Roberts Lake

Forest County, Wisconsin

Aquatic Plant Management Plan

June 2025

Official First Draft

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Funded by: Roberts Lake Association
Wisconsin Department of Natural Resources
(AEPP77624)

Acknowledgements

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

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1.0 INTRODUCTION

Roberts Lake, Forest County, is a 415-acre spring lake with an average depth of 17 ft and a maximum depth of 32 ft. Roberts Lake is within the Chequamegon-Nicolet National Forest. The lake is accessible through a paved boat launch site operated by the US Forest Service. It features parking for many vehicle/trailer units, vault restrooms, and ADA accessibility features. A second private access, owned by the Wild Rose Supper Club, is also a popular access point.

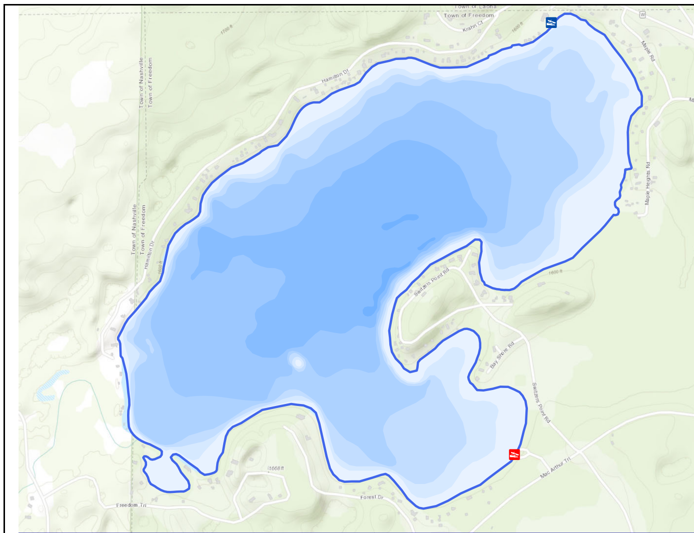

Figure 1.0-1. Roberts Lake, Forest County.

Roberts Lake is listed as a WDNR Priority Navigable Waterway due to natural reproducing walleye and muskellunge.

A point-intercept survey in 2015 indicated a Floristic Quality Index value of 30.4, which is indicative of a high-quality aquatic plant population. Eurasian water milfoil (*Myriophyllum spicatum*; EWM) was first discovered in Roberts Lake in 2015 by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC). This population has since been genetically confirmed to include pure-strain EWM and hybrid watermilfoil.

The Roberts Lake Association, Inc. (RLA) is the local citizen-based organization leading the management of Roberts Lake. The RLA received two WDNR Aquatic Invasive Species (AIS) Early Detection & Response Grants to conduct manual removal efforts from 2015-2020 with final reporting occurring in January 2021 for those projects. Periodic monitoring of the invasive watermilfoil population has been conducted by the RLA, with the late-summer EWM mapping surveys occurring in 2022.

The RLA successfully applied for a WDNR Surface Water Planning Grant in the fall 2023 cycle which provides funding assistance towards a project to update the aquatic vegetation surveys and create the first formal Aquatic Plant Management Plan for the RLA. This includes assessments of the aquatic invasive species through a late-season EWM Mapping survey, a point-intercept survey, and a floating-leaf and emergent community mapping survey. Stakeholder input will be sought through a stakeholder survey, strategic planning committee meetings, and a public comment review period.

This project is focused on creating an aquatic plant management-related Implementation Plan that aligns with current information about the lake and is consistent with the current understanding of best management practices and science and policy relating to aquatic plant management in Wisconsin.

2.0 STAKEHOLDER PARTICIPATION

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

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

2.1 Strategic Planning Committee Meetings

Planning Committee meetings would be used to raise project awareness, gather comments, create the management goals and actions, and deliver the study results and draft plan to the sponsor.

Two meetings were held with the planning committee. The first meeting occurred following the completion of the draft report sections of the document. 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 the lake's aquatic plant community among the committee members. The second planning committee meeting would be held a few weeks after the first and concentrate on the development of management goals and actions that would make up the framework of the implementation plan.

The planning committee meetings would serve to educate the lake riparians about general lake ecology, the group's understanding of their role in lake management, and feasible options for protecting and enhancing the lake. These meetings would also allow lake riparian owners to voice their concerns and opinions on matters pertaining to the lake to WDNR representatives and the planners. The integration of stakeholder opinions and concerns would be crucial in determining the lake group's capacity for managing various aspects of the lake ecosystem, and ultimately, the creation of realistic lake management goals and actions.

Planning Committee Meeting I

On April 21, 2025, Todd Hanke met with the RLA Planning Committee members through a virtual meeting platform. This roughly 2.5-hour meeting largely consisted of a presentation of the available data from the lake and the latest science and perspective on aquatic plant management activities.

Planning Committee Meeting II

The second planning committee meeting was held virtually on May 21, 2025, and concentrated on the development of management goals and actions that make up the framework of the implementation plan. This meeting had extensive discussions on EWM management options, particularly the use of mechanical harvesters and herbicides, how the techniques could be used in reaching potential management goals, and applicable risk assessment. WDNR representatives Scott Van Egeren and Ty Krajewski participated virtually in the meeting and provided perspective on the direction of the plan and permitting considerations.

2.2 Management Plan Review and Adoption Process

After the Planning Committee/RLA approved the Implementation Plan (Section 5.0), a draft of the entire APM Plan document was provided to WDNR for agency review in June 2025.

In summer 2025, the Draft Plan document will be made available for public comment via the RLA's communication routes. Members will be made aware of the public review opportunity and how to access the draft plan and will be provided an email address for which to send comments or questions.

The final Plan will be compiled after all public comments and agency comments are received and integrated as appropriate, followed by Plan adoption by the RLA.

2.3 Riparian Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to Roberts Lake Association members and riparian property owners around Roberts Lake. The survey was designed by Onterra staff and the Roberts Lake Association planning committee and reviewed by a WDNR social scientist. uring summer and fall 2024, the eight-page, 34-question survey was posted online through Survey Monkey for survey-takers to answer electronically. If requested, a hard copy was sent with a self-addressed stamped envelope for returning the survey anonymously. Of the 170 surveys that were distributed, 103 were returned which results in a response rate of 60.5%. 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.

The primary activities that are important reasons for owning property on the lake include relaxing/entertaining, swimming, and open water fishing, and motor boating (Figure 2.3-1). Top concerns regarding Roberts Lake listed by the stakeholders were current AIS within the lake, introduction of new AIS, and excessive plant growth (Figure 2.3-2).

Question 8: Please rank up to three activities that are important reasons for owning your property on or near the lake.

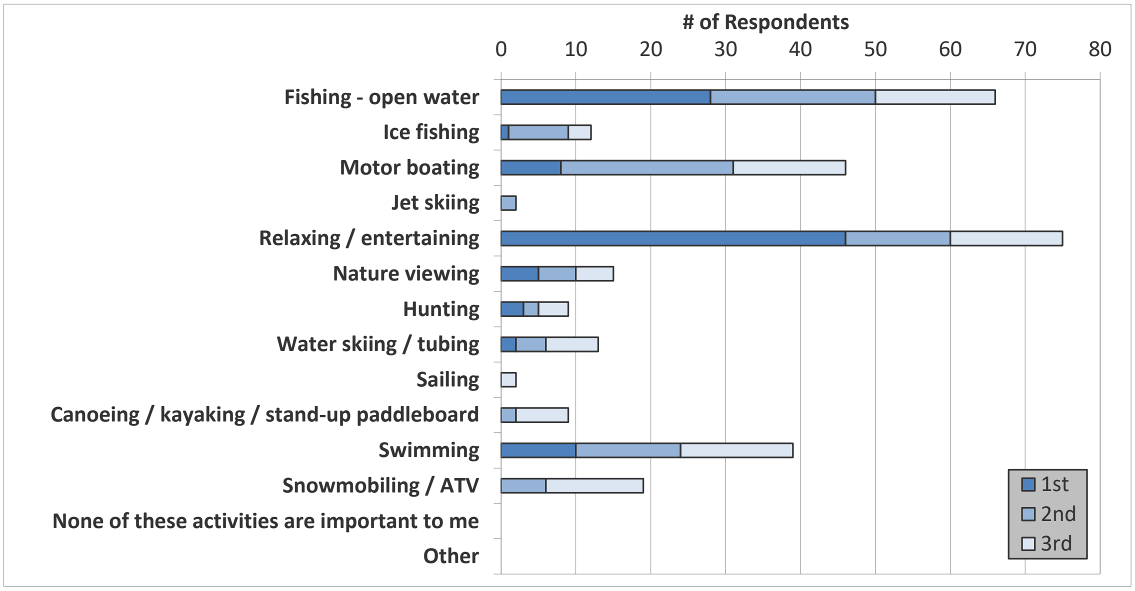

Figure 2.3-1. Select survey responses from the Roberts Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Question 16: From the list below, please rank your top three concerns regarding Roberts Lake, with 1 being your greatest concern.

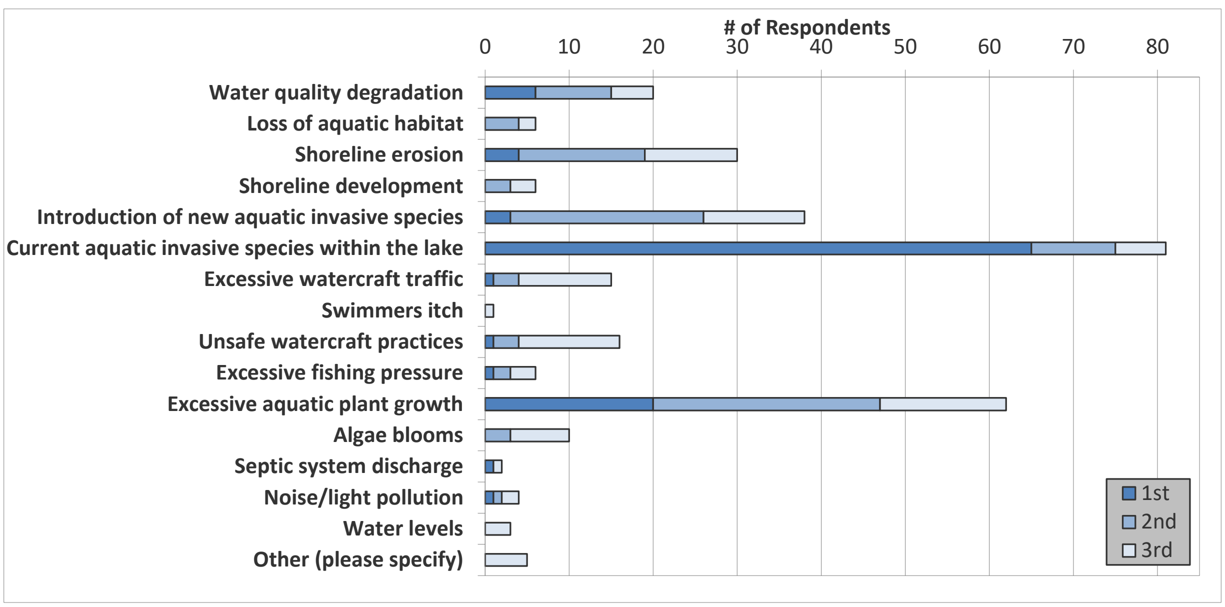

Figure 2.3-2. Select survey responses from the Roberts Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

3.0 AQUATIC PLANTS

3.1 Primer on Aquatic Plant Data Analysis & Interpretation

Native aquatic plants are an important element in every healthy aquatic ecosystem, providing food and habitat to wildlife, improving water quality, and stabilizing bottom sediments. Because most aquatic plants are rooted in place and are unable to relocate in wake of environmental alterations, they are often the first community to indicate that changes may be occurring within the system. Aquatic plant communities can respond in a variety of ways; there may be increases or declines in the occurrences of some 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.

The point-intercept method as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell, et al., 2010) have been conducted on Roberts Lake in 2015 and 2024. At each point-intercept location within the *littoral zone*, information regarding the depth, substrate type (soft sediment, sand, or rock), and the plant species sampled along with their relative abundance 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 (at depths < 15 ft) or using an onboard sonar unit (at depths > 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. At each point that is sampled the surveyor records a total rake fullness (TRF) value ranging from 0-3 as a somewhat subjective indication of plant biomass. 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 the following section.

Species List

The species list is simply a list of all of the aquatic plant species, both native and non-native, that were located during the surveys completed in Roberts Lake during 2015 and 2024. The list also contains each species' scientific name, common name, status in Wisconsin, and 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

> **Littoral Zone** is the area of a lake where sunlight is able to penetrate down to the sediment and support aquatic plant growth.

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

Floristic Quality Assessment

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

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

Roberts Lake falls within the Northern Lakes and Forests (NLF) *ecoregion* (Figure 3.1-1), and the floristic quality of its aquatic plant community will be compared to other lakes within this ecoregion as well as the entire State of Wisconsin. Ecoregions are areas related by similar climate, physiography, hydrology, vegetation and wildlife potential. Comparing ecosystems within the same ecoregion is sounder than comparing systems within manmade boundaries such as counties, towns, or states. Ecoregional and state-wide medians were calculated from whole-lake point-intercept surveys conducted on 392 lakes throughout Wisconsin by Onterra and WDNR ecologists.

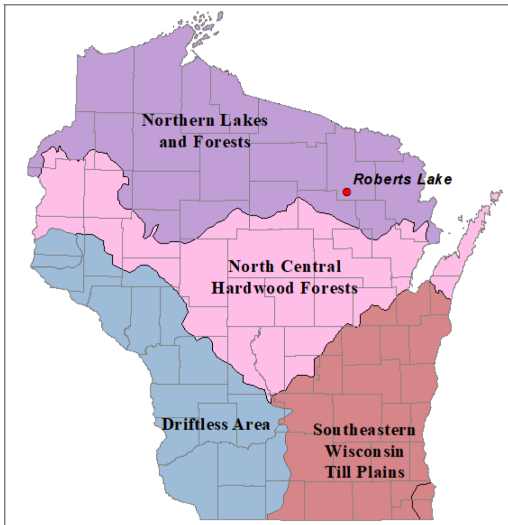

Figure 3.1-1. Location of Roberts Lake within the ecoregions of Wisconsin. After (Obernik, 2000)

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. Some managers believe a lake with a diverse plant community is also better suited to compete against exotic infestations than a lake with a lower diversity. However, in a recent study of 1,100 Minnesota lakes, researchers concluded that more diverse communities were not more resistant or resilient to invaders (Muthukrishnan, Davis, Jordan, & Forester, 2018).

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
D is a value between 0 and 1

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from Roberts Lake is 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.

3.2 Roberts Lake Aquatic Plant Survey Results

Whole-lake point-intercept surveys have been completed on Roberts Lake in 2015 and 2024. This report will highlight the 2024 point-intercept survey results and will integrate comparisons to the previous 2015 survey throughout the section. Appendix C contains a table that displays the occurrence of all aquatic plants encountered during each of the point-intercept surveys.

The data that continues to be collected from Wisconsin lake's is revealing that aquatic plant communities are highly dynamic, and populations of individual species have the capacity to fluctuate, sometimes greatly, in their occurrence from year to year and over longer periods of time. These fluctuations can be driven by a combination of natural factors including variations in temperature, ice and snow cover (winter light availability), nutrient availability, water levels and flow, water clarity, length of the growing season, herbivory, disease, and competition (Lacoul & Freedman, 2006). Adding to the complexity of factors which affect aquatic plant community dynamics, human-related disturbances such as the application of herbicides for non-native plant management, mechanical harvesting, watercraft use, and pollution runoff also affect aquatic plant community composition (Asplund & Cook, 1997); (Lacoul & Freedman, 2006).

Figure 3.2-1 displays the littoral frequency of occurrence of aquatic plants from the 2024 point-intercept survey. Littoral frequency of occurrence is used to describe how often each species occurred in the points that are within the maximum depth of plant growth (littoral zone), and is displayed as a percentage. A total of 22 native aquatic plant species were documented in Roberts Lake during the 2024 point-intercept survey. Of these 22 species, coontail (*Ceratopyllum demersum*), wild celery (*Vallisneria americana*), and muskgrasses (*Chara spp.*) were the most frequently encountered. Eurasian watermilfoil, a non-native invasive species, was the second most frequently encountered species in the 2024 survey with an occurrence of 18.3%. Additional discussion about EWM is included in section 3.3 below.

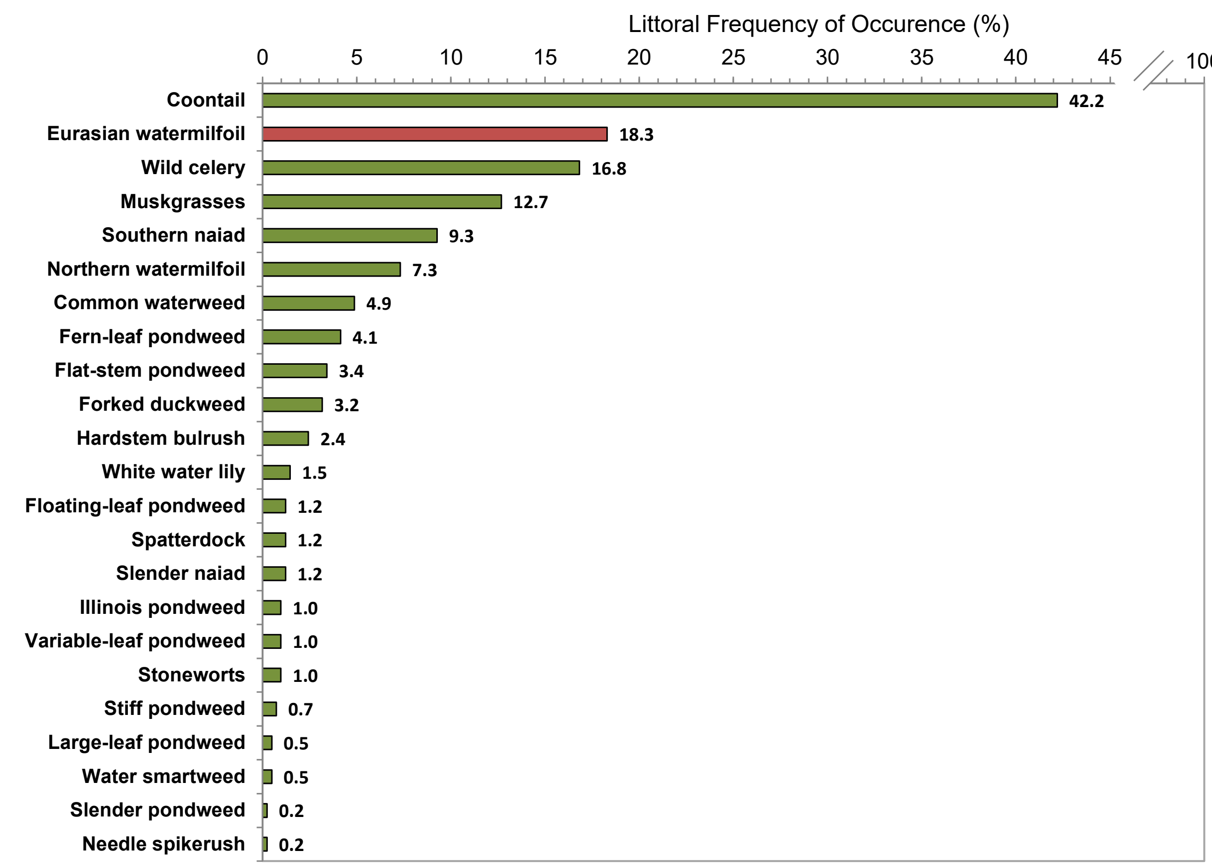

Figure 3.2-1. Littoral frequency of occurrence of aquatic plant species in Roberts Lake in 2024. Data from 2024 point-intercept survey.

In addition to the point intercept surveys, a floating-leaf and emergent plant community mapping survey was also completed in 2024. Table 3.2-1 displays all species that have been documented during all surveys on Roberts Lake. Table 3.2-1 is organized by growth form which separates out species based on whether they are emergent species, floating-leaf species, submergent species, or free-floating species. Species with an “X” on the table indicates the species was physically encountered on the rake during the point-intercept survey. Examples of other species that were observed, but were not sampled on the survey rake are referred to as incidentals and are listed with an “I” on table 3.2-1. Often these species are found growing on the shoreline or in shallow areas of the lake.

