Town of Plum Lake

Phases I, II, & III

Vilas County, Wisconsin

Comprehensive Management Plan

September 2020

Final Draft – Phase I

This document contains the Phase I Implementation Plan & Phase I-III Report Sections

Created by: Tim Hoyman, Paul Garrison, Heather Lutzow, and Josephine Barlament
Onterra, LLC
De Pere, WI

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Town of Plum Lake Planning Committees

Phase I: Plum Lake, West Plum Lake, Star Lake, Little Star Lake

Lynn Wiggins
Doug Pinney
Jim Haberle
Bob Munsen
Ann Willer
John Richter
Vicki Haberle
Vern Wiggenhauser
Cheryl Carper
Gail Shea
Patti Scribner

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Note: Individual lake maps are included within each individual lake section

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Will be included in the final phase report (Phase III).

1.0 INTRODUCTION

The Town of Plum Lake is located near the middle of Vilas County between Boulder Junction and Eagle River, and as of 2000 held a population of 486 residents. The Town of Plum Lake project lakes are adjacent to many high-quality natural areas, including the Plum Lake Hemlock Forest State Natural Area and the Lake Laura Hardwoods State Natural Area. This area of Vilas County is a popular tourist destination during the summer months, due to the size and quality of the Town of Plum Lake project lakes. While up until 2017 these lakes had avoided an aquatic invasive plant, these lakes have seen their share of other aquatic invasive species including rusty crayfish and spiny waterflea. The discovery of Eurasian watermilfoil in Little Star Lake in 2017 was the first occurrence of a submersed invasive aquatic plant. Many of these lakes have minimal ecosystem-related data, and a project was initiated in 2017 to collect baseline data and assess the overall health of 10 lakes within the township (Map 1).

This project was designed to systematically conduct studies on 10 lakes within the township over the course of three years, with two to four lakes being studied each year (Table 1.0-1 and Map 1). Developing management plans for subsets of lakes within the town each year allows for financial savings to be realized in overall project costs while creating a manageable process that allows for sufficient attention to be applied to each lakes' needs. This is opposed to completing all plans simultaneously, which would facilitate great cost savings, but only produce generic plans for each lake and the town as a whole. Financial assistance was obtained through the Wisconsin Department of Natural Resources (WDNR) Lake Management Grant Program for each phase of the project.

This report discusses the study results from the Phase I lakes (Plum Lake, West Plum Lake, Star Lake, and Little Star Lake), Phase II lakes (Ballard Lake, Irving Lake, White Birch Lake, and Lake Laura), and Phase III lakes (Big Muskellunge Lake and Razorback Lake). These studies included an assessment of each lakes' water quality, watershed, shoreline habitat, and aquatic plant community. In addition, anonymous stakeholder surveys were distributed to riparian property owners for each of the Phase I and II lakes to gauge stakeholder perceptions and concerns. Note that no stakeholder survey was distributed to Phase III lake riparians due to the low number of properties around the Phase III lakes. The results are presented first from a town-wide perspective where the results from each lake are compared to one another. This section is followed by the Town-Wide Implementation Plan, which will include management goals that the Town of Plum Lake Committee will use to guide future management actions. The Town-Wide Implementation Plan will be developed in later phases of the project as common challenges all of the lakes share become more evident. Following the town-wide sections, the study results from each lake are discussed in detail within the individual lake sections. Each individual lake section may also contain a lake-specific implementation plan which was developed by members of the respective lake's planning committee, Onterra ecologists, and WDNR staff.

Table 1.0-1. Town of Plum Lake Management Planning Project study lakes. The location of these lakes can be found on Map 1.

	Phase I 2017				Phase II 2018				Phase III 2019	
	Plum Lake	West Plum Lake	Star Lake	Little Star Lake	White Birch Lake	Ballard Lake	Irving Lake	Lake Laura	Big Muskellunge Lake	Razorback Lake
Morphometry										
Lake Type	TSF	SHDL	TSF	SHDL	DLDL	SHDL	SHDL	DSL	DHDL	DSL
Surface Area (acres) - WDNR	1,057	69	1,219	95	113	503	419	628	897	381
Surface Area (acres) - Onterra	1,074	71	1,240	101	116	511	427	619	900	381
Max Depth (ft)	57	5	68	9	27	25	8	43	70	35
Mean Depth (ft)	22	3	23	4	12	11	4	22	26	15
Perimeter (miles) - WDNR	13.2				2.3	5.5	4.1	4.8	8.2	5.9
Perimeter (miles) - Onterra	13.6	1.8	12.1	1.7	2.6	5.9	4.3	5.0	10.4	6.3
Shoreline Complexity	8.8	2.3	6.0	1.5	3.1	3.4	2.2	2.1	6.1	5.2
Watershed Area (acres)	11,631	770	3,346	516	2,683	2,339	1,233	2,027	2,213	876
Watershed to Lake Area Ratio	10:1	10:1	2:1	4:1	22:1	4:1	2:1	2:1	1:1	1:1
Water Quality										
Trophic State	OM	E	O	E	OM	M	ME	O	O	OM
Limiting Nutrient	P	P	P	P	P	P	P	P	P	P
Avg Summer P (µg/L)	12.6	31.8	8.1	51.7	13.3	15.3	32.0	9.5	6.7	11.3
Avg Summer Chl-α (µg/L)	3.4	8.2	1.8	25.9	3.6	3.6	8.0	1.6	2.0	4.7
Avg Summer Secchi Depth (ft)	14.9	-	12.1	2.1	14.0	11.7	6.0	16.8	21.1	13.5
Summer pH	7.9	-	7.7	-	7.8	8.3	7.6	7.9	8.0	7.7
Alkalinity (mg/L as CaCO$_3$)	38.8	-	31.3	-	27.2	30.3	25.3	25.7	24.9	22.5
Vegetation										
Number of Native Species	44	32	41	18	37	40	46	40	43	46
NHI-Listed Species	PVA	None	None	PVA	UTR	PVA, UTR	None	None	-	PVA
Exotic Species	PYI	PYI, TYA	PYI, PPL	EWM	None	None	None	None	PPL, TYA	TYA
Average Conservatism	6.7	6.8	6.5	6.5	6.9	7.1	7.0	7.3	6.8	7.0
Floristic Quality	34.8	27.8	31.3	22.5	33.9	36.3	37.2	35.9	35.4	35.0
Simpson's Diversity (1-D)	0.91	0.74	0.90	0.86	0.83	0.74	0.90	0.88	0.91	0.88

DHDL = Deep Headwater Drainage Lake
SHDL = Shallow Headwater Drainage Lake
DLDL = Deep Lowland Drainage Lake
DSL = Deep Seepage Lake
TSF = Two-Story Fishery
O = Oligotrophic
OM = Oligo-mesotrophic
M = Mesotrophic
ME = Meso-eutrophic
E = Eutrophic

P = Phosphorus
Chl-α = Chlorophyll-α
NHI = WDNR Natural Heritage Inventory
PVA = Vasey's pondweed (Potamogeton vaseyi)
UTR = Utricularia resupinata (Northeastern bladderwort)
PYI = Pale-yellow iris (Iris pseudacorus)
TYA = Narrow-leaved cattail (Typha angustifolia)
PPL = Purple loosestrife (Lythrum salicaria)
EWM = Eurasian watermilfoil (Myriophyllum spicatum)

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 stakeholder surveys, and updates within the lake group's newsletter and/or website. The highlights of this component are described below. Materials used during the planning process can be found in Appendix A.

General Public Meetings

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

Phase I Kick-off Meeting

On July 8, 2017, a project kick-off meeting was held at the Town of Plum Lake Town Hall and Community Building to introduce the project to the general public. The attendees observed a presentation given by Mr. Tim Hoyman, an aquatic ecologist with Onterra. Mr. Hoyman'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.

Phase I Wrap-up Meeting

To be scheduled.

Phase II Kick-off Meeting

The Phase II project kick-off meeting was held on July 27, 2018 at White Birch Village. Riparians from White Birch, Ballard, Irving, and Laura lakes attended the meeting, as well several people from Big Muskellunge and Razorback lakes. The folks from Big Muskellunge and Razorback, the two lakes that are included in Phase III were invited to attend because that phase did not include a kick-off meeting because there are very few properties on each of the lakes. The presentation given by Tim Hoyman included general lake ecology and project specifics

Phase II Wrap-up Meeting

Will be updated after meeting.

Phase III Kick-off Meeting

There was not a Phase III kick-off meeting included in the project because the riparians from Razorback and Big Muskellunge lakes were invited to the Phase II kick-off meeting described above.

Committee Level Meetings

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

Phase I Planning Committee Meetings

Planning meetings, led by Tim Hoyman, were held with riparians from the four Phase I lakes on June 11, and July 16, 2018. The first meeting included a detailed presentation regarding the studies and data that had been compiled for Little Star, Star, Plum, and West Plum Lakes. The second meeting focused upon creating the framework of an implementation plan by first developing a list of challenges facing the lakes, the lake groups, and the town. Following a discussion, the challenges or groups of challenges were converted to management goals. Actions were then discussed for each goal and assigned to it. A full draft of the implementation plan was provided to the planning committee the following spring and reviewed over the summer.

Phase II Planning Committee Meetings

The Phase II planning meetings were held at the White Birch Village Main Lodge on July 29 and August 29, 2019. Each lake in the Phase II project were represented by at least two representatives. Discussion during the first planning meeting centered on learning about the lakes, while the second meeting was used to refine and add to goals and actions created during the first phase of the project.

Phase III Planning Committee Meetings

Will be updated after meeting.

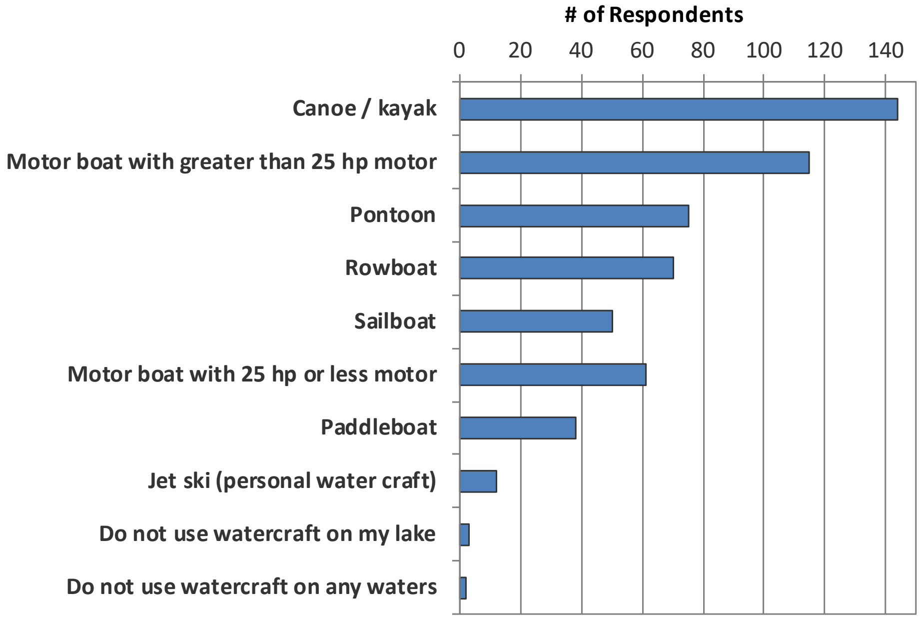
Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to riparian property owners around the Phase I and II project lakes. The surveys were designed by Onterra staff, the Plum Lake, Star Lake, Ballard-Irving-White Birch Lakes Associations, and the Town of Plum Lake planning committee and reviewed by a WDNR social scientist. Combining both Phase I and II results, just under 41% 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 Surveys, much was learned about the people that use and care for the Town of Plum Lake Phase I and II project lakes. Thirty-nine percent of survey respondents live on the lake during the summer months only, while 22% are year-round residents, 22% visit on weekends throughout the year, 5% have an undeveloped property, 3% own resort properties, and 1% own rental properties. Seventy-four percent of respondents have owned their property for over 15 years, with 52% of those stakeholders owning 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. Figure 2.0-1 highlights other questions found within this survey. Over 40% of survey respondents indicate that they use a canoe or kayak, a motorboat with greater than a 25hp motor, or a combination of these vessels on their lake (Question 15). Pontoons and rowboats were also popular options.

Question 15: What types of watercraft do you currently use on your lake?



Question 18: Please rank up to three activities that are important reasons for owning your property on or near your lake.

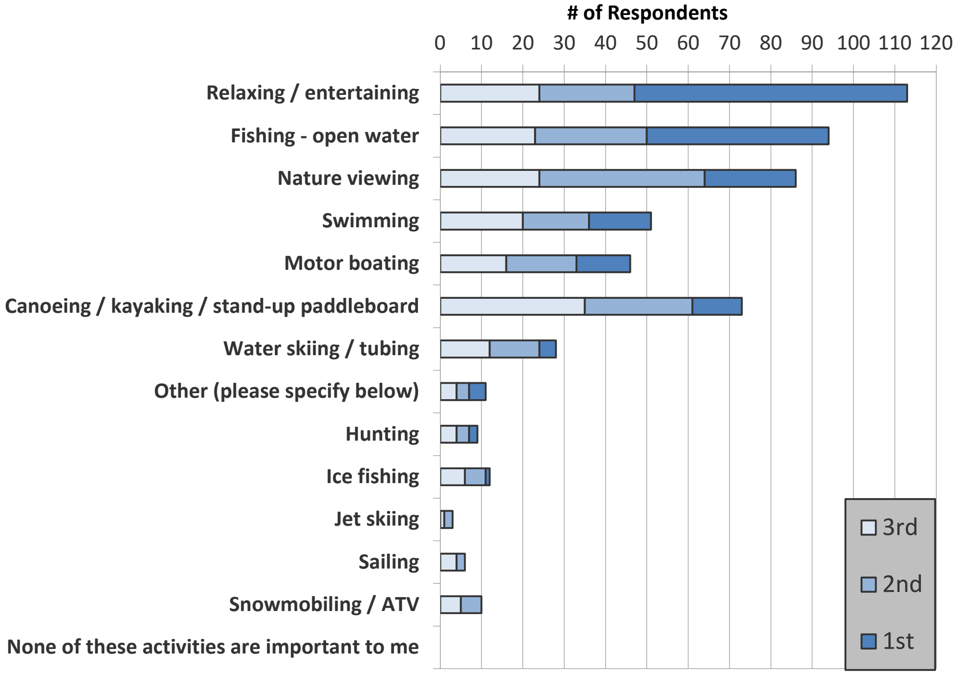


Figure 2.0-1. Select survey responses from the Town of Plum Lake Phase I and II project lakes Stakeholder Surveys. Additional questions and response charts may be found in Appendix B.

Management Plan Review and Adoption Process

Will be completed in Phase III Report

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Water Quality Data Analysis and Interpretation

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

Many types of analyses are available for assessing the condition of a particular lake's water quality. In this document, the water quality analysis focuses upon attributes that are directly related to the productivity of the lake. In other words, the water quality that impacts and controls the fishery, plant production, and even the aesthetics of the lake are related here. Specific forms of water quality 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 Town of Plum Lake project 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 Town of Plum Lake project 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, fishkills 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 2018 Consolidated Assessment and Listing Methodology* (WDNR 2017A) 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 Town of Plum Lake project 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, and 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 four square miles.

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

Plum and Star Lakes, two of the Phase I project lakes, are classified as two-story fishery lakes (Category 9 in Figure 3.1-1). However, regional data for two-story lakes are not available, so the water quality of Star and Plum lakes will be compared to deep lowland drainage lakes (Category 5 in Figure 3.1-1) as both lakes also have watersheds greater than four square miles and possess tributary inlets and outlets. White Birch Lake is also classified as a deep lowland drainage lake for these same reasons. Big Muskellunge Lake is classified as a headwater drainage lake because it has a watershed less than four square miles and has no inlets, but does have an outlet. West Plum, Little Star, Ballard, and Irving lakes are classified as shallow headwater drainage lakes as they each have watersheds smaller than four square miles and possess tributary outlets (Category 2 in Figure 3.1-1). Lake Laura and Razorback Lake are classified as deep seepage lakes (Category 7 in Figure 3.1-1), with their watersheds being less than four square miles and the lakes having no tributary inlets or outlets. The community classifications for the Town of Plum Lake project lakes can be found in Table 3.1-1.

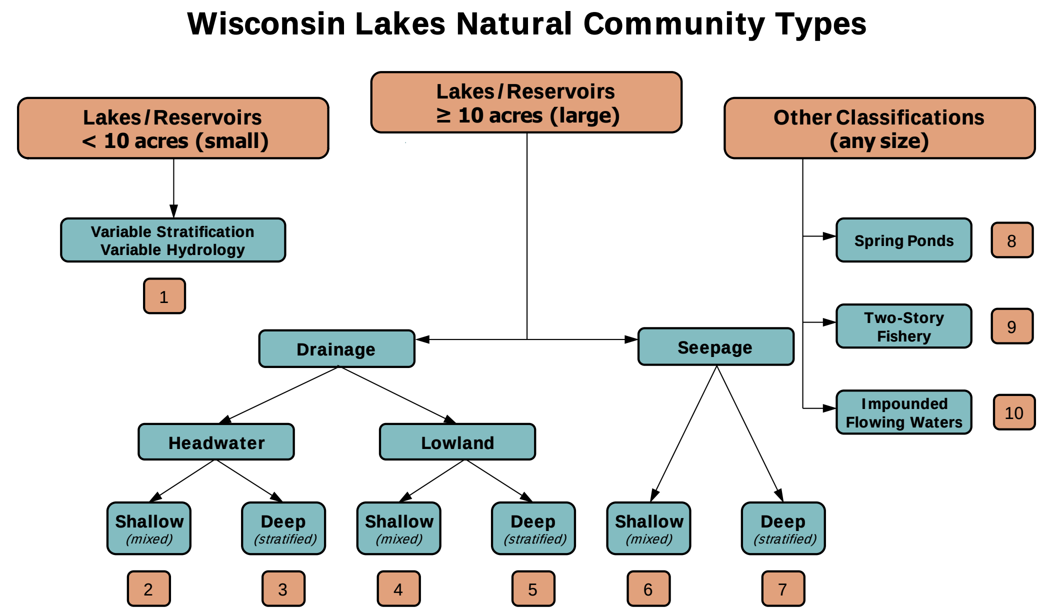


Figure 3.1-1. Wisconsin Lake Classifications. Adapted from WDNR 2013A.

Table 3.1-1. Community classification of project lakes within the Town of Plum Lake. Created using equations from WDNR 2013A.

Project Phase	Lake	Lake Classification
Phase I	Plum Lake	Deep Lowland Drainage
	West Plum Lake	Shallow Headwater Drainage
	Star Lake	Deep Lowland Drainage
	Little Star Lake	Shallow Headwater Drainage
Phase II	White Birch Lake	Deep Lowland Drainage
	Ballard Lake	Shallow Headwater Drainage
	Irving Lake	Shallow Headwater Drainage
	Lake Laura	Deep Seepage
Phase III	Big Muskellunge Lake	Deep Headwater Drainage
	Razorback Lake	Deep Seepage

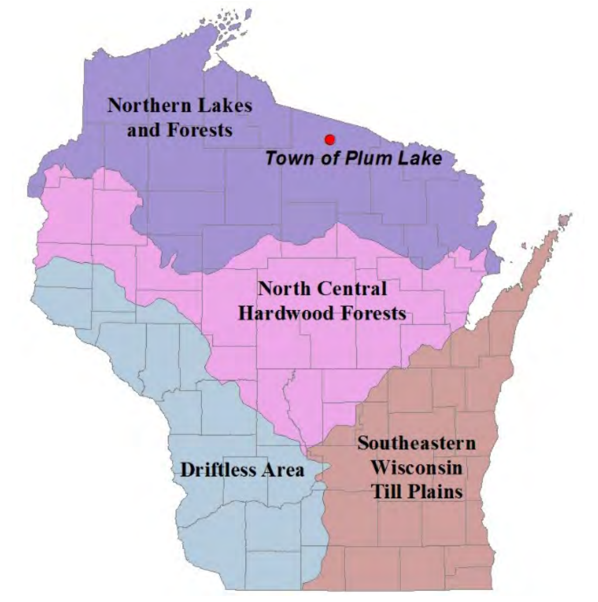


Figure 3.1-2. Location of the Town of Plum Lake within the ecoregions of Wisconsin. After Nichols 1999.

Garrison, et. al (2008) developed state-wide median values for total phosphorus, chlorophyll-*a*, and Secchi disk transparency for six of the ten lake classifications. While 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 Town of Plum Lake and its lakes fall within the Northern Lakes and Forests (NLF) ecoregion, and the water quality of the town's lakes will be compared to other lakes within the NLF ecoregion. (Figure 3.1-2).

The Wisconsin 2018 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.

Water quality data from the Town of Plum Lake project lakes is presented along with comparable data from similar lakes throughout the state and lakes within the NLF ecoregion in the subsequent section. Please note that these data represent samples collected during the growing season (April – October) or summer months (June, July, and August) unless otherwise indicated. The chlorophyll-*a* data represent only samples collected from the near-surface because they represent the depths at which phytoplankton grow.

Town of Plum Lake Project Lakes Water Quality Analysis

Town of Plum Lake Project Lakes Nutrients, Phytoplankton, and Water Clarity

This final version of the Town of Plum Lake Comprehensive Lake Management Plan contains water quality data from the Phases I - III project lakes. Monitoring occurred for the Phase I project lakes during the summer and winter of 2017-2018, the Phase II lakes were sampled in the summer and winter of 2018-2019, and Razorback Lake from Phase III was sampled during the summer and winter of 2019-2020. Big Muskellunge Lake has been sampled regularly since 1981 as a part of the Long-Term Ecological Research (LTER) Network and all water quality data from this lake was collected by the UW-Trout Lake Station. The individual lake sections provide in-depth discussions of each respective lake's water quality. The data presented in this section will serve to compare the lakes within the township. While these lakes are in close proximity to one another, their morphology and watershed size/comparison differ which results in differences in water quality. Within this section, the Phase I - III lakes' total phosphorus concentrations, chlorophyll-*a* concentrations, and water clarity are compared. It should be noted that due to their size, depth, and access, West Plum and Little Star lakes had reduced water quality monitoring conducted during Phase I.

Total Phosphorus

As discussed previously, phosphorus is the primary nutrient controlling the growth of algae (phytoplankton) in the majority of Wisconsin's lakes. To determine whether phosphorus is the limiting nutrient within a lake, the concentration of phosphorus is compared to the concentration of nitrogen. Mid-summer total phosphorus and total nitrogen concentrations from the Town of Plum Lake project lakes indicate that all of the lakes are phosphorus-limited (Figure 3.1-3). The mid-summer nitrogen to phosphorus ratios ranged from 17:1 in Little Star Lake to 44:1 in White Birch Lake. In general, this means that increases in phosphorus inputs would likely result in increased algal production in the lakes.

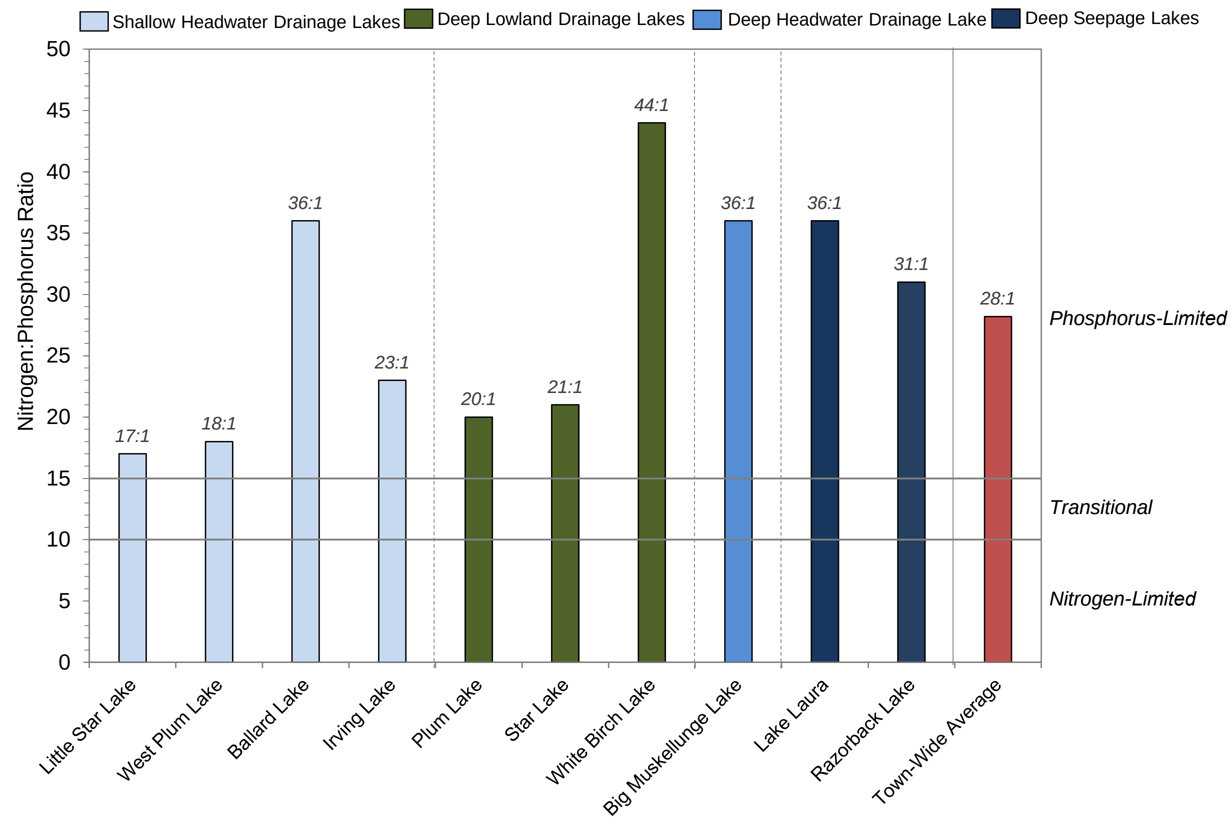


Figure 3.1-3. Town of Plum Lake project lakes mid-summer total nitrogen to total phosphorus ratios. Data represent surface samples collected during mid-summer during each respective project phase.

Average summer near-surface total phosphorus concentrations were calculated for the Phase I - III lakes using data collected as part of this project along with any available historical data. Near-surface summer total phosphorus concentrations ranged from 6.7 µg/L in Big Muskellunge Lake to 51.7 µg/L in Little Star Lake (Figure 3.1-4). The summer total phosphorus concentrations fall within the *excellent* category for their respective lake types in Wisconsin for all project lakes except West Plum, Little Star, and Irving lakes. The summer total phosphorus concentration for West Plum and Irving lakes fall into the *good* category, and Little Star Lake is near the border between *good* and *fair* for shallow headwater drainage lakes in Wisconsin.

Total phosphorus concentrations in Plum, Star, and White Birch lakes are better than the median value for deep lowland drainage lakes in the state and better than the median value for all lake types within the NLF ecoregion. Total phosphorus concentrations for Little Star Lake are significantly higher than the median value for shallow headwater drainage lakes in the state and over two times higher than the median value for all lake types within the NLF ecoregion. Total phosphorus concentrations for West Plum and Irving lakes are relatively similar to the median value for shallow headwater drainage lakes in the state and exceed the median value for all lake types within the NLF ecoregion median. Total phosphorus concentrations for Ballard Lake are well below the median value for shallow headwater drainage lakes in the state and below the NLF ecoregion median of 21.0 µg/L. Total phosphorus concentrations for Lake Laura and Razorback Lake are lower than the median for deep seepage lakes in the state and the median for all lake types within the NLF ecoregion.

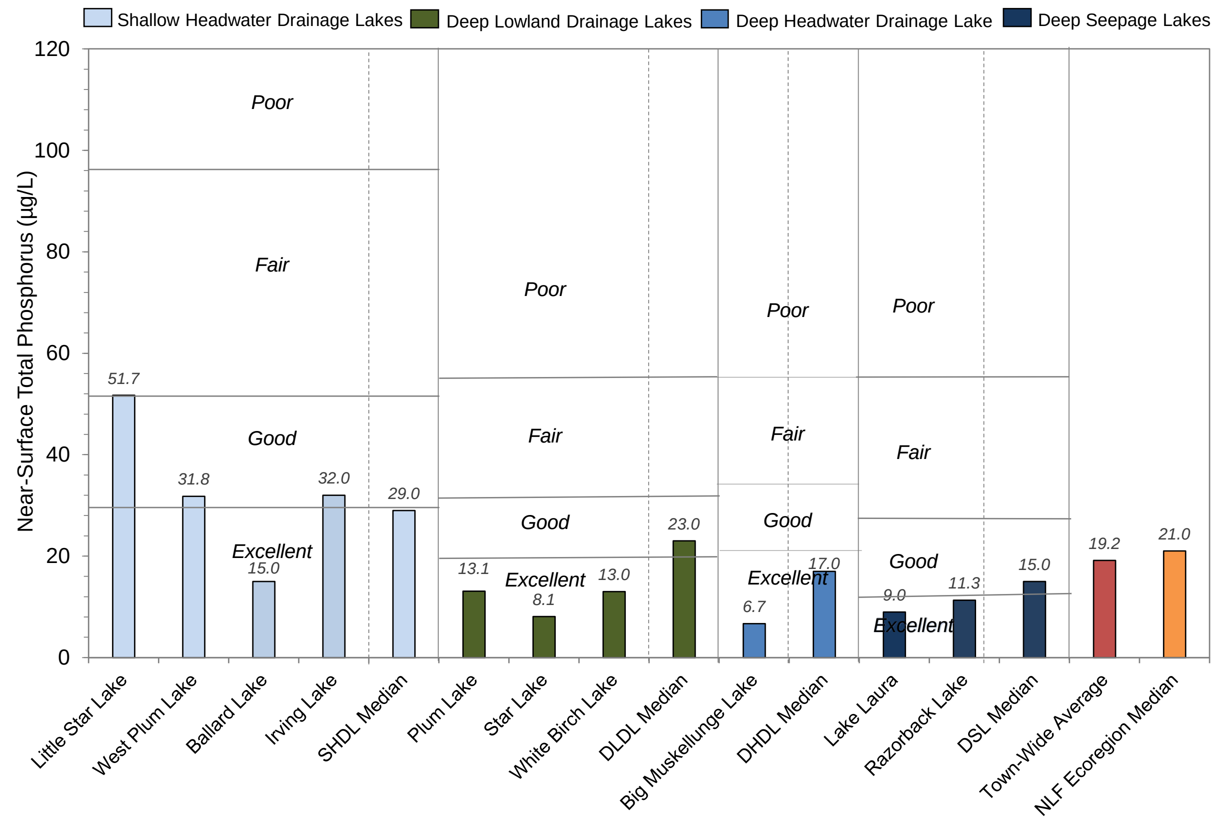


Figure 3.1-4. Town of Plum Lake project lakes summer average near-surface total phosphorus concentrations and median summer near-surface total phosphorus concentrations from comparable lakes.

Chlorophyll-α

As discussed earlier, chlorophyll-*a*, or the measure of free-floating algae within the water column, is usually positively correlated with total phosphorus concentrations. While phosphorus limits the amount of algae growth in the majority of Wisconsin's lakes, other factors also affect the amount of algae produced within the lake. Water temperature, sunlight, and the presence of small crustaceans called zooplankton, which feed on algae, also influence algal abundance.

Summer average chlorophyll-*a* concentrations measured within the project lakes ranged from 1.8 µg/L in Star Lake to 25.9 µg/L in Little Star Lake (Figure 3.1-5). Chlorophyll-*a* concentrations were positively correlated with total phosphorus concentrations. Summer average chlorophyll-*a* concentrations for Plum, Star, and White Birch lakes fall within the *excellent* category for deep lowland drainage lakes in Wisconsin. Chlorophyll-*a* concentrations for West Plum, Ballard, and Irving lakes fall within the *excellent* category, while Little Star Lake falls within the *fair* category for shallow headwater drainage lakes in Wisconsin. Big Muskellunge Lake's chlorophyll-*a* concentrations fell within the *excellent* category for deep headwater drainage lakes in the state. Lake Laura's chlorophyll- *a* concentrations fall within the *excellent* category, while Razorback Lake falls into the *good* category for deep seepage lakes in the state. These classifications are almost the same as for phosphorus which would be expected when the phosphorus concentration largely controls the amount of algal growth. Little Star, West Plum, and Irving lakes are the only lakes which had average chlorophyll- *a* concentrations higher than the NLF ecoregion median.

