Crooked Lake Area Lakes

Oconto County, Wisconsin

Comprehensive Management Plan

December 2018

Sponsored by:

Crooked Lake Area Lakes Protection & Rehabilitation District

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Lake Management Planning

Crooked Lake Area Lakes

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B. Stakeholder Survey Response Charts and Comments
C. Water Quality Data
D. Watershed Analysis WiLMS Results
E. WDNR Aquatic Herbicide Regulations FAQ & WDNR Chemical Fact Sheets
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1.0 INTRODUCTION

Crooked Lake, Oconto County, is a 166-acre drainage lake with a max depth of 37 feet and a mean depth of 10 feet. Gilkey and Bass Lakes, 23 and 14 acres, are smaller lakes directly connected to Crooked Lake. At the time of this report, the most current orthophoto (aerial photograph) was from the *National Agriculture Imagery Program (NAIP*) collected in June 2015. Based upon heads-up digitizing the water level from that photo, the lake was determined to be the listed acres. Gilkey Lake has a max depth of 6 feet and a mean depth of 3 feet. Bass Lake has a max depth of 11 feet and a mean depth of 4 feet. All three lakes have a relatively small watershed when compared to the size of the lakes. Both Gilkey and Bass Lakes contain 24 native plant species, of which water bulrush and fern-leaf pondweed is the most common plant, respectively. Crooked Lake contains 37 native plant species, of which common waterweed is the most common plant. Two exotic plant species are known to exist in the system.

Field Survey Notes

The Crooked Lake Area Lakes have a wide variety of native vegetation with moderately clear water. The presence of Robbins' spikerush found in Gilkey Lake speaks to the relatively pristine nature of the system.

Photograph 1.0-1. Crooked Lake, Oconto

Lakes at a Glance – Crooked Lake Area Lakes

		Bass Lake	Crooked Lake	Gilkey Lake
Morphology	Acreage	14	166	23
	Max. Depth (ft)	11	37	6
	Volume (Acre-ft)	54	1,663	62
	Mean Depth (ft)	4	10	3
Vegetation	Number of Native Species	24	37	24
	Non-Native Species	Eurasian watermilfoil, curly-leaf pondweed	Eurasian watermilfoil, curly-leaf pondweed	Eurasian watermilfoil
	Threatened/Special Concern Species	-	-	Robbins' spikerush (*Eleocharis robbinsii*)
Water Quality	Trophic State	Oligo-mesotrophic	Oligo-mesotrophic	Lower mesotrophic
	Limiting Nutrient	Phosphorus	Phosphorus	Phosphorus
	pH	8.2	8.1	8.1
	Sensitivity to Acid Rain	Not sensitive	Not sensitive	Not sensitive
	Watershed to Lake Area Ratio	5:1	8:1	10:1

The Crooked Lake Area Lakes Protection & Rehabilitation District (CLALPRD) was formed in 2004 to take advantage of the opportunities a District offers under Chapter 33 (Public Inland Waters) of the Wisconsin State Statues. The purpose of the District is to maintain, protect, and improve the quality of lakes for the landowners and those that use the lake for recreation purposes. The opportunities a District offers include applying for grants, conducting surveys and studies, implementing various lake treatment and other quality improvement projects. The District is funded by the property owners and run by a group of commissioners that hold regular open meetings throughout the year. The commissioners are elected by the property owners with additional appointees from the Town of Riverview and Oconto County.

The CLALPRD has sponsored several projects to manage the ecosystem, including a lake management planning project in 1993 (LPL-208), an aquatic plant management plan in 2006 (AEPP-026-06), and an aquatic plant monitoring, control and education project commenced in 2007 (ACEI-027-08). The later project completed an Aquatic Plant Management Plan that was approved by the WDNR in June 2012. In cooperation with the USFS, a tree-drop project was conducted in Gilkey Lakes to improve in-lake fish and wildlife habitat.

EWM was first discovered in Crooked Lake in 2002 and has undergone management since 2008. EWM populations have been professionally mapped since 2011, including the monitoring of herbicide treatments and professional hand-harvesting efforts. A pioneer population of CLP was first detected in the system in June 2014.

Crooked Lake contains a dam on system's outlet (Map 1). This Oconto County-owned dam was constructed in 1942 and repairs were made in 1984. The dam helps keep lakes levels two feet higher than if the lake were in a natural state and has a discharge rate of 85 cubic feet per second. As mentioned in the 1993 management plan, the water moving through Crooked Lake from the inlet to the outlet does not seem to impact the lake, overall, due to the inlet and outlet being on the northern portion of the lake.

Photograph 1.0-2. Crooked Lake outlet post-dam construction. Photo courtesy of WDNR.

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 on the lake group's website.

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

Kick-off Meeting

On July 16, 2016, a project kick-off meeting was held at the Crooked Lake Community Center to introduce the project to the general public. The meeting was announced through a mailing and personal contact by CLALPRD board members. The approximately 27 attendees observed a presentation given by Eddie Heath, an aquatic ecologist with Onterra. Mr. Heath's presentation started with an educational component regarding general lake ecology and ended with a detailed description of the project including opportunities for stakeholders to be involved. The presentation was followed by a question and answer session.

Planning Committee Meeting I

On June 12, 2017, Mr. Eddie Heath of Onterra met with five members of the Crooked Lake Planning Committee for nearly 3 hours. In advance of the meeting, attendees were provided an early draft of the study report sections 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 aquatic invasive species (AIS) control strategies, aquatic plant inventories, water quality analysis, shoreland conditions, coarse woody habitats, and watershed modeling were presented and discussed. Many concerns were raised by the committee, including nuisance levels of aquatic plants, boating safety, and AIS populations within the lake.

Planning Committee Meeting II

On July 17, 2017, Mr. Eddie Heath met with four members of the Planning Committee to develop management goals and actions for the Crooked Lake management plan. Prior to the meeting, a draft outline of the Implementation Plan Section was created and served as the framework for the meeting.

Management Plan Review and Adoption Process

A preliminary draft of the Comprehensive Lake Management Plan was provided to the Planning Committee and the Board of Directors in mid-February, 2018.

In mid-May 2018, an official first draft of the CLALPRD's Comprehensive Management Plan was supplied to the WDNR, Great Lakes Indian Fish and Wildlife Commission, Oconto County, Town of River, and CLALPRD's Planning Committee for official review.

In early-August 2018, official WDNR comments were provided by Brenda Nordin (local lakes biologist) and Christopher Long (local fisheries biologist). Their comments and how they are addressed in the final plan are contained in Appendix F.

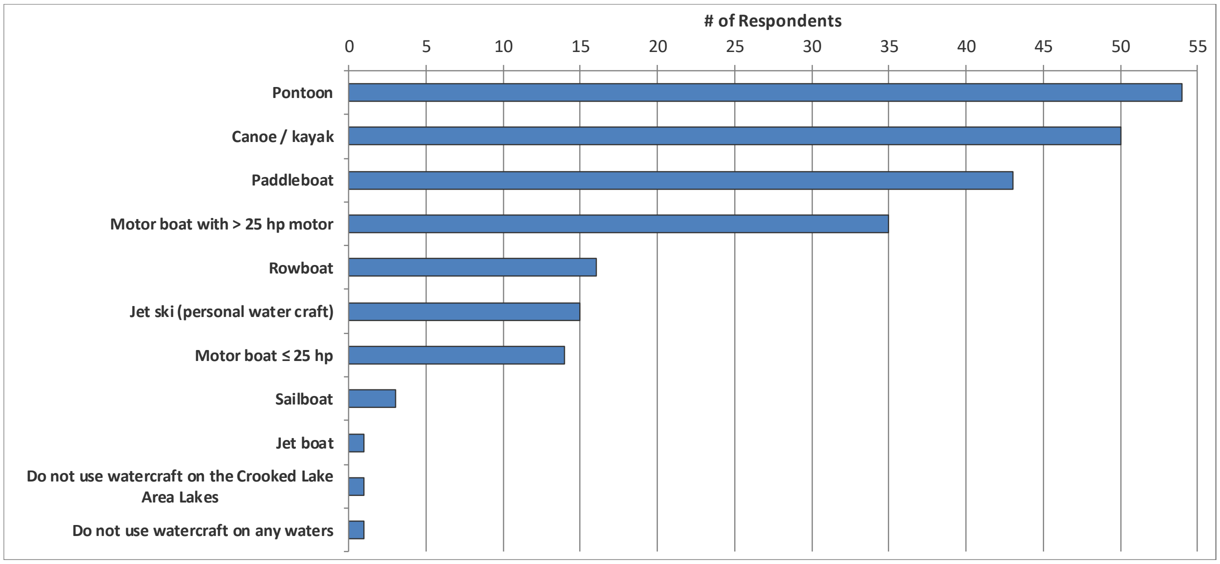
Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to CLALPRD members. The survey was designed by Onterra staff and the CLALPRD planning committee and reviewed by a WDNR social scientist. During January 2017, the eight-page, 35-question survey was posted online through Survey Monkey for property owners to answer electronically. If requested, a hard copy was sent to the property owner with a self-addressed stamped envelope for returning the survey anonymously. The returned hardcopy surveys were entered into the online version by a CLALPRD volunteer for analysis. Forty-four percent of the surveys were returned. Please note that typically a benchmark of a 60% response rate is required to portray population projections accurately, and make conclusions with statistical validity. The data were analyzed and summarized by Onterra for use at the planning meetings and within the management plan. The full survey and results can be found in Appendix B, while discussion of those results is integrated within the appropriate sections of the management plan and a general summary is discussed below.

Based upon the results of the Stakeholder Survey, much was learned about the people that use and care for the Crooked Lake Area Lakes. The majority of stakeholder respondents (44%) visit on weekends throughout the year, 18% live on the lake during the summer months only, and 15% are year-round residents. 68% of stakeholder respondents have owned their property for over 15 years, and 43% have owned their property for over 25 years.

The following sections (Water Quality, Watershed, Aquatic Plants and Fisheries Data Integration) discuss the stakeholder survey data with respect these particular topics. Figures 2.0-1 and 2.0-2 highlight several other questions found within this survey. More than half of survey respondents indicate that they use either a pontoon boat, canoe/kayak, paddleboat, or a combination of these three vessels on the lakes (Question 16). Larger motor boats were also a popular option. On a relatively small lakes such as Crooked Lake Area Lakes, the importance of responsible boating activities is increased. The need for responsible boating increases during weekends, holidays, and during times of nice weather or good fishing conditions as well, due to increased traffic on the lake. As seen on Question 19, several of the top recreational activities on the lake involve boat use. Watercraft traffic was listed as the top factor potentially impacting the lakes in a negative manner (Question 25), and it was ranked 1st on a list of stakeholder's top concerns regarding the lake (Question 26).

Question 16: What types of watercraft do you currently use on the Crooked Lake Area Lakes?



Question 19: Please rank up to three activities that are important reasons for owning your property on or near the Crooked Lake Area Lakes.

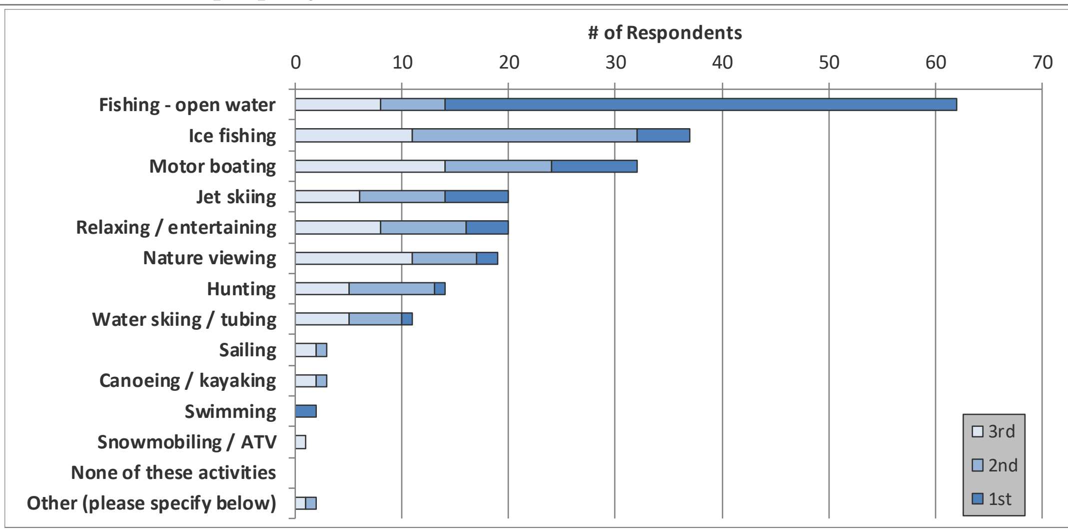
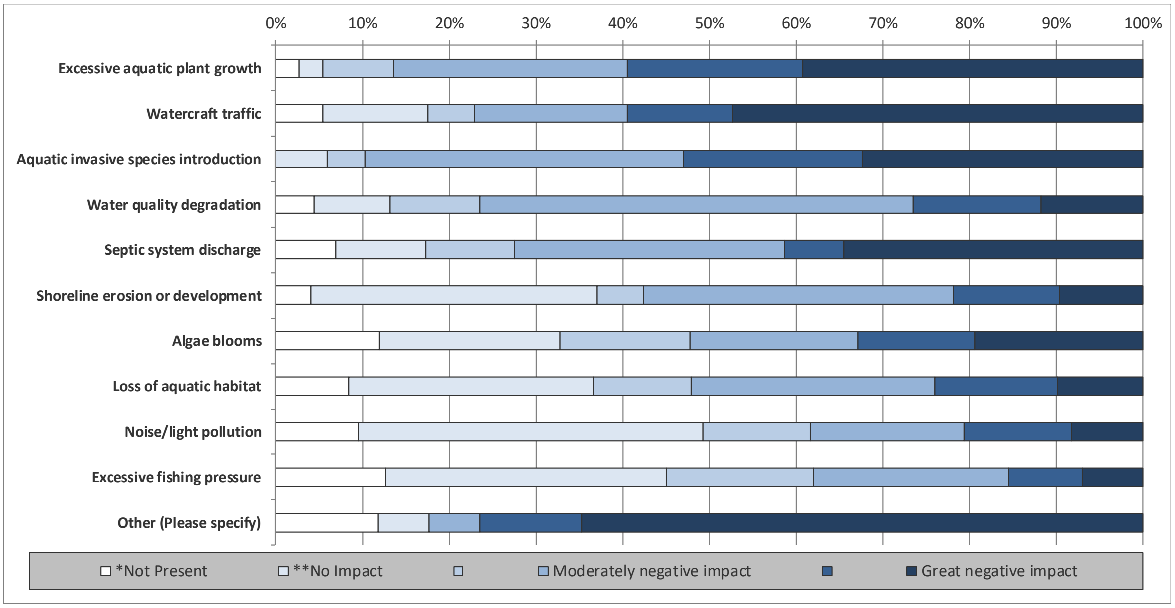


Figure 2.0-1. Select survey responses from the Crooked Lake Area Lakes Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Question 25: To what level do you believe these factors may be negatively impacting the Crooked Lake Area Lakes?



Question 26: Please rank your top three concerns regarding the Crooked Lake Area Lakes.

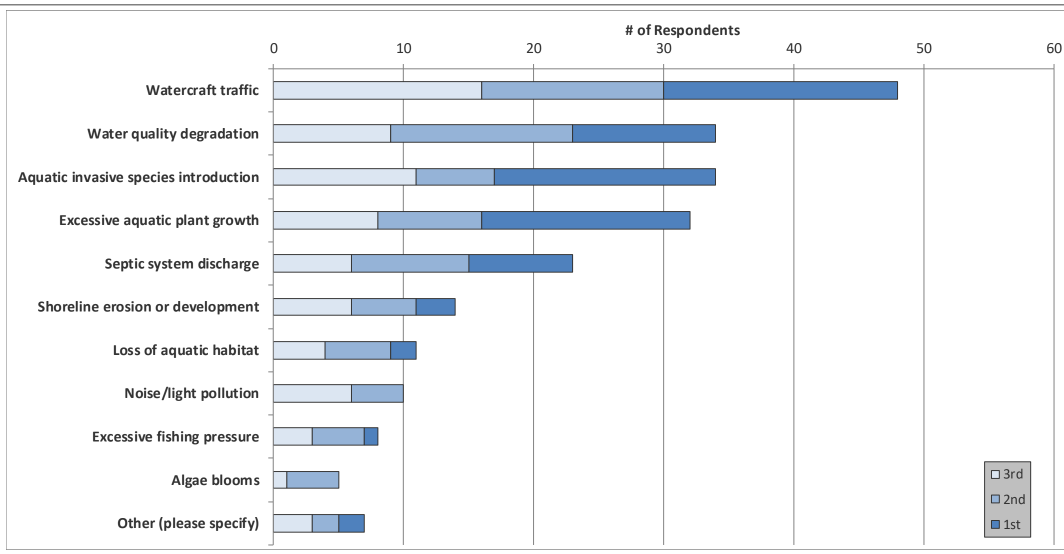


Figure 2.0-2. Select survey responses from the Crooked Lake Area Lakes Stakeholder Survey, continued. Additional questions and response charts may be found in Appendix B.

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Primer on Water Quality Parameters and Data Analysis

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 analysis 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 the Crooked Lake Area Lakes is compared to other lakes in the state with similar characteristics as well as to lakes within the northern region (Appendix C). 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 Crooked Lake Area Lakes' 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 quadrates (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, and 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 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 2014 Consolidated Assessment and Listing Methodology* (WDNR 2013) 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 the Crooked Lake Area Lakes 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, hydrology. An equation developed by 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, small watershed and hydrology, Crooked Lake is classified as a deep, headwater drainage lake (category 3 on Figure 3.1-1). With the same scheme, Gilkey and Bass Lakes are shallow, headwater drainage lakes (category 2 on Figure 3.1-1). However, due to the sizes of their watersheds and the lack of inlets, Gilkey and Bas lakes are considered *drained* lakes.

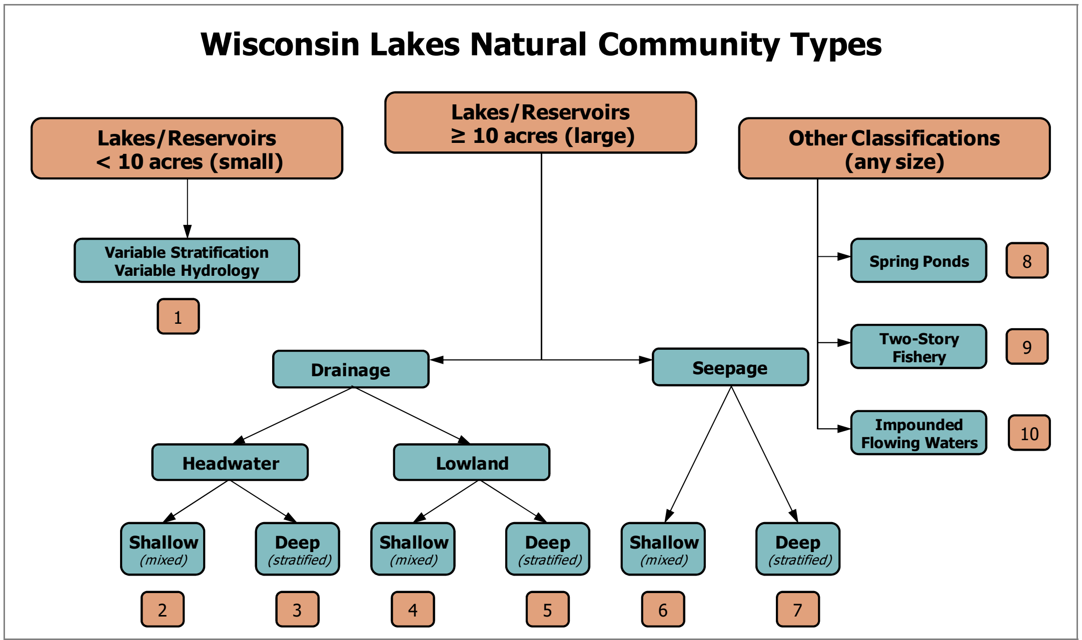


Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2013A.

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

Figure 3.1-2. Location of the Crooked Lake Area Lakes within the ecoregions of Wisconsin. After Nichols 1999.

The Wisconsin 2014 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 the Crooked Lake Area Lakes are displayed in Figures 3.1-3 - 3.1-19. 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, as 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.

Crooked Lake Area Lakes Water Quality Analysis

Historical water quality data are available from Crooked Lake; however, very little historical water quality data are available from Gilkey and Bass Lakes. The lack of historical data for these lakes makes long-term trends analyses impossible, but an understanding of Gilkey and Bass Lakes' current state can be discerned from the 2016 water quality data collection. The data collected in 2016 can be compared against median values for lakes within the NLF ecoregion and lakes throughout Wisconsin.

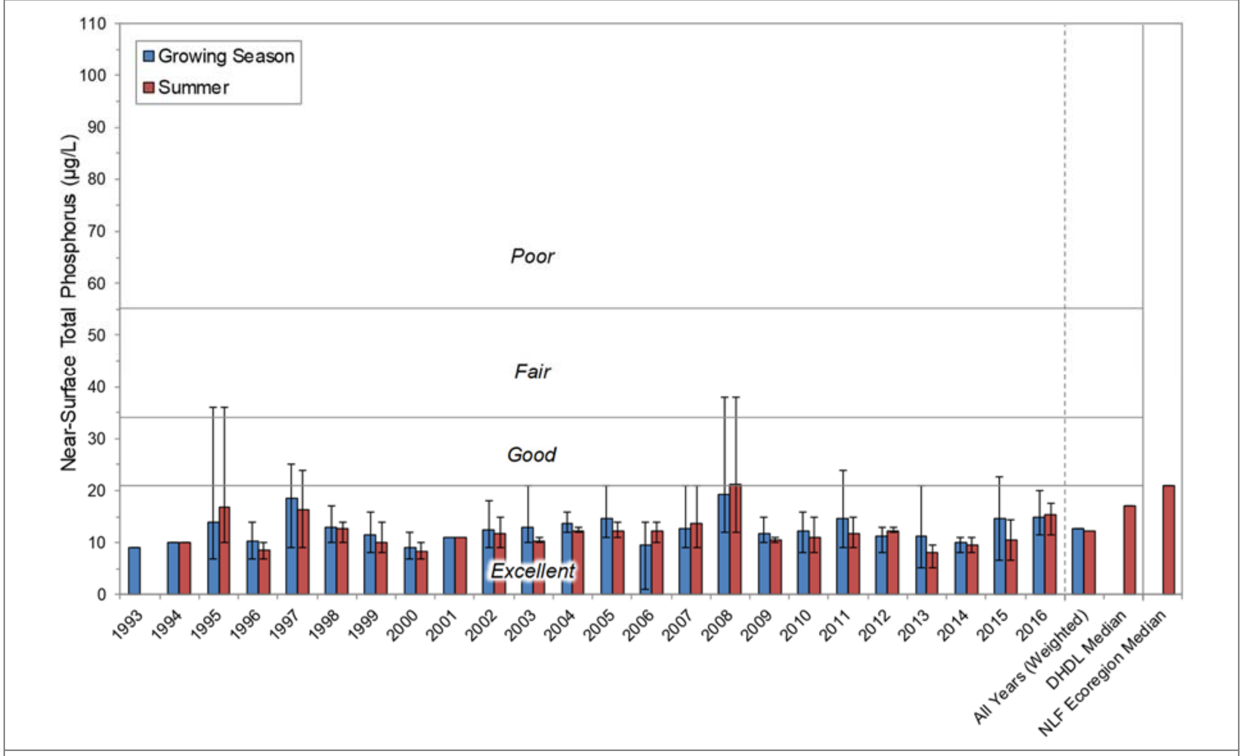


Figure 3.1-3. Crooked Lake, state-wide deep headwater drainage lakes, and regional total phosphorus concentrations. Mean values calculated with summer month surface sample data along with spring through fall (growing season) surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Crooked Lake Long-term Trends

Near-surface total phosphorus data from Crooked Lake are available annually from 1993 to 2016 (Figure 3.1-3). Average summer total phosphorus concentrations ranged from 8.1 µg/L in 2013 to 21.3 µg/L in 2008. The weighted summer average total phosphorus concentration is 12.2 µg/L and falls into the *excellent* category for Wisconsin's deep, headwater drainage lakes and indicates that Crooked Lake's phosphorus concentration are lower than the NLF ecoregion median. Simple linear regression of total phosphorus concentrations over time revealed that while average total phosphorus concentrations were variable, there are no statistically valid trends in total phosphorus concentration in Crooked Lake over the time periods for which data are available.

Chlorophyll-*a* concentration data are available from Crooked Lake annually from 1993 to 2016 (Figure 3.1-4). Average summer chlorophyll-*a* concentrations ranged from 1.1 µg/L in 1999 to 4.2 µg/L in 2008. The weighted summer average chlorophyll-a concentration is 2.9 µg/L and falls below the median concentrations for deep, headwater drainage lakes in Wisconsin and all lake types within the NLF ecoregion. Similarly, while average chlorophyll-*a* concentrations were variable, simple linear regression of chlorophyll-*a* concentrations over time revealed no statistically valid trends in chlorophyll-*a* concentration in Crooked Lake over the time periods for which data are available.

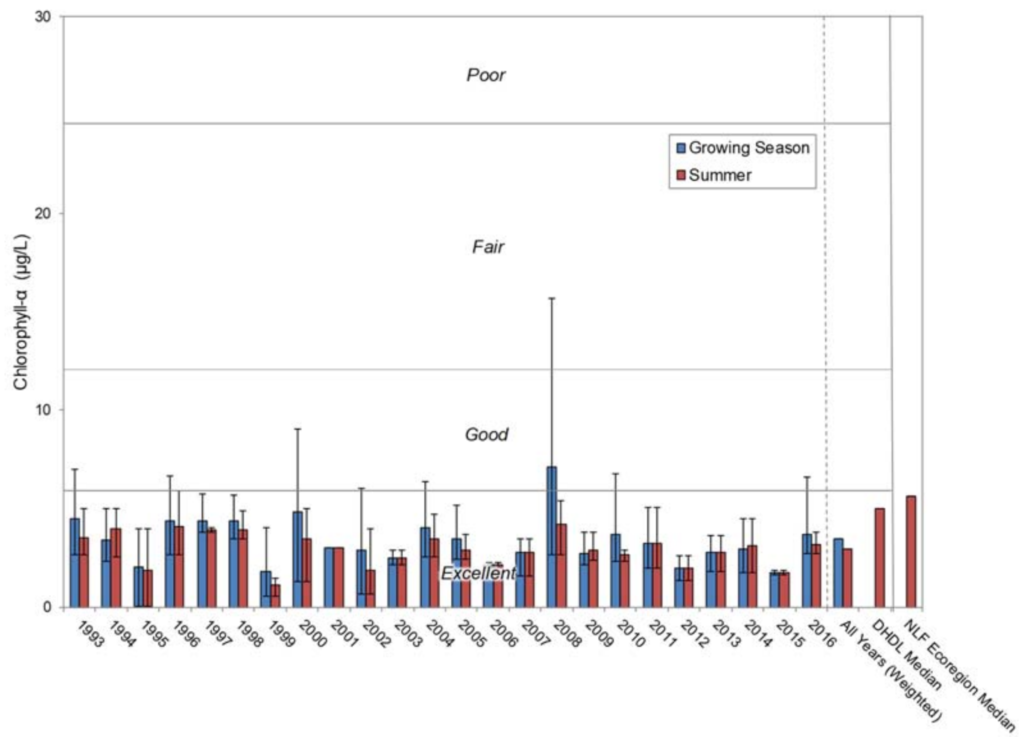


Figure 3.1-4. Crooked Lake, state-wide deep headwater drainage lakes, and regional chlorophyll-a concentrations. Mean values calculated with summer month surface sample data along with spring through fall (growing season) surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Annual Secchi disk transparency data are available from Crooked Lake from 1976 and from 1993 to 2016 (Figure 3.1-5). Average summer Secchi disk depth ranged from 7.2 feet in 2012 to 14.8 feet in 1998. The weighted summer average Secchi disk depth is 10.5 feet, which falls into the *excellent* category for Secchi disk depth in Wisconsin's deep, headwater drainage lakes. The weighted average summer Secchi disk depth is slightly less than the average for other deep, headwater drainage lakes in Wisconsin and exceeded the median value for all lake types in the NLF ecoregion.

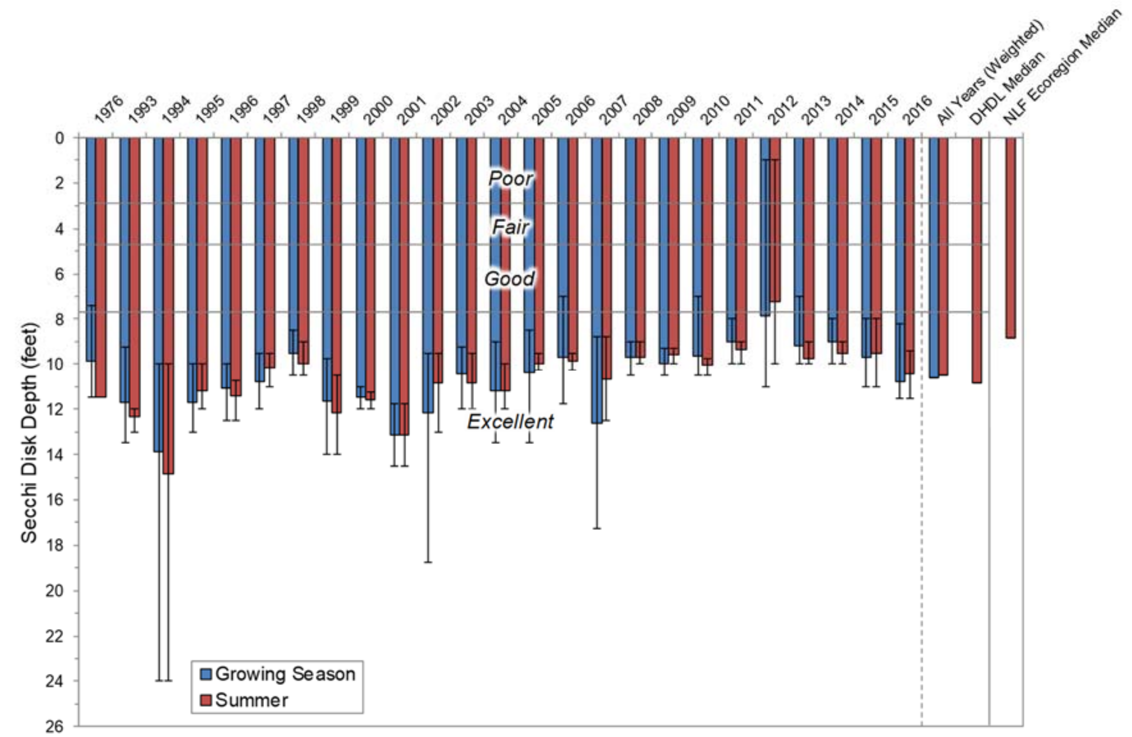


Figure 3.1-5. Crooked Lake, state-wide deep headwater drainage lakes, and regional Secchi disk clarity values. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Linear regression analysis was completed on the summer Secchi disk depth data from 1993 to 2016 (Figure 3.1-6). While this linear regression yielded a low r^2 value of 0.2704, indicating high variability in the dataset, it yielded a *p*-value of < 0.001 indicating that Secchi disk depth has declined in Crooked Lake over the period. It is unclear why water clarity has decreased in Crooked Lake over time as total phosphorus and chlorophyll-*a* concentration have not seen statistically valid decreasing trends over essentially the same period.

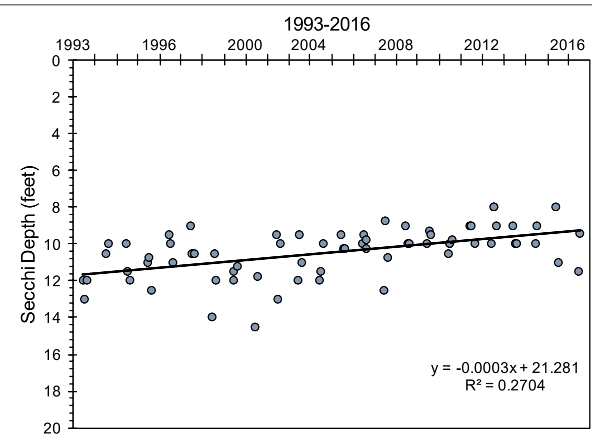


Figure 3.1-6. Simple linear regression of Secchi disk depth over time within Crooked Lake. Trend is statistically significant (p-value <0.001).

Abiotic suspended particulates, such as sediment, can also cause a reduction in water clarity. However, *total suspended solids*, a measure of both biotic and abiotic suspended particles within the water, were low in Crooked Lake in 2016, indicating minimal amounts of suspended material within the water. While suspended particles are minimal in the lakes, water clarity can also be influenced by dissolved compounds within the water. Many lakes in the northern region of Wisconsin contain higher concentrations of natural dissolved organic acids that originate from decomposing plant material within wetlands in the lake's watershed. In higher concentrations, these dissolved organic compounds give the water a tea-like color or staining and decrease water clarity.

A measure of water clarity once all 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 values measured from Crooked Lake in 2016 averaged 10 SU (standard units) indicating the lake's water is *clear to slightly colored* and that the lake's water clarity is primarily influenced by phytoplankton and suspended sediments (Figure 3.1-10).

Gilkey and Bass Lakes Total Phosphorus

As stated previously, very little historical data are available for Gilkey or Bass Lakes, making long-term trends analysis impossible. Total phosphorus concentrations were measured four times in both lakes in 2016 and three times in 1994 (Figure 3.1-7). The data collected in 1994 are similar to the data collected in 2016. In 2016, the average summer total phosphorus concentrations in Gilkey and Bas lakes were 18.1 µg/L and 18.5 µg/L, respectively. The average summer total phosphorus concentrations for both lakes fall within the excellent category for shallow, headwater drainage lakes in Wisconsin and are slightly lower than the median concentration for all lakes within the NLF ecoregion.

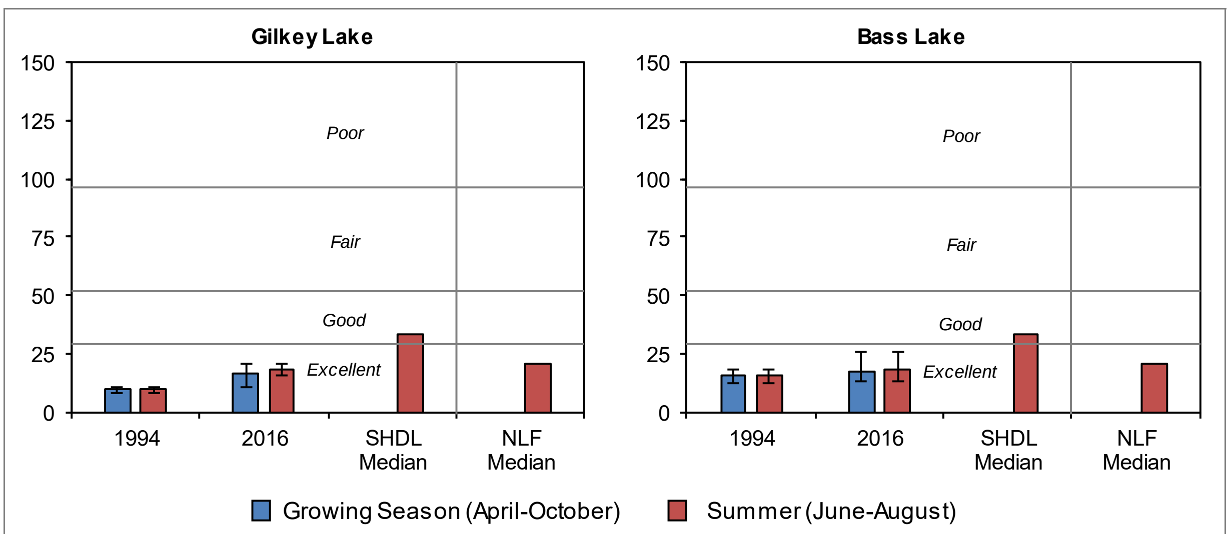


Figure 3.1-7. Gilkey and Bass Lakes, state-wide shallow headwater drainage lakes, and regional total phosphorus concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Gilkey and Bass Lakes Chlorophyll-*a*

Chlorophyll-*a* concentrations were measured four times in both lakes in 2016, twice in Gilkey Lake in 1994, and three times in Bass Lake in 1994 (Figure 3.1-8). Again, the data collected in 1994 are similar to the data collected in 2016. In 2016, the average summer chlorophyll-*a* concentrations in Gilkey and Bass Lakes were 2.9 µg/L and 2.3 µg/L, respectively. The average summer chlorophyll-*a* concentrations for both lakes fall within the excellent category for shallow, headwater drainage lakes in Wisconsin and are lower than the median concentration for both shallow, headwater drainage lakes in Wisconsin and all lakes within the NLF ecoregion.