Table 3.2-1. Aquatic plant species located in Roberts Lake during surveys.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2015	2024
Emergent	*Calla palustris*	Water arum	Native	9		I
Emergent	*Carex sp. 1*	Sedge sp. 1	Native	N/A		I
Emergent	*Equisetum fluviatile*	Water horsetail	Native	7		I
Emergent	*Leersia orysoides*	Rice Cutgrass	Native	N/A		I
Emergent	*Lysimachia thyrsifloria*	Tufted loosestrife	Native	N/A		I
Emergent	*Sagittaria latifolia*	Common arrowhead	Native	3		I
Emergent	*Schoenoplectus acutus*	Hardstem bulrush	Native	5	X	X
Emergent	*Sparganium americanum*	American bur-reed	Native	8		I
Emergent	*Sparganium eurycarpum*	Common bur-reed	Native	5		I
Emergent	*Typha spp.*	Cattail spp.	Unknown (Sterile)	N/A		I
FL	*Brasenia schreberi*	Watershield	Native	7		I
FL	*Nuphar variegata*	Spatterdock	Native	6	X	X
FL	*Nymphaea odorata*	White water lily	Native	6	X	X
FL	*Persicaria amphibia*	Water smartweed	Native	5	X	X
FL/E	*Sparganium sp.*	Bur-reed sp.	Native	N/A		I
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X
Submergent	*Chara spp.*	Muskgrasses	Native	7	X	X
Submergent	*Elodea canadensis*	Common waterweed	Native	3	X	X
Submergent	*Heteranthera dubia*	Water stargrass	Native	6	X	
Submergent	*Myriophyllum sibiricum*	Northern watermilfoil	Native	7	X	X
Submergent	*Myriophyllum spicatum*	Eurasian watermilfoil	Non-Native - Invasive	N/A	I	X
Submergent	*Najas flexilis*	Slender naiad	Native	6	X	X
Submergent	*Najas guadalupensis*	Southern naiad	Native	7	X	X
Submergent	*Nitella spp.*	Stoneworts	Native	7	X	X
Submergent	*Potamogeton amplifolius*	Large-leaf pondweed	Native	7	X	X
Submergent	*Potamogeton amplifolius x praelongus*	Large-leaf x White-stem pondweed	Native	N/A	X	
Submergent	*Potamogeton berchtoldii*	Slender pondweed	Native	7	X	X
Submergent	*Potamogeton epihydrus*	Ribbon-leaf pondweed	Native	8	I	
Submergent	*Potamogeton gramineus*	Variable-leaf pondweed	Native	7	X	X
Submergent	*Potamogeton illinoensis*	Illinois pondweed	Native	6	X	X
Submergent	*Potamogeton natans*	Floating-leaf pondweed	Native	5	X	X
Submergent	*Potamogeton pusillus*	Small pondweed	Native	7	X	
Submergent	*Potamogeton robbinsii*	Fern-leaf pondweed	Native	8	X	X
Submergent	*Potamogeton strictifolius*	Stiff pondweed	Native	8	X	X
Submergent	*Potamogeton zosteriformis*	Flat-stem pondweed	Native	6	X	X
Submergent	*Stuckenia pectinata*	Sago pondweed	Native	3	I	
Submergent	*Vallisneria americana*	Wild celery	Native	6	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5	X	X
S/E	*Sagittaria cuneata*	Arum-leaved arrowhead	Native	7	I	
FF	*Lemna trisulca*	Forked duckweed	Native	6	X	X

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

Figure 3.2-2 compares the littoral frequency of occurrence of aquatic plants located in the 2015 and 2024 point-intercept surveys. Eight native species exhibited statistically valid decreases in occurrence between the two surveys with one species increasing in occurrence during the same timeframe (Figure 3.2-2). Eurasian watermilfoil was not encountered on the survey rake during the 2015 survey (0% occurrence) and exhibited a statistically valid increase in occurrence between the two surveys.

Coontail has whorls of leaves which fork into two to three segments and provides ample surface area for the growth of periphyton and habitat for invertebrates. Unlike most of the submersed plants found in Wisconsin, coontail does not produce true roots and is often found growing entangled amongst other aquatic plants or matted at the surface. Since it lacks true roots, coontail derives most of its nutrients directly from the water (Gross, Erhard and Ivanyi 2003). This ability in combination with a tolerance for low-light conditions allows coontail to become more abundant in eutrophic waterbodies with higher nutrients and low water clarity. Coontail has the capacity to form dense beds that can float and mat on the water's surface. Coontail was the almost always the only species that was encountered at depths beyond 17' in the 2024 survey while it was also present at all littoral depths as well.

Common waterweed can be found in waterbodies across Wisconsin, is tolerant of high-nutrient, low-light conditions, and can grow to nuisance levels under ideal conditions. Common waterweed has blade-like leaves in whorls of three produced on long, slender stems. Like other submersed aquatic plants, common waterweed helps to stabilize bottom sediments and provides structural habitat and food for wildlife. In the 2024 survey, common waterweed was present between 2-15 feet. The 2024 occurrence of 4.9% represents a statistically significant 87.4% decrease compared to 2015.

Wild celery produces long, ribbon-like leaves which emerge from a basal rosette, and it prefers to grow over harder substrates and is tolerant of low-light conditions. Its long leaves provide valuable structural habitat for the aquatic community while its network of roots and rhizomes help to stabilize bottom sediments. In mid- to late-summer, wild celery often produces abundant fruit which are important food sources for wildlife including migratory waterfowl. In Roberts Lake, wild celery was most abundant at littoral depths of 5-11 feet with a littoral frequency of occurrence of 16.8% in 2024. The occurrence of wild celery was not statistically different between 2015-2024.

Photograph 3.2-1. Common native aquatic plant species in Roberts Lake (Left: Common waterweed (*Elodea canadensis*). Center: Coontail (*Ceratophyllum demersum*). Right: Wild celery (*Valisneria americana*). Photo credits Onterra.

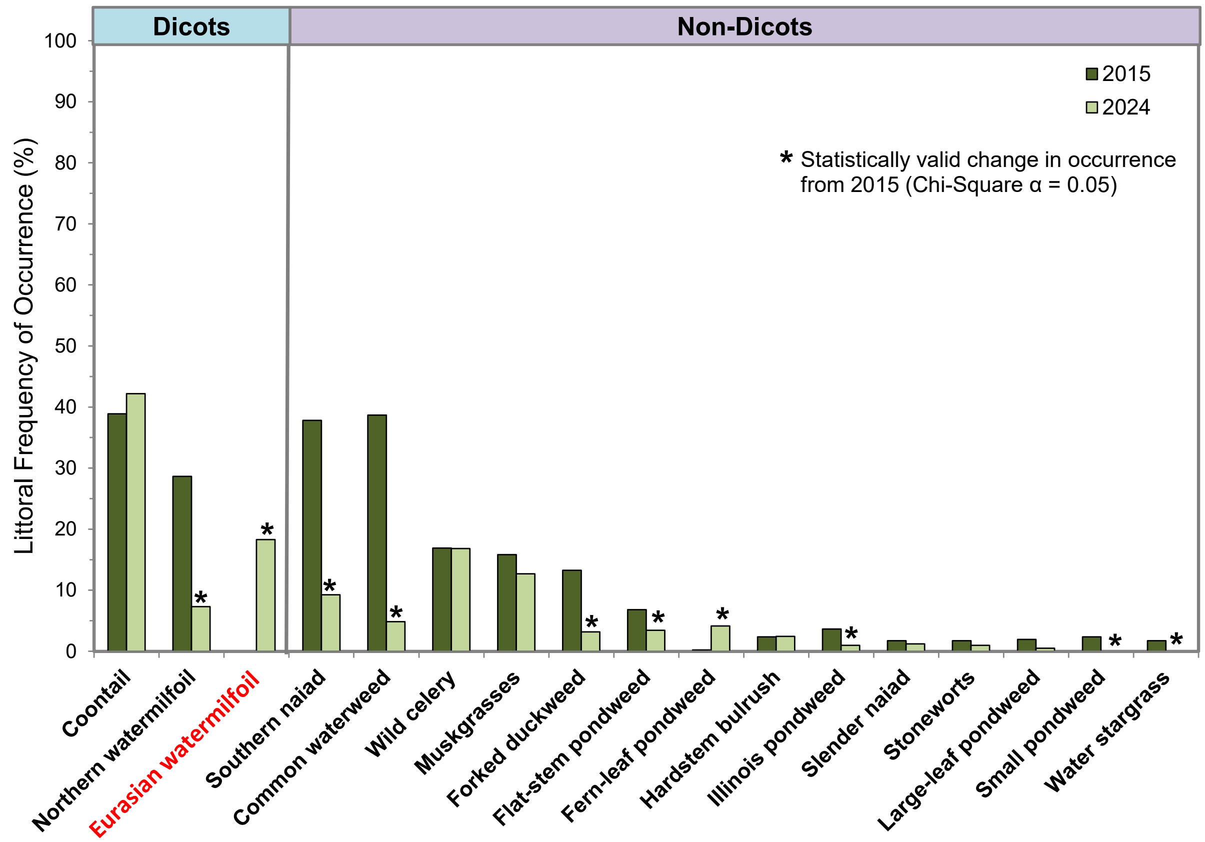

Figure 3.2-2. 2015 and 2024 Littoral Frequency of Occurrence of aquatic plant species. Only species with an occurrence of at least 1.5% in either survey is displayed.

Photo 3.2-2. Slender naiad (*Najas flexilis*; left) and southern naiad (*N. guadalupensis*; right). Photo credit Onterra.

Southern naiad is a slender, low-growing species with narrow, short greenish-brown leaves and exhibits many similar morphological characteristics as slender naiad. Slender naiad, a common annual species in Wisconsin, is considered to be one of the most important food sources for a number of migratory waterfowl species (Borman et al. 1997). Their numerous seeds, leaves, and stems all provide sources of food. The small, condensed network of leaves provide excellent habitat for aquatic invertebrates. In Roberts Lake, southern naiad is more prevalent than slender naiad. The occurrence of southern naiad exhibited a statistically valid 75.5% decrease in occurrence from 2015-2024. Slender naiad has been documented at relatively low levels (<2%) in each of the two point-intercept surveys.

Northern watermilfoil, arguably the most common milfoil species in Wisconsin lakes, is frequently found growing in soft sediments and higher water clarity. Northern watermilfoil can be mistaken for EWM, especially since it is known to take on the reddish appearance of EWM as the plant reacts to sun exposure as the growing season progresses. The feathery foliage of northern watermilfoil traps filamentous algae and detritus, providing valuable invertebrate habitat. Because northern watermilfoil prefers high water clarity, its populations are declining state-wide as lakes are becoming more eutrophic. The occurrence of northern watermilfoil exhibited a statistically valid 74.4% decrease in occurrence between the 2015 and 2024 surveys in Roberts Lake.

Photo 3.2-3. Northern watermilfoil – Myriophyllum sibiricum. Photo credit Onterra.

The maximum depth of plant growth was similar between the two surveys with aquatic plants growing out to 23 feet in the 2015 survey and 21 feet in the 2024 survey. The occurrence of aquatic plants was similar between the two surveys at depths ranging from 1-15 feet, however, more plants were documented in the 2015 survey growing at depths between 15-23 feet as compared to 2024 (Figure 3.2-3). The species that were most common at greater depths in 2015 included coontail, common waterweed, and southern naiad, with lesser amounts of other species. A cursory overview of available water clarity data from Roberts Lake does not show any meaningful trend in terms of lower water clarity during this timeframe, but this still may be a factor that impacts depth of plant colonization.

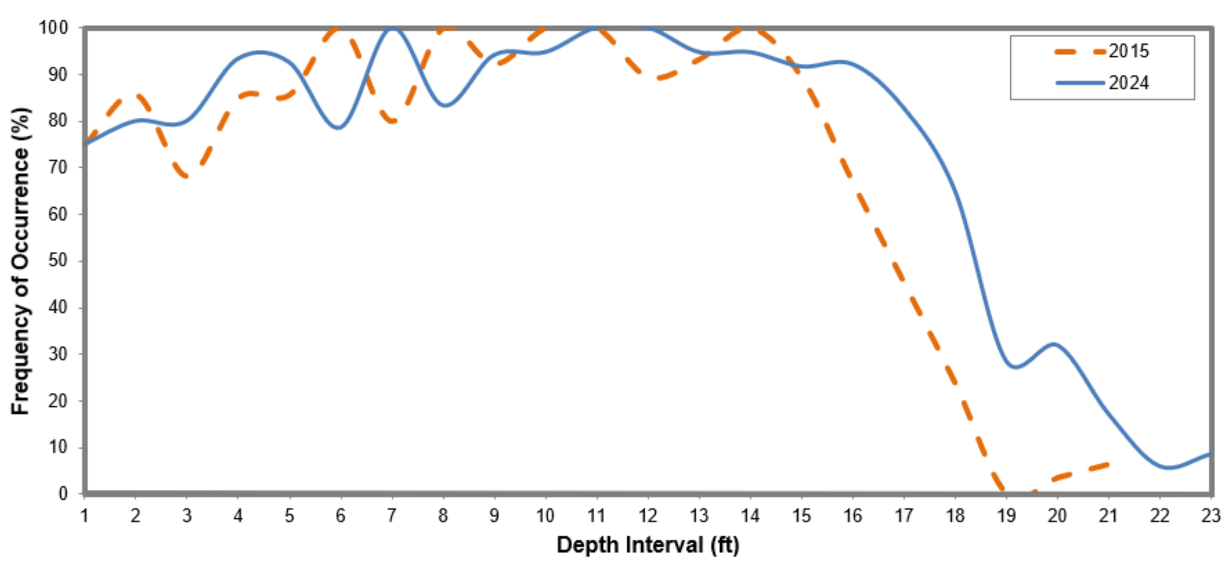

Figure 3.2-3. 2015 and 2024 Depth Distribution of aquatic plant species.

Data collected during the aquatic plant surveys was also used to complete a Floristic Quality Assessment (FQA) which incorporates the number of native aquatic plant species recorded on the rake during the point-intercept survey and their average conservatism. The data used for these calculations does not include any incidental species (visual observations) but only considers plants that were sampled on the rake during the point-intercept survey. Figure 3.2-4 displays the species richness, average conservatism, and floristic quality of Roberts Lake along with ecoregion and state median values.

Roberts Lake's native plant species richness values were 25 in 2015 and 22 in 2024, respectively, and are both above the median values for lakes within the NLFL ecoregion (21) and lakes across Wisconsin (19). Roberts Lake's average species conservatism values were 6.1 in 2015 and 6.0 in 2024 falling below the ecoregion median (6.7) and state median (6.3). Using the species richness and average conservatism values, Roberts Lake's Floristic Quality Index was 30.4 in 2015 which is near the ecoregion median (30.8) and was 28.4 in 2024. Both years fell slightly below the ecoregion median value and above the state median value. These data indicate that the overall aquatic plant community in Roberts Lake is of near average quality.

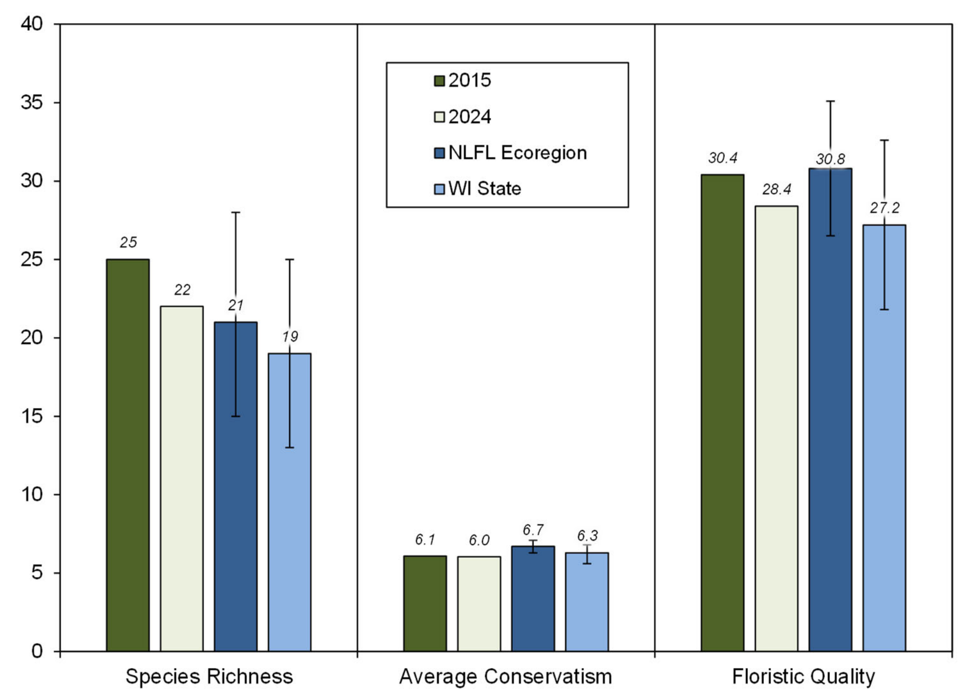

Figure 3.2-4. Roberts Lake Floristic Quality Assessment. Created using data from point-intercept surveys. Analysis following (Nichols, 1999) where NLFL = Northern Lakes & Forests - Lakes Ecoregion.

Species diversity is often confused with species richness. 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 where 50% of the community was comprised of just one or two species.

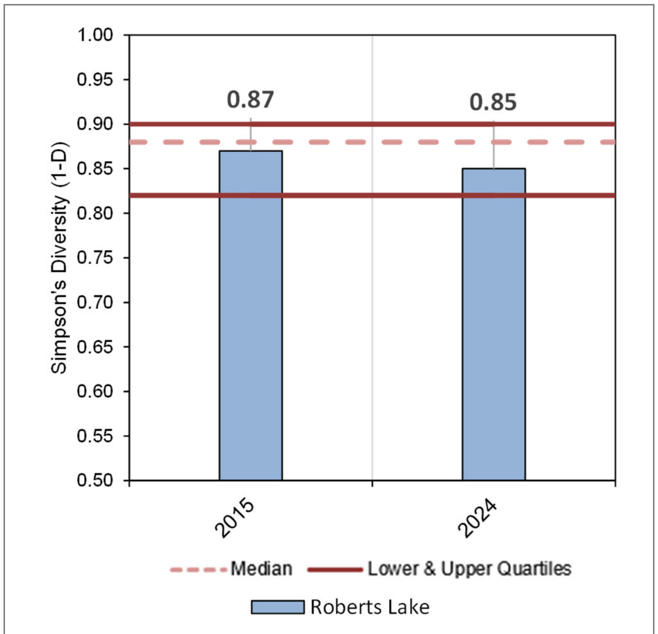

Figure 3.2-5. Simpson's Diversity Index. Created using data from point-intercept surveys.

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from Roberts Lake is compared to data collected by Onterra and the WDNR Science Services on lakes within the Northern Lakes and Forests ecoregion and on lakes throughout Wisconsin (Figure 3.2-5). 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 Roberts Lake's diversity values rank. Roberts Lake's Simpson's Diversity Index value was 0.87 in 2015 which fell just below the median value. The value decreased to 0.85 in 2024 which between the lower quartile and the median values.

Figure 3.2-6 investigates the average number of native plant species at each littoral point-intercept sampling location. The 2024 survey indicated 1.17 native species per littoral sampling site which is about one species less per sampling site than was recorded on the 2015 survey. Map 1 indicates richness values from the 2024 survey and demonstrates that most points that had plants present typically had 1-2 species present, while a few sites around the lake harbored a greater number of native species.

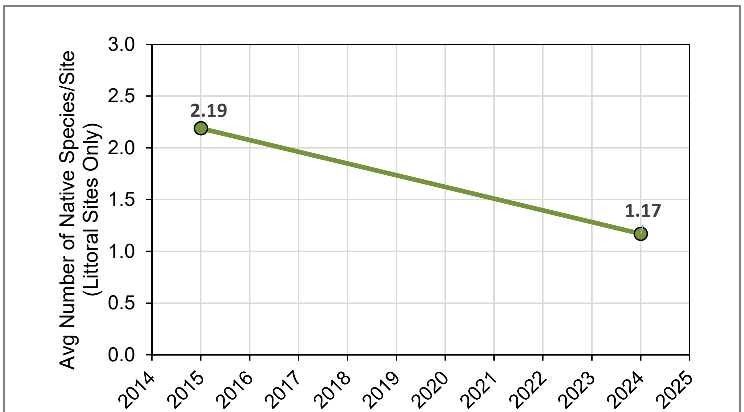

Figure 3.2-6. Average number of native aquatic plant species per littoral sampling site.

In 2024, Onterra ecologists also conducted a survey aimed at mapping emergent and floating-leaved plant communities in Roberts Lake. Emergent and floating-leaf plant communities are a wetland community type dominated by species such as cattails, bulrushes, and water lilies. Like submersed aquatic plant communities, these communities provide valuable habitat, shelter, and food sources for organisms that live in and around the lake. Floating-leaf and emergent plant communities provide other valuable services such as erosion control and nutrient filtration and their root systems stabilize bottom sediments and reduce sediment resuspension. Because they often occur in near-shore areas, they act as a buffer against nutrients and other pollutants in runoff from upland areas.

These communities are often negatively affected by recreational use and shoreland development. (Radomski & Goeman, Consequences of Human Lakeshore Development on Emergent and Floating-leaf Vegetation Abundance, 2001) found a 66% reduction in vegetation coverage on developed shorelands when compared to the undeveloped shorelands in Minnesota lakes. Furthermore, they also found a significant reduction in abundance and size of northern pike (*Esox lucius*), bluegill (*Lepomis macrochirus*), and pumpkinseed (*Lepomis gibbosus*) associated with these developed shorelands.

Emergent and floating-leaf plant communities often recede or expand in response to changes in water levels. As water levels fall, these communities expand as water at their lakeward extent becomes shallower. In contrast, these communities often recede during periods of high-water levels.

In 2024, approximately 22.0 acres of emergent and floating-leaf aquatic plant communities were delineated in Roberts Lake (Figure 3.2-7). Some of the largest contiguous colonies were located along the eastern shoreline of the lake or within bays of the lake (Map 2). These communities were sparser along stretches of the northern shoreline of the lake.