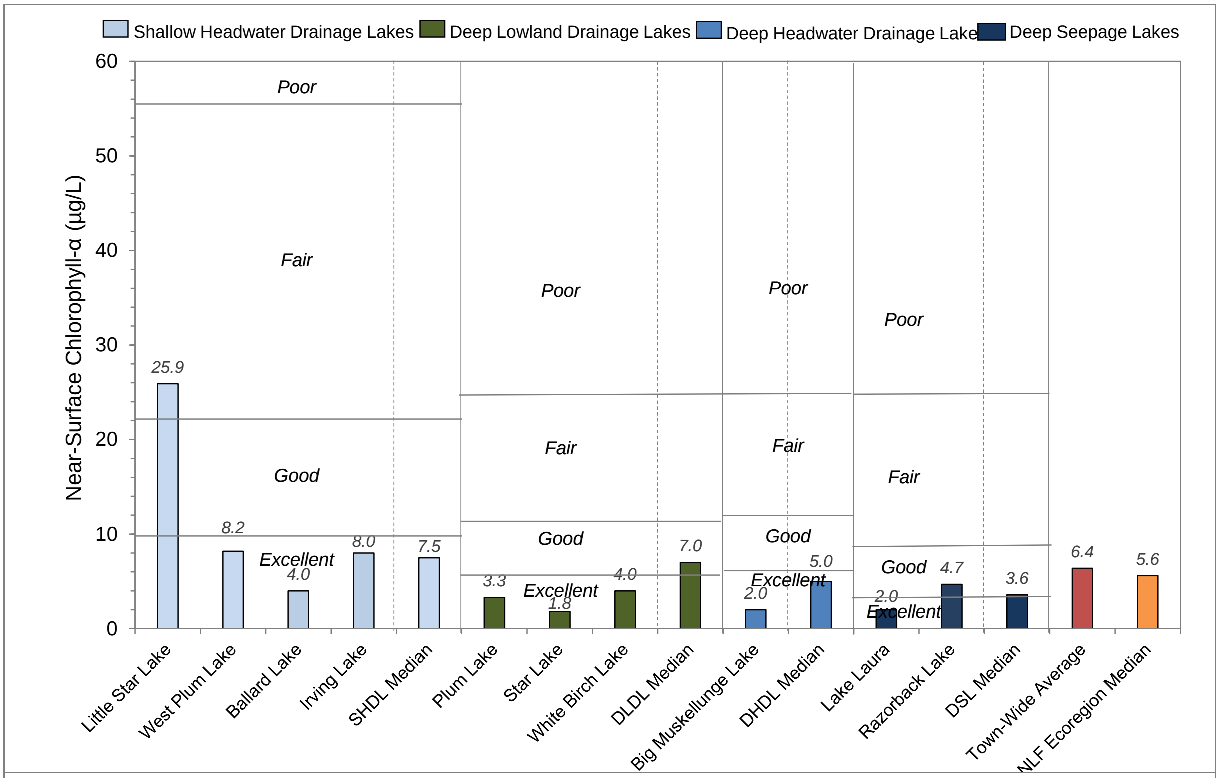


Figure 3.1-5. Town of Plum Lake project lakes summer average near-surface chlorophyll-α concentrations and median summer near-surface chlorophyll-α concentrations from comparable lakes.

As discussed previously, all eight lakes were found to be phosphorus-limited, meaning that algal production is regulated largely by phosphorus availability. Figure 3.1-6 illustrates that average chlorophyll-*a* concentrations were positively correlated with average summer phosphorus concentrations.

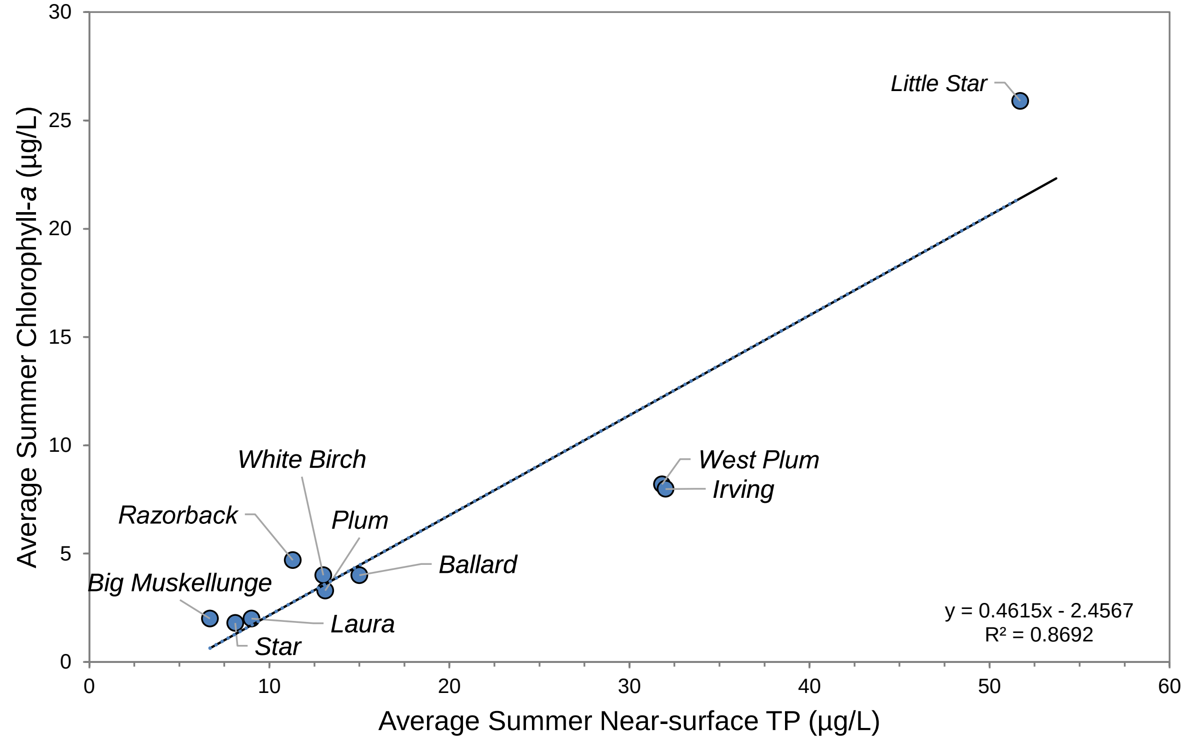


Figure 3.1-6. Town of Plum Lake project lakes average summer chlorophyll-α concentrations plotted against average summer total phosphorus concentrations. Phosphorus is a good predictor of chlorophyll in all project lakes.

Water Clarity

Average summer Secchi disk depth measured in the project lakes ranged from 2.1 feet in Little Star Lake to 21.1 feet in Big Muskellunge Lake (Figure 3.1-7). The Secchi disk depth for Plum, Star, and White Birch lakes falls within the *excellent* category for deep lowland drainage lakes in Wisconsin and exceeds the median values for other deep lowland drainage lakes in the state and all lake types within the NLF ecoregion. The Secchi disk depth for Little Star Lake falls within the *fair* category for shallow headwater drainage lakes in Wisconsin and is shallower than the median values for shallow headwater drainage lakes in the state and all lake types within the NLF ecoregion. The Secchi disk depth for Ballard and Irving Lakes falls within the *excellent* category for shallow headwater drainage lakes in the state and exceeds the median value for other lakes of this type in the state. Ballard Lake's average Secchi disk depth is deeper than the NLF ecoregion median, while Irving Lake falls below the ecoregion median. Big Muskellunge Lake had the deepest average Secchi disk depth of all the project lakes, fell within the *excellent* category, and far exceeded both the median for deep headwater drainage lakes within the state as well as the NLF ecoregion median. Lake Laura and Razorback Lake's average Secchi disk depths fell within the *excellent* category and exceed both the median for deep seepage lakes within the state and the NLF ecoregion median for all lake types. In West Plum Lake, the Secchi disk measurement hit bottom during every sampling event, indicating that water clarity exceeded the maximum depth of the sampling location which was 5 to 6 feet. Because these measurements hit bottom, they cannot be included within the seasonal average and cannot be compared against median values for other shallow headwater drainage lakes in the state.

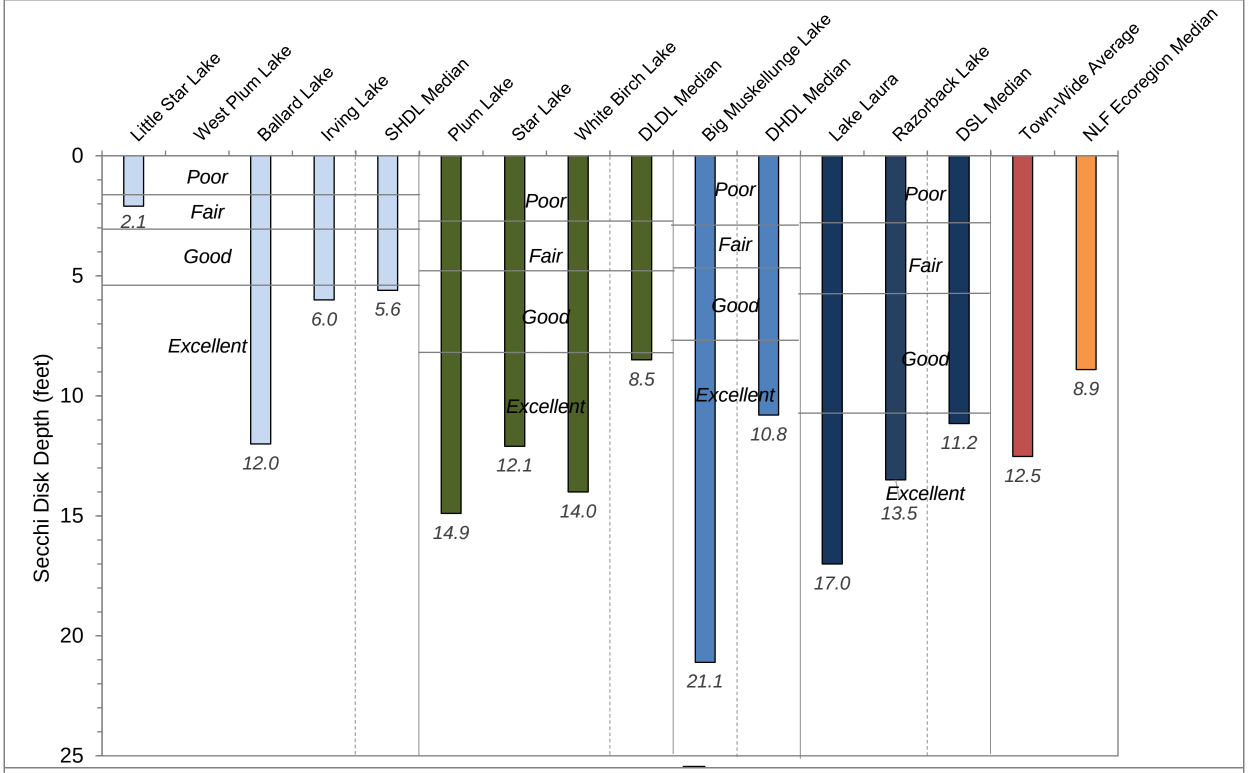


Figure 3.1-7. Town of Plum Lake project lakes summer average Secchi disk transparency and median summer Secchi disk transparency from comparable lakes. Data is not presented for West Plum Lake as the Secchi disk was always visible on the bottom of the lake (5-6 feet).

In the manuscript by Carlson (1977), he develops an equation to predict Secchi disk depths based upon the average chlorophyll-*a* concentration. This equation was developed from a large number of lakes distributed across the USA. Secchi disk depths in Star, Little Star, and Razorback lakes aligned relatively closely with the predicted Secchi disk depth based upon total chlorophyll-*a* concentrations. Secchi disk depth in White Birch Lake was higher than predicted by 18%, 21% higher than predicted in Plum Lake, and 22.5% higher than predicted in Big Muskellunge Lake. Average summer Secchi disk depths in Ballard and Irving lakes were 45% lower than predicted, and 62% lower than predicted in Lake Laura. *Total suspended solids*, a measure of both biotic and abiotic suspended particles within the water were near or below the limit of detection in the surface samples from the project lakes when it was measured. As discussed previously, West Plum and Little Star lakes had reduced water quality monitoring and total suspended solids were not measured in the lakes during Phase I. Apart from suspended material within the water, water clarity in Wisconsin's lakes can also be affected by dissolved components within the water. Many lakes in northern Wisconsin contain higher concentrations of dissolved humic substances and organic acids that originate from decomposing plant material within wetlands and coniferous forests in the lakes' watersheds. In higher concentrations, these dissolved compounds give the water a brown or tea-like color, decreasing water clarity. In addition, the underlying geology of northern Wisconsin is largely low in calcium, and lower concentrations of calcium within the water inhibit the breakdown of these organic compounds by bacteria allowing concentrations to be higher (Cole and Weihe 2016).

A measure of water clarity once all of the suspended material (i.e. algae and sediments) have been removed, is termed *true color*, and indicates the level of dissolved organic material within the water. Average true color values measured from the project lakes ranged from 5.0 standard units (SU) in Razorback Lake (classified as *clear*) to 20.0 SU in Plum and Irving lakes (between *slightly colored* and *lightly tea-colored*) (Figure 3.1-8). Again, due to reduced water quality monitoring in West Plum and Little Star lakes, true color measurements were not collected during Phase I. True color was also not a component measured in the data collected on Big Muskellunge Lake as part of the LTER program. The combination of low chlorophyll-*a* concentrations and low concentration of dissolved compounds in both Plum and Star Lakes result in the lakes' high water clarity.

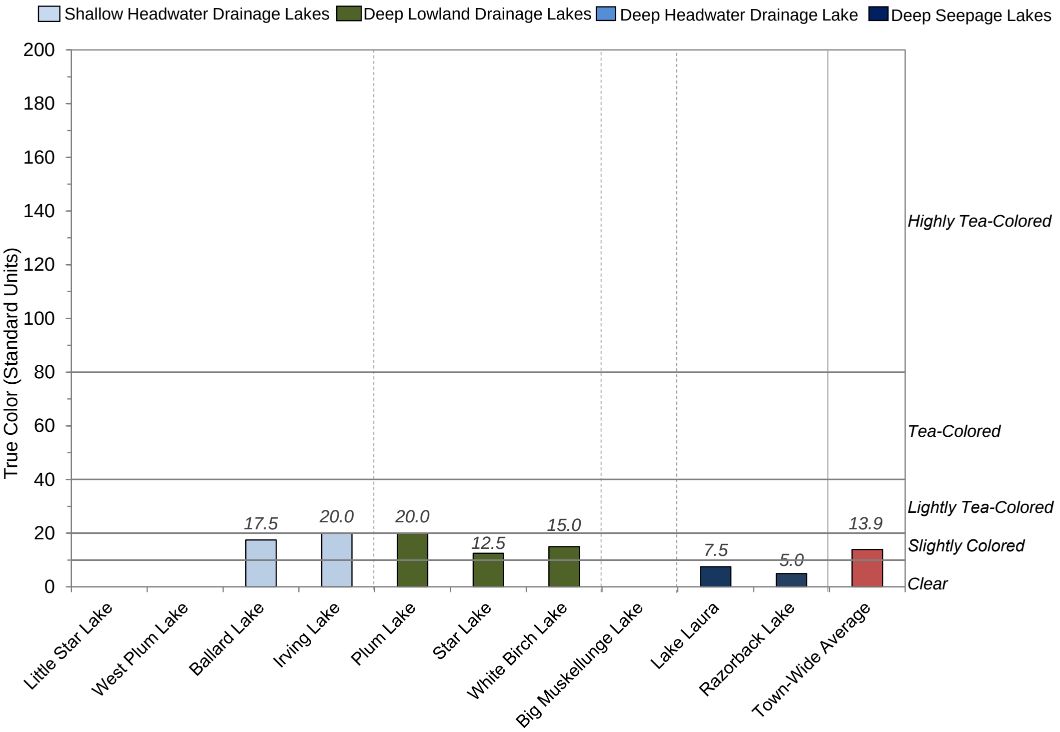


Figure 3.1-8. Town of Plum Lake project lakes average growing season true color values. Samples collected from the near-surface. Color range adapted from UNH Center for Freshwater Biology (2014).

Town of Plum Lake Project Lakes Trophic State

Figure 3.1-9 contains the weighted average Trophic State Index (TSI) values for each of the Town of Plum Lake project 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 factors other than phytoplankton such as dissolved compounds within the water. The closeness of the calculated TSI values for these three parameters to one another indicates a higher degree of correlation.

The weighted TSI values for total phosphorus and chlorophyll-*a* in the project lakes range from oligotrophic to eutrophic (Figure 3.1-9). When compared to other deep lowland drainage lakes in the state, Plum, Star, and White Birch lakes have slightly lower levels of productivity. When compared to other shallow headwater drainage lakes in the state, West Plum and Irving lakes have similar levels of productivity while Little Star Lake is much more productive, and Ballard Lake is less productive. Big Muskellunge Lake is less productive than other deep headwater drainage lakes in the state. Lake Laura is slightly less productive than other deep seepage lakes in the state, while Razorback Lake is near the median value for this lake type.

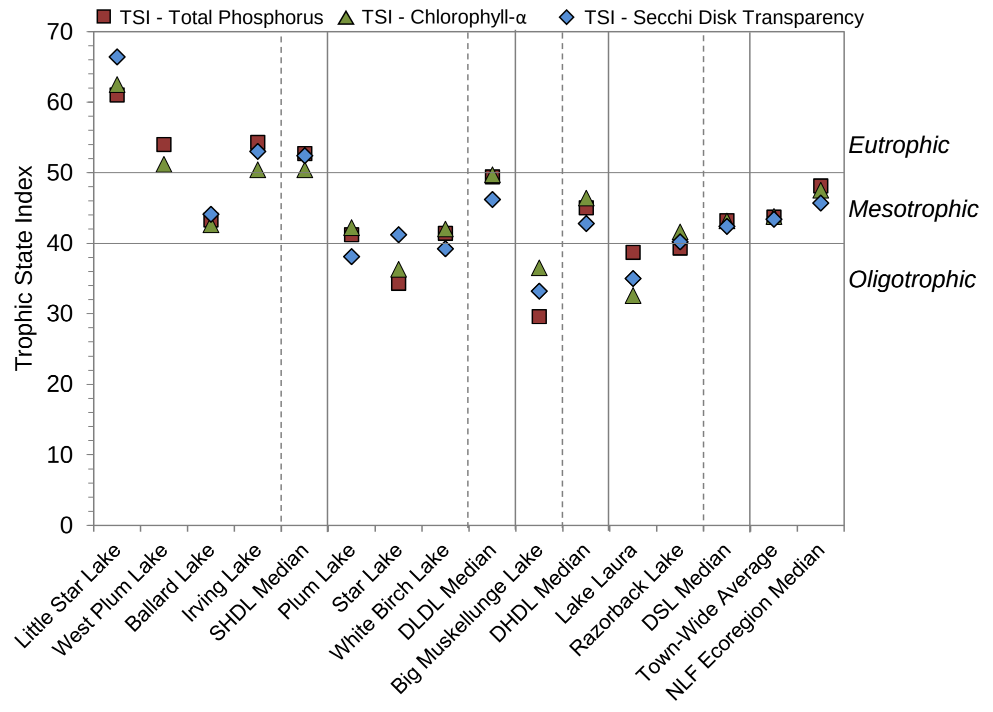


Figure 3.1-9. Town of Plum Lake project lakes Trophic State Index. In West Plum Lake the Secchi disc hit bottom during every sampling event so it is not used in this analysis. Values calculated with summer month surface sample data using WDNR PUB-WT-193. SHDL = Shallow Headwater Drainage Lake, DLDL = Deep Lowland Drainage Lake, DSL = Deep Seepage Lake, NLF = Northern Lakes & Forests Ecoregion.

The TSI values for all three parameters in Ballard, Plum, White Birch, and Razorback lakes were relatively similar, indicating that algal production is largely regulated by phosphorus availability and water clarity is largely influenced by algal production. In Little Star and Star lakes the TSI values for phosphorus and chlorophyll-*a* were similar indicating that phosphorus largely impacts algal production. Measured chlorophyll-*a* concentrations in West Plum, Irving, and Lake Laura were lower than expected based upon phosphorus levels and can be seen in the lower chlorophyll-*a* TSI value in Figure 3.1-9. This is an indication that a factor other than total phosphorus is limiting algal production in these lakes. It is unclear why there is a discrepancy, but one likely hypothesis is that there is a healthy zooplankton community which is consuming a significant amount of the algal population in these lakes. In contrast, chlorophyll- *a* concentrations in Big Muskellunge Lake were higher than expected when compared to the measured phosphorus and Secchi disk depth values.

Additional Water Quality Data Collected at the Town of Plum Lake Project Lakes

The previous sections were largely focused on lake eutrophication. However, parameters other than nutrients, chlorophyll-*a*, and water clarity were collected as part of the project. These other parameters were collected to increase the understanding of the Town of Plum Lake project 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.

pH

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 and highly productive 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 variability in pH between lakes is most likely attributable to a number of environmental factors, most influential being the geology within the lake's surficial and ground watershed. On a smaller scale within a lake or between similar lakes, photosynthesis by phytoplankton and macrophytes can impact pH because the process uses dissolved carbon dioxide, which forms carbonic acid in water. Carbon dioxide removal through photosynthesis reduces the acidity of lake water, so pH increases. In the Town of Plum Lake project lakes, summer near-surface pH values ranged from 7.6 in Irving Lake to 8.3 in Ballard Lake (Figure 3.1-10). Both of these values indicate the two lakes are just slightly alkaline, and all project lakes fall within the normal range for Wisconsin lakes. Summer near-surface pH was not measured in West Plum and Little Star lakes.

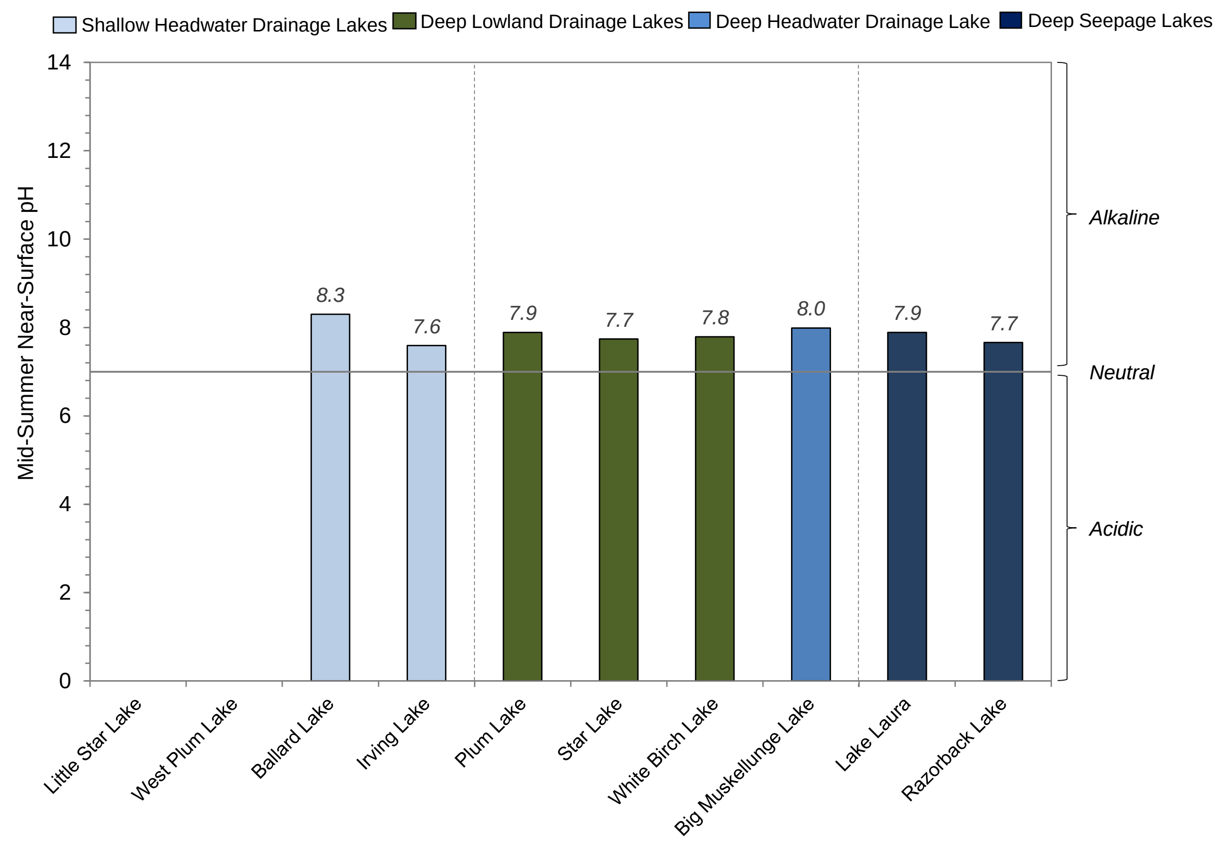


Figure 3.1-10. Town of Plum Lake project lakes mid-summer near-surface pH values. Data for each lake collected during the respective project phase.

Alkalinity

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 it contains. Rainwater in northern Wisconsin is slightly acidic naturally with a pH of around 5.0 due to dissolved carbon dioxide from the atmosphere. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs.

Within the project lakes, alkalinity ranged from 24.9 mg/L as $CaCO_3$ in Big Muskellunge Lake to 38.0 mg/L as $CaCO_3$ in Plum Lake (Figure 3.1-11). Alkalinity was not measured in West Plum and Little Star lakes. Given the alkalinity in these lakes, none are sensitive to inputs from acid rain.

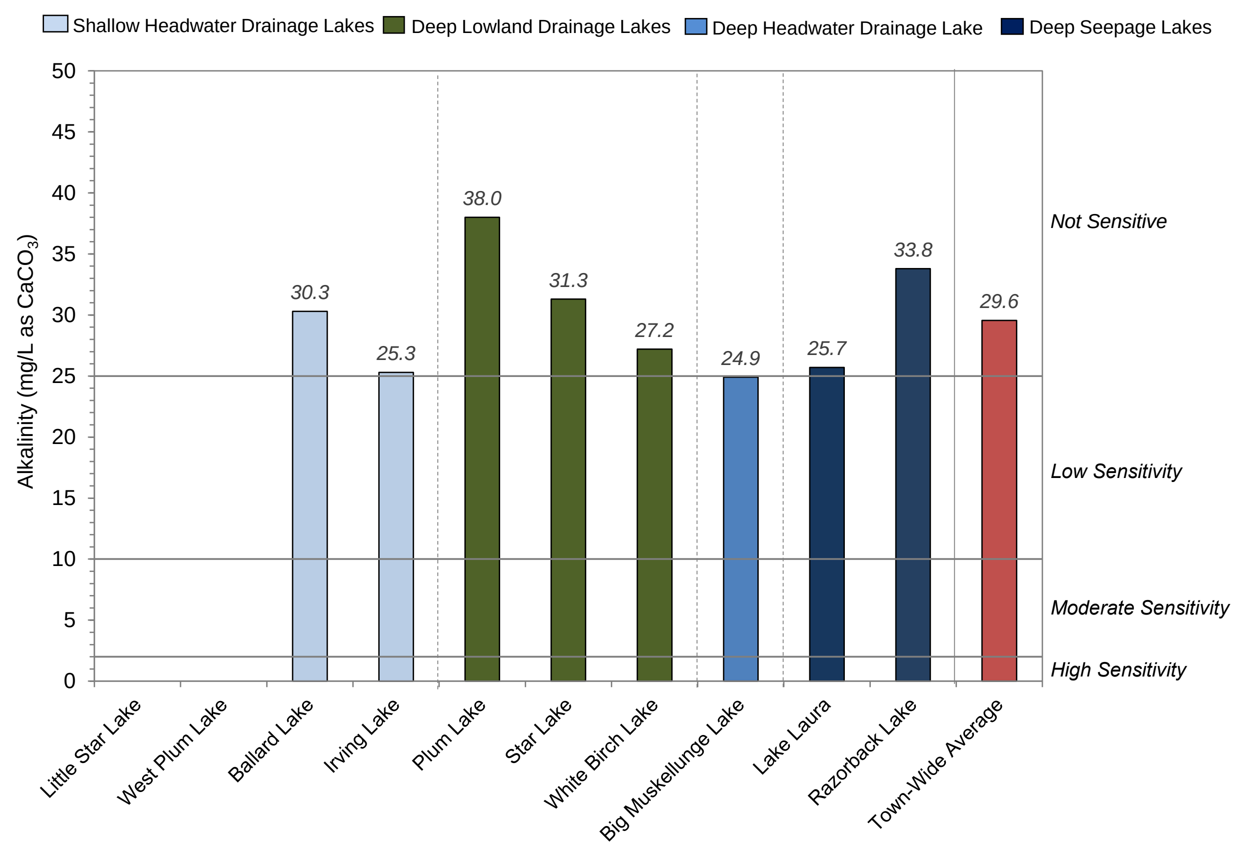


Figure 3.1-11. Town of Plum Lake project lakes average growing season total alkalinity and sensitivity to acid rain. Samples collected from near-surface.

Calcium

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 which lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, and the pH of each of the project lakes falls within this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have *very low susceptibility* to zebra mussel establishment. Measured calcium concentrations within the project lakes ranged from 5.8 in Razorback Lake to 11.1 in Plum Lake (Figure 3.1-12). Alkalinity was not measured in West Plum and Little Star lakes. Calcium concentrations in all of the measured project lakes fall within the *very low susceptibility* category for zebra mussel establishment. The calcium concentrations in these lakes indicate zebra mussels have a low probability of establishing if they were to be accidentally introduced.

Onterra ecologists collected three plankton tows from three different locations within all of the project lakes. These samples underwent analysis to check for the presence of zebra mussel veligers, the planktonic larval stage of the zebra mussel. Analysis of these samples were negative for the presence of zebra mussel veligers, and no adult zebra mussels were observed during the surveys. It is believed that zebra mussels are currently not present in any of the Phase I - III project lakes.

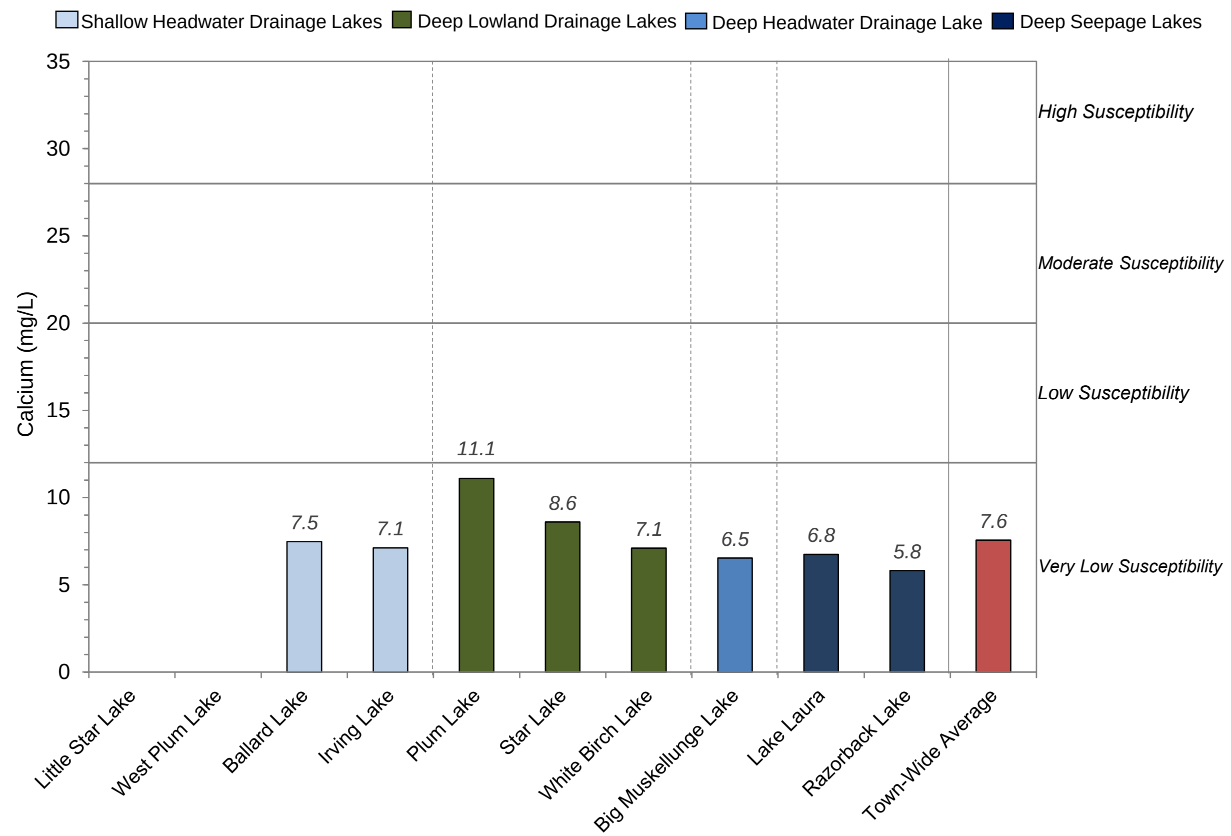


Figure 3.1-12. Town of Plum Lake project lakes average growing season calcium concentrations and susceptibility to zebra mussel establishment. Samples collected from the near-surface.

3.2 Paleoecology

Questions often arise concerning how a lake's water quality has changed through time as a result of watershed disturbances. In most cases, there is little or no reliable long-term data. They also want to understand when the changes occurred and what the lake was like before the transformations began. Paleoecology offers a way to address these issues. The paleoecological approach depends upon the fact that lakes act as partial sediment traps for particles that are created within the lake or delivered from the watershed. The sediments of the lake entomb a selection of fossil remains that are more or less resistant to bacterial decay or chemical dissolution. These remains include frustules (silica-based cell walls) of a specific algal group called diatoms, cell walls of certain algal species, and subfossils from aquatic plants. The diatom community are especially useful in reconstructing a lake's ecological history as they are highly resistant to degradation and are ecologically diverse. Diatom species have unique features as shown in Figure 3.2.1, which enable them to be readily identified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. Some species float in the open water areas while others grow attached to objects such as aquatic plants or the lake bottom.

