netting survey. A catch rate of 1.6 ranks out in the 48th percentile when compared to lakes throughout Wisconsin. Catch rates of Northern Pike on Silver Lake in historical fyke netting surveys have been similar, from 1.0 - 1.6/ net night.
- Size structure of Northern Pike in the 2021 fyke netting survey was moderate with a PSD of 39 which ranks out in the 45th percentile when compared to lakes throughout Wisconsin. Size structure in 2021 was similar to a previous fyke netting survey in 2015, when PSD was 36.
- Population estimates of Northern Pike have slightly increased over the last six years in Silver Lake, but show a below average fishery while having 1.1 adult Northern Pike per acre captured with only 4.3% of the catch being ≥26 inches.
- Growth rates are below average taking more than 6 years to reach 26 inches.



Largemouth Bass

- Electrofishing is the preferred sampling gear for Largemouth Bass. All results presented for Largemouth Bass are from SE2 surveys.

2021 LARGEMOUTH BASS SIZE STRUCTURE METRICS								
Total Number Sampled	Average Length (inches)	Length Range (inches)	Stock and Quality Size (inches)	Stock Number	Quality Number	PSD	Percentile Rank	Size Rating
366	9.9	3.2 - 20.4	8.0 and 12.0	210	121	58	47th	Moderate

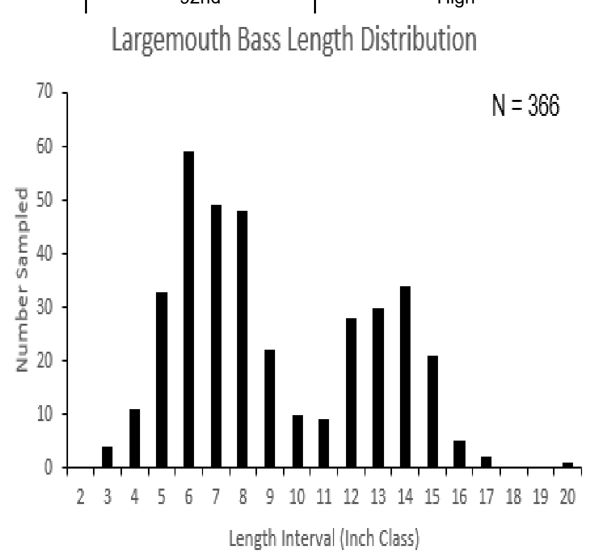
2021 LARGEMOUTH BASS RELATIVE ABUNDANCE (CPUE = NUMBER PER MILE TOTAL AND ≥ STOCK SIZE							
CPUE ≥ Stock	CPUE ≥ Stock\Hour	Percentile Rank	Overall Abundance Rating	Length Index	Length Index CPUE	Length Index Percentile Rank	Length Index Abundance Rating
45.7	97.7	87th	High	≥ 14.0 inches	13.7	92nd	High

LARGEMOUTH BASS RELATIVE ABUNDANCE TRENDS (CPUE = NUMBER PER MILE ≥ Stock Size)			
CPUE by Year			Historical Median
2010	2015	2021	
39.8	41	45.7	42.2

LARGEMOUTH BASS SIZE STRUCTURE TRENDS (PSD)			
PSD by Year			Historical Median
2010	2015	2021	
70	52	58	60

Largemouth Bass Summary

- Silver Lake supports a high density Largemouth Bass population. Catch rates of Largemouth Bass in the spring electrofishing survey were 45.7 Largemouth Bass per mile of electrofishing, which ranks out in the 87th percentile when compared to lakes throughout Wisconsin. Catch rates fish ≥ 8 inches over the years of electrofishing surveys are very similar, ranging between 39.8—45.7 per mile of electrofishing.
- Size structure of Largemouth Bass in 2021 was also good with a PSD of 58 but down from the 2010 survey when 70% of fish larger than 8 inches were also larger than 12 inches.



Black Crappie

- Fyke netting is the only gear that we sampled enough numbers of crappies to use for analysis.