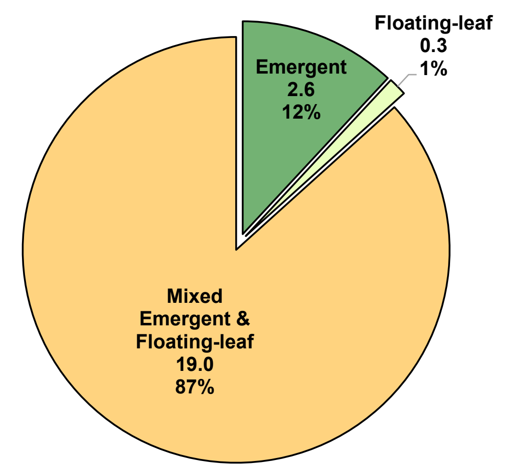

Figure 3.2-7. Acres of floating-leaf and emergent plant communities on Roberts Lake. Data from 2024 community mapping survey conducted by Onterra.

The floating-leaf community is dominated by white water lily (*Nymphaea odorata*) and spatterdock (*Nuphar variegata*). Common emergent species include hardstem bulrush (*Schoenoplectus acutus*), and cattails (*Typha* spp.). During this survey, surveyors also search the shoreland areas for other non-native species such as purple loosestrife, reed canary grass, narrow-leaf cattail, or giant reed. No non-native shoreland species were confirmed during the survey, although it is unclear whether the sterile cattail species are comprised of native, non-native, or hybrid varieties.

The 2024 community mapping survey serves as a snapshot or baseline dataset for comparison to future replications of the survey.

3.3 Non-native Aquatic Plants in the Roberts Lake

Eurasian watermilfoil (Myriophyllum spicatum)

Eurasian watermilfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties. Eurasian watermilfoil is unique in that its primary mode of propagation is not by seed. It spreads by shoot fragmentation, which has supported its transport between lakes via boats and other equipment. In addition to its propagation method, Eurasian watermilfoil has two other competitive advantages over native aquatic plants, 1) it starts growing very early in the spring when water temperatures are too cold for most native plants to grow, and 2) once its stems reach the water surface, it does not stop growing like most native plants, instead it continues to grow along the surface creating a canopy that blocks light from reaching native plants.

Eurasian watermilfoil can create dense stands and dominate submergent communities, reducing important natural habitat for fish and other wildlife, and impeding recreational activities such as swimming, fishing, and boating. However, in some lakes, EWM appears to integrate itself within the community without becoming a nuisance or having a measurable impact to the ecological function of the lake.

The non-native plant that is of primary concern in Roberts Lake is EWM. EWM was discovered in Roberts Lake in 2021 and genetically identified as pure-strain EWM. Subsequently, hybrid watermilfoil (HWM) was also genetically verified within the lake in 2022. The concept of heterosis, or hybrid vigor, is important in regards to HWM management in Roberts Lake. The root of this concept is that hybrid individuals typically have improved function compared to their pure-strain parents. In general, HWM typically has thicker stems, is a prolific flowerer, and grows much faster than pure-strain EWM (LaRue, Zuellig, Netherland, Heilman, & Thum, 2012). These conditions may likely contribute to this plant being particularly less susceptible to chemical control strategies (Glomski & Nehterland, 2010), (Poovey, Slade, & Netherland, 2007), (Nault, et al., 2018). In lakes that contain both EWM and HWM, concern exists that the more-easily controlled EWM component of a lake's invasive milfoil population may be controlled by herbicide treatment, but the slightly less-susceptible HWM component will survive, rebound in a short period of time, and then comprise a larger proportion of the invasive milfoil population.

Fragmentation

It is true that EWM fragments transferred from one lake to another is the cause of essentially every new EWM population. It is also true that EWM fragments are the vector of population spread within a lake. Everyone has been conditioned that EWM fragments are bad. But in reality, it is much more complex.

Photograph 3.3-1. EWM fragment with adventitious roots. Photo credit Onterra.

There are two types of EWM fragments, auto-fragments and allo-fragments. Auto-fragmentation is the purposeful fragmentation of EWM for the purposes of asexual reproduction. This plant has evolved a mechanism to increase its population in this manner. The parent plant sends carbohydrate reserves to the growing tip (apical meristem) before the fragment separates. Also, before separation, the fragment will start growing root-like structures (adventitious roots, Photograph 3.3-1). Applying an analogy, that plant has packed its bags and is ready to endure floating around in the lake for a few days and then trying to grow in a new place in the lake. This naturally happens in all lakes. Onterra's experience is that there are two main events – once in late-spring and again towards the end of the growing season. Allo-fragments are those fragments that break off by mechanical breakage by boats, wind, mechanical harvesting, etc. These fragments have a smaller chance of producing a new plant – continuing with the analogy, because they did not get to pack their bags and must try to make it with what they have on hand.

For a new infestation, lake managers are concerned with all types of fragments. But for an established population with auto fragmentations occurring naturally, a few additional allo-fragments are insignificant to worry about from a population management perspective. However, fragments of any plant species can be unwelcomed by riparians when they accumulate on their shoreline.

Frankly, for established populations like those that now exist on Roberts Lake, lake managers are not really concerned with EWM fragments at all (either kind). The footprint of EWM is everywhere conducive for the plant under the current environmental conditions. If it is not growing in a part of the lake, it is not because it has never been exposed to that area. It is because the conditions are not favorable at this time. Conditions change from year to year and the footprint and density of EWM will also, even if unmanaged.

WDNR Long-Term EWM Trends Monitoring Research Project

Starting in 2005, WDNR Science Services began conducting annual point-intercept aquatic plant surveys on a set of lakes to understand how EWM populations vary over time. This was in response to commonly held beliefs of the time that once EWM becomes established in a lake, its population would continue to increase over time.

Like other aquatic plants, EWM populations are dynamic and annual changes in EWM frequency of occurrence have been documented in many lakes, including those that are not being actively managed for EWM control (no herbicide treatment or hand-harvesting program). The data are clearest for unmanaged lakes in the Northern Lakes and Forests Ecoregion (NLFL) and the North Central Hardwood Forests Ecoregion (NCHF) (Figure 3.3-1).

The results of the study clearly indicate that EWM populations in unmanaged lakes can fluctuate greatly between years (Figure 3.3-1). Following initial infestation, EWM expansion was rapid on some lakes, but overall was variable and unpredictable (Nault 2016). On some lakes, the EWM populations reached a relatively stable equilibrium whereas other lakes had more moderate year-to-year variation. Regional climatic factors also seem to be a driver in EWM populations, as many EWM populations declined in 2015 even though the lakes were at vastly different points in time following initial detection within the lake. 2019 also experienced record rainfall which may have had an impact on the EWM population indirectly through a decrease in water clarity.

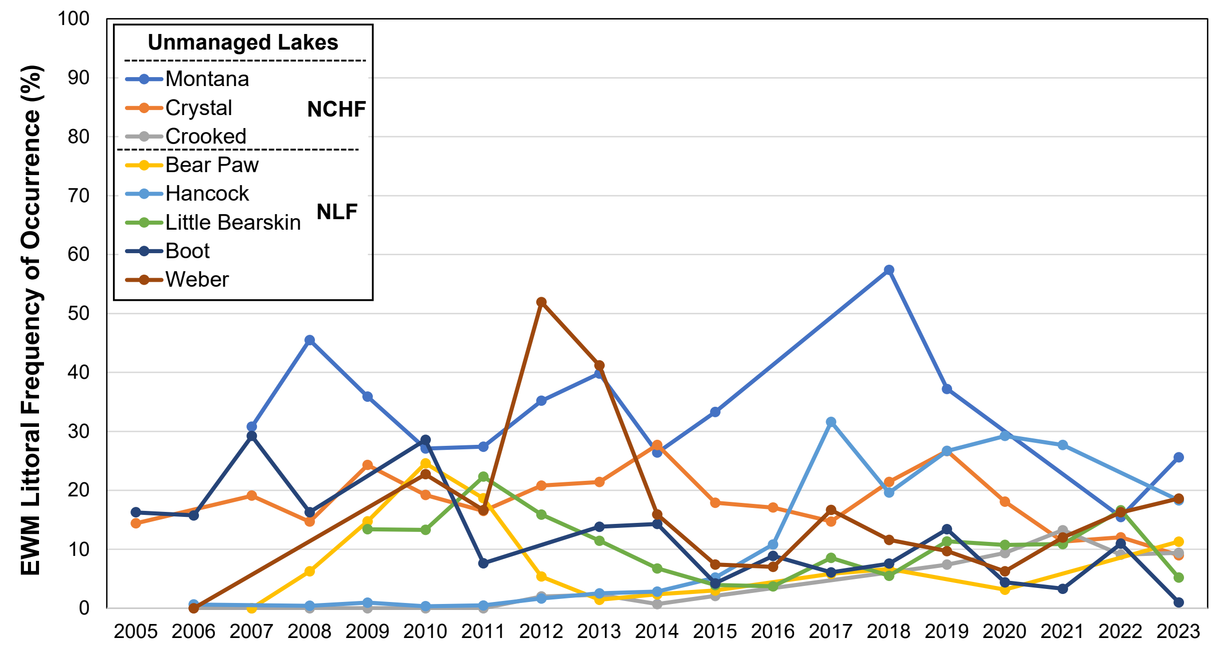

Figure 3.3-1. LFOO of EWM in northern ecoregions without management. Data provided by and used with permission from WDNR. LFOO = littoral frequency of occurrence.

It is important to note that two types of surveys are discussed in the subsequent materials: 1) whole lake point-intercept surveys and 2) EWM mapping survey. Overall, each survey has its strengths and weaknesses, which is why both are utilized in different ways as part of this project.

The point-intercept survey provides a standardized way to gain quantitative information about a lake's aquatic plant population through visiting predetermined locations and using a rake sampler to identify all the plants at each location. The point-intercept survey can be applied at various scales. Most commonly, the point-intercept survey is applied at the whole-lake scale to provide a lake-wide assessment of the overall plant community.

While the point-intercept survey is a valuable tool to understand the overall plant population of a lake, it does not offer a full account (census) of where a particular species exists in the lake. During the EWM mapping survey, the entire littoral area of the lake is surveyed through visual observations from the boat (Photograph 3.3-2). Field crews supplemented the visual survey by deploying a submersible camera along with periodically doing rake tows. The EWM population is mapped using sub-meter GPS technology by using either 1) point-based or 2) area-based methodologies. Large colonies >40 feet in diameter are mapped using polygons (areas) and are qualitatively attributed a density rating based upon a five-tiered scale from *highly scattered* to *surface matting*. Point-based techniques were applied to AIS locations that were considered as *small plant colonies* (<40 feet in diameter), *clumps of plants*, or *single or few plants*.

Photograph 3.3-2. Point-intercept survey on a WI lake. Photo credit Onterra.

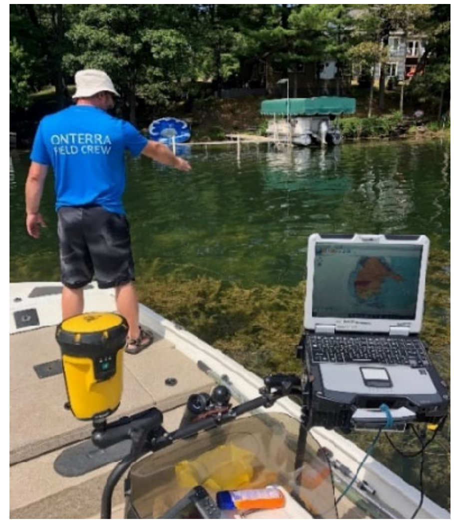

Photo 3.3-3. EWM mapping survey on a Wisconsin lake. Photo credit Onterra.

EWM population of Roberts Lake

Using data collected from the point-intercept surveys, the littoral frequency of occurrence of EWM can be compared for Roberts Lake. EWM was not physically encountered on the survey rake in 2015 so the 2015 occurrence was 0%. Of the 410 littoral sampling locations in the 2024 survey, EWM was recorded on 75 of them resulting in an occurrence of 18.3% (Map 3, left frame).

The EWM population was monitored through a series of annual late-season EWM mapping surveys spanning from 2015-2020 as well as 2022 and 2024 (Figure 3.2-3). Please note that this figure only represents only the acreage of mapped EWM polygons, not EWM mapped with point-based methodologies (*Single or Few Plants, Clumps of Plants,* or *Small Plant Colonies*). Said another way, EWM marked with point-based mapping methods do not contribute to colonized acreage as shown on Figure 3.3-5. From 2015-2017 only point-based EWM occurrences were documented with no large contiguous areas forming colonized beds of plants. From 2018-2020, modest colonized areas were mapped which totaled around 2 acres each year; however, the population continued to increase within the lake, particularly at the northwest end (Map 4). No mapping survey took place in 2021, but the 2022 survey indicated a large increase in colonized EWM in the lake with over 17 acres present (Map 5). Further expansion into new areas of the lake was

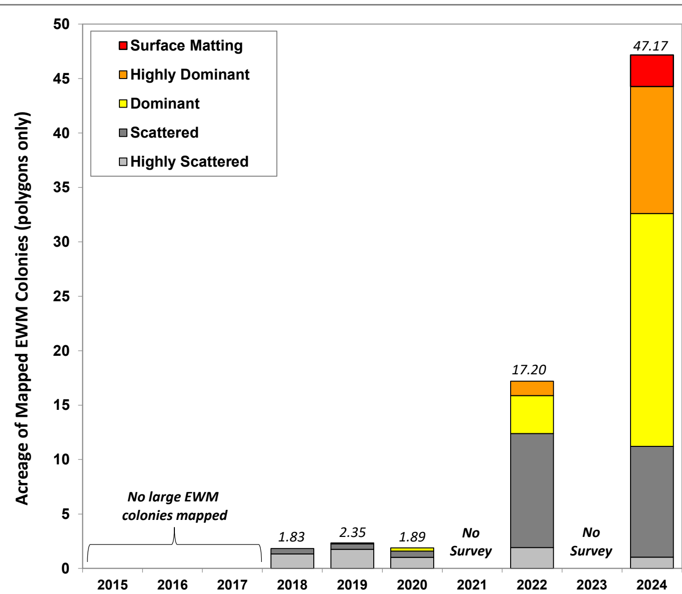

Figure 3.3-2. Acres of EWM Mapped on Roberts Lake. Data from late-season EWM mapping surveys.

documented in 2022 including along stretches of the northern shoreline. No mapping survey took place in 2023.

Onterra ecologists completed the late-season EWM mapping survey on Roberts Lake on August 27, 2024. During this survey, the crew systematically meandered the entire littoral zone tracking the survey path to ensure full coverage of the lake. The EWM population was widespread around the littoral areas of the lake with several large colonized beds of plants (Map 6). Lesser densities were present in the southern end of the lake including near the public boat landing, while dense colonies were located along much of the northern shoreline and the northeast end of the lake. In total, 47.2 acres of EWM was delineated with polygons. Approximately 36 acres consisted of density ratings of either *dominant*, *highly dominant*, or *surface matting* which are contributing to impacts to recreational uses in those areas.

Roberts Lake Historic HWM Management

The EWM population in Roberts Lake was found to be relatively low during the August 2015 survey and professional hand-harvesting efforts were determined to be the most appropriate method for control. Professional hand-harvesting efforts have been conducted on Roberts Lake from 2015-2020. The initial goal of the hand harvesting program during this project of maintaining the EWM population below levels requiring area-based mapping was not met, however; as the project progressed, the goal of the harvesting strategy evolved. The 2020 hand harvesting strategy of inhibiting EWM from populating new areas of the lake, should be considered successful. All areas where professional hand harvesting efforts took place either saw a reduction in EWM or were maintained at a low population in the area.

A total of 131.2 combined diver hours was spent over the seven years and yielded approximately 615 cubic feet of EWM harvest during that time span (Table 4.0-1). Initial hand harvesting efforts targeted the entire known EWM population in the lake, however as the population increased in the northeast end of the lake in particular, the harvesting strategy was modified to target isolated and smaller density occurrences around the remainder of the lake. The last harvesting effort in 2022 lead to a much higher harvest yield compared to all previous years, likely as a result of the increasing EWM population in the lake during that time span.

Table 3.3-1. Roberts Lake, 2015-2022 professional hand-harvesting activities.

Year	Dive Time (hr)	EWM Removed (cubic feet)
2015	12.8	37.0
2016	9.3	22.0
2017	13.0	23.3
2018	48.3	25.5
2019	10.8	57.5
2020	11.5	44.5
2022	25.6	405.5
Total:	**131.2**	**615.3**

Over the course of the RLA's AIS EDR project, the RLA has learned a great deal about the applicability of a coordinated professional hand harvesting program in managing EWM in Roberts

Lake. The RLA has gained valuable insights as to the capabilities as well as the limitations of hand harvesting with or without the aid of DASH, as a tool to manage EWM.

Question 25. Eurasian watermilfoil has been managed with manual removal methods which includes traditional hand-harvesting and the use of Diver Assisted Suction Harvesting (DASH) equipment. What is your level of support or opposition for the past hand-harvesting/DASH to target Eurasian watermilfoil in Roberts Lake?

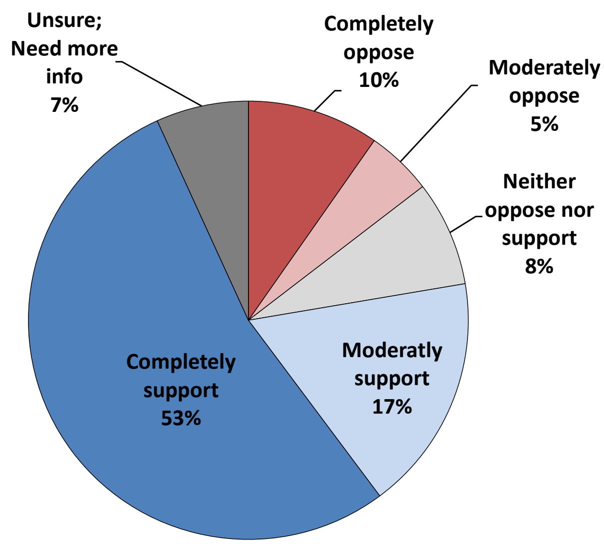

Figure 3.3-3. Select survey responses from the Roberts Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Future AIS Management Philosophy

The term *Best Management Practice (BMP)* is often used in environmental management fields to represent the management option that is currently supported by that latest science and policy. When used in an action plan, the term can be thought of as a placeholder with anticipation of having an evolving definition over time. BMPs for aquatic plant management change rapidly, as new information about effectiveness, non-target impacts, and risk assessment emerges. One of the primary purposes of completing an APM Update is to ensure that the group's goals and actions align with what is considered to be the current BMP for AIS management. Materials included within the text below serve to provide an overview of current BMP's for EWM management for the RLA to review and consider when creating their updated APM Plan.

During the Planning Committee meetings, Onterra will outline three broad EWM population management perspectives for consideration, including a generic potential action plan for each (Figure 3.3-3). Onterra has extracted relevant chapters from the WDNR's *APM Strategic Analysis Document* to serve as an objective baseline for the RLA to weigh the benefits of the management strategy with the collateral impacts each management action may have on the Roberts Lake ecosystem. These chapters are included as Appendix D. The RLA Planning Committee will review these management perspectives in the context of perceived riparian stakeholder support, which is discussed in the subsequent sub-section.

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

Figure 3.3-4. Potential EWM Management Perspectives

Let Nature Take its Course: In some instances, the EWM population of a lake may plateau or reduce without conducting active management, as shown in the WDNR Long-Term EWM Trends Monitoring Research Project on Figure 3.3-1. Some lake groups decide to periodically monitor the EWM population, typically through a mapping survey, but do not coordinate active management (e.g., hand-harvesting or herbicide treatments). This requires that the riparians tolerate the conditions caused by the EWM, acknowledging that some years may be problematic to recreation, navigation, and aesthetics. Individual riparians may choose to hand-remove the EWM within their recreational footprint, but most often the lake group chooses not to assist financially or with securing permits. In some instances, the lake group may select this management goal, but also set an EWM population threshold or management *trigger* where they would revisit their management strategy if the population reached that level. Said another way, the lake group would let nature take its course up until populations reached a certain lake-wide level or site-specific density threshold. At that time, the lake group would investigate whether active management measures may be justified.

Lake-Wide Population Management: Some believe that there is an intrinsic responsibility to correct for changes in the environment that are caused by humans. For lakes with EWM populations, that may be to manage the EWM population at a reduced level with the perceived goal to allow the system to function as it had prior to EWM establishment. It must also be acknowledged that some lake managers and natural resource regulators question whether that is an achievable goal as management actions have unintended collateral impacts.

In early EWM populations, the entire population may be targeted through hand-harvesting or spot treatments. On more advanced or established populations, this may be accomplished through large-scale control efforts such as water-level drawdowns or whole-lake herbicide treatment strategies. In areas of the state that contain highly established and prevalent EWM populations, lake-wide population management is often considered too aggressive by local WDNR regulators. In these instances, the nuisance conditions are targeted for management and other areas are tolerated or avoided.

Nuisance Control: Some lake groups acknowledge that the most pressing issues with the EWM population on their lake is the reduced recreation, navigation, and aesthetics compared to before EWM became established in their lake. Particularly on lakes with large EWM populations that may be impractical or unpopular to target on a lake-wide basis, the lake group would coordinate (secure permits and financially support the effort) a strategy to improve these cultural ecosystem services.