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

One often used paleoecological technique is collecting and analyzing top/bottom cores. The top/bottom core only analyzes the top (usually 1 cm) and bottom sections. The top section represents present day conditions and the bottom section is hoped to represent pre-settlement conditions by having been deposited at least 100 years ago. While it is not possible to determine the actual date of deposition of bottom samples, a determination of the radionuclide lead-210 estimates if the sample was deposited at least 100 years ago. The primary analysis conducted on this type of core is the diatom community leading to an understanding of past nutrients, pH, and general macrophyte coverage.

Plum Lakes Paleoecological Results

Top/bottom cores were collected from eight lakes (Star, Little Star, West Plum, Plum, Laura, Ballard, and White Birch). The core from Plum Lake was collected by Wisconsin DNR staff during the summer 2012 as part of the U.S. EPA National Lake Assessment. The cores from Ballard and White Birch lakes were collected in 1999 by Wisconsin DNR staff. That year a full core was collected from Irving Lake by Wisconsin DNR staff. The cores from the first three lakes were collected by Onterra staff on August 8 and 9, 2017 and the core from Laura Lake was collected on July 30, 2018. The length of the cores collected by Onterra were: West Plum, 68 cm; Star, 48 cm; Little Star, 70 cm; and Laura, 45 cm. For all of the cores, the top 1 cm and bottom 2 cm were analyzed for the diatom community. A radiochemical analysis can be done on the bottom samples from the cores to estimate whether the samples had been deposited at least 100 years ago which would be before significant watershed disturbances occurred because of settlement. This analysis was done on the bottom samples from Plum and Little Star lakes but the diatom community at the bottom samples of West Plum, Star, and Laura lakes made it very likely this sediment was deposited prior to the logging era which occurred in this area from 1890 through about 1910. The full core from Irving Lake was analyzed for geochemical parameters, the diatom community, and plant pollen. In addition a radiochemical analysis was performed to determine the dates for the various depths as well as the sedimentation rate.

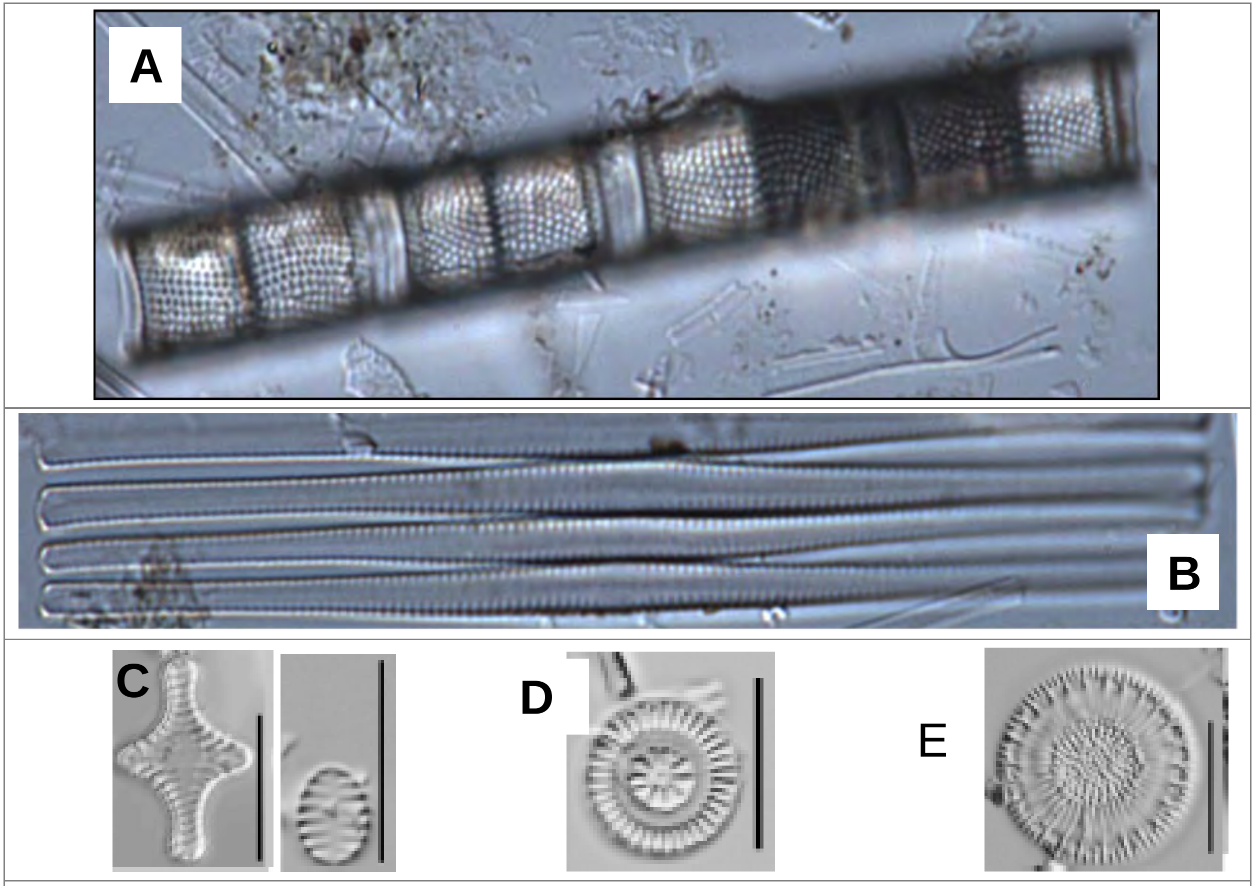


Figure 3.2-1. Photomicrographs of the diatoms commonly found in the sediment cores from these lakes. The top diatom (A) is *Aulacoseira ambigua* which was common in all of the lakes except West Plum and Laura. In these lakes this diatom indicates low phosphorus concentrations. The next diatom, *Fragilaria crotonensis* (B) is more common with moderate phosphorus levels but indicates higher nitrogen concentrations. *Staurosira construens* and *S. construens var. venter* (C) are typically found growing on the lake sediments and were common in Laura and West Plum lake. *Discostella stelligera* (D) and *Lindavia intermedia* (E) were found in the top sample from Star Lake.

Multivariate Statistical Analysis

In order to make a comparison of environmental conditions between the bottom and top samples of the cores from the project lakes, an exploratory detrended correspondence analysis (DCA) was performed (CANOCO 5 software, ter Braak and Smilauer, 2012). The DCA analysis has been done on many WI lakes to examine the similarities of the diatom communities between the top and bottom samples of the same lake. These lakes are those that are relatively deep and stratify during the summer. The results revealed two clear axes of variation in the diatom data, with 32% and 19% of the variance explained by axis 1 and axis 2, respectively (Figure 3.2-2). Sites with similar sample scores occur in close proximity reflecting similar diatom composition. The arrows symbolize the trend from the bottom to the top samples.

With the exception of Little Star Lake, and to a lesser extent Laura Lake, the rest of the lakes show significant change between the bottom and the top of the cores. In case of Little Star Lake, the bottom sample may not have been deposited prior to arrival of European settlers. (The radiochemical analysis will determine if the bottom sample was deposited at least 100 years ago.) Irving and Laura as well as the bottom of West Plum and the top of Ballard lakes are located away from the other samples because these samples are dominated by benthic *Fragilaria* such as *S. construens* and *S. construens* var. *venter* (Figure 3.2-1c). These diatoms grow attached macrophytes in the case of Irving and Ballard lakes and on the lake sediments as in the case of Laura and West Plum lakes. The diatom community in the other samples were dominated by planktonic diatoms, which are diatoms that grow in the open water of the lakes.

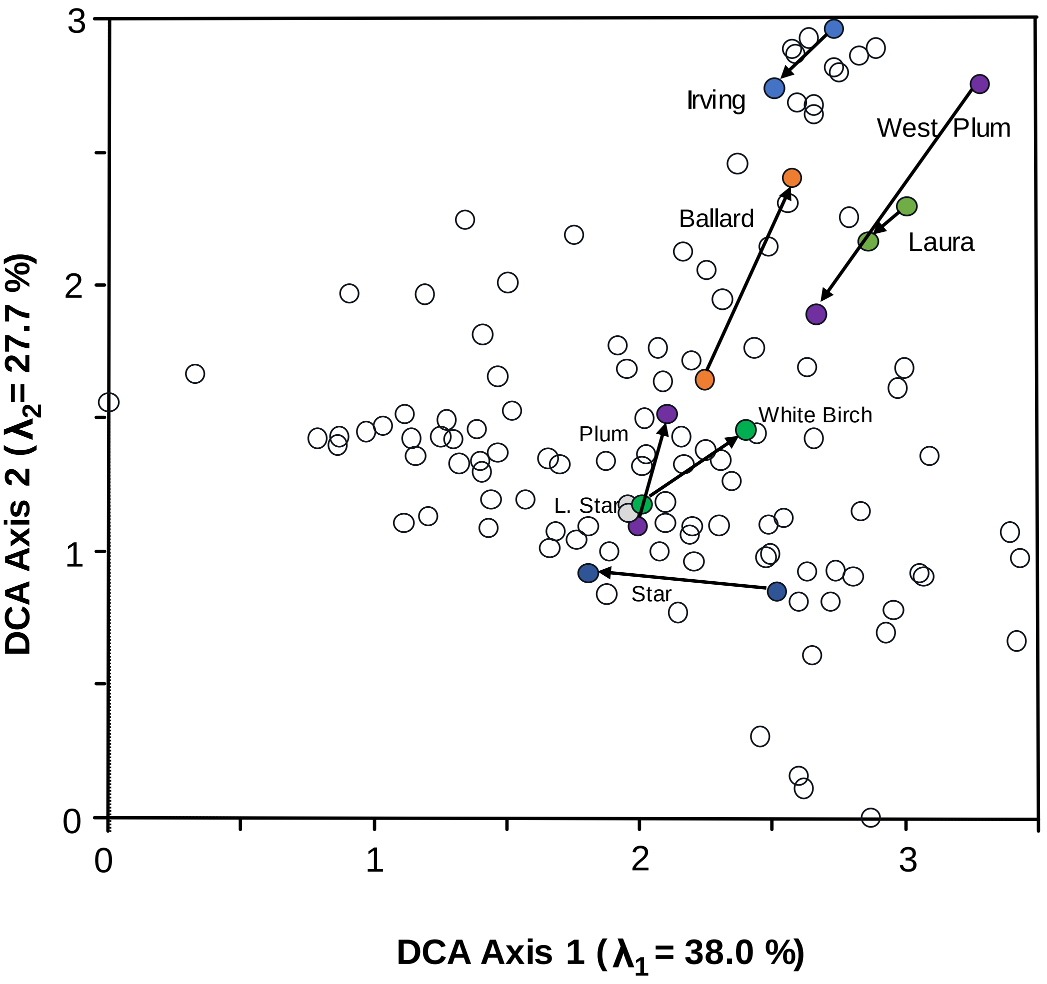


Figure 3.2-2. DCA plot of top/bottom samples from study lakes in the Town of Plum Lake. The arrows connect bottom to top samples in the same lake. The open circles are other Wisconsin lakes where top/bottom samples have been analyzed. West Plum, Laura, and Irving lakes and the top of Ballard Lake are separated from the other lakes because the diatom communities are very different from the other study lakes because of the dominance of benthic dwelling diatoms..

While it is not possible to determine which were the most important environmental variables ordering the diatom communities, one trend is apparent. Axis 1 likely represents the alkalinity of the lakes. Other studies on Wisconsin and Vermont lakes indicate that the most important variable ordering the diatom communities is alkalinity. Lakes on the right side of the DCA graph tend to have the highest alkalinity values while the lowest are on the left side. A study by Eilers et al. (1989) on 149 lakes in north central Wisconsin found that as a consequence of lake shoreland development, alkalinity and conductivity concentrations increase. This is because of the sediment that enters the lake during cottage and road construction.

Star Lake

In the bottom sample, planktonic diatoms dominated the diatom community (Figure 3.2-3). The most common diatom was *Aulacoseira ambigua* which is frequently the dominant diatom in deep oligotrophic lakes in northern Wisconsin, Michigan, and Minnesota prior to the arrival of Euroamerican settlers (Camburn and Kingston 1986, Kingston et al. 1990, Garrison and Fitzgerald 2005). In fact in Star Lake this diatom comprised over 60% of the historic diatom community. In the top sample, the presence of *A. ambigua* was reduced to less than 10% and all of the planktonic diatoms only constituted less than one half of the diatom community (Figure 3.2-3). The dominant taxa in the diatom community of the top sample was the group benthic *Fragilaria* which typically grow attached to submerged aquatic vegetation or on the lake sediments.

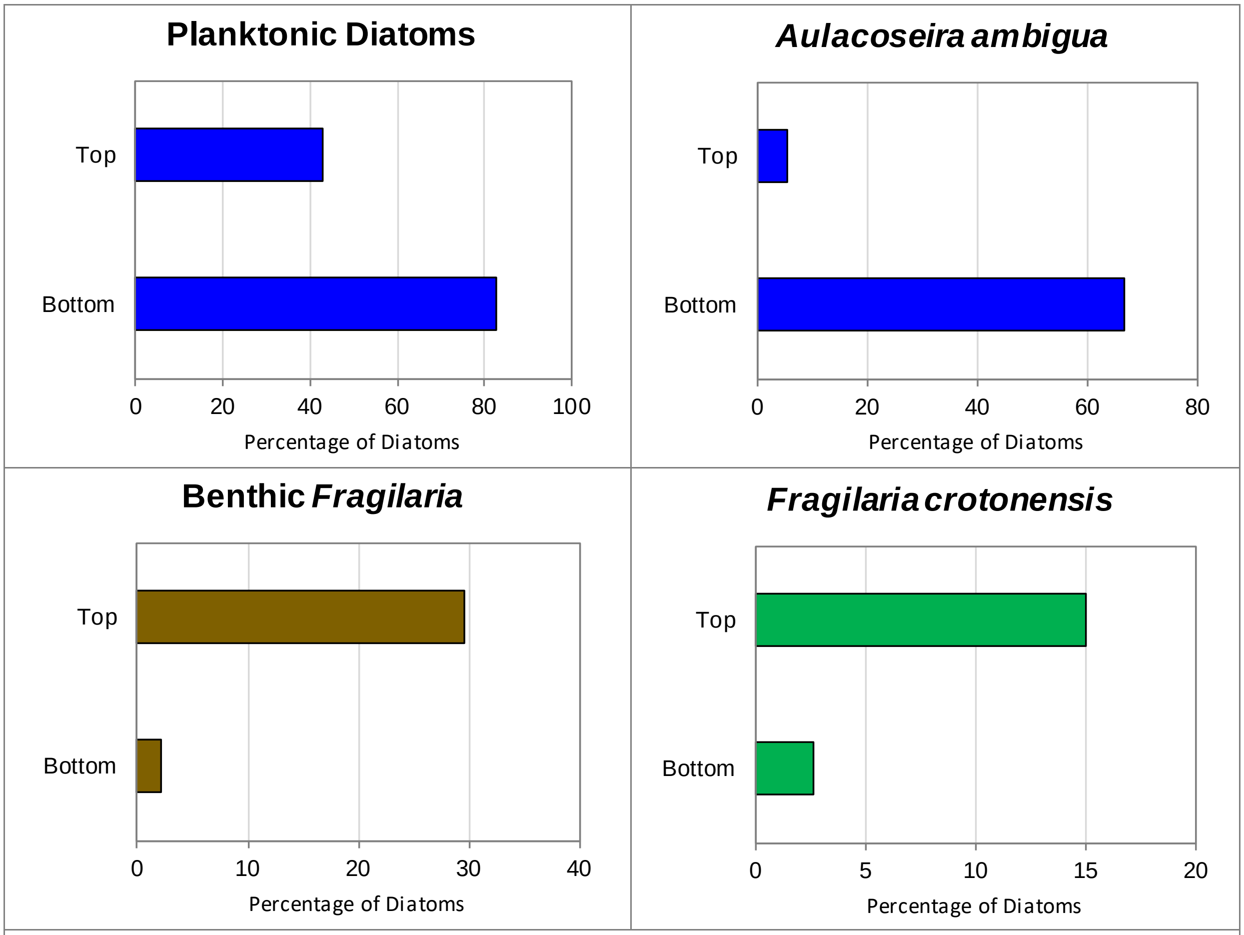


Figure 3.2-3. Changes in abundance of important diatoms found in the top and bottom of the sediment core from Star Lake. The bottom sample is dominated by planktonic diatoms while the top is dominated by nonplanktonic diatoms. This indicates a significant habitat change in the lake.

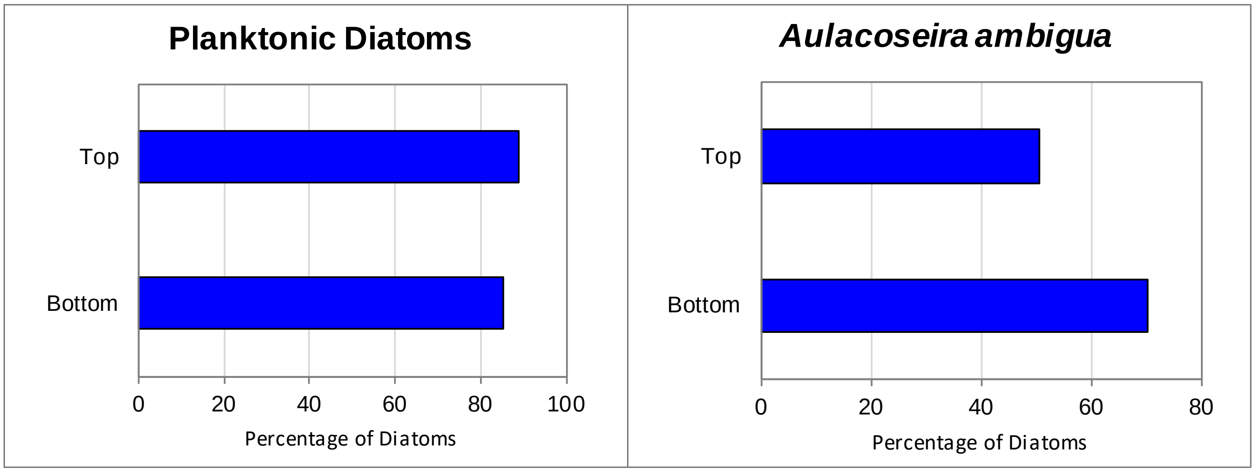
Studies have found that the littoral area of a lake often responds earliest to increased nutrient input from the watershed. This is because the littoral zone is the interface between the surrounding watershed and the main body of the lake. Often the first sign of increased nutrients is an increased growth of periphyton (Goldman and deAmezaga, 1975, Loeb 1986, Jacoby et al. 1991, Garrison and Wakeman 2000). Often with early shoreland development there is an increase in macrophyte growth. Borman (2007) found that in northwestern Wisconsin, the macrophyte community often changed in seepage lakes, from one dominated by low growing plants to a community dominated by larger macrophytes, as a result of shoreline development. The structure of the macrophyte community changes because the increased runoff of sediment during construction on the shoreline enables the establishment of the larger plants. With the larger plants there is much more surface area available on which diatoms and the other periphytic algae are able to grow.

Although the percentage of planktonic diatoms in the top sample is reduced compared with the historic sample, the composition of the top sample indicates an increase in nutrient concentrations. There is an increase in *Fragilaria crotonensis* (Figure 3.2-3) and *Asterionella formosa* (not shown) which can indicate an increase in nutrients, especially nitrogen (Wolfe et al. 2001).

It is likely that change in habitat with increased macrophyte growth and increased nutrients in the open water began during the logging era which in this area was in the 1890s through about 1910. The town of Star Lake, which is located on the shore of the lake of the same name, at its peak had a population of over 600. Undoubtedly significant nutrients and sediment entered Star Lake at this time.

Little Star Lake

The diatom community in Little Star Lake is much more similar in the top and bottom samples. Over 80% of the community is composed of planktonic diatoms (Figure 3.2-4). The most common taxa is *A. ambigua* although there are less of these diatoms in the top sample compared with the bottom sample. As with Star Lake, there is an increase in the mesotrophic diatoms *F. crotonensis* and *A. formosa* compared with the bottom sample. Diatoms of the genus *Cyclotella* also increase in the top sample. This is primarily due to the diatom *Cyclotella michiganiana.* This diatom often is found in the metalimnion of stratified lakes where nutrient levels can be higher and light levels reduced. Since Little Star Lake does not stratify, the increase in this taxa may indicate a reduction in water clarity between the time periods represented in the bottom and top samples. Given the present day eutrophic water quality condition of Little Star Lake it is surprising that there is not a greater change in the diatom community between the bottom and top samples. This could be because the sediments where the core was collected had been disturbed, meaning that the top or bottom samples do not represent present day or historic conditions. A radiochemical analysis will be performed on the bottom sample which will determine whether this sample was deposited at least 100 years ago.



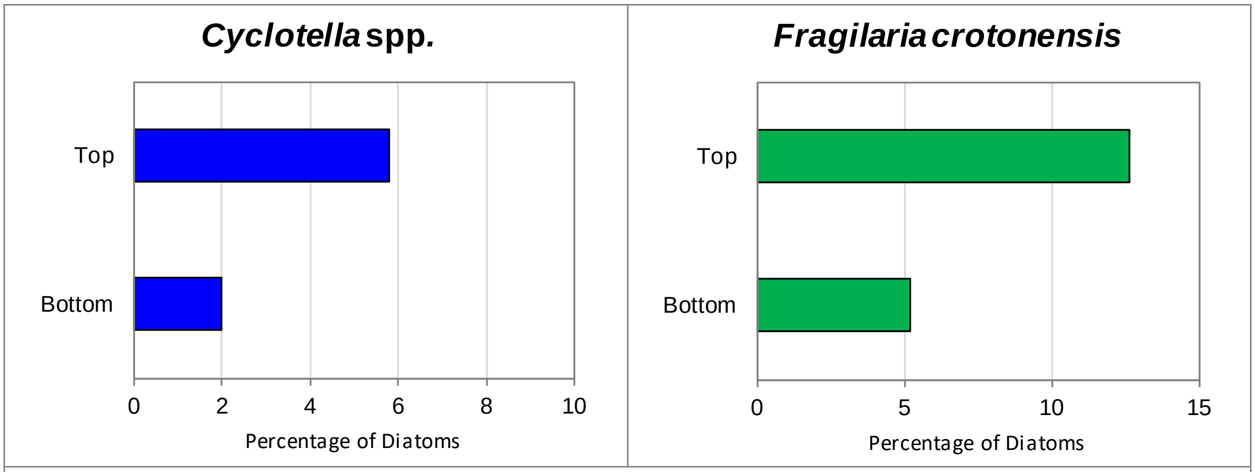


Figure 3.2-4. Changes in abundance of important diatoms found in the top and bottom of the sediment core from Little Star Lake. The bottom and top samples are dominated by planktonic diatoms. There is an increase in *F. crotonensis* which indicates an increase in nutrients, especially nitrogen.

Plum Lake

The diatom community in the bottom sample was not as well preserved as it was in the other lakes. Typically, 500 valves are counted in a sample. Because of the scarcity of the diatoms only 78 valves were counted even though an extensive part of the slide was examined. In addition, some of the diatom valves showed signs of degradation. Nevertheless, it was felt that there were sufficient diatoms present to complete the analysis. Part of this conclusion is based upon the fact the diatom community in the bottom sample is similar to the presettlement community of many other stratified lakes in northern Wisconsin.

As with Star Lake, the diatom community in the bottom sample is dominated by planktonic diatoms (Figure 3.2-5). The dominant taxa is *A. ambigua* although they are not as prevalent as in the bottom sample of Star Lake. As with Star Lake, in the top sample the diatom community was dominated by nonplanktonic diatoms, especially diatoms in the group benthic *Fragilaria* (Figure 3.2-5). As with Star Lake it appears that as a result of activities associated with logging around the beginning of the twentieth century, there has been an increase in macrophytes which has resulted in a significant change in habitat in the near shore environment. This has frequently occurred in northern Wisconsin lakes that have even small amounts of lakeshore development. The few lakes that have been cored that do not have cottages or homes do not generally show an increase in diatoms that are indicative of increased macrophyte growth. This trend of increased macrophyte cover with shore land development has also been seen in lakes in northeastern US (Vermaire and Gregory-Eaves 2008) and these types of diatoms have been noted as the earliest indicators of increased nutrients because of development (Lambert et al. 2008).

The top sample in Plum Lake also has a greater percentage of the mesotrophic diatoms *F. crotonensis* and *A. formosa* indicating an increase in nutrients, especially nitrogen. This trend was also observed in Star and Little Star lakes and other lakes in northern Wisconsin. As with Star Lake, it is likely this change in habitat and increased nutrients occurred during the logging era.

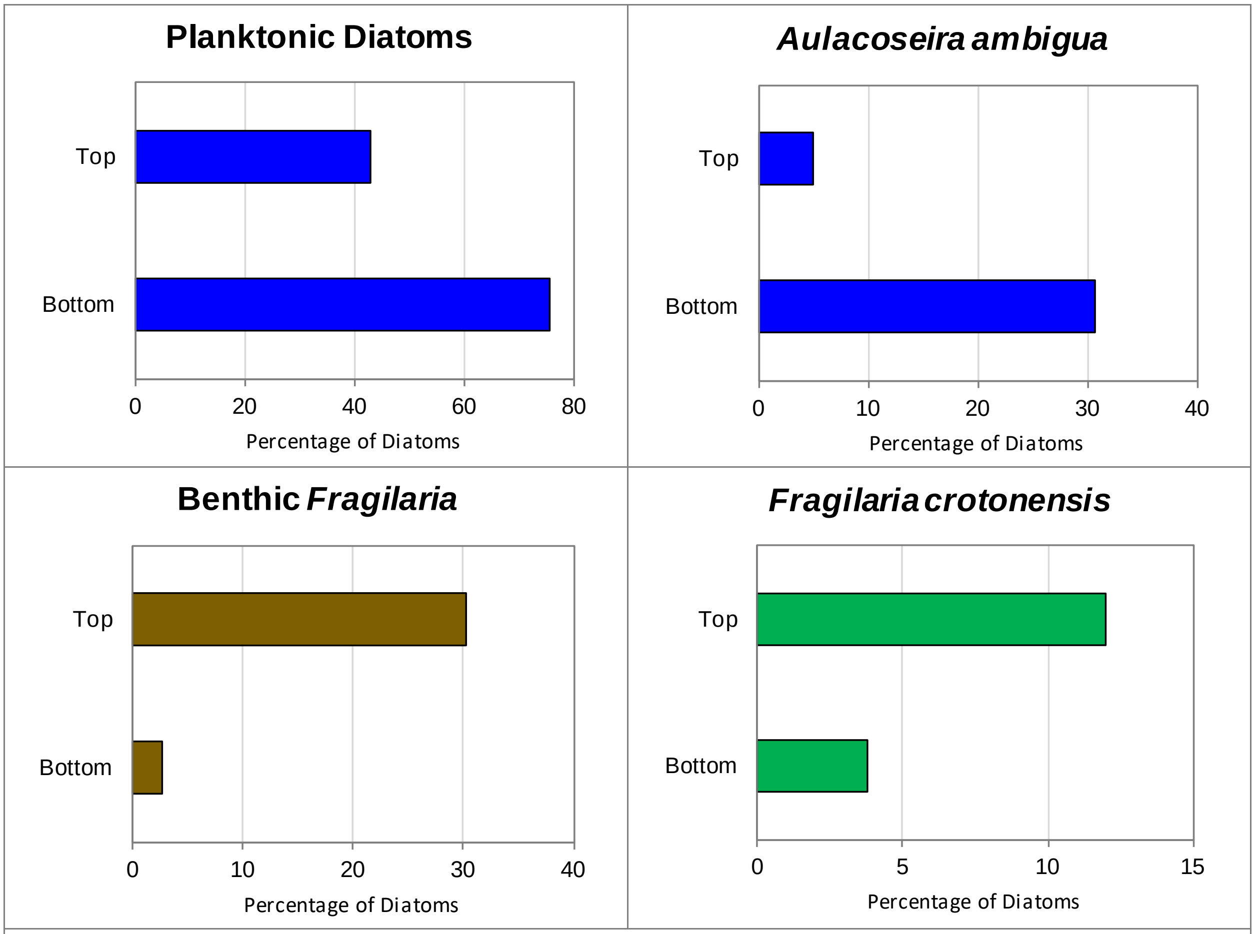
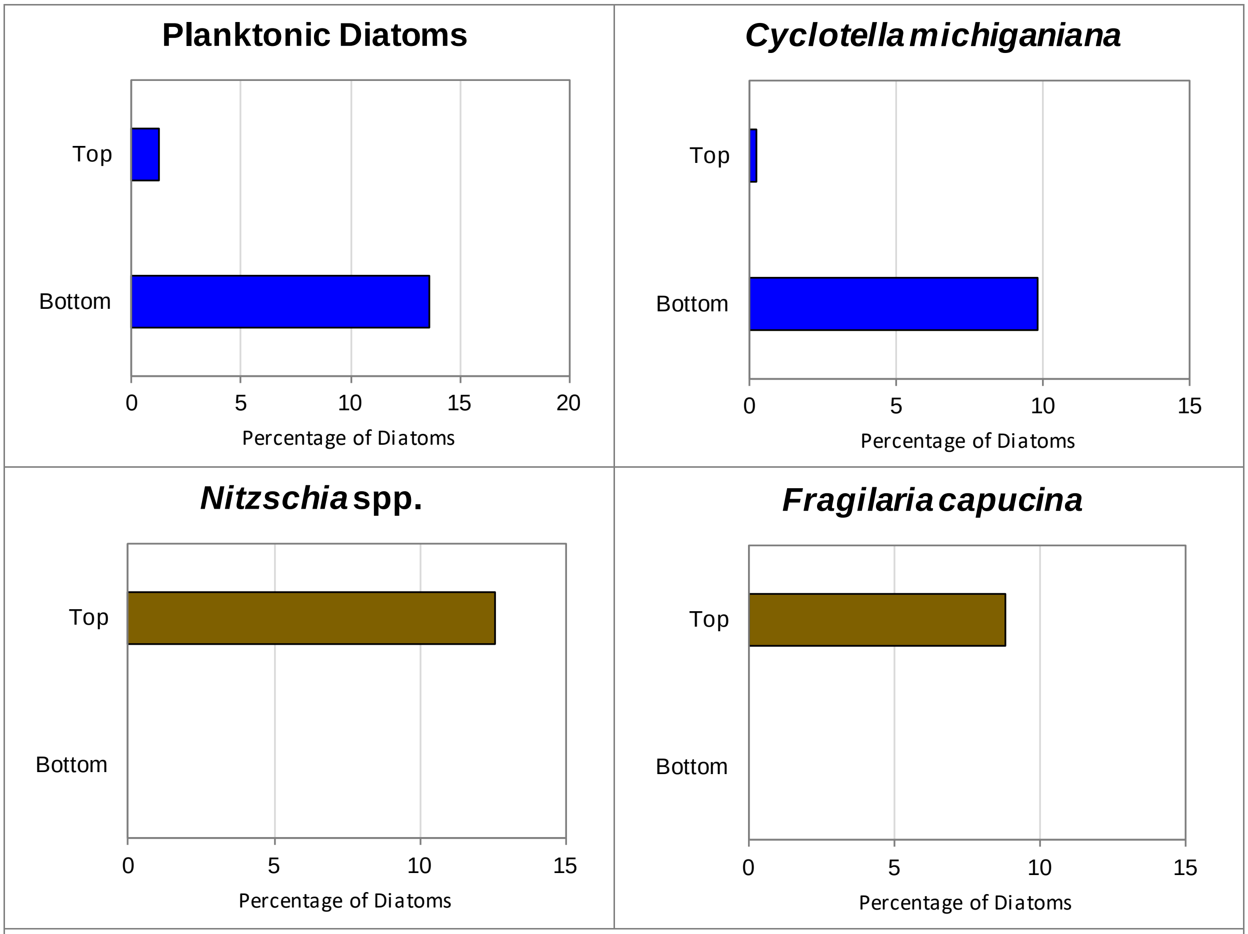


Figure 3.2-5. Changes in abundance of important diatoms found in the top and bottom of the sediment core from Plum Lake. The bottom sample is dominated by planktonic diatoms while the top is dominated by nonplanktonic diatoms. This indicates a significant habitat change in the lake.

West Plum Lake

The diatom community in this lake is much different than the previous three lakes. Even in the bottom sample, the diatom community is dominated by diatoms that grow attached to macrophytes or the lake bottom (Figure 3.2-6). This is because this lake is much shallower than the other lakes with a maximum depth of about 4.5 feet. In the bottom sample the planktonic diatoms are more common than the top sample, but this is probably because historically West Plum Lake was better connected to Plum Lake. At the present time there is a roadway (County Road N) with a culvert which separates the lake from Plum Lake. The dominant planktonic diatom in the bottom sample was *Cyclotella michiganiana* which was also found in the bottom sample of the Plum Lake core. It is possible that the macrophyte coverage at the present time is more dense than it was prior to the arrival of Euroamericans.

The benthic community in the top sample is significantly different than it is in the bottom sample. Specifically, *Nitzschia* and *Fragilaria capucina* and varieties are more common in the top sample. These diatoms typically are found at higher nutrient concentrations, especially phosphorus. It is likely that in West Plum Lake at the present time, phosphorus concentrations are higher and there are more macrophytes compared to 100 years ago. It is likely that at least in part, part of the reason for the increased trophic state of the lake is the separation of this lake from Plum Lake with the construction of the roadway. This resulted reduced hydrologic flow between Plum Lake and this lake which was previously a bay of the much larger Plum Lake. With a reduction of interchange of water, nutrients are retained in West Plum Lake at a higher rate than they were prior to the construction of the roadway.