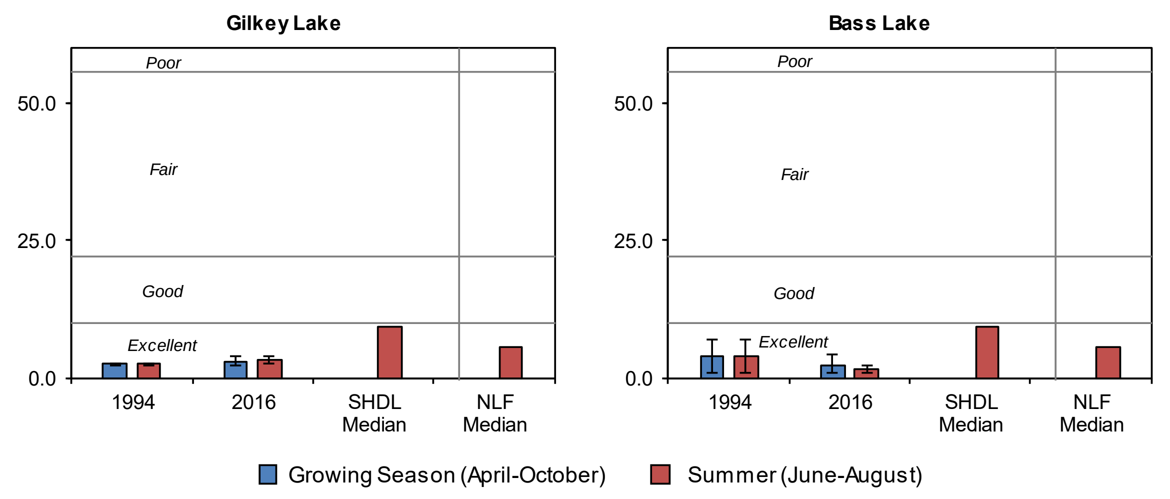


Figure 3.1-8. Gilkey and Bass Lakes, state-wide shallow headwater drainage lakes, and regional chlorophyll-a concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Gilkey and Bass Lakes Water Clarity

Water clarity was measured using a Secchi disk at both lakes in 2016 (Figure 3.1-9). In Gilkey Lake, the Secchi disk measurement hit bottom at all sampling events except in April. Because these measurements hit bottom, they cannot be included within the seasonal average. The data collected on Gilkey Lake in 1993 falls into the *excellent* category for shallow, headwater drainage lakes in Wisconsin and is less than the median value for lakes within the NLF ecoregion. The average 2016 summer Secchi disk depth for Bass Lake falls into the *excellent* category for shallow, headwater drainage lakes in Wisconsin and is nearly identical to the median value for lakes within the NLF ecoregion. The data collected from 1992-1994 is very similar to the data collected in 2016.

Total suspended solids were low in both Gilkey and Bass Lakes in 2016, indicating minimal amounts of suspended material within the water.

Color was also measured in Gilkey and Bass Lakes during the spring and mid-summer. Gilkey Lake's samplings both resulted in a value of 10 Standard Units (SU). These values indicate that Gilkey Lake's water can be described as *clear to slightly colored* (UNH Center for Freshwater Biology 2014), and that the lake's water clarity is primarily influenced by phytoplankton and suspended sediments (Figure 3.1-10). Bass Lake's samplings both resulted in a value of 15 Standard Units (SU). These values indicate that Bass Lake's water can be described as *slightly* *colored* and that the lake's water clarity is also primarily influenced by phytoplankton and suspended sediments.

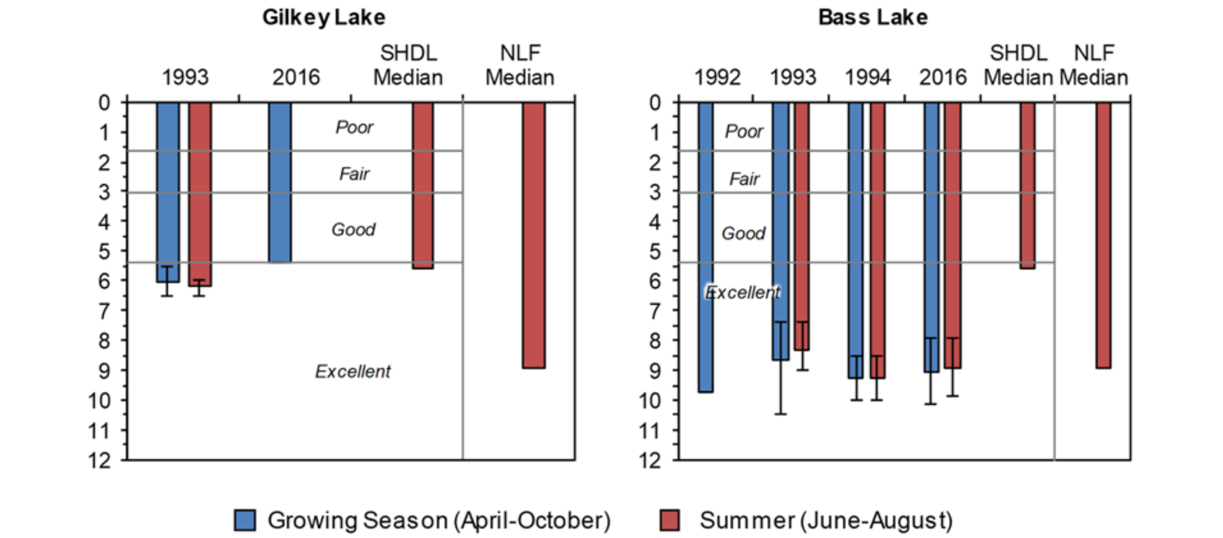


Figure 3.1-9. Gilkey and Bass Lakes, state-wide shallow headwater drainage lakes, and regional Secchi disk clarity values. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

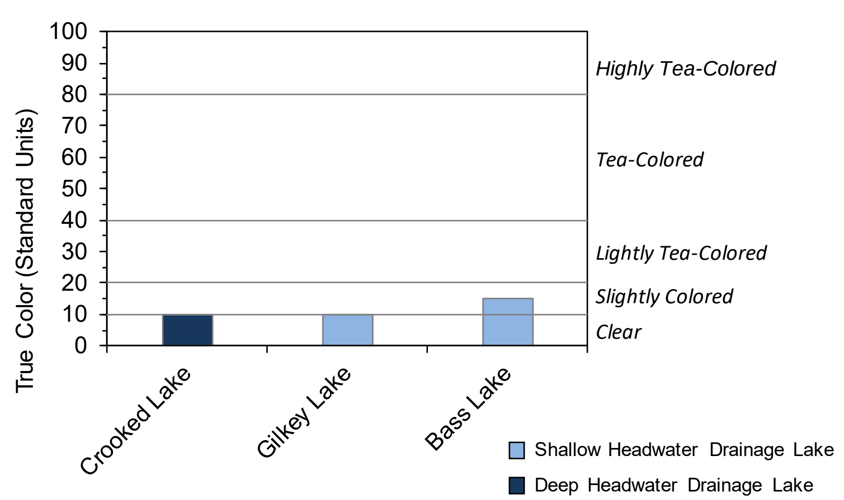


Figure 3.1-10. Crooked Lake Area Lakes true color values.

Limiting Plant Nutrient of Crooked Lake Area Lakes

Using midsummer nitrogen and phosphorus concentrations from Crooked Lake, a nitrogen:phosphorus ratio of 44:1 was calculated. Similarly, a nitrogen:phosphorus ratio of 39:1 and 40:1 were calculated on Gilkey and Bass Lakes, respectively. This finding indicates that the Crooked Lake Area Lakes are indeed phosphorus limited, as are the vast majority of Wisconsin lakes. In general, this means that cutting phosphorus inputs may limit plant growth within the lake.

Crooked Lake Area Lakes Trophic State

Figures 3.1-11 – 3.1-13 contain the TSI values for the Crooked Lake Area Lakes. These TSI values are calculated using summer near-surface total phosphorus, chlorophyll-*a*, and Secchi disk transparency data collected as part of this project along with available historical data. In general, the best values to use in assessing a lake's trophic state are chlorophyll-*a* and total phosphorus, as water clarity can be influenced by other factors other than phytoplankton such as dissolved organic compounds. The closer the calculated TSI values for these three parameters are to one another indicates a higher degree of correlation.

The weighted TSI values for total phosphorus and chlorophyll-*a* (and Secchi disk depth) in Crooked Lake indicate the lake is at present in an oligo-mesotrophic state (Figure 3.1-11). Crooked Lake's productivity is lower when compared to other deep, headwater drainage lakes in Wisconsin and other lakes within the NLF ecoregion.

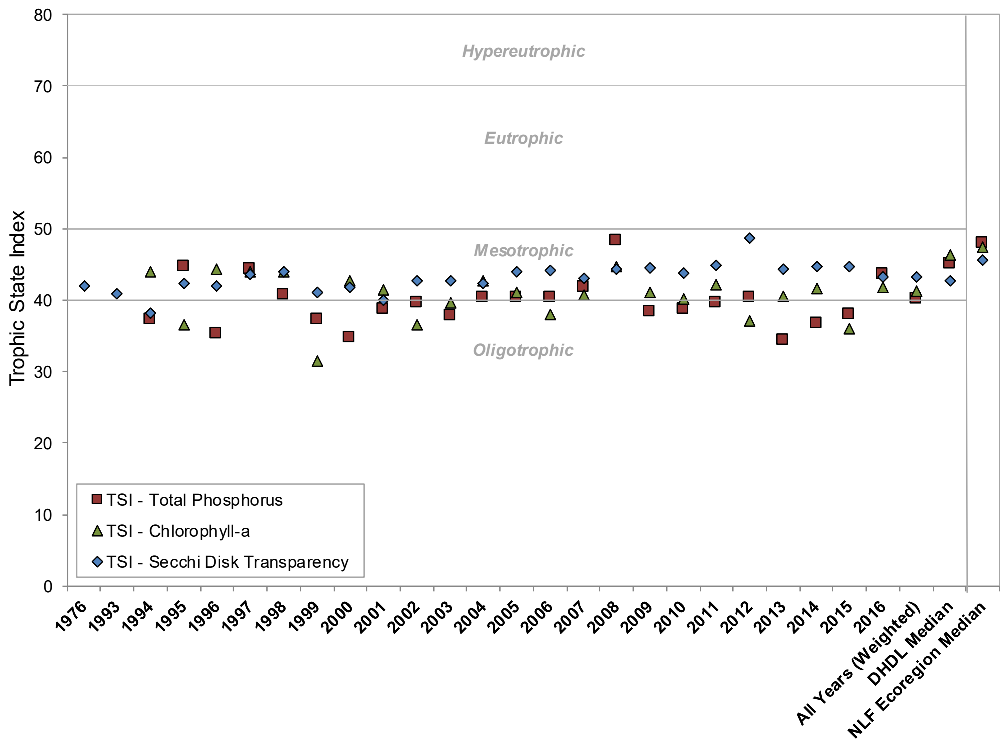


Figure 3.1-11. Crooked Lake, state-wide deep headwater drainage lakes, and regional Trophic State Index values. Values calculated with summer month surface sample data using WDNR PUB-WT-193.

The weighted TSI values for total phosphorus and chlorophyll-*a* in Gilkey Lake indicate the lake is at present in a mid to lower mesotrophic state (Figure 3.1-12). Crooked Lake's productivity is lower when compared to both other shallow, headwater drainage lakes in Wisconsin and other lakes within the NLF ecoregion.

The weighted TSI values for total phosphorus and chlorophyll-*a* in Bass Lake indicate the lake is at present in an oligo-mesotrophic state (Figure 3.1-12). Bass Lake's productivity is lower when compared to both other shallow, headwater drainage lakes in Wisconsin and other lakes within the NLF ecoregion.

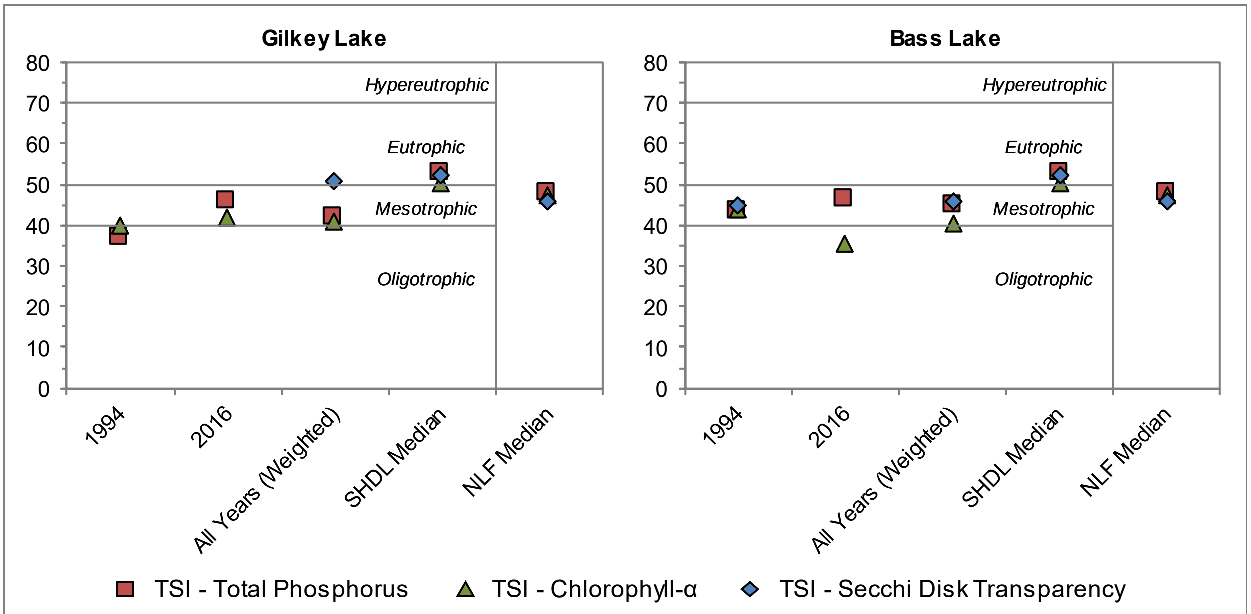


Figure 3.1-12. Gilkey and Bass Lakes, state-wide shallow headwater drainage lakes, and regional Trophic State Index values. Values calculated with summer month surface sample data using WDNR PUB-WT-193.

Dissolved Oxygen and Temperature in the Crooked Lake Area Lakes

Dissolved oxygen and temperature were measured during water quality sampling visits to the Crooked Lake Area Lakes by Onterra staff. Profiles depicting these data are displayed in Figures 3.1-13 – 3.1-15. These data indicate that only Crooked Lake consistently stratifies during the summer and during that time, the hypolimnion becomes anoxic. This is a typical occurrence in moderately productive lakes. These data also indicate that in Crooked and Gilkey lakes there was sufficient oxygen throughout the water column under the ice to support the fishery during late-winter sampling in these lakes. However, while oxygen levels in Bass Lake did not reach zero, levels were found to be less than 3.0 mg/L below three feet. During the winter months, fish can largely withstand dissolved oxygen levels as low as 3.0 mg/L, so the bulk of Bass Lake's volume was unavailable for fish during the February 2017 sampling event. Still, there is likely only limited impact to the fisheries as fish can migrate into large oxygenated volumes in Crooked Lake.

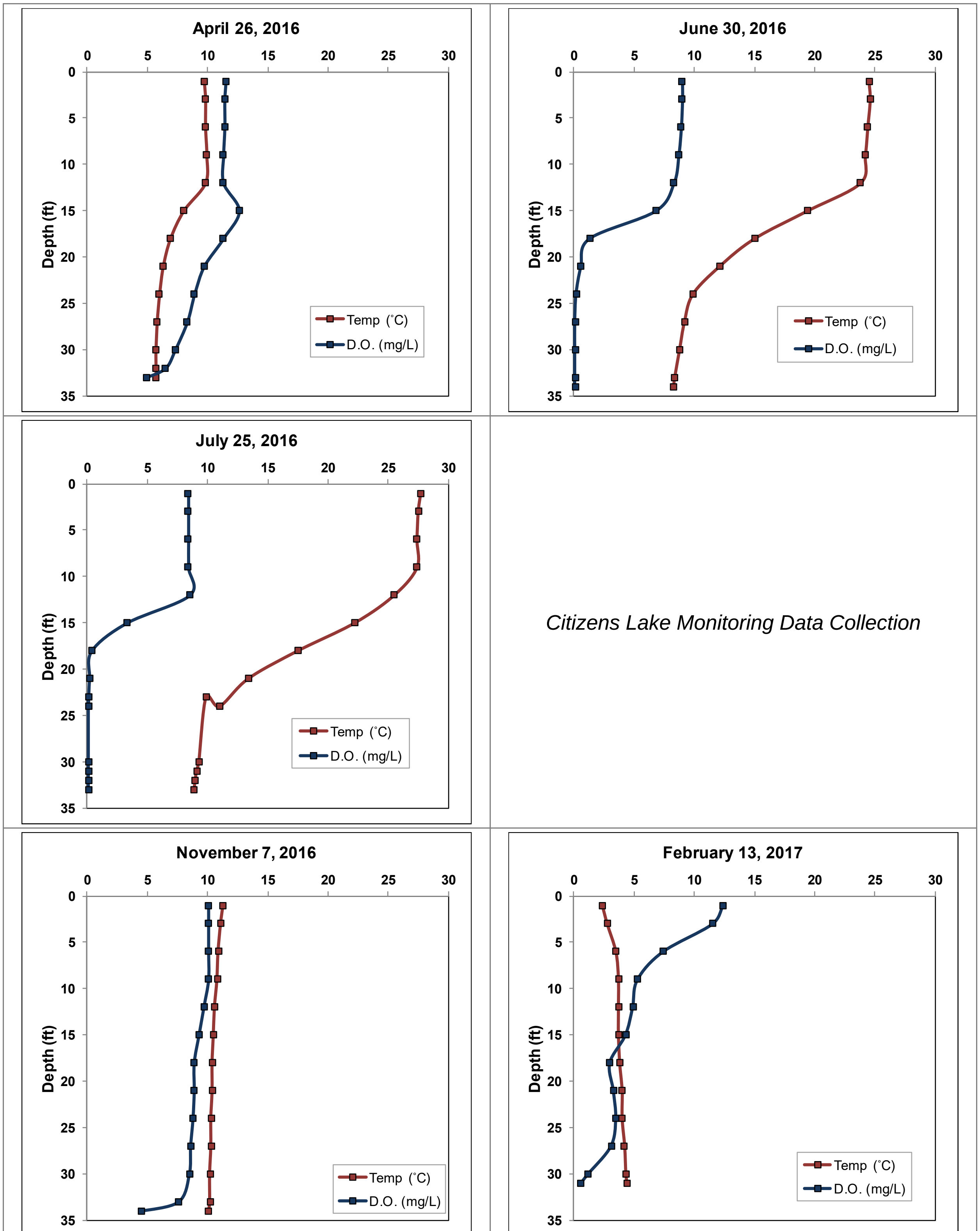


Figure 3.1-13. Crooked Lake dissolved oxygen and temperature profiles.

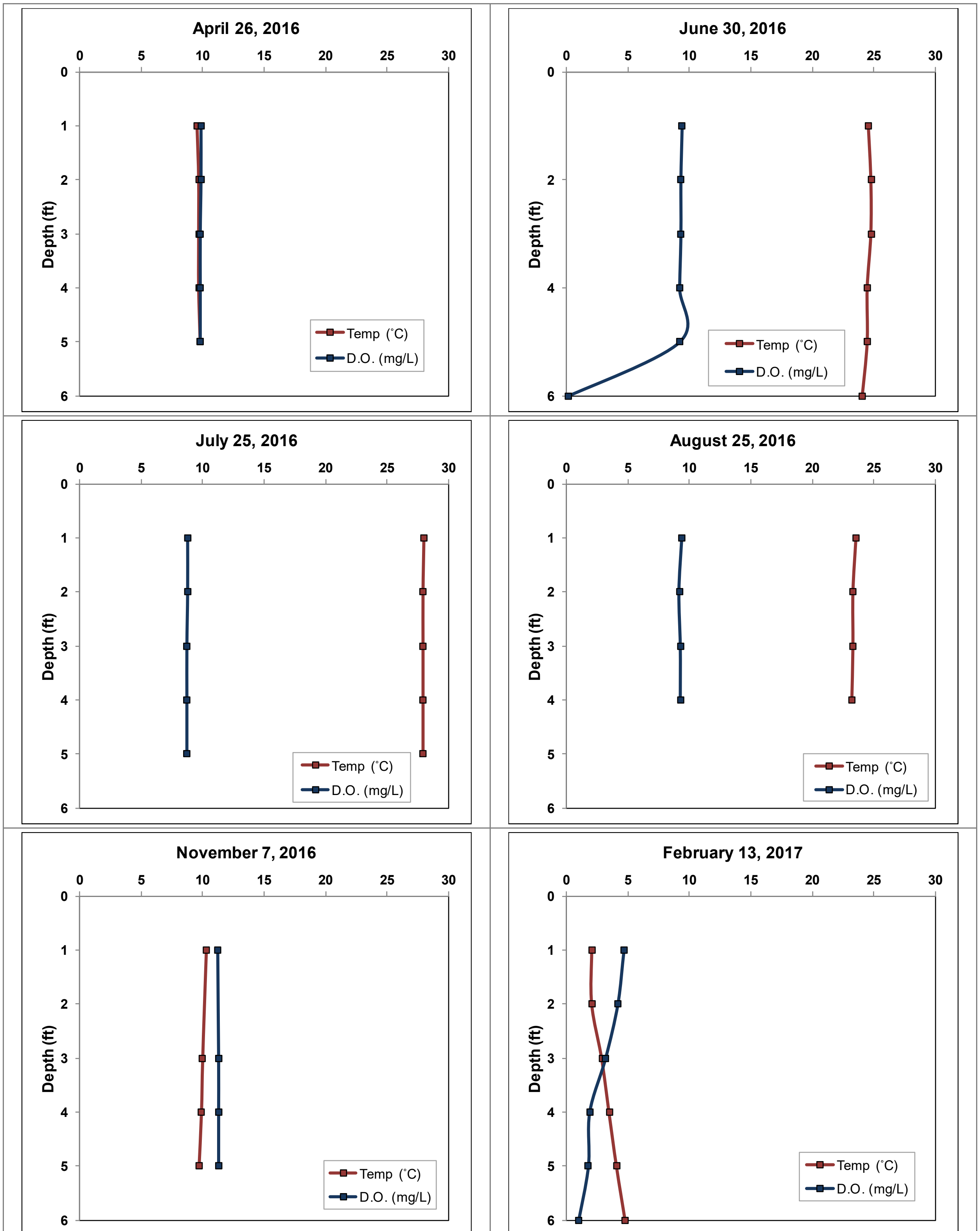


Figure 3.1-14. Gilkey Lake dissolved oxygen and temperature profiles.

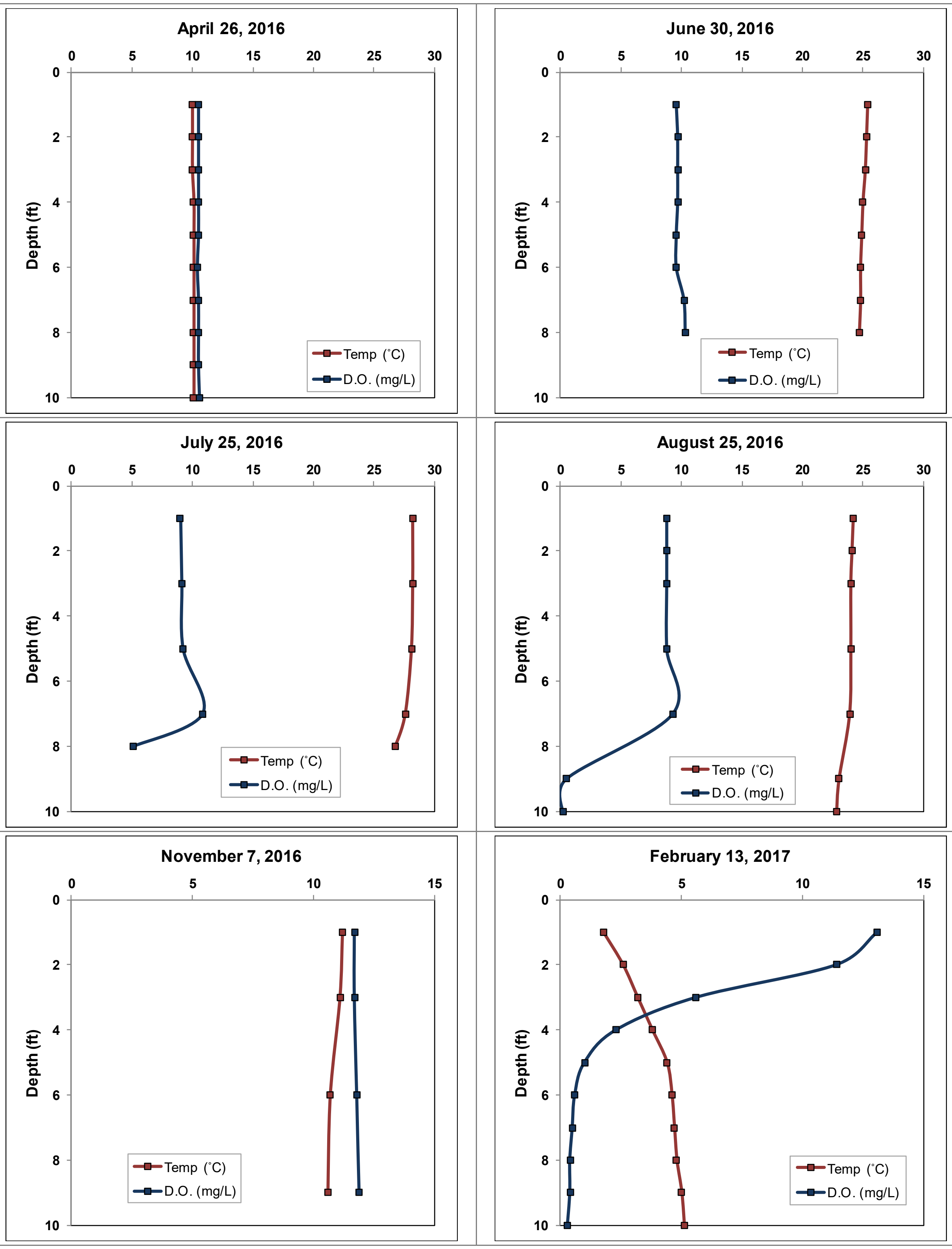


Figure 3.1-15. Bass Lake dissolved oxygen and temperature profiles.

Additional Water Quality Data Collected at the Crooked Lake Area Lakes

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

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-), and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic; meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl lakes. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985). The pH of the water in both Crooked and Gilkey lakes were found to be a value of 8.06 which fall within the normal range for Wisconsin lakes (Figure 3.1-16). The pH of the water in Bass Lake was found to be a value of 8.21, and falls within the normal range for Wisconsin lakes. All three lakes have a slightly alkaline pH value.

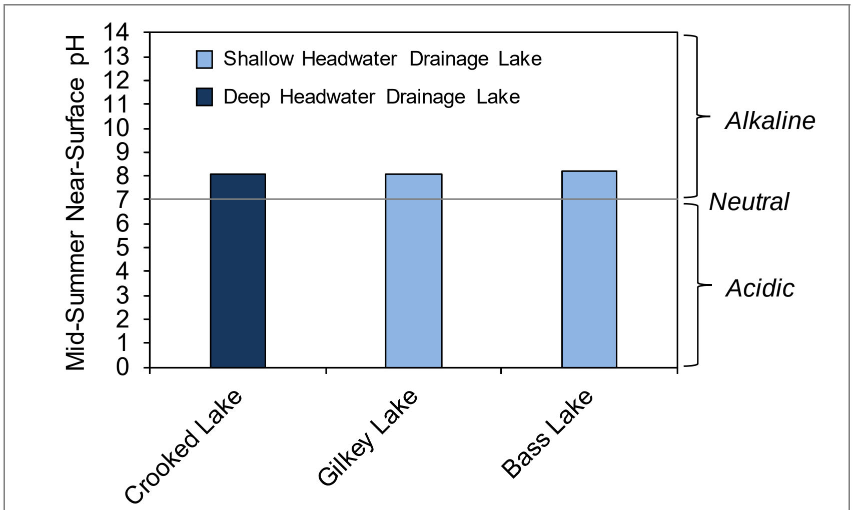


Figure 3.1-16. Crooked Lake Area Lakes mid-summer near-surface pH values.

Alkalinity is a lake's capacity to resist fluctuations in pH by neutralizing or buffering against inputs such as acid rain. The main compounds that contribute to a lake's alkalinity in Wisconsin are bicarbonate (HCO_3^-) and carbonate (CO_3^-), which neutralize hydrogen ions from acidic inputs. These compounds are present in a lake if the groundwater entering it comes into contact with minerals such as calcite ($CaCO_3$) and/or dolomite ($CaMgCO_3$). A lake's pH is primarily determined by the amount of alkalinity. Rainwater in northern Wisconsin is slightly acidic naturally due to dissolved carbon dioxide from the atmosphere with a pH of around 5.0. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The alkalinity in Crooked Lake was measured at 71.7 (mg/L as $CaCO_3$), the alkalinity in Gilkey Lake was measured at 76.4, and the alkalinity in Bass Lake was measured at 73.0, indicating that the lakes have a substantial capacity to resist fluctuations in pH and have no sensitivity to acid rain (Figure 3.1-17).

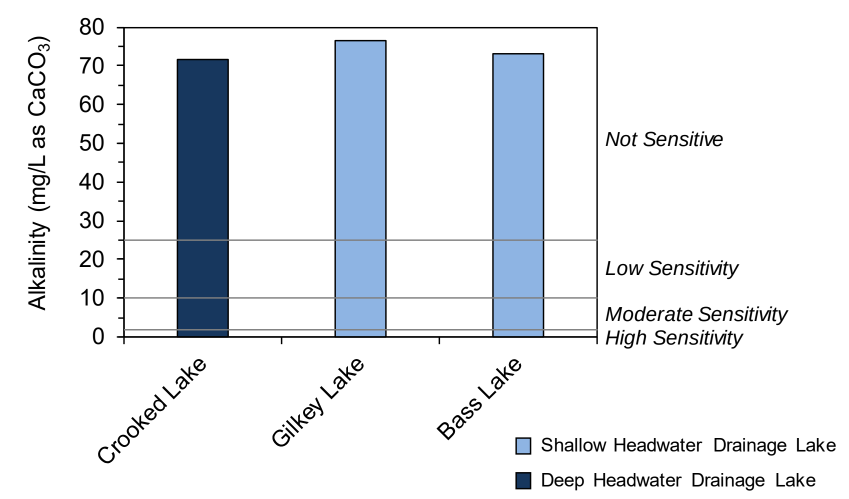


Figure 3.1-17. Crooked Lake Area Lakes average growing season total alkalinity and sensitivity to acid rain. Samples collected from the near-surface.

Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed. Recently, the combination of calcium concentration and pH has been used to determine what lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, so the Crooked Lake Area Lakes' pH falls inside this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. The calcium concentration of Crooked Lake was found to be 17.5 mg/L, Gilkey Lake was found to be 17.9, and Bass Lake was found to be 19.10, all three falling into the low susceptibility range for zebra mussel establishment (Figure 3.1-18).

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.

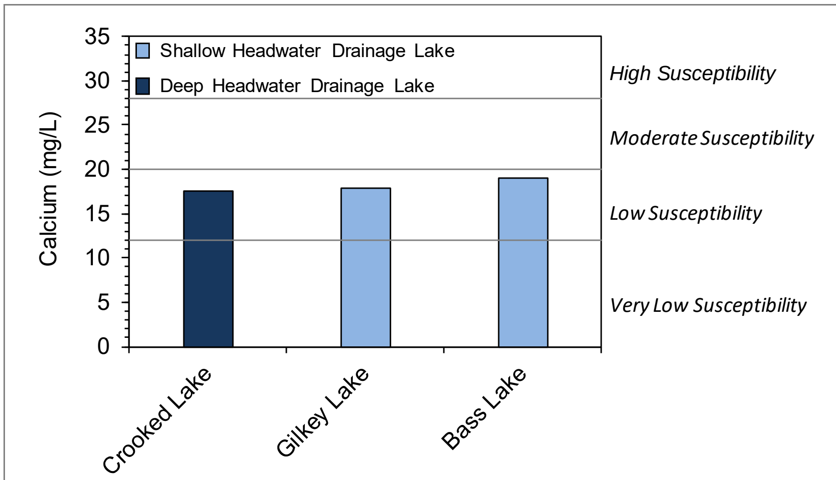


Figure 3.1-18. Crooked Lake Area Lakes spring calcium concentration and zebra mussel susceptibility. Samples collected from the near-surface.

Researchers at the University of Wisconsin - Madison have developed an AIS suitability model called smart prevention (Vander Zanden and Olden 2008). In regards to zebra mussels, this model relies on measured or estimated dissolved calcium concentration to indicate whether a given lake in Wisconsin is suitable, borderline suitable, or unsuitable for sustaining zebra mussels. Within this model, suitability was estimated for approximately 13,000 Wisconsin waterbodies and is displayed as an interactive mapping tool (www.aissmartprevention.wisc.edu). Based upon this analysis, Crooked Lake and Gilkey Lake were considered borderline suitable for mussel establishment and Bass Lake was considered suitable. Plankton tows were completed by Onterra ecologists in the Crooked Lake Area Lakes in 2016 that underwent analysis for the presence of zebra mussel veligers, their planktonic larval stage. Analysis of these samples were negative for zebra mussel veligers and Onterra ecologists did not observe any adult zebra mussels during the 2016 surveys.

Stakeholder Survey Responses to the Crooked Lake Area Lakes Water Quality

As discussed in section 2.0, the stakeholder survey asks many questions pertaining to perception of the lakes and how they may have changed over the years. Of the 183 surveys distributed, 81 (44%) were returned. Without a response rate of 60% or higher, the responses to the following questions regarding water quality cannot be interpreted as being statistically representative of the population sampled. At best, the results may indicate possible trends and opinions about the stakeholder perceptions of water quality in the Crooked Lake Area Lakes, but cannot be stated with statistical confidence.

Figure 3.1-19 displays the responses of members of Crooked Lake Area Lakes Protection & Rehabilitation District (CLALRD) stakeholders to questions regarding water quality and how it has changed over their years visiting the Crooked Lake Area Lakes. When asked how they would describe the current water quality of the lakes, the majority, 43% of Crooked Lake respondents indicated *good*, 33% indicated *fair*, 13% indicated *poor*, 8% indicated they were *unsure*, and 3% indicated *excellent*. The majority, 50%, of Gilkey Lake respondents indicated *good*, 38% indicated *fair*, and 12% indicated *poor*. The majority, 46%, of Bass Lake respondents indicated *fair*, 27% indicated *good*, 18% indicated *excellent*, and 9% indicated *poor*. The distribution of responses was relatively similar between the three lakes.

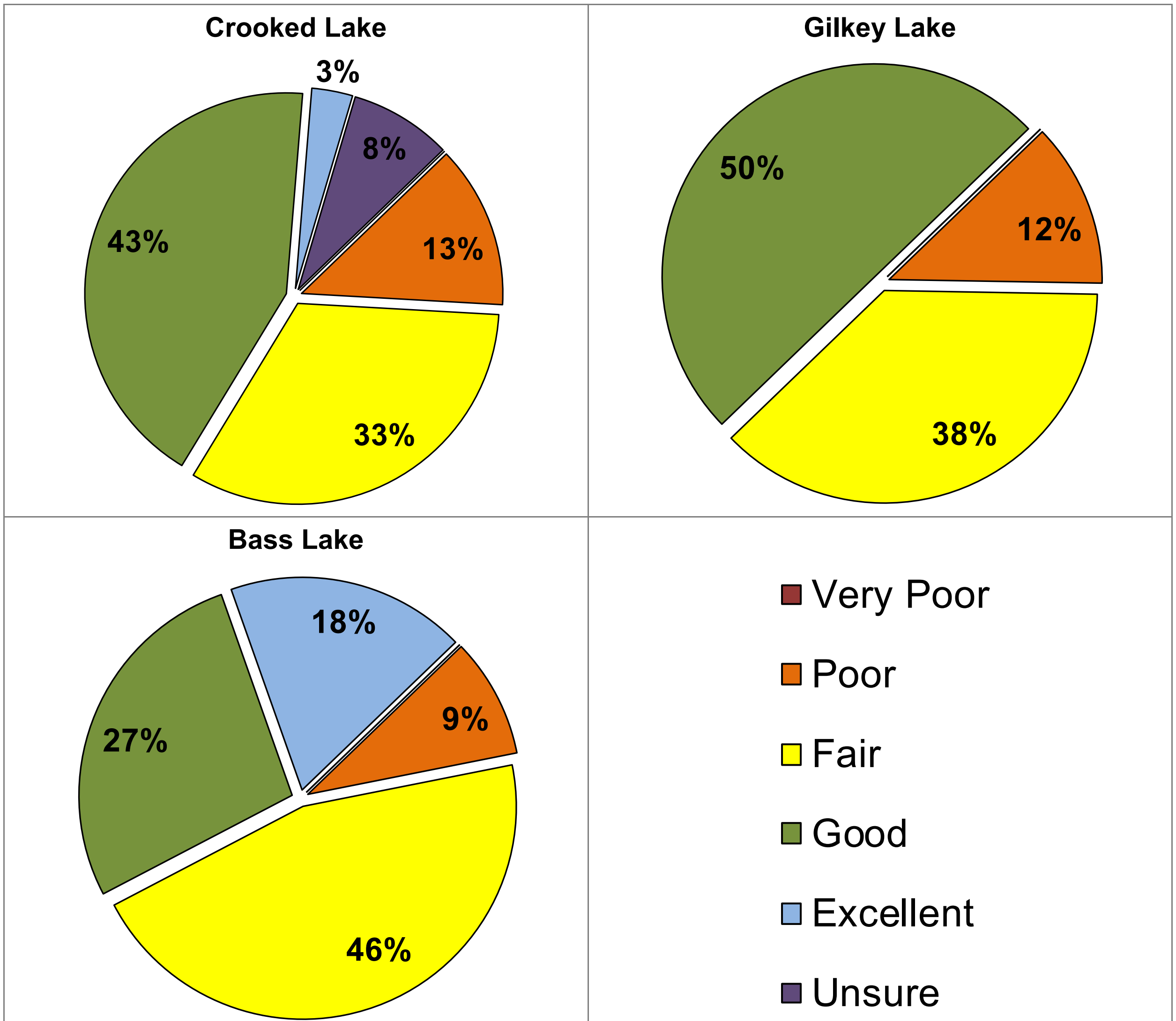


Figure 3.1-19. Stakeholder survey response Question #19. How would you describe the current water quality of the Crooked Lake Area Lakes?