There has been a change in preferred strategy amongst many lake managers and regulators when it comes to established EWM population in recent years. Instead of chasing the entire EWM population with management, perhaps focusing on the areas that are causing the largest impacts can be more economical and cause less ecological stress. The majority of EWM management in Wisconsin would be considered nuisance management, where dense areas that are causing navigation or recreation issues are prioritized for management and dense areas not meeting these criteria being left unmanaged. Mechanical harvesting and herbicide spot treatments are most typically employed to reach nuisance management goals, although hand-harvesting/DASH is sometimes employed to target small footprints.

Eurasian watermilfoil Management Best Management Practices

Manual Removal (Hand-Harvesting & DASH)

Photograph 3.3-4. Manual Removal with DASH. Photo credit Aquatic Plant Management, LLC.

Manual removal methods include hand-pulling, raking, and hand-cutting. Hand-pulling involves the manual removal of whole plants, including roots, from the area of concern and disposing them out of the waterbody. Raking entails the removal of partial and whole plants from the lake by dragging a rake with a rope tied to it through plant beds. Specially designed rakes are available from commercial sources or an asphalt rake can be used. Hand-cutting differs from the other two manual methods because the entire plant is not removed, rather the plants are cut similar to mowing a lawn; however, Wisconsin law states that all plant fragments must be removed.

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

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

Mechanical Harvesting

Photograph 3.3-5. Mechanical harvester.

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

A theoretical mechanical harvesting strategy on Roberts Lake would likely be designed with the intention of providing nuisance relief in the form of cutting navigation lanes through dense aquatic plants in high-use areas such as riparian piers or high traffic corridors. Multiple (usually 2-3) cutting events during the growing season may be required to maintain navigation lanes. A WDNR permit (NR 109) is required when conducting mechanical harvesting operations with permits often issued as either 1-year permit or a 5-year permit.

Biological Controls

There are many insects, fish and pathogens within the United States that are used as biological controls for aquatic macrophytes. 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 potential 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. Milfoil weevils are not currently available for purchase. Some lake groups have investigated rearing weevils on their own. Groups may measure weevil population density in the lake or document weevil herbivory impacts to EWM. Expectations of this management technique may be to damage EWM plants or potentially suppress its biomass. A manual that is authored by

Golden Sands RC&D, and is referenced by WDNR, explains weevil biocontrol considerations for Wisconsin Lakes (Golden Sands, 2017).

Herbicide Treatment

Photograph 3.3-6. Liquid herbicide application. Photo credit: Amy Kay, Clarke.

The use of herbicides to control aquatic plants and algae is a technique that is widely used by lake managers. Traditionally, herbicides were used to control nuisance levels of aquatic plants and algae that interfere with navigation and recreation. While this practice still takes place in many parts of Wisconsin, the use of herbicides to control aquatic invasive species is becoming more prevalent. Resource managers employ strategic management techniques towards aquatic invasive species, with the objective of reducing the target plant's population over time; and an overarching goal of attaining long-term ecological restoration. For submergent vegetation, this largely consists of implementing control strategies early in the growing season; either as spatially-targeted, small-scale spot treatments or low-dose, large-scale (whole lake) treatments. Emergent species are targeted with foliar applications at strategic times of the year when the target plant is more likely to absorb the herbicide.

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

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

Aquatic herbicides can be classified in many ways. 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.

Both types are commonly used in Wisconsin with varying degrees of success. In northern Wisconsin, use of contact herbicides for EWM management is generally not supported or permitted by WDNR as these tend to be non-selective herbicides that impact many native species while only resulting in seasonal sub-lethal impacts to EWM. 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.

Herbicide control strategies may be applicable on Roberts Lake. Further information is included below for the RLA to review as a part of building an understanding of current BMP’s for EWM management in Wisconsin.

ProcellaCOR™ has been the state’s most popular herbicide for EWM management in recent years, supplanting the use of 2,4-D in many applications. The active ingredient florpyrauxifen-benzyl is sold exclusively by SePRO under the tradename ProcellaCOR™. This herbicide has largely been used in spot treatment scenarios, but has recently been adopted as a whole-lake treatment option on a number of Wisconsin lakes. Onterra has monitored numerous ProcellaCOR™ treatments in Wisconsin since 2019 with data analysis related to herbicide concentration monitoring and native aquatic plant impacts being investigated in most treatments. Analysis of these data have allowed lake managers to better understand the ways in which the herbicide dissipates or mixes within a lake in the hours and days after application. Additionally, aquatic plant monitoring data provides insights as to which native species are typically impacted with ProcellaCOR™ treatments. The WDNR's fact sheet on this chemistry can be found in Appendix D.

Monitoring ProcellaCOR treatments has indicated that most spot-treatments have resulted in multi-year EWM reductions in the treated area. Many spot treatments have also shown impacts to EWM beyond the direct application area, sometimes resulting in measurable EWM impacts within the volume of water in which the herbicide mixed within after treatment. Intentional whole-lake treatment designs have been completed in recent years, with favorable results to date with some treatments demonstrating 3 or more years of reduced EWM to-date.

Native plant impacts from ProcellaCOR treatments have become more predictable over time through analysis of aggregate case studies. Species that are known to be susceptible include northern watermilfoil (highly impacted), coontail (moderately impacted), with suspected susceptibility amongst some other non-dicot species such as water crowfoot and water marigold. Pondweeds and most other native species have shown little to no negative impacts from ProcellaCOR treatments.

Lake managers continue to learn how to successfully implement this form of treatment after being registered for use in Wisconsin in 2019. ProcellaCOR™ is in a new class of synthetic auxin mimic herbicides with reportedly short concentration and exposure time (CET) requirements compared to other systemic herbicides. Auxin-mimic herbicides are translocated throughout the plant and suppress growth regulation hormones, so the plant grows uncontrollably at the cellular level which causes mortality.

Fluridone is a systematic herbicide that disrupts photosynthetic pathways (carotenoid synthesis inhibitor). The herbicide degrades via photolysis (some microbial degradation may also occur) and requires long exposure times (>90 days) to cause mortality to EWM. Herbicide concentrations within the lake are kept at target levels by periodically adding additional herbicide ("bump treatment") over the course of the summer based upon herbicide concentration monitoring results. While liquid fluridone treatments result in a high initial concentration that tapers off over time as the herbicide degrades, pelletized fluridone treatments gradually reach peak concentrations over time (extended release) and result in a lower, sustained lake-wide herbicide concentration. Fluridone has relatively well understood impacts to native aquatic plant species and is generally less selective towards EWM as compared to 2,4-D or ProcellaCOR. Fluridone is not used in spot-treatment scenarios. The WDNR's fact sheet for fluridone can be found in Appendix D.

Liquid 2,4-D amine has historically been commonly used in whole-lake or whole-basin approaches for EWM control. Some strains of HWM have shown to be more tolerant of 2,4-D use patterns, but properly implemented whole-lake 2,4-D herbicide treatments on pure-strain EWM populations can be highly effective, with minimal EWM, often zero, being detected for a year or two following the treatment. 2,4-D is broken down biologically (microbial digestion) and can degradation rates can differ from lake to lake depending on the microbial community. Studies have indicated that population rebound is typically quicker for hybrid watermilfoil compared to pure-strain EWM in whole-lake 2,4-D treatment applications. The WDNR's fact sheet for 2,4-D can be found in Appendix D.

Herbicide application charges vary greatly depending on the chemical used, who applies it, permitting procedures, and the size/depth of the treatment area.

Herbicide Resistance

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

Repetitive treatments with the same herbicide mode-of-action may cause a shift towards increased herbicide tolerance in the population. This has been observed in many lakes with a history of repetitive 2,4-D treatments. Rotating herbicide use-patterns can help avoid population-level herbicide tolerance evolution from occurring.

Stakeholder Survey Responses to Eurasian Watermilfoil Management

As discussed in Section 2.0, the stakeholder survey asks many questions pertaining to perception of the lake and how it may have changed over the years. Several questions were included relating to opinions on Eurasian watermilfoil and its management with select questions and responses displayed in the following figures. All survey results are included within Appendix B.

Survey respondents indicated EWM having negative impacts for recreational uses including boating, swimming, and fishing, as well as aesthetics (Figure 3.3-6).

Question 24. Has the Eurasian watermilfoil population ever had a negative impact on your enjoyment of Roberts Lake?

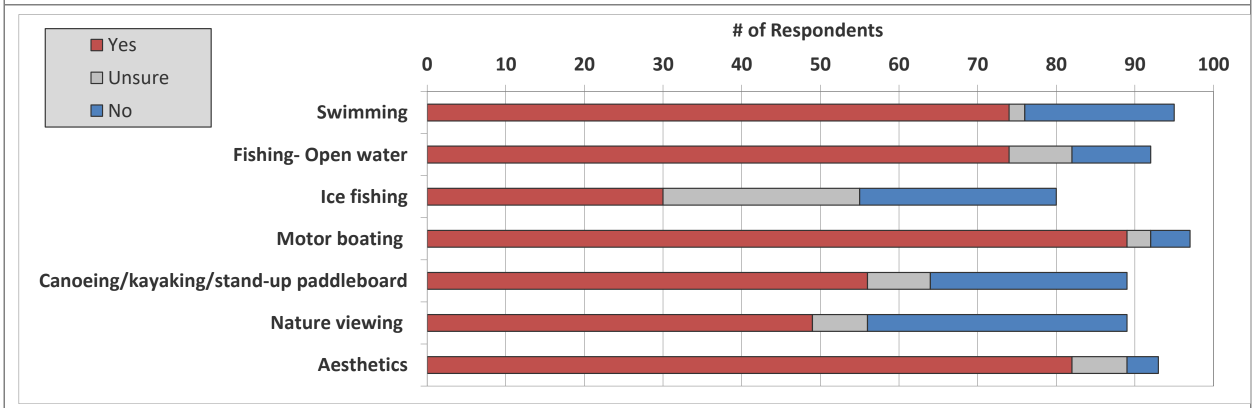

Figure 3.3-5. Select survey responses from the Roberts Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

When asked to indicate their level of support or opposition to various EWM management strategies, hand harvesting/DASH and herbicide treatment showed high levels of support while mechanical harvesting showed more mixed support and opposition (Figure 3.3-7). The no active management approach was not supported by respondents, indicating that stakeholders favor active EWM management.

Question 26. Eurasian watermilfoil can be managed in several ways. What is your level of support or opposition for future management strategies to target EWM in Roberts Lake?

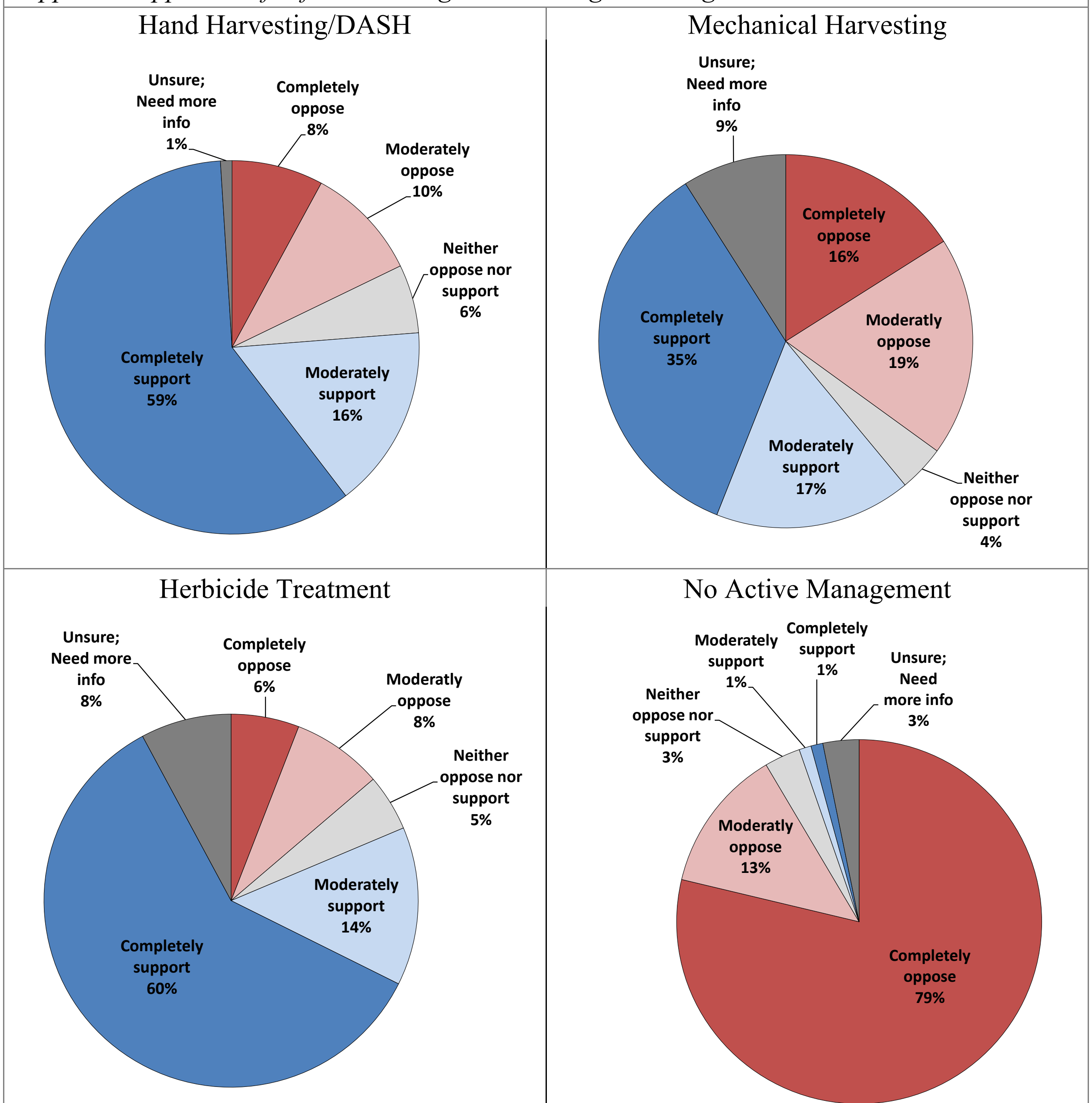

Figure 3.3-6. Select survey responses from the Roberts Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

4.0 SUMMARY & CONCLUSIONS

Monitoring studies completed during 2024 show an average quality aquatic plant population based on floristic quality index metrics and comparison to other lakes in the ecoregion and state. Limited data is available for conducting trend analysis; however, a comparison of point-intercept surveys from 2015 and 2024 shows variability in occurrence for several species.

After considering past EWM management experience and the information gathered during the Onterra studies completed in 2024, the RLA has developed an aquatic plant management plan for Roberts Lake that serves to address the concerns of stakeholders around the lake. As is outlined in the subsequent Implementation Plan Section (5.0), the RLA has developed an Integrated Pest Management Strategy for Eurasian watermilfoil management. This includes the RLA's intention to pursue herbicide treatment in as soon as 2026, with future considerations for follow-up professional hand harvesting efforts.

Discussion during the planning meetings for this project included extended conversation about the use of various techniques available for meeting EWM control goals in Roberts Lake. The RLA understands that EWM eradication is not attainable and has reviewed different management perspectives. The RLA intends to conduct an integrated pest management approach to EWM in the future and will use an adaptive approach to manage the species in the long term.

The RLA has outlined goals to ensure their management plan is up to date and to conduct basic aquatic plant monitoring activities going forward. The RLA developed a proactive management goal of preventing new AIS species from being introduced to the lake, largely through pursuing actions at the public boat landing.

Further, RLA seeks to enhance its capacity to manage the lake through promoting education, awareness, and participation amongst membership and non-members around Roberts Lake while maintaining partnerships with other management entities that have a role in managing the lake.

5.0 AQUATIC PLANT IMPLEMENTATION PLAN SECTION

The Implementation Plan presented below was created through the collaborative efforts of the Roberts Lake Planning Committee and ecologist/planners from Onterra. 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 Roberts Lake stakeholders as portrayed by the returned stakeholder survey and communications with the RLA. The Implementation Plan is a living document in that it will be under periodic review and adjustment depending on the condition of the lake, the availability of funds, level of volunteer involvement, and the needs of the stakeholders.

Management Goal 1: Ensure the RLA has a Functioning and Up-to-Date Management Plan

Management Action:	Ensure the RLA has an updated management plan including aquatic plant management aspects
Timeframe:	Aquatic Plant Management Plan Update every 5 years, Comprehensive Plan Update approximately every 10 years
Facilitator:	RLA Board
Description:	The term *Best Management Practice (BMP)* is often used in environmental management fields to represent the management option that is currently supported by the latest science and policy. When used in an action plan, the term can be thought of as a placeholder with anticipation of having an evolving definition over time. ***Aquatic Plant Management Plan*** BMPs for aquatic plant management change rapidly, as new information about effectiveness, non-target impacts, and risk assessment emerges. To be eligible to apply for grants that provide cost share for AIS control and monitoring, "a current plan must have a completion date of no more than 5 years prior to submittal of the recommendation for approval". The department may determine that a longer lifespan is appropriate for a given management plan if the applicant can demonstrate it has been actively implemented and updated during its lifespan. However, a [whole-lake] point-intercept survey of the aquatic plant community conducted within 5 years of the year an applicant applies for a grant is required." An Aquatic Plant Management (APM) Plan is one component of a Comprehensive Lake Management Plan, which the RLA has not completed to-date. The RLA would revisit this APM Plan in roughly 5 years. ***Comprehensive Management Plan*** The WDNR recommends *Comprehensive Lake Management Plans (CLMP)* generally get updated every 10 years. Implementation projects require a completion date of "no more than 10 years prior to the year in which an implementation grant application is submitted." This allows a review of the available data from the lake, as well as considering changing BMPs for water quality, watershed, shoreland condition, and fisheries management. With the APM update occurring in 2025, the RLA will consider updating the other

	aspects of their Comprehensive Management Plan in a future project to provide an updated assessment of all aspects of the lake including the water quality, shoreland condition, and fisheries management. ***Annual Control & Monitoring Plan*** It is important to note that the APM Plan provides a framework to guide the aquatic plant management action but may not include the specific action plan for a given year. If the action being considered does not fall within the framework of the overall management plan, it is likely that an updated plan is needed regardless of its relative age. If the RLA intends to conduct active management towards aquatic plants, a written control and monitoring plan, consistent with the *Management Plan*, would be produced typically January-March prior to its implementation to outline the control and monitoring strategy. The annual report offers specific details of proposed management strategies for the upcoming season such as number of acres being managed, method of management (herbicide, mechanical, DASH, etc.), and accompanying monitoring plan. The annual report is useful for WDNR and other regulators when considering approval of the action, as well as to convey the control plan to RLA members for their understanding. An annual report would also be created following the management action, assessing the results of the activity.

Management Goal 2: Monitor Aquatic Vegetation within Roberts Lake

Management Action:	Periodically monitor the Eurasian watermilfoil population
Timeframe:	Annually while active management strategies are being considered or implemented. Timing: later portion of growing season, likely August or September
Facilitator:	RLA Board
Description:	As the name implies, the Late-Season EWM Mapping Survey is a professionally contracted survey completed towards the end of the growing season when EWM is at its anticipated peak growth stage, allowing for a true assessment of the extent of the population within the lake. For Roberts Lakes, this survey would likely take place in August or September, dependent on the growing conditions of the particular year and occurring after all management activities have ceased. This survey would include a complete meander survey of the lake's littoral zone by professional ecologists and mapping using GPS technology (sub-meter accuracy is preferred).

	Since the discovery of EWM in 2015, late-season EWM mapping surveys have occurred on Roberts Lake most years. The RLA intends to continue conducting Late-Season EWM Mapping Surveys annually to support their EWM management program but will consider a longer timeframe between surveys if EWM management is not occurring in a given year.

Management Action:	Coordinate periodic aquatic plant surveys
Timeframe:	Periodic: point-intercept survey at least once every 5 years
Facilitator:	RLA Board
Description:	The point-intercept aquatic plant monitoring methodology as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) have been completed in Roberts Lake in 2008 and 2023. This survey provides quantitative population estimates for all aquatic plant species within the lake and is designed to allow comparisons with past surveys in Roberts Lake as well as to other waterbodies throughout the state. The RLA will plan to have a point-intercept survey completed at least once every five years. This will allow a continued understanding of the submergent aquatic plant community dynamics within the lake. This frequency of data collection will ensure the RLA is eligible for future WDNR grant applications. More frequent surveys, possibly annually, would be expected to be occur surrounding periods of active EWM management, particularly management with herbicides. A sub-set of the whole lake point-intercept survey may be appropriate for use in studying management sites, whereas a finer-scale sub-sample point-intercept grid may be created for studying smaller-sized management sites.