Planktonic Diatoms | ***Cyclotella michiganiana*** | ***Nitzschia* spp.** | ***Fragilaria capucina***

Figure 3.2-6. Changes in abundance of important diatoms found in the top and bottom of the sediment core from West Plum Lake. This lake has a much lower percentage of planktonic diatoms in the bottom sample because of the lake's shallow depth. The bottom sample was probably deposited before the roadway was built which separated this lake from Plum Lake.

Laura Lake

The diatom community in this lake is much different than the other four lakes. Despite Laura Lake being a deep lake, nearly all of the diatom community is composed of taxa that grow on the lake bottom. The dominant diatoms in the bottom and top samples are the benthic *Fragilaria*, *Staurosira construens* and *S. construens var. venter*. These taxa are dominant because of the good water clarity of the lake. This allows sufficient light to reach much of the lake bottom for growth of the diatoms. If nutrients concentrations were somewhat higher, there would be sufficient growth of planktonic diatoms such that water clarity would be reduced and benthic diatoms would not completely dominate the diatom community. The diatom community is similar in the bottom and top samples suggesting that the water quality at the present time is similar to what it was historically.

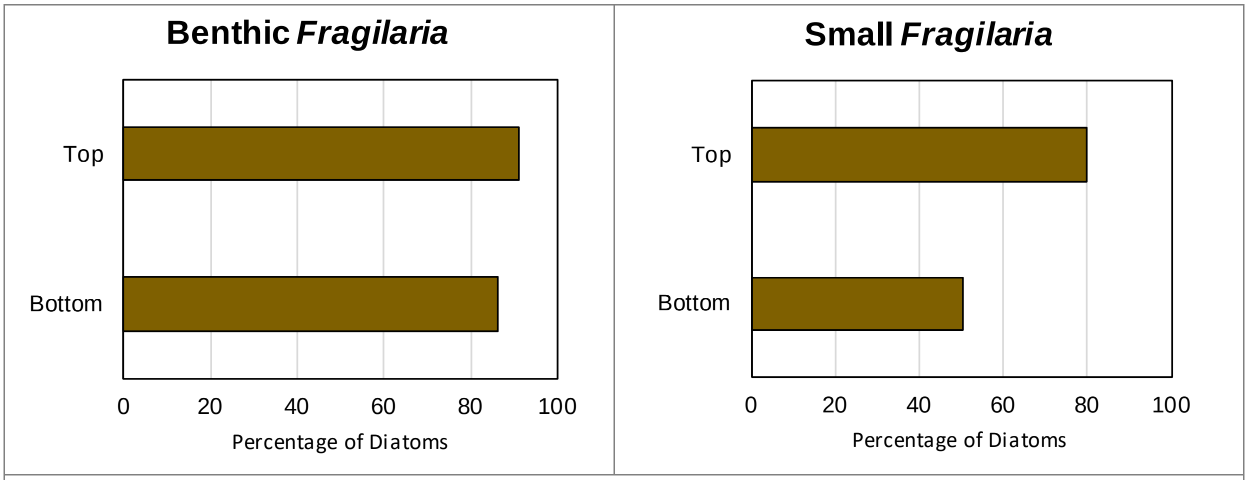


Figure 3.2-7. Changes in abundance of important diatoms found in the top and bottom of the sediment core from Laura Lake. The diatom community was completely dominated by taxa that grow on the lake bottom. This is because of the very good water clarity in the lake.

White Birch Lake

Planktonic diatoms, especially *Cyclotella stelligera*, where much more common at the top of the core compared with the bottom sample (Figure 3.2-8). The relative decline in diatoms that grow attached to submerged aquatic plants is the result of either fewer vascular plants or an increase phosphorus. Since the lake at the present time contains a significant macrophyte community it is most likely there has been an increase in phosphorus. There was also an increase in the abundance of *F. crotonensis* (not shown) which responds to increased nutrients, especially nitrogen. Because there is only a small increase in benthic *Fragilaria*, it is likely the increase in phosphorus concentrations has been small. Often with a substantial increase in phosphorus benthic *Fragilaria* such as *S. construens* and *S. construens* var. *venter* (Figure 3.2-1) increase to the point where diatoms of the genus *Navicula* are only present in small abundances. This is not the case in White Birch Lake.

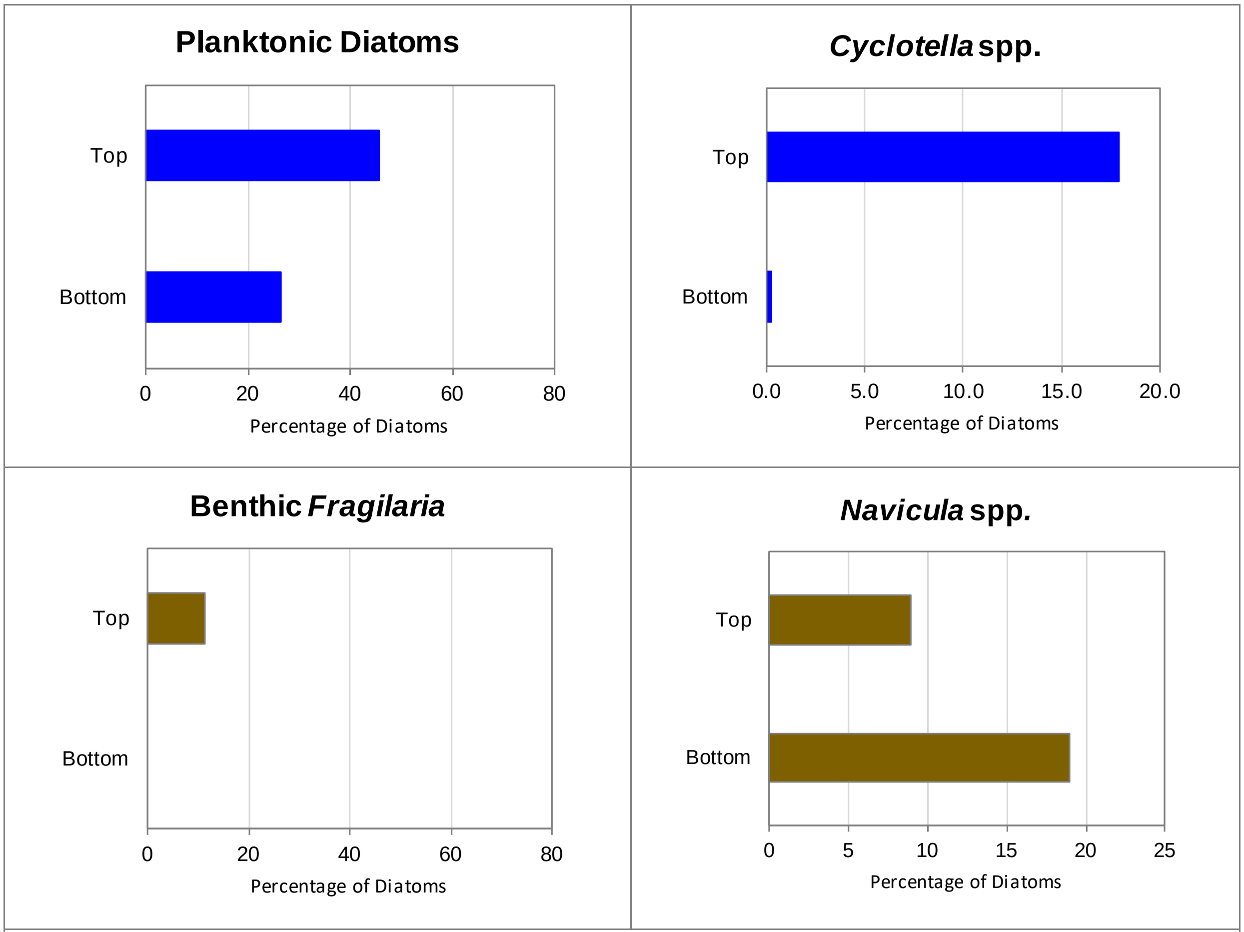


Figure 3.2-8. Changes in abundance of important diatoms found in the top and bottom of the sediment core from White Birch Lake. Planktonic diatoms are more common at the top of the core, likely signaling an increase in nutrients.

Ballard Lake

Unlike White Birch Lake, there is not a greater relative abundance of planktonic diatoms in the top sample compared with the bottom sample. In fact the abundance of planktonic diatoms in the surface sample is small and this is largely the result of the decline in *Cyclotella* spp., especially *C.*

michiganiana (Figure 3.2-9). The increase in benthic *Fragilaria* and *Navicula* spp. signals an increase in macrophyte coverage.

Studies have found that the littoral area of a lake often responds earliest to increased nutrient input from the watershed. This is because the littoral zone is the interface between the surrounding watershed and the main body of the lake. Often the first sign of increased nutrients is an increased growth of periphyton (Goldman and deAmezaga, 1975, Loeb 1986, Jacoby et al. 1991, Garrison and Wakeman 2000). Often with early shoreland development there is an increase in macrophyte growth. Borman (2007) found that in northwestern Wisconsin, the macrophyte community often changed in seepage lakes, from one dominated by low growing plants to a community dominated by larger macrophytes, as a result of shoreline development. The structure of the macrophyte community changes because the increased runoff of sediment during construction on the shoreline enables the establishment of the larger plants. With the larger plants there is much more surface area available on which diatoms and the other periphytic algae are able to grow.

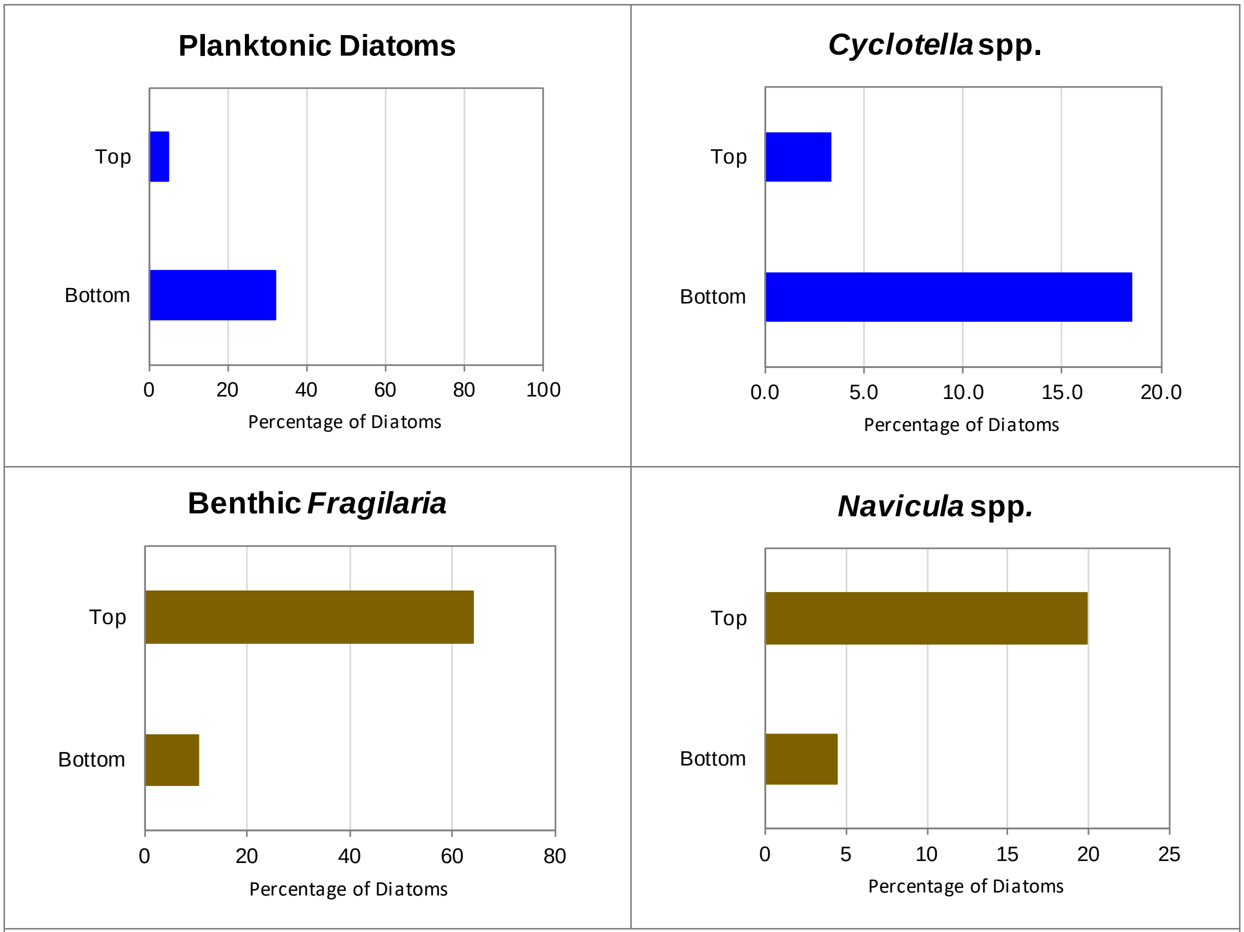


Figure 3.2-9. Changes in abundance of important diatoms found in the top and bottom of the sediment core from Ballard Lake. Planktonic diatoms are more common at the top of the core, likely signaling an increase in nutrients.

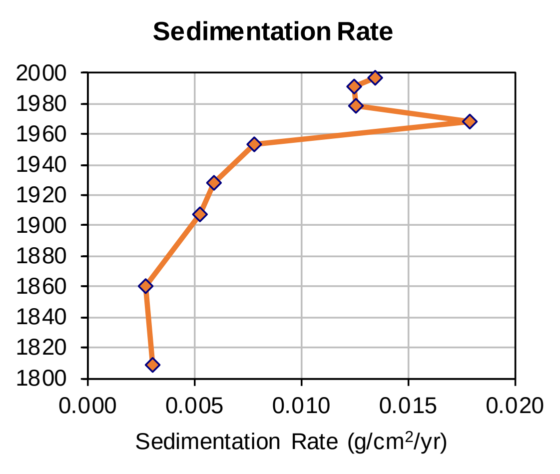
Although an increased abundance of benthic *Fragilaria* can indicate an increase in phosphorus concentrations they can also be found in low phosphorus conditions as in Laura Lake. These diatoms have a wide tolerance range of nutrients because they grow on the sediments and macrophytes and can extract necessary nutrients from the sediments or excretions from the plants. The increase in *Navicula* in the top sample indicates that although there are considerably more macrophytes, phosphorus concentrations have not increased.

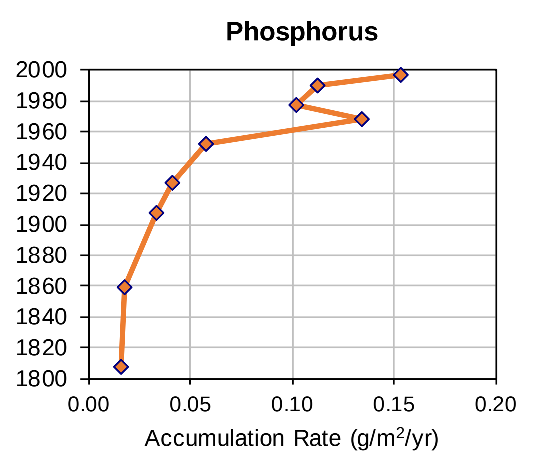
Irving Lake

In Irving Lake a full core was collected from near the middle of the lake in 1999. The total length of the core was 61 cm. Numerous samples throughout the core were analyzed for the diatom community, wild rice pollen, selected geochemical parameters, and sedimentation rate while the core was dated using lead-210.

Sedimentation rate and dating is usually measured by the constant rate of supply model (Appleby 1998, 2001; Appleby and Oldfield 1978). The radionuclides lead-210 (^{210}Pb) and cesium-137 (^{137}Cs) are measured in samples throughout the core. Lead-210 is a naturally occurring radionuclide and is the result of natural decay of uranium-238 to radium-226 to radon-222. Since radon-222 is a gas (that is why it is sometimes found in high levels in basements) it moves into the atmosphere where it decays to ^{210}Pb. The ^{210}Pb is deposited on the lake during precipitation and with dust particles. After it enters the lake sediments, it slowly decays through the radionuclides described above. The half-life of ^{210}Pb is 22.26 years (time it takes to lose one half of the concentration of ^{210}Pb) which means that it can be detected and used for dating on samples that are about 130-150 years old.

The sedimentation rate in Irving Lake was very low during the 1800s at 0.003 g/cm^2/yr (Figure 3.2-10a). At the beginning of the twentieth century it slightly increased, most likely as a result of early logging practices followed by road and cottage construction. The rate significantly increased in the 1960s and has remained elevated compared with presettlement times. The higher rate during the last fifty years likely is related to the large increase in wild rice which began in the 1960s. At the present time, during most years the entire lake basin is covered with rice which is deposited in the lake following its senescence in the fall. Associated with the increased sediment infilling during the last fifty years has been the increase in the accumulation rate of phosphorus in the lake (Figure 3.2-10b). It is not likely that this increase is the result of increased delivery of nutrients from the watershed but instead a greater retention of sediment and phosphorus within the lake.





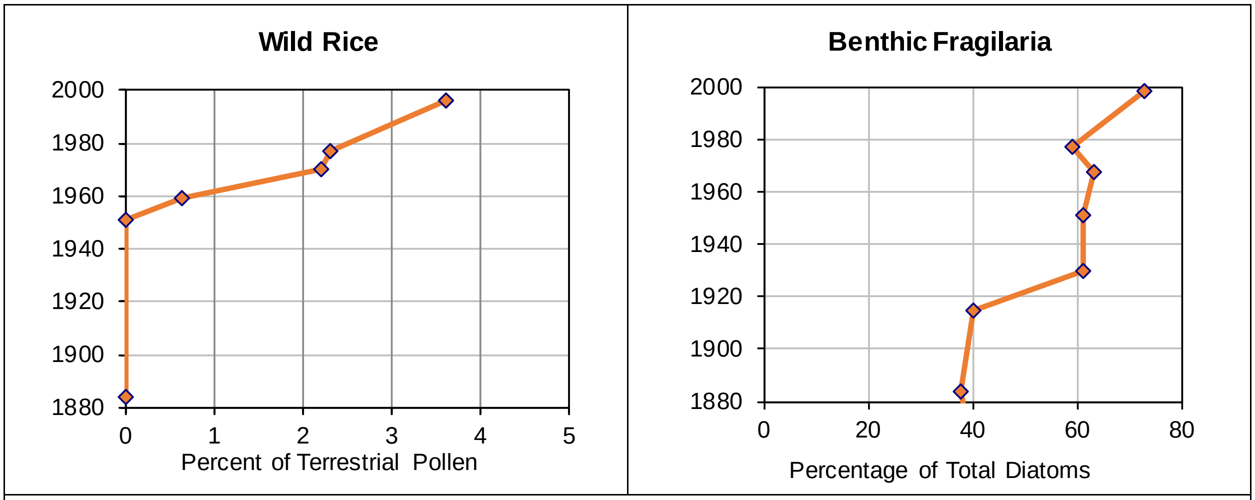


Figure 3.2-10. Profiles of sedimentation rate, phosphorus accumulation rate, percentages of benthic *Fragilaria* and wild rice pollen.

Prior to the 1960s, wild rice was not present or in undetectable levels in Irving Lake (Figure 3.2-10c). Wild rice produces relatively low amounts of pollen compared to terrestrial flora such as conifers. Even though the percentage of wild rice pollen is less than five percent, this does not mean there is a small population of rice in Irving Lake. In fact, in most years rice covers the entire lake basin.

The majority of the diatoms in Irving Lake are those that grow attached to plants or on the lake sediments. This is expected since this is a shallow lake and at the present time has an abundant aquatic plant community. It is estimated that the bottom of the core was deposited during the early part of the sixteenth century. At that time about 90% of the diatom community was composed of nonplanktonic diatoms. Benthic *Fragilaria* which grow on the lake sediments as well as attached to vegetation were an important component of the diatom community throughout the core. Their abundance increased during the twentieth century (Figure 3.2-10d), first as a result of early cottage development and road construction. The abundance of these diatoms has remained high during the last fifty years, most likely with the abundant wild rice as their stems provide a substrate for the diatoms.

Lake Diatom Condition Index

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

The LDCI classifies Star, Plum, and White Birch lakes as good at the present time (Figure 3.2-8). Little Star Lake is classified as fair and West Plum and Ballard lakes are on the border between fair and poor. Laura and Irving are classified as in poor condition but this is an artifact of the how the LDCI is calculated. The index favors planktonic algae and because Irving Lake is shallow, most of its diatom community is benthic. Laura Lake actually has a high abundance of benthic algae because of its excellent water clarity which allows diatoms to grow on much of the lake sediments. In reality, Laura Lake should have a high LDCI. The LCDI for Ballard Lake is much lower in the top sample because of the abundance of benthic diatoms as a result of the increase in macrophyte coverage at the present time compared with historical conditions.

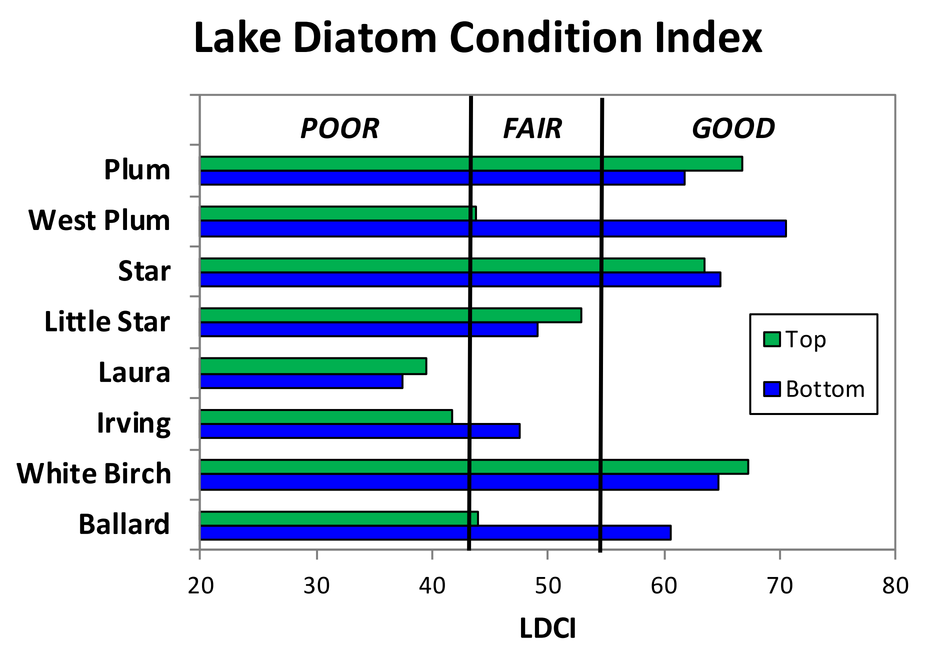


Figure 3.3-8. The Lake Diatom Condition Index (LDCI) for the project lakes. The biotic integrity has changed the most in West Plum Lake most likely because County Road N has reduced the hydrologic interaction between West Plum and Plum lakes.

Even though the diatom community at the present time in Star and Plum lakes is much different than it was prior to the arrival of Euroamericans, the biotic integrity is very good in these lakes. This is reflected in their low phosphorus concentrations and good water clarity. In contrast, West Plum Lake's biotic integrity has been degraded with the arrival Euroamericans, probably largely as a result of the construction of the roadway which is now County Road N. Constructing the causeway and placing a culvert to connect West Plum Lake to Plum lake effectively changed the hydrology of the lake by reducing interflow with Plum Lake. This increased the hydraulic residence time in West Plum Lake allowing nutrients to be retained in the lake.

Inference models

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

The species-environment relationships are then used to infer environmental conditions from fossil diatom assemblages found in the sediment core.

Weighted averaging calibration and reconstruction (Birks et al., 1990) were used to infer historical water column summer average phosphorus in the sediment cores. A training set was divided into deep and shallow lakes. There were 60 deep lakes and 89 shallow lakes. The deep lake training set was used for Laura, Star, Little Star, and Plum lakes while the shallow lake training set was used for West Plum Lake. Training set species and environmental data were analyzed using weighted average regression software (C2; Juggins 2014).

The estimated phosphorus concentrations in the top samples are similar to what has been measured in the lakes in the last few years with the exception of Little Star Lake. As mentioned above, the sediment core from this lake may have been collected in an area where the sediments were disturbed. The estimated historical phosphorus concentrations in Star and Plum lakes is 10 to 11 µg/L (Table 3.2-1). In West Plum Lake the phosphorus concentration estimated from the diatom community is 35 µg/L which is very similar to the mean summer concentration measured in 2017 of 32 µg/L. The historical phosphorus concentration was 14 µg/L. The increase in concentration reflects the impact the County Road N is having upon the lake's trophic status. The Lake Diatom Condition Index in this lake is much worse at the present time compared with historical times and supports the large increase in phosphorus indicated by the inference model. The inference model does not work well for Laura Lake because of the dominance by diatoms that grow on the lake bottom. These diatoms grow in a wide range of phosphorus concentrations because they can extract phosphorus from the sediments. Studies have found that they are not an accurate predictor of phosphorus concentrations. In the case of Laura Lake the model overpredicts the phosphorus concentration. It is more likely that present day phosphorus concentrations are very similar to historical levels. The model works well for Irving, Ballard, and White Birch lakes. Although Irving and Ballard lakes have undergone significant change in their aquatic plant communities, their phosphorus concentrations have changed little.

Table 3.2-1. Diatom inferred phosphorus concentrations in core samples (µg/L). The estimated phosphorus levels in Laura Lake are not accurate (see text).

Star Top	12
Star Bottom	11
Little Star Top	31
Little Star Bottom	36
Plum Top	14
Plum Bottom	10
West Plum Top	35
West Plum Bottom	14
Laura Top	22
Laura Bottom	19
Ballard Top	10
Ballard Bottom	11
White Birch Top	10
White Birch Bottom	12
Irving Top	21
Irving Bottom	21

Summary

Star and Plum lakes have experienced the most significant change in their diatom communities when comparing present day with presettlement times. Historically these lakes were oligotrophic, meaning they had low phosphorus concentrations and very good water clarity. The macrophyte communities in these lakes was reduced and likely generally consisted low growing isoetids. As if often the case in deeper oligotrophic lakes, the species richness and diversity of the diatom community was very low in the presettlement samples but increased considerably as increased macrophyte growth provided additional niches for diatom growth. At the present time there has been a shift from a community dominated by diatoms found in the open water to one where benthic diatoms are much more important than they were 150 years ago. This type of shift typically is one of the earliest indicators of increased nutrients because of development in the lake's watershed. In the case of these lakes, this change likely occurred as the result of nutrient inputs during the logging era around the beginning of the twentieth century. There were logging towns located on the shores of both lakes. At its height, Star Lake had a lumber mill, planing operation, and over 600 residents. At the present time, the trophic status of both lakes is mesotrophic with moderately low phosphorus concentrations. Before the logging era these concentrations would have been lower. At the present time there are more macrophytes than there were historically and this likely is the result of nutrient and sediment inputs during the logging era. Shoreland development is relatively low around both of these lakes, especially compared with many other lakes in the area.

Little Star Lake has shown the least change between the bottom and top samples in the core but this may be because the sediment core was collected in an area where the sediments had previously been disturbed. At the present time this lake is classified as eutrophic with high phosphorus concentrations and poor water clarity. It would be expected that prior to the arrival of Euroamerican settlers these lakes would have possessed much better water quality.

West Plum Lake has a diatom community comprised mostly of diatoms that are attached to macrophytes or grow on the lake sediments. This is because of the lake's shallow depth. The construction of County Road N effectively reduced the interchange of water between Plum and West Plum lakes and this likely adversely affected the lake's water quality. Prior to the road being built, the diatom community possessed some planktonic diatoms that likely entered the lake from much deeper Plum Lake. With a change in the hydraulic connectiveness with Plum Lake, more nutrients were retained in this shallow lake and phosphorus levels increased. West Plum Lake is the only lake of the four lakes in this project where the biotic integrity of the lake was significantly reduced in the top sample compared with the bottom sample. Also, this lake experienced the greatest increase in phosphorus concentration between presettlement and the present time; 14 to 35 µg/L.

Laura Lake has a diatom community composed almost entirely of diatoms which grow on the lake sediments, even though this lake is relatively deep. This indicates that the lake has excellent water clarity at the present time and historically. The dominant diatoms found in Laura Lake are often found in eutrophic lakes with substantial macrophyte communities where they grow attached to the plants. Since these diatoms can grow in a wide range of environmental conditions, the diatom community is not as informative as it is in the other project lakes. Because of the dominance by these very tolerant species, the estimated diatom biotic integrity finds the lake in poor condition and the estimated phosphorus concentrations are much higher that what has been measured in the lake. In reality, the lake has a very good biotic integrity and phosphorus concentrations at the present time are very similar to the historical levels.

The paleoecological study on Irving, Ballard, and White Birch lakes was not part of this project. These studies were done by Wisconsin DNR staff in the early 2000s. The results of these studies are described above and summarized here. Of the three lakes, White Birch Lake showed the least change. Phosphorus concentrations at the present time are similar to presettlement levels and there has only been a small increase in the macrophyte community. While Ballard Lake has not shown a significant increase in phosphorus concentrations, at the present time there are considerably more macrophytes than there were prior to the arrival of Euroamericans. This trend is not uncommon in northern Wisconsin lakes and was observed in Star and Plum lakes. Irving Lake has experienced a large change in the macrophyte community with a large increase in wild rice. At the present time, in most years the lake is completely inhabited by rice but this was not the case prior to the 1960s. Irving Lake is the only lake of the study lakes where a full core was analyzed. The bottom of the core was deposited in the early 1500s. Wild rice pollen does not show up in the lake until the 1960s. With the arrival of the rice, more sediment and phosphorus has been retained in the lake. This has not resulted in an increase in phosphorus concentrations in the lake's water column because most of the phosphorus is associated with the rice and associated attached algae.

Please note, that due to the low amount of development on the Phase III lakes, Razorback and Big Muskellunge, paleocores were not collected on these lakes.

3.3 Watershed Assessment

Watershed Modeling

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

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

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

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

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

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

A reliable and cost-efficient method of creating a general picture of a watershed's effect on a lake can be obtained through modeling. The WDNR created a useful suite of modeling tools called the Wisconsin Lake Modeling Suite (WiLMS). Certain morphological attributes of a lake and its watershed are entered into WiLMS along with the acreages of different types of land cover within the watershed to produce useful information about the lake ecosystem. This information includes an estimate of annual phosphorus load and the partitioning of those loads between the watershed's different land cover types and atmospheric fallout entering through the lake's water surface. WiLMS also calculates the lake's flushing rate and residence times using county-specific average precipitation/evaporation values or values entered by the user. Predictive models are also included within WiLMS that are valuable in validating modeled phosphorus loads to the lake in question and modeling alternate land cover scenarios within the watershed. Finally, if specific information is available, WiLMS will also estimate the significance of internal nutrient loading within a lake and the impact of shoreland septic systems.

Town of Plum Lake Project Lakes Watershed Assessment

The watershed sizes among the Town of Plum Lake project lakes range in size from 516 acres for Little Star Lake to 11,631 acres for Plum Lake (Figure 3.3-1, left frame). The watershed area to lake area ratios range from 1:1 in Big Muskellunge and Razorback lakes to 22:1 in White Birch Lake (Figure 3.3-1, right frame). The largest portion of land cover within the lakes' watersheds is forest, wetlands, and lake surface (Figure 3.3-2). Smaller portions of the watershed include areas of pasture/grass, rural residential areas (shoreland development), and row crop agriculture; however, agricultural land was only present in the Plum Lake watershed. The high proportion of natural land cover types within these watersheds results in minimal amounts of phosphorus being delivered to these lakes and with the exception of Little Star Lake, is the primary reason for the high-grade water quality found in these lakes. Maintaining these minimally-developed watersheds is essential for maintaining the excellent water quality currently found in these waterbodies.

Watershed modeling indicated that the estimated annual phosphorus loading delivered to these lakes varied, ranging from 71 pounds per year in Little Star Lake to 984 pounds per year in Plum Lake (Figure 3.3-3, left frame). However, as discussed, lake size and volume also have to be taken into consideration when discussing phosphorus loading. Using the estimated annual phosphorus loads and the volume of each lake, the annual phosphorus load per acre-foot of lake was calculated (Figure 3.3-3, right frame). This analysis shows, for example, that while Plum Lake receives an estimated 913 pounds more phosphorus per year than Little Star Lake, the phosphorus loading relative to lake volume is much lower in Plum Lake than in Little Star Lake and the phosphorus concentration within Plum Lake would be expected to be lower than in Little Star Lake. Annual phosphorus loading per acre-foot ranged from 0.01 pounds/acre-foot/year in Big Muskellunge Lake to 0.53 pounds/acre-foot/year in West Plum Lake. The watershed analysis results for each of the lakes can be found in Appendix D.