When asked how they believe the current water quality has changed since they first visited the Crooked Lake Area Lakes, 41%, of Crooked Lake respondents indicated it has *somewhat degraded*, 25% indicated it has *remained the same*, 18% indicated it has *somewhat improved*, 7% indicated it has *severely degraded*, 7% indicated they were *unsure*, and 2% indicated it has *greatly improved* (Figure 3.1-20). The majority of Gilkey Lake respondents, 62%, indicated it has *somewhat degraded* and 38% indicated it has *remained the same*. The majority of Bass Lake respondents, 37%, indicated that it has *somewhat degraded*, 36% indicated it has *somewhat improved*, 18% indicated it has *remained the same*, and 9% indicated it has *severely degraded*.

Overall, the majority of respondents indicated that the water quality has *somewhat degraded* since they first visited the lakes. As discussed in the previous section, Secchi disk data indicates that Crooked Lake has seen a decrease in water clarity over the period from 1993 to 2016. Due to a lack of historical data, statistical analysis of Gilkey Lake and Bass Lake data was impossible and it is unknown if the lakes have seen a decrease in water clarity like Crooked Lake. The proportion of stakeholders who indicated the Crooked Lake Area Lakes' water quality has somewhat or severely degraded may also be taking into account Eurasian watermilfoil growth in the lakes or may have observed increases in aquatic plant abundance within them. But again, the lack of historical data for Gilkey and Bass Lakes does not allow for analyses indicating whether water quality has been degrading over time or not in the lakes.

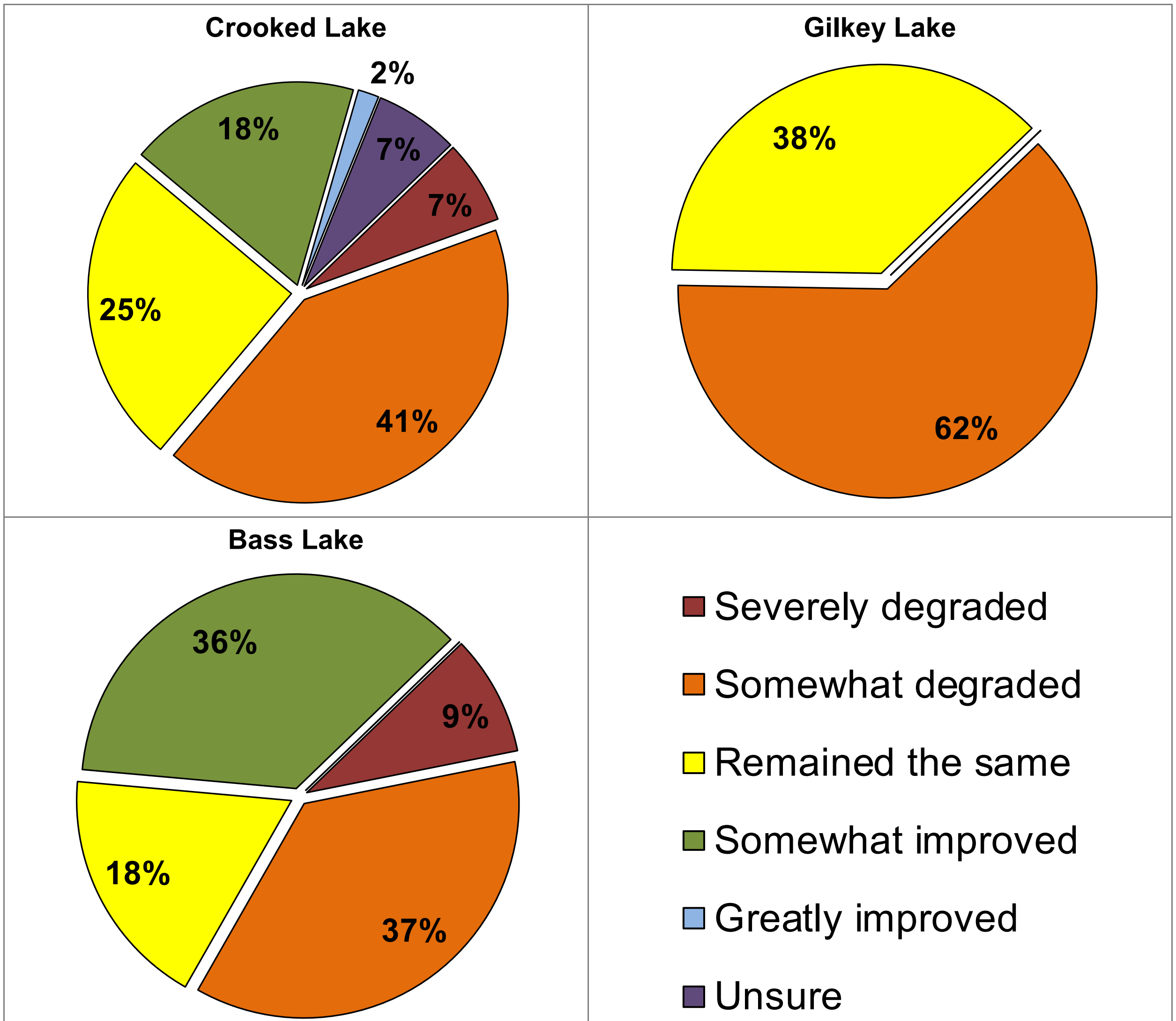


Figure 3.1-20. Stakeholder survey response Question #20. How as the water quality changed in Crooked Lake Area Lakes since you first visited the lake?

Another concern of stakeholder respondents, in regards to water quality, is the use of "the point." Listed as a concern within the lake and as one of the top three concerns, "the point" is a concern in regards to the boats mooring and the area being used as a party spot for residents or non-resident boaters. This area is owned by the Town of Riverview and has an acreage of 0.2 acres. It is unlikely that the use of this area has an impact on the water quality of the system, but further investigations of specific bacteria (enterococci and *Escherichia coli*) may be worth testing in the future.

3.2 Watershed Assessment

Primer on Watersheds and Watershed Modeling

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.

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

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.

Crooked Lakes Watershed Assessment

The Crooked Lakes total watershed is approximately 1,474 acres (2.3 square miles) in Oconto County (Map 2). Crooked and Gilkey lakes have watershed to lake area ratios of 8:1 and 10:1, respectively. In other words, approximately 10 acres of land drain to every one acre of Gilkey Lake and 8 acres drains to every one acre of Crooked Lake. Bass Lake has a watershed to lake area ratio of 5:1. According to WiLMS modeling, Crooked Lake's water is completely replaced approximately every 383 days (residence time) or every 0.7 years (flushing rate), Gilkey Lake's water is replaced approximately every 102 days or approximately 3.6 times per year, and Bass Lake's water is replaced approximately every 296 days (residence time) or approximately every 1.2 years (flushing rate).

When a lake feeds into another lake, that lake acts as a point source for the downstream lake. These lakes are modeled in series, with phosphorus outflow from the upstream lake estimated using total phosphorus concentrations and by estimating how much water is draining from the upstream lake to the downstream lake. For modeling purposes Gilkey and Bass Lakes were treated as point sources to Crooked Lake and the entire watershed was split into three subwatersheds, Crooked Lake's watershed, Gilkey Lake's direct watershed, and Bass Lake's direct watershed (Map 2). Approximately 77% of the entire Crooked Lake watershed is composed of the Crooked Lake direct watershed, 17% is composed of the Gilkey Lake direct watershed, and 6% is composed of the Bass Lake direct watershed (Figure 3.2-1).

Typically, lakes act as a sedimentation basin and through chemical, physical, and biological processes, phosphorus is settled to the bottom of the lake. Gilkey and Bass Lakes are likely retaining some phosphorus from their direct watersheds before the water makes its way to Crooked Lake.

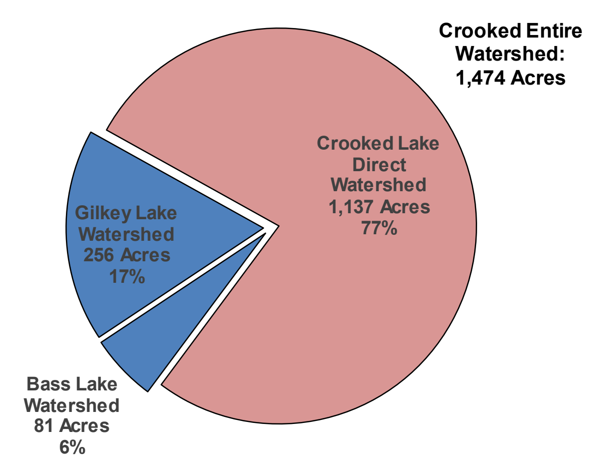


Figure 3.2-1. Crooked Lakes three subwatersheds.

Approximately 52% of Crooked Lake's direct watershed is composed of wetlands, 23% forest, 15% Crooked Lake's surface, 8% pasture/grass, 1% row crop agriculture, 1% rural residential areas, and <1% medium density urban areas (Figure 3.2-2, top left). Approximately 51% of Gilkey Lake's direct watershed is composed of wetlands, 23% forest, 17% pasture/grass, 9% Gilkey Lake's surface, and <1% rural residential areas (Figure 3.2-2, top right). Approximately 36% of Bass Lake's direct watershed is composed of pasture/grass, 20% forest, 20% wetlands, 17% Bass Lake's surface, and 7% rural residential areas (Figure 3.2-2, bottom).

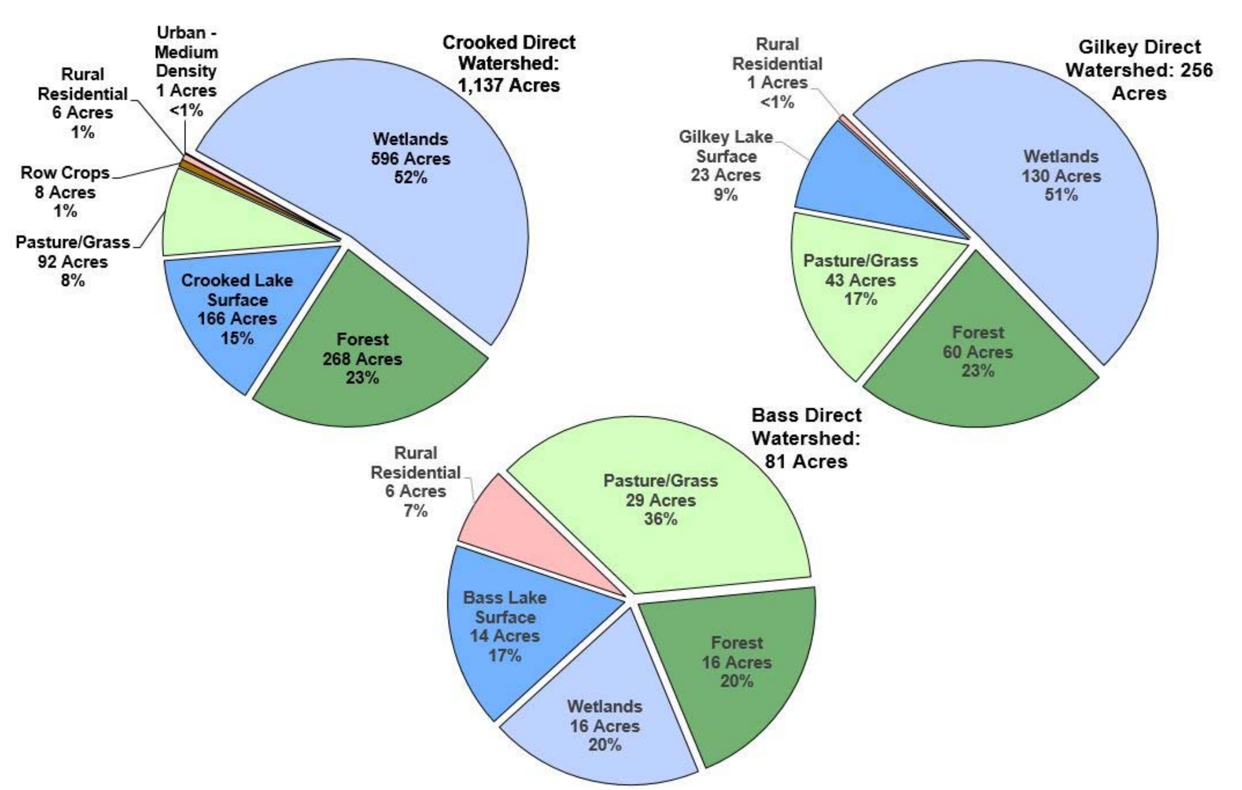


Figure 3.2-2. Crooked Lakes' watershed land cover types in acres. Based upon National Land Cover Database (NLCD – Fry et. al 2011).

Using the landcover data described above, WiLMS was utilized to estimate the annual potential phosphorus load from the three direct watershed's along with estimated outflow of phosphorus from Gilkey and Bass Lake into Crooked Lake. It was estimated that approximately 34 pounds of phosphorus are delivered to Gilkey Lake from its direct watershed and approximately 18 pounds of phosphorus are delivered to Bass Lake from its direct watershed on an annual basis (Figure 3.2-3, Gilkey - top right, Bass - bottom). It was also estimated that 165 pounds are delivered to Crooked Lake from its direct watershed and from Gilkey and Bass Lake on an annual basis (Figure 3.2-3, top right). Phosphorus loading from septic systems was also estimated using data obtained from the 2016 stakeholder survey of riparian property owners, which illustrates that only about 4 pounds (3%) of the annual phosphorus load in Crooked Lake is attributed to septic systems, only about 1 pound (1%) of the annual phosphorus load in Gilkey Lake is attributed to septic systems, and only about 1 pound (4%) of the annual phosphorus load in Bass Lake is attributed to septic systems.

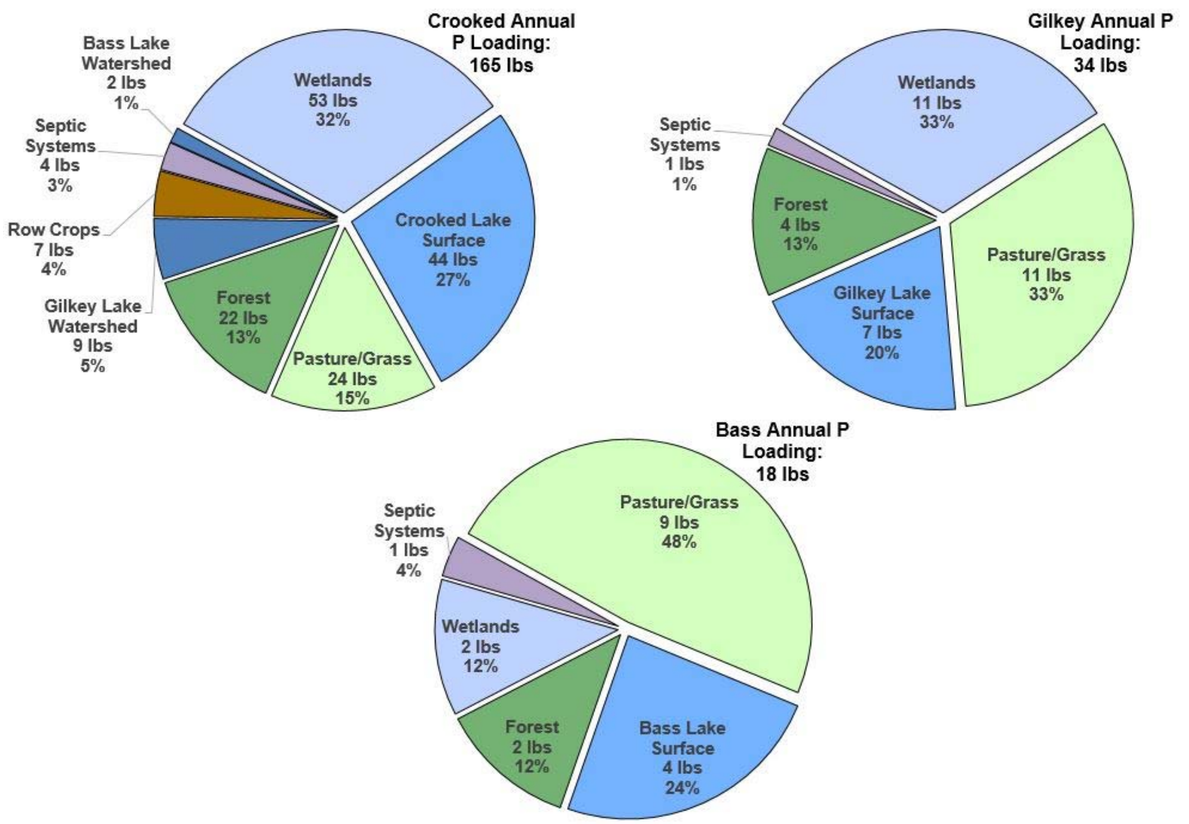


Figure 3.2-3. Crooked Lakes' watershed phosphorus loading in pounds. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates.

Of the estimated 34 pounds being delivered to Gilkey Lake on an annual basis, 33% is estimated to originate from wetlands, 33% from forest, 20% from direct atmospheric deposition into the lake, and 1% from septic systems (Figure 3.2-3, top right). Of the estimated 18 pounds being delivered to Bass Lake, the majority, 48%, is estimated to originate from pasture grass, 24% from direct atmospheric deposition into the lake, 12% from forest, 12% from wetlands, and 4% from septic systems (Figure 3.2-3, bottom). Of the estimated 165 pounds being delivered to Crooked Lake, 32% is estimated to originate from wetlands, 44% from direct atmospheric deposition into the lake, 15% from pasture/grass, 13% from forest, 5% from Gilkey Lake, 4% from row crops, 3% from septic systems, and 1% from Bass Lake (Figure 3.2-3, top right).

Using predictive equations, WiLMS estimates that Gilkey Lake should have a growing season mean (GSM) total phosphorus concentration of approximately 38 µg/L and that Bass Lake should have a concentration of 40 µg/L. These estimates are greater than 2.25 times higher than the 2016 measured GSM total phosphorus concentrations from the lakes. These vast differences occur because WiLMS assumes that the lake it is modeling has an actual tributary watershed, which neither of these lakes have; therefore, much of the precipitation that falls in their drainage basins percolates into the groundwater and does not accumulate pollutants like surface runoff does.

WiLMS estimates that Crooked Lake should have a GSM total phosphorus concentration of 24 µg/L. The estimated GSM total phosphorus concentration is approximately 2 times higher than the measured GSM total phosphorus concentration of 12.8 µg/L. This over estimate is likely brought about largely for the same reason as described above; however, the data used in this project were collected in the deepest area of the lake, which is away from the area where the inlet enters and the outlet leaves the lake; therefore, a true indication of the lake's tributary impact may not have been measured. However, very limited data were collected in the north bay during 1994, which were found to have similar concentrations of total phosphorus as the deep hole site.

Overall, the WiLMS modeling indicate that the watershed of the Crooked Lakes are in good shape and are not currently, at least based upon the data available, impacting the lakes in a negative manner.

3.3 Shoreland Condition

Primer on the Shoreland Zone of a lake

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

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

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

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

Shoreland Zone Regulations

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

Wisconsin-NR 115: Wisconsin's Shoreland Protection Program

Wisconsin's shoreland zoning rule, NR 115, sets the minimum standards for shoreland development. First adopted in 1966, the code set a deadline for county adoption of January 1, 1968. By 1971, all counties in Wisconsin had adopted the code and were administering the shoreland ordinances it specified. Interestingly, in 2007 it was noted that many (27) counties had recognized inadequacies within the 1968 ordinance and had actually adopted stricter shoreland ordinances. Passed in February of 2010, the final 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. Please note that at the time of this writing, changes to NR 115 were last made in October of 2015 (Lutze 2015).

- 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: 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.

- 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 with the following caveats:
    - No expansion or complete reconstruction within 0-35 feet of shoreline
    - Re-construction may occur if the same type of structure is being built in the previous location with the same footprint. All construction needs to follow general zoning or floodplain zoning authority
    - Construction may occur if mitigation measures are included either within the existing footprint or beyond 75 feet.
    - Vertical expansion cannot exceed 35 feet

- 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.

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 (2003) found that green frog density was negatively correlated with development density in Wisconsin lakes. As development increased, the habitat for green frogs decreased and thus populations became significantly lower. 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 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 (boating, swimming, and, ironically, fishing).

National Lakes Assessment

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

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

Cost

The cost of native, aquatic, and shoreland plant restorations is highly variable and depends on the size of the restoration area, the depth of buffer zone required to be restored, the existing plant density, the planting density required, the species planted, and the type of planting (e.g. seeds, bare-roots, plugs, live-stakes) being conducted. Other sites may require erosion control stabilization measures, which could be as simple as using erosion control blankets and plants and/or seeds or more extensive techniques such as geotextile bags (vegetated retaining walls), geogrids (vegetated soil lifts), or bio-logs (see above picture). Some of these erosion control techniques may reduce the need for rip-rap or seawalls which are sterile environments that do not allow for plant growth or natural shorelines. Questions about rip-rap or seawalls should be directed to the local Wisconsin DNR Water Resources Management Specialist. Other measures possibly required include protective measures used to guard newly planted area from wildlife predation, wave-action, and erosion, such as fencing, erosion control matting, and animal deterrent sprays. One of the most important aspects of planting is maintaining moisture levels. This is done by watering regularly for the first two years until plants establish themselves, using soil amendments (i.e., peat, compost) while planting, and using mulch to help retain moisture.

Most restoration work can be completed by the landowner themselves. To decrease costs further, bare-root form of trees and shrubs should be purchased in early spring. If additional assistance is needed, the lakefront property owner could contact an experienced landscaper. For properties with erosion issues, owners should contact their local county conservation office to discuss cost-share options.

In general, a restoration project with the characteristics described below would have an estimated materials and supplies cost of approximately $1,400. The more native vegetation a site has, the lower the cost. Owners should contact the county's regulations/zoning department for all minimum requirements. The single site used for the estimate indicated above has the following characteristics:

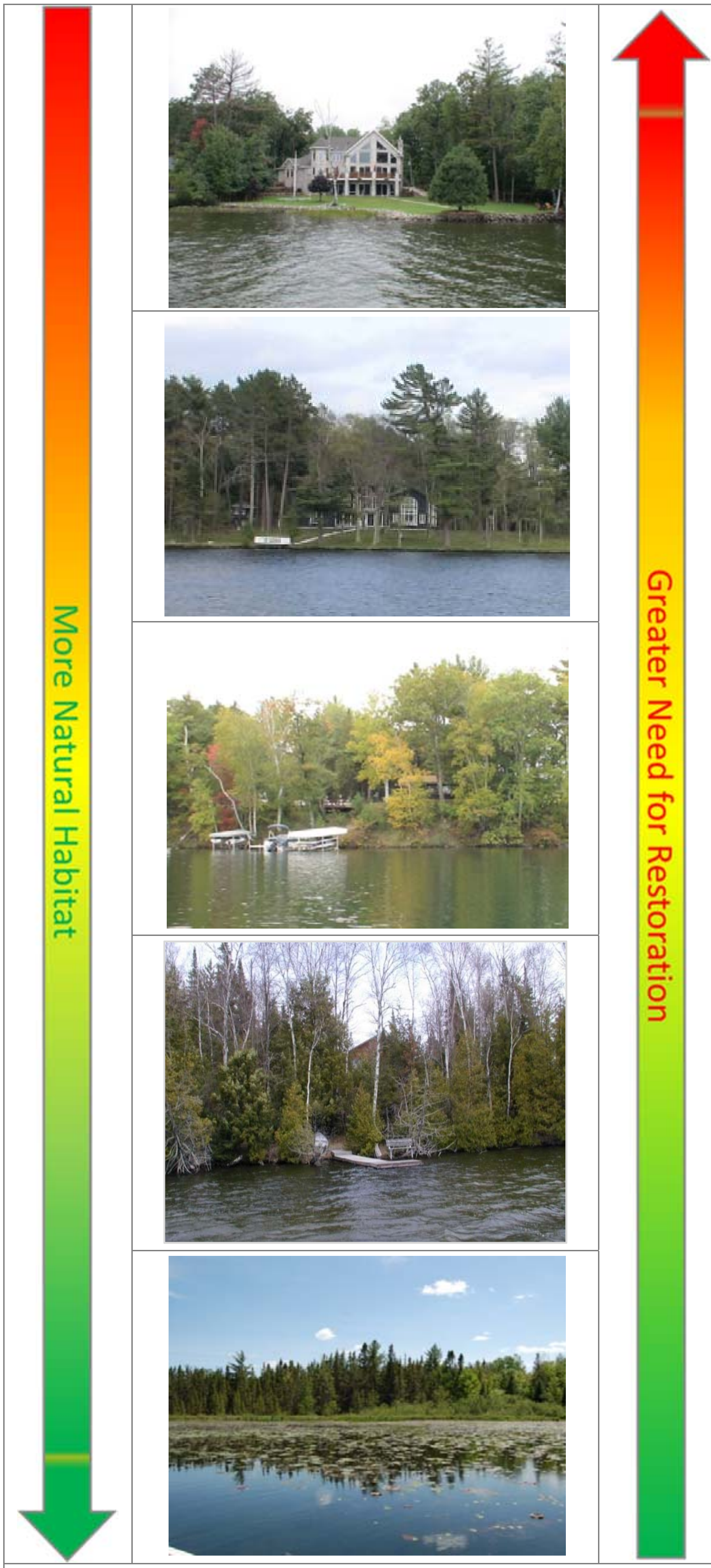
- Spring planting timeframe.
- 100' of shoreline.
- An upland buffer zone depth of 35'.
- An access and viewing corridor 30' x 35' free of planting (recreation area).
- Planting area of upland buffer zone 2- 35' x 35' areas
- Site is assumed to need little invasive species removal prior to restoration.
- Site has only turf grass (no existing trees or shrubs), a moderate slope, sandy-loam soils, and partial shade.
- Trees and shrubs planted at a density of 1 tree/100 sq. ft and 2 shrubs/100 sq. ft, therefore, 24 native trees and 48 native shrubs would need to be planted.
- Turf grass would be removed by hand.
- A native seed mix is used in bare areas of the upland buffer zone.
- An aquatic zone with shallow-water 2 - 5' x 35' areas.
- Plant spacing for the aquatic zone would be 3 feet.
- Each site would need 70' of erosion control fabric to protect plants and sediment near the shoreland (the remainder of the site would be mulched).
- Soil amendment (peat, compost) would be needed during planting.
- There is no hard-armor (rip-rap or seawall) that would need to be removed.
- The property owner would maintain the site for weed control and watering.

Advantages	***Disadvantages***
• Improves the aquatic ecosystem through species diversification and habitat enhancement. • Assists native plant populations to compete with exotic species. • Increases natural aesthetics sought by many lake users. • Decreases sediment and nutrient loads entering the lake from developed properties. • Reduces bottom sediment re-suspension and shoreland erosion. • Lower cost when compared to rip-rap and seawalls. • Restoration projects can be completed in phases to spread out costs. • Once native plants are established, they require less water, maintenance, no fertilizer; provide wildlife food and habitat, and natural aesthetics compared to ornamental (non-native) varieties. • Many educational and volunteer opportunities are available with each project.	• Property owners need to be educated on the benefits of native plant restoration before they are willing to participate. • Stakeholders must be willing to wait 3-4 years for restoration areas to mature and fill-in. • Monitoring and maintenance are required to assure that newly planted areas will thrive. • Harsh environmental conditions (e.g., drought, intense storms) may partially or completely destroy project plantings before they become well established.

Crooked Lake Area Lakes Shoreland Zone Condition

Shoreland Development

The Crooked Lake Area Lakes' shoreland zone can be classified in terms of their degree of development. In general, more developed shorelands are more stressful on a lake ecosystem, while definite benefits occur from shorelands that are left in their natural state. Figure 3.3-1 displays a diagram of shoreland categories, from "Urbanized", meaning the shoreland zone is completely disturbed by human influence, to "Natural/Undeveloped", meaning the shoreland has been left in its original state.



Urbanized: This type of shoreline has essentially no natural habitat. Areas that are mowed or unnaturally landscaped to the water's edge and areas that are rip-rapped or include a seawall would be placed in this category.

Developed-Unnatural: This category includes shorelines that have been developed, but only have small remnants of natural habitat yet intact. A property with many trees, but no remaining understory or herbaceous layer would be included within this category. Also, a property that has left a small (less than 30 feet), natural buffer in place, but has urbanized the areas behind the buffer would be included in this category.

Developed-Semi-Natural: This is a developed shoreline that is mostly in a natural state. Developed properties that have left much of the natural habitat in state, but have added gathering areas, small beaches, etc. within those natural areas would likely fall into this category. An urbanized shoreline that was restored would likely be included here, also.

Developed-Natural: This category includes shorelines that are developed property, but essentially no modifications to the natural habitat have been made. Developed properties that have maintained the natural habitat and only added a path leading to a single pier would fall into this category.

Natural/Undeveloped: This category includes shorelines in a natural, undisturbed state. No signs of anthropogenic impact can be found on these shorelines. In forested areas, herbaceous, understory, and canopy layers would be intact.

Figure 3.3-1. Shoreland assessment category descriptions.

On the Crooked Lake Area Lakes, the development stage of the entire shoreland was surveyed during fall of 2016, using a GPS unit to map the shoreland. Onterra staff only considered the area of shoreland 35 feet inland from the water's edge, and did not assess the shoreland on a property-by-property basis. During the survey, Onterra staff examined the shoreland for signs of development and assigned areas of the shoreland one of the five descriptive categories in Figure 3.3-2.

The total shoreline of the Crooked Lake Area Lakes is 6.2 miles, but includes stretches of the inlet and outlet that are best described as wetland. Within the following analysis, only the 4.6 miles of the three main lakes are evaluated. These areas are shown on Map 3.

The Crooked Lake Area Lakes have stretches of shoreland that fit all of the five shoreland assessment categories. In all, 1.7 miles of *natural/undeveloped* and *developed-natural* shoreland were observed during the survey (Figure 3.3-2). These shoreland types provide the most benefit to the lake and should be left in their natural state if at all possible. During the survey, 2.5 miles of urbanized and developed–unnatural shoreland were observed. If restoration of the Crooked Lake Area Lakes' shoreland is to occur, primary focus should be placed on these shoreland areas as they currently provide little benefit to, and actually may harm, the lakes ecosystem.

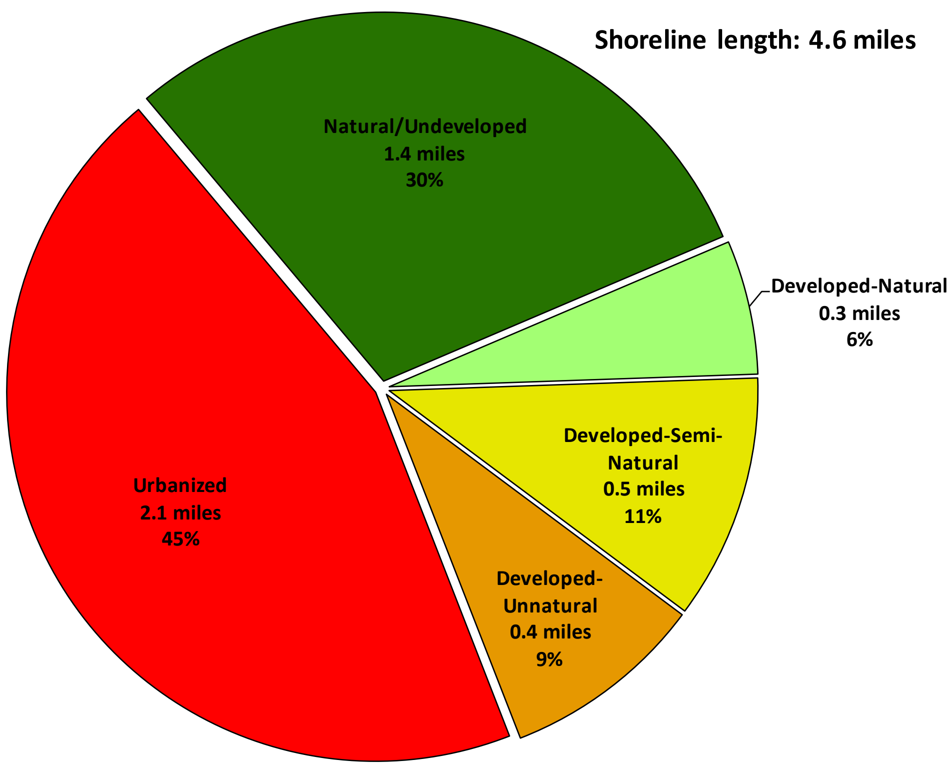


Figure 3.3-2. Crooked Lake Area Lakes shoreland categories and total lengths. Based upon a Fall 2016 survey. Locations of these categorized shorelands can be found on Map 3.

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.

Coarse Woody Habitat

As part of the shoreland condition assessment, the Crooked Lake Area Lakes were also surveyed to determine the extent of their 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, 78 total pieces of coarse woody habitat were observed along 4.6 miles of shoreline (Map 4), which gives the Crooked Lake Area Lakes a coarse woody habitat to shoreline mile ratio of 17:1 (Figure 3.3-3). Only instances where emergent coarse woody habitat extended from shore into the water were recorded during the survey. Thirty-seven pieces of 2-8 inches in diameter pieces of coarse woody habitat were found, 41 pieces of 8+ inches in diameter pieces of coarse woody habitat were found, and no instances of clusters of pieces of coarse woody habitat were found.

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

Onterra has completed coarse woody habitat surveys on 98 lakes throughout Wisconsin since 2012, with the majority occurring in the NLF ecoregion on lakes with public access. The number of coarse woody habitat pieces per shoreline mile in the Crooked Lake Area Lakes falls just above the 25th percentile of these 98 lakes (Figure 3.3-3).

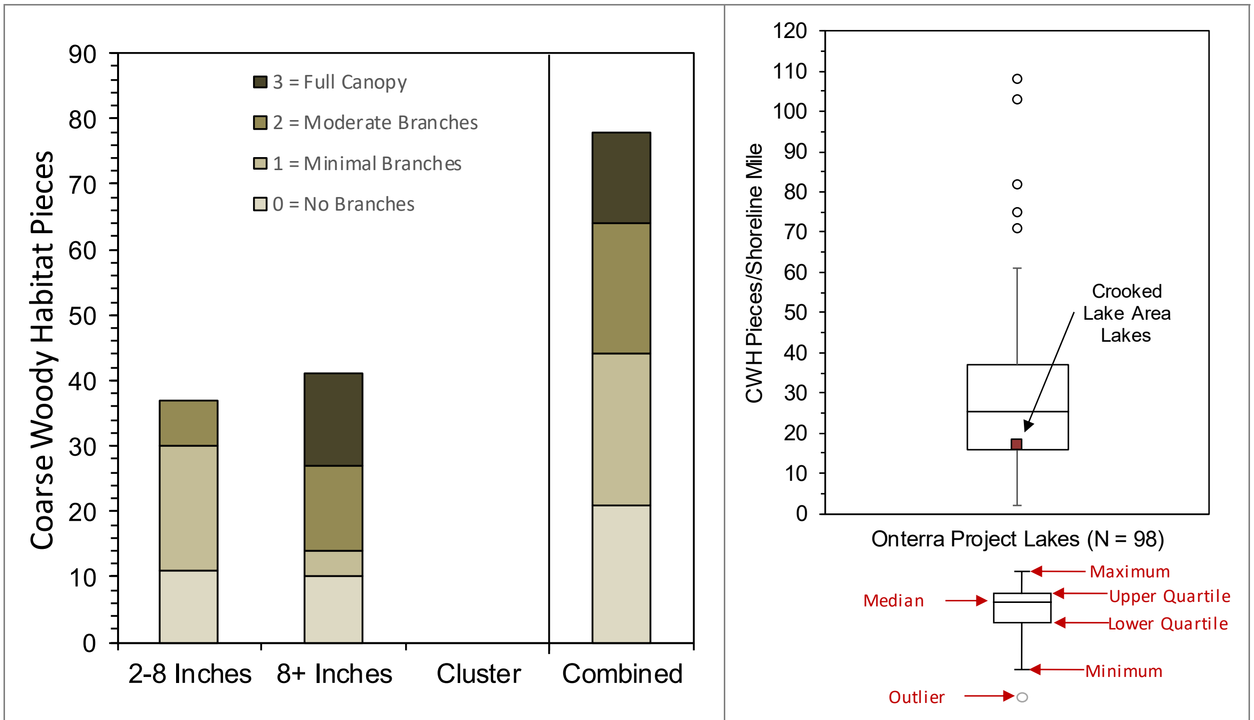


Figure 3.3-3. Crooked Lake Area Lakes coarse woody habitat survey results. Based upon a fall 2016 survey. Locations of the Crooked Lake Area Lakes coarse woody habitat can be found on Map 4.

3.4 Aquatic Plants

Primer on Aquatic Plants

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

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

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

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

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

Aquatic Plant Management and Protection

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

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

Permits

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

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

Manual Removal

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

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

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

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

Cost

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

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

Bottom Screens

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

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

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

Water Level Drawdown

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

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

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

Mechanical Harvesting


Photograph 3.4-3. Mechanical harvester.