2021 BLACK CRAPPIE SIZE STRUCTURE METRICS

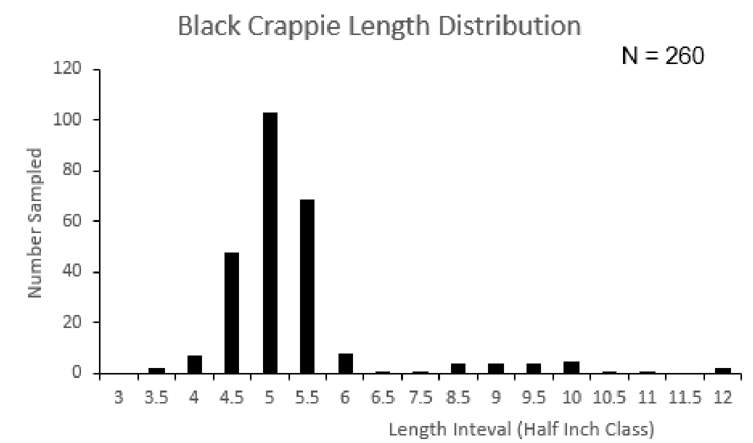
Gear	Number Measured	Average Length	Length Range	Stock and Quality	Stock	Quality	PSD	Percentile Rank	Size Rating
Fyke Netting	276	5.6	3.9 - 12.4	5.0 and 8.0 inches	203	21	10	6th	Low
Electrofishing	6	8.5	5.2 - 9.7	5.0 and 8.0 inches	6	5	83	Too Few Fish	Too Few Fish

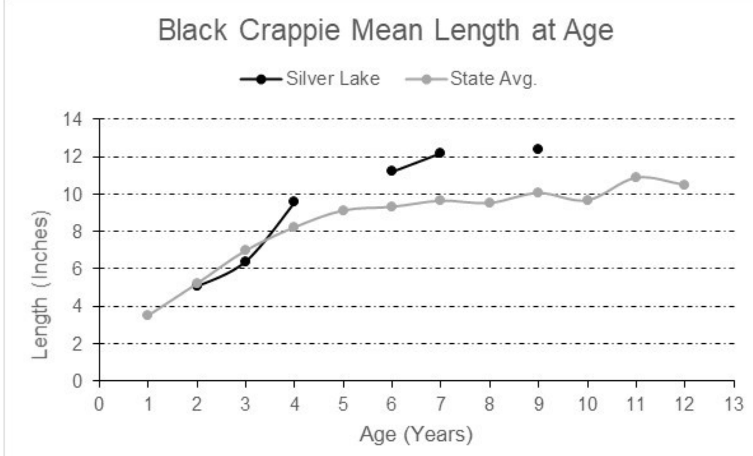
BLACK CRAPPIE TRENDS CPUE (NUMBER PER NET NIGHT)

2021 Number Sampled	2015	2021	Historical Median	2021 Statewide Percentile Rank	2021 Abundance Rating
260	6.6	3.3	5.0	50th	Moderate

BLACK CRAPPIE FYKE NETTING SIZE STRUCTURE (PSD) TRENDS

PSD by Year		Historical Median
2015	2021	
5	10	7.5





Bluegill

- Both fyke netting and electrofishing can be useful gears to sample Bluegill. Therefore, results from both gears will be presented.

2021 BLUEGILL SIZE STRUCTURE METRICS

Gear	Number Measured	Average Length (inches)	Length Range (inches)	Stock and Quality Sizes (inches)	Stock Number	Quality Number	PSD	Percentile Rank	Size Rating
Fyke Netting	491	4.8	2.7 - 9.6	3.0 and 6.0 inches	490	59	12	7st	Low
Electrofishing	339	4.9	2.0 - 9.5	3.0 and 6.0 inches	243	48	20	33rd	Low

BLUEGILL FYKE NETTING CPUE (NUMBER PER NET NIGHT) TRENDS

2021 Number Sampled	2015	2021	Historical Median	2021 Statewide Percentile Rank	2021 Abundance Rating
491	8.0	13.6	10.8	80th	High