Management Goal 3: Ensure recreational use of the lake is maintained

Management Action:	Conduct Integrated Pest Management program for EWM
Timeframe:	Ongoing
Potential Grant:	WDNR AIS Established Population Control (EPC) Grant
Facilitator:	RLA Board
Description:	The long-term objective of this action is to minimize the negative attributes that EWM causes on Roberts Lake by maintaining navigation, recreational use, and aesthetics. The RLA has outlined an Integrated Pest Management (IPM) approach toward managing EWM in order to reach the intended goal. Each of the potential management strategies are discussed below. *Volunteer hand harvesting*

	The RLA will inform property owners of options available to them for improving recreational use of their individual frontage. Each riparian owner can legally harvest any aquatic plants in a 30' wide area of one's frontage directly adjacent to one's pier without a permit. Simply wading into the lake and removing aquatic plant vegetation by hand or with the aid of a rake or other hand-held accessories can be helpful in managing aquatic plants on a small and individual property-based scale. Non-native species including EWM can be hand removed anywhere in the lake without a permit and therefore is not limited to the 30' corridor zone. A WDNR permit is required if an area larger than the 30' corridor is being harvested or if a mechanical assistance mechanism, like DASH (Diver Assisted Suction Harvesting), is being used. Individual property owners may seek a WDNR permit to utilize DASH to manage aquatic plants in their frontage zone. One or two days of harvesting each year would likely provide seasonal relief from dense aquatic plants in an area being used for recreational purposes. Some professional firms offer services to remove aquatic vegetation from within the riparian property owner's 30' frontage zone, though it is more economical to solicit these efforts from local sources if available. *Contracted Hand harvesting/Diver Assisted Suction Harvest* This type of control strategy is particularly effective when targeting small and low-density EWM populations. As the size of the EWM population increases, the utility of a hand harvesting strategy becomes scale limited and can be cost prohibitive. The RLA has utilized professional hand harvesting efforts during 2015-2022. Early efforts targeted the entire known EWM population, while after a few years the strategy shifted towards targeting isolated occurrences around the lake to slow the overall rate of expansion. These efforts suppressed EWM in targeted areas but made no measurable difference in the population of EWM within the lake. This technique has utility on a small scale in Roberts Lake, such as within a riparian's 30' use corridor; however, DASH is not feasible for use on a lake-wide scale EWM population management. One of the most-commonly employed uses of a hand harvesting strategy in lakes with an established EWM population is to target remnant or resurgent plants in the years after herbicide management occurs. The smaller EWM population expected after herbicide management is typically of a more feasible scale for a hand harvesting approach to be an effective method of management. The goal of using this type of integrated pest management approach is to delay the need for future herbicide management and slow the inevitable resurgence of the EWM population in the lake. The RLA would consider conducting hand harvesting, including the use of DASH, to target EWM in the years following herbicide treatments. Contracted hand harvesting efforts may also be conducted at individual riparian properties to aid in ensuring navigability and recreational use or in other high use areas of the

lake such as the vicinity of the public boat landing. EWM mapping surveys would be used to guide the hand harvesting efforts when these data are available. If DASH is to be used, the RLA will submit a permit application to WDNR including a map of the areas to be harvested.

Mechanical Harvesting
A theoretical mechanical harvesting strategy was discussed during the planning meetings for this project. This type of management technique has the potential to serve as a long-term aquatic plant management tool for lakes where impacts to recreational use are taking place, either through native and/or non-native aquatic plant species alike. The use of a mechanical harvester would likely involve cutting lanes from high-use areas of the lake such as from pierheads out to deeper waters, or in other high use areas of the lake. This technique would be much more efficient than DASH in terms of accomplishing the creation of recreational use lanes. Cutting operations on one or two occasions during the growing season would likely be sufficient in achieving the seasonal relief from nuisance level plant growth and this type of program may require annual implementation to meet management goals. A WDNR permit would be required to conduct mechanical harvesting with clearly delineated harvesting areas displayed on a map. A disposal location for the harvested plant materials would be determined as a part of a mechanical harvesting plan.

The RLA has reservations about the high cost of implementation vs the short-term gain of the effort. This management technique would be something that the RLA would investigate in future APM updates, particularly if nuisance level growth of aquatic plants occurs on a regular basis and if the use of herbicide to mitigate the EWM population is not permitted or otherwise taking place.

Herbicide Treatment
Considerations for conducting an herbicide treatment would be made utilizing the current understanding of best management practices for this technique. RLA prefers a conservative approach to herbicide use with intentions to avoid multiple consecutive years with their use. Limited use of herbicides is also looked at more favorably than annual treatments by WDNR fisheries managers and from a regulatory perspective.

While some herbicide spot treatments show promise, the unpredictability of spot treatments state-wide has resulted in less favorability of this strategy with some WDNR regulators and lake managers. This is particularly true in areas of increased water exchange via flow, exposed and offshore EWM colonies, or when traditional weak-acid herbicides like 2,4-D are used. Any herbicide spot-treatments on Roberts Lake would consider herbicides thought to be effective under short exposure situations. At the time of this writing, florpyrauxifen-benzyl (ProcellaCOR™), is an example of an herbicide with reported short exposure time requirements that is employed for spot treatments of invasive watermilfoil control in Wisconsin. Advancements in research into new herbicides and use

	patterns will need to be integrated into future management strategies, including effectiveness, native plant selectivity, and environmental risk profile. The RLA understands that herbicide treatment will not eradicate EWM from the lake, but would ideally result in several years of a reduced population that could potentially be extended longer through follow-up management efforts such as hand harvesting. Stakeholders indicated a relatively high level of support for the future use of herbicide treatments as an EWM management technique in Roberts Lake (74%) pooled either *highly support*, or *somewhat support*. (Question 26, Appendix A). Some respondents were opposed to the future use of herbicides to manage EWM (14%, pooled as either *completely opposed* or *moderately opposed*). The RLA would use the following trigger to initiate discussion for considering herbicide treatment: *colonized areas of EWM where a sufficiently large treatment area can be constructed to hold concentration and exposure times that would be expected to result in plant mortality (preference to dominant or greater density EWM populations).* In practice, spot-treatments require a minimum size of approximately 5 acres to be able to hold concentration exposure times long enough to achieve EWM mortality. Sites that are somewhat protected from dissipation, such as being located in a bay of a lake, and sites that are broader in shape rather than narrow, would have a greater likelihood of success in a spot-treatment design scenario compared to offshore sites. Dominant or greater density ratings mapped from a late-season EWM mapping survey are approximately indicative of conditions in which recreational use of the lake is impacted. Recent regulatory interpretations of NR 107 have often required navigational impairment conditions to be present when considering issuance of herbicide permits. If the trigger is met and the RLA is considering herbicide treatment, early consultation with WDNR would occur along with the following set of bullet points: • Create a Control and Monitoring Plan. The Control and Monitoring Plan would likely be created based on the results of a late-summer EWM mapping survey or in combination with the results of a whole-lake point-intercept survey. These data would be used to create a specific EWM control strategy for the following year including information such as the herbicide to be used, dosing strategy, targeted areas, and an accompanying monitoring strategy. The Control and Monitoring Plan would include applicable risk assessment materials for the RLA to review. This might include a summary of available research, toxicity, selectivity, etc.

- Monitoring for EWM efficacy at the scale of likely impact. If the treatment is a true spot treatment, the application area should be monitored. If the Area of Potential Impact (AOPI) is larger, such the entire lake, monitoring would occur on a whole lake level.
- EWM control efficacy would occur by comparing annual late-summer EWM mapping surveys
- If grant funds are being used or new-to-the-region herbicide strategies are being considered, the WDNR may request a quantitative evaluation monitoring plan be constructed that is consistent with the *Draft Aquatic Plant Treatment Evaluation Protocol (October 1, 2016)*. This generally consists of collecting quantitative point-intercept the *late-summer prior to treatment* (pre) and the summer following the treatment (post) at the scale of AOPI.
- Herbicide concentration monitoring may also occur surrounding the treatment if grant funds are being used or the RLA believes important information would be gained from the effort.

An herbicide applicator firm would be selected and a permit application would be applied to the WDNR as early in the calendar year as practical, allowing interested parties sufficient time to review the control plan as well as review the permit application.

Unless specified otherwise by the manufacturer of the herbicide, an early-season use-pattern would occur. This would consist of the herbicide treatment occurring towards the beginning of the growing season (typically in June), after active growth tissue is confirmed on the target plants. A focused pretreatment survey would take place approximately a week or so prior to treatment. This site visit would evaluate the growth stage of the EWM (and native plants) and confirm the proposed treatment area extents and water depths. This information would be used to finalize and confirm the treatment specifics and dictate approximate ideal treatment timing. Additional aspects of the treatment may also be investigated, depending on the use pattern being considered, such as the role of stratification.

A minimum indication of meeting herbicide treatment success criteria would be such that little to no EWM would persist in treated areas during the year of treatment, with minimal sign of recovery during the year after treatment as well.

Short Term EWM Management Strategy (2025-2026)
The RLA intends to share information to members during 2025 about actions that individual property owners can take within their individual frontage to manage EWM and aquatic plants. A larger coordinated aquatic plant management strategy is not planned during 2025 as the RLA seeks to reserve funds for potential management efforts in 2026.

RLA plans to collect pre-treatment data during 2025 that would support the potential for an herbicide management strategy in 2026. These data would be in

	the form of both quantitative (point-intercept survey) and qualitative monitoring surveys (late-summer EWM mapping survey). Further, RLA anticipates applying for a WDNR AIS-control grant during the fall 2025 cycle that would provide funding support to carry out the management strategy for 2026. At this time, the most likely management activity being considered for 2026 includes a spot ProcellaCOR herbicide treatment targeting some of the densest areas of EWM in the lake where impacts to recreational uses are occurring. As of late-summer 2024, large and dense colonies of EWM were present around portions of the lake that meet the threshold discussed above for considering herbicide management strategies. Data from a 2025 late-summer EWM mapping survey will ultimately be used to design the final treatment strategy for 2026. In the event that the AIS control grant application is unsuccessful, RLA would likely move forward with a proposed treatment strategy for 2026 without the aid of state funds.
Action Steps:	
1.	Retain qualified professional assistance to develop a specific project design utilizing the methods discussed above.
2.	Initiate control and monitoring plan.
3.	Update management plan to reflect changes in control needs and those of the lake ecosystem.

Management Goal 4: Prevent Introduction of New Aquatic Invasive Species to Roberts Lake

Management Action:	Investigate means by which to enhance AIS introduction prevention measures at public access location
Timeframe:	Initiate 2025
Facilitator:	RLA Board
Description:	The RLA continues to be wary of the potential for additional AIS to be introduced into the lake and has identified the public boat landing access point as the primary pathway for introduction of AIS. Examples of known AIS in the region that RLA seeks to prevent introduction into Roberts Lake are curly-leaf pondweed (*Potamogeton crispus*) and starry stonewort (*Nitellopsis obtusa*). Both of these species have the potential for excessive growth that impacts recreational uses in lakes. RLA has participated in the Clean Boats Clean Waters (CBCW) program in the past and continues to make AIS prevention a point of emphasis. The RLA plans to enhance their AIS prevention strategy by increasing preventative measures the public access location. RLA will evaluate the applicability for installation of boat cleaning station, video surveillance (ILIDS), volunteer inspector presence, AIS signage, or other means of prevention. RLA will contact their local WDNR AIS

	coordinator for direction and informative resources in order to meet this objective. Small scale WDNR grants may be applicable for use in enhancing preventative measures. RLA supports local ordinances that limit the use of wake boats on the lake as a means of preventing AIS introduction through ballast waters. RLA will include information about AIS preventative measures within their educational materials shared with stakeholders as component of Management Plan Goal #5. Question #33 of the riparian stakeholder survey indicates that there are people willing to participate in watercraft inspections at the boat landing. The RLA will reach out to membership to connect with those willing to participate in this AIS prevention activity.

Management Goal 5: Increase the RLA'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:	Continuation of current efforts
Facilitator:	RLA Board
Description:	Education represents an effective tool to address many lake issues. The RLA has a website which is regularly updated with RLA information. RLA hosts social events during the summer to provide information to members and encourage support and participation in RLAA initiatives. These mediums allow for communication with association members, but increasing the level of communication is important within a management group because it facilitates the spread of important association news, social events, educational topics, and dispels misconceptions. The stakeholder survey indicated that some people were interested in writing newsletter articles and in managing the RLA's social media accounts and website. RLA will reach out to membership to connect with these persons to participate in this endeavor. The RLA will continue to make the education of lake-related issues a priority. These may include educational materials, awareness events, and demonstrations for lake users as well as activities which solicit local and state government support. Many respondents in the stakeholder survey indicated interest in participating in water quality or aquatic plant monitoring (Appendix B, Question #32). The RLA seeks to reach out to membership to connect with persons that are interested in getting involved in RLA activities.

	Example Educational Topics • Aquatic invasive species identification • Aquatic invasive species monitoring and management • Role of native aquatic plants • Human tolerance to EWM conditions • EWM fragmentation as a natural means of propagation • EWM management techniques • Means of prevention of further introduction of AIS into the lake • Basic lake ecology • Impacts of drought and low water levels • Boating safety • Swimmers itch • Shoreline habitat restoration and protection • WDNR Healthy Lakes Program • Noise and light pollution • Fishing regulations • Recreational use of the lake

Management Action:	Continue RLA's involvement with other entities that have responsibilities in managing Roberts Lake
Timeframe:	Continuation of current efforts
Facilitator:	RLA Board
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 others organizations rely on voluntary participation. It is important that the RLA actively engage with all management entities to enhance the association's understanding of common management goals and to participate in the development of those goals. This also helps all management entities understand the actions that others are taking to reduce the duplication of efforts. Each entity will be specifically addressed in the table on the next page:
Action Steps:	
	See table guidelines on the next pages.

Table 5.0-1 Management Partners

Partner	Contact Person	Role	Contact Basis
Forest County Land & Water Conservation Department	Staff 715-478-1387 lcctech@forest.wi.us	Oversees conservation for land and water projects in Forest County.	Can aid with conservation plans, shoreland restorations, and habitat improvements.
Town of Freedom	Town Clerk Amanda Wondrash 262/206-4634	Roberts Lake falls within the Town of Freedom.	Town staff may be contacted regarding ordinance reviews or questions, and for information on community events
FLOW AIS	AIS Coordinator Derek Thorn flowais@lumberjackrcd.org 715-490-3325	Provides education and outreach for AIS	Partner for AIS identification training
Forest County Association of Lakes	https://fcal-wis.org/contact-us/	Facilitate education and research	RLA currently has a representative on the Board
Wild Rivers Invasive Species Coalition	Staff wildriverscwma@gmail.com 906-774-1550 ext. 102	Connects multiple partners on AIS related topics	AIS prevention, detection, control, restoration, particularly for shoreland/wetland species
Wisconsin Lakes	General staff (800.542.5253)	Facilitates education, networking and assistance on all matters.	Reps can assist on education and outreach materials
Wisconsin Department of Natural Resources	Fisheries Biologist: Greg Matzke Gregory.Matzke@Wisconsin.gov Phone: (715) 528-4400 ext 5	Manages the fish populations and fish habitat enhancement efforts.	Stocking activities, scheduled surveys, survey results, volunteer opportunities for improving fishery.
	Lake Biologist (Scott Van Egeren) (715) 471-0007 Scott.VanEgeren@wi.gov	Oversees management plans, grants, all lake activities.	Information on updating a lake management plan, submitting grants & permits, and general lake issues. CLMN program contact.
	Environmental Grant Specialist Jill Sunderland Jill.Sunderland@wisconsin.gov	Surface water grant program	Surface water grants, planning grants

6.0 LITERATURE CITED

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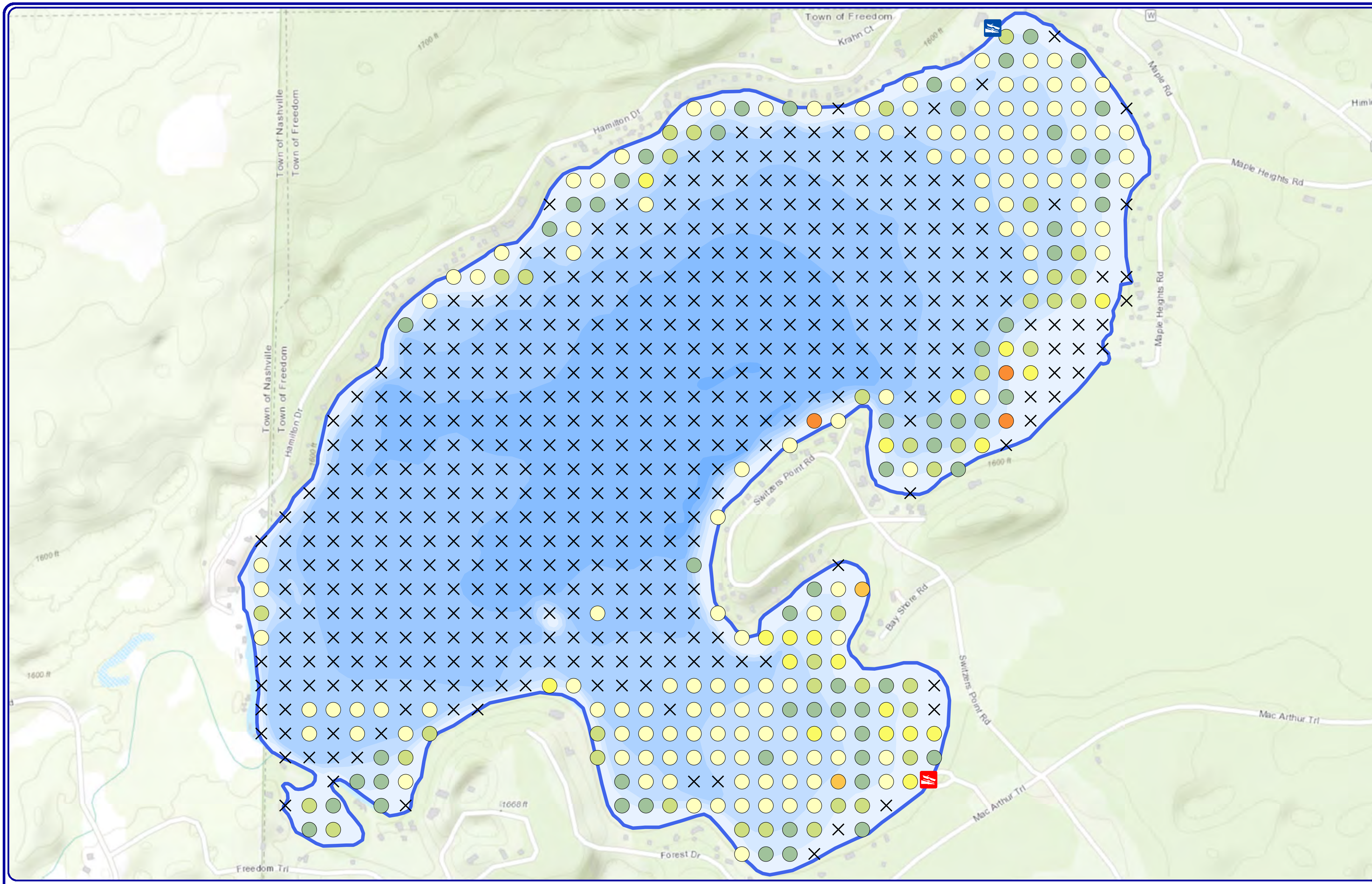


900
Feet

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

Sources:
Hydro: WDNR
Basemap: ESRI
Aquatic Plants: Onterra, 2024
Map Date: December 6, 2024 ALC

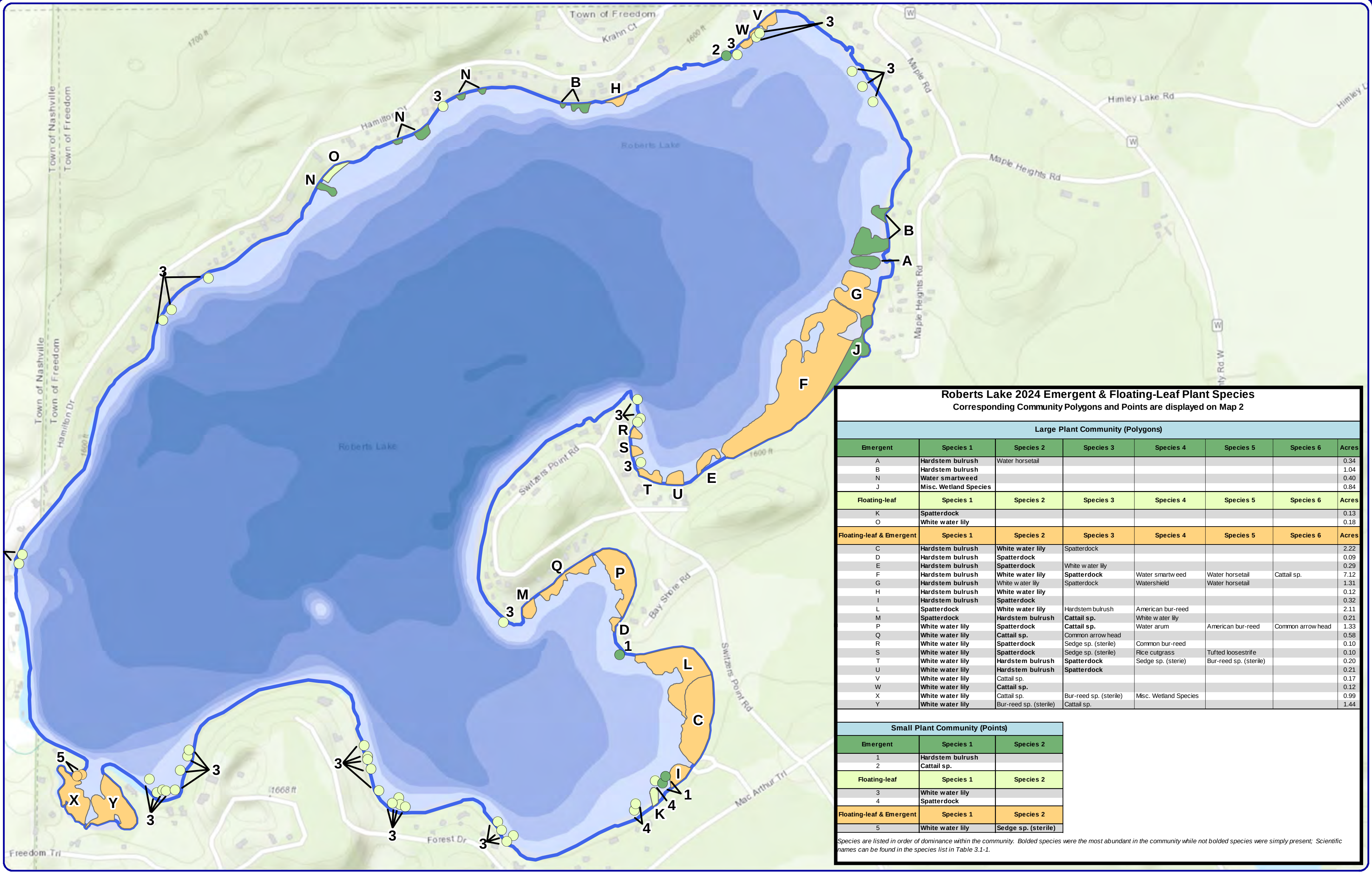
Project Location in Wisconsin

Legend

Number of Native Species per Littoral Sampling Site

0 1 2 3 4 5 6

Map 1
Roberts Lake
Forest County, Wisconsin
2024 PI Survey: Native Species Richness