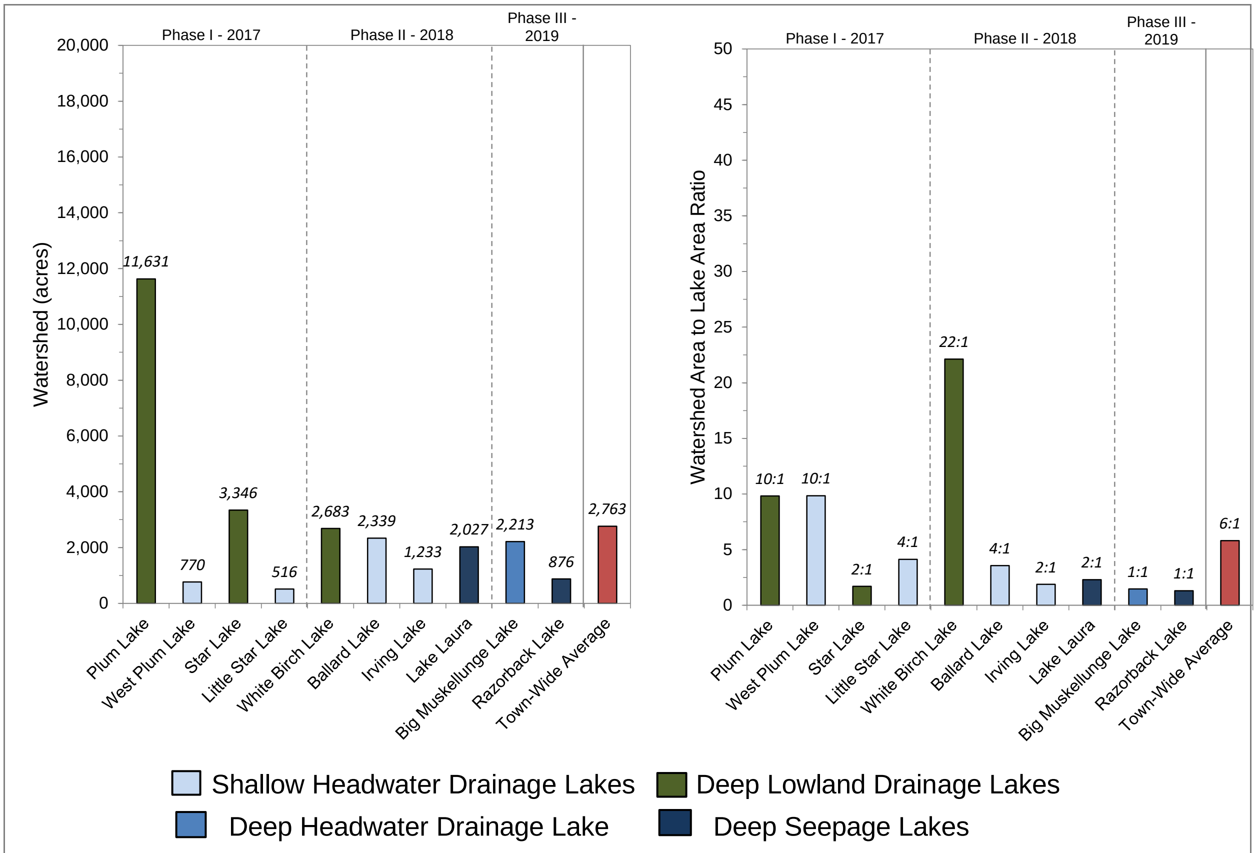


Figure 3.3-1. Town of Plum Lake project lakes watershed size (left) and watershed to lake area ratios (right). Maps displaying watershed boundaries can be found within the individual lake report sections.

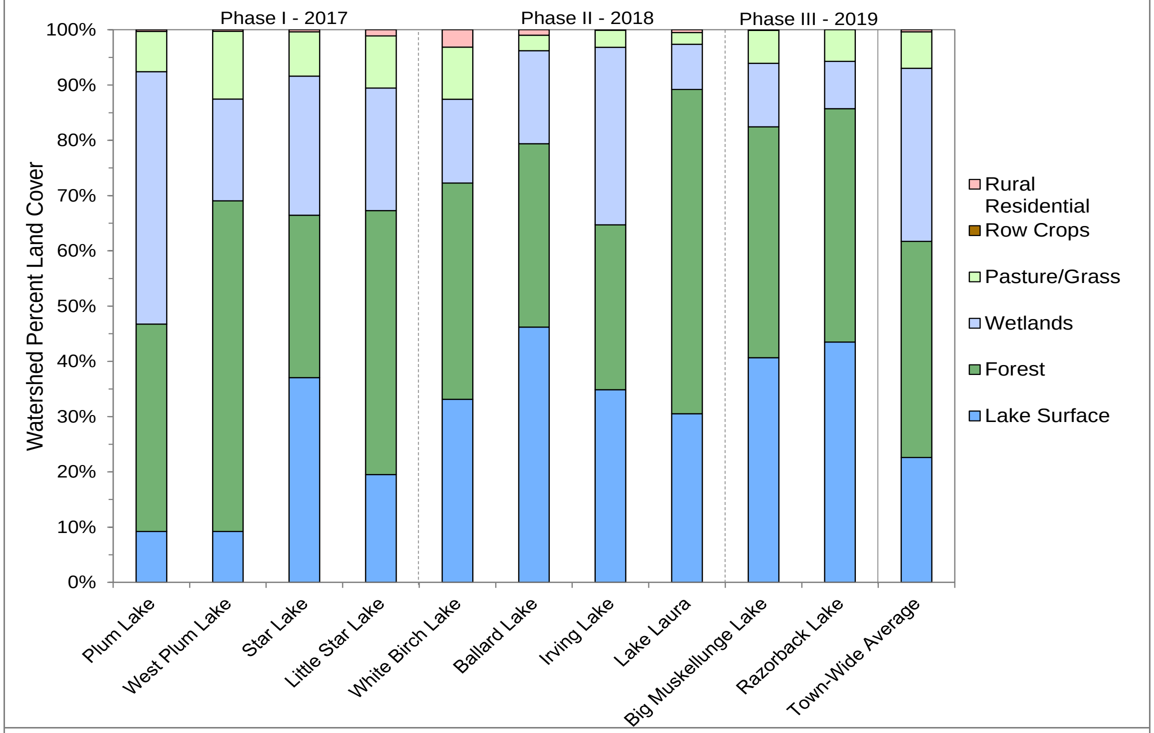


Figure 3.3-2. Town of Plum Lake project lakes watershed land cover composition. Maps displaying watershed boundaries can be found within the individual lake report sections.

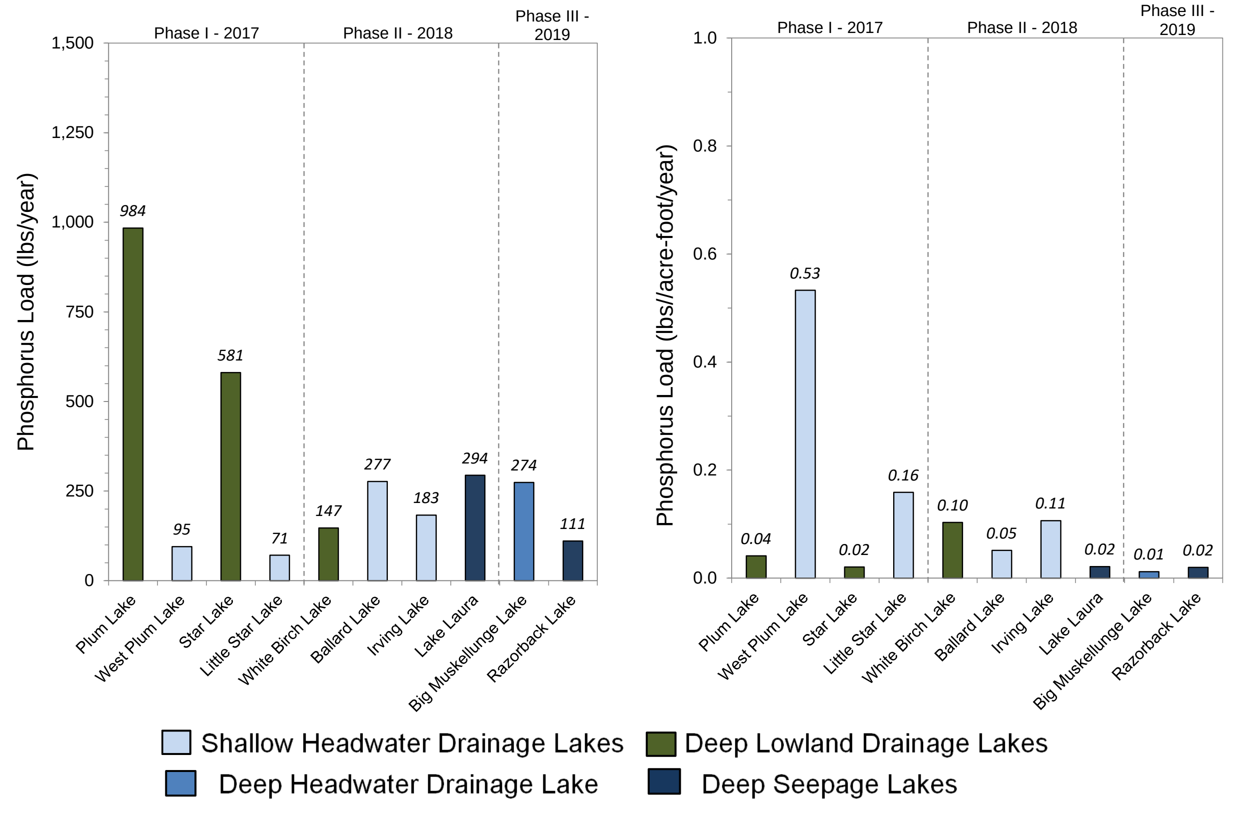


Figure 3.3-3. Town of Plum Lake project lakes WiLMS estimated annual phosphorus loading in pounds (right) and calculated annual phosphorus loading in pounds/acre-feet/year. Maps displaying watershed boundaries can be found within the individual lake report sections.

In addition to estimating the annual amount of phosphorus delivered to each lake, WiLMS also provides a predicted growing season total phosphorus concentration for each lake. The predicted phosphorus concentrations are compared against measured concentrations collected from each lake. If the measured phosphorus concentrations are higher than the model predictions, it is an indication that phosphorus may be entering the lake from a source that was unaccounted for within the model. If the measured and predicted phosphorus concentrations are relatively similar, it is an indication that the watershed was modeled accurately and there are likely no significant sources of unaccounted phosphorus entering the lake.

Figure 3.3-4 displays the measured growing season (April-October) near-surface total phosphorus concentrations compared to WiLMS predicted concentrations from the Town of Plum Lake project lakes. The measured and predicted phosphorus concentrations were relatively similar for Plum and West Plum Lakes. Measured total phosphorus concentrations in Star Lake were approximately 33% lower than the predicted concentration and measured total phosphorus concentrations in Little Star Lake were approximately 66% higher than the concentration predicted by WiLMS. In Phase II, the measured growing season mean total phosphorus for Irving, Ballard, White Birch, and Laura lakes was lower than predicted by 16%, 24%, 14%, and 43%, respectively. Both Phase III lakes also had lower actual measured phosphorus than predicted, with Big Muskellunge being overpredicted by 29% and Razorback Lake by 39%.

As mentioned within the Lake Water Quality Section (section 3.1), when measured phosphorus concentrations are higher than predicted in a lake which has a watershed largely comprised of natural land cover, internal nutrient loading is often the source of the unaccounted phosphorus. Internal nutrient loading involves the release of phosphorus (and other nutrients) from anoxic bottom sediments into the overlying water. This analysis indicates that Little Star Lake is the only one of the project lakes that experiences significant internal loading.

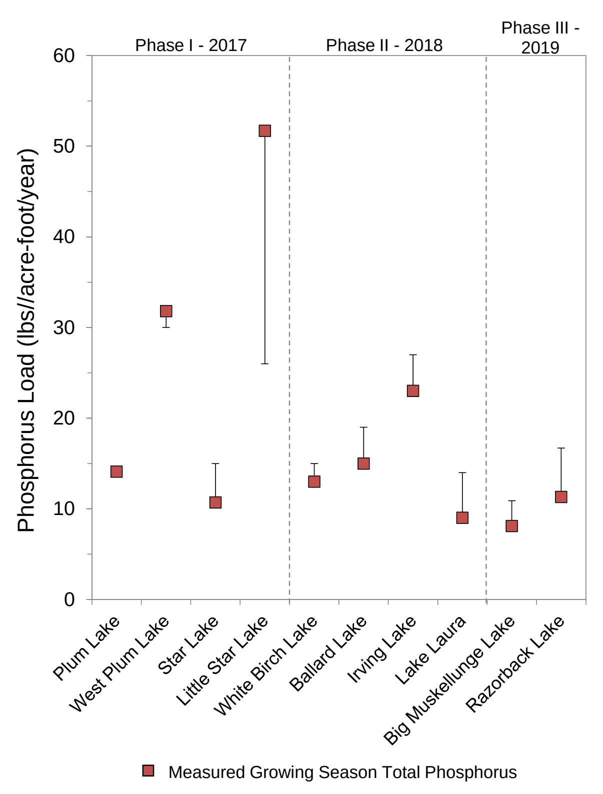


Figure 3.3-4. Town of Plum Lake project lakes measured versus WiLMS-predicted growing season total phosphorus concentrations. Error bar represents WiLMS-predicted concentration.

As noted in the trophic state index discussion in the Lake Water Quality Section (3.1), the trophic condition of Little Star Lake is much worse than the other lakes and worse than most other lakes in the Northern Lakes and Forests Ecoregion. It is likely the elevated phosphorus concentrations are a legacy of the logging era around the beginning of the twentieth century. An aerial photograph from 1937 shows that at that time the lake had high algal levels. Little Star Lake may have been the recipient of pollution from the town of Star Lake as well as lumbering operations. Because the lake is shallow, the phosphorus that entered Little Star Lake during the logging era moves from the sediments to the surface waters during the summer.

The potential impact of septic systems on phosphorus loading to these lakes was also estimated using data collected from the Phase I and II stakeholder survey. These data indicate that phosphorus originating from septic systems around the Phase I and II Town of Plum Lake project lakes is negligible. Please see the individual lake report sections to see estimated phosphorus loading from shoreline septic systems for each lake. Overall, the watersheds for the Town of Plum Lake project lakes are in excellent shape being primarily comprised of intact, natural land cover types. These natural land cover types decrease soil erosion and nutrient runoff into these lakes and maintain their good water quality.

3.4 Shoreland Condition

Lake Shoreland Zone and its Importance

One of the most vulnerable areas of a lake's watershed is the immediate shoreland zone (approximately from the water's edge to at least 35 feet 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 swimmer's 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 swimmer's 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 more strict 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. Ground-water inputs to the lake were found to be significant in terms of water flow and nutrient input. Nitrate plus nitrite nitrogen and total phosphorus yields to the ground-water system from a lawn catchment were three or sometimes four times greater than those from wooded catchments.

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

Shorelands provide much in terms of nutrient retention and mitigation, but also play an important role in wildlife habitat. Woodford and Meyer (2003) found that green frog density was negatively correlated with development density in Wisconsin lakes. As development increased, the habitat for green frogs decreased and thus populations became significantly lower. 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 3.4-1. 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 in many macroinvertebrates found in these areas, who themselves are feeding upon algae and periphyton growing on the wood surface. Newbrey et al. (2005) found that some fish species prefer different complexity of branching on coarse woody habitat, though in general some degree of branching is preferred over coarse woody habitat that has no branching.

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

National Lakes Assessment

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

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

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

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

Native Species Enhancement

The development of Wisconsin's shorelands has increased dramatically over the last century and with this increase in development a decrease in water quality and wildlife habitat has occurred. Many people that move to or build in shoreland areas attempt to replicate the suburban landscapes they are accustomed to by converting natural shoreland areas to the "neat and clean" appearance of manicured lawns and flowerbeds. The conversion of these areas immediately leads to destruction of habitat utilized by birds, mammals, reptiles, amphibians, and insects (Jennings et al. 2003). The maintenance of the newly created area helps to decrease water quality by considerably increasing inputs of phosphorus and sediments into the lake. The negative impact of human development does not stop at the shoreland. Removal of native plants and dead, fallen timbers from shallow, near-shore areas for boating and swimming activities destroys habitat used by fish, mammals, birds, insects, and amphibians, while leaving bottom and shoreland sediments vulnerable to wave action caused by boating and wind (Jennings et al. 2003, Radomski and Goeman 2001, and Elias & 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 3.4-2. Example of a biolog restoration site.

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

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

Wisconsin's Healthy Lakes & Rivers Action Plan

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

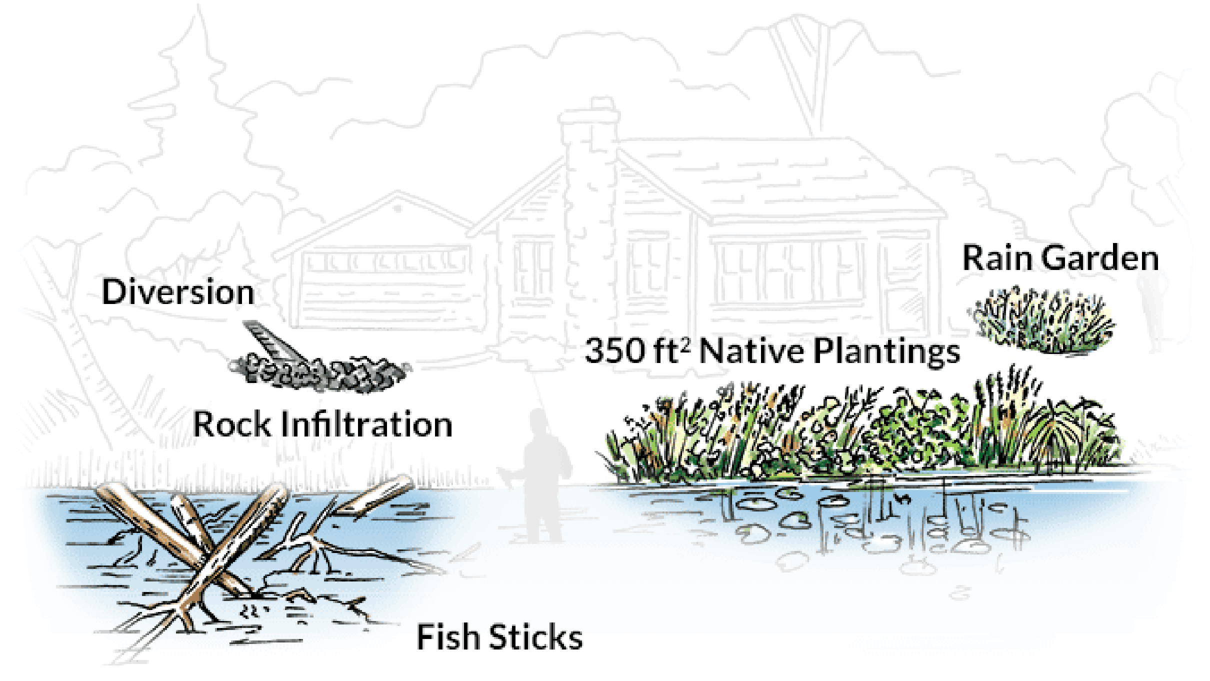


Figure 3.3-1. Healthy Lakes & Rivers 5 Best Practices. Illustration by Karen Engelbretson, extracted from healthylakeswi.com.

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

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

https://healthylakeswi.com/

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

Plum Lake Town Lakes Shoreland Zone Condition

Shoreland Development

The Town of Plum Lake project lakes were surveyed as a part of this project to determine the extent of their degree of development. Lakes were visited during each appropriate phase, generally during the fall to conduct this survey.

A lake’s shoreland zone can be classified in terms of its 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 3.4-1 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 3.4-1. Shoreland assessment category descriptions.

On each Town of Plum Lake project lakes, the development stage of the entire shoreland was surveyed during field studies, 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 3.4-1.

The Town of Plum Lake project lakes have stretches of shoreland that fit all of the five shoreland assessment categories. Of the four lakes surveyed in Phase I, approximately 84% (24.8 miles) of the shoreline is comprised of natural/undeveloped and developed-natural shorelines (Figure 3.4-2). Of the four lakes surveyed in Phase II, approximately 91% (16.4 miles) of the shoreline is comprised of natural/undeveloped and developed-natural shorelines (Figure 3.4-2). Of the two lakes surveyed in Phase III, approximately 92% (15.3 miles) of the shoreline contains natural/undeveloped and developed-natural shorelines. These shoreland types provide the most benefit to the lakes and should be left in their natural state if at all possible. Approximately 6% (1.8 miles) of the shorelines surveyed during Phase I are comprised of urbanized and developed-unnatural shorelines. Approximately 6% (1.1 miles) of these same shoreland types were observed during the Phase II surveys, and approximately 4% (0.7 mile) of these shoreland types were recorded during Phase III surveys. If restoration of the Town of Plum Lake project lakes shoreland is to occur, primary focus should be placed on these shoreland areas as they currently provide little benefit to the lake ecosystem. Figure 3.4-2 provides a breakdown of each of the project lakes' shoreland condition, while each individual lake section discusses the shoreline condition further. Maps of each lake and the location of these categorized shorelands are included within each individual lake section as well.

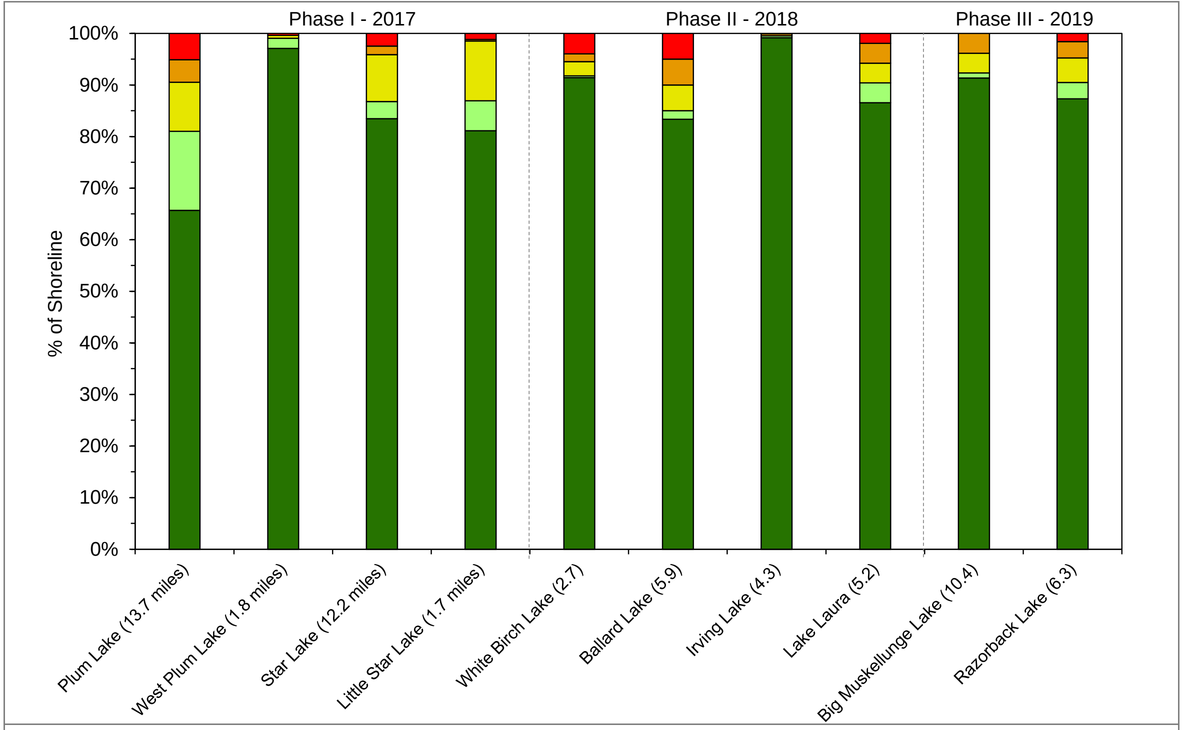


Figure 3.4-2. Town of Plum Lake project lakes shoreland categories and total lengths. Maps displaying the locations of these categorized shorelands can be found in the individual report sections.

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, unsloped 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. Allowing tree falls and other natural habitat features to remain along a shoreline may result not only in reducing shoreline erosion, but also creates wildlife habitat

Coarse Woody Habitat

Surveys for coarse woody habitat were conducted in conjunction with the shoreland assessment (development) surveys on the Town of Plum Lake project lakes. Coarse woody habitat was identified and classified in two size categories (2-8 inches diameter, >8 inches diameter) 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).

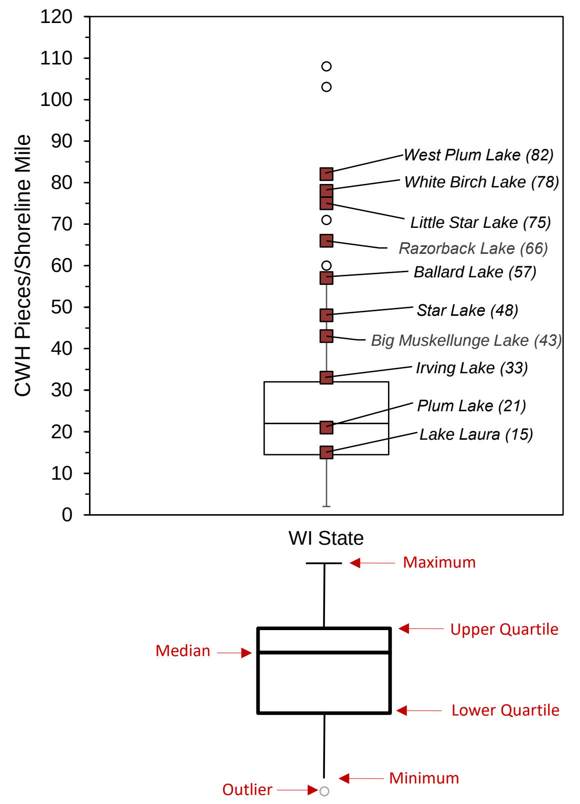


Figure 3.4-3. Town of Plum Lake project lakes total number of coarse woody habitat (CWH) pieces per shoreline mile. Created using data from Fall 2017, 2018, and 2019 (Phase I, II, and III) surveys.

Onterra has completed coarse woody habitat surveys on 75 lakes throughout Wisconsin since 2012. Figure 3.4-3 displays the number of coarse woody habitat pieces per shoreline mile from the Town of Plum Lake project lakes and how they compare with data from the 75 lakes surveyed and Figure 3.4-4 displays the number of coarse woody habitat pieces mapped on the Town of Plum Lake project lakes. The number of coarse woody habitat pieces per shoreline mile ranged from 15 in Lake Laura to 82 in West Plum Lake (Figure 3.4-4). The number of coarse woody habitat pieces per shoreline mile in all project lakes falls above the 75th percentile except for in Plum Lake and Lake Laura which are ranked in the 47th and 26th percentile, respectively.

The individual lake reports discuss the composition of the coarse woody habitat in terms of the size and branching. Refraining from removing woody habitat from the shoreland area will ensure this high-quality habitat remains in these lakes. Maps displaying the locations of the coarse woody habitat pieces located during the surveys on each lake can be found within the individual lake report sections.

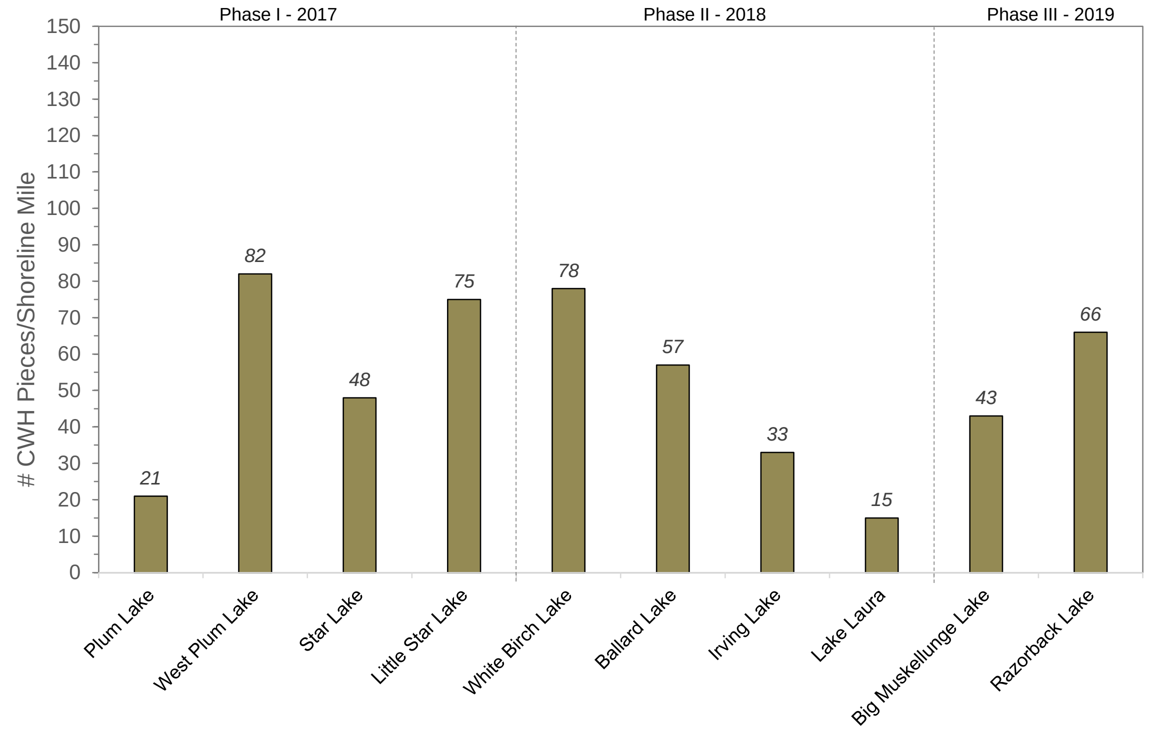
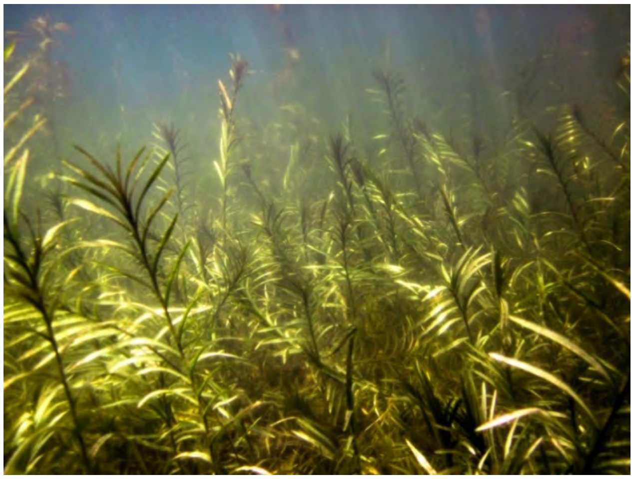


Figure 3.4-4. Town of Plum Lake project lakes coarse woody habitat survey results. Created using data from Fall 2017-2019 (Phase I - III) surveys.

3.5 Aquatic Plants

Introduction



Photograph 3.5-1. Native aquatic plant community. Fern pondweed (*Potamogeton robbinsii*). Photo credit Onterra.

Although the occasional lake user considers aquatic plants (macrophytes) to be weeds and are often considered as a nuisance to the recreational use of the lake, these plants are an essential element in a healthy and functioning lake ecosystem (Photograph 3.5-1). 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.

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 sago pondweed (*Stuckenia pectinata*) 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.

Aquatic 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 bottom 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 nutrient levels that may lead to phytoplankton blooms. Lake plants also produce oxygen through photosynthesis and use nutrients that may otherwise be used by phytoplankton, which helps to minimize nuisance phytoplankton blooms.

Because most aquatic plants are rooted in place and are unable to relocate in the wake of environmental change, they are often the first aquatic community to indicate that changes may be occurring within the system. For this reason, aquatic plants are used as indicators of environmental health. Aquatic plant communities can respond in variety of ways; there may be increases or reductions in the occurrence of sensitive species, or a complete loss. Or, certain growth forms, such as emergent and floating-leaf communities may disappear from certain areas of the waterbody. With periodic monitoring and proper analysis, these changes are relatively easy to detect and provide relevant information for making management decisions.

Under certain conditions, a few species may grow to levels which can interfere with the use of the lake. 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 and curly-leaf pondweed can also upset the delicate balance of a lake ecosystem by out competing native plants and reducing species diversity. These invasive plant species can form dense stands that are a nuisance to humans and provide low-value habitat for fish and other wildlife.

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

Aquatic Plant Management and Protection

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

Many times, an aquatic plant management plan is aimed at only controlling nuisance plant growth that has limited the recreational use of the lake, usually navigation, fishing, and swimming. It is important to remember the vital benefits that native aquatic plants provide to lake users and the lake ecosystem, as described above. Therefore, all aquatic plant management plans also need to address the enhancement and protection of the aquatic plant community.

Below are general descriptions of the many techniques that can be utilized to control and enhance aquatic plants. Each alternative has benefits and limitations that are explained in its description. Please note that only legal and commonly used methods are included. For instance, the herbivorous grass carp (*Ctenopharyngodon idella*) is illegal in Wisconsin and rotovation, a process by which the lake bottom is tilled, is not a commonly accepted practice. Unfortunately, there are no silver bullets that can completely cure all aquatic plant problems, which makes planning a crucial step in any aquatic plant management activity. Many of the plant management and protection techniques commonly used in Wisconsin are described below.