BLUEGILL FYKE NETTING SIZE STRUCTURE (PSD) TRENDS

PSD by Year		Historical Median
2015	2021	
49	12	30.5

2021 BLUEGILL ELECTROFISHING CPUE (NUMBER PER MILE)

CPUE Total	Percentile Rank	Overall Abundance Rating	Length Index	Length Index CPUE	Length Index Percentile Rank	Length Index Abundance Rating
339	93rd	High	≥ 3.0 inches	243	92nd	High

BLUEGILL ELECTROFISHING CPUE (NUMBER PER MILE ≥ 3 INCHES) TRENDS

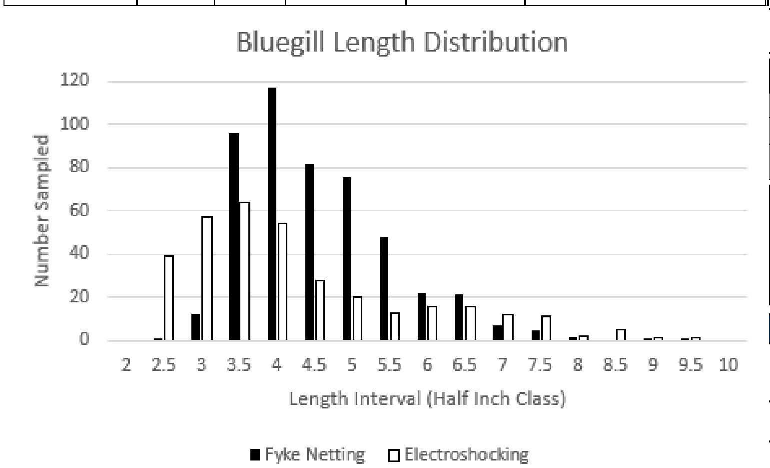
CPUE by Year			Historical Median
2010	2015	2021	
394	324	243	320.3

BLUEGILL ELECTROFISHING SIZE STRUCTURE (PSD) TRENDS

PSD by Year			Historical Median
2010	2015	2021	
19	26	20	21.7

2021 BLUEGILL GROWTH METRICS

Number Measured	Length Bin (inches)	Mean Age	Age Range	Percentile Rank	Growth Rating
11	5.5 - 6.4	4.3	3 - 6	55.7	Moderate
10	6.5 - 7.4	4.8	4 -6	66.5	Moderate

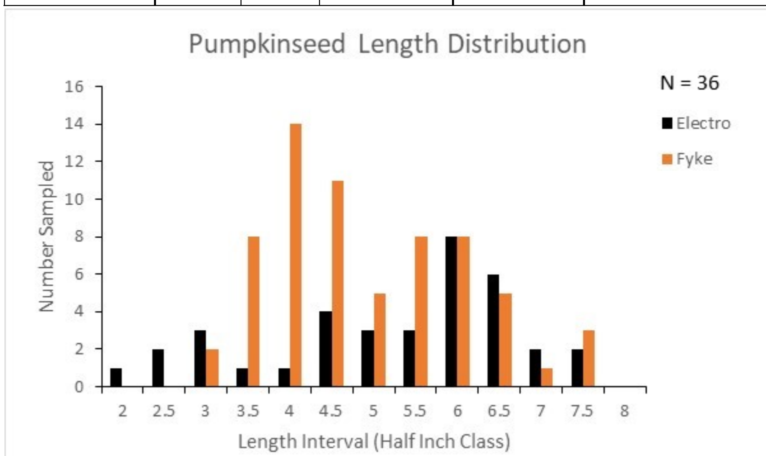


Pumpkinseed

- Both fyke netting and electrofishing can be useful gears to sample Pumpkinseed. Therefore, results from both gears will be presented.