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

Cost

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

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

<u>Herbicide Treatment</u>

Photograph 3.4-4. Granular herbicide application.

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 et al. (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.

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

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

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

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

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

Cost

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

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

Biological Controls

There are many insects, fish and pathogens within the United States that are used as biological controls for aquatic macrophytes. For instance, the herbivorous grass carp has been used for years in many states to control aquatic plants with some success and some failures. However, it is illegal to possess grass carp within Wisconsin because their use can create problems worse than the plants that they were used to control. Other states have also used insects to battle invasive plants, such as water hyacinth weevils (*Neochetina spp.*) and hydrilla stem weevil (*Bagous spp.*) to control water hyacinth (*Eichhornia crassipes*) and hydrilla (*Hydrilla verticillata)*, respectively.

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

Cost

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

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

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

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

Cost

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

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

Analysis of Current Aquatic Plant Data

Aquatic plants are an important element in every healthy lake. Changes in lake ecosystems are often first seen in the lake's plant community. Whether these changes are positive, such as variable water levels or negative, such as increased shoreland development or the introduction of an exotic species, the plant community will respond. Plant communities respond in a variety of ways. For example, there may be a loss of one or more species. Certain life forms, such as emergents 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 the Crooked Area Lakes; the first looked strictly for the exotic plant, curly-leaf pondweed, while the others that followed assessed both native and non-native species. Combined, these surveys produce a great deal of information about the aquatic vegetation of the lake. These data are analyzed and presented in numerous ways; each is discussed in more detail below.

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 the Crooked Area Lakes 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 the Crooked Area Lakes, plant samples were collected from plots laid out on a grid that covered the lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. The occurrence of aquatic plant species is displayed as the *littoral frequency of occurrence*. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are within the maximum depth of plant growth (littoral zone), and is displayed as a percentage.

Floristic Quality Assessment

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

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

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

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

<u>Species Diversity</u>

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 the Crooked Area Lakes is compared to data collected by Onterra and the WDNR Science Services on 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 the Crooked Area Lakes were mapped using a Trimble Global Positioning System (GPS) with sub-meter accuracy.

Exotic Plants

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

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

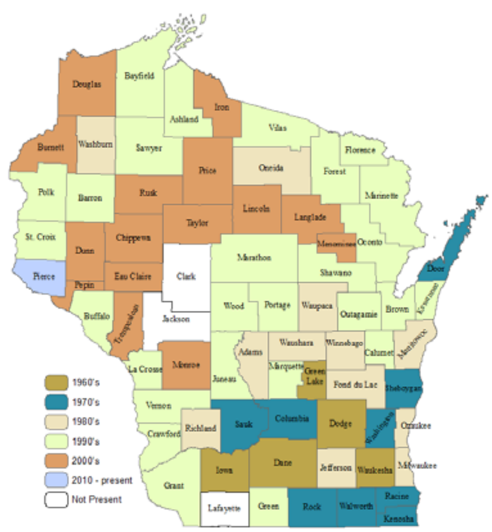


Figure 3.4-1. Spread of Eurasian watermilfoil within WI counties. WDNR Data 2011 mapped by Onterra.

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

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

Aquatic Plant Survey Results

During the aquatic plant surveys completed, a total of 45 species of plants were located in the Crooked Lake Area Lakes (Table 3.4-1), two are considered non-native species: Eurasian watermilfoil and curly-leaf pondweed. On May 31 – June 1, 2017, an Early-Season AIS Survey was completed on the Crooked Lake Area Lakes that focused on locating and mapping potential occurrences of curly-leaf pondweed. This meander-based, visual survey located curly-leaf pondweed within Bass and Crooked Lakes. This survey is also used as an early assessment of the Eurasian watermilfoil population within the lakes. Because the non-native plants found in the Crooked Lake Area Lakes have the ability to negatively impact lake ecology, recreation, and aesthetics, the populations of these plants are discussed in detail later within this section.

The whole-lake aquatic plant point-intercept and emergent and floating-leaf aquatic plant community mapping surveys were conducted on the Crooked Lake Area Lakes on August 2-3, 2016 by Onterra. Lakes in Wisconsin vary in their morphology, water chemistry, substrate composition, recreational use, and management; and all of these factors influence aquatic plant community composition. On August 15, 2016, Onterra ecologists completed an acoustic survey on the Crooked Lake Area Lakes. The sonar-based technology records aquatic plant bio-volume, or the percentage of the water column that is occupied by aquatic plants at a given location. Data pertaining to the Crooked Lake Area Lakes' substrate composition were also recorded during this survey. The sonar records substrate hardness, ranging from the hardest substrates (i.e. rock and sand) to the more flocculent, softer organic sediments.

Data regarding substrate hardness collected during the 2016 acoustic survey revealed that the Crooked Lake Area Lakes' average substrate hardness does not vary much and is considered moderately hard across all depths (Figure 3.4-2). Shallower depths have more variance in substrate type while substrate in deeper waters stays more consistent. Bass Lake and the northwestern part of Crooked Lake contain the most organic sediments. The soft sediments in Bass Lake are likely a result of decaying aquatic vegetation. 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 areas, and some can be found growing in either. Lakes that have varying substrate types generally support a higher number of plant species because of the different habitat types that are available.

Table 3.4-1. Aquatic plant species located in the Crooked Lake Area Lakes during the August 2016 aquatic plant surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2016 Crooked	2016 Gilkey	2016 Bass
Emergent	*Calla palustris*	Water arum	9	I		I
	Cladium mariscoides	Smooth sawgrass	10		I	
	Decodon verticillatus	Water-willow	7	I		I
	Dulichium arundinaceum	Three-way sedge	9	I		I
	Eleocharis robbinsii	Robbins' spikerush	10		I	
	Glyceria canadensis	Rattlesnake grass	7		I	
	Iris sp.	Iris sp.	N/A	I		I
	Iris versicolor	Northern blue flag	5		I	
	Pontederia cordata	Pickerelweed	9	I		I
	Sagittaria latifolia	Common arrowhead	3		I	I
	Schoenoplectus acutus	Hardstem bulrush	5	I	I	
	Sparganium americanum	American bur-reed	8	I		I
	Typha spp.	Cattail spp.	1	I	I	I
FL	*Brasenia schreberi*	Watershield	7	I	X	X
	Nuphar variegata	Spatterdock	6	X	X	I
	Nymphaea odorata	White water lily	6	X	X	I
	Sparganium angustifolium	Narrow-leaf bur-reed	9	I		
Submergent	*Ceratophyllum demersum*	Coontail	3	X		
	Chara spp.	Muskgrasses	7	X	X	X
	Elodea canadensis	Common waterweed	3	X	X	X
	Myriophyllum spicatum	Eurasian watermilfoil	Exotic	I	X	I
	Myriophyllum tenellum	Dwarf watermilfoil	10	X	I	
	Najas flexilis	Slender naiad	6	X	X	X
	Najas guadalupensis	Southern naiad	7	X	X	X
	Nitella spp.	Stoneworts	7	X		
	Potamogeton amplifolius	Large-leaf pondweed	7	X	X	X
	Potamogeton crispus	Curly-leaf pondweed	Exotic	I		X
	Potamogeton epihydrus	Ribbon-leaf pondweed	8	X		
	Potamogeton foliosus	Leafy pondweed	6	X		
	Potamogeton gramineus	Variable-leaf pondweed	7	X	X	X
	Potamogeton illinoensis	Illinois pondweed	6	X	X	X
	Potamogeton natans	Floating-leaf pondweed	5			X
	Potamogeton praelongus	White-stem pondweed	8	X	X	
	Potamogeton pusillus	Small pondweed	7	X	X	X
	Potamogeton robbinsii	Fern-leaf pondweed	8	X	X	X
	Potamogeton strictifolius	Stiff pondweed	8	X		
	Potamogeton zosteriformis	Flat-stem pondweed	6	X		X
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	N/A	X	X	X
	Utricularia gibba	Creeping bladderwort	9	X		
	Utricularia intermedia	Flat-leaf bladderwort	9	X		
	Utricularia vulgaris	Common bladderwort	7	X		
	Vallisneria americana	Wild celery	6	X		X
S/E	*Eleocharis acicularis*	Needle spikerush	5	X		
	Juncus pelocarpus	Brown-fruited rush	8	X		
	Schoenoplectus subterminalis	Water bulrush	9	X	X	

FL = Floating-leaf; FL/E = Floating-leaf and Emergent; S/E = Submergent and Emergent; FF = Free-floating
X = Located on rake during point-intercept survey; I = Incidental species

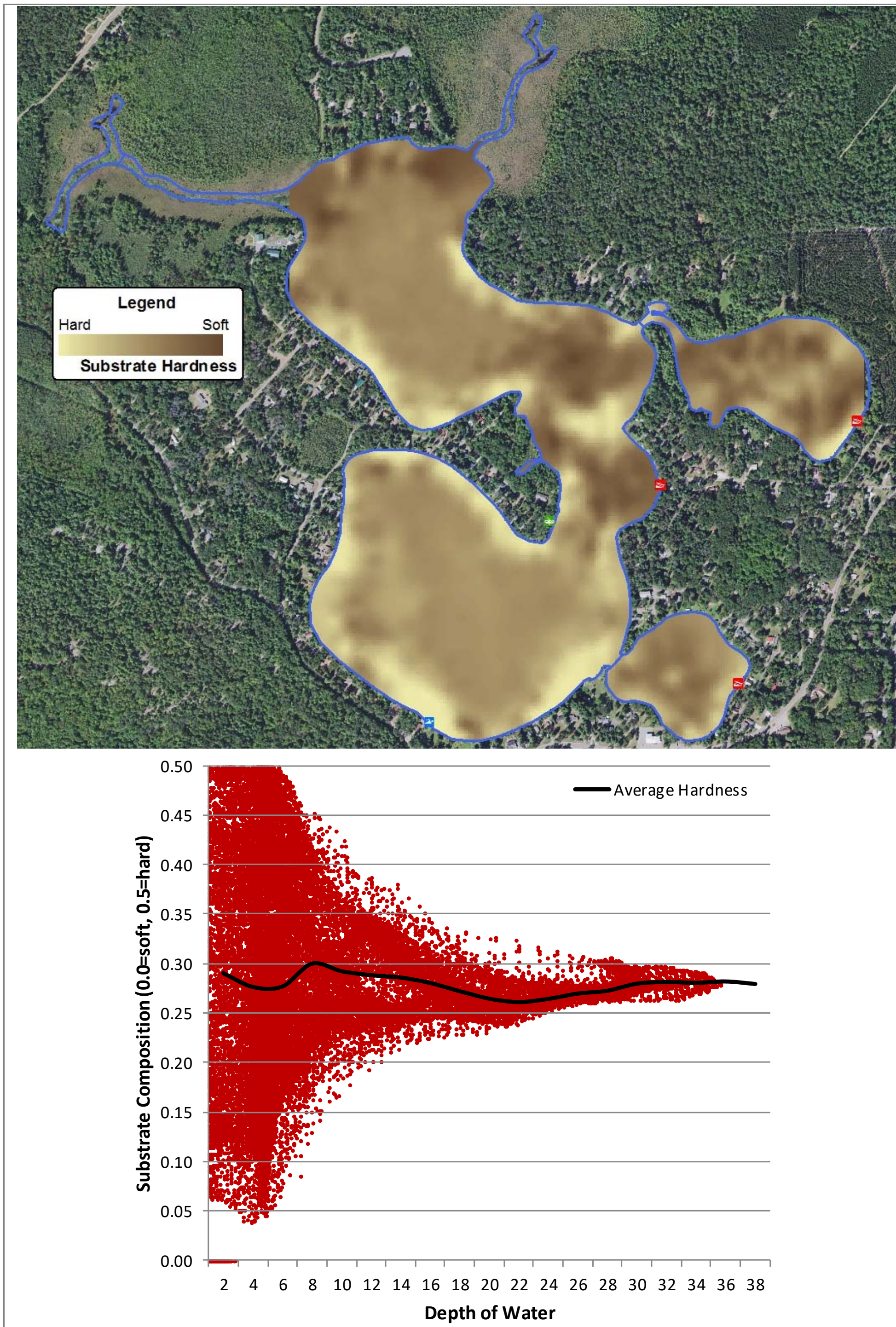


Figure 3.4-2. Crooked Lake Area Lakes spatial distribution of substrate hardness (top) and substrate hardness across water depth (bottom). Individual data points are displayed in red. Created using data from August 2016 acoustic survey.

The acoustic survey also recorded aquatic plant bio-volume throughout the entire system. As mentioned earlier, aquatic plant bio-volume is the percentage of the water column that is occupied by aquatic plants. The 2016 aquatic plant bio-volume data are displayed in Figure 3.4-3. Areas where aquatic plants occupy most or all of the water column are indicated in red while areas of little to no aquatic plant growth are displayed in blue. The 2016 whole-lake point-intercept survey and acoustic survey found aquatic plants growing to a maximum depth of 16 feet in Crooked Lake, 6 feet in Gilkey Lake, and 10 feet in Bass Lake. Overall, the 2016 acoustic survey indicates that approximately 63% of the Crooked Lake Area Lakes contains aquatic vegetation (Figure 3.4-3). Gilkey and Bass Lakes both are shallow enough that vegetation exists across all depths. In Crooked Lake, most vegetation is within the first 11 feet of the lake with most common species growing out to 16 feet. Lower-growing aquatic plants and algae are primarily the only plants found deeper.

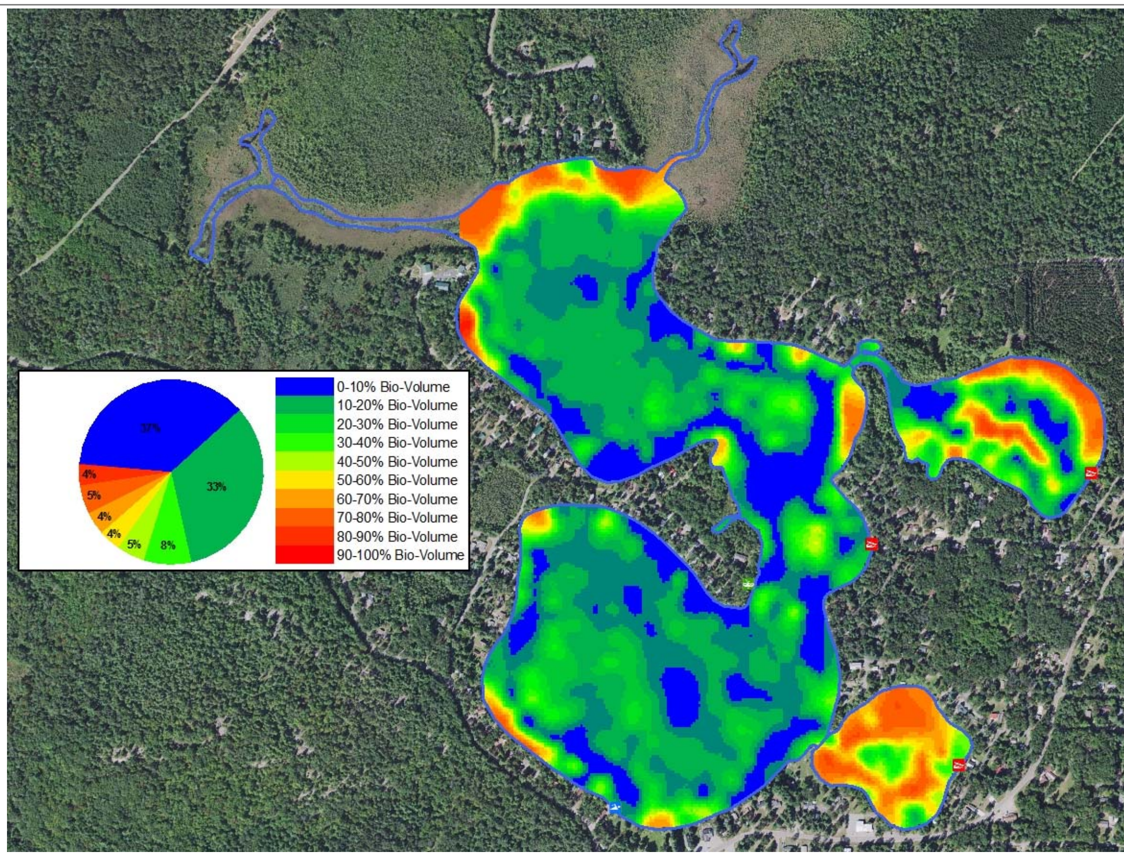


Figure 3.4-3. Crooked Lake Area Lakes 2016 aquatic plant bio-volume. Created using data from August 2016 acoustic survey.

While the acoustic mapping is an excellent survey for understanding the distribution and levels of aquatic plant growth throughout the lake, this survey does not determine what aquatic plant species comprise the aquatic plant community. Whole-lake point-intercept surveys are used to quantify the abundance of individual plant species within the lake. Of the 365 point-intercept sampling locations that fell at or shallower than the maximum depth of plant growth (the littoral zone) in Crooked Lake in 2016, approximately 77% contained aquatic vegetation. Aquatic plant rake fullness data collected in 2016 indicates that 33% of the 365 sampling locations contained vegetation with a total rake fullness rating (TRF) of 1, 14% had a TRF rating of 2, and 30% had a TRF rating of 3 (Figure 3.4-4). The TRF data indicates that where aquatic plants are present in Crooked Lake, they are moderately dense. Comparing the TRF data from the 2011 survey, the vegetation was less abundant in 2016.

Of the 80 point-intercept sampling locations in Gilkey Lake in 2016, approximately 50% contained aquatic vegetation. Aquatic plant rake fullness data collected in 2016 indicates that 35% of the 80 sampling locations contained vegetation with a total rake fullness rating (TRF) of 1, 10% had a TRF rating of 2, and 5% had a TRF rating of 3 (Figure 3.4-4). The TRF data indicates that where aquatic plants are present in Gilkey Lake, they are sparse with dense plants in a few areas.

Of the 49 point-intercept sampling locations in Bass Lake in 2016, 100% contained aquatic vegetation. Aquatic plant rake fullness data collected in 2016 indicates that 15% of the 49 sampling locations contained vegetation with a total rake fullness rating (TRF) of 1, 6% had a TRF rating of 2, and 79% had a TRF rating of 3 (Figure 3.4-4). The TRF data indicates that where aquatic plants are present in Bass Lake, they are high in density.

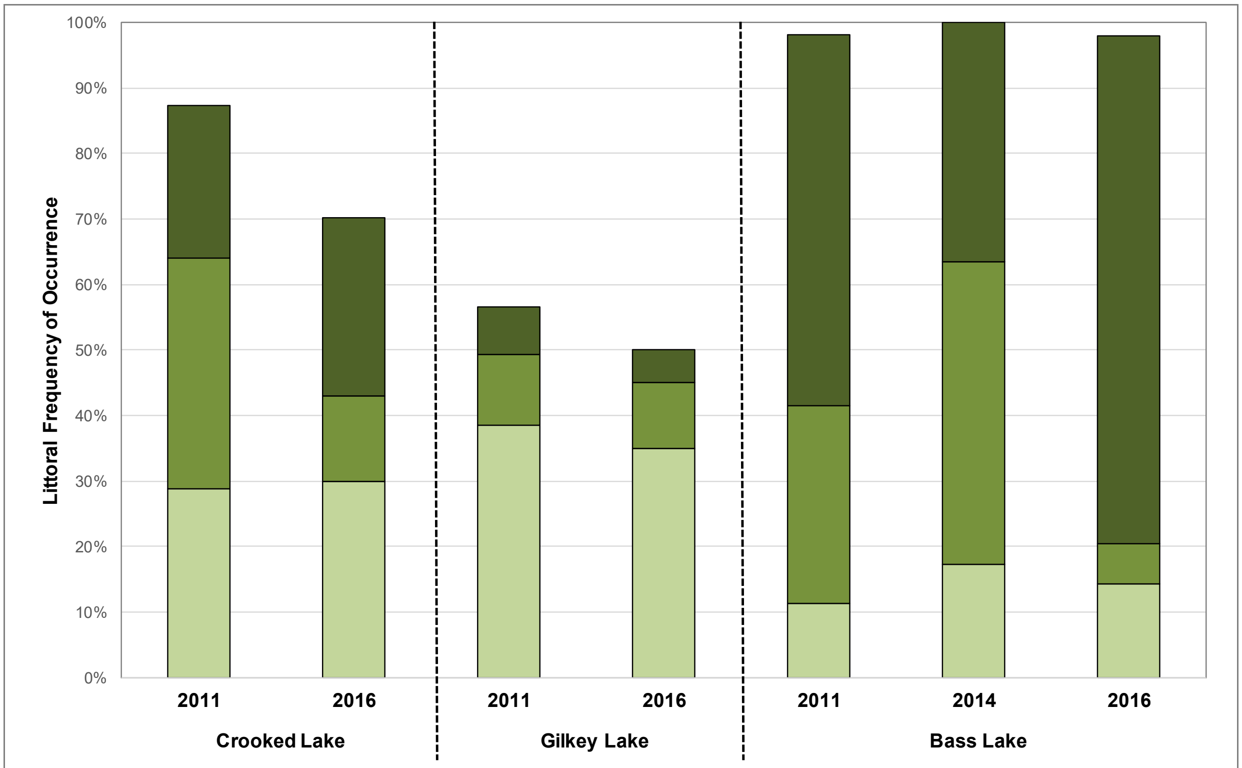


Figure 3.4-4. Crooked Lake Area Lakes 2016 aquatic vegetation total rake fullness (TRF) ratings within littoral areas. Created using data from the 2016 whole-lake aquatic plant point-intercept survey.

Of the 39 aquatic plant species located in Crooked Lake in 2016, 27 were encountered directly on the rake during the whole-lake point intercept survey. The remaining 12 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. Of these 27 species, common waterweed was the most frequently encountered, followed by stoneworts, muskgrasses, and southern naiad (Figure 3.4-5). Common waterweed was the most frequently-encountered aquatic plant with a littoral frequency of occurrence of 38%, is an aquatic plant species with a wide distribution across North America and obtains the majority of its nutrients directly from the water. While common waterweed can be found growing in many of Wisconsin's waterbodies, excessive growth of common waterweed is often observed in waterbodies which receive excessive amounts of nutrients. It can tolerate the low light conditions found in eutrophic systems better than many other aquatic plant species.

Stoneworts, the second-most frequently encountered aquatic plant in Crooked Lake with a littoral frequency of occurrence of 23%, are a genus of macroalgae. The stems and branches of these plants are often bright green and semi-transparent. These plants were found growing in large beds along the bottom in Crooked Lake, where they are not likely seen from the surface. The fine, whorled branches of stoneworts provide excellent habitat for aquatic invertebrates and provide foraging and cover areas for fish. Stoneworts were found to be most dominant from 10 to 17 feet, the deepest portion of Crooked Lake's littoral zone. Finding stoneworts growing so deep is a testament to the water clarity and quality of Crooked Lake.


Photograph 3.4-5. The aquatic macroalgae muskgrasses (Chara spp.). Photo credit Onterra.

Muskgrasses are a genus of macroalgae of which there are seven species in Wisconsin (Photograph 3.4-5). In 2016, muskgrasses, the third-most encountered aquatic plant, had a littoral frequency of occurrence of approximately 20% (Figure 3.4-5). Dominance of the aquatic plant community by muskgrasses is common in alkaline lakes like Crooked Lake, and these macroalgae have been found to more competitive against vascular plants (e.g. pondweeds, milfoils, etc.) in lakes with higher concentrations of calcium carbonate in the sediment (Kufel and Kufel 2002; Wetzel 2001). Muskgrasses require lakes with good water clarity, and their large beds stabilize bottom sediments. Studies have also shown that muskgrasses sequester phosphorus in the calcium carbonate incrustations which from on these plants, aiding in improving water quality by making the phosphorus unavailable to phytoplankton (Coops 2002). In Crooked Lake, muskgrasses were most abundant between three and thirteen feet in 2016.

Southern naiad was the fourth-most frequently encountered aquatic plant in Crooked Lake in 2016 with a littoral frequency of occurrence of approximately 17% (Figure 3.4-5). While southern naiad is native to North America, observations have been indicating that populations of this plant have been expanding and behaving invasively, particularly in northern Wisconsin lakes. It is not known if this behavior represents recent introductions of these plants to waterbodies where it was not found naturally, or if certain environmental conditions are favoring the expansion of southern naiad. As is discussed further in this section, southern naiad was recorded during the 2011 point-intercept survey complete on Crooked Lake, and these data indicate southern naiad occurrence has significantly decreased over this time period.

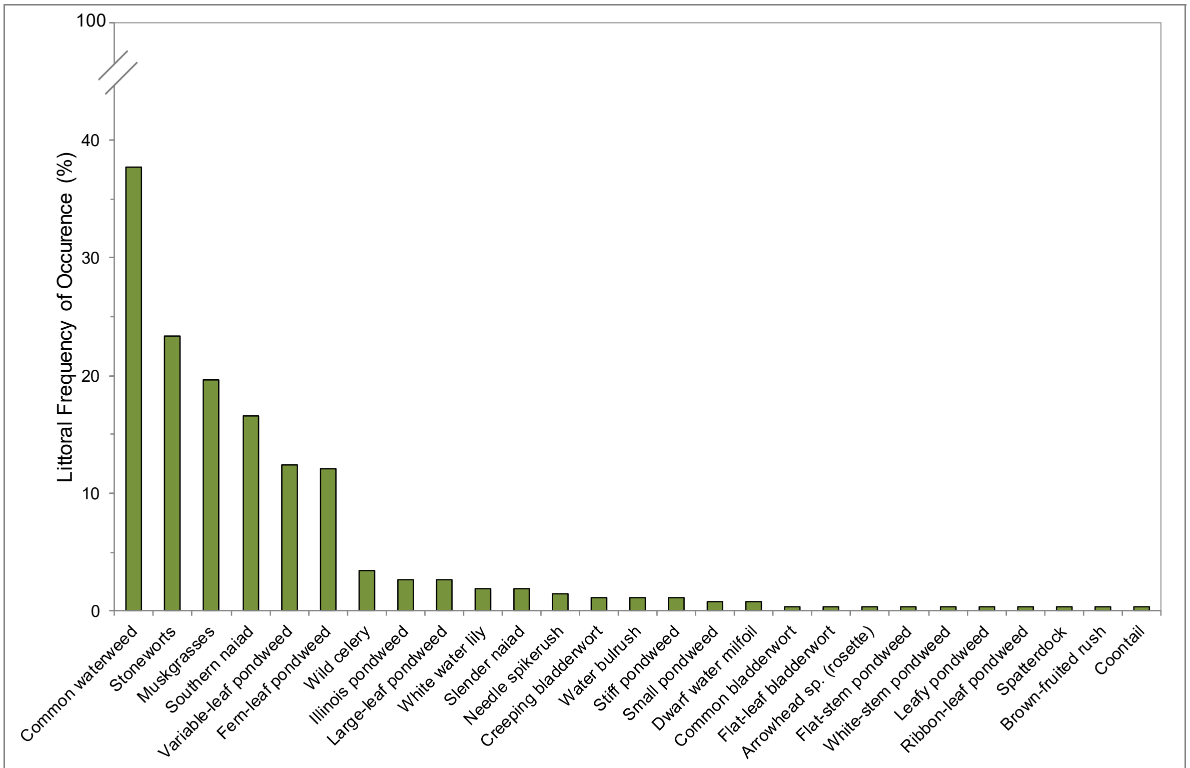


Figure 3.4-5. Crooked Lake aquatic plant littoral frequency of occurrence. Created using data from August 2016 surveys.

Of the 25 aquatic plant species located in Gilkey Lake in 2016, 15 were encountered directly on the rake during the whole-lake point intercept survey. The remaining 10 species were located incidentally during the community mapping survey. Of these 15 species, water bulrush was the most frequently encountered, followed by white water lily, white-stem pondweed, and southern naiad (Figure 3.4-6). Water bulrush, the most frequently-encountered species found in Gilkey Lake with a littoral frequency of 11%, is a totally submerged bulrush species found in calm, shallow waters of lakes and streams in Wisconsin. This species has fine, hair-like leaves and forms large mats along the bottom which provide habitat to aquatic organisms while its extensive root system stabilizes bottom sediments.

While white water lily was found in all three lakes, it was the second-most frequently encountered plant in Gilkey Lake with a littoral frequency of 10%. The shallow water in Gilkey Lake allows white water lily to grow over a large area. This floating-leaf species has easily recognizable white flowers and round leaves. Large areas of white water lily can help stabilize sediments and provides a sanctuary for fish and plankton.

White-stem pondweed, the third-most encountered plant in Gilkey Lake with a littoral frequency of occurrence of approximately 9%, is a large pondweed with zig-zag stems and leaves with boat tips. Like all other pondweeds, it contains a lot of biomass and are found growing relatively close to the surface. During years that favor the growth of these species, they may have the capacity to greatly interfere with recreation and navigation within the lakes.

Southern naiad was the fourth most encountered species in Gilkey Lake. It had a littoral frequency of occurrence of approximately 9%. As discussed above, southern naiad has been known to overtake other native plants, but in Gilkey Lake southern naiad saw a decrease from 2011 to 2016 but the decrease was not significant.

A species of special concern in Wisconsin, Robbin's spikerush (*Eleocharis robbinsii*), was found in several locations within Gilkey Lake. This plant possesses triangular stems that emerge from the water and are topped with a spikelet where seeds are produced. In addition, fine sterile stems are also produced that remain submersed. Usually found growing in lakes with lower alkalinity and pH, it is a curiosity that this plant was found growing in Porters Lake which has relatively higher alkalinity and pH. The colonies of Robbins' spikerush observed in Gilkey Lake is likely helping to stabilize bottom and shoreline sediments while providing structural habitat in the shallower areas of the lake.

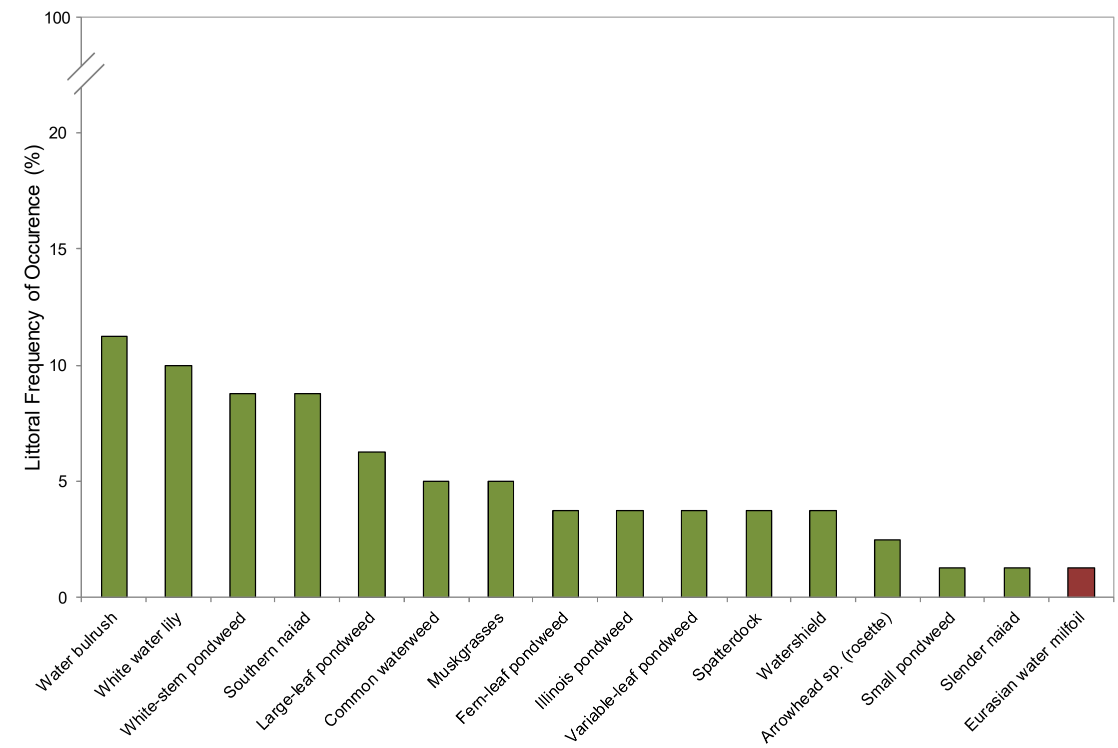


Figure 3.4-6. Gilkey Lake aquatic plant littoral frequency of occurrence. Created using data from the August 2016 surveys.

Of the 26 aquatic plant species located in Bass Lake in 2016, 15 were encountered directly on the rake during the whole-lake point intercept survey. The remaining 11 species were located incidentally during the community mapping survey. Of these 15 species, fern-leaf pondweed was the most frequently encountered, followed by southern naiad, common waterweed, and large-leaf pondweed (Figure 3.4-7). Fern-leaf pondweed was the most encountered aquatic plant species in Bass Lake with a littoral frequency of 90%. As its name suggests, the appearance of fern-leaf pondweed resembles that of a terrestrial fern or a frond of a palm tree. This species is one of the most common pondweed species in Wisconsin and is able to grow to deeper depths than many other plants. Even though it is the most abundant aquatic plant in Bass Lakes, this species rarely grows in a way that would interfere with navigation and recreational activities. Fern pondweed is low-growing within the water column and spreads along the bottom via rhizomes, forming large beds that provide valuable habitat to invertebrates and fish. Analyses of the point-intercept data indicate that the majority of fern pondweed in these lakes was found growing between four and ten feet.

Southern naiad, the second-most encountered species, and common waterweed, the third-most encountered species, have been discussed at length within the Crooked and Gilkey Lakes. Southern naiad populations have varied slightly from 2011 to 2016 but there have been no significantly changes in its population.

Large-leaf pondweed, the fourth-most encountered species, had a littoral frequency of 20%. Large-leaf pondweed is often called "cabbage" due to its appearance, has the broadest leaf (3.5-7 cm wide) of any pondweed in the Midwest. The leaves are arched and slightly folded, and though often found in a greenish color can take on a reddish appearance in the late summer. Large-leaf pondweed was found frequently at depths of 3-8 feet.

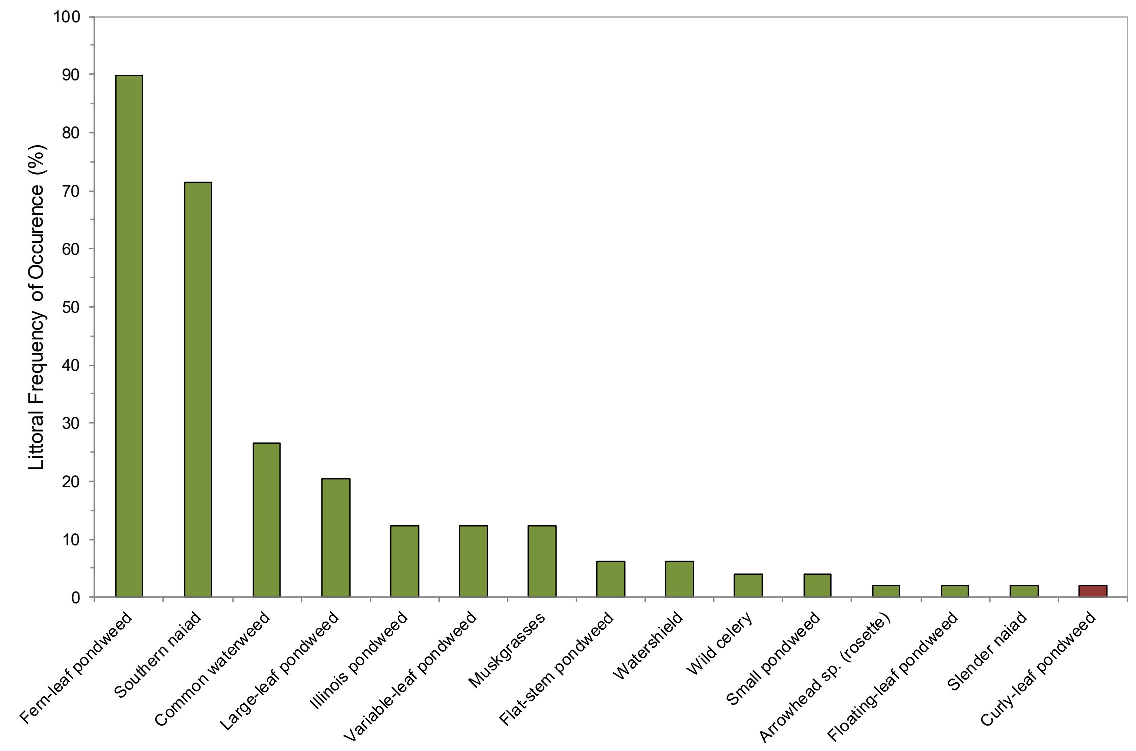


Figure 3.4-7. Bass Lake aquatic plant littoral frequency of occurrence. Created using data from the August 2016 surveys.

Aquatic plant point-intercept datasets are also available from 2011 in Crooked and Gilkey Lakes and 2011 and 2014 for Bass Lake. The methodology and sampling locations were the same as the survey completed in 2016. The datasets from all the years can be statistically compared to determine if any significant changes in the overall occurrence of vegetation or in species' abundance have occurred over this time period. Comparison between these surveys indicates that the littoral frequency of occurrence of all vegetation within Crooked Lake has increased from 68% in 2011 to 72% in 2016. This increase is not significant. Gilkey Lake saw a decrease in littoral frequency of occurrence of all vegetation from 93% in 2011 to 90% in 2016. This decrease in vegetation is not significant. Bass Lake also saw a decrease in littoral frequency of occurrence of all vegetation from 90% in 2011, 88% in 2014, to 83% in 2016. None of the decreased for Bass Lake were a significant decrease.