Roberts Lake 2024 Emergent & Floating-Leaf Plant Species

Corresponding Community Polygons and Points are displayed on Map 2

Large Plant Community (Polygons)

Emergent	Species 1	Species 2	Species 3	Species 4	Species 5	Species 6	Acres
A	**Hardstem bulrush**	Water horsetail					0.34
B	**Hardstem bulrush**						1.04
N	**Water smartweed**						0.40
J	**Misc. Wetland Species**						0.84
Floating-leaf	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Acres**
K	**Spatterdock**						0.13
O	**White water lily**						0.18
Floating-leaf & Emergent	**Species 1**	**Species 2**	**Species 3**	**Species 4**	**Species 5**	**Species 6**	**Acres**
C	**Hardstem bulrush**	**White water lily**	Spatterdock				2.22
D	**Hardstem bulrush**	**Spatterdock**					0.09
E	**Hardstem bulrush**	**Spatterdock**	White w ater lily				0.29
F	**Hardstem bulrush**	**White water lily**	**Spatterdock**	Water smartw eed	Water horsetail	Cattail sp.	7.12
G	**Hardstem bulrush**	White w ater lily	Spatterdock	Watershield	Water horsetail		1.31
H	**Hardstem bulrush**	**White water lily**					0.12
I	**Hardstem bulrush**	**Spatterdock**					0.32
L	**Spatterdock**	**White water lily**	Hardstem bulrush	American bur-reed			2.11
M	**Spatterdock**	**Hardstem bulrush**	**Cattail sp.**	White w ater lily			0.21
P	**White water lily**	**Spatterdock**	**Cattail sp.**	Water arum	American bur-reed	Common arrow head	1.33
Q	**White water lily**	**Cattail sp.**	Common arrow head				0.58
R	**White water lily**	**Spatterdock**	Sedge sp. (sterile)	Common bur-reed			0.10
S	**White water lily**	**Spatterdock**	Sedge sp. (sterile)	Rice cutgrass	Tufted loosestrife		0.10
T	**White water lily**	**Hardstem bulrush**	**Spatterdock**	Sedge sp. (sterie)	Bur-reed sp. (sterile)		0.20
U	**White water lily**	**Hardstem bulrush**	**Spatterdock**				0.21
V	**White water lily**	Cattail sp.					0.17
W	**White water lily**	**Cattail sp.**					0.12
X	**White water lily**	Cattail sp.	Bur-reed sp. (sterile)	Misc. Wetland Species			0.99
Y	**White water lily**	Bur-reed sp. (sterile)	Cattail sp.				1.44

Small Plant Community (Points)

Emergent	Species 1	Species 2
1	**Hardstem bulrush**	
2	**Cattail sp.**	
Floating-leaf	**Species 1**	**Species 2**
3	**White water lily**	
4	**Spatterdock**	
Floating-leaf & Emergent	**Species 1**	**Species 2**
5	**White water lily**	**Sedge sp. (sterile)**

Species are listed in order of dominance within the community. Bolded species were the most abundant in the community while not bolded species were simply present; Scientific names can be found in the species list in Table 3.1-1.

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Feet

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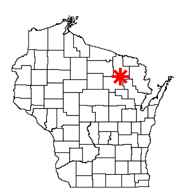
Sources
Basemap: ESRI
Hydro: WDNR
Aquatic Plants: Onterra, 2024
Map date: November 5, 2024 - SCD



Project Location in Wisconsin

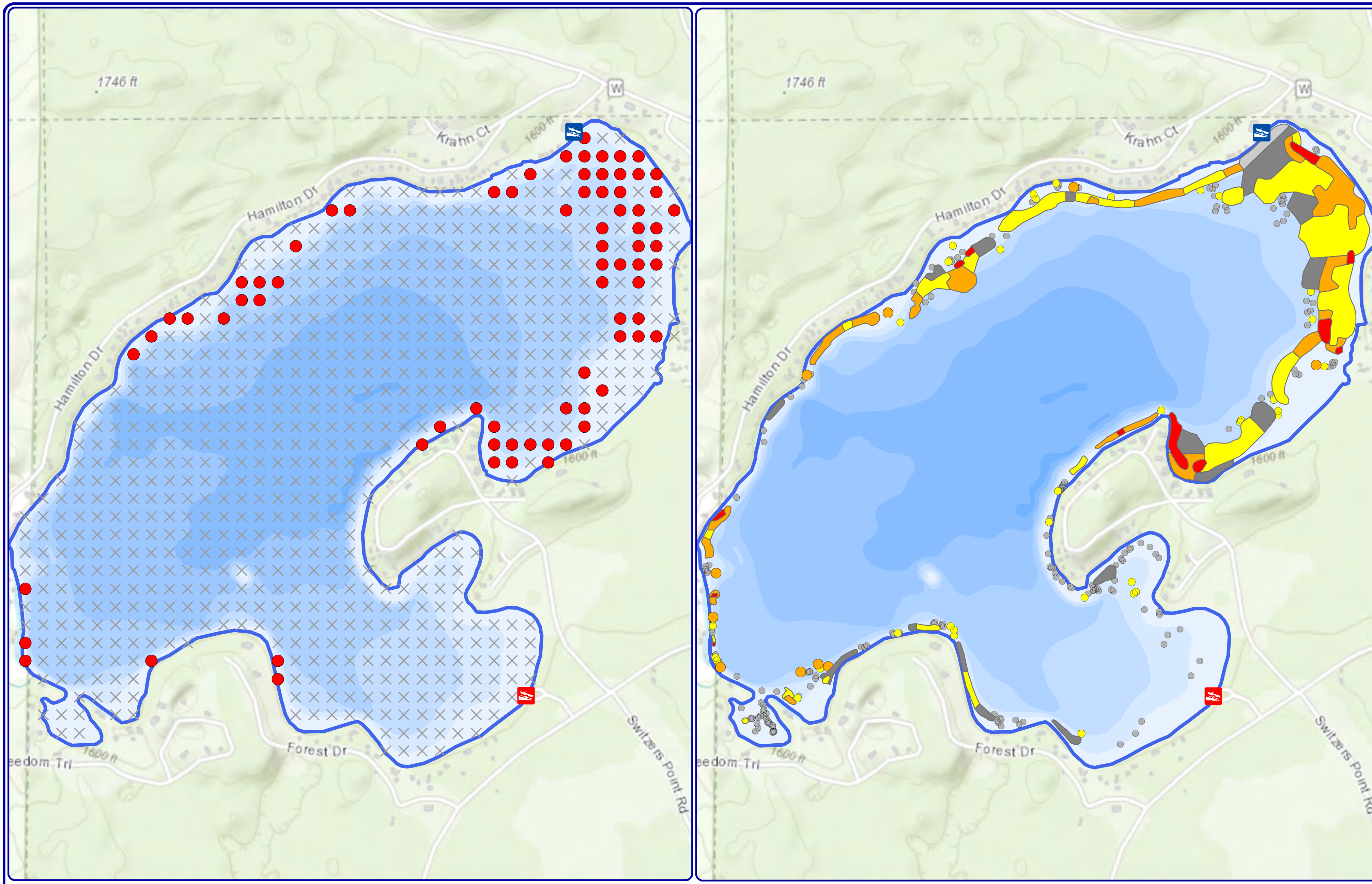
Legend

Survey Results: (September 17, 2024)

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

Map 2
Roberts Lake
Forest County, Wisconsin

2024 Floating-leaf & Emergent Aquatic Plant Communities



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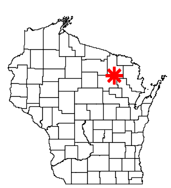
Sources:
Hydro: WDNR
Basemap: ESRI
Aquatic Plants: Onterra, 2024
Map Date: 4-15-2025 TWH



Project Location in Wisconsin

Legend

Point-Intercept Survey (July 11, 2024)

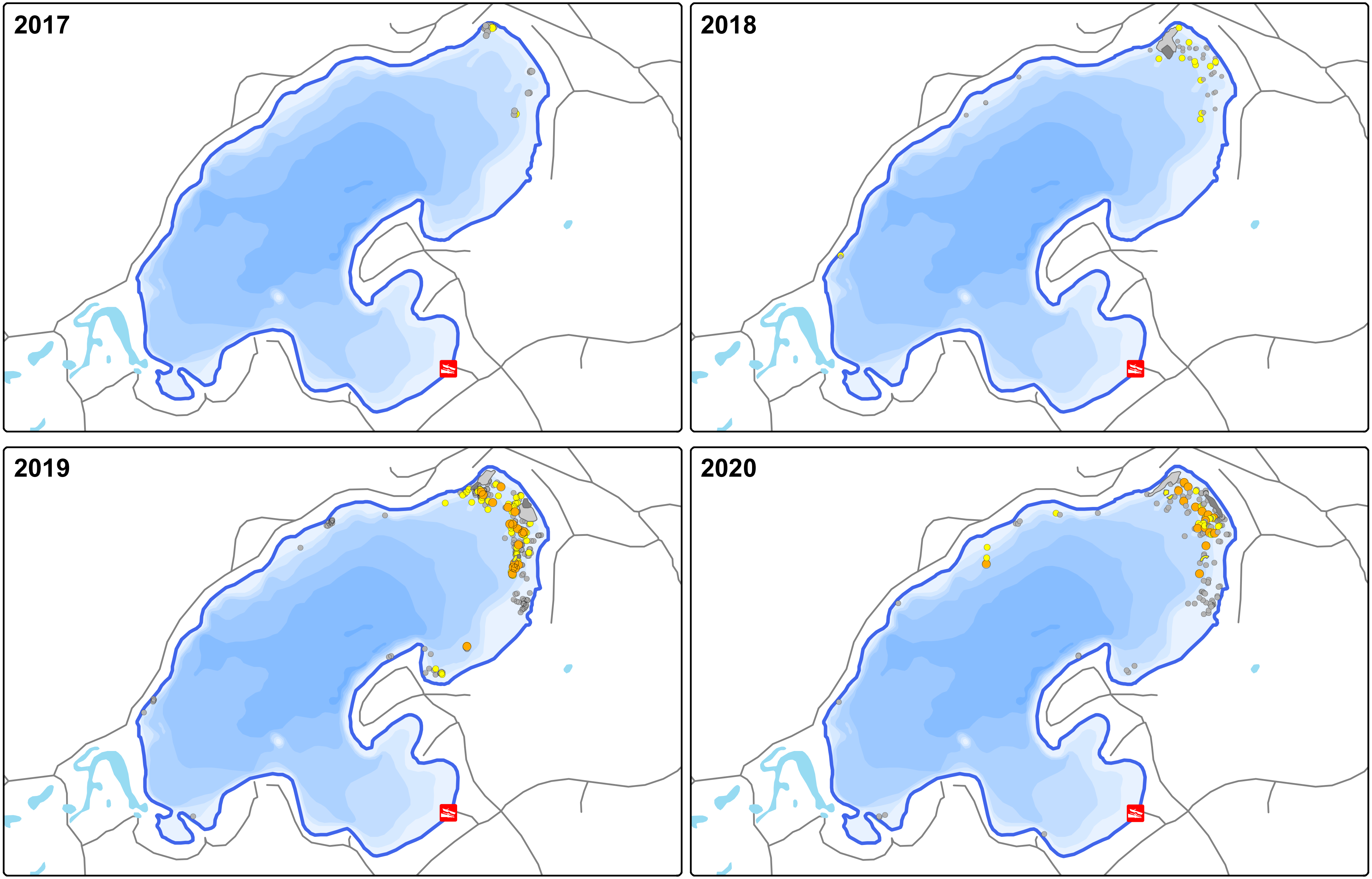
- Sampling Location (EWM absent)
- EWM Present

EWM Mapping Survey (August 27, 2024)

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clump of Plants
- Small Plant Colony

Map 3
Roberts Lake
Forest County, Wisconsin

2024 EWM Locations
PI Survey &
Mapping Survey



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Feet

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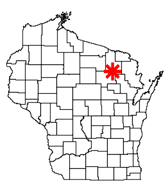
Sources:
Roads and Hydro: WDNR
Bathymetry: Onterra
Aquatic Plants: Onterra, 2017-2020

Map Date: January 20, 2021



Project Location in Wisconsin

Legend

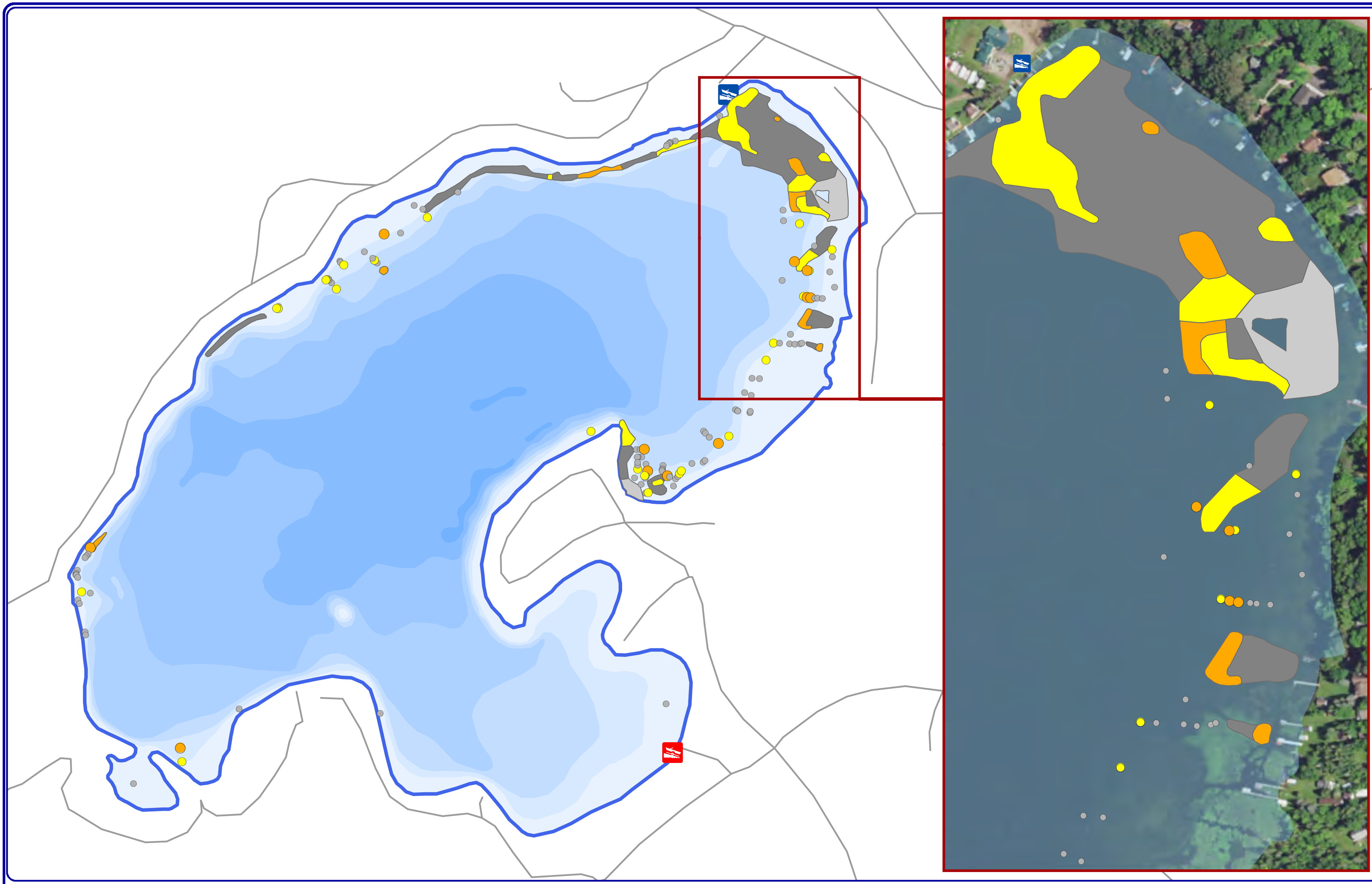
- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony

Map 4

Roberts Lake

Forest County, Wisconsin

EWM Survey Results 2017-2020



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Sources:
Roads and hydro: WDNR
Aquatic Plants: Onterra, 2022
Orthophotography: NAIP, 2020
Map Date: September 2, 2022 AMS

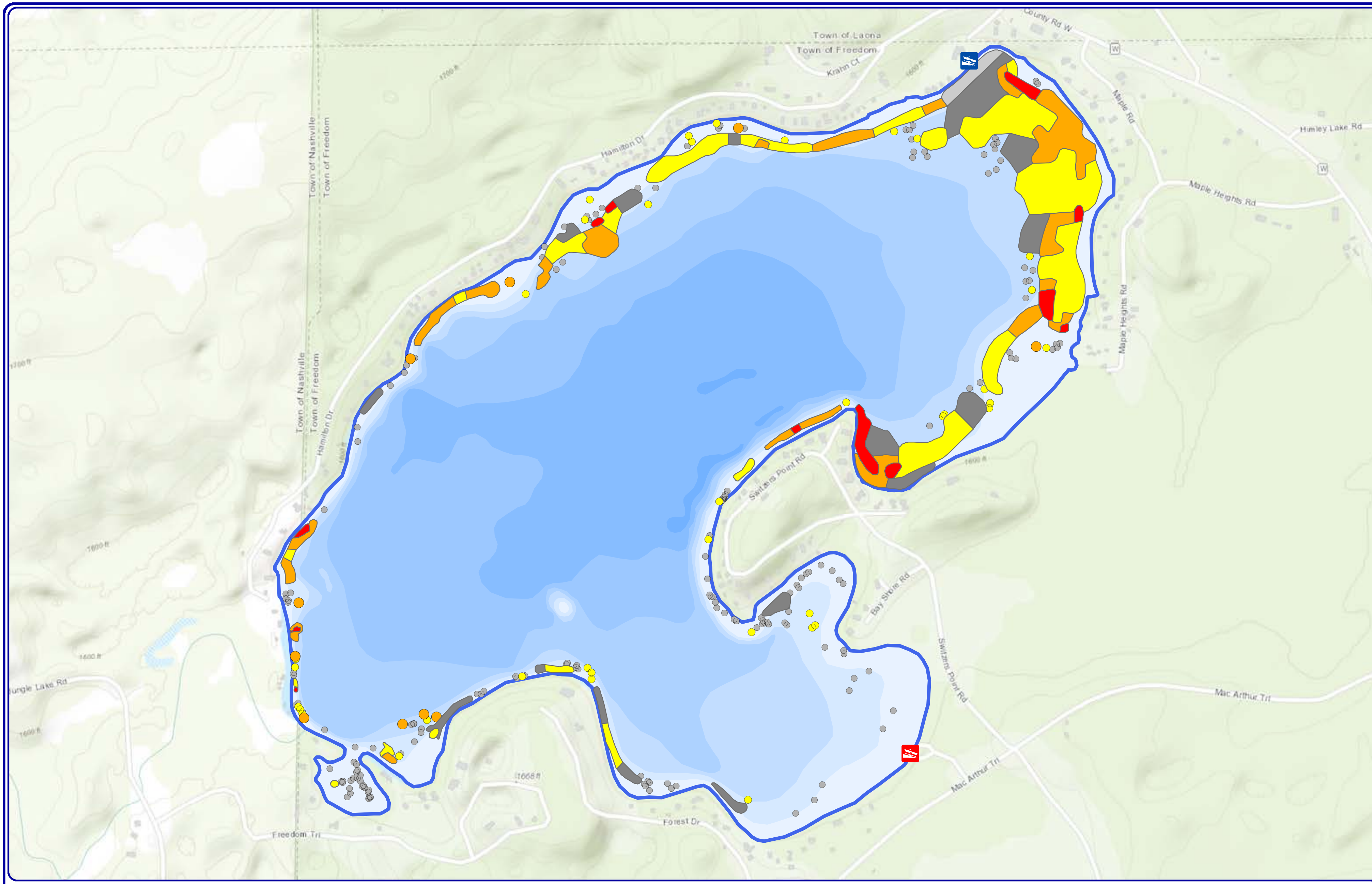
Project Location in Wisconsin

Legend

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting *(none found)*
- Single or Few Plants
- Clump of Plants
- Small Plant Colony

Map 5
Roberts Lake
Forest County, Wisconsin

August 2022 EWM Survey Results



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Feet

Legend

EWM Survey Results (August 27, 2024)

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clump of Plants
- Small Plant Colony

Project Location in Wisconsin

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Lake Management Planning
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De Pere, WI 54115
920.338.8860
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Sources:
Hydro: WDNR
Basemap: ESRI
Aquatic Plants: Onterra, 2024
Map Date: October 11, 2024 -ALC

Map 6
Roberts Lake
Forest County, Wisconsin
Late-Season 2024
Eurasian Watermilfoil
Survey Results

A

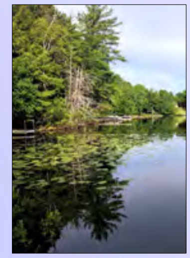
APPENDIX A

Public Participation Materials

1

Planning I Meeting Agenda

- Intro to Onterra
- Project timeline
- What is an Aquatic Plant Management Plan?
- Aquatic Plants Data Results Overview
- Eurasian watermilfoil
  - Impacts & Propagation
  - Monitoring Methods
  - EWM population in Roberts Lake
  - Management Perspectives
  - Management Options
- Next Steps



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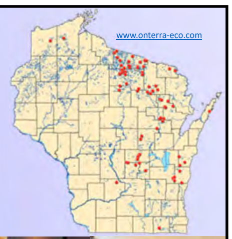
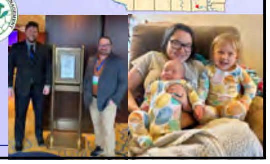
2

Onterra, LLC

- Founded in 2005, 20 years in 2025
- Head Quarters in De Pere, WI
- Staff
  - Three full-time ecologists
  - One part-time paleoecologist
  - Four full-time field technicians
  - Four summer interns
- Services
  - Science and planning
- Philosophy
  - Promote realistic planning
  - Assist, not direct





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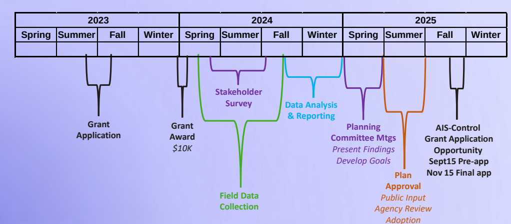
3

Project Timeline



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What is a Lake Management Plan?