2021 PUMPINSEED SIZE STRUCTURE METRICS									
Gear	**Number Measured**	**Average Length (inches)**	**Length Range (inches)**	**Stock and Quality Sizes (inches)**	**Stock Number**	**Quality Number**	**PSD**	**Percentile Rank**	**Size Rating**
Fyke Netting	65	5.1	3.2 - 7.7	3.0 and 6.0 inches	65	17	26	30th	Low
Electrofishing	36	5.4	2.4 - 7.9	3.0 and 6.0 inches	33	18	55	71th	Moderate

PUMPKINSEED FYKE NETTING CPUE (NUMBER PER NET NIGHT) TRENDS					
2021 Number Sampled	**2015**	**2021**	**Historical Median**	**2021 Statewide Percentile Rank**	**2021 Abundance Rating**
65	1.1	0.8	0.95	50th	Moderate



PUMPKINSEED FYKE NETTING SIZE STRUCTURE (PSD) TRENDS		
PSD by Year		**Historical Median**
2015	**2021**	
-	26	-

2021 PUMPKINSEED ELECTROFISHING CPUE (NUMBER PER MILE)						
CPUE Total	**Percentile Rank**	**Overall Abundance Rating**	**Length Index**	**Length Index CPUE**	**Length Index Percentile Rank**	**Length Index Abundance Rating**
36	88th	High	≥ 7.0 inches	7	93rd	High

PUMPKINSEED ELECTROFISHING CPUE (NUMBER PER MILE) TRENDS		
CPUE by Year		**Historical Median**
2015	**2021**	
59	36	47.5

PUMPKINSEED ELECTROFISHING SIZE STRUCTURE (PSD) TRENDS		
PSD by Year		**Historical Median**
2015	**2021**	
44	55	49.5

Panfish Summary

- Catch rates of Black Crappies in Silver Lake were moderate in the 2021 spring fyke netting survey being 3.3 per net night. Catch rates from the fyke netting and electrofishing survey ranked out in the 50th percentiles when compared to lakes throughout Wisconsin. Black cCappie populations are typically variable through time and driven by strong year classes.

- Black Crappie PSD in the spring 2021 fyke netting survey was poor, with the majority of fish sampled coming from the 2019 year class. The 2019 year class appears to be a strong one made up of 4 –6 inch fish. Black Crappies above average growth rates should put these fish in the quality size of 8 inches by fall of 2021. Another good year class appears to be from 2017 and these fish are in the 10 inch range. Neither one of these surveys are designed to target crappies and most of the fish we sample are incidental either prior to or after they spawn.

- Catch rates of Bluegill ≥ 3 inches in Silver Lake were high in the spring electrofishing survey at 243 per mile of electrofishing. Ranking out in the 92nd percentiles when compared to lakes throughout Wisconsin. Even though numbers were high in this survey they are still down from surveys conducted in 2015 and 2010 (324 and 394 per mile).

- Bluegills PSD values in the 2021 spring fyke netting (12) and spring electrofishing (20) both show the size structure of Bluegills in Silver Lake currently is poor. Furthermore, Bluegill growth rates are moderate as they grow to 6 inches in roughly 4 - 5 years. Bluegill abundance for Silver Lake appears to be good, but it may be a year or two until it produces a good number of quality size fish.

- Catch rates of Pumpkinseed were high in the spring electrofishing survey at 36 per mile of electrofishing (88th percentile), but not as high as the 59 per mile in the 2015 survey.

- Pumpkinseed PSD values have been good over the last couple surveys and provide an opportunity for harvestable fish (≥6 inches).

- Netting surveys don’t always give us a good assessment of the Yellow Perch population. Generally, the perch population in Silver Lake appears to be relatively low at this time with smaller fish less than 8 inches making up most of it.

- When it comes to spawning habitat, Yellow Perch rely heavily on wood in the form of trees and branches to lay their eggs on. Silver Lake is lacking in this type of habitat.

Final Summary

Northern Pike:

- Silver Lake supports a moderate density Northern Pike population. Plenty of cold water along with ample forage should allow for Northern Pike to grow to 30+ inches. Though we only sampled one.
- Areas of Silver lake that have shallow water and emergent vegetation should be protected or enhanced to ensure Northern Pike have abundant spawning and nursery habitat in the future.
- Northern Pike in Silver Lake can be difficult to sample because the lake is deep, lacks good Northern Pike spawning habitat and takes a longer time to warm up at ice out for optimal spawning conditions. In 2021, we believe many of the larger fish went into Irogami Lake to spawn, as water levels were high enough to allow this.