Figure 3.4-8 displays the littoral frequency of occurrence of aquatic plant species from the 2011 and 2016 point-intercept surveys for Crooked Lake. Only the species that had a littoral frequency of occurrence of at least 5% in one of the two surveys are displayed. In total, nine aquatic plant species exhibited statistically valid changes in their littoral frequency of occurrence between 2011 and 2016 (Figure 3.4-8). Creeping bladderwort, white water lily, common bladderwort, fern-leaf pondweed, southern naiad, flat-stem pondweed, large-leaf pondweed, and stiff pondweed all decreased in their littoral occurrence from 2011-2016. Eurasian watermilfoil also decreased from 2011-2016 but EWM is still present within the lake, it was just not sampled on a point during the 2016 survey.

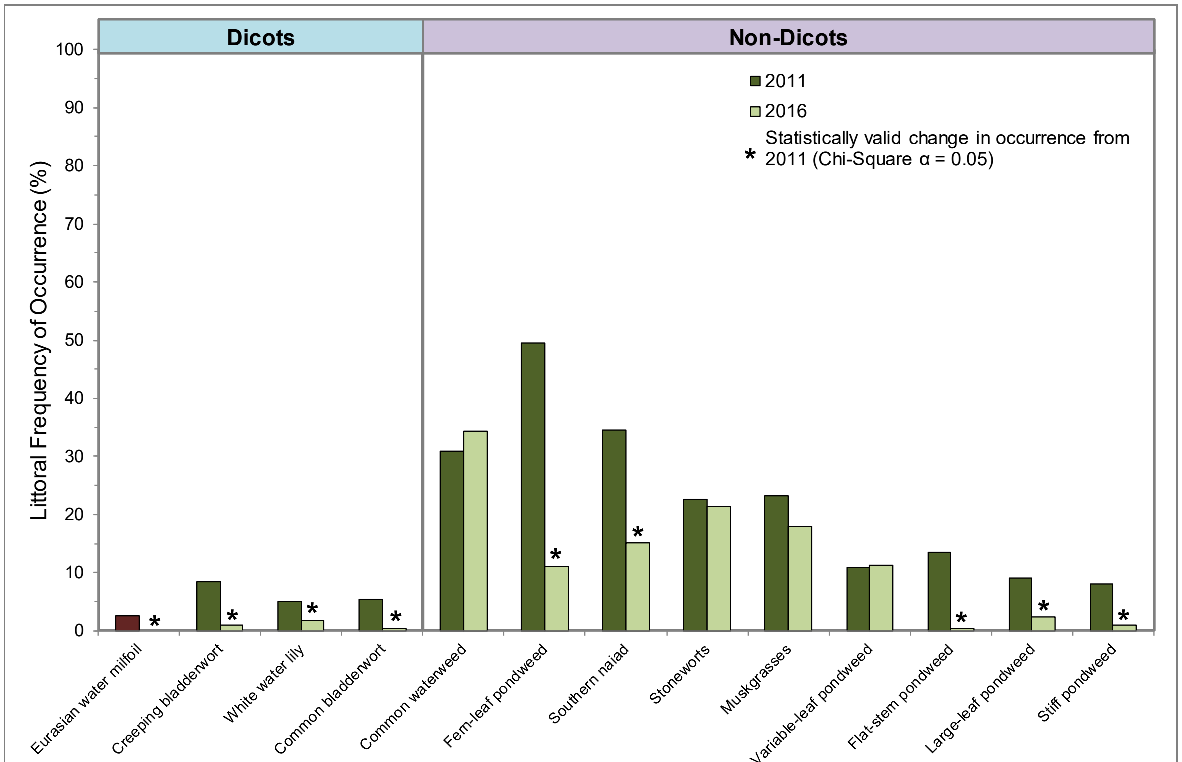


Figure 3.4-8. Crooked Lake aquatic plant littoral frequency of occurrence from 2011 and 2016. Created using data from the 2011 and 2016 surveys.

Figure 3.4-9 displays the littoral frequency of occurrence of aquatic plant species from the 2011 and 2016 point-intercept surveys for Gilkey Lake. Only the species that had a littoral frequency of occurrence of at least 5% in one of the two surveys are displayed. None of the aquatic species exhibited statistically valid changes in their littoral frequency of occurrence between 2011 and 2016 (Figure 3.4-9).

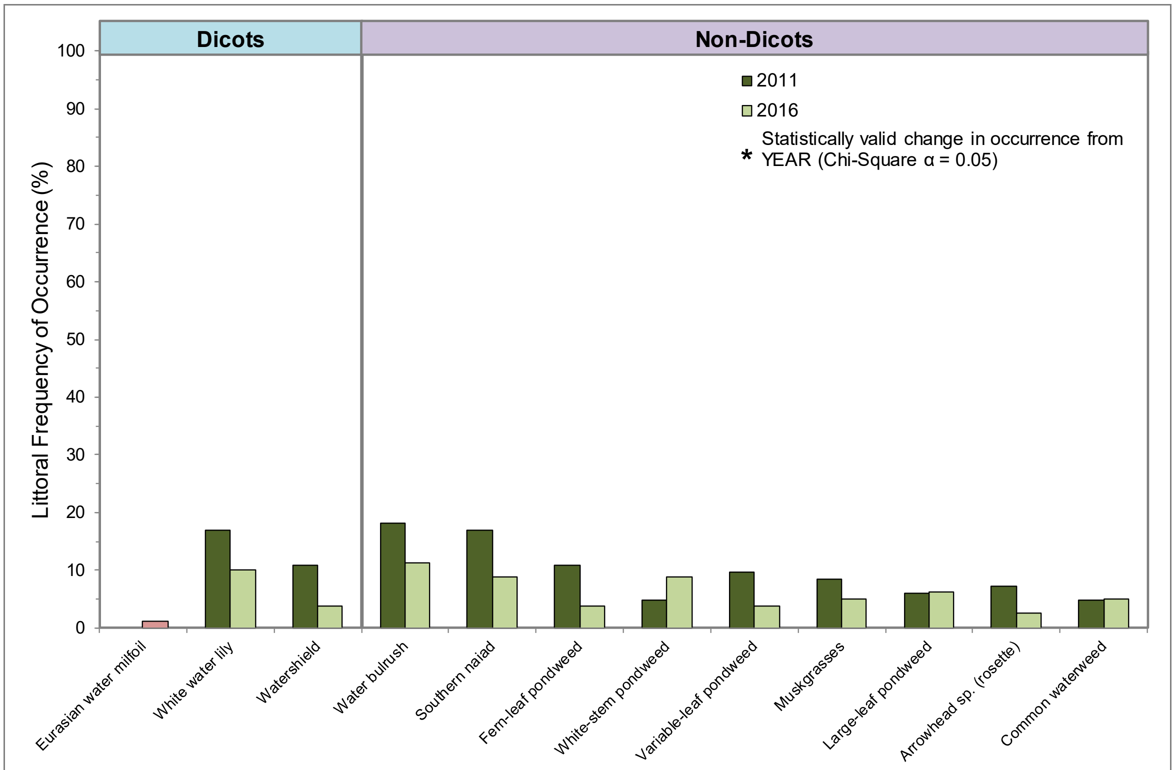


Figure 3.4-9. Gilkey Lake aquatic plant littoral frequency of occurrence from 2011 and 2016. Created using data from the 2011 and 2016 surveys.

Figure 3.4-10 displays the littoral frequency of occurrence of aquatic plant species from the 2011, 2014, and 2016 point-intercept surveys for Bass Lake. Only the species that had a littoral frequency of occurrence of at least 5% in one of the three surveys are displayed. In total, eight aquatic plant species exhibited statistically valid changes in their littoral frequency of occurrence between 2011 and 2016 (Figure 3.4-10). Creeping bladderwort, white water lily, common waterweed, and variable-leaf pondweed all significantly decreased in their littoral occurrence from 2011 to 2016 while spatterdock, Illinois pondweed, flat-stem pondweed and white-stem pondweed saw a decrease from 2014 to 2016 (Figure 3.4-10).

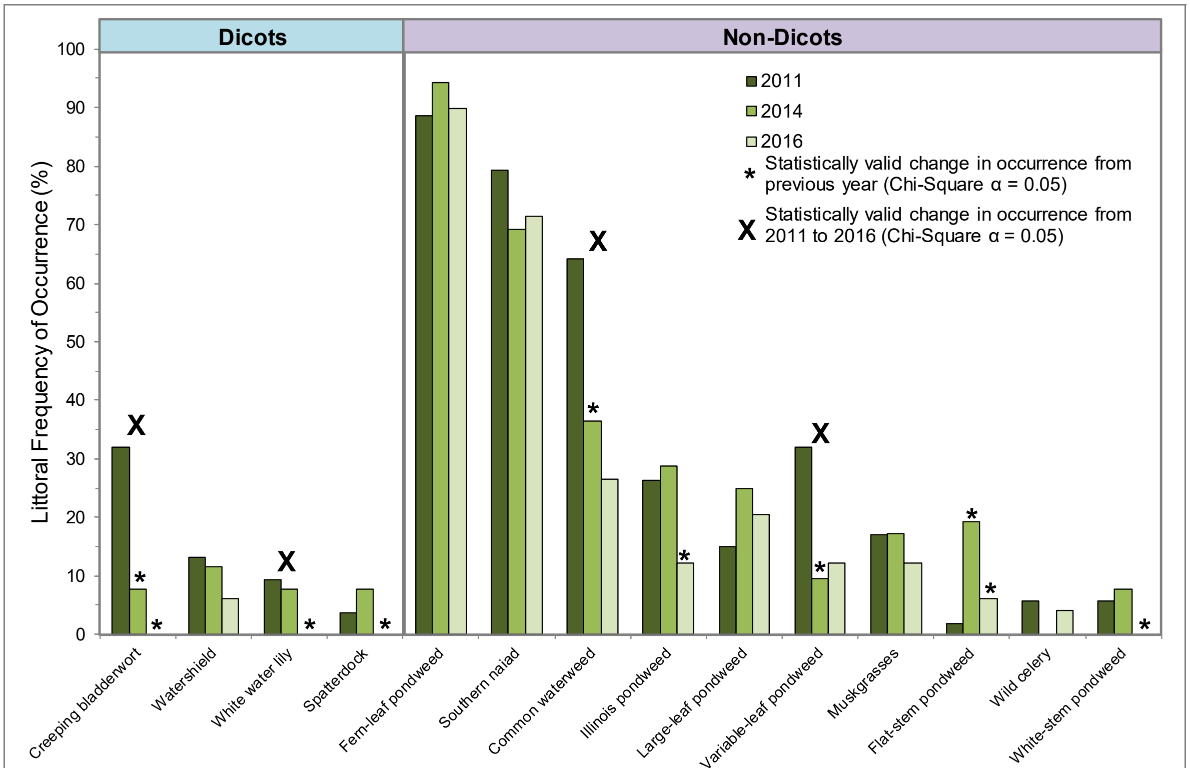


Figure 3.4-10. Bass Lake aquatic plant littoral frequency of occurrence from 2011, 2014 and 2016. Created using data from the 2011, 2014, and 2016 surveys.

Aquatic plant communities are dynamic and the abundance of certain species from year to year can fluctuate depending on climatic conditions, water levels, changes in clarity, herbivory, competition, and disease among other factors. Certain native aquatic plants can also decline following the implementation of herbicide applications to control non-native aquatic plants; however, the treatments completed to control Eurasian watermilfoil in Crooked Lake haven been relatively small and are not believed to have been able to impact native plant populations on a lake-wide level. Bass Lake had a whole-lake herbicide treatment in 2014 and this may have had an effect of the plants lake-wide. Most likely, these observed reductions and increases in occurrence of certain species are believed to be due to varying interannual environmental conditions. Ongoing collection of aquatic plant data from Wisconsin's lakes shows that aquatic plant populations have the capacity to fluctuate widely on an interannual basis under natural conditions.

As discussed in the primer section, the calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. For example, while a total of 37 native aquatic plant species were located in Crooked Lake during the 2016 surveys, 27 were directly encountered on the rake during the point-intercept survey. Crooked Lake's native aquatic plant species richness in 2016 exceeded the median value for lakes within the Northern Lakes and Forests (NLF) ecoregion and for lakes throughout Wisconsin while Gilkey and Bass Lakes fall below the median for the NLF ecoregion and the for lakes throughout Wisconsin (Figure 3.4-11). The species richness recorded in 2016 for Crooked (27) was higher than that recorded during the 2011 (26) point-intercept surveys. Gilkey and Bass Lakes both decreased from 20 species found during the 2011 point-intercept surveys to 16 and 14 species, respectively.

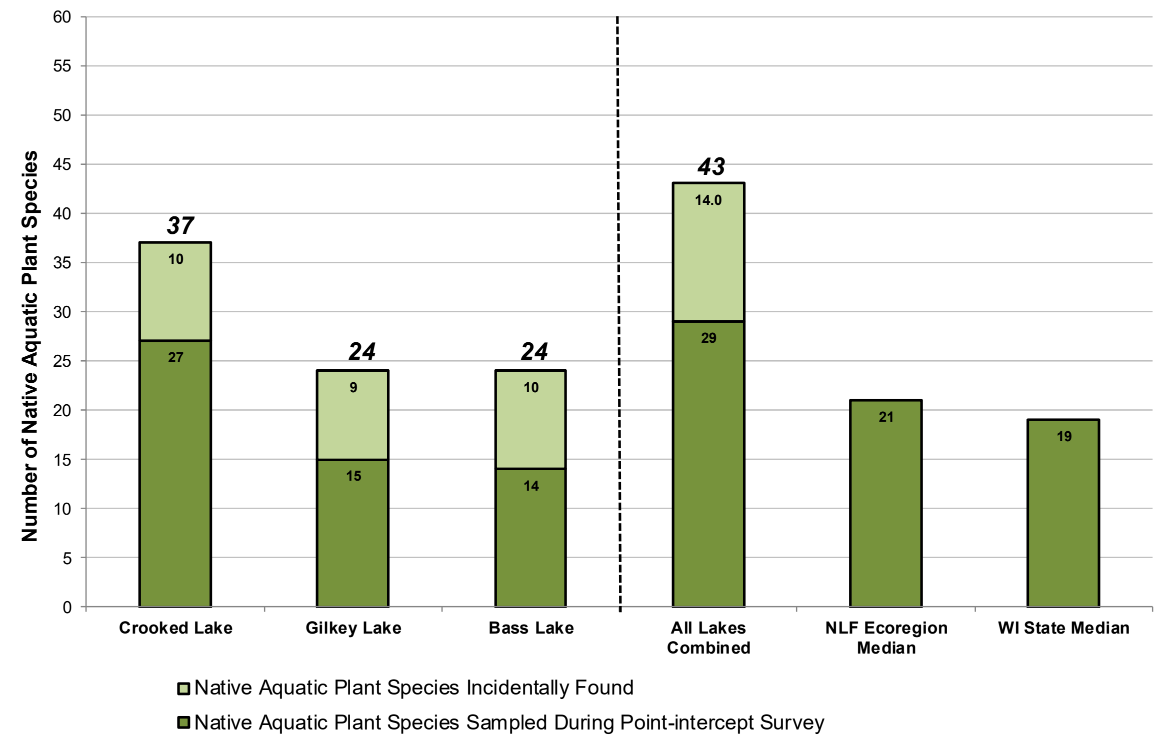


Figure 3.4-11. Crooked Lake Area Lakes species richness. Created using data from the August 2016 surveys. Analysis follows Nichols (1999).

The average conservatism of Crooked Lake's 27 native aquatic plants recorded on the rake in 2016 was 6.9, falling just above the median value (6.7) for lakes within the NLF ecoregion and above the median value (6.3) for lakes throughout Wisconsin (Figure 3.4-12). Gilkey Lake's average conservatism for the 16 native aquatic plants recorded on the rake in 2016 was 3.7, falling well below the NLF ecoregion and the state value. The average conservatism value for Bass Lake was 6.3 for the 14 native aquatic plants recorded on the rake in 2016, which is below the median for the NLF ecoregion and is the same for lake throughout Wisconsin (Figure 3.4-12). Overall, the Crooked Lake Area Lakes have a lower number of native aquatic plant species with high conservatism values when compared to the majority of lakes within the NLF ecoregion and the state. Average conservatism in 2016 was lower when compared to the average conservatism values recorded in 2011 surveys, fitting within the theme that the aquatic vegetation within the Crooked Lake Area Lakes decreased slightly in quality.

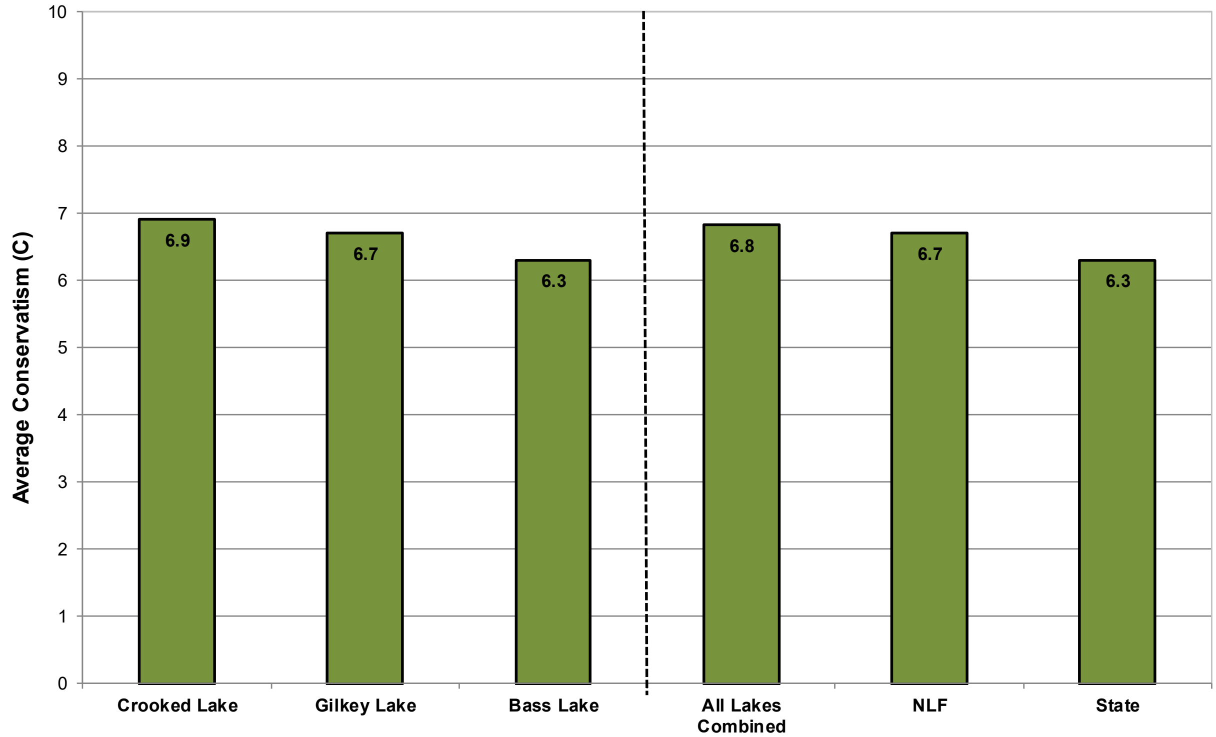


Figure 3.4-12. Crooked Lake Area Lakes average conservatism. Created using data from the August 2016 surveys. Analysis follows Nichols (1999).

Using the Crooked Lake Area Lakes' 2016 native aquatic plant species richness and average conservatism to calculate the Floristic Quality Index (FQI) value yields values of 35.8, 26.0, and 23.6, respectively. Crooked Lake's FQI value is well above the median for the NLF ecoregion as well as the state. Gilkey and Bass Lakes both fall below the median for the NLF ecoregion and the state (Figure 3.4-13). This indicates that Crooked Lake's aquatic plant community is of higher quality in terms of species richness and community composition than the majority of lakes within the ecoregion and the state. Gilkey Lake has a surprisingly high FQI value when compared to the average conservatism value meaning that even though there are not a high number of native plants present, they are of higher quality. Crooked Lake's FQI value is higher than found in 2011 while both Gilkey and Bass Lake's FQI values are lower.

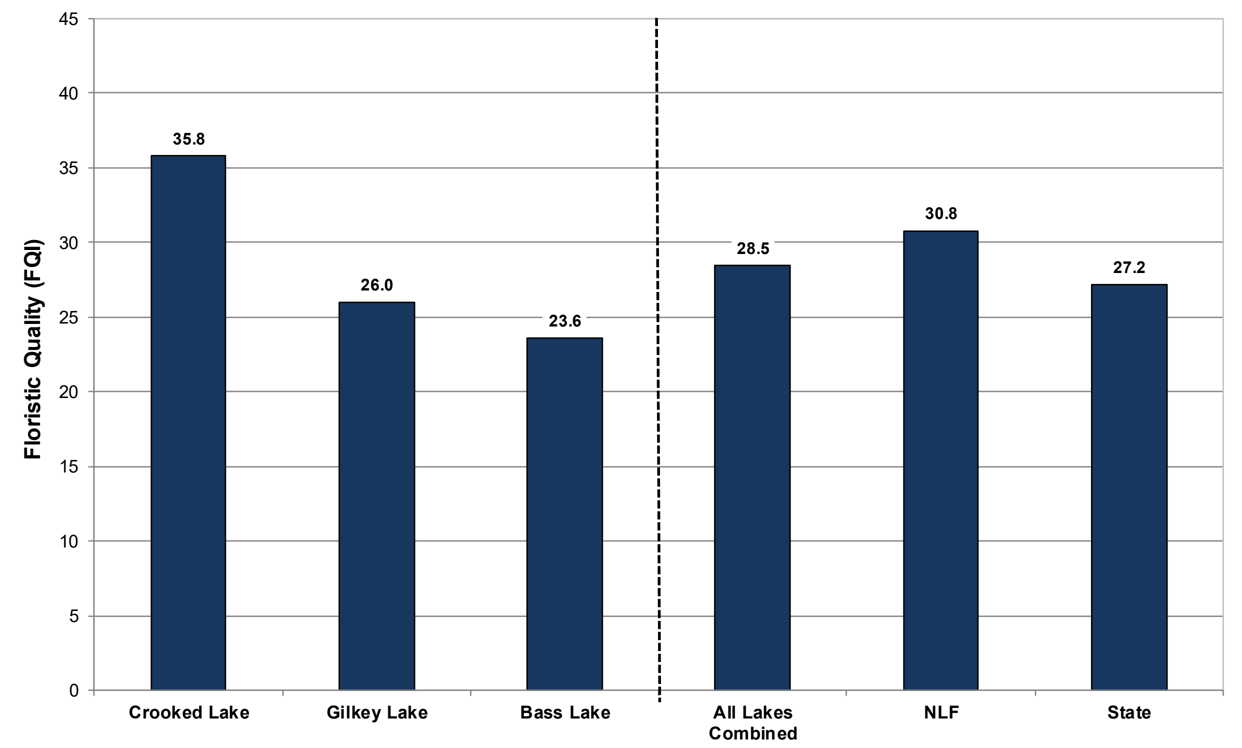


Figure 3.4-13. Crooked Lake Area Lakes Floristic Quality Index. Created using data from the August 2016 surveys. Analysis follows Nichols (1999).

Lakes with diverse aquatic plant communities have higher resilience to environmental disturbances and greater resistance to invasion by non-native plants. In addition, 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. Because the Crooked Lake Area Lakes contain a high number of native aquatic plant species, one may assume the aquatic plant community also has high species diversity. However, species diversity is also influenced by how evenly the plant species are distributed within the community.

While a method for characterizing diversity values of fair, poor, etc. does not exist, lakes within the same ecoregion may be compared to provide an idea of how the Crooked Lake Area Lakes diversity value ranks. Using data collected by Onterra and WDNR Science Services, quartiles were calculated for 212 lakes within the NLF ecoregion and the data collected from the 2016 point-intercept surveys, it can be seen that Crooked and Bass Lakes' Simpson's Diversity Index fall below the ecoregion median (Figure 3.4-14). Gilkey Lake's Simpson's Diversity Index is above the upper quartile for the NLF ecoregion, speaking to the high quality of plants found within Gilkey Lake.

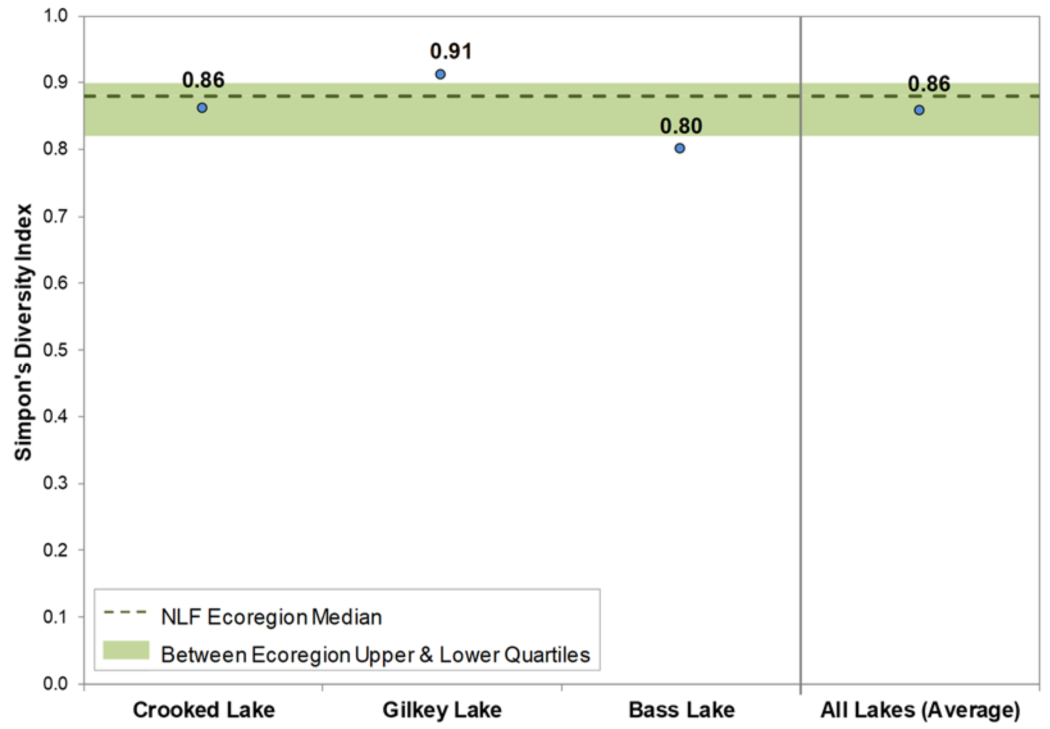


Figure 3.4-14. Crooked Lake Area Lakes species diversity index. Created using data from the 2016 aquatic plant surveys. Ecoregion data from 212 NLFL lakes collected by WDNR Science Services and Onterra.

While the Crooked Lake Area Lakes all contain a high number species within their community all three are dominated by three to four species. One way to visualize this is to look at the relative occurrence of aquatic plant species. Figure 3.4-15 displays the relative frequency of occurrence of aquatic plant species created from the 2016 whole-lake point-intercept surveys and illustrates the relatively uneven distribution of aquatic plant species within the community. 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).

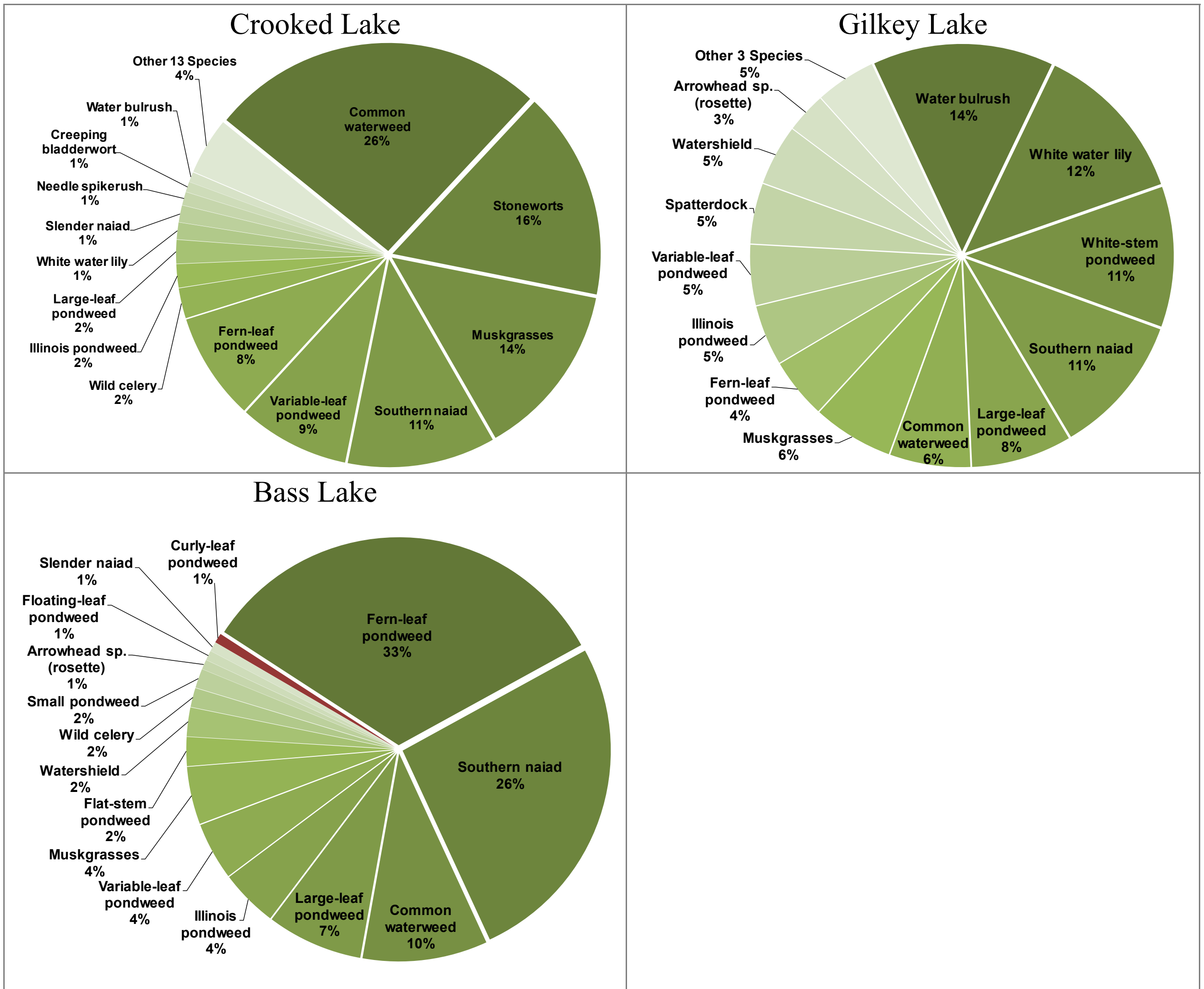


Figure 3.4-15. Crooked Lake Area Lake relative frequency of occurrence. Created using data from August 2016 surveys.

For instance, while fern-leaf pondweed had a littoral frequency of occurrence of 90%, its relatively frequency of occurrence was 33%. Explained another way, if 100 plants were sampled from Bass Lake, 33 would be fern-leaf pondweed. Figure 3.4-14 illustrates that 67% of Crooked Lake's aquatic plant community was comprised of just four species in 2016: common waterweed, stoneworts, muskgrasses, and southern naiad. 59% of Bass Lake's aquatic plant community is comprised of just two species. Gilkey is a little more evenly distributed with six species making up 62% of the population. Despite having a higher number of aquatic plant species (species richness), the dominance of the plant community by a few number of species results in lower species diversity. The lower species diversity in the Crooked Lake Area Lakes is not an indication of degraded conditions, but rather the result of the water quality as a result of the underlying geology around the lakes.

The quality of the Crooked Lake Area Lakes' plant community is also indicated by the high incidence of emergent and floating-leaf plant communities that occur in near-shore areas around the lake. The 2016 community map indicates that approximately 32 acres (16%) of the 202 acres of the three lakes contain these types of plant communities (Table 3.4-2 and Map 5-7). 17 floating-leaf and emergent species were located on the Crooked Lake Area Lakes, 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.

Table 3.4-2. Crooked Lake Area Lakes acres of plant community types. Created from the August 2016 community mapping surveys.

Plant Community	Acres
Emergent	10.8
Floating-leaf	19.5
Mixed Emergent & Floating-leaf	1.6
Total	32.0

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 the Crooked Area Lakes. This is important because these communities are often negatively affected by recreational use and shoreland development. Radomski and Goeman (2001) found a 66% reduction in vegetation coverage on developed shorelands when compared to the undeveloped shorelands in Minnesota lakes. Furthermore, they also found a significant reduction in abundance and size of northern pike (*Esox lucius*), bluegill (*Lepomis macrochirus*), and pumpkinseed (*Lepomis gibbosus*) associated with these developed shorelands.

Non-native Plants in the Crooked Area Lakes

Eurasian watermilfoil

Eurasian watermilfoil (Photograph 3.4-6) was first documented in the Crooked Lake Area Lakes in 2002. Since 2008, the CLALPRD has been actively managing the EWM population through strategically targeted herbicide applications and volunteer or professional based hand harvesting removal efforts (Table 3.4-3).

Photograph 3.4-6. Eurasian watermilfoil, a non-native, invasive aquatic plant. Photo credit Onterra.

Table 3.4-3. Crooked Lake Area Lakes EWM active management history.

	Treatment Acres	Herbicide Product	Dosing Strategy	Lbs of Active Ingredient	Bass	Lake Crooked	Gilkey
2003	5.1	2,4-D granular ester	100 lbs/acre	96.9	X	X	-
2004	7.1	2,4-D granular ester	100 lbs/acre	135.7	X	X	-
2005	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-
2007	19.0	2,4-D granular ester	100 lbs/acre	361.0	X	X	X
2008	20.0	2,4-D granular ester	100 lbs/acre	380.0	X	X	-
2009	9.0	2,4-D granular ester	~125 lbs/acre	211.9	X	X	X
2010	6.0	2,4-D granular ester	~200 lbs/acre	225.0	X	X	-
2011	3.8	2,4-D granular ester	200 lbs/acre	144.4	X	X	X
2012	14.1	2,4-D granular amine	2.5-3.0 ppm	525.7	X	X	-
2013	2.7	2,4-D granular amine	4.0 ppm	144.7	-	X	X
2014	13.3	2,4-D liquid amine	0.375 ppm ae lake-wide	76.0	X	-	-
2015	2.4	2,4-D liquid amine + endothall liquid	4.0 ppm ae + 1.5 ppm ai	155.8/60.9	HH	X + HH	-
2016	-	-	-	-	HH	HH	-
2017	-	-	-	-	HH	HH	-

X = herbicide treatment occurred, HH = professional hand-harvesting occurred

Up until late-2010, granular 2,4-D spot treatments were conducted based upon surface acreage of the lake, and not based upon the depth of the water within that area. During the winter of 2010-2011, it became more common for application rates of granular 2,4-D to be formulated based upon the volume of water in which the herbicide application would occur.

This means that sufficient 2,4-D was applied within the *Application Area* such that if it mixed evenly with the *Treatment Volume*, it would equal the desired concentration (Figure 3.4-16). This standard method for determining spot treatment use rates is not without flaw, as no physical barrier keeps the herbicide within the *Treatment Volume* and herbicide dissipates horizontally out of the area before reaching equilibrium (Figure 3.3-16). While lake managers may propose that a particular volumetric dose be used, such as 4.0 ppm acid equivalent (ae), it is understood that actually achieving 4.0 ppm ae within the water column is not likely due to dissipation and other factors.

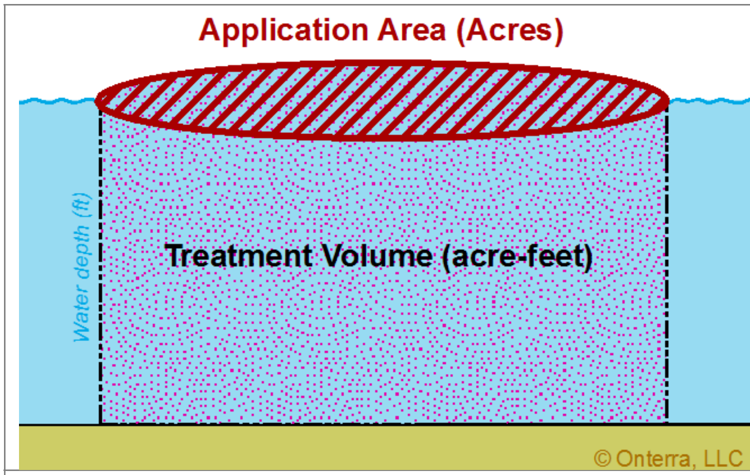


Figure 3.4-16. Herbicide Spot Treatment diagram.

Subsequent research has helped understand that the herbicide concentrations and exposure times of large (> 5 acres each) spot treatment sites are higher and longer than for small sites (Nault et al. 2015). These data also showed that concentrations were not higher for granular products compared to liquid, and therefore liquid 2,4-D treatments have become the standard in Wisconsin. Research also indicates that higher herbicide concentrations and exposure times are observed in protected parts of a lake compared with open and exposed parts of the lake. Areas targeted containing water exchange (i.e. flow) are often not able to meet herbicide concentration-exposure time (CET) requirements for control. Even in some cases where larger treatment areas can be constructed, their narrow shape or exposed location within a lake may result in insufficient herbicide concentrations and exposure times for long-term control. Ongoing field trials are assessing the efficacy (EWM control) and selectivity (collateral native plant impacts) of herbicides that may be effective with a shorter exposure time.