- Comprehensive Lake Management Plans take holistic look at all aspects of the lake.
- Aquatic Plant Management (APM) Plan is one component of a Comprehensive Plan, but focus is limited to aquatic plants.
- This project will create the first APM Plan for the RLA.
- Plan is based upon organization's capacity
  - Addressing your concerns
  - Tailored to your specific needs
- Long-term & useable plan (~5 years)
- Living plan subject to revision over time

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5

Management Plan and Grants

- WDNR recommends ***Comprehensive Management Plans*** generally get updated every 10 years
  - Aquatic Plant Management (APM) Plan is one component of a Comprehensive Plan, along with water quality, watershed, shoreland, fisheries, etc.
  - Particularly for grants/permits related to water quality/watershed improvements
- WDNR recommends lakes conducting active plant management update aspects of the plan every 5 years (***APM Plan***)
  - Particularly for grants/permits related to aquatic plant management (AIS control grants, NR107, NR109)
  - Updates management goals and actions to be consistent with changing BMP's, incorporates knowledge gained from past APM activities on the lake
  - Management action in AIS Grant needs to be supported by Plan
- Annual AIS Control Plan
  - Consistent with the framework outlined in APM Plan
  - Includes specific plans, delineated prioritized areas and description of monitoring components

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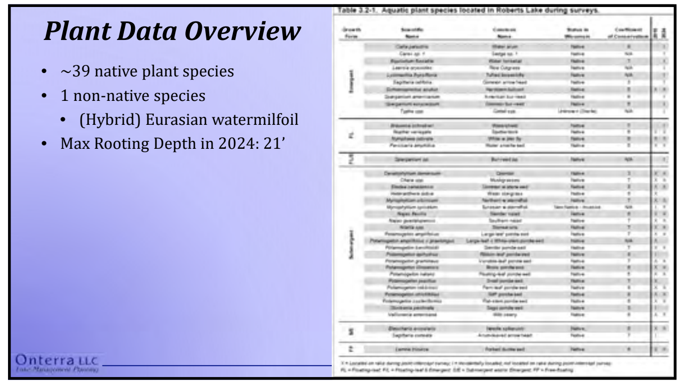
6


Aquatic Plants

7


Plant Data Overview
• ~39 native plant species
• 1 non-native species
• (Hybrid) Eurasian watermilfoil
• Max Rooting Depth in 2024: 21'
Table 3.2-1. Aquatic plant species located in Roberts Lake during surveys.
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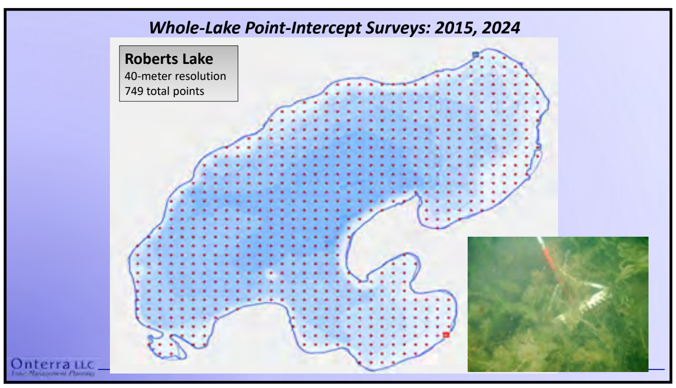
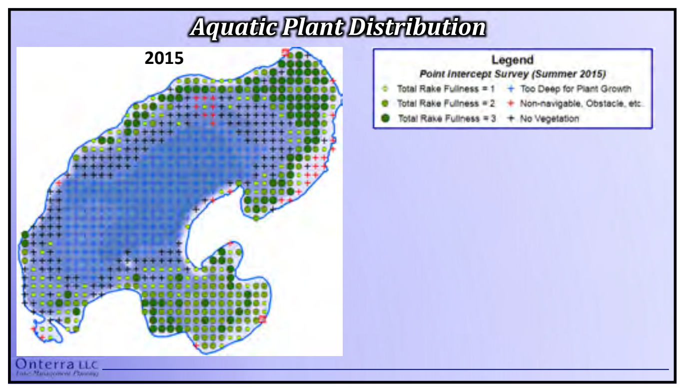
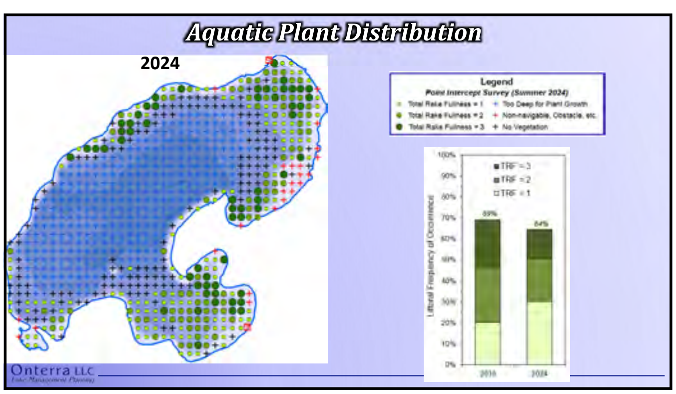
8


Whole-Lake Point-Intercept Surveys: 2015, 2024
Roberts Lake
40-meter resolution
749 total points
Onterra LLC

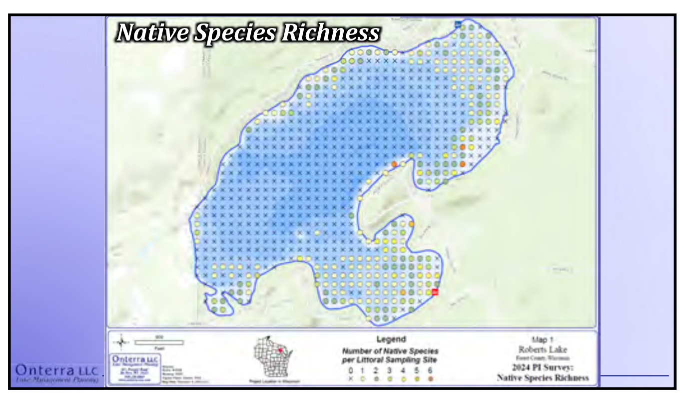
9


Aquatic Plant Distribution
2015
Legend
Point Intercept Survey (Summer 2015)
Total Rake Fullness = 1
Total Rake Fullness = 2
Total Rake Fullness = 3
Too Deep for Plant Growth
Non-navigable, Obstacle, etc.
No Vegetation
Onterra LLC

10


Aquatic Plant Distribution
2024
Legend
Point Intercept Survey (Summer 2024)
Total Rake Fullness = 1
Total Rake Fullness = 2
Total Rake Fullness = 3
Too Deep for Plant Growth
Non-navigable, Obstacle, etc.
No Vegetation
Onterra LLC

11


Native Species Richness
Legend
Number of Native Species per Littoral Sampling Site
0 1 2 3 4 5 6
Map 1
Roberts Lake
2024 PI Survey:
Native Species Richness
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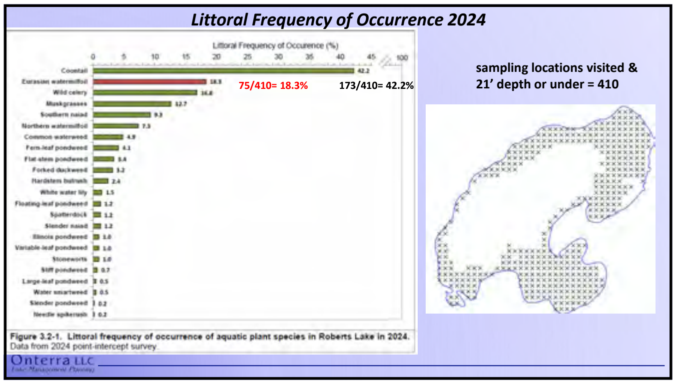
12



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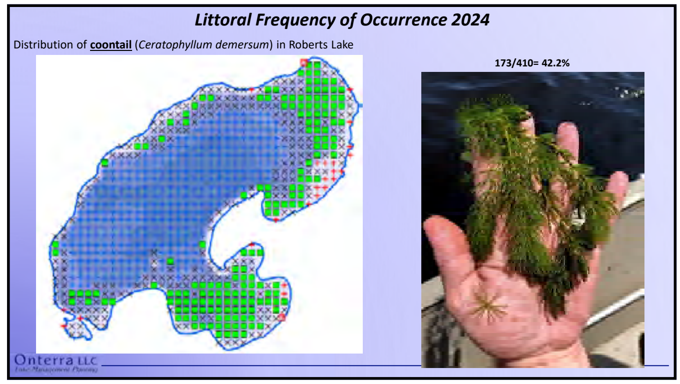

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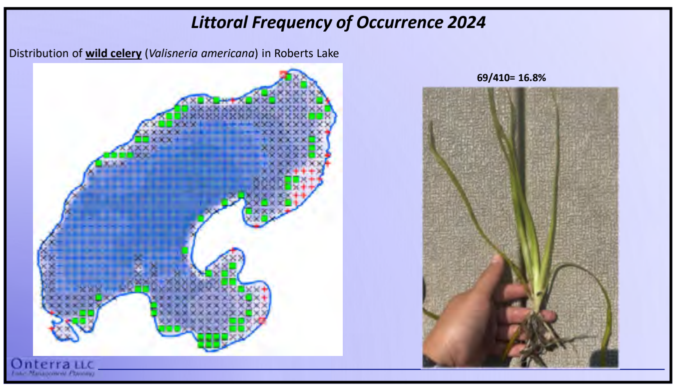

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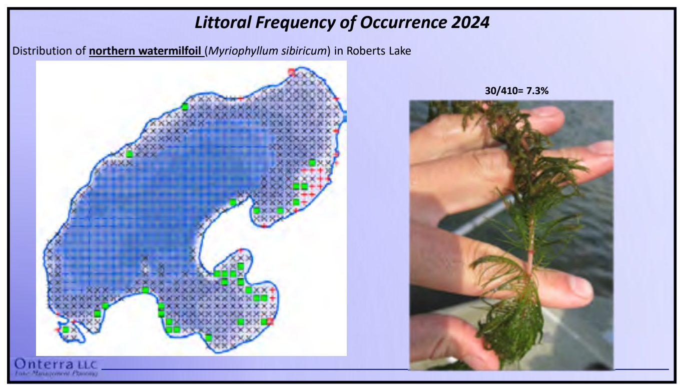

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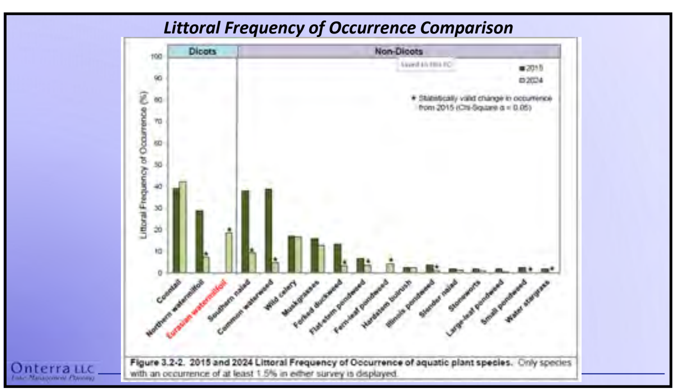

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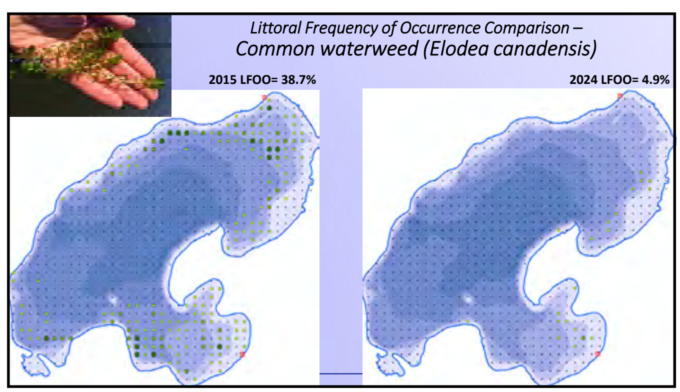

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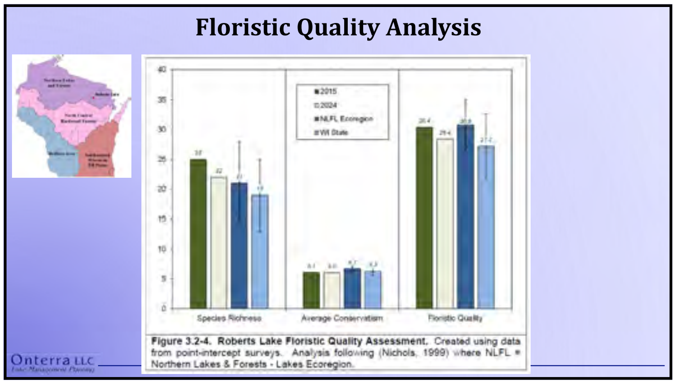

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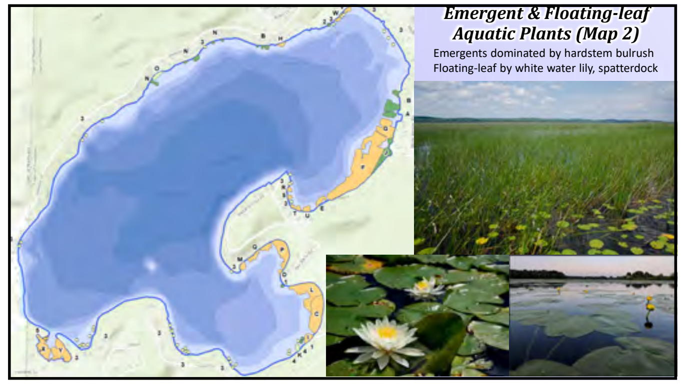

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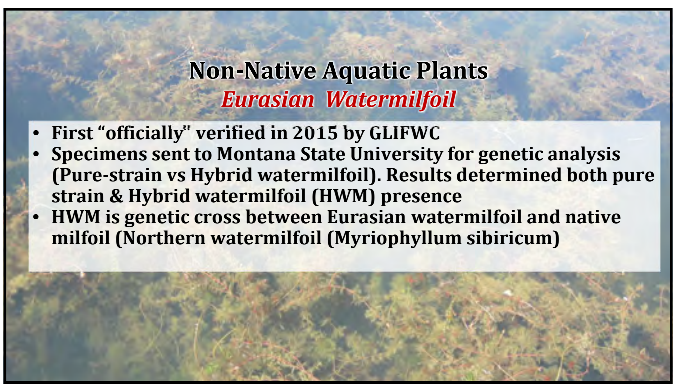

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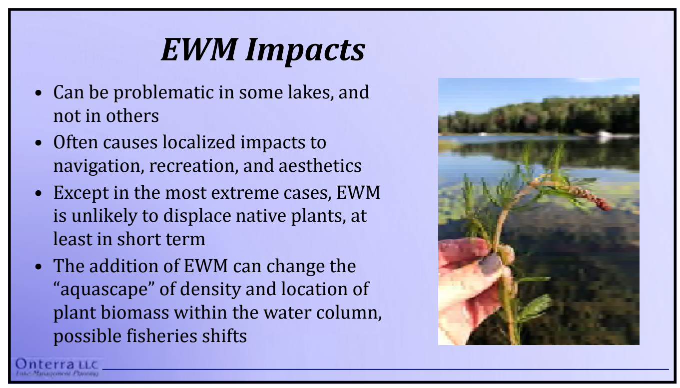

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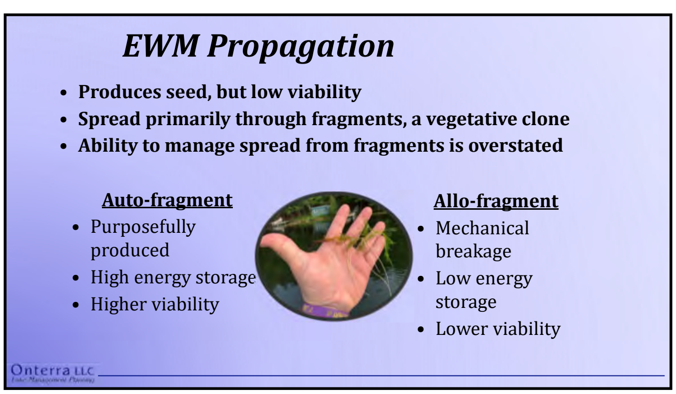

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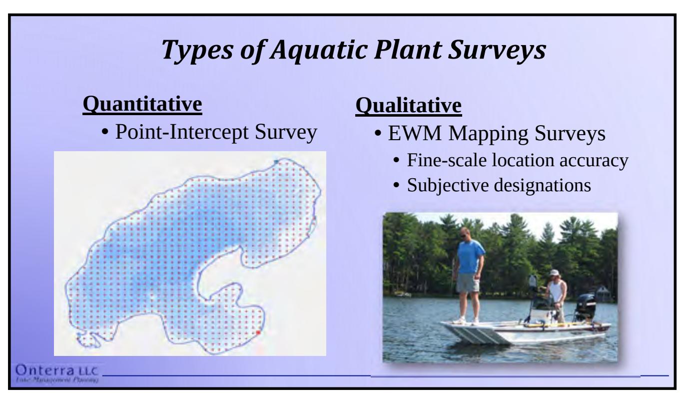

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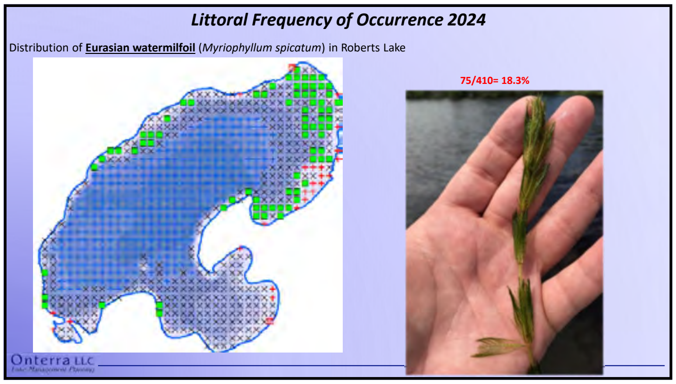

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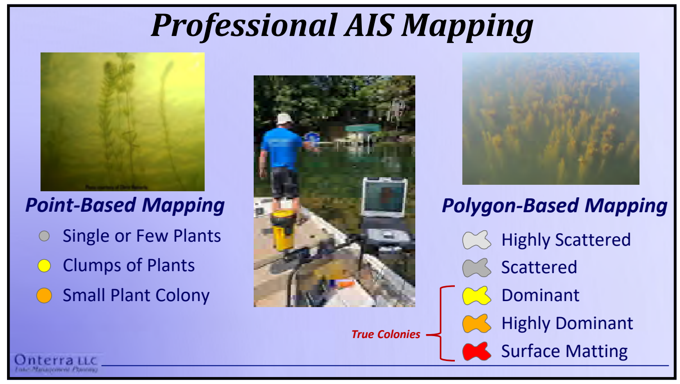