Permits

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

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

Manual Removal

Native aquatic plants are an essential component of aquatic environments as they provide valuable habitat, improve water quality, and prevent the establishment of non-native species. Because of this, maintaining a healthy native aquatic plant community should be the priority of every lake riparian property owner. While the control of native aquatic plants is generally not recommended for the reasons previously discussed, riparian property owners can manually remove native aquatic plants in areas around their dock and/or swim area without a permit with certain restrictions (see below). If a riparian property owner feels the need to manually remove aquatic plants around their dock or within a swim area, it is strongly recommended that they first get in touch with local WDNR staff. These professionals will be able to help identify if the plants are native or non-native, determine if any native plants present are Natural Heritage Inventory-listed species (e.g. endangered or threatened), and determine the most environmentally-sound manual removal methods that could be employed.

Photograph 3.5-2. Example of aquatic plants that have been removed manually.

Manual methods for aquatic plant removal 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. 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. Wisconsin law states that all plants and plant fragments removed via manual techniques must be removed from the water (Photograph 3.5-2).

Manual removal of aquatic plants can only occur within a 30-foot wide area that extends directly out from a use area which contains a dock or swim area. However, non-native species can manually be removed from any area outside of the 30-foot wide zone as long as the manual technique does not remove native species. Wild rice has special protections and may not be manually removed without a permit, even if it occurs within the 30-foot wide manual removal zone.

Cost
Commercially available hand-cutters and rakes range in cost from $85 to $150.

Advantages	***Disadvantages***
• Very cost effective for clearing areas around docks, piers, and swimming areas. • 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 removal 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

Aquatic plant harvesting is frequently used in Wisconsin and involves the cutting and removal of plants much like mowing and bagging a lawn (Photograph 3.5-3). 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

Photograph 3.5-3. Aquatic plant mechanical harvester.

and/or the lake is large, a transport barge may be needed to move the harvested plants from the harvester to the shore in order to cut back on the time that the harvester spends traveling to the shore conveyor. Some lake organizations contract to have nuisance plants harvested, while others choose to purchase their own equipment. If the latter route is chosen, it is especially important for the lake group to be very organized and realize that there is a great deal of work and expense involved with the purchase, operation, maintenance, and storage of an aquatic plant harvester. In either case, planning is very important to minimize environmental effects and maximize benefits.

Cost

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

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

Herbicide Treatment

The use of herbicides to control aquatic plants and algae is a technique that is widely used by lake managers (Photograph 3.5-4). 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.

Photograph 3.5-4. Granular herbicide application.

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 fishkills 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

Primer on Data Analysis & Data Interpretation

Three aquatic plant surveys were completed by Onterra on each of the project lakes during their respective phase. The first, the Early-Season Aquatic Invasive Species (ESAIS) Survey, is a meander-based survey completed in June. The primary goal of this survey is to detect potential occurrences of non-native plants, primarily curly-leaf pondweed and pale-yellow iris. Curly-leaf pondweed reaches its peak growth in June before naturally dying back by July, while pale-yellow iris reaches peak bloom in June making it easier to locate. The second survey completed was the whole-lake point-intercept survey, a quantitative survey designed to determine the frequency of occurrence of each plant species, both native and non-native, within the lake. The final survey completed was an Emergent and Floating-leaf Aquatic Plant Community Mapping Survey focused upon mapping areas of emergent and floating-leaf aquatic plants in each lake.

A specimen representing each aquatic plant species located from each lake was collected, pressed, and sent to the University of Wisconsin-Stevens Point Herbarium. The correct identification of these plants was confirmed by Dr. Robert Freckmann. The point-intercept survey method as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) was used to complete the whole-lake point-intercept surveys on the Town of Plum Lake project lakes. The sampling location spacing (resolution) and resulting total number of locations varied by lake and were created based upon guidance from the WDNR (Table 3.5-1).

Table 3.5-1. Resolution and number of point-intercept sampling locations used on the Town of Plum Lake project lakes.

Project Phase	Lake	Sample Location Resolution (m)	Number of Sampling Locations
Phase I	Plum Lake	63	1078
	West Plum Lake	37	205
	Star Lake	65	1184
	Little Star Lake	45	186
Phase II	White Birch Lake	34	394
	Ballard Lake	57	626
	Irving Lake	68	364
	Lake Laura	67	562
Phase III	Big Muskellunge Lake	57	1109
	Razorback Lake	51	587

At each point-intercept location within the *littoral zone*, information regarding the depth, substrate type (soft sediments, sand, or rock/gravel), and the plant species sampled along with their relative abundance (Figure 3.5-1) on the sampling rake was recorded. A pole-mounted rake was used to collect the plant samples, depth, and sediment information at point locations of 15 feet or less. A rake head tied to a rope (rope rake) was used at sites greater than 15 feet. Depth information was collected using graduated marks on the pole of the rake or using an onboard sonar unit at depths greater than 15 feet. Also, when a rope rake was used, information regarding substrate type was not collected due to the inability of the sampler to accurately feel the bottom with this sampling device. The point-intercept survey produces a great deal of information about a lake's aquatic vegetation and overall health. These data are analyzed and presented in numerous ways; each is discussed in more detail in the following section.

The **Littoral Zone** is the area of the lake where sunlight is able to penetrate to the sediment providing aquatic plants with sufficient light to carry out photosynthesis.

Figure 3.5-1. Aquatic plant rake fullness ratings. Adapted from Hauxwell et al (2010).

Species List

The species list is simply a list of all of the species, both native and non-native, that were located during the surveys completed on the Town of Plum Lake project lakes. 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 surveys completed on the Town of Plum Lake project lakes, plant samples were collected from plots laid out on a grid that covered the lake (point-intercept survey). 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 each lake to be compared to other lakes within the region and state.

FQI = Average Coefficient of Conservatism * √ Number of Native Species

Species Diversity

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

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

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

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

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index values from the Town of Plum Lake project lakes are compared to data collected by Onterra and the WDNR Science Services on 212 lakes within the Northern Lakes and Forests ecoregion and on 392 lakes throughout Wisconsin. Comparisons are displayed in the individual lake report sections using *boxplots* that display median values and upper/lower quartiles of lakes in the same ecoregion and in the state.

Box Plot or box-and-whisker diagram graphically shows data through five-number summaries: minimum, lower quartile, median, upper quartile, and maximum. Just as the median divides the data into upper and lower halves, quartiles further divide the data by calculating the median of each half of the dataset.

Emergent and Floating-leaf Community Mapping

A key component of the aquatic plant surveys 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 and watershield. Submersed aquatic plants species are often mixed throughout large areas of the lake and are often not visible from the surface, and therefore do not lend themselves well to mapping. However, the point-intercept survey allows for a general understanding of the distribution of submersed species within each lake.

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 3.5-2). 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 cool and the majority of native plants are still dormant, and 2) in some instances once its stems reach the water surface, it does not stop growing like most native plants and instead 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.

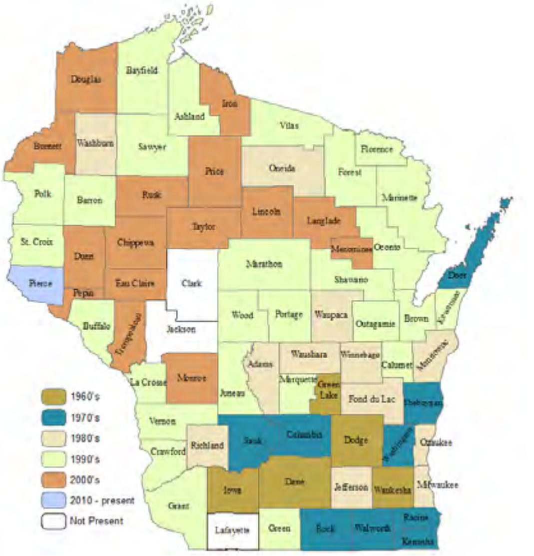


Figure 3.5-2. Spread of Eurasian watermilfoil within WI counties. WDNR Data mapped by Onterra (2011).

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 phytoplankton blooms spurred from the nutrients released during the plant's decomposition.

Aquatic Plant Survey Results

Within the Town of Plum Lake project lakes that have been studied, a total of 105 aquatic plant species representing 26 families have been documented and collected by Onterra staff and verified by the UW-Stevens Point Herbarium (Table 3.5-2 and Table 3.5-3). Thirty-seven of these plant species (36%) belong to two families: *Potamogetonaceae* (the pondweeds) and *Cyperaceae* (the sedges). Seven plant species were located in all 10 project lakes and include spatterdock, white water lily, muskgrasses, common waterweed, slender naiad, fern-leaf pondweed, and wild celery. Growth forms include 42 submergent species, 42 emergent species, seven floating-leaf species, six submergent/emergent species, two floating-leaf/emergent species, and six free-floating species. The number of native aquatic plant species ranged from 46 in Irving and Razorback lakes down to 18 in Little Star Lake, with an average of 39 native species per lake. Of the 105 species located to date, five species are considered to be a non-native, invasive species: pale-yellow iris (Plum Lake, West Plum Lake, and Star Lake), purple loosestrife (Star Lake, Big Muskellunge Lake), narrow-leaved cattail (West Plum Lake, Big Muskellunge Lake, Razorback Lake), reed canary grass (Razorback Lake) and Eurasian watermilfoil (Little Star Lake). Because of their importance, the non-native, invasive plants are discussed in detail in the subsequent Non-Native Aquatic Plants Subsection.

Vasey's pondweed, located during these studies, is listed as special concern by the WDNR Natural Heritage Inventory (NHI) Program due to "a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors" (Wisconsin Natural Heritage Program 2016). Vasey's pondweed was located in Plum Lake, Little Star Lake, Ballard Lake, and Razorback Lake (Photograph 3.5-5). This plant requires high-quality conditions to survive, and its presence in these lakes is indicative of environments with minimal disturbance.


Photograph 3.5-5. Flowers and floating-leaves of Vasey's pondweed. Photo credit Onterra.

Northeastern bladderwort (*Utricularia resupinata*) is also listed by the WDNR's NHI Program as a special concern plant in the state and has been found in White Birch Lake and Ballard Lake (Photograph 3.5-6). Northeastern bladderwort is one of nine bladderwort species found in Wisconsin, and one of five found in the Town of Plum Lake project lakes. Bladderworts are *insectivorous,* meaning they supplement their nutrient demand by trapping and digesting small insects and crustaceans. These plants possess small sac-like bladders containing small hairs, which when touched by unsuspecting prey trigger a door on the trap to open rapidly drawing in water and the insect. Trapped within the bladder, the insect is slowly digested. Northeastern bladderwort is often difficult to locate, as the majority of the plant is buried within the substrate.


Photograph 3.5-6. Flower of Northeastern bladderwort. Photo credit Onterra.

Lakes in Wisconsin vary in their morphometry, water chemistry, water clarity, and substrate composition, and all of these factors influence aquatic plant community composition. Like terrestrial plants, aquatic plants vary in their preference for a particular substrate type; some species are usually only found growing in soft sediments, others only course substrates like sand, while some are more generalists and can be found growing in either. Lakes with varying types of substrates generally support a higher number of aquatic plant species because of the different habitat types that are available. During the whole-lake point-intercept surveys completed on the Town of Plum Lake project lakes, substrate data were also recorded at each sampling location in one of three general categories: soft sediments, sand, or rock/gravel.

Table 3.5-2. List of emergent and floating-leaf aquatic plant species located in the Town of Plum project lakes.

				2017				2018				2019	
Growth Form	Scientific Name	Common Name	Coefficient of Conservatism	Plum Lake	West Plum Lake	Star Lake	Little Star Lake	White Birch Lake	Ballard Lake	Irving Lake	Lake Laura	Big Muskellunge Lake	Razorback Lake
Emergent	*Calamagrostis canadensis*	Bluejoint grass	5								I	I	I
	Calla palustris	Water arum	9			I		I	I	I			
	Carex aquatilis	Long-bracted tussock sedge	7							I	I		I
	Carex comosa	Bristly sedge	5	I		I		I	I	I			I
	Carex crinita	Fringed sedge	6										I
	Carex hystericina	Porcupine sedge	3										I
	Carex lasiocarpa	Narrow-leaved woolly sedge	9									I	
	Carex pseudocyperus	Cypress-like sedge	8			I				I			
	Carex retrorsa	Retrorse sedge	6			I							
	Carex sp. 1 (sterile)	Sedge sp. 1 (sterile)	N/A			I		I			I		
	Carex sp. 2 (sterile)	Sedge sp. 2 (sterile)	N/A			I							
	Carex utriculata	Common yellow lake sedge	7	I						I		I	I
	Cladium mariscoides	Smooth sawgrass	N/A								I		I
	Comarum palustre	Marsh cinquefoil	N/A					I		I			
	Decodon verticillatus	Water-willow	7	I	I				I				
	Dulichium arundinaceum	Three-way sedge	9	I				I	I	I	I	I	X
	Eleocharis palustris	Creeping spikerush	6	I		I	I				X	X	X
	Equisetum fluviatile	Water horsetail	7		I	I							I
	Glyceria borealis	Northern manna grass	8								I		
	Iris pseudacorus	Pale yellow iris	Exotic	I	I	I							
	Iris sp.	Iris sp.	N/A							I			I
	Iris versicolor	Northern blue flag	5	I	I	I	I		I				I
	Juncus canadensis	Canadian rush	9			I							
	Juncus effusus	Soft rush	4	I						I		I	
	Lythrum salicaria	Purple loosestrife	Exotic			I						I	
	Phalaris arundinacea	Reed canary grass	Exotic										I
	Phragmites australis subsp. americanus	Common reed	5								I	I	I
	Pontederia cordata	Pickerelweed	9	X	X			I	I	X			
	Ranunculus flammula	Creeping spearwort	9					X	X		X	X	X
	Sagittaria latifolia	Common arrowhead	3		I	I		I	I	I		I	I
	Schoenoplectus acutus	Hardstem bulrush	5	X	X	X	I		I		I	X	
	Schoenoplectus tabernaemontani	Softstem bulrush	4								I		X
	Scirpus atrocinctus	Black-girdled wool grass	7										I
	Scirpus cyperinus	Wool grass	4	I				I		I	I	I	I
	Sparganium americanum	American bur-reed	8	I	I	I	I	I	I			I	I
	Sparganium androcladum	Shining bur-reed	8							I			I
	Sparganium eurycarpum	Common bur-reed	5	I	I								
	Typha angustifolia	Narrow-leaved cattail	Exotic		I							I	X
	Typha latifolia	Broad-leaved cattail	1									I	I
	Typha spp.	Cattail spp.	1	I		I	I	I	I	I	I		
	Zizania palustris	Northern wild rice	8							X			
	Zizania spp.	Wild rice sp.	8	X	X				I	I			
FL/E	*Sparganium emersum* var. *acaule*	Green-fruited Bur-reed	6	I									
	Sparganium sp. (sterile)	Sterile bur-reed sp.	N/A			I		I					
FL	*Brasenia schreberi*	Watershield	7	I	X			X	I	X	X	I	
	Nuphar variegata	Spatterdock	6	X	I	X	X	X	X	I	I	I	X
	Nymphaea odorata	White water lily	6	X	X	X	X	X	X	X	I	X	X
	Persicaria amphibia	Water smartweed	5	I	I					I	I	X	I
	Potamogeton natans	Floating-leaf pondweed	5					X		X		X	
	Sparganium angustifolium	Narrow-leaf bur-reed	9					I	X	I	I	I	
	Sparganium fluctuans	Floating-leaf bur-reed	10						I				

FL/E = Floating Leaf and Emergent; FL = Floating Leaf
X = Located on rake during point-intercept survey; I = Incidental Species

Table 3.5-3. List of submersed aquatic plant species located in the Town of Plum Lake project lakes.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism	2017				2018				2019	
				Plum Lake	West Plum Lake	Star Lake	Little Star Lake	White Birch Lake	Ballard Lake	Irving Lake	Lake Laura	Big Muskellunge Lake	Razorback Lake
Submergent	*Bidens beckii*	Water marigold	8	X		X				X		X	
	Ceratophyllum demersum	Coontail	3	X	I	X			X	X			
	Chara spp.	Muskgrasses	7	X	X	X	X	X	X	X	X	X	X
	Elatine minima	Waterwort	9	I								X	X
	Elodea canadensis	Common waterweed	3	X	X	X	X	X	X	X	X	X	X
	Eriocaulon aquaticum	Pipewort	9	I					X		X	X	X
	Heteranthera dubia	Water stargrass	6	X			I						
	Isoetes echinospora	Spiny-spored quillwort	8								I		
	Isoetes spp.	Quillwort spp.	8			X		X				X	
	Lobelia dortmanna	Water lobelia	10	I		I		I	X		X	I	
	Myriophyllum alterniflorum	Alternate-flowered watermilfoil	10								X		
	Myriophyllum sibiricum	Northern watermilfoil	7	X	X	X		X		X	X		
	Myriophyllum spicatum	Eurasian watermilfoil	Exotic				I						
	Myriophyllum tenellum	Dwarf watermilfoil	10	X		X		X	X		X	X	X
	Najas flexilis	Slender naiad	6	X	X	X	X	X	X	X	X	X	X
	Najas guadalupensis	Southern naiad	7					X	X				
	Najas gracillima	Northern naiad	7										X
	Nitella spp.	Stoneworts	7	X		X	X			X	X	X	X
	Potamogeton amplifolius	Large-leaf pondweed	7			X	X	X	X	X	X	X	X
	Potamogeton berchtoldii	Slender pondweed	7						X		X	X	X
	Potamogeton epihydrus	Ribbon-leaf pondweed	8			I			X	X		X	X
	Potamogeton foliosus	Leafy pondweed	6			X	X						X
	Potamogeton friesii	Fries' pondweed	8		X								
	Potamogeton gramineus	Variable-leaf pondweed	7	X		X		X	X	X	X	X	X
	Potamogeton illinoensis	Illinois pondweed	6	X				X	X				
	Potamogeton obtusifolius	Blunt-leaved pondweed	9							X			
	Potamogeton praelongus	White-stem pondweed	8	X		I		X		X	X		
	Potamogeton pusillus	Small pondweed	7	X		X		X		X			
	Potamogeton richardsonii	Clasping-leaf pondweed	5	X	X	X					X		X
	Potamogeton robbinsii	Fern-leaf pondweed	8	X	X	X	X	X	X	X	X	X	X
	Potamogeton spirillus	Spiral-fruited pondweed	8			X			X			I	I
	Potamogeton strictifolius	Stiff pondweed	8		X					X	X		
	*Potamogeton vaseyi**	Vasey's pondweed	10	X			X		X				X
	Potamogeton zosteriformis	Flat-stem pondweed	6	X	X	X	X	X	X	X			
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	N/A		X			X					I
	Stuckenia pectinata	Sago pondweed	3		I								
	Utricularia geminiscapa	Twin-stemmed bladderwort	9		X								
	Utricularia gibba	Creeping bladderwort	9							X	X		
	Utricularia intermedia	Flat-leaf bladderwort	9							X		I	
	Utricularia resupinata	Northeastern bladderwort	9					X	X				
	Utricularia vulgaris	Common bladderwort	7	X						X		X	I
	Vallisneria americana	Wild celery	6	X	X	X	X	X	X	X	X	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	5	X	I	X		X	X	X	X	X	X
	Juncus pelocarpus	Brown-fruited rush	8						X	X	X	X	X
	Sagittaria cuneata	Arum-leaved arrowhead	7								X		
	Sagittaria cristata	Crested arrowhead	9	X		X							
	Sagittaria graminea	Grass-leaved arrowhead	9			I		X	I	I		X	
	Schoenoplectus subterminalis	Water bulrush	9							X			
FF	*Lemna minor*	Lesser duckweed	5			I			X				
	Lemna trisulca	Forked duckweed	6	X	I								
	Lemna turionifera	Turion duckweed	2		I							I	
	Riccia fluitans	Slender riccia	7		I							X	
	Ricciocarpus natans	Purple-fringed riccia	N/A									I	
	Spirodela polyrhiza	Greater duckweed	5		I							I	

S/E = Submergent and Emergent; FF = Free Floating
X = Located on rake during point-intercept survey; I = Incidental Species
** = Species listed as special concern by WI Natural Heritage Inventory*

The studied lakes varied greatly in terms of their substrate composition. Figure 3.5-3 illustrates the proportion of substrate types (soft sediments, sand, and rock) as determined from the whole-lake aquatic plant point-intercept surveys. Substrate composition within littoral areas ranged from being primarily comprised of sand and rock in Plum, Star, and Big Muskellunge lakes, to littoral areas primarily comprised of soft sediments in the remainder of the project lakes. Like terrestrial plants, aquatic plants vary in their preference for a particular substrate type; some species are usually only found growing in soft sediments, others in only coarse substrates like sand, while some are generalists and can be found growing in either. Lakes with varying types of substrates generally support a higher number of aquatic plant species because of the different habitat types that are available.

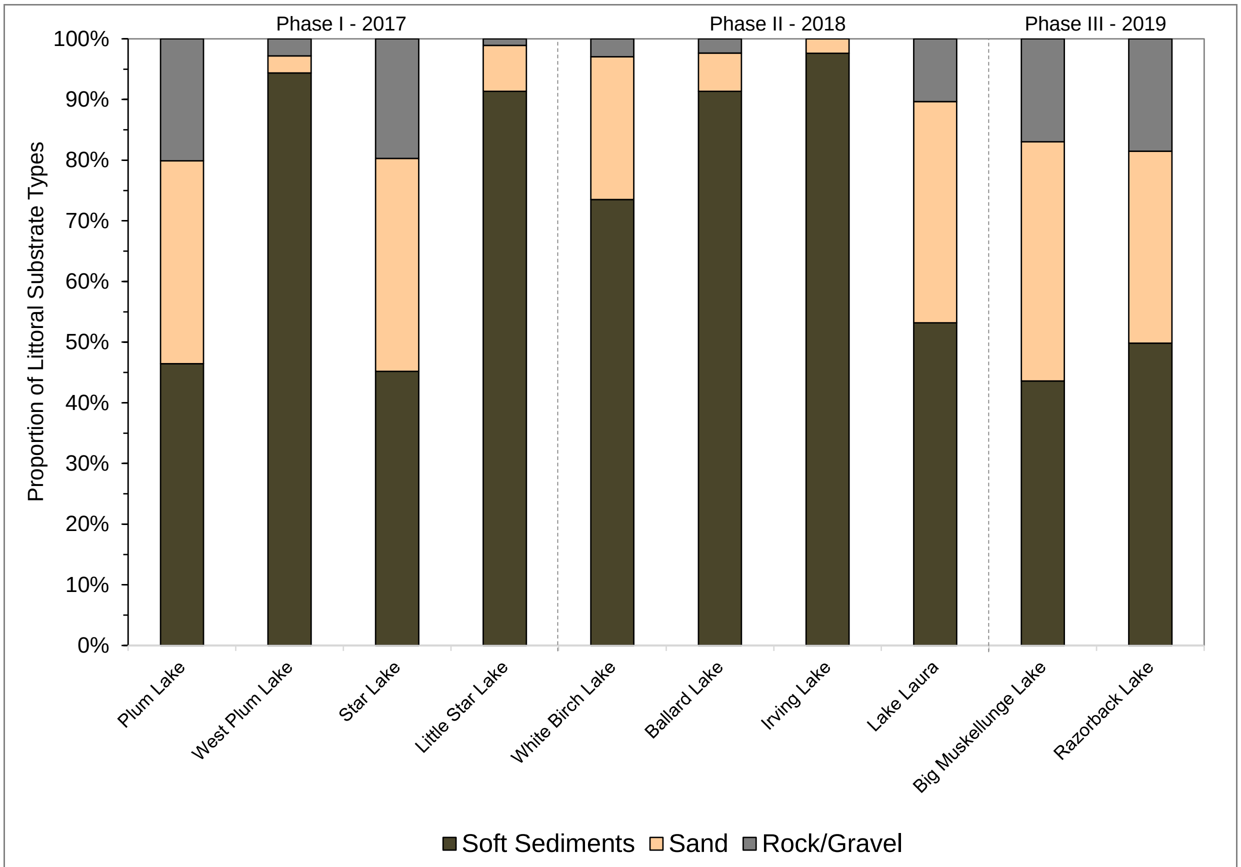


Figure 3.5-3. Town of Plum Lake project lakes proportion of substrate types. Created using data collected during the whole-lake point-intercept surveys.

The maximum depth of aquatic plant growth within the project lakes ranged from 6 feet in West Plum Lake (max depth of West Plum Lake) to 37 feet in Lake Laura. Thirty-seven feet is exceptionally deep for plants to be found growing in relation to the other project lakes and it should be noted that when excluding muskgrasses and stoneworts (not technically plants, but types of macroalgae) from the dataset for Lake Laura, the maximum depth of plants was 17 feet. Maximum depth of aquatic plant growth is generally correlated with average summer Secchi disk depth. The lakes with higher average Secchi disk depth indicating higher water clarity had aquatic plants growing deeper. Higher water clarity allows light to penetrate deeper into the water column allowing plants to grow at deeper depths. Big Muskellunge Lake has exceptional water clarity, and because of this, aquatic plants grow to deeper depths. Big Muskellunge Lake had the second deepest maximum depth of plants at 32 feet in 2019.

The littoral frequency of occurrence of aquatic vegetation in the project lakes ranged from 83% in White Birch Lake to 22% in Little Star Lake, with an average of 51% (Figure 3.5-4). The proportion of aquatic plant total rake fullness (TRF) ratings varied across the ten lakes. Of the sampling locations that contained aquatic vegetation in all of the project lakes besides Little Star, the majority had TRF ratings of 1, indicating that where plant growth occurs it is relatively sparse. In contrast, of the sampling locations that contained aquatic vegetation in Little Star Lake, the majority had a TRF rating of 3, indicating that the growth of aquatic plants in this lake is relatively dense. The substrate within littoral areas of West Plum, Little Star, White Birch, Ballard, and Irving lakes were mostly comprised of soft, organic sediments which are conducive for supporting aquatic plant growth. Roughly half of the littoral areas within Plum, Star, Lake Laura, Big Muskellunge, and Razorback lakes were comprised of sand and/or rock, which support smaller, less-dense growing plant species.

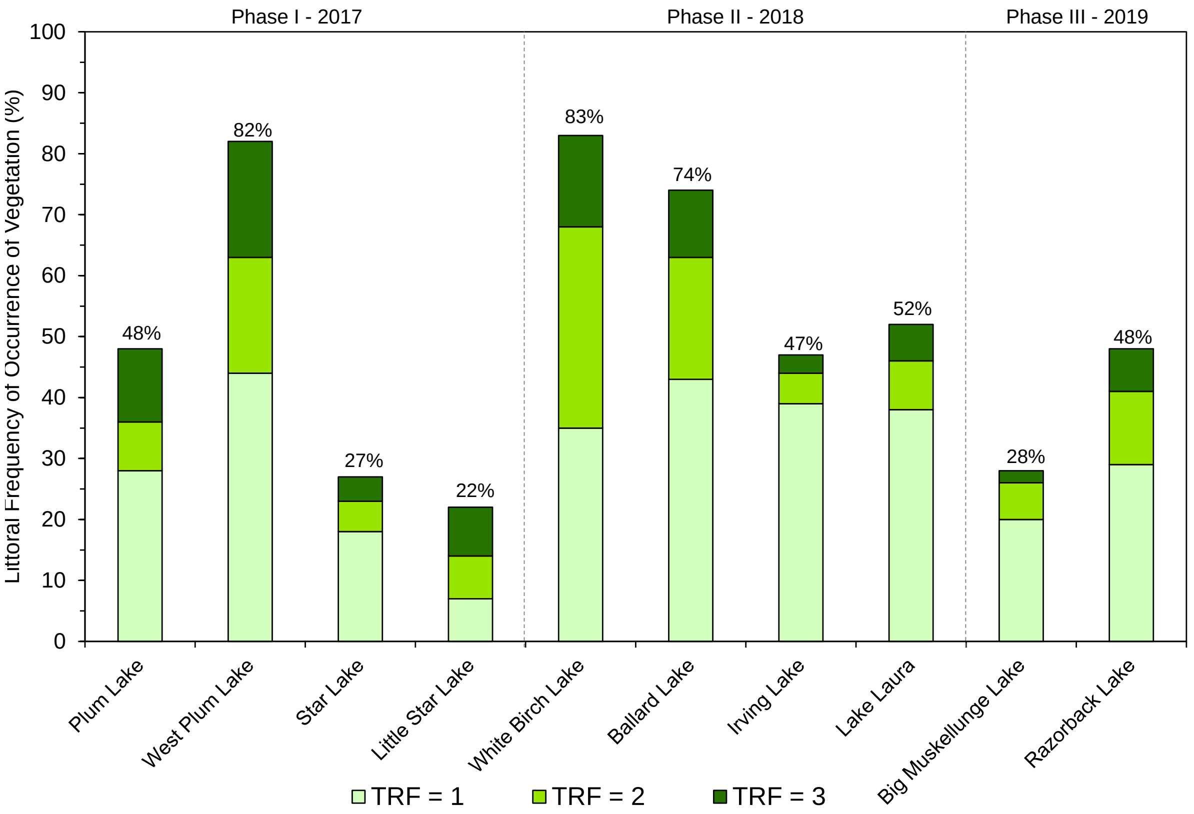


Figure 3.5-4. Town of Plum Lake project lakes littoral frequency of occurrence of aquatic vegetation and total rake fullness (TRF) ratings. Created using data collected during the whole-lake point-intercept surveys.

Of the ten Town of Plum Lake project lakes, the number of native aquatic plant species (species richness) per lake ranged from 46 in Irving and Razorback lakes to 18 in Little Star Lake with an average of 39 native species per lake (Figure 3.5-5). When comparing a lake's aquatic plant community to other lakes within the ecoregion and the state, only the native plant species that were directly encountered on the rake during the whole-lake point-intercept survey are used in the analysis. For example, while a total of 46 native aquatic plant species were located in Irving Lake in 2018, 28 were directly encountered on the rake during the point-intercept survey and 18 were located *incidentally*. An incidentally-located species means the plant was not directly sampled on the rake during the point-intercept survey at any of the sampling locations but it was observed in the lake by Onterra ecologists and was also recorded and collected. The majority of incidentally-located plants typically include emergent species growing along the lake's margins, and submersed species that are relatively rare within the lake's plant community.

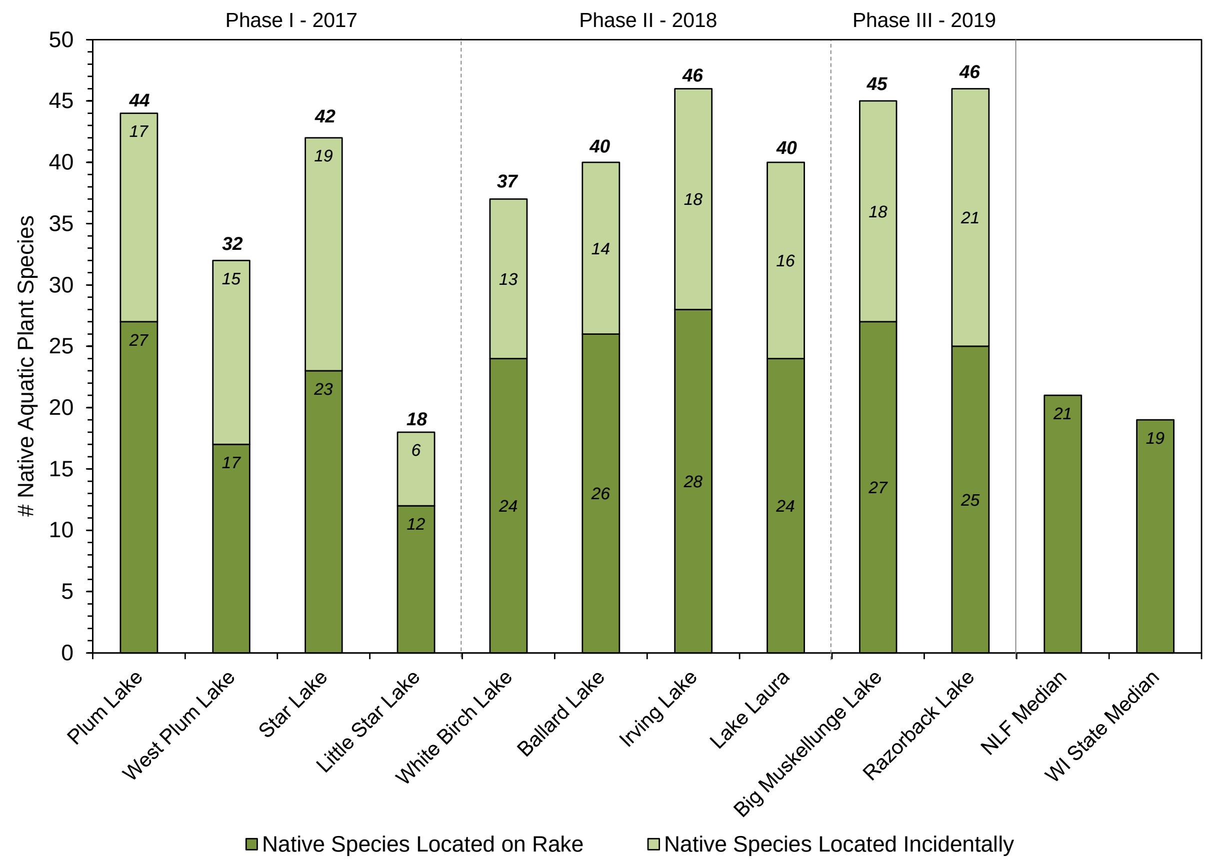


Figure 3.5-5. Town of Plum Lake project lakes native aquatic plant species richness and median species richness for Northern Lakes and Forests (NLF) ecoregion lakes and Wisconsin lakes. Includes species located on rake during point-intercept surveys and incidentally-located species.