During 2015 a small area of EWM (2.4 acres) was targeted with a combination of 2,4-D (4.0 ppm ae) and endothall (1.5 ppm ai). Prior treatments with 2,4-D alone were unable to provide control. The combination of 2,4-D and endothall has been proven successful in some large-scale treatment situations but has not been fully evaluated in spot-treatment situations. Combination applications of 2,4-D and endothall are theorized to have additive and potentially synergistic effects compared to when the respective herbicide is used independently. These treatments appeared to have better short-term control than 2,4-D alone.

From an ecological perspective, large-scale 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 lakewide low-concentration equilibriums were reached within the first few days after application." WDNR administrative code defines large-scale treatments as those that exceed 10% of the littoral zone (NR 107.04[3]). As spot treatments approach 10% of a lake's area, they are more likely to have large-scale impacts, which is why the WDNR has this check mechanism within the permitting process.

Due to Bass Lake's relatively small water volume, almost any spot-treatment that would be conducted in this basin would have whole-lake implications. Therefore, a large-scale herbicide approach was embraced in 2014. This control strategy was moderately effective as target concentrations were reached but the exposure time was shorter than anticipated. Subsequent dosing of large-scale treatments on Bass Lake should account for a higher amount of herbicide loss from Bass Lake into Crooked Lake.

Starting in 2015, the CLALPRD adopted an integrated approach to EWM management. In areas where spot herbicide treatments were not anticipated to be effective because they were too small to hold sufficient herbicide concentration and exposure times, but control of EWM was still a priority, professional-based hand-harvesting methods were used. 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.

The CLALPRD gained an understanding of the abilities and limitations of using hand-harvesting as an EWM management tool. Generically, the hand-harvesting proved more successful when a small site was targeted. Sites with low densities of EWM could be tackled, but require continuous repositioning of the DASH boat and equipment. Sites that had a lot of native plants, were more effectively targeted earlier in the growing season before the plants amassed significant biomass.

As part of this project, the CLALPRD wanted to understand the stakeholders' perceptions on the use of various active management techniques (Figure 3.4-17). 60% of stakeholder respondents indicated they were supportive (pooled *highly supportive* and *moderately supportive* responses) of responsibly using herbicides in the system, whereas 17% were unsupportive (pooled *not supportive* and *moderately un-supportive* responses). Similarly, 50% of stakeholder respondents indicated they were supportive (pooled *highly supportive* and *moderately supportive* responses) of responsibly conducting hand-harvesting with divers, whereas 25% were unsupportive (pooled *not supportive* and *moderately un-supportive* responses). Only 4% of the stakeholders were supportive of not managing the aquatic plants and just monitoring.

Question 29: What is your level of support for the responsible use of the following techiniques on the Crooked Lake Area Lakes?

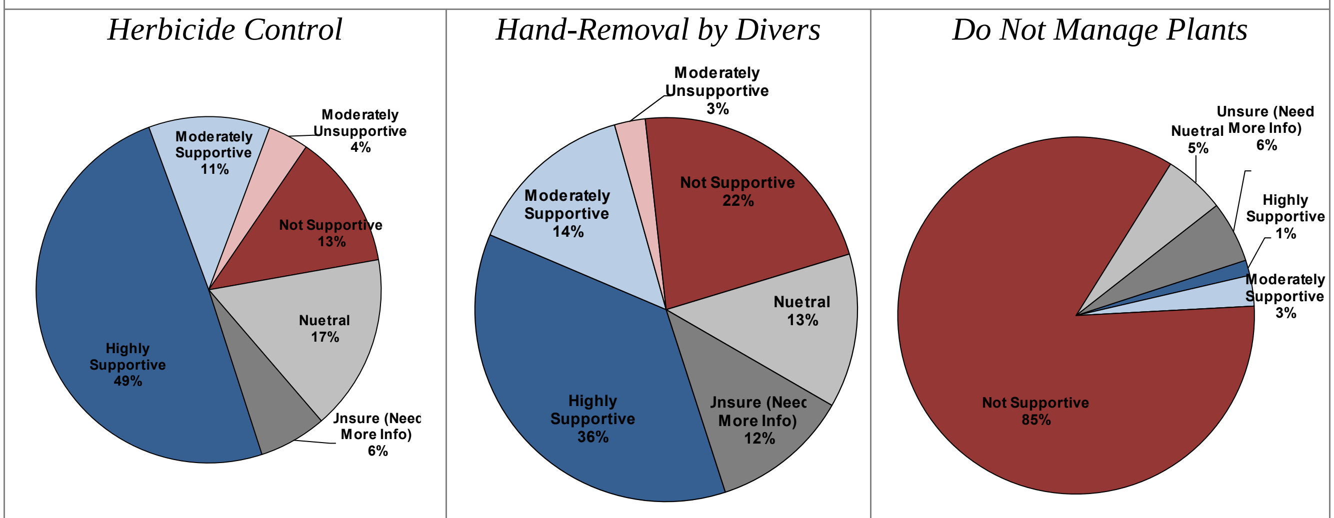


Figure 3.4-17. Select survey responses from the CLALPRD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

On May 31 – June 1, 2017, Onterra ecologists completed the Early-Season AIS Survey on the Crooked Lake system. During this meander-based survey, the entire littoral areas of the lakes were surveyed for exotic plants. While EWM is usually not at its peak growth at this time of year, the water is typically clearer during the early summer allowing for more effective viewing of submersed plants, and EWM is often growing higher in the water column than many of the native aquatic plants at that time of year. The EWM mapped during the Early-Season AIS Survey is refined during the Late-Summer Peak-Biomass survey.

The CLALPRD hired DASH, LLC to professionally hand-harvest EWM in 2017. DASH, LLC utilizes Diver Assisted Suction Harvest (DASH) allowing for EWM to be suctioned out of the lake creating minimal fragmentation and spread of the plant. The DASH system is considered a form of mechanical harvesting and thus requires a WDNR permit prior to being implemented. DASH, LLC was contracted for three days of work in 2017 on Crooked Lake and scheduled a visit for mid to late-June. On June 20 – 21 and June 23, 2017, DASH, LLC harvested a total of

195 pounds of EWM from eight sites in Crooked lake over the course of approximately 18 diver hours.

On September 18, 2017, Onterra ecologists visited Crooked Lake to complete the EWM Peak Biomass survey. This meander-based survey, which mimics the methodology used in the ESAIS survey, is completed late in the growing season (August/September) when EWM has reached its peak growth stage. Because EWM should be at or near its maximum density, the results of this survey provide an understanding of where EWM is in the lake and what its full impact on the ecology of the lake may be. As a result, these data are useful in determining the efficacy of control actions used during the summer months as well assisting in the next year's control planning.

During the survey, the EWM population was found to be relatively low lake-wide with three locations requiring mapping with area-based methodologies. A small highly scattered colony was mapped in the northern end of Crooked Lake and two colonies consisting of scattered to dominant densities were mapped in the western end of Crooked Lake (Figure 3.4-18). The EWM population in Gilkey Lake remained very low with only a handful of single or few plant occurrences located at the southeastern end of the lake. Bass Lake was found to harbor low density EWM occurrences all mapped with point-based methods (Figure 3.4-18).

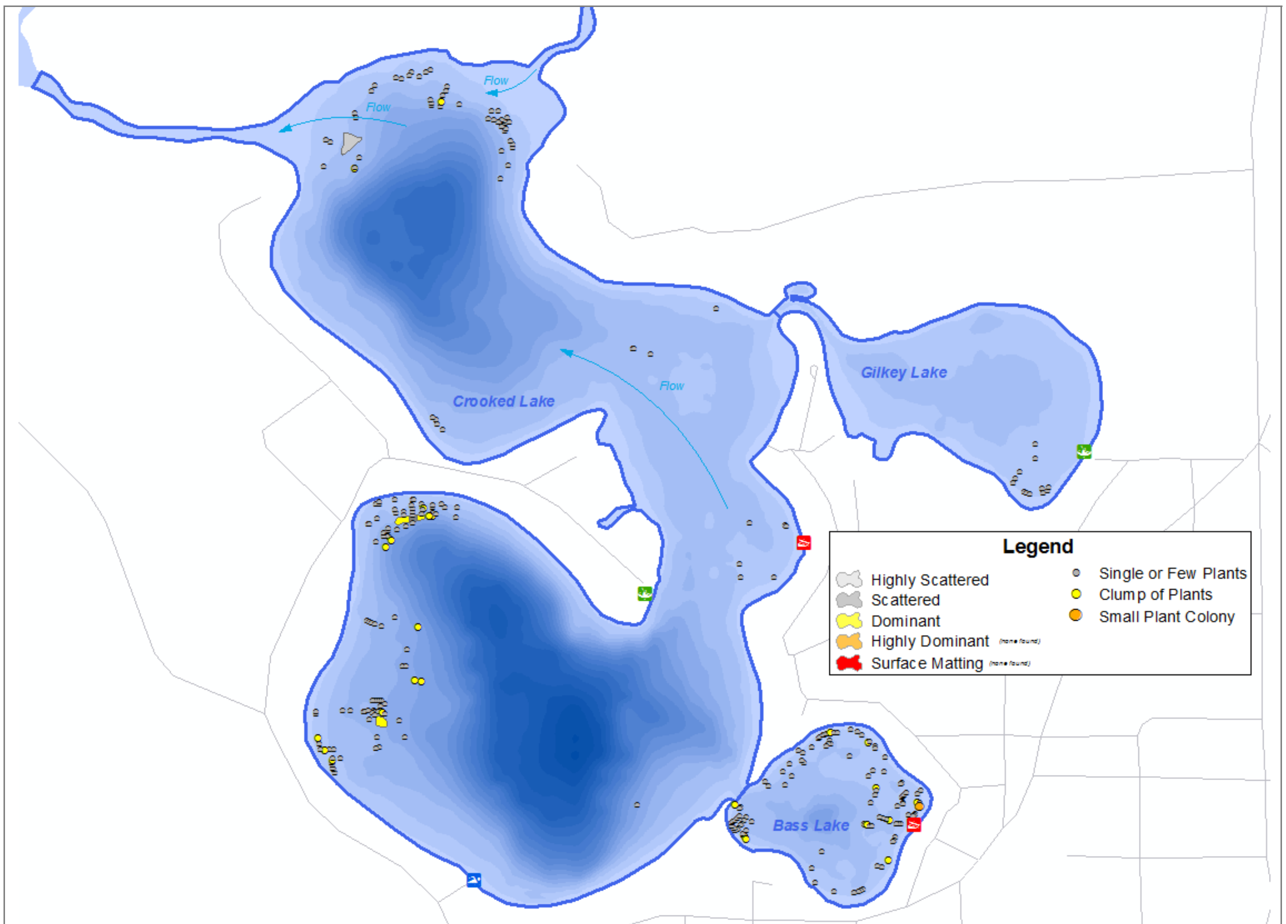


Figure 3.4-18. Crooked Lake Area Lakes 2017 Eurasian watermilfoil locations. Locations mapped during survey completed on September 18, 2017.

Onterra LLC
Lake Management Planning

Curly-leaf pondweed

Curly-leaf pondweed (*Potamogeton crispus*), another non-native exotic plant species commonly found in Wisconsin, was discovered within Crooked Lake in 2014. Limited hand-harvesting efforts were directed at the known CLP occurrences in 2014 and 2015 in an effort to maintain the low-density population in the lake. CLP is at or near its peak growth in early summer before naturally senescing (dying back) in mid-summer, making early summer the most probable time to locate this species. Onterra ecologists located several CLP occurrences in the approximate area in which it was documented in 2014-2016 in the eastern portion of Crooked Lake during the June 2017 ESAIS survey as well as a small colony of *scattered* CLP in the northern portion of Crooked Lake (Figure 3.4-19). A *clump of plants* as well as two *single or few* CLP plants were found within Bass Lake.

Photograph 3.4-7. Curly-leaf pondweed, a non-native, invasive aquatic plant. Photo credit Onterra.

The CLP population in Crooked Lake was found to have expanded somewhat since previous surveys, although is still considered relatively modest (Figure 3.4-19). In certain lakes, CLP can become so abundant that it hampers recreational activities within the lake. In instances where large CLP populations are present, its mid-summer die-back can cause significant algal blooms spurred from the release of nutrients during the plants' decomposition. However, in some lakes, mostly in northern Wisconsin, CLP appears to integrate itself within the community without becoming a nuisance.

The CLP population has increased incrementally since first being detected during June 2014. The population level observed in 2016 is still considered to be relatively low and is likely not causing any significant negative impacts to the ecology of the lake. Traditionally, CLP control consists of numerous annual herbicide treatments conducted a few weeks following ice-off. The treatment will kill each year's plants before they are able to produce reproductive turions (asexual seed-like structures). After multiple years of treatment, the turion supply in the sediment becomes exhausted and the CLP population decreases significantly. Normally a control strategy such as this includes five or more years of repetitive treatments to the same areas. Research indicates that herbicide treatments targeting relatively small sites (5 acres or less) often do not reach the necessary concentration exposure times (CET's) necessary to achieve successful results. If the CLP population continues to expand in Crooked Lake, further considerations for using herbicide control actions may be undertaken.

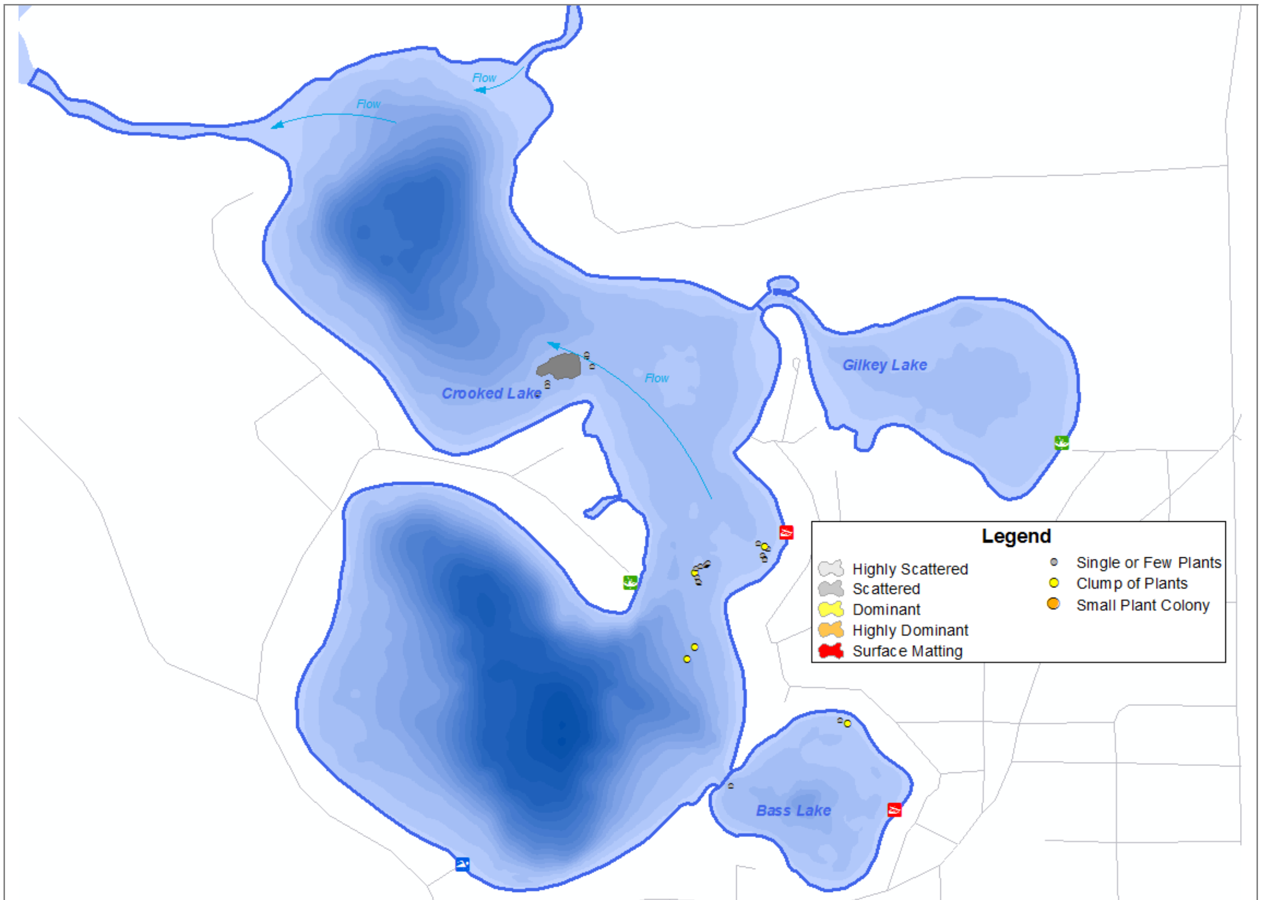


Figure 3.4-19. Crooked Lake Area Lakes 2017 curly-leaf pondweed locations. Locations mapped during survey completed on May 31 – June 1, 2017.

Mechanical Harvesting

The CLALPRD supports the reasonable and environmentally sound actions to facilitate navigability on the Crooked Lake Area Lakes. These actions target nuisance levels of aquatic plants in order to benefit watercraft navigation patterns. Reasonable and environmentally sound actions are those that meet WDNR regulatory and permitting requirements and do not impact anymore shoreland or lake surface area than absolutely necessary.

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. Figure 3.4-20 displays the responses of members of Crooked Lake Area Lakes stakeholder respondents to questions regarding aquatic plants, their impact on enjoyment of the lake and if aquatic plant control is needed. When asked how often aquatic plant growth, during the open water season, negatively impacts the enjoyment of the Crooked Lake Area Lakes, 36% of stakeholder survey respondents indicated *sometimes*, 31% indicated *often*, 15% indicated *rarely,* 8% indicated *always*, and 5% indicated never (Figure 3.1-20, top left frame). When asked if they believe aquatic plant control is needed on Crooked Lake Area Lakes, 91% of respondents indicated *definitely yes* and *probably yes*, 3% indicated that they were *unsure*, and 6% indicated *probably no* or *definitely no* (Figure 3.1-20, top right frame). These results indicate that the majority of Crooked Lake Area Lakes stakeholder respondents believe recreational use of the system is hindered by excessive aquatic plant growth, free-floating algae, and algae blooms.

The majority (60%) of respondents were supportive (pooled *Strongly Support* and *Moderately Support*) of the responsible use of mechanical harvesting on the Crooked Lake Area Lakes, whereas just 17% were not supportive (pooled *Strongly Oppose* and *Moderately Oppose*). Approximately 23% of stakeholder respondents indicated they were *Neutral* or *Unsure* regarding the responsible use of mechanical harvesting to manage aquatic plants in the Crooked Lake Area Lakes (Figure 3.3-20, bottom right frame).

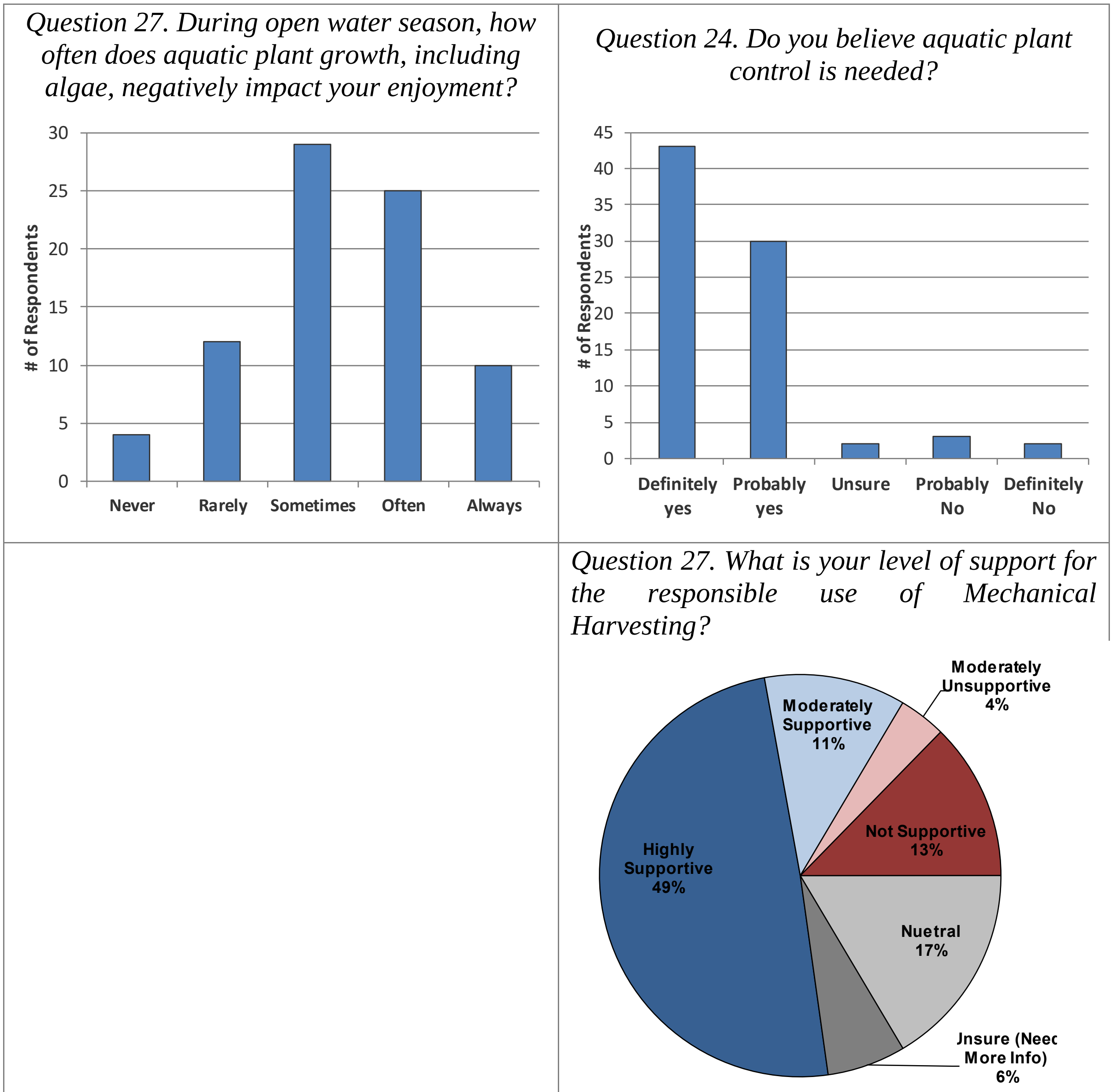


Figure 3.4-20. Select survey responses from the CLALPRD Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

3.5 Aquatic Invasive Species

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

Table 3.5-1. AIS present within the Crooked Lake Area Lakes.

Type	Common name	Scientific name	Location within the report
Plants	Eurasian watermilfoil	*Myriophyllum spicatum*	Section 3.4 – Aquatic Plants
	Curly-leaf pondweed	*Potamogeton crispus*	Section 3.4 – Aquatic Plants
Invertebrates	Banded mystery snail	*Viviparus georgianus*	Section 3.5 – Aquatic Invasive Species

Figure 3.5-1 displays the 12 aquatic invasive species that Crooked Lake Area Lake stakeholders believe are in the Crooked Lake Area Lakes. Only the species present in the Crooked Lake Area Lakes are discussed below or within their respective locations listed in Table 3.5-1. While it is important to recognize which species stakeholders believe to 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

Aquatic Animals

Mystery snails

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

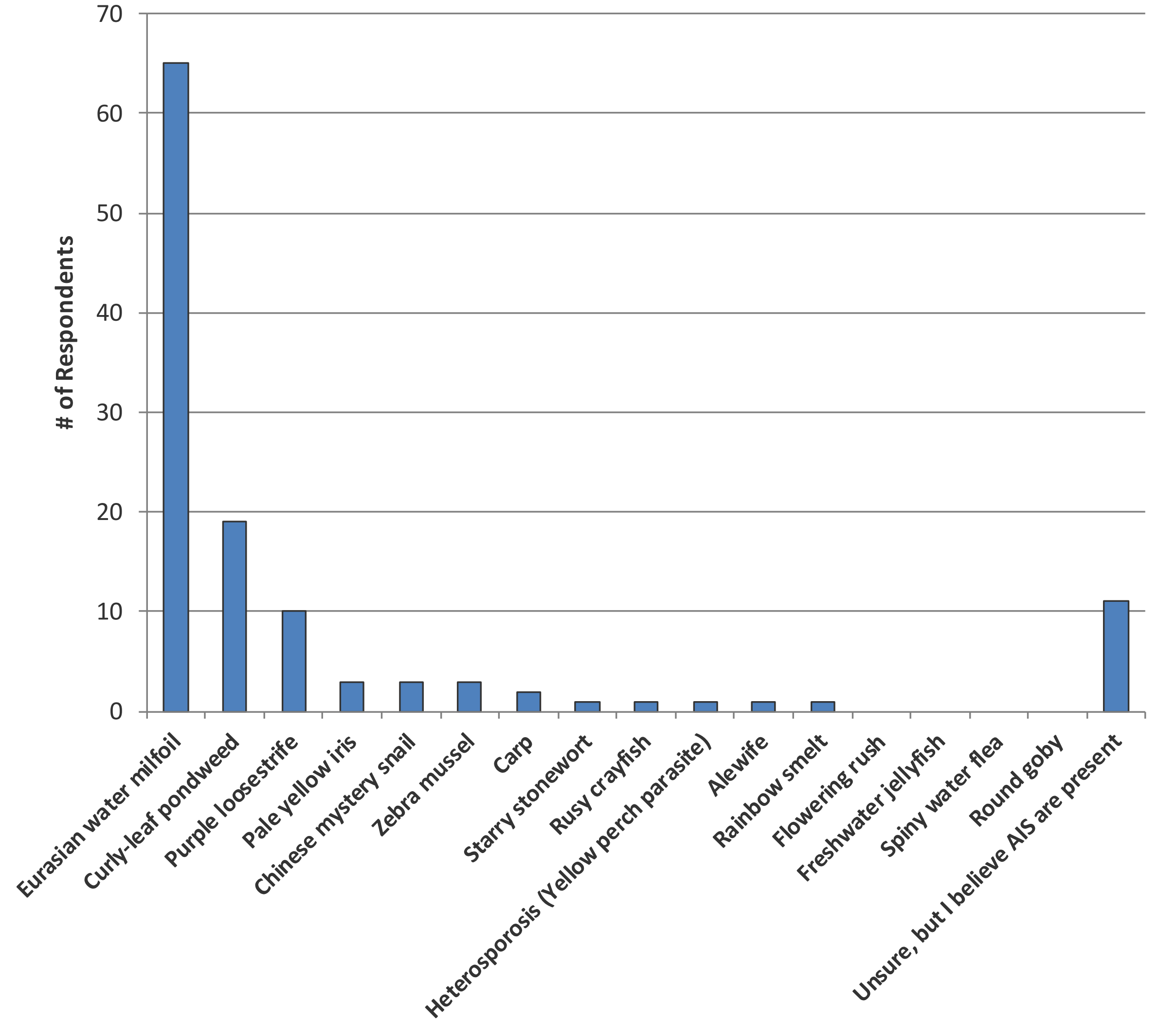


Figure 3.5-1. Stakeholder survey response Question #24. Which aquatic invasive species do you believe are in the Crooked Lake Area Lakes?

3.6 Fisheries Data Integration

Fishery management is an important aspect in the comprehensive management of a lake ecosystem; therefore, a 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 the Crooked Lake Area Lakes. The goal of this section is to provide an overview 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) (WDNR 2017) and personal communications with DNR Fisheries Biologist Chip Long.

Herbicide Use and Fisheries/Wildlife Impacts

As is discussed in the Aquatic Plant Section (3.4), several aquatic herbicides have been historically applied on the Crooked Lake Area Lakes to target aquatic invasive species. There is a potential that future in-lake herbicide treatments would use 2,4-D (EWM), endothall (EWM and CLP), or diquat (EWM). It is important to note that US EPA registration of aquatic herbicides requires organismal toxicity studies to be conducted using concentrations and exposure times consistent with spot-treatment use patterns (high concentrations, short exposure times). These toxicity studies are briefly discussed below as they apply to potential future herbicide use on the Crooked Lake Area Lakes. The use of aquatic herbicides includes regulatory oversight and must comply with the following list. Additional information from the WDNR on aquatic herbicide regulation is included within Appendix E, along with the herbicide fact sheets of 2,4-D, endothall, and diquat.

- Labeled and registered with U.S. EPA's office of Pesticide Programs;
- Registered for sale and use by the Department of Agriculture, Trade, and Consumer Protection (DATCP);
- Permitted by the Wisconsin Department of Natural Resources (WDNR); and
- Applied by a DATCP-certified and licensed applicator,

Diquat is a fact-acting contact herbicide that does not breakdown (degrade), rather binds with organic matter indefinitely. At approved label rates, diquat does not have any short-term effects on most aquatic organisms that were tested, except for certain zooplankton (*Daphnia* spp.) and benthic insects (*Amphipoda* spp.) (Appendix E). Also, walleye have been shown to be sensitive to diquat treatments at labeled rates. Diquat has not been used to date on the Crooked Lake Area Lakes.

Endothall is an aquatic herbicide that is applied as either a dipotassium salt or an amine salt. These active ingredients break down following application to endothall acid, the form that acts as an herbicide (Netherland 2009). Amine salt forms of endothall (Hydrothol®) can be highly toxic to aquatic invertebrate and fish so it is recommended that they not be used in areas where fish are considered an important resource (e.g. agriculture irrigation channels). The dipotassium salt form of endothall (Aquathol® K) has been shown to have a very low to no toxicity to fish and other invertebrates (Appendix E). The 2015 treatments on Crooked Lake between the inlet and outlet combined liquid 2,4-D amine with the dipotassium salt from of endothall at a concentration of 1.5 ppm active ingredient (ai). The maximum application rate of endothall is 5.0 ppm ai.

2,4-D is an auxin mimic herbicide that gets translocated throughout the plant (acts systemically) and suppresses growth regulation hormones. While the ester formulations of 2,4-D have been shown to be toxic to some fish and important invertebrates, the amine formulations of 2,4-D are considered "non-toxic" and spot treatment use rates (Appendix E). The majority of the historic granular 2,4-D treatments on the Crooked Lake Area Lakes utilized the ester 2,4-D formulation (Navigate ®).

The EPA-approved maximum application rate for liquid 2,4-D amine is 4.0 ppm acid equivalent (ae). At these rates, there are no restrictions on swimming or fish consumption. There are irrigation restrictions such that specific plants, particularly dicot species, should not be watered with concentrations above 0.07 ppm ae for concerns of herbicidal impacts. The EPA's maximum contaminant level of public drinking water (sole water source) for 2,4-D amine is 0.07 ppm ae.

As outlined within the WDNR's 2,4-D chemical fact sheet (Appendix E), there are human risks of being exposed to 2,4-D, especially for high-exposure populations (herbicide applicators and farmers). These include possible lymphoma and endocrine disruption (tier 1 screening by EPA). 2,4-D is currently classified by EPA as a Group D herbicide, which indicates that the inability to prove or disprove that there is human carcinogenicity (USDA FS 2006). The World Health Organization classifies 2,4-D as being "possibly carcinogenic to humans."

It is important to note that US EPA registration of aquatic herbicides requires organismal toxicity studies to be conducted using concentrations and exposure times consistent with their intended use. For herbicides like 2,4-D, the historical registration was aimed at spot-treatment use patterns (high concentrations, short exposure times). Therefore, only limited organismal toxicity data is available for concentrations and exposure times consistent with whole-lake treatment use patterns (low concentrations, long exposure times). Highlighted below is a recent and relevant research project from Wisconsin consistent with large-scale 2,4-D use patterns.

Because of their durability as a laboratory species, fathead minnows are often the subject of organismal toxicity studies. The LC50 (lethal concentration when half die) for fathead minnow exposure to 2,4-D (amine salt) has been determined to be 263 ppm ae sustained for 96 hours, a thousand times higher than fish would be exposed to in a large-scale treatment (target of approximately 0.300 ppm ae). With the assistance of a WDNR AIS-Research Grant, DeQuattro and Karasov (2015) investigated the impacts on fathead minnow of 2,4-D concentrations more relevant to what would be observed in large-scale treatments. The focus of their investigations was on reproductive toxicity and/or possible endocrine disruption potential from the herbicide. The study revealed morphological changes in reproducing male fathead minnows, such that they had lower tubercle scores (analogous to smaller antlers on a male white-tail deer) with some 2,4-D products/use-rates and not with others. This may suggest that the "inert" carrier may be the cause, not the 2,4-D itself. At a static exposure of 0.05 ppm ae for 58 days (adult fish exposed for 28 days then larval fish from eggs they laid were continued to be exposed for 30 more days post hatching) uncovered a reduction in larval fathead survival from 97% to 83% at the lowest dose of the 2,4-D (amine salt) formulation that was tested (no reduction at higher doses).

A current cooperative UW-Steven's Point and WDNR research project entitled *Effects of 2, 4-D Herbicide Treatments Used to Control Eurasian Watermilfoil on Fish and Zooplankton in*

Northern Wisconsin Lakes was conducted in response to this laboratory work to see if changes could be observed in a series of field trials. Three lakes were given large-scale 2,4-D amine treatments and a paired set of three lakes served as untreated reference lakes. The limnological, zooplankton, fisheries, and aquatic plant communities of these lakes were thoroughly sampled during the year prior to treatment, the year of treatment, and the year after treatment. A plethora of important data came from the study; however, measurable direct impacts from the herbicide treatments on the zooplankton and fisheries were not documented. A one-page summary report from the UWSP/WDNR study is included as part of Appendix E to this report.

Crooked 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 the Crooked Lake Area Lakes are supported by an underlying food chain. At the bottom of this food chain are the elements that fuel algae and plant growth – nutrients such as phosphorus and nitrogen, and sunlight. The next tier in the food chain belongs to zooplankton, which are tiny crustaceans that feed upon algae and plants, and insects. Smaller fish called planktivores feed upon zooplankton and insects, and in turn become food for larger fish species. The species at the top of the food chain are called piscivores, and are the larger gamefish that are often sought after by anglers, such as bass and walleye.

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

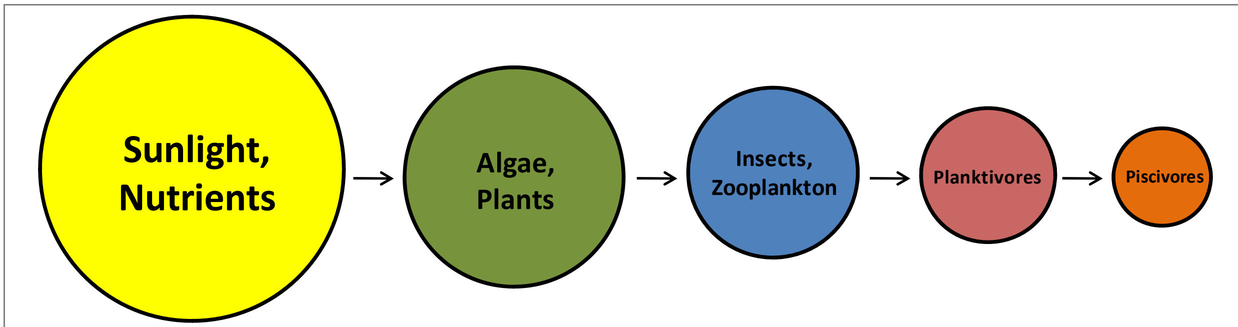


Figure 3.6-1. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, the Crooked Lake Area Lakes are 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 the Crooked Lake Area Lakes should be able to support an appropriately sized population of predatory fish (piscovores) when compared to eutrophic or oligotrophic systems. Table 3.6-1 shows the popular game fish present in the system. Although not an exhaustive list of species present in the lake, additional species found in the Crooked Lake Area Lakes include suckers (*Catostomidae*).

Table 3.6-1. Gamefish present in the Crooked Lake Area Lakes 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
Brown Bullhead (*Ameiurus nebulosus*)	5	Late Spring - August	Sand or gravel bottom, with shelter rocks, logs, or vegetation	Insects, fish, fish eggs, mollusks and plants
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)
Rock Bass (*Ambloplites rupestris*)	13	Late May - Early June	Bottom of course sand or gravel, 1 cm - 1 m deep	Crustaceans, insect larvae, and other invertebrates
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 common passive trap used 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 and 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 and sort the fish that were captured.

The other commonly used sampling method is electroshocking (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 easy for fisheries technicians to net and place into a livewell to recover. Contrary to what some may believe, electroshocking does not kill the fish and after being placed in the livewell fish generally recover within minutes. As with a fyke net survey, biological characteristics are recorded and any fish that has a mark (considered a recapture from the earlier fyke net survey) are also documented before the fish is released.

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

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

Fish Stocking

To assist in meeting fisheries management goals, the WDNR may permit the stocking of fry, fingerling or adult fish in a waterbody that were raised in nearby permitted hatcheries (Photograph 3.6-2). Stocking of 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.

Photograph 3.6-2. Walleye fingerling. (Photo from UWSP)

The Crooked Lake Sportsman's Club has been actively working to increase fishing opportunities and enhance fisheries habitat within the Crooked Lake Area Lakes. The Sportsman's Club has been leading a stocking program with walleye and yellow perch in an effort to increase angling opportunities for these species. The WDNR does not fund the stocking efforts of walleye or perch in the Crooked Lake Area Lakes because the current fishery is managed as a bass and panfish dominated system with a northern pike component. It is believed that adding another top predator such as walleye may not be sustainable in the lake due to high predation of the stocked fish (Chip Long, personal comm). A summary of the available stocking history from 1989 to 2016 are displayed in Table 3.6-2.

Table 3.6-2. Stocking data available for the Crooked Lake Area Lakes (1989-2016).