Walleye:

- Silver Lake supports a very low density Walleye population due to stocking efforts from the public. Only eight were sampled during fyke netting and none during electrofishing. Habitat for Walleyes in Silver lake is minimal and the only documented natural reproduction was in 1966, despite regular stocking from 1935-1990. The last recorded stocking of Walleyes was in 2011 and two of those fish were caught during this survey. Both fish were females and in the 24 inch range.
- While anglers aren't likely to catch many Walleyes in the Silver Lake, Walleyes growth rates are average and we did sample one fish that was 27.3 inches.

Largemouth Bass:

- The Largemouth Bass fishery on Silver Lake has been and continues to be one of the best in Waushara County and keeping the CPUE of 3 inch and larger fish between 35–70 fish/mile is recommended.
- The size structure continues to be in good shape with a PSD=58 and RSD = 30. The PSD has fluctuated from 52 in 2015 to 70 in 2010 and managing for between 50-70 is our goal.

Bluegill:

- Bluegill are the dominant panfish in Silver Lake and are present in good numbers. The CPUE of fish 3 inches and larger was 243/mile, which is down from 394 in 2010 and 324 in 2015, but still in the management zone of 200-300/mile we like to see in this area.
- Size structure of Bluegill was low with a PSD = 12. We would like to see that PSD from 40-50. Growth rates appear to be average with fish reaching 6 inches in a little over four years.

Black Crappie:

- Neither of these surveys were targeting Black Crappies but comparisons are made to other like surveys around the state.
- Black Crappie are well known for their cyclical populations and Silver Lake is no exception. There appears to be a good year classes from 2019 and 2017. Growth rates are average for smaller fish, but improve as the fish reach around 8 inches.

Pumpkinseed:

- Pumpkinseed densities were high and size structure is good compared to other waters in the state. We don't manage for Pumpkinseed, but they do provide a fishing/harvest opportunity for anglers at their current numbers. Like all fish, Pumpkinseed would benefit from nearshore habitat.

Yellow Perch:

- Yellow Perch were present in our sampling but in low densities. Neither of these surveys directly target Yellow Perch, but if a healthy population exist it will show. Numbers are compared to other like surveys from around the state. Perch rely heavily on the proper type of spawning habitat such as wood to sustain a healthy population. We have seen positive responses on area lake after wood has been added.

Recommendations:

- Change the Northern Pike regulation on Silver Lake to match the regulation on Irogami Lake may be a benefit given the potential for movement between the lakes. The Irogami Lake regulation changed on April 1, 2022 from a minimum length of 26 inch and 2 fish bag limit to no fish between 25-35 inches and a 2 fish bag limit.
- Manage Largemouth Bass densities at or near current levels to provide quality bass fishing and maintain panfish densities to avoid overabundance.
- Optimal fish habitat is very limited in most parts of Silver Lake. Interested lakeshore owners should promote a diverse mix of native emergent, floating and submergent vegetation as well as add wood in the form of tree drops, fish sticks or dock hab along their shoreline.

F

APPENDIX F

Comment Response Document for the Official First Draft

Eddie Heath

From: Johnson, Ted M - DNR <TedM.Johnson@wisconsin.gov>
Sent: Friday, September 1, 2023 2:31 PM
To: Mark Magnusson
Cc: Eddie Heath; Kolasinski, Christopher E - DNR
Subject: Approval of 2023 Comprehensive Lake Management Plan

Hello Mark & Eddie,

Please consider this email as formal department approval for your Comprehensive Lake Management Plan. The Department appreciates the hard work necessary to complete this process. I look forward to working with you on implementation in the future.

If you are planning to purse a large-scale AIS Control Grant this year, I recommend that we discuss the details of what you propose to do in the relatively near future.

Sincerely,

Ted

We are committed to service excellence.
Visit our survey at http://dnr.wi.gov/customersurvey to evaluate how I did.

Ted M. Johnson
Lake Biologist – Bureau of Water Quality – Eastern District
Wisconsin Department of Natural Resources
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