The native aquatic plant species richness in all of the project lakes except West Plum Lake and Little Star Lake exceeded the median species richness values for lakes within the NLF ecoregion and for lakes throughout Wisconsin (Figure 3.5-5). Native aquatic plant species richness in West Plum Lake and Little Star Lake fell below the median value for lakes within the NLF ecoregion and for lakes in Wisconsin. Studies have shown that aquatic plant species richness increases with littoral area (Vestergaard and Sand-Jensen 2000).

In addition, studies have also shown that aquatic plant species richness also tends to increase with increasing *shoreline complexity* (Vestergaard and Sand-Jensen 2000). Shoreline complexity is an index that relates the area of the lake to the perimeter of its shoreline. If a lake were a perfect circle, its shoreline complexity value would be 1.0. The farther a lake deviates from a perfect circle, the higher its shoreline complexity value is. Lakes with greater shoreline complexity harbor more areas that are sheltered from wind and wave action creating additional habitat types for aquatic plants.

Figure 3.5-6 compares the average conservatism values of the native aquatic plant species located on the rake during each of the point-intercept surveys conducted on the Town of Plum Lake project lakes. All ten lakes have average conservatism values higher than 6.3 meaning they all exceed the state median conservatism value. All project lakes except Plum, Star, and Little Star lakes exceed the median conservatism value for lakes within NLF ecoregion. The average conservatism values for these lakes means they harbor a moderate to high number of aquatic plant species that are considered sensitive to environmental disturbance (higher C-values) and indicate slightly-disturbed conditions. Plum Lake matched the NLF ecoregion median conservatism value of 6.7, while Star and Little Star lakes were slightly below that.

As discussed in the primer section, the calculations used to create 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. The number of native species encountered on the rake during the whole-lake point-intercept surveys and their conservatism values were used to calculate the FQI of the Town of Plum Lake project lakes. Figure 3.5-7 displays the FQI values for the Town of Plum Lake project lakes and compares them to median values of lakes within the NLF ecoregion and lakes throughout Wisconsin. While average conservatism values were relatively similar among the project lakes, the FQI values are more variable and range from 22.5 in Little Star Lake to 37.2 in Irving Lake, with an average of 33.

The differences in FQI values among these ten lakes is largely the result of differences in native aquatic plant species richness. The FQI value for West Plum Lake falls below the median value for lakes within the ecoregion and slightly above the median for the state. Little Star Lake's FQI value falls below the median value for the NLF ecoregion as well as for the state; however, this is not an indication of a degraded aquatic plant community, but the result of the natural conditions present in this lake as discussed previously. The FQI values for the remaining lakes exceed the median values for lakes within the NLF ecoregion and lakes throughout Wisconsin.

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. If a lake has a high number of aquatic plant species, it does not necessarily mean that the lake will also have high species diversity as diversity is also influenced by how evenly the aquatic plant species are distributed within the community.

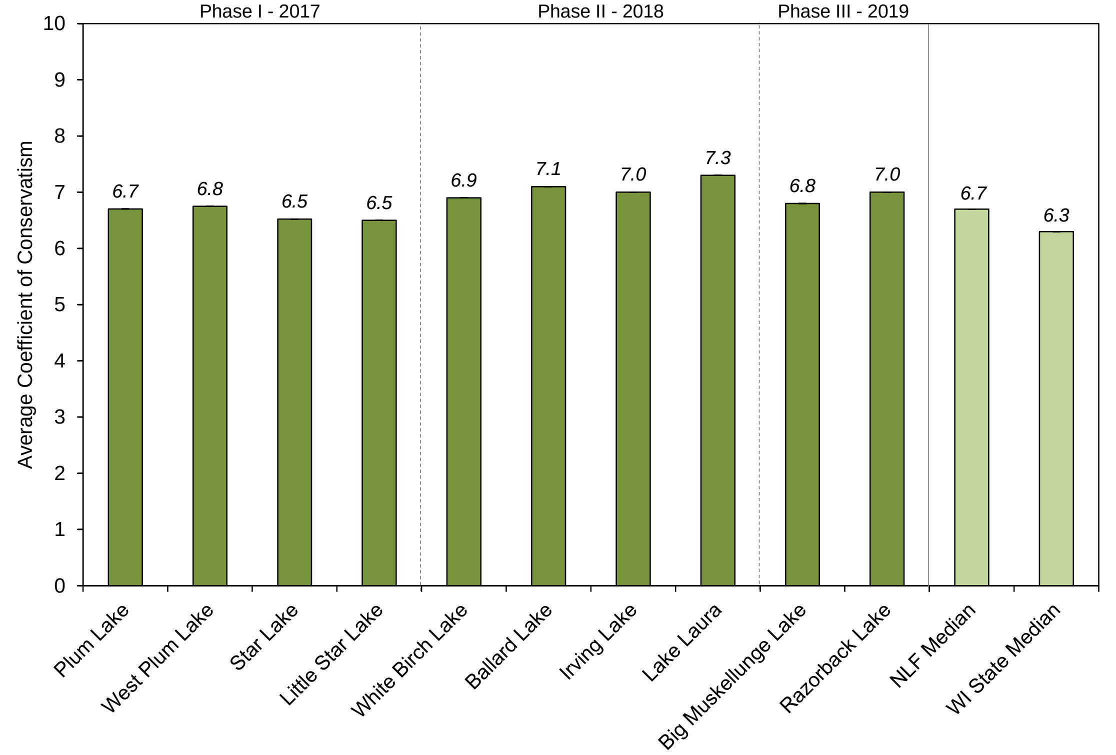


Figure 3.5-6. Town of Plum Lake project lakes native aquatic plant average coefficients of conservatism. Created using conservatism values of native aquatic plant species located on the rake during the whole-lake point-intercept surveys. Analysis follows Nichols (1999).

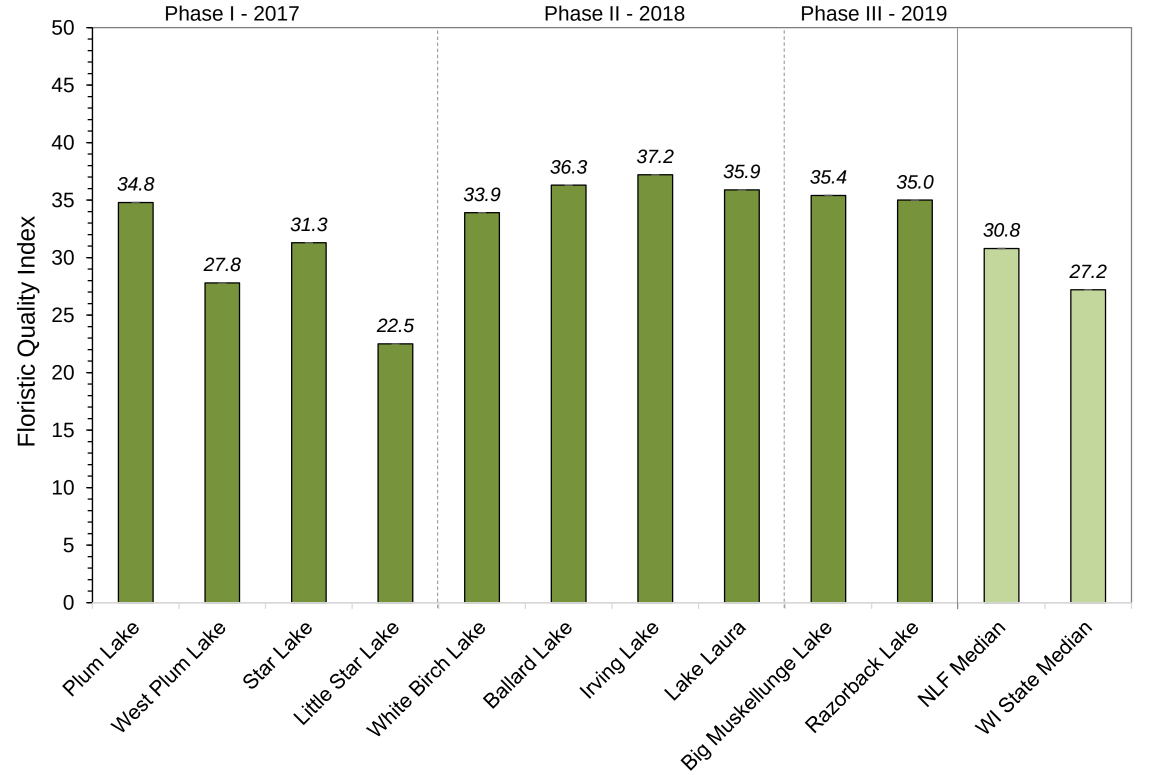


Figure 3.5-7. Town of Plum Lake project lakes Floristic Quality Index values. Created using conservatism values and number of native aquatic plant species located on the rake during the whole-lake point-intercept surveys. Analysis follows Nichols (1999).

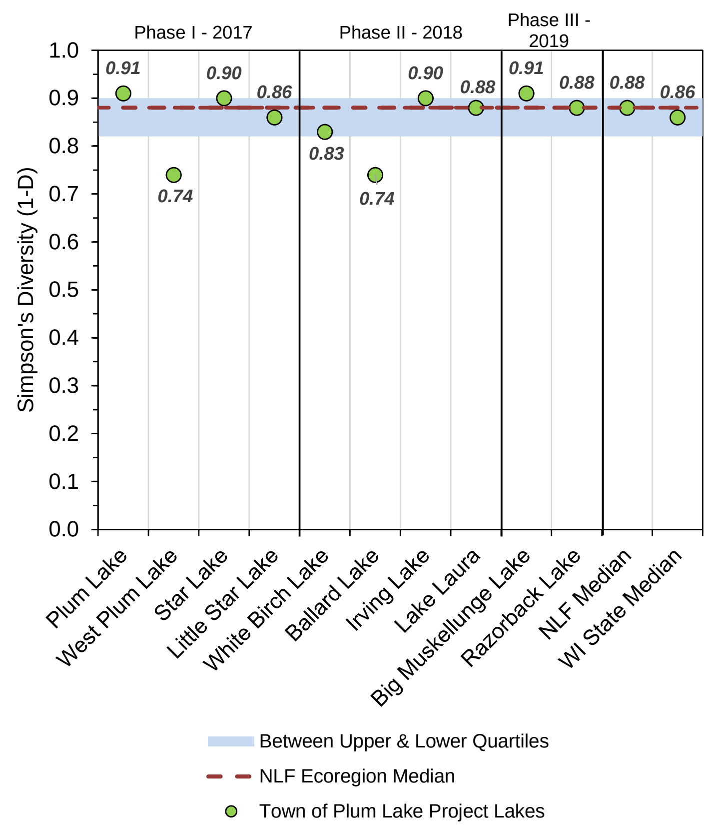


Figure 3.5-8. Town of Plum Lake project lakes Simpson's Diversity Index. Created using data collected from whole-lake point-intercept surveys. Ecoregion data calculated using Onterra and WDNR science services point-intercept survey data.

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 Town of Plum Lake project lakes' diversity values rank. Using data collected by Onterra and WDNR Science Services, quartiles were calculated for 212 lakes within the NLF Ecoregion. Simpson's Diversity Index values were calculated using data collected from the whole-lake aquatic plant point-intercept surveys. Simpson's Diversity Index values range from 0.74 in West Plum Lake and Ballard Lake to 0.91 in Plum and Big Muskellunge lakes (Figure 3.5-8). In other words, if aquatic plants were to be randomly sampled from two locations in Plum Lake, there would be a 91% probability that they would be different species. The diversity values for Plum, Star, Irving, and Big Muskellunge lakes exceed the median value for lakes within the NLF ecoregion. The diversity value of 0.88 for Lake Laura and Razorback Lake matches that of the NLF ecoregion median. The diversity values for Little Star Lake and White Birch Lake fall just slightly below the NLF ecoregion median value, and the diversity values for West Plum Lake and Ballard Lake fall well below the lower quartile for lakes within the ecoregion. Like species richness, the differences in species diversity among the Town of Plum Lake project lakes are primarily due to differences in lake morphometry, water clarity, water chemistry, and substrate composition.

The previous analyses indicate that the native plant communities of the project lakes are healthy and of high quality. The aquatic plant communities within these lakes provide essential habitat and aid in maintaining the high water quality of these lakes. An important component of a lake's aquatic plant community are the emergent and floating-leaf communities which provide valuable structural habitat and stabilize bottom and shoreland sediments. These communities are even more important during periods of lower water levels when coarse woody habitat becomes exposed above the water line. The mapping of emergent and floating-leaf aquatic plant communities in the project lakes found that the acreage of these communities range from 7.2 acres in Razorback Lake to 151.3 acres in Irving Lake, with the percentage of lake area inhabited by these communities ranging from 1% in Star Lake to 91% in West Plum Lake (Table 3.5-4). A total of 51 emergent and floating-leaf aquatic plant species were located within these ten lakes (Table 3.5-2).

Table 3.5-4. Acreage of emergent and floating-leaf aquatic plant communities in the Town of Plum Lake project lakes.

	Phase I -2017				Phase II - 2018				Phase III - 2019	
Plant Community	**Plum Lake**	**West Plum Lake**	**Star Lake**	**Little Star Lake**	**White Birch Lake**	**Ballard Lake**	**Irving Lake**	**Lake Laura**	**Big Muskellunge Lake**	**Razorback Lake**
Emergent Acres	6.1	18.7	3.5	0.0	0.4	1.7	0.2	4.1	29.4	1.4
Floating-leaf Acres	2.1	4.0	8.2	16.1	13.9	7.1	0.4	0.7	28.8	0.0
Mixed Emergent & Floating-leaf Acres	21.9	42.1	1.1	0.0	2.4	4.0	150.6	19.0	12.3	5.7
Total Acres	**30.1**	**64.8**	**12.8**	**16.1**	**16.6**	**12.9**	**151.3**	**23.7**	**70.5**	**7.2**
% Lake Area	**2.8**	**91.3**	**1.0**	**16.0**	**14.3**	**2.5**	**35.2**	**3.8**	**7.8**	**1.9**

Figure 3.5-9 illustrates the composition of emergent and floating-leaf aquatic plant communities in the Town of Plum Lake project lakes. The composition of these communities varied among lakes. Little Star Lake’s communities were comprised solely of floating-leaf plants while Plum, West Plum, Lake Laura, Irving, and Razorback lakes’ communities were primarily comprised of mixed emergent and floating-leaf plants. Star, White Birch, and Ballard lakes’ communities included all types, but the majority consisted of floating-leaf plants. Big Muskellunge Lake had the highest proportion of emergent plants compared to the other project lakes. Continuing the analogy that 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 Town of Plum Lake project 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 shorelines when compared to undeveloped shorelines 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 developed shorelines.

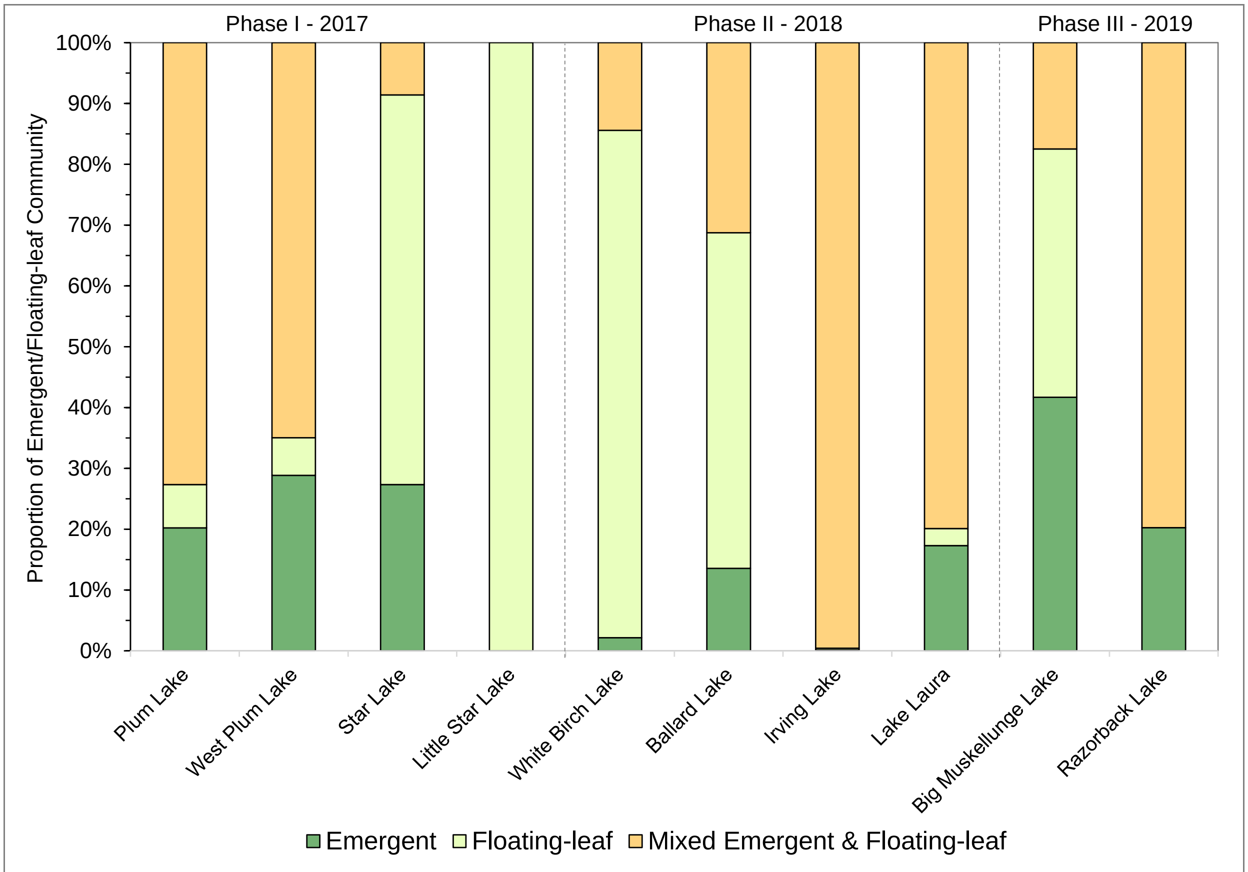


Figure 3.5-9. Town of Plum Lake project lakes emergent and floating-leaf aquatic plant community composition. Locations of these aquatic plant communities are displayed on maps within the individual lake report sections.

Non-native Aquatic Plants in the Town of Plum Lake project lakes

Eurasian watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum*; EWM; Photograph 3.5-7) is a non-native aquatic plant that has invaded over 400 waterbodies in Wisconsin. The plant may outcompete other native aquatic vegetation with its dominating, aggressive growth and reach the point where its populations form dense mats on the surface of a lake's littoral zone. These dense mats impact recreation as well as the ecology of the lake.

Photograph 3.5-7. Eurasian watermilfoil, a non-native, invasive aquatic plant. Photo credit Onterra.

Of all of the Town of Plum Lake project lakes, Eurasian watermilfoil has only been found in Little Star Lake. Eurasian watermilfoil was first discovered in Little Star Lake in an early-summer 2017 aquatic plant survey conducted by Onterra ecologists. EWM was monitored in Little Star Lake during the summer of 2018 and was found to have increased somewhat in point-based occurrences compared to 2017 despite professional hand-harvesting efforts being completed in both 2017 and 2018. Professional EWM monitoring surveys continued during 2019 and found the EWM population continued to be present in low densities in many of the same areas of the lake as in previous years. More specifics regarding the hand-harvesting that was completed on Little Star Lake can be found in the individual lake section. The Town of Plum Lake received a WDNR grant (LPL-1700-19) for the completion of Phase III of the Lake Management Plan which included funds for continued monitoring of the EWM population in Little Star Lake. The most recently completed EWM monitoring survey was completed in September 2020 and the results of the survey are displayed on Figure 3.5-10. The September 2020 EWM mapping survey showed that the EWM population in Little Star Lake continues to be present in low levels with the largest concentration of plants being located in shallow waters along the northeast side of the lake in the vicinity of the public carry-in access location.

Figure 3.5-10. Locations of EWM in Little Star Lake in Late-Summer 2020.

Pale-yellow iris

Pale yellow iris (*Iris pseudacorus*) is a large, showy iris with bright yellow flowers. Native to Europe and Asia, this species was sold commercially in the United States for ornamental use and has since escaped into Wisconsin’s wetland areas forming large monotypic colonies and displacing valuable native wetland species. Pale-yellow iris was observed growing in Plum Lake, West Plum

Lake and Star Lake. Control of pale-yellow iris on the Town of West Plum project lakes will be discussed in the Implementation Plan Section.

Narrow-leaved Cattail

Narrow-leaved cattail (*Typha angustifolia*) is a non-native wetland plant introduced to North America from Europe and is widespread throughout wetland areas across Wisconsin. Like other non-native, invasive species, narrow-leaved cattail is aggressive and often forms dense monotypic stands which displace native wetland plants. Current control methods for narrow-leaved cattail include maintaining higher water levels to flood the plants, hand or mechanical harvesting followed by flooding, controlled burning, and chemical control using 2,4-D or glyphosate. Narrow-leaved cattail was found on the northern shore of West Plum Lake (West Plum – Map 7) during Phase I, and in Big Muskellunge and Razorback lakes during Phase III.

Purple loosestrife

Purple loosestrife (*Lythrum salicaria*) is a perennial herbaceous plant native to Europe and was likely brought over to North America as a garden ornamental. This plant escaped from its garden landscape into wetland environments where it is able to out-compete our native plants for space and resources. First detected in Wisconsin in the 1930’s, it has now spread to 70 of the state’s 72 counties. Purple loosestrife largely spreads by seed, but also can vegetatively spread from root or stem fragments. Populations of purple loosestrife were observed along shoreline areas in Star Lake (Star Lake – Map 7) and Big Muskellunge Lake (Big Muskellunge Lake – Map 7).

There are a number of effective control strategies for combating this aggressive plant, including herbicide application, biological control by native beetles, and manual hand removal. At this time, hand removal by volunteers is likely the best option as it would decrease costs significantly. Control of purple loosestrife on the Town of Plum Lake project lakes will be discussed in the Implementation Plan Section.

Reed canary grass

Reed canary grass (*Phalaris arundinacea*) is a large, coarse perennial grass that can reach up to six feet in height. Often difficult to distinguish from native grasses, this species can form dense, highly productive stands that outcompete native species. Unlike native grasses, few wildlife species utilize the grass as a food source, and the stems grow too densely to provide cover for small mammals and waterfowl. It grows best in moist soils such as wetlands, marshes, stream banks and lake shorelines. It is difficult to eradicate and is quite resilient to herbicide applications.

3.6 Aquatic Invasive Species in the Town of Plum Lake project lakes

As is discussed in section 2.0 Stakeholder Participation, the lake stakeholders were asked about aquatic invasive species (AIS) and their presence in the Town of Plum Lake project lakes within the anonymous stakeholder survey. Onterra and the WDNR have confirmed that there are 11 AIS present with the Town of Plum Lake project lakes (Table 3.6-1).

Table 3.6-1. AIS present within the Town of Plum project lakes.

Type	Common name	Scientific name	Lake	Location within report
Plants	Eurasian watermilfoil	*Myriophyllum spicatum*	Little Star Lake	Section 3.5 – Aquatic Plants
	Pale-yellow iris	*Iris pseudacorus*	Plum Lake, West Plum Lake, Star Lake	Section 3.5 – Aquatic Plants
	Purple loosestrife	*Lythrum salicaria*	Star Lake, Big Muskellunge	Section 3.5 – Aquatic Plants
	Narrow-leaved cattail	*Typha angustifolia*	West Plum, Big Muskellunge, Razorback	Section 3.5 – Aquatic Plants
	Phragmites/Giant reed	*Phragmites australis* subsp. *australis*	Lake Laura (by WDNR, 2018)	Section 8.7.5 – AIS in Lake Laura
	Reed canary grass	*Phalaris arundinacea*	Razorback Lake	Section 3.5 – Aquatic Plants
Invertebrates	Freshwater jellyfish	*Craspedacusta sowerbyi*	Plum Lake, Razorback Lake	Section 3.6 - Aquatic Invasive Species
	Rusty crayfish	*Orconectes rusticus*	Plum Lake, Star Lake, Little Star Lake, Big Muskellunge	Section 3.6 - Aquatic Invasive Species
	Banded mystery snail	*Viviparus georgianus*	Plum Lake, Star Lake, Ballard Lake, Lake Laura, Razorback Lake	Section 3.6 - Aquatic Invasive Species
	Chinese mystery snail	*Cipangopaludina chinensis*	Plum Lake, West Plum Lake, Star Lake, Razorback Lake	Section 3.6 - Aquatic Invasive Species
	Spiny waterflea	*Bythotrephes longimanus*	Star Lake	Section 3.6 - Aquatic Invasive Species

Figure 3.6-1 displays the 15 aquatic invasive species that the Phase I & II Town of Plum Lake stakeholder respondents believe are in the Town of Plum Lake Phase I & II project lakes. Only the species present in the Phase I and II project lakes are discussed below or within their respective locations listed in Table 3.6-1. 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

Rusty Crayfish

Rusty crayfish (*Orconectes rusticus*) are originally from the Ohio River basin and are thought to have been transferred to Wisconsin through bait buckets. These crayfish displace native crayfish and reduce aquatic plant abundance and diversity. Rusty crayfish can be identified by their large, smooth claws, varying in color from grayish-green to reddish-brown, and sometimes visible rusty spots on the sides of their shell. They are not eaten by fish that typically eat crayfish because they are more aggressive than the native crayfish. Rusty crayfish reproduce quickly but with intensive harvesting their populations can be greatly reduced within a lake.

Spiny Water Flea

The spiny water flea (*Bythotrephes longimanus*) first entered the Great Lakes through ship ballast water in the 1980s. They are ¼ to ½ inches in length so individuals are not generally seen with the naked eye, but spiny water fleas will gather in masses on fishing lines or downrigger cables. They eat small, native zooplankton and are direct competitors with juvenile fish. Small fish are unable to eat the spiny water fleas due to their long, spiny tails. At this time, there is no control method to control the spiny water flea. The UW-Center for Limnology has done extensive research on the spiny water flea and its introduction to Lake Mendota. Their findings show that the spiny water flea eats Daphnia, a main consumer of algae, which then causes the lake to become greener due to an absence of algae predator (Hinterthuer 2015). Basically, spiny water fleas can be detrimental to a lake's water quality because they eat the organism that eats the algae causing algae to become more prevalent

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).

Freshwater jellyfish

Freshwater jellyfish (*Craspedacusta sowerbyi*) are believed to have been introduced to the Great Lakes region around 1933 with the first Wisconsin sightings dating back to 1969. They are quite small, growing to about one inch in diameter. These jellyfish are ephemeral, living for only six to seven weeks and then disappearing, sometimes forever. While there is not yet a thorough understanding of how freshwater jellyfish affect their ecosystems, it is thought that they may outcompete other native species for zooplankton. Crayfish are a natural predator of freshwater jellyfish.

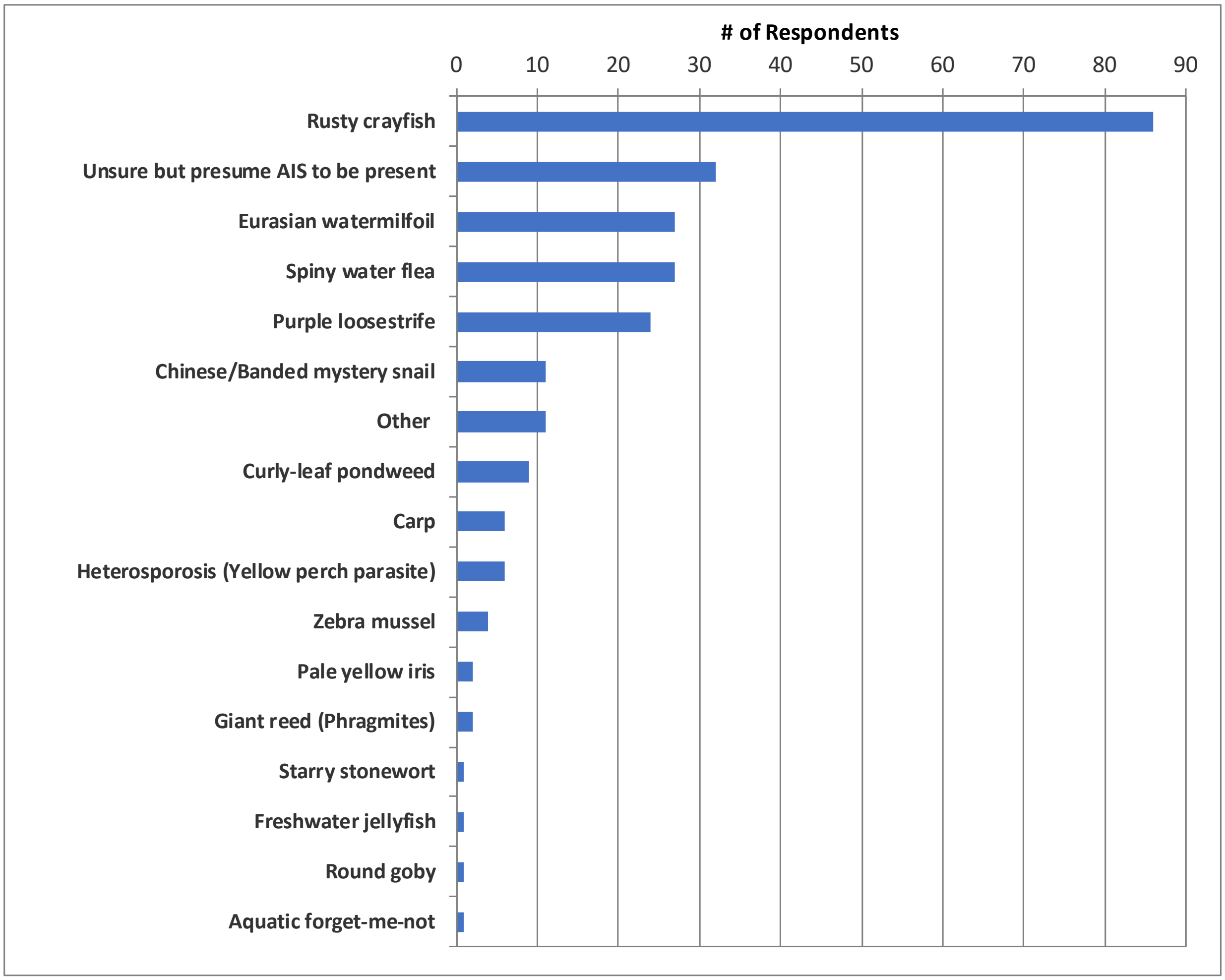


Figure 3.6-1. Stakeholder survey responses to AIS question. "Which aquatic invasive species do you believe are in your lake?" Results are compiled from Phase I & II lakes.

3.7 Fisheries Data Integration

Fishery management is an important aspect in the comprehensive management of a lake ecosystem; therefore, a brief summary of available data is included within each lake's individual report section. The fishery data integration sections are not intended to be a comprehensive plan for the lake's fishery, as those aspects are currently being conducted by the numerous fisheries biologists overseeing the Town of Plum Lake project lakes. The goal of these sections is to provide an overview of some of the data that exists, particularly in regards to specific issues (e.g. spear fishery, fish stocking, angling regulations, etc.) that were brought forth by the stakeholders within the stakeholder survey and other planning activities. Although current fish data were not collected as a part of this project, the fisheries information was compiled based upon some of the data available from the WDNR and the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) (WDNR 2017 & GLIFWC 2017).

4.0 SUMMARY AND CONCLUSIONS

Will be completed in Phase III Report

5.0 TOWN-WIDE IMPLEMENTATION PLAN (PHASE I)

The Implementation Plan presented below was created through the collaborative efforts of the Lakes Committee of the Town of Plum Lake (Town Lakes Committee), the Planning Committees created as a part of each of the three phases, and ecologist/planners from Onterra. It represents the path the Town of Plum Lake and the individual lake groups will follow in order to meet their lake management goals. The goals detailed within the plan are realistic and based upon the findings of the studies completed in conjunction with this planning project and the needs of the project lake stakeholders as portrayed by the members of the Town Lakes Committee, the Planning Committees, the returned stakeholder surveys, and numerous communications between the Town Lakes Committee and 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 implementation plan detailed below is written to be implemented primarily by the Town of Plum Lakes Lake Committee; however, certain aspects are implementable by specific lake groups or groups of lake groups. Further, while 10 lakes where included in this project, the town-wide plan is intended to be appropriate for all lakes within the Town of Plum Lake.

After each individual lake section, lake-specific management goals and associated actions are described. These goals and actions will be carried out by the individual lake groups.