Year	Species	Age Class	# Fish Stocked	Avg Fish Length (in)
2011	Yellow Perch	Adult	350	7.0
2012	Yellow Perch	Adult	390	8.0
2013	Yellow Perch	Large Fingerling	350	7.0
2014	Yellow Perch	Adult	350	7.0
2016	Yellow Perch	Adult	350	7.0
1989	Walleye	Yearling	2,900	10.0
1990	Walleye	Fingerling	2,800	8.0
1991	Walleye	Fingerling	2,800	7.0
1992	Walleye	Fingerling	3,800	6.8
1993	Walleye	Yearling	3,800	6.8
1994	Walleye	Yearling	2500	7.5
1995	Walleye	Fingerling	3,000	6.5
1997	Walleye	Large Fingerling	3,000	6.0
2003	Walleye	Large Fingerling	2,500	7.5
2005	Walleye	Fall Yearling	2,285	7.0
2006	Walleye	Large Fingerling	2,170	7.5
2007	Walleye	Large Fingerling	1,100	6.9
2010	Walleye	Yearling	1,798	8.0
2011	Walleye	Large Fingerling	999	8.0
2012	Walleye	Large Fingerling	1,000	8.0
2013	Walleye	Large Fingerling	1,000	7.0
2014	Walleye	Large Fingerling	1,000	7.0
2015	Walleye	Yearling	989	8.0
2016	Walleye	Large Fingerling	1,000	7.0

Fishing Activity

Based on data collected from the stakeholder survey (Appendix B), fishing was the second important reason for owning property on or near the Crooked Lake Area Lakes (Question #19), relaxing/entertaining was the first most important reason. Figure 3.6-2 displays the fish that Crooked Lake Area Lakes stakeholders enjoy catching the most, with bluegill/sunfish, crappie and largemouth bass being the most popular. Approximately 75% of the Crooked Lake Area Lake stakeholders believe the quality of fishing on the lakes was either good or fair (Figure 3.6-3). Approximately 76% of these same respondents believed the quality of fishing on the lakes has either remained the same or had gotten worse since they first started fishing the lake (Figure 3.6-4).

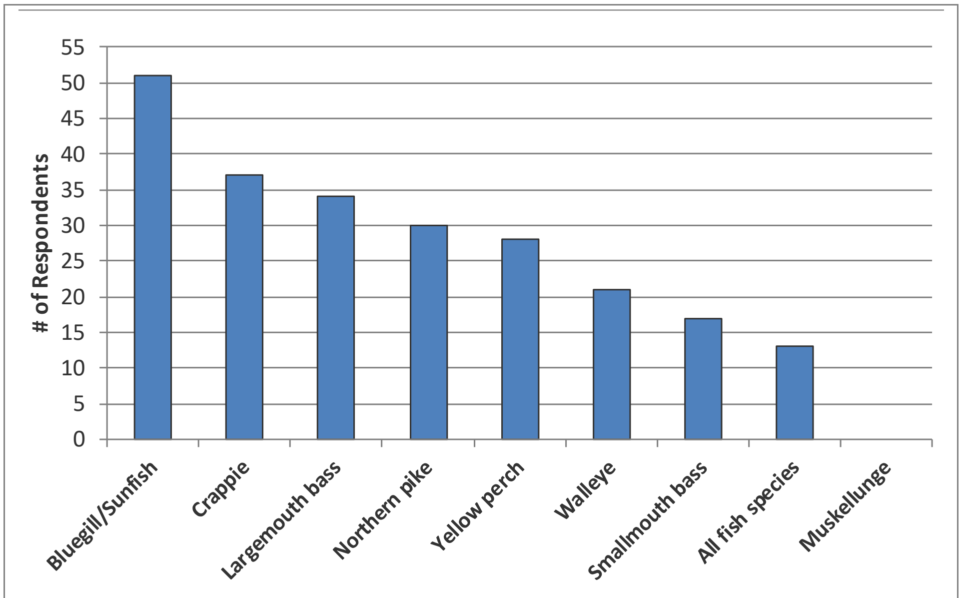


Figure 3.6-2. Stakeholder survey response Question #12. What species of fish do you like to catch on Crooked Lake Area Lakes?

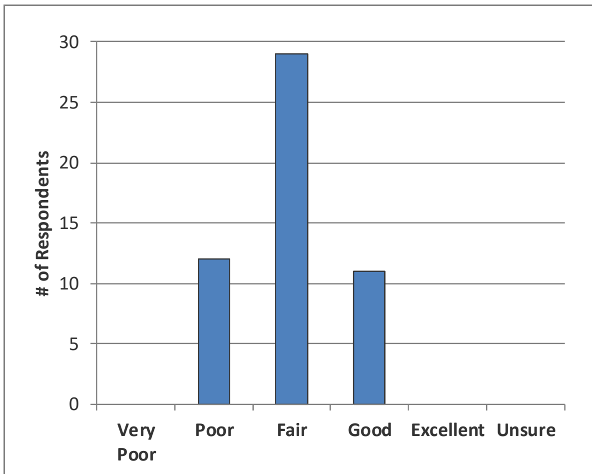


Figure 3.6-3. Stakeholder survey response Question #13. How would you describe the current quality of fishing on Crooked Lake Area Lakes?

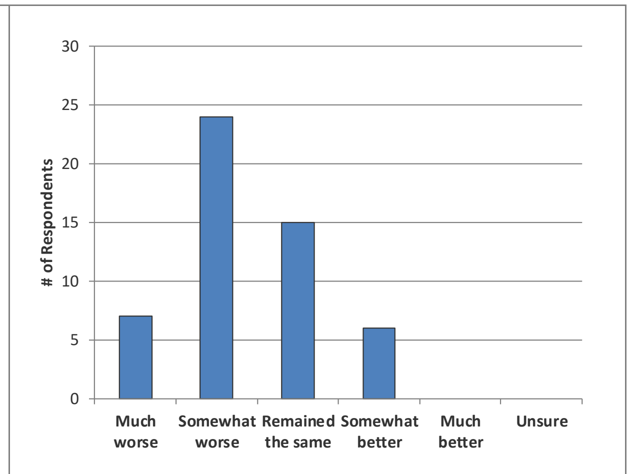


Figure 3.6-4. Stakeholder survey response Question #14. How has the quality of fishing changed on Crooked Lake Area Lakes since you started fishing the lake?

The Sportsman's Club organizes fishing tournaments with a goal of raising funds for projects on the Crooked Lake Area Lakes. The tournaments that have taken place on the Crooked Lake area Lakes have not required a permit from the WDNR likely by limiting participation to below 20 boats or 100 participants.

Crooked Lake Spear Harvest Records

Approximately 22,400 square miles of northern Wisconsin was ceded to the United States by the Lake Superior Chippewa tribes in 1837 and 1842 (Figure 3.6-5). Crooked Lake falls within the ceded territory based on the Treaty of 1842. This allows for a regulated open water spear fishery by Native Americans on lakes located within the Ceded Territory.

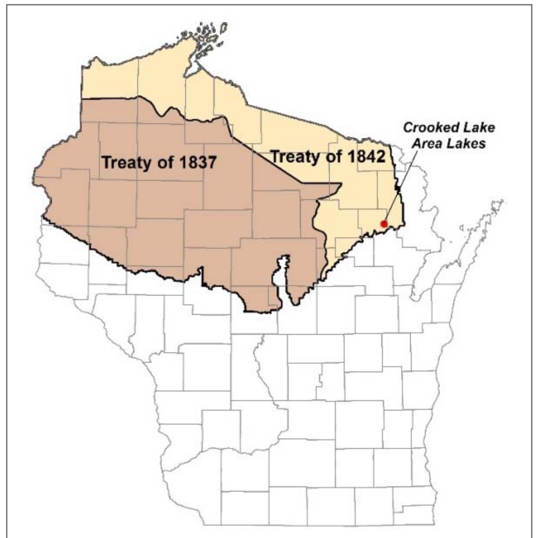


Figure 3.6-5. Location of the Crooked Lake Area Lakes within the Native American Ceded Territory (GLIFWC 2017). This map was digitized by Onterra; therefore, it is a representation and not legally binding.

While within the ceded territory, Crooked Lake Area Lakes have not experienced a spearfishing harvest. A small quota for walleye harvest has been listed for the Crooked Lake Area Lakes in recent years; however no spearing efforts have been undertaken.

Crooked Lake Area Lakes Fish Habitat

Substrate Composition

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

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

According to the point-intercept survey conducted by Onterra in 2016, 88% of the substrate sampled in the littoral zone of the Crooked Lake Area Lakes was soft sediments and 12% was composed of sand substrate.

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 2006).

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. 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. 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. A United States Forest Service (USFS) tree drop project was completed on Gilkey Lake in February of 2013. This project included the installation of 45 large, and 8-10 smaller trees in 15 or 16 groups on the ice (Chip Long, personal communication).

The Sportsman's Club and CLALPRD worked with the local fisheries biologist Chip Long to investigate other sites around the lake for consideration of installment of additional fish sticks. Due to low volunteerism from riparian property owners willing to install fish sticks on their parcels, an alternative method for enhancing woody habitat through installing fish cribs was explored. Over the winter of 2017-18 12 fish cribs were built and dropped in Crooked Lake (Figure 3.6-6, Photograph 3.6-3). The Sportsman's Club and WDNR plan to implement more fish habitat over the next several years.

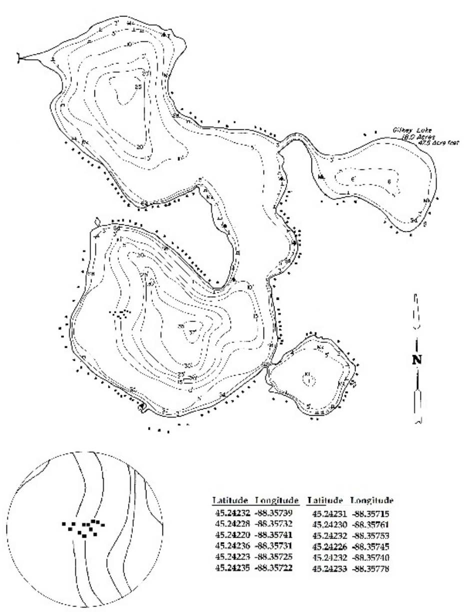


Figure 3.6-6. Fish crib locations. Data provided by WDNR.

Photograph 3.6-3. Crooked Lake Fish Cribs. Photo from WDNR.

Fish cribs are a fish habitat structure that is placed on the lakebed. Placement of fish cribs in a lake does not require a permit if the project meets certain conditions outlined by the WDNR's checklist available online:

(*http://dnr.wi.gov/topic/waterways/documents/permitExemptionChecklists/02A-fishCrib.pdf*).

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 may be requested. Installing fish cribs may 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. Through working with the local WDNR fisheries biologist, approximately 10-12 fish cribs were under construction during February 2018 and planned for placement at pre-determined sites in Crooked Lake (Chip Long, personal comm). Consideration will be made to deploy additional fish cribs over several years in order to continue to enhance woody habitat and limit the potential for concentrating fish at each crib.

Regulations and Management

The Crooked Lake Area Lakes are managed as a bass, bluegill and northern pike dominated fishery by the WDNR. Spring fisheries assessment surveys conducted by the WDNR are designed to evaluate the bass and panfish populations in the system. The most recent spring assessment was completed in 2016 and found the mean bluegill length at age was similar to or slightly above the northern Wisconsin mean values whereas the mean lengths of largemouth bass tended to be slightly below the average of northern Wisconsin lakes (C. Long, 2016). The overall condition of the fishery in the Crooked Areas Lakes is generally healthy (personal comm, C. Long). High predation of the stocked walleye and perch may limit the establishment of these populations in the lake.

Regulations for the Crooked Lake Area Lakes gamefish species as of February 2018 are displayed in Table 3.6-3. The Crooked Lake Area Lakes fall into the northern bass management zone in Wisconsin and thus smallmouth bass may not be harvested (catch and release only) from May 6, to June 16, 2017. For specific fishing regulations on all fish species, anglers should visit the WDNR website (*www. http://dnr.wi.gov/topic/fishing/regulations/hookline.html)* or visit their local bait and tackle shop to receive a free fishing pamphlet that contains this information.

Table 3.6-3. WDNR fishing regulations for the Crooked Lake Area Lakes as of February 2018.

Species	Daily bag limit	Length Restrictions	Season
Panfish (bluegill, pumpkinseed, sunfish, crappie and yellow perch)	25 panfish may be kept	None	Open All Year
Smallmouth bass (Early Season)	Catch and release only	None	May 6, 2017 to June 16, 2017
Smallmouth bass	5	14"	June 17, 2017 to March 4, 2018
Largemouth bass	5	14"	May 6, 2017 to March 4, 2018
Muskellunge and hybrids	1	40"	May 27, 2017 to November 30, 2017
Northern pike	5	None	May 6, 2017 to March 4, 2018
Walleye, sauger, and hybrids	3	18"	May 6, 2017 to March 4, 2018
Bullheads	Unlimited	None	Open All Year

General Waterbody Restrictions: Motor Trolling is allowed with up to 3 hooks, baits, or lures, per angler.
No person shall operate a boat faster than slow-no-wake during the hours of 4:00 p.m. to 10:00 a.m. local time on Town of Riverview Lakes. No person shall operate a boat faster than slow-no-wake in the waters of Crooked Lake, Gilkey Lake, Bass Lake beginning 100 feet from each end of each channel entering Crooked Lake and Gilkey Lake, and Crooked Lake and Bass Lake.

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 3.6-7. 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 3.6-7. 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/)

4.0 SUMMARY AND CONCLUSIONS

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

1) Collect detailed information on the Crooked Lake Area Lakes' water quality, watershed, shoreland habitat, and aquatic plant community.
2) Collect sociological information from Crooked Lake Area Lakes stakeholders regarding their use of the lake and their thoughts pertaining to the past and current condition of the lake and its management.
3) Using the ecological and sociological data, work with the CLALPRD to develop an updated management plan to protect and enhance the Crooked Lake Area Lakes into the future.

These three objectives were fulfilled during this project and have led to an updated and detailed picture of the Crooked Lake Area Lakes ecosystem, the people who care for it, and the management actions that need to be taken to continue to protect and enhance the Crooked Lake Area Lakes ecosystem. The studies completed on Crooked Lake Area Lakes indicate that the lake is overall very healthy. Almost all of the water quality parameters that were assessed fell within the *excellent* category for comparable lakes, and the system harbors a native aquatic plant community which is of similar or higher quality than the majority of the lakes within the region.

The favorable water quality conditions observed in the Crooked Lake Area Lakes are a result of the overall watershed. The majority of the Crooked Lake Area Lakes' watershed contains land cover types that contribute the least amount of phosphorus to the lake (i.e. forest, wetlands, and lake surface). Because the inlet is close to the outlet, a portion of the nutrients that enter the system do not mix within the system, rather get transported directly downstream.

Over half of the Crooked Lake Area Lakes' shoreline is in *urbanized* or *developed-unnatural* condition. These are the shoreland types that provide the least nutrient buffering capabilities and provide almost no habitat value for aquatic and terrestrial wildlife. The health of the ecosystem would be greatly improved if the condition of shoreland properties shifted away from the urban landscape and towards a condition resembling nature. This would include the addition of important woody habitat along the shoreline of the lake that is currently lacking. Folks from the Crooked Lake Area Lakes can take advantage of cost share opportunities with Oconto County and through the WDNR's Healthy Lakes Initiative.

The aquatic plant community within the lake and along the shorelines of Crooked Lake Area Lakes was found to be of good quality. Crooked Lake Area Lakes contains a high number of native plant species, although they may periodically create nuisance conditions that impact the riparian use of the lake. The CLALPRD will continue to investigate ways to alleviate these conditions by favoring shoreland practices that minimize the nutrients that ultimately cause the high quantities of aquatic plants as well as potentially conducting mechanical harvesting activities when these symptoms arise.

Eurasian watermilfoil and curly-leaf pondweed populations are present, but currently extremely low in Crooked Lake Area Lakes. Continued monitoring and potential small-scale management will be a priority of the CLALPRD.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the CLALPRD Planning Committee and ecologist/planners from Onterra. It represents the path the CLALPRD 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 Crooked Lake Area Lakes 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.

The CLALPRD will be responsible for deciding whether the formation of sub-committees and or directors is needed to achieve the various management goals.

Management Goal 1: Control Existing and Prevent Further Aquatic Invasive Species Infestations within Crooked Lake Area Lakes

Management Action:	Continue Clean Boats Clean Waters watercraft inspections at public access location
Timeframe:	Board of Directors, Planning Committee, or possible coordinator
Facilitator:	Clean Boats Clean Waters Committee, Volunteer Coordinator
Description:	Crooked Lake Area Lakes is a popular destination by recreationists and anglers, making the lake vulnerable to new infestations of exotic species. The intent of the boat inspections would not only be to prevent additional invasive species from entering the lake through its public access point, but also to prevent the infestation of other waterways with invasive species that originated in Crooked Lake Area Lakes. The goal is to cover the landing during the busiest times in order to maximize contact with lake users, spreading the word about the negative impacts of AIS on lakes and educating people about how they are the primary vector of its spread. The CLALPRD has set an ambitious goal of 200 hours of annual volunteer-based watercraft inspections with focus on high-use periods such as weekends and holidays. The CLALPRD continues to brainstorm ways to keep the program fresh and volunteerism from falling. If the CLALPRD find it difficult to find sufficient volunteerism to conduct boat landing inspections, they may consider the stream-lined WDNR Clean Boats Clean Waters Grant Program that provide cost coverage for paid watercraft inspections. Volunteer efforts may be sufficient to use as the local match to fund the program.
Action Steps:	
	See description above.

Management Action:	Coordinate volunteer monitoring of AIS
Timeframe:	Continuation of current effort
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	CLALPRD members have received past training on AIS identification from WDNR and Oconto County staff. The CLALPRD has a dedicated GPS to transfer information to and from professional surveyors. These surveys would be conducted to augment professional surveys, not replace them. As a goal, the CLALPRD would like to find a coordinator who is responsible for recruiting riparian property owners to participate in looking for AIS in the water and along specific stretches of shorelines.
Action Steps:	
1.	Volunteers from CLALPRD update their skills by attending a training session conducted by WDNR/UW-Extension (Paul Skawinski – 715.346.4853).
2.	Trained volunteers recruit and train additional district members.
3.	Complete lake surveys following protocols.
4.	Report results to consultant and CLALPRD, entering hours spent into SWIMS.

Management Action:	Coordinate annual professional AIS Monitoring
Timeframe:	Continuation of current effort
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	As the name implies, the EWM peak-biomass survey is completed when the plant is at its peak growth, allowing for a true assessment of the amount of this exotic within the lake. For the Crooked Lake Area Lakes, this survey will likely take place in late-August or September. This survey would include a complete meander survey of the lake's littoral zone by professional ecologists and mapping using sub-meter GPS technology. This survey would serve three main roles: 1) document the EWM population at the peak of its growth stage in a given year, 2) access the management efforts that took place over the summer, and 3) be used to propose management for the following year. If the management strategy for a given year contains a professional hand-harvesting component, an Early Season AIS (ESAIS) Survey would be conducted during June to setup that years' program. With direction from the CLALPRD, the consultant would coordinate the professional hand-harvest effort by designing the strategy

	(prioritization if needed) and providing the spatial data to the third-party firm as appropriate. The ESAIS Survey would also be important for monitoring the CLP population, which is at its peak growth stage during this time period.
Action Steps:	
	See description above as.

<u>Management Action:</u>	Conduct EWM Population Control Using Hand-Harvesting and/or Herbicide Spot Treatments
Timeframe:	Continuation of current effort
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	The EWM population of the Crooked Area Lakes is currently at relatively low population levels. At these low levels, the EWM population is not likely causing measurable negative ecological impacts to the system. Along with being a source population for future expansion, the EWM populations may be diminishing the navigability, recreation, aesthetics in localized areas. Conducting AIS management at a small scale, either with professional hand-harvesting or herbicide spot treatments, can be difficult to reach control goals and is relatively expensive. Overall, the CLALPRD will evaluate the effectiveness of the management option, financial costs, and other factors to determine the control effort chosen. <u>*Hand-Harvesting*</u> If areas of EWM are comprised of point-based mapping (i.e. *single plants*, *clumps of plants*, or *small plant colonies*) or low-density colonies (i.e. *highly scattered* or *scattered*), the CLALPRD will consider them applicable for hand-harvesting. The CLALPRD will prioritize areas of hand-harvesting depending on the overall EWM population, available resources, and strategic location of the EWM populations that meet this criterion. The hand-harvesting would occur following the June ESAIS Survey in roughly mid-June to mid-September. 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 EWM survey will occur following the hand-harvesting activities to assess the control efforts and to initiate the following years planning. If a Diver Assisted Suction Harvest (DASH) component is utilized, the CLALPRD and contracted firm would be responsible for the WDNR permit procedures. The contracted firm would be guided with GPS data

	from the consultant following the ESAIS Survey and would track their efforts (when, where, time spent, quantity removed) for post assessments. A day of traditional hand-harvesting effort can cost approximately $1,000, whereas the use of DASH typically approaches $2,000 a day. This type of work is manually intensive and can take a number of days to reach control goals. The CLALPRD is critically accessing their hand-harvesting strategy to determine if expectations are being met considering the high costs of the efforts. *Herbicide Spot Treatment* If the following trigger is met, the CLALPRD would consider conducting herbicide spot treatments: "colonized (polygons) areas where a sufficiently large treatment area can be constructed to hold concentration and exposure times." It is believed that these areas are too large to be controlled using hand-harvesting techniques. It is likely that these areas may be small (3-5 acres) and would need to be conducted with herbicides that require short exposure times, such as diquat or herbicide combinations (diquat/endothall, 2,4-D/endothall, etc.). If large areas (>5 acres) or sites in protected parts of the lake are to be targeted with an herbicide spot treatment, more traditional systemic herbicides like 2,4-D may be appropriate. If populations exceed spot-treatment thresholds, large-scale (whole-basin) herbicide strategies may be given consideration. The least expensive herbicide option would be to use liquid 2,4-D, which can be around $500 an acre, depending on water depth. But as indicated above, spot-treatments with liquid 2,4-D need to be relatively large and/or within protected parts of the system to be effective. Herbicides that have a better likelihood of being successful in small and exposed situations can cost $1,000-$3,000 an acre. These herbicides also carry additional risk for environmental impacts that need to be considered. In late-winter, an herbicide applicator firm would be selected and a conditional permit application would be applied to the WDNR. The herbicide treatment would occur when surface water temperatures are roughly below 60°F and active growth tissue is confirmed on the target plants. A pretreatment survey, a week or so prior to treatment would be used to finalize the permit, potentially with adjustments, and dictate approximate ideal treatment timing. If individual treatment sizes exceed 10 acres, a quantitative (sub-sample point-intercept) monitoring component may be required by the WDNR.
Action Steps:	
	See description above

Management Action:	Conduct CLP Population Control Using Hand-Harvesting
Timeframe:	Continuation of current effort
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	The relatively new CLP population of the Crooked Area Lakes is currently at low population levels. In some lakes, mostly in northern Wisconsin, CLP appears to integrate itself within the community without becoming a nuisance or causing measurable impacts the lake ecosystem. Many groups resist commencing an herbicide control strategy for CLP, as it often consists of multiple annual treatments (5 or more) of the same areas which can have large financial and ecological costs. The CLALPRD has decided to continue with a hand-harvesting strategy each year targeting the largest population sources within the system. If this strategy proves unable to keep the population from getting to levels where nuisance conditions are presented or the ecosystem function may be threatened, the CLALPRD will consider a revised strategy. In order to have sufficient time for the hand-harvesting to be conducted, each year's June ESAIS Survey would occur as early in the seasonal spectrum as possible. Hand-harvesting would occur following the ESAIS Survey until roughly the first week of July when CLP populations naturally die off. If a Diver Assisted Suction Harvest (DASH) component is utilized, the CLALPRD and contracted firm would be responsible for the WDNR permit procedures. The contracted firm would be guided with GPS data from the consultant following the ESAIS Survey and would track their efforts (when, where, time spent, quantity removed) for post assessments.
Action Steps:	
	See description above

Management Action:	Coordinate Periodic Quantitative Vegetation Monitoring
Timeframe:	Point-Intercept Survey every 3-5 years, Community Mapping every 7-8 years
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	Lake-wide point-intercept surveys following WDNR protocols (WDNR PUB-SS-1068 2010) should be conducted at a minimum once every 5 years. This will allow an understanding of the submergent aquatic plant community dynamics within Crooked Lake Area Lakes. Point-intercept surveys have been conducted on the system in 2011 and 2016. Building this dataset over time will assist

	in understanding natural and unnatural population dynamics. In order to understand the dynamics of the emergent and floating-leaf aquatic plant communities in Crooked Lake Area Lakes, a community mapping survey would be conducted every 7-8 years. The community mapping survey has been conducted on Crooked Lake Area Lakes in 2011 and 2016, and will serve as a comparative for future replicated surveys. This effort is typically conducted as part of each future lake management planning project update.
Action Steps:	
	See description above

Management Goal 2: Maintain Current Water Quality Conditions

Management Action:	Monitor water quality through WDNR Citizens Lake Monitoring Network.
Timeframe:	Continuation of current effort.
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
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 is currently being completed annually by Crooked Lake Area Lakes 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 CLALPRD currently monitor a single site in Crooked Lake under the advanced CLMN program. This includes collecting Secchi disk transparency and dissolved oxygen readings, as well as sending in water chemistry samples (chlorophyll-*a*, and total phosphorus) to the Wisconsin State Laboratory of Hygiene for analysis. The samples are collected three times during the summer and once during the spring. 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). Currently, water quality information is not being collected on Bass Lake or Gilkey Lake. The CLALPRD will strive to at least collect Secchi disk transparency data on these lakes in conjunction with the sampling that is currently being conducted on Crooked Lake. Perhaps

	at a later date, Bass Lake and/or Gilkey Lake may be elevated to the advanced CLMN program where water chemistry data is also collected. It will be the Board of Directors responsibility to ensure that a volunteer is prepared to communicate with WDNR representatives and collect water quality samples within each basin during each year.
Action Steps:	
1.	Trained CLMN volunteer(s) collects data and report results to WDNR and to district members during annual meeting.
2.	CLMN volunteer and/or CLALPRD Board of Directors would facilitate new volunteer(s) as needed
3.	Coordinator contacts Sandra Wickman (715.365.8951) to acquire necessary materials and training for new volunteer (s)

Management Goal 3: Increase CLALPRD's Capacity to Communicate with Lake Stakeholders and Facilitate Partnerships with Other Management Entities

Management Action:	Conduct Periodic Riparian Stakeholder Surveys
Timeframe:	Every 5-6 years
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	Approximately once every 5-6 years, an updated stakeholder survey would be distributed to the Crooked Lake Area Lakes riparians. 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 2016, with modified or additional questions as appropriate. The survey would again receive approval from a WDNR Research Social Scientist, particularly if WDNR grant funds are used to offset the cost of the effort.
Action Steps:	
	See description above

Management Action:	Use education to promote lake protection and enjoyment through stakeholder education
Timeframe:	Continuation of current efforts
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	Education represents an effective tool to address many lake issues. The CLALPRD would like to send out a regularly distributes newsletters (at least once per year) and possibly maintain a public Facebook page. These mediums allow for exceptional communication with district members. This level of communication is important within a management group because it facilitates the spread of important district news, educational topics, and even social happenings. The CLALPRD will continue to make the education of lake-related issues a priority. These may include educational materials, awareness events, and demonstrations for lake users as well as activities which solicit local and state government support. The CLALPRD will work with UW-Extension Lakes staff (Patrick Goggin: Patrick.Goggin@wisconsin.gov) to use stock articles as appropriate to lessen the workload and ensure the messaging is accurate. *www.uwsp.edu/cnr-ap/UWEXLakes* *Example Educational Topics* • Specific topics brought forth in other management actions • Aquatic invasive species identification • Basic lake ecology • Sedimentation • Septic system maintenance • Boating safety (promote existing guidelines) • Swimmers itch • Shoreline habitat restoration and protection • Fireworks use and impacts to the lake • Noise and light pollution • Fishing regulations and overfishing • Minimizing disturbance to spawning fish • Recreational use of the lakes
Action Steps:	
	See description above as this is an established program.

Management Action:	Continue CLALPRD's involvement with other entities that have responsibilities in managing (management units) Crooked Lake Area Lakes
Timeframe:	Continuation of current efforts
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	The purpose of the CLALPRD 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 CLALPRD actively engage with all management entities to enhance the district'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 table on the next page:
Action Steps:	
	See table guidelines on the next pages.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Crooked Lake Sportsman's Club		The Sportsman's Club has historically taken the active and lead role in fisheries management (stocking & habitat improvments)	On an as-needed basis. The CLALPRD strives to have a member of the sportsman's club on the district board of directors	Can provide assistance with shoreland habitat improvements and fish stocking.
Town of Riverview	Town Clerk (Kris Barthel clerktownofriverview@gmail.com.	Crooked Lake Area Lakes falls within this township.	Check website (www.townofriverview.com) for updates. A representative from the Town is always on the district board of directors.	Town staff may be contacted regarding ordinance reviews or questions, and for information on community events
Oconto County Lakes & Waterways Association	President (Mike Winius– 920.740.2110)	Protects Oconto Co. waters through facilitating discussion and education.	Twice a year or as needed. May check website (http://www.oclawa.org) for updates	Become aware of training or education opportunities, partnering in special projects, or networking on other topics pertaining to Oconto Co. waterways.
Oconto County Land Conservation Department.	County Conservationist (Ken Dolta – 920.834.7152)	Oversees conservation efforts for land and water projects.	Twice a year or more as needed. A representative from the County is always on the district board of directors.	May have County-level funding opportunities available. Can provide assistance with shoreland restorations and habitat improvements.
Wisconsin Department of Natural Resources	Fisheries Biologist (Christopher [Chip] Long– 715-582-5017)	Manages the fishery of Crooked Lake Area Lakes.	Once a year, or more as issues arise.	Stocking activities, scheduled surveys, survey results, volunteer opportunities for improving fishery and fish structure
	Lakes Coordinator (Brenda Nordin – 920.360.3167)	Oversees management plans, grants, all lake activities.	Once a year, or more as issues arise	Information on updating a lake management plan (every 5 years) or to seek advice on other lake issues including AIS management.
	Citizens Lake Monitoring Network contact (Sandra Wickman – 715.365.8951)	Provides training and assistance on CLMN monitoring, methods, and data entry.	Twice a year or more as needed.	Late winter: arrange for training as needed, in addition to planning out monitoring for the open water season. Late fall: report monitoring activities.
Wisconsin Lakes	General staff (800.542.5253)	Facilitates education, networking and assistance on all matters involving WI lakes.	As needed. May check website (www.wisconsinlakes.org) often for updates.	CLALPRD members may attend WL's annual conference to keep up-to-date on lake issues. WL reps can assist on grant issues, AIS training, habitat enhancement techniques, etc.

Management Action:	Educate Stakeholders on Boating Regulation and Boating Safety
Timeframe:	Continuation of current efforts
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	Crooked Lake Area Lakes is a popular destination by multiple types of users including recreationists and anglers. In an effort to promote boating safety and minimize the negative impacts watercraft can have on a lake, the CLALPRD uses education its primary tool. Crooked Lake Area Lakes has a slow-no-wake curfew between 4:00 pm and 10:00 am, per a Town of Riverview Ordinance. There are also slow-no-wake buoys 100 ft out from the entrance to Bass and Gilkey Lakes that need to be abided by. Because Bass and Gilkey Lake are less than 50 acres, they are state-madidate slow-no-wake lakes. The State of Wisconsin laws demand that boats observe slow-no-wake rules within 100 feet of the shore and all lake users and objects. This law is more restrict for personal watercrafts, as they need to operate at slow-no-wake speeds within 200 feet of the shore (Map 8). The CLALPRD also requests that recreational watercraft use, such as waterskiing, occur in a counter-clockwise direction.
Action Steps:	
	See description above as this is an established program.

Management Goal 4: Maintain Navigability on the Crooked Lake Area Lakes

Management Action:	Conduct Mechanical Harvesting Feasibility Study
Timeframe:	Continuation of Current Effort
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	The CLALPRD understands the importance of native aquatic vegetation on Crooked Lake Area Lakes. However, nuisance aquatic plant conditions exist in certain parts of the lake, caused largely by native vegetation such as southern naiad (*Najas guadalupensis*), common waterweed (*Elodea canadensis*), and coontail (*Ceratophyllum demersum*). The CLALPRD supports the reasonable and environmentally sound actions to facilitate navigability on the Crooked Lake Area Lakes. These actions target nuisance levels of aquatic plants in order to benefit watercraft navigation patterns. Reasonable and environmentally sound actions are those that meet WDNR regulatory and permitting requirements and do not impact anymore

shoreland or lake surface area than absolutely necessary.

The WDNR oversees the management of aquatic plants on inland lakes. The manual cutting and raking of native aquatic plant species within a 30-foot-wide area containing a pier, boatlift, or swim raft is exempt from a state permit provided that the cut plants are removed from the lake (and wild rice is not being removed). However, the use of mechanized or mechanical devices requires a WDNR permit.

During approximately 1994, the CLALPRD purchased a used mechanical harvester and off-loading equipment from a contractor. During the following decade or so, the CLALPRD conducted mechanical harvesting to alleviate nuisance conditions. The structure of these operations was dictated by onsite conditions and decisions.

The WDNR currently requires more definition of these activities, such that the mechanical harvesting is conducted in predefined navigation lanes. Typically, this consists of 30-ft wide common-use lanes and 10 to 20-ft wide riparian access lanes (aka spokes). The mechanical harvesting activities are guided by GPS and reporting of effort (where, when, how long, how much removed) is provided to the WDNR at the end of each season. Mechanical harvesting cannot occur in waters less than 3-feet of water as that activity causes sediment disruption in the shallow waters. This depth is also insufficient for the mechanical harvester to operate in (i.e. it gets stuck).

In 2016, an acoustic-based vegetation survey was conducted on the Crooked Lake Area Lakes (Figure 3.4-3) in an effort to determine where high aquatic plant biomass exists in the lake to define a mechanical harvesting strategy. During the growing season of 2016, aquatic plant growth was insufficient to warrant mechanical harvesting except for within Bass Lake.

In most years, including 2016, floating plants that uprooted from wind and wave action caused perceived nuisance conditions in front of properties where the predominant wind direction blew them into shore. It is important to note that mechanical harvesting can have little assistance to that phenomenon. Mechanical harvesting prior to these conditions will have little impact on the plants becoming uprooted. The mechanical harvesting operations does a poor job of picking up these “floaters.” This is due to the inability of the harvester to operate in waters less than 3 feet of water and to navigate into areas where docks, boats, and other obstructions exist. Even when these floating mats exist in deeper water, the mechanical harvest has trouble conveying the plants onto the unit itself and

	often simply pushes the mat of plants. The long-term uncertainty of the mechanical harvesting program has resulted in the CLALPRD Planning Committee to discuss conducting a mechanical harvesting feasibility study. This would include a determination of the cost of owning, operating, maintaining, and storing the equipment vs selling the existing equipment and contracting the services from a third-party vendor if conditions warrant mechanical harvesting in the future. This may also include replicating the acoustic-based survey in a future year to document which areas consist of navigation impairment so a strategic set of navigation lanes can be constructed. Starting in 2019, a committee will be formed to advance an application that seeks to build on the surveys discussed above that identifies areas that the harvester was not allowed to cut for various reasons like depth. The new application would seek to permit as broadly as possible all remaining areas for harvesting with the new committee developing deployment and cutting criteria to address and prioritize activity.
Action Steps:	
1.	See description above

Management Goal 5: Improve Lake and Fishery Resource of Crooked Lake Area Lakes

Management Action:	Educate Stakeholders on the Importance of Shoreland Condition and Shoreland Restoration
Timeframe:	Initiate 2018
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	As discussed in the Shoreland Condition Section (3.3), the shoreland zone of a lake is highly important to the ecology of a lake. When shorelands are developed, the resulting impacts on a lake range from a loss of biological diversity to impaired water quality. Because of its proximity to the waters of the lake, even small disturbances to a natural shoreland area can produce ill effects. Approximately 54% of the Crooked Lake Area Lakes' shoreline is either *urbanized* or *developed-unnatural* and could be the focus of potential future restoration efforts. The CLALPRD believes its constituents are concerned about perceived overreach of property rights and policing of shorelines when the topic of shoreland restoration is discussed. The CLALPRD will continue to provide

	information to district members on shoreland restoration and the WDNR's Healthy Lakes Implementation Plan. The WDNR's Healthy Lakes Implementation Plan allows partial cost coverage for native plantings in transition areas. This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through Oconto County. Oconto County has been a proponent of shoreland restoration activities and has been seeking participation from landowners and lake groups, including offering additional funding. • 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance • Maximum of $1,000 per 350 ft^2 of native plantings (best practice cap) • Implemented according to approved technical requirements (WDNR, County, Municipal, etc.) and complies with local shoreland zoning ordinances • Must be at least 350 ft^2 of contiguous lakeshore; 10 feet wide • Landowner must sign Conservation Commitment pledge to leave project in place and provide continued maintenance for 10 years • Additional funding opportunities for water diversion projects and rain gardens (maximum of $1,000 per practice) also available
Action Steps:	
1.	Recruit facilitator from Planning Committee
2.	Facilitator contacts the Oconto County Land Conservation department to gather information on initiating and conducting shoreland restoration projects. If able, the County Conservationist would be asked to speak to CLALPRD members about shoreland restoration at their annual meeting.
3.	The CLALPRD would encourage property owners that have restored their shorelines to serve as demonstration sites.