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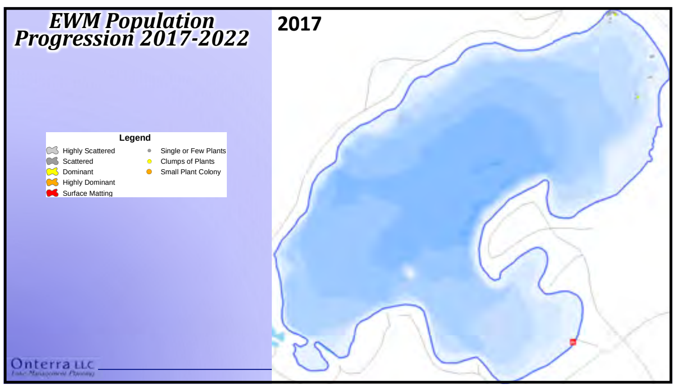

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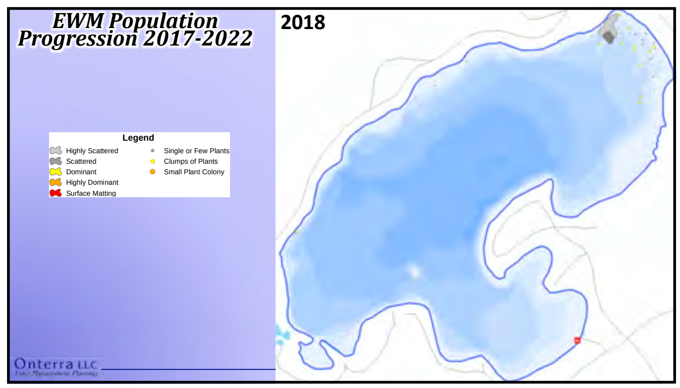

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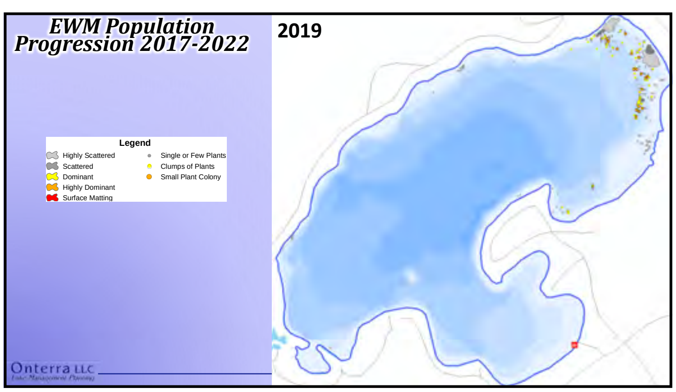

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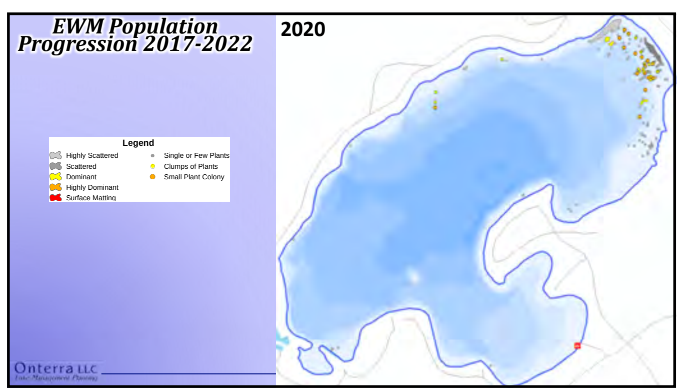

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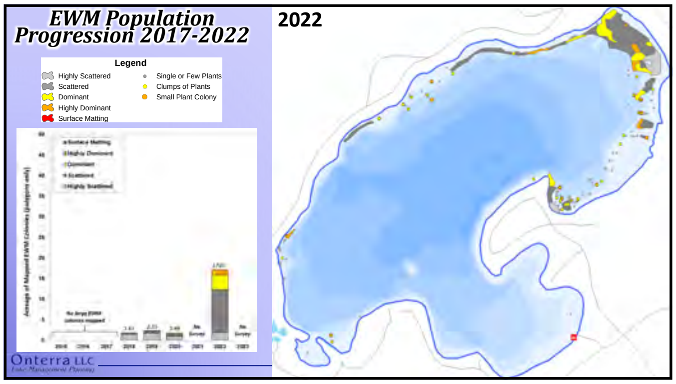

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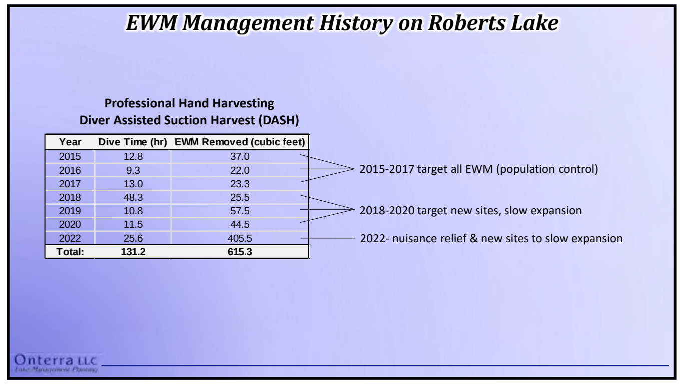

Year	Dive Time (hr)	EWM Removed (cubic feet)
2015	12.8	37.0
2016	9.3	22.0
2017	13.0	23.3
2018	48.3	25.5
2019	10.8	57.5
2020	11.5	44.5
2022	25.6	405.5
Total:	131.2	615.3

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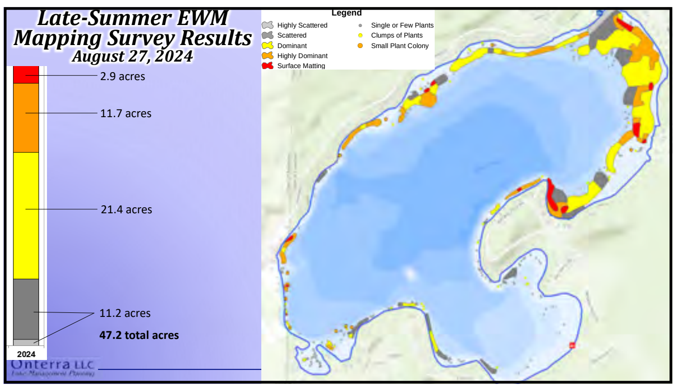

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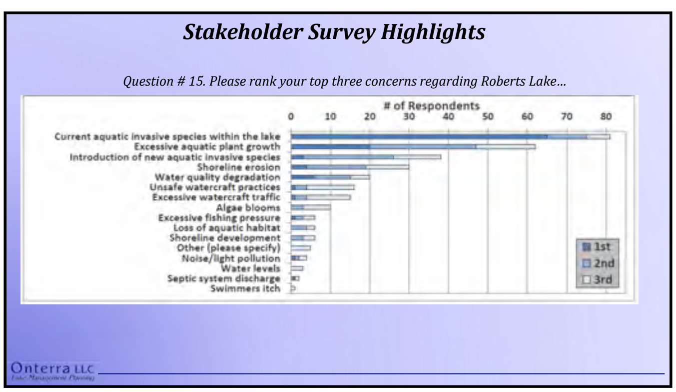

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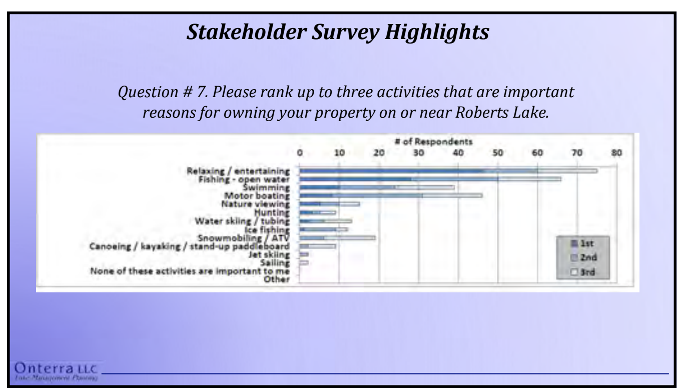

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Stakeholder Survey Highlights

Question # 24. Has the EWM population ever had a negative impact on your enjoyment of Roberts Lake?

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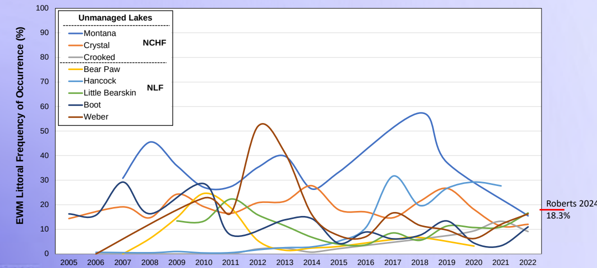
WDNR EWM Long-Term Monitoring Trends

Unmanaged



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EWM Management Perspectives

1. **No Coordinated Active Management (Let Nature Take its Course)**
   - Group does not organize or fund nuisance manual removal efforts
   - Monitoring encouraged
2. **Reduce AIS Population on a lake-wide level (Population Management – "Control")**
   - Will not *eradicate* EWM
   - Early populations may be targeted with manual removal efforts, established populations may need to entertain herbicide treatment (risk assessment)
   - Set triggers (thresholds) of implementation and tolerance
3. **Minimize navigation and recreation impediment (Nuisance Control)**
   - Often accomplished through mechanical harvesting or herbicide treatment, limited applicability for hand harvesting
   - Prioritize areas based on human use & EWM density

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Biological Control - Weevils

- **Goal – Let nature takes its course but impact EWM plant health & suppress biomass**
- **Largely unproven, not a common EWM control technique**
- **Feed on stems, impact buoyancy/carb reserves for overwintering, reduce competitive advantage**
- **Weevils are native to Wisconsin, already in many lakes, programs aimed at increasing their density through stocking**
- **Habitat requirements – leaf litter, natural shores**
- **WDNR AIS-Control grants - eligible for supplies,**

-weevils not available for purchase

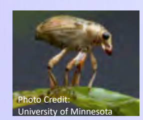
Photo Credit: University of Minnesota

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Manual Removal – *Hand Harvesting & DASH*

- **Goal – to manage the EWM population or nuisance control**

EWM population	Nuisance control
Initial populations Low density & isolated occurrences Follow-up after herbicide treatments	In riparian footprint Navigation lanes or small areas

- **Removal of entire root material required for mortality**
- **Scale limitations, not for large or dense areas**
- **Diver-Assisted Suction Harvest (DASH) can increase efficiency**
- **Limitations**
  - –Density of EWM & native plants
  - –Clarity of water
  - –Sediment type
  - –Obstructions


Photo credit Anvil Lake Association

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Utility of Hand Harvesting based on EWM Population

EWM Population	Realistic Strategy or Goal (Site by Site or Lake-wide Population)
High, very dense, established population	Seasonal Nuisance Relief
Moderate, expanding, forming colonies, rebounding population	Reduce population & Inhibit Expansion
Low, not established, isolated occurrences, new introductions	Locally eradicate

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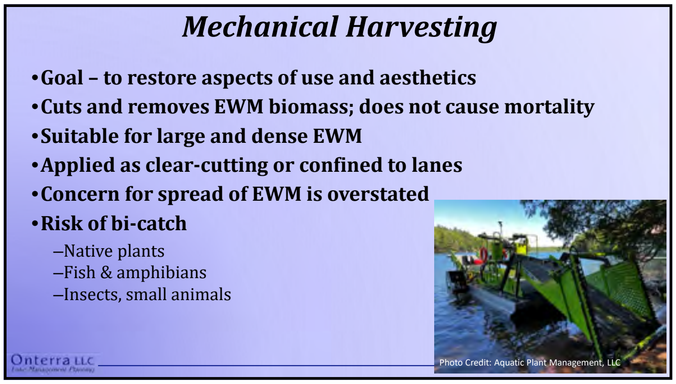

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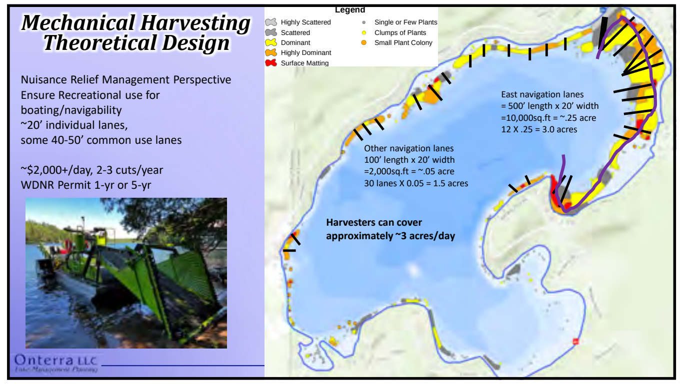

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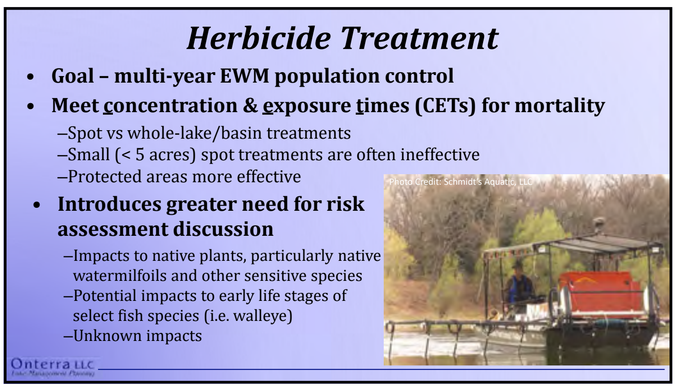

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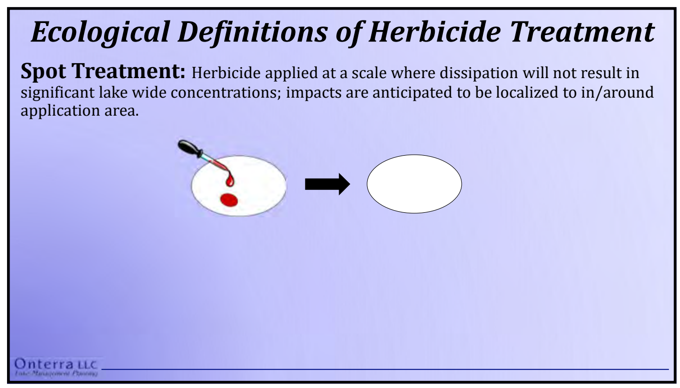

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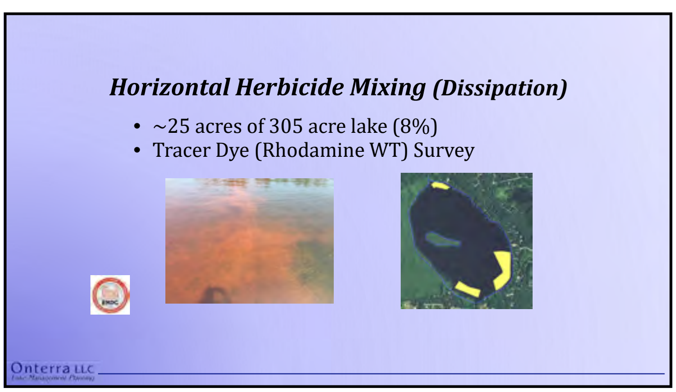

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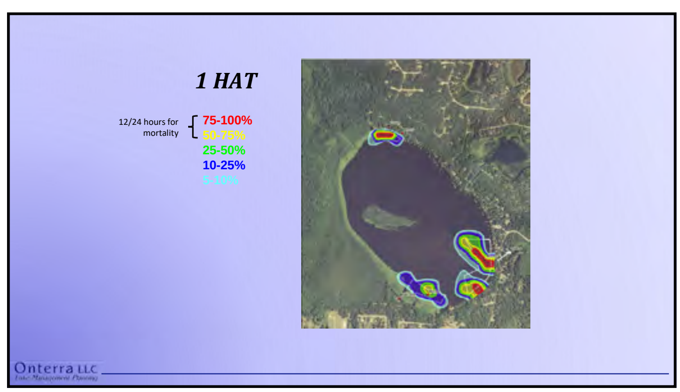

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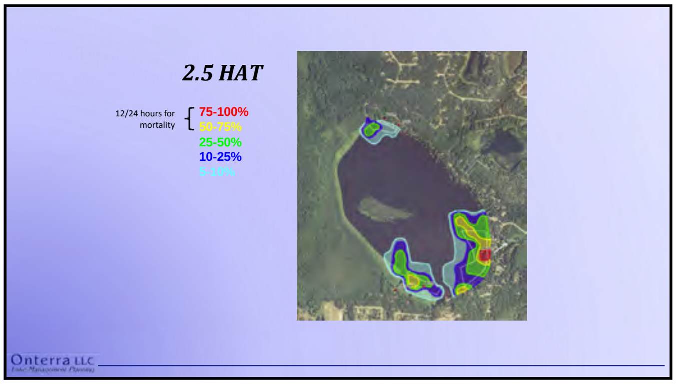

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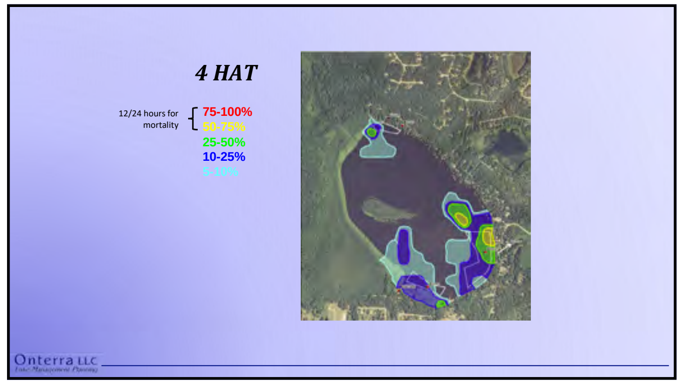

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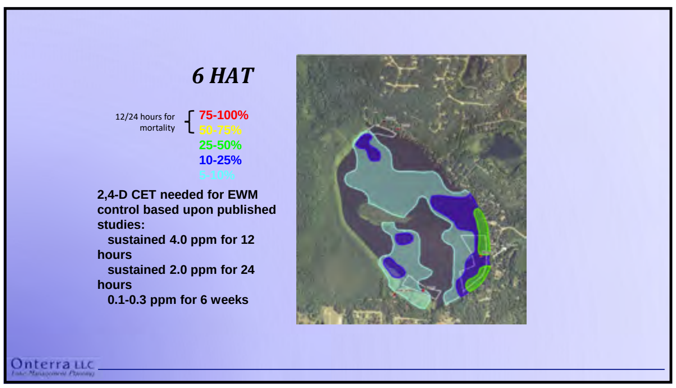

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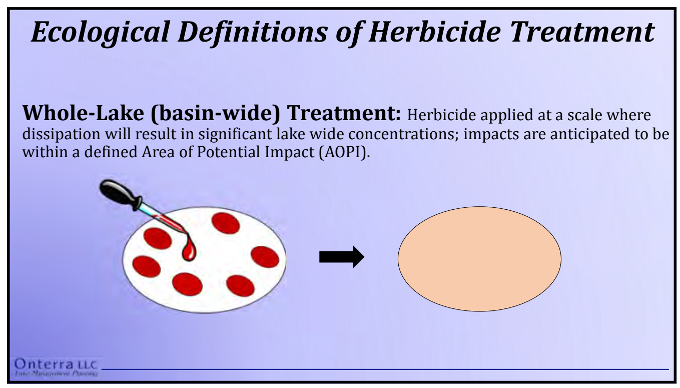

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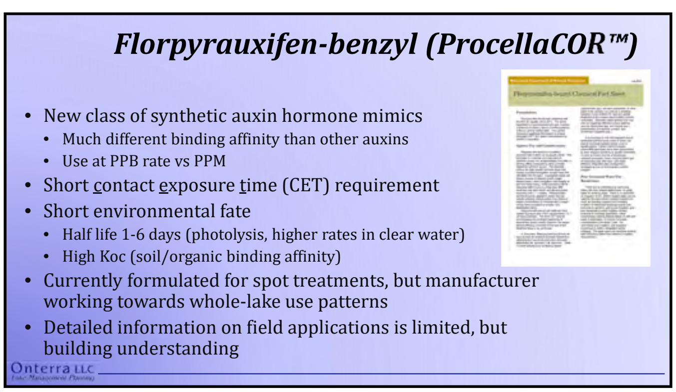

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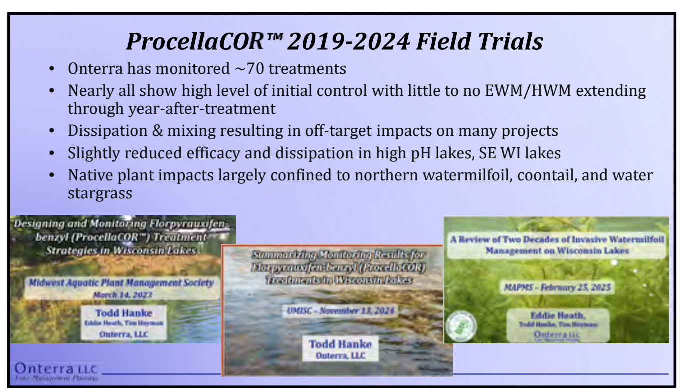

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