Management Goal 1: Maintain Lake Water Quality in the Town of Plum Lake

Management Action:	Monitor water quality through WDNR Citizens Lake Monitoring Network and/or Town of Plum Lake-Coordinated Program.
Timeframe:	2020 or earlier
Potential Grant:	Small-scale Planning Grant for program start-up
Facilitator:	Lakes Committee of the Town of Plum Lake
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. A consistent water quality database also allows for the documentation of improvements brought on by management activities. As of 2019, the 10 Town of Plum Lake Management Planning Project Lakes had varying levels of historical and recent water quality data available. Further, some of the lakes are involved in existing programs for water quality data collections, while others are not. The table below summarizes the available water quality data for the 10 project lakes.

Lake	Water Quality Data Availability Summary	Water Quality Data Collection Frequency
Big Muskellunge	North Temperate Lakes Long Term Ecological Research: 1986-present	Annual
Laura	Planning project data: 2018	Annual
Plum	CLMN Adv. WQ: 2000-present	Annual
Razorback	WDNR Baseline Monitoring: Late '70s and '80s, Planning project data:	3 years
Star	Limited: 1979 & '89, CLMN Secchi 1993-2002, Planning project data: 2017	Annual
Ballard	CLMN Secchi 2017, CLMN Adv. WQ: 1993-2000 & 2018-present, Planning project data: 2018	Annual
Irving	CLMN Secchi 2000 & 2017, CLMN Adv. WQ: 2018-present, Planning project data: 1998-99 & 2018	Annual
White Birch	CLMN Secchi 2003 & 2017-present, CLMN Adv. WQ 1998-99, Planning project data: 2018	Annual
Little Star	National Lakes Survey 2007, Planning project data: 2017	3 years
West Plum	Planning project data: 2017	3 years

Not all lakes need to have water quality data collected every year; for instance, small lakes and lakes with little development. The table above also lists the recommended frequency at which water quality data would be collected. Developed lakes, for example, Star and Plum, are recommended for annual monitoring. Lakes with existing programs for data collection are also listed as annual. Smaller lakes, like West Plum and Little Star, would collect water quality every 3rd year, as would a minimally developed lake like Razorback. Other town lakes not included in this project that are small and/or minimally developed would also fall into the 3-year program as well.

The Citizen Lake Monitoring Network (CLMN) is a WDNR program in which volunteers are trained to collect water quality information on their lake. During the first year of participation, volunteers are trained by

WDNR staff to monitor Secchi disk transparency at the deep hole site of their lake. In subsequent years, if the volunteers are interested and funding is available, as a part of the advanced CLMN program, the volunteers are trained how to collect and process water quality samples in addition to Secchi readings. This includes sending in lake water samples for chlorophyll-a and total phosphorus analysis by the Wisconsin State Laboratory of Hygiene (WSLH). The samples are collected once during the spring and three times during the summer. 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).

The CLMN advanced water quality program has been at capacity in the WDNR’s Northern Region for nearly a decade and a waiting list is used to bring new lakes into the program as enlisted lakes dropout or more funding becomes available. Further, the WDNR, in some cases, has begun to remove lakes that have participated for several years and offer newly enrolled lakes the opportunity to participate for three years before they are removed from the program. Enrollment for the Secchi disk transparency program is still open and enrollment is perpetual. The CLMN contact with the WDNR is Ms. Sandra Wickman and her contact information can be found in Table 5.0-1.

To start or continue water quality monitoring on their lakes, some lake groups are sponsoring their own program that mimics the CLMN collection regime. As a part of this multi-phased management planning project, the Town of Plum Lake set up an account with the WSLH. That account remains active; therefore, water quality analysis can be completed and billed to the town through the account. The CLMN program includes the analysis of total phosphorus in spring, June, July, and August; and the analysis of chlorophyll-*a* in June, July, and August. As of spring 2019, the annual cost of that analysis through the WSLH would be $200.00.

The Plum Lake Association and the Friends of Star Lake have provided volunteers to the CLMN in past years. These associations have a sufficient number of members to be able to consistently train one or more of their members for CLMN. Some other lakes in the Town of Plum Lake have informal groups of land owners who have supported the Clean Boats Clean Waters through donations in the past. These lakes have generally not participated in CLMN in the past.

As yet to be determined: There are two primary options for the town and individual lakes to collect water quality data. A combination could also be utilized.

1. *Town maintains a list of trained water quality monitoring volunteers that it schedules to sample the lakes in the town program each year.*
2. *Individual lakes recruit volunteers to complete sampling on their respective lake.*

How the town and individual lakes proceed in this action will be discussed by the Town Lakes Committee as the project proceeds.

WSLH contact information is below. Kathleen Dax-Klister is available to assist the Town of Plum Lake in obtaining the correct forms and supplies for submitting samples for analysis by the WSLH. The contact will also assist in assuring that the forms are filled-in correctly.

Wisconsin State Laboratory of Hygiene
http://www.slh.wisc.edu/
Wisconsin State Laboratory of Hygiene
2601 Agriculture Drive, PO Box 7904
Madison, WI 53718
(800) 442-4618
Town of Plum Lake Account Number: 351059

Action Steps:

1. The Town Lakes Committee coordinates with town lake association that have existing CLMN program volunteers in place on an annual basis to assure the program is continuing on those systems.
2. The Town Lake Committee recruits volunteers for each of the lakes in the town to participate at least in the Secchi disk collection program of the CLMN.
3. The Town Lake Committee develops a testing schedule for town lakes where no volunteer has been identified and hires a technician or locates a volunteer to complete the sampling.

Management Goal 2: Prevent Further Introductions and Manage Current Aquatic Invasive Species in Town of Plum Lake Lakes

Management Action:	Continue Clean Boats Clean Waters watercraft inspections at Town of Plum Lake boat landings.
Timeframe:	Continuation current effort
Potential Grant:	WDNR Clean Boats Clean Waters Grant
Facilitator:	Lakes Committee of the Town of Plum Lake
Description:	The Town of Plum Lake has completed in excess of 9000 hours of Clean Boats Clean Waters (CBCW) monitoring since 2007, through town volunteers and UW-Oshkosh's summer program since 2014. The town and lake groups understand the importance of this program in preventing the introduction of AIS to town lakes; therefore, they will strive to continue this program into the future. The CBCW program benefits extend beyond the actual physical prevention of AIS introduction by literally stopping infested watercraft from being launched into the system, by spreading important information to watercraft owners regarding their potential role in spreading AIS. The WDNR has a streamlined application process allowing qualified lake groups to apply for funding for CBCW program activities. The Town of Plum Lake has utilized these grants since 2013. Grant funding is available for 75% of project costs up to a maximum of $4,000 per boat landing or pair of landings. The remaining 25% of the project cost must come from the project sponsor in the form of cash, donated labor or services, or "in-kind" items. These grants are reimbursement grants, meaning all costs must first be paid by project sponsor before reimbursement can be requested from the DNR. A 25% advance payment will be automatically provided to help get the project started. More information can be found on the WDNR Surface Water Grants website (dnr.wi.gov/aid/surfacewater.html). The Town of Plum Lake has contracted with the University of Wisconsin-Oshkosh to provide and schedule summer interns to monitor town landings. The success of this program has been mixed due to the scheduling of the interns at times when fishing is unlikely to occur and problems with "no shows" for scheduled times. The Town of Plum Lake also employs monitors for town landings after the summer interns have returned to school. These paid employees tend to be retired town residents who are interested in working in the outdoor environment that a boat landing offers. The cost of these employees is paid for with donations from the lake associations and informal groups of land owners on other lakes. The Town Lakes Committee determines which lakes are monitored taking into account

the amount of donations from the lake property owners and the expected number of boat launches. All of the paid employees fish themselves and can move between landings based on where boats are being launched. The Town Lakes Committee has consistently good results with the monitoring performed by the paid employees.

Action Steps:

1. The Town Lakes Committee will continue to participate in the CBCW program to monitor town boat landings.
2. The Town Lakes Committee will expand the use of paid employees and replace the University of Wisconsin-Oshkosh summer interns as feasible.
3. The Town Lakes Committee will continue to evaluate the effectiveness of the I-Lids cameras and consider revising which town landings are monitored.

Management Action: Coordinate annual volunteer monitoring for Aquatic Invasive Species in the lakes of the Town of Plum Lake.

Timeframe: 2020

Potential Grant: Small-scale AIS-Education, Prevention, & Planning for start-up

Facilitator: Lakes Committee of the Town of Plum Lake

Description: In lakes without Eurasian watermilfoil and other submersed invasive species like curly-leaf pondweed, early detection of pioneer colonies commonly leads to successful control and in cases of very small infestations, possibly even eradication. One way in which lake residents can spot early infestations of AIS is through conducting “Lake Sweeps” on their lake. During a lake sweep, volunteers monitor the entire area of the system in which plants grow (littoral zone) twice annually in search of non-native plant species. This program uses an “adopt-a-shoreline” approach where volunteers are responsible for surveying specified areas of the system.

In order for accurate data to be collected during these sweeps, volunteers must be able to identify non-native species such as Eurasian watermilfoil and curly-leaf pondweed. Distinguishing these plants from native look-a-likes is very important.

The Plum Lake Association has conducted lakewide sweeps for AIS. The first sweep is typically in early to mid-June and is intended to identify any curly-leaf pondweed. A second sweep is conducted after mid-August to identify any Eurasian watermilfoil. These sweeps involve visual observation and occasional sampling of lake vegetation with a modified rake attached to a rope. Identification of AIS is facilitated by laminated brochures available at www.uwsp.edu/cnr/uwex/CLMN/publications.asp. Suspicious vegetation is placed in a plastic bag with the location of collection noted and retained for review by a member with more experience in identification of AIS.

The University of Wisconsin Center of Limnology-Trout Lake Station in Boulder Junction holds an annual open house on the first Friday in August. As part of this open house, actual specimens of Eurasian watermilfoil and curly-leaf pondweed can be inspected and compared to native species Northern watermilfoil and clasping-leaf pond weed. Members of the Town Lakes Committee have increased their ability to recognize AIS by attending this event.

Action Steps:

1. The Town Lakes Committee communicates annually with town lake groups that have existing AIS monitoring volunteers conducting sweeps to assure the program is continuing.
2. The Town Lakes Committee recruits volunteers for each of the other lakes in the town to sweep for AIS twice each year.
3. The Town Lakes Committee develops a schedule for the periodic sweeping of town lakes with paid employees or contracted professionals.

Management Action: Purchase and install Environmental Sentry Protection, LLC I-LIDS at Town of Plum Lake boat landings.

Timeframe: Continuation of current effort

Potential Grant: AIS-Education, Prevention, and Planning

Facilitator: Lakes Committee of the Town of Plum Lake

Description: The Town Lakes Committee has purchased and installed four I-Lids cameras on town boat landings with partial funding by the WDNR. Three of these installations are on landings in the Northern Highlands State Forest and one is on a town easement. The cameras are activated by a combination of a metal detector and a motion sensor. The audio reminder and the camera are intended to only be activated by a boat trailer and not a deer or person walking by.

The camera is of sufficient quality so as to be able to read the registration number of each boat being launched. The camera is also able to view any vegetation that may be present on the boat trailer. It is unlawful to launch a boat in Wisconsin with vegetation present on the boat trailer.

The audio reminds the boater to look for vegetation before launching the boat and, as a boat is removed from the lake, reminds the boater to drain all water from boat compartments. The audio can be tailored to each landing and changed as needed.

The I-Lids cameras provide coverage of all day-light boat launches through the fishing season of mid-May through mid-October. To cover these hours with monitoring by paid employees would be cost prohibitive for the Town of Plum Lake.

A sampling of launchings is reviewed by employees of Environmental Sentry Protection, LLC and volunteers from the Town Lakes Committee; potential violations of Wisconsin law are noted and provided to members of the Town Lakes Committee for follow-up.

Action Steps:

1. The Town Lakes Committee will purchase and install additional I-Lids cameras on town boat landings as funding from the WDNR or the Town of Plum Lake is available.
2. The Town Lakes Committee will develop a town ordinance with a fine for launching a boat with vegetation attached to the boat trailer. The purpose of the ordinance would be to draw attention to Wisconsin law through publication of violations of the town ordinance in the local press.

<u>Management Action:</u> Manage existing shoreline/wetland invasive plants on Town of Plum Lake lakes.

Timeframe: 2021

Potential Grant: AIS-Education, Prevention, and Planning

Facilitator: Lakes Committee of the Town of Plum Lake

Description: During the aquatic plant studies completed during 2017, the shoreline/wetland invasive plants purple loosestrife and pale-yellow iris were documented on three or the Town of Plum Lakes Phase I project lakes. Specifically, purple loosestrife was located on Star Lake and pale-yellow iris was located on Star, Plum, and West Plum lakes.

Purple Loosestrife Methods for controlling this non-native plant include digging individual plants out of the soil, cutting flower heads and treating with appropriate herbicide, and the raising and planting of *Galerucella* beetle, which eat and complete their lifecycle on purple loosestrife. Purple loosestrife was found infrequently around the shore of Star Lake (Star Lake Map 7); therefore, the use of beetles is likely not warranted.

Pale-yellow Iris This emergent invasive is also controlled through physical removal, but some studies have shown that cutting its foliage under the surface of the water also works to “drown” the plant out. Pale-yellow iris was found infrequently around the shores of Star Lake (Star Lake Map 7), Plum Lake (Plum Lake Maps 7 & 8), and West Plum Lake (West Plum Lake Map 7).

Specialists from the Vilas County Land and Water Conservation Department (see Table 5.0-1 for contact information) have assisted many groups throughout the county to establish monitoring and control programs for these shoreline/wetland exotics. Town Lakes Committee will contact Vilas County Land and Water Conservation Department to determine if and how they can assist with managing these exotics

Action Steps:

See description above.

<u>Management Action:</u> Initiate rapid response plan following detection of new AIS in a lake in the Town of Plum Lake.

Timeframe: If/When Necessary

Potential Grant: AIS-Early Detection & Response Grant

Facilitator: Lakes Committee of the Town of Plum Lake

Description: If riparians or volunteers locate a suspected new AIS within a Town of Plum Lake lake, the location would be marked (e.g. GPS, maker buoy) and a specimen would be taken to the Trout Lake Field Station or Vilas County Land Conservation Department for verification (see Table 5.0-1 for contacts). If the suspected specimen is indeed a non-native species, the WDNR will fill out an incident form and develop a strategy to determine the population level within the lake. The lake would be professionally surveyed, either by agency personnel or a private consulting firm during that species' peak growth phase.

If the AIS is a NR40 prohibited species (i.e. red swamp crayfish, starry stonewort, hydrilla, etc.), the WDNR may take an active role in the response.

If the AIS is a NR40 restricted species (i.e. purple loosestrife, curly-leaf pondweed, Eurasian watermilfoil, etc.), the Town Lakes Committee would need to reach out to a consultant to develop a formal monitoring and/or control strategy. The WDNR would be able to help financially through the AIS Grant Program's Early Detection and Response Grant. This grant program is non-competitive and doesn't have a specific application deadline, but is offered on a first-come basis to the sponsor of project waters that contain new infestations (found within less than 5% of the lake and officially documented less than 5 years from grant application date). Currently this program will fund up to 75% percent of monitoring and control costs, up to $20,000.

Action Steps:

See description above

<u>Management Action:</u> Manage Eurasian watermilfoil in Little Star Lake.

Timeframe: Continuation of current effort

Potential Grant: AIS-Early Detection & Response Grant in 2020

Facilitator: Lakes Committee of the Town of Plum Lake

Description: Eurasian watermilfoil was verified in Little Star Lake in the summer of 2017. The Town Lakes Committee has self-funded professional hand-harvesting during the summers of 2017, 2018 and 2019. This is the first AIS that has required treatment in a lake in the town.

A lake is eligible to receive AIS-EDR Grant funds within the 5 years of the AIS verification in the lake. The Town Lakes Committee intends to apply for an AIS-EDR Grant for Little Star Lake in 2020. The grant will assure continued monitoring and control.

Action Steps:

See description above

Management Goal 3: Preserve and Restore Ecological Integrity of Lakes in Town of Plum Lakes

Management Action:	Educate stakeholders on the importance of shoreland condition and shoreland restoration for the lakes of the Town of Plum Lake.
Timeframe:	2020
Facilitator:	Lakes Committee of the Town of Plum Lake
Description:	As discussed in the Shoreland Condition Section, 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.

Star Lake and Plum Lake are the two most developed lakes in the town, yet both have the majority of the shorelands as completely undeveloped and natural at 83% and 66%. Both have small amounts of their shorelands classified as either completely urbanized or developed-unnatural (Star: 4% and Plum 9%). Still, these areas of development on these lakes, and other in the Town of Plum Lake, limits shoreland habitat, but it also reduces natural buffering of shoreland runoff and allows nutrients to enter the chain. Because property owners may have little experience with or be uncertain about restoring a shoreland to its natural state, the Town Lakes Committee and lake groups will educate town shoreland property owners regarding shoreland restoration and protection opportunities. This would include inviting Vilas County staff (see Table 5.0-1) to present on the subject at association and town-wide meetings.

Protecting Shorelands Currently, Town of Plum Lake shorelands are mostly undeveloped and much are under public ownership. Therefore, a primary objective of this action is to educate current and future property owners on the importance of maintaining their property in a manner that does not impact lake water quality or reduce shoreland habitat value. This includes reducing the buffering capacity of near shore areas and removal of natural, existing coarse woody habitat. This objective can be met by inviting speakers to association annual meetings, including articles in newsletters, and posting information on association and town websites. Reminding property owners that retaining that “Up North Feel” is important to the lake environment and their property values is critical.

Restoring Shorelands Shoreland restorations do not only include the restoration of native plants along the shoreline. Runoff diversions, rain gardens, and partial restorations are also important in reducing impacts that developed properties have on lakes. The WDNR's Healthy Lakes Initiative Grant program allows partial cost coverage for native plantings in transition areas, along with other shoreland restoration 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 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:

See description above

Management Action: Coordinate with WDNR and private landowners to expand coarse woody habitat in the lakes of the Town of Plum.

Timeframe: Initiate 2020

Facilitator: Lakes Committee of the Town of Plum Lake

Description: Town of Plum Lake stakeholders realize the complexities and capabilities of town lakes with respect to the fishery they 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 and Fisheries Data Integration Section discuss the benefits of coarse woody habitat in detail.

The WDNR's Healthy Lakes Initiative Grant allows partial cost coverage for coarse woody habitat improvements (referred to as "fish sticks"). This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through the county.

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

Action Steps:

1. Town Lakes Committee contacts WDNR Lakes Coordinator and WDNR Fisheries Biologist to gather information on initiating and conducting coarse woody habitat projects within the Town of Plum Lake. This step is important to assure that the action will meet the fisheries goals of the WDNR fisheries management specialists.
2. The Town Lakes Committee and individual lake associations will encourage property owners that have enhanced coarse woody habitat to serve as demonstration sites.

Management Action: Investigate feasibility of restoring a portion of shoreland area of Plum Lake Golf Club to a more natural condition.

Timeframe: 2020

Potential Grant: Healthy Lakes Initiative Grant

Facilitator: Plum Lake Association

Description: Approximately 200 feet of shoreline owned by the Plum Lake Golf Course is considered completely urbanized. While this is not the only urbanized shoreline on the lake and it is not suspected of causing unreasonable harm to the lake, restoring a portion of it in partnership with the golf course owners would provide an opportunity for promoting shoreland restoration on Plum Lake and other lakes in the Town of Plum Lake. As discussed in the town-wide action regarding shoreland restoration and protection, there are easily assessable WDNR grants for this type of management action. Vilas County also offers assistance in the form or financial contributions and technical guidance (See Quita Sheehan's contact information in Table 5.0-1).

Action Steps:

1. Members of Plum Lake Association approach Plum Lake Golf Course owners regarding possibility of completing shoreland restoration on shoreline between Plum Lake and clubhouse.
2. If interest exists, Plum Lake Association contacts Quita Sheehan regarding preliminary design ideas and cost-share applicability.
3. Preliminary designs are presented to club ownership for consideration and modification, if needed.
4. Once the design is finalized, Plum Lake Association applies for appropriate grant funding.
5. Restoration is implemented and promoted.

Management Action: Coordinate with the Northwoods Land Trust and other public charities to understand options to acquire or preserve undeveloped lakefront property on town lakes.

Timeframe: 2020

Potential Grant: Lake Protection Land Acquisition Grant

Facilitator: Lakes Committee of the Town of Plum Lake and public charities

Description: Many Town lakes benefit from undeveloped shoreland. Most of this shoreland is State-owned. However, some of the undeveloped shoreland is privately owned. The development of this privately-owned shoreland is potentially detrimental to the health of a lake. The recent change in shoreland zoning to reduce minimum lot size to 100-foot lot size increases the threat.

Maintaining the undeveloped shoreland can be achieved with the help of the Northwoods Land Trust under the right circumstances.

Action Steps:

1. Chair of the Town Lakes Committee to contact Ted Anchor, Executive Director of the Northwoods Land Trust (715.479.2490) to schedule a presentation for the Town Lakes Committee.
2. A representative from the Northwoods Land Trust presents how the Trust can help preserve undeveloped property.
3. The Town Lakes Committee makes an informal inventory of undeveloped town lake property.
4. The Town Lakes Committee develops a strategy to encourage private property owners to consider using a restrictive easement registered with the Northwoods Land Trust when disposing of property.
5. The Town Lakes Committee develops a strategy to encourage sellers of undeveloped town lake property to sell to conservation-minded public charities to preserve the undeveloped property.

Management Action: Monitor scientific research on spiny water fleas (present in Star and Plum Lake) to determine when a viable treatment option exists and develop a treatment plan for infected lakes.

Timeframe: 2020 and ongoing.

Potential Grant: To be determined.

Facilitator: Lakes Committee of the Town of Plum Lake

Description: Spiny water flea is an invasive species that disrupts the food chain in an otherwise healthy lake. Spiny water fleas are predators of algae-eating zooplankton like Daphnia and, if they eat enough Daphnia, more algae can be expected on a lake and the resulting reduction in water quality.

Spiny water flea was recently verified as present in Plum Lake by a researcher from the University of Wisconsin Center of Limnology Trout Lake Station (Ben Martin) and were previously verified as present in Star Lake (2013).

Action Steps:

1. Representatives of the Town Lakes Committee attend various statewide conferences focusing on lake management issues to stay in touch with the latest thinking on treatment of invasive species.
2. A representative from the Town Lakes Committee should stay in touch with the research scientist (Ben Martin) who discovered the spiny water fleas in Plum Lake and is conducting scientific research on potential predators to the spiny water flea.
3. Develop a management plan for spiny water fleas after a viable control option exists. Yellow perch have been shown to be an effective predator of spiny water flea in recent research by UW. The Plum Lake Association should continue investigation of a potential research project suggested by Dr. Jake Vander Zanden, UW limnology director. This project could include construction of new CWH in the form of Fish Stick projects and rehabilitation of historic aquatic plant beds to create habitat for yellow perch in proximity of the deep basins of the lake.

Management Goal 4: Increase the Town of Plum Lake's Capacity to Communicate with Lake Stakeholders and Facilitate Partnerships with Other Management Entities

Management Action:	Promote lake protection and enjoyment through stakeholder education.
Timeframe:	2020
Possible Grant	Small-scale Lake Planning and/or AIS-Education, Prevention & Planning
Facilitator:	Lakes Committee of the Town of Plum Lake and Lake Associations

Description: Education represents an effective tool to address many lake issues. Lake association and town websites, newsletters, Facebook Groups, among other mediums are excellent tools for spreading information. Additional opportunities exist in the creation and distribution of specific information packets to targeted groups, such as new property owners, renters, or transient boaters.

The Town of Plum Lake and individual lake association will work together to inform town riparian property owners and others who use and care for town lakes. The following projects will be tackled by this partnership:

- New property owner information - Oneida County example
- Boating safety and lake-specific hazard areas – Signs at landings
- Lake-friendly property management – Brochure for existing and new property owners
- Rental property information packet, including protection of wildlife and loons
- Communicate information from planning project to people on and off lake
    - Written summary
    - Presentations to civic organizations

As this project progresses, I would like to expand upon this action with specific facilitators (possibly a town-wide committee?) and timelines. This is an excellent idea that could lead to the town being recognized for its innovation on a state-wide basis.

Action Steps:

See description above.

Management Action: Continue the Town of Plum Lake's involvement with other entities that have responsibilities in managing (management units) town lakes.

Timeframe: Continuation of current efforts

Facilitator: Lakes Committee of the Town of Plum Lake

Description: 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 other organizations rely on voluntary participation.

It is important that the Town of Plum Lake actively engage with all management entities to enhance the town'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 Table 5.0-1 below:

Action Steps:

See table guidelines on the next pages.

Table 5.0-1 Management Partner List.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Town of Plum Lake	General Town Chair (Will Maines,715.542.4531, office@townofplumlake.com)	Oversees ordinances, funding, and other items pertaining to town	As needed.	Involved in lake management activities, monitoring, implementation, funding, volunteer recruitment. May be contacted regarding ordinance questions, and for information on community events.
Great Lakes Indian Fish and Wildlife Commission	General (715.682.6619)	Resource management within Ceded Territory	As needed.	Collaborate on lake related studies, AIS management, inform of meetings, etc.
Vilas County Lakes & Rivers Association (VCLRA)	President (Tom Ewing, president@vclra.us)	Protects Vilas Co. waters through facilitating discussion and education.	Twice a year or as needed.	Become aware of training or education opportunities, partner in special projects, or networking on other topics pertaining to Vilas Co. waterways.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Vilas County Land and Water Conservation Department	Lake Conservation Specialist (Mariquita (Quita) Sheehan, 715.479.3721, mashee@co.vilas.wi.us)	Oversees conservation efforts for lake grants and projects.	Twice a year or more as needed.	Contact for shoreland remediation/restoration techniques and cost-share procedures, wildlife damage programs, education and outreach documents.
	Lake Conservation Specialist (Cathy Higley, 715.479.3738, cahigl@co.vilas.wi.us)	Oversees AIS monitoring and education activities county-wide.	Twice a year or more as issues arise.	AIS training and ID, monitoring techniques, CBCW training, report summer activities.
Wisconsin Department of Natural Resources	Fisheries Biologist (Eric Wegleitner, 715.356.5211 Ext. 246 eric.wegleitner@wisconsin.gov)	Manages the fish populations and fish habitat enhancement efforts.	Once a year, or more as issues arise.	Stocking activities, scheduled surveys, survey results, volunteer opportunities for improving fishery.
	Lakes Coordinator (Kevin Gauthier – 715.365.8937)	Oversees management plans, grants, all lake activities.	As needed.	Information on planning/AIS projects, grant applications or to seek advice on other lake issues.
	Environmental Grant Specialist (Laura MacFarland, 715.365.8900)	Oversees financial aspects of grants.	As needed.	Information on grant financials and reimbursement, CBCW grant applications.
	Conservation Warden (Rich Thole, 715.605.2130)	Oversees regulations handed down by the state.	As needed. May call the WDNR violation tip hotline for anonymous reporting (1-800-847-9367, 24 hours a day).	Contact regarding suspected violations pertaining to recreational activity, include fishing, boating safety, ordinance violations, etc.
	Trout Lake Station staff (Susan Knight and Carol Warden 715.356.9494)	Conducts lake research on multiple levels	As needed.	Can be contacted for identification or consultation on AIS.
	Citizen Lake Monitoring Network (Sandy Wickman – 715.365.8951, sandra.wickman@wisconsin.gov)	Provides information, training, and equipment for CLMN volunteers.	As needed.	Contact of information regarding CLMN program, including training, equipment, and data entry into SWIMS
Vilas County Sheriff Dept.	1.800.472.7290 or 715.479.4441 non-emergency, 911 emergencies only.	Perform law enforcement duties to protect lakes, especially pertaining to compliance with boating safety rules.	As needed.	Contact regarding suspected violations pertaining to boating safety rules on the lake.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
University of Wisconsin Extension Office	Lakes Specialist (Pat Goggin, 715.365.8943, Patrick.Goggin@wisconsin.gov)	Provides guidance for lakes, shoreline restoration, and outreach/education.	As needed.	Contact for shoreland remediation/restoration techniques, outreach/education.
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	Those interested 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.

6.0 METHODS

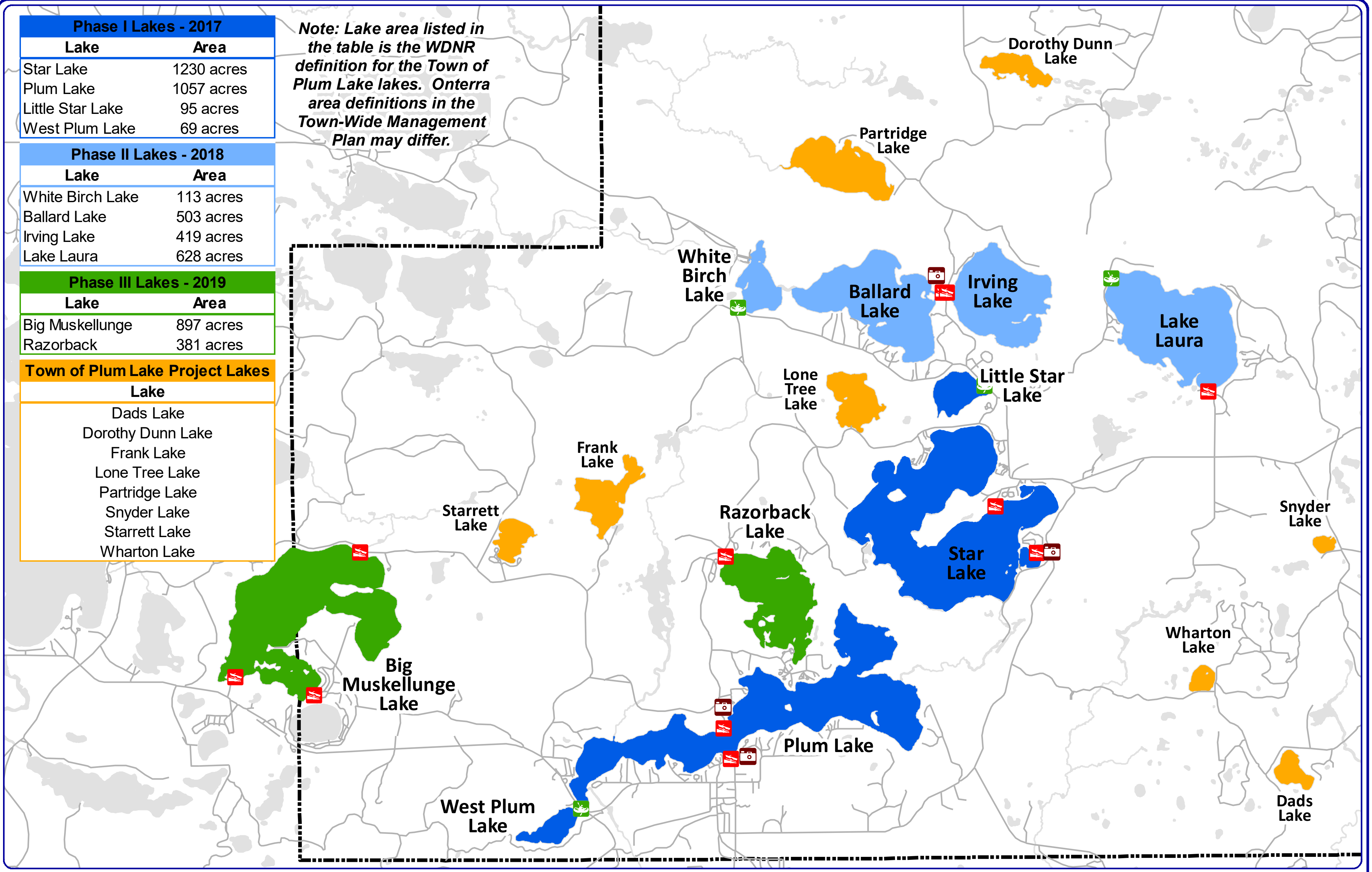
Will be completed in Phase III Report

7.0 LITERATURE CITED

Will be completed in Phase III Report

8.0 INDIVIDUAL LAKE REPORTS

The following sections contain the individual lake reports for the Town of Plum Lake Management Planning Project. The study methods and explanations of analysis for these reports can be within the Town of Plum Lake Town-wide Management Planning Document (Sections 1-7).



Phase I Lakes - 2017	
Lake	**Area**
Star Lake	1230 acres
Plum Lake	1057 acres
Little Star Lake	95 acres
West Plum Lake	69 acres

Phase II Lakes - 2018	
Lake	**Area**
White Birch Lake	113 acres
Ballard Lake	503 acres
Irving Lake	419 acres
Lake Laura	628 acres

Phase III Lakes - 2019	
Lake	**Area**
Big Muskellunge	897 acres
Razorback	381 acres

Town of Plum Lake Project Lakes
Lake
Dads Lake
Dorothy Dunn Lake
Frank Lake
Lone Tree Lake
Partridge Lake
Snyder Lake
Starrett Lake
Wharton Lake

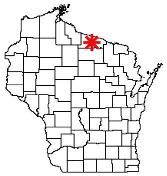
Note: Lake area listed in the table is the WDNR definition for the Town of Plum Lake lakes. Onterra area definitions in the Town-Wide Management Plan may differ.

N
W E
S

5,500
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
Map Date: February 21, 2018
Filename: *PlumTownof_Phases_proposal*


Project Location in Wisconsin

Legend

🟥 Public Access
🟩 Carry-In
▣ I-Lid Camera Monitoring
▭ Plum Lake Township

Map 1
Town of Plum Lake
Vilas County, Wisconsin

Project Location & Lake Boundaries