Management Action:	Coordinate with WDNR and private landowners to expand coarse woody habitat in Crooked Lake Area Lakes
Timeframe:	Initiate 2018
Facilitator:	Board of Directors, Planning Committee, or possible coordinator
Description:	CLALPRD stakeholders must realize the complexities and capabilities of Crooked Lake Area Lakes ecosystem with respect to the fishery it can produce. With this, an opportunity for education

and habitat enhancement is present in order to help the ecosystem reach its maximum fishery potential. Often, property owners will remove downed trees, stumps, etc. from a shoreland area because these items may impede watercraft navigation shore-fishing or swimming. However, these naturally occurring woody pieces serve as crucial habitat for a variety of aquatic organisms, particularly fish. The Shoreland Condition Section (3.3) and Fisheries Data Integration Section (3.5) discuss the benefits of coarse woody habitat in detail.

The Crooked Lake Sportsman's Club has been the primary organization leading fisheries and fish habitat components. The CLALPRD will continue to work with the Sportsman's Club on future fish habitat improvements. While a United States Forest Service tree drop project was completed on Gilkey Lake in February of 2013, Crooked Lake Sportsman's Club, and WDNR fisheries biologist have been unable to secure volunteerism for additional fish stick projects on private properties. The highly parceled nature of the system may be less conducive for public involvement in this program than on other lakes. The Regional WDNR Biologist has recommended 20 additional coarse woody habitat improvements (referred to as "fish sticks") for the system.

The WDNR's Healthy Lakes Implementation Plan allows partial cost coverage for fish stick projects. This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through the county.

- 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance
- Maximum of $1,000 per cluster of 3-5 trees (best practice cap)
- Implemented according to approved technical requirements (WDNR Fisheries Biologist) and complies with local shoreland zoning ordinances
- Buffer area (350 ft^2) at base of coarse woody habitat cluster must comply with local shoreland zoning or:
  - The landowner would need to commit to leaving the area un-mowed
  - The landowner would need to implement a native planting (also cost share thought this grant program available)
- Coarse woody habitat improvement projects require a general permit from the WDNR
- Landowner must sign Conservation Commitment pledge to leave project in place and provide continued maintenance

	for 10 years
Action Steps:	
1.	Recruit facilitator from Planning Committee (potentially same facilitator as previous management actions).
2.	Facilitator contacts Brenda Nordin (WDNR Lakes Coordinator) and Chip Long (WDNR Fisheries Biologist) to gather information on initiating and conducting coarse woody habitat projects.
3.	The CLALPRD would encourage property owners that have enhanced coarse woody habitat to serve as demonstration sites.

6.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in the Crooked Lake Area Lakes (e.g., elevated phosphorus levels, anaerobic conditions, etc.). Water quality was monitored at the deepest point in the lake that would most accurately depict the conditions of the lake (Map 1). Samples were collected with a 3-liter Van Dorn bottle at the subsurface (S) and near bottom (B) in Crooked Lake and subsurface (S) only for Gilkey and Bass Lakes. Sampling occurred once in spring, fall, and winter and three times during summer. Samples were kept cool and preserved with acid following standard protocols. All samples were shipped to the Wisconsin State Laboratory of Hygiene for analysis. The parameters measured included the following:

<u>Crooked Lake</u>

	Spring		June	July	July	August	Fall		Winter	
Parameter	**S**	**B**	**S**	**S**	**B**	**S**	**S**	**B**	**S**	**B**
Total Phosphorus	■	■	■	■	■	■	■	■	■	■
Dissolved Phosphorus	■	■							■	■
Chlorophyll-*a*	■		■	■		■	■			
Total Kjeldahl Nitrogen	■	■		■					■	■
Nitrate-Nitrite Nitrogen	■	■		■					■	■
Ammonia Nitrogen	■	■		■					■	■
Total Nitrogen			■			■				
Laboratory Conductivity	■	■								
Laboratory pH	■	■		■	■					
Total Alkalinity	■	■		■	■					
Total Suspended Solids	■	■		■	■		■	■	■	■
Calcium	■									
True Color	■			■						
Hardness	■									

Gilkey and Bass Lakes

	Spring	June	July	August	Fall	Winter
Parameter	**S**	**S**	**S**	**S**	**S**	**S**
Total Phosphorus	■	■	■	■	■	■
Dissolved Phosphorus	■					■
Chlorophyll-*a*	■	■	■	■	■	
Total Kjeldahl Nitrogen	■		■			■
Nitrate-Nitrite Nitrogen	■		■			■
Ammonia Nitrogen	■		■			■
Total Nitrogen		■		■		
Laboratory Conductivity	■					
Laboratory pH	■		■			
Total Alkalinity	■		■			
Total Suspended Solids	■		■		■	■
Calcium	■					
True Color	■		■			
Hardness	■					

In addition, during each sampling event Secchi disk transparency was recorded and a temperature and dissolved oxygen profile was completed using a HQ30d with a LDO probe.

Watershed Analysis

The watershed analysis began with an accurate delineation of the Crooked Lake Area Lakes' drainage area using U.S.G.S. topographic survey maps and base GIS data from the WDNR. The watershed delineation was then transferred to a Geographic Information System (GIS). These data, along with land cover data from the National Land Cover Database (NLCD – Fry et. al 2011) were then combined to determine the watershed land cover classifications. These data were modeled using the WDNR's Wisconsin Lake Modeling Suite (WiLMS) (Panuska and Kreider 2003)

Aquatic Vegetation

Curly-leaf Pondweed Survey

Surveys of curly-leaf pondweed were completed on the Crooked Lake Area Lakes during a May 31 – June 1, 2017 field visit, in order to correspond with the anticipated peak growth of the plant. Visual inspections were completed throughout the lake by completing a meander survey by boat.

Comprehensive Macrophyte Surveys

Comprehensive surveys of aquatic macrophytes were conducted on the Crooked Lake Area Lakes to characterize the existing communities within the lake and include inventories of emergent, submergent, and floating-leaved aquatic plants within them. The point-intercept method as described in the Wisconsin Department of Natural Resource document, Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry, and Analysis, and Applications (WDNR PUB-SS-1068

2010) was used to complete these study on August 2-3, 2016. On Crooked Lake a point spacing of 40 meters was used resulting in 403 points. On Gilkey Lake a point spacing of 30 meters was used resulting in 89 points. On Bass Lake a point spacing of 30 meters was used resulting in 59 points.

Community Mapping

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

Representatives of all plant species located during the point-intercept and community mapping survey were collected and vouchered by the University of Wisconsin – Steven's Point Herbarium.

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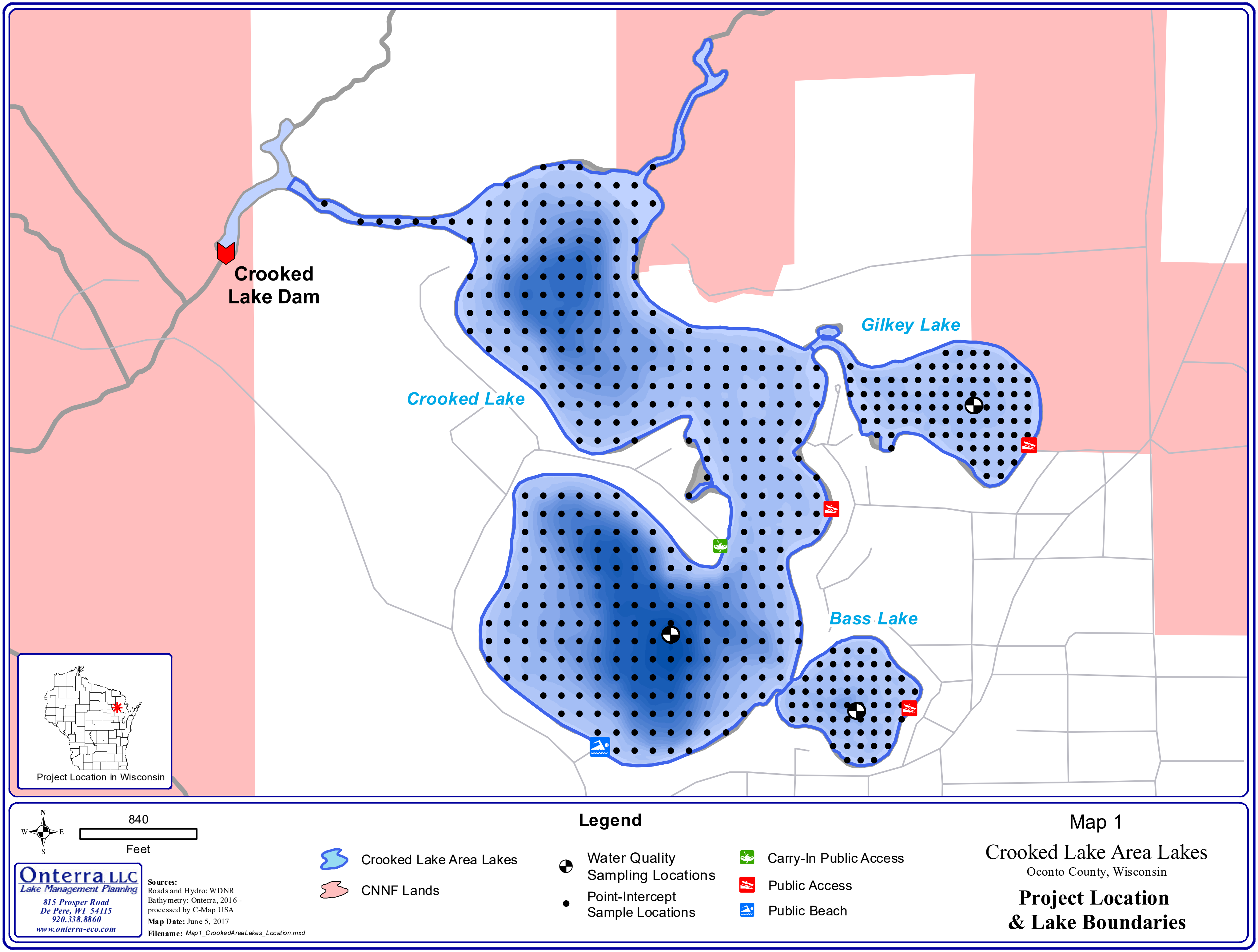
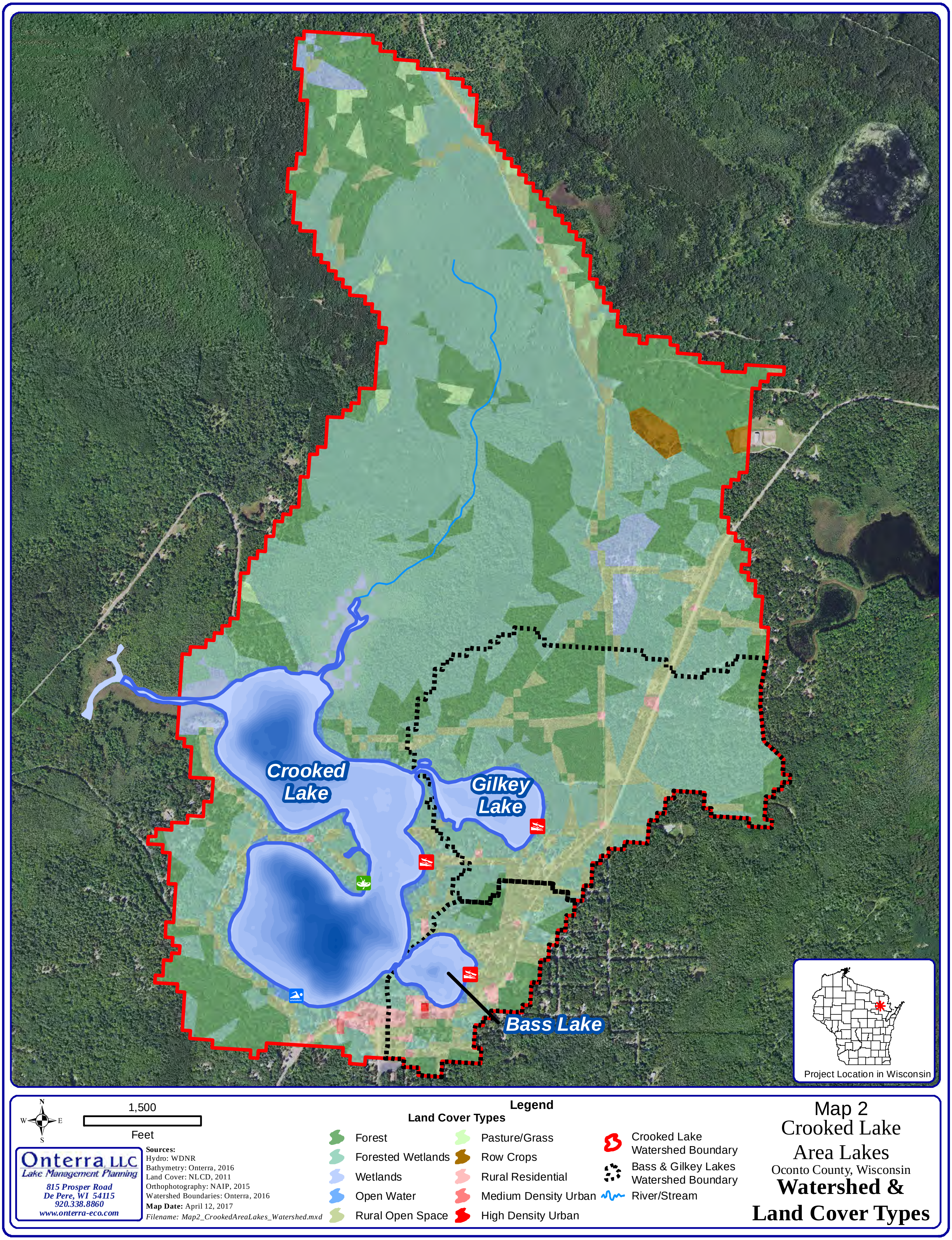


Crooked
Lake Dam
Crooked Lake
Gilkey Lake
Bass Lake
Project Location in Wisconsin
N
W
E
S
840
Feet
Onterra LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
www.onterra-eco.com
Sources:
Roads and Hydro: WDNR
Bathymetry: Onterra, 2016 -
processed by C-Map USA
Map Date: June 5, 2017
Filename: Map1_CrookedAreaLakes_Location.mxd
Legend
Crooked Lake Area Lakes
CNNF Lands
Water Quality
Sampling Locations
Point-Intercept
Sample Locations
Carry-In Public Access
Public Access
Public Beach
Map 1
Crooked Lake Area Lakes
Oconto County, Wisconsin
Project Location
& Lake Boundaries



Crooked Lake
Gilkey Lake
Bass Lake
Project Location in Wisconsin
N
W
E
S
1,500
Feet
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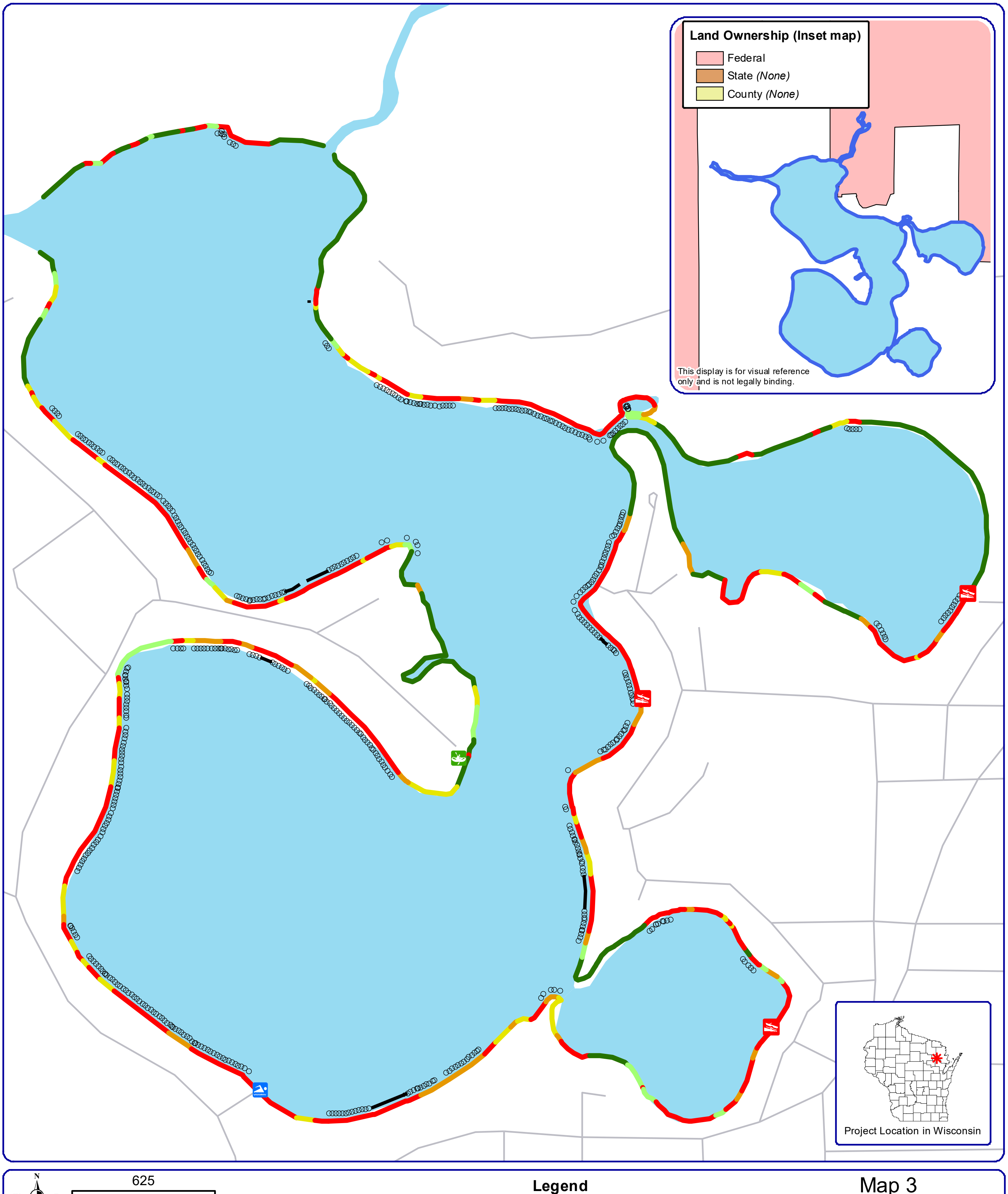
Sources:
Hydro: WDNR
Bathymetry: Onterra, 2016
Land Cover: NLCD, 2011
Orthophotography: NAIP, 2015
Watershed Boundaries: Onterra, 2016
Map Date: April 12, 2017
Filename: Map2_CrookedAreaLakes_Watershed.mxd
Legend
Land Cover Types
Forest
Forested Wetlands
Wetlands
Open Water
Rural Open Space
Pasture/Grass
Row Crops
Rural Residential
Medium Density Urban
High Density Urban
Crooked Lake Watershed Boundary
Bass & Gilkey Lakes Watershed Boundary
River/Stream
Map 2
Crooked Lake Area Lakes
Oconto County, Wisconsin
Watershed & Land Cover Types



Map 3
Crooked Lake Area Lakes
Oconto County, Wisconsin

2016 Shoreline Condition Assessment

Legend

- Natural/Undeveloped
- Developed-Natural
- Developed-Semi-Natural
- Developed-Unnatural
- Urbanized

Seawall
- Masonry/Wood/Metal
- Rip-Rap

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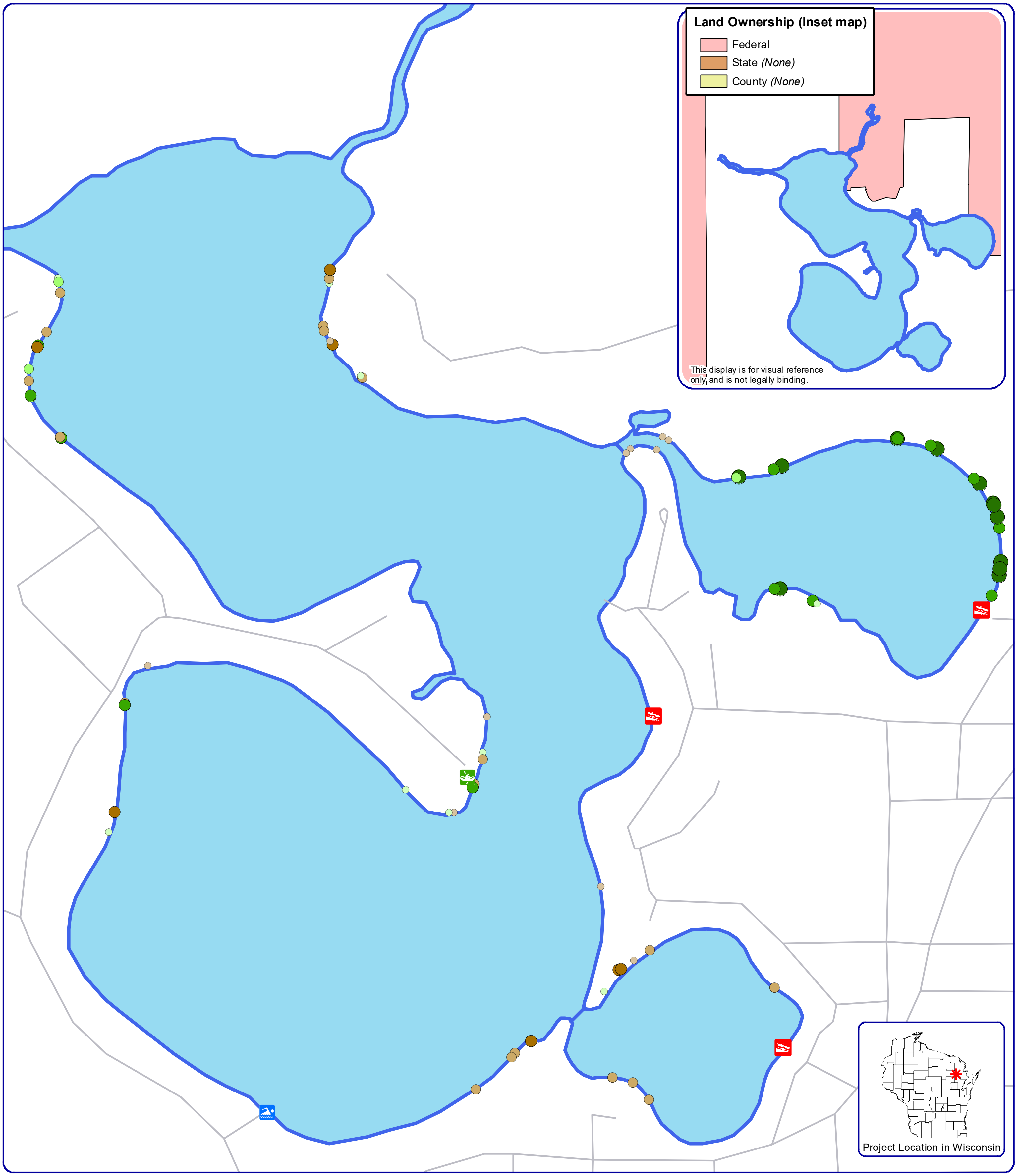
Sources:
Roads and Hyrdo: WDNR
Aquatic Plants: Onterra, 2016
Map Date: November 22, 2016
Filename: Map3_CrookedLakes_ShorelandCondition_2016.mxd



N
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550
Feet

Legend

2-8 Inch Pieces	8+ Inch Pieces	Cluster of Pieces
No Branches	No Branches	No Branches *(None)*
Minimal Branches	Minimal Branches	Minimal Branches *(None)*
Moderate Branches	Moderate Branches	Moderate Branches *(None)*
Full Canopy *(None)*	Full Canopy	Full Canopy *(None)*

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Sources:
Roads and Hyrdo: WDNR
Aquatic Plants: Onterra, 2016
Map Date: November 22,2016
Filename: Map4_CrookedLakes_CWH_2016.mxd

Map 4
Crooked Lake Area Lakes
Oconto County, Wisconsin
2016 Coarse Woody Habitat Survey Results

650

Feet

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Sources:
Roads and Hyrdo: WDNR
Aquatic Plants: Onterra, 2016
Map Date: November 8, 2016
Filename: Map5_Crooked_Comm_2016.mxd

Project Location in Wisconsin

Legend

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

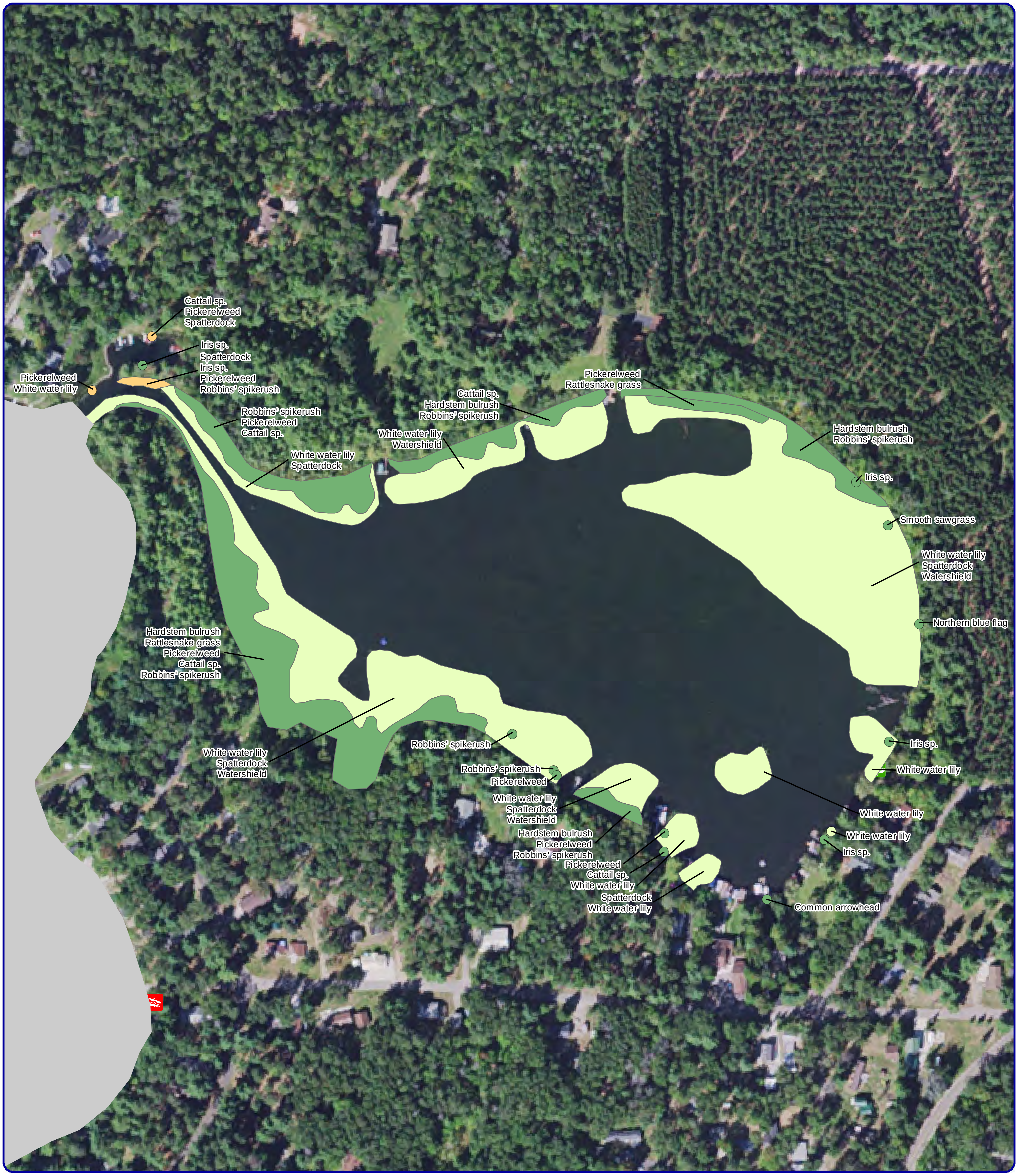
Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Map 5

Crooked Lake

Oconto County, Wisconsin

2016 Aquatic Plant Communities



N
W E
S
250
Feet

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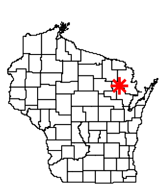
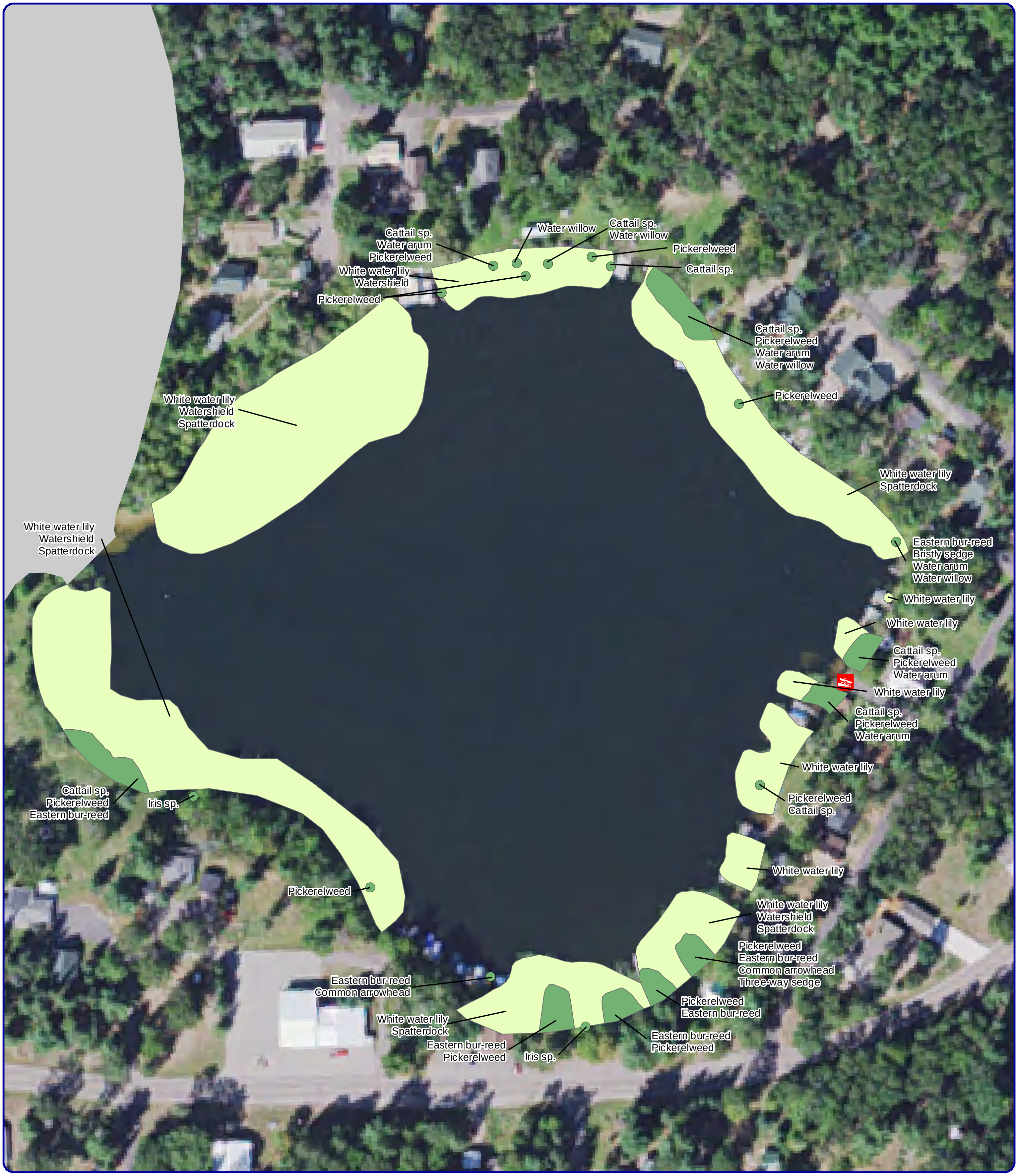
Sources:
Roads and Hyrdo: WDNR
Aquatic Plants: Onterra, 2016
Map Date: November 8, 2016
Filename: Map6_Gilkey_Comm_2016.mxd


Project Location in Wisconsin

Legend

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

Map 6
Gilkey Lake
Oconto County, Wisconsin
2016 Aquatic Plant Communities



150

Feet

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920.338.8860
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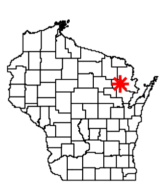
Sources:
Roads and Hyrdo: WDNR
Aquatic Plants: Onterra, 2016
Map Date: November 8, 2016
Filename: Map7_Bass_Comm_2016.mxd



Project Location in Wisconsin

Legend

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

Map 7

Bass Lake

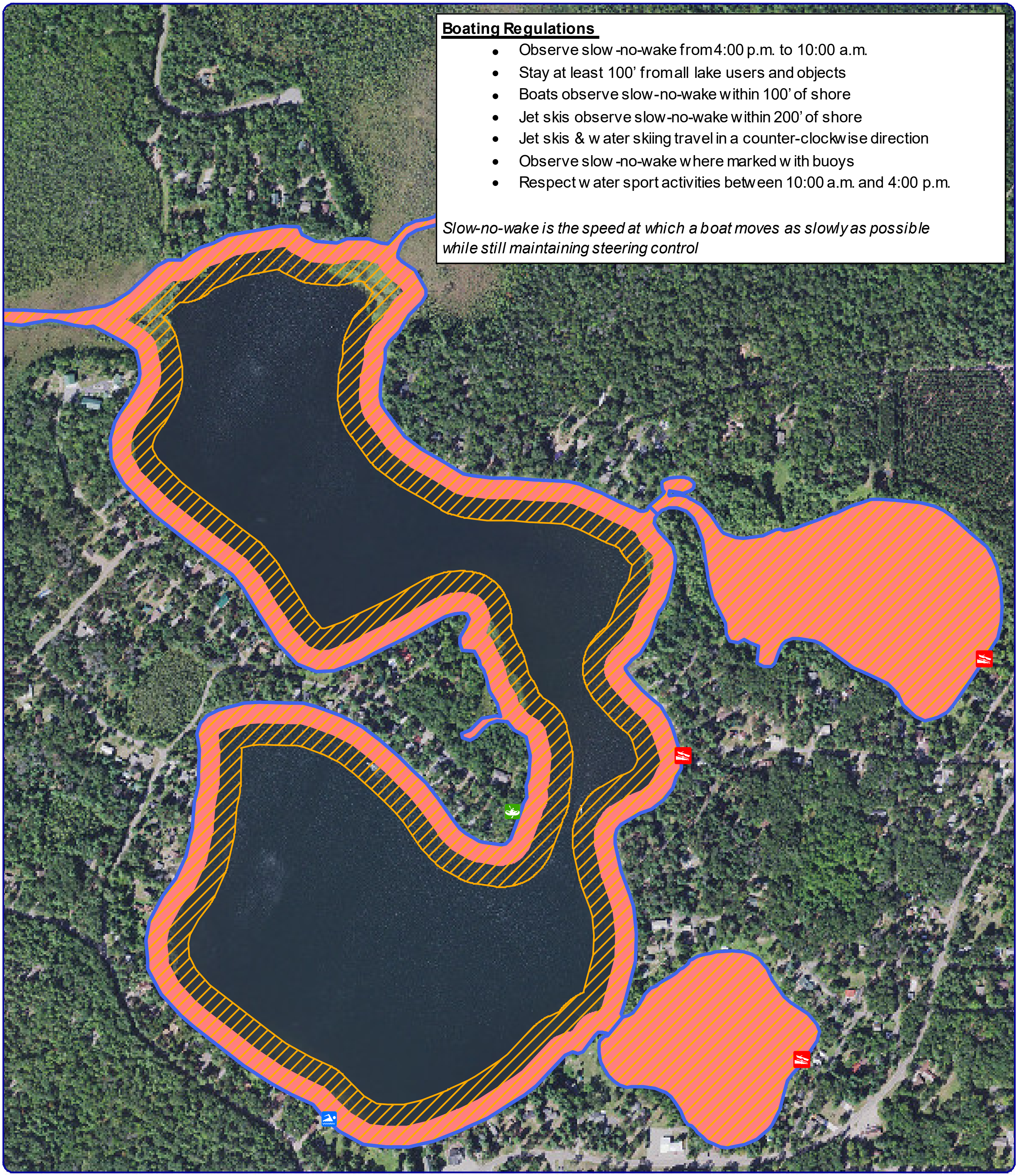
Oconto County, Wisconsin

2016 Aquatic Plant Communities

Boating Regulations

- Observe slow -no-wake from 4:00 p.m. to 10:00 a.m.
- Stay at least 100' from all lake users and objects
- Boats observe slow-no-wake within 100' of shore
- Jet skis observe slow-no-wake within 200' of shore
- Jet skis & water skiing travel in a counter-clockwise direction
- Observe slow -no-wake where marked with buoys
- Respect water sport activities between 10:00 a.m. and 4:00 p.m.

Slow-no-wake is the speed at which a boat moves as slowly as possible while still maintaining steering control



N
W E
S

600
Feet

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920.338.8860
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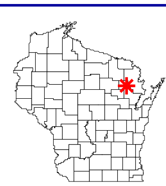
Sources:
Roads and Hyrdo: WDNR
Aquatic Plants: Onterra, 2016
Map Date: November 22, 2016
Filename: MapX_CrookedAreaLakes_Boating_Ordinances.mxd



Project Location in Wisconsin

Legend

Motorized Boat Slow-No-Wake Area *(100 ft from shore)*

Personal Watercraft Slow-No-Wake Area *(200 ft from shore)*

Map 8
Crooked Lake Area Lakes
Oconto County, Wisconsin
Watercraft Regulation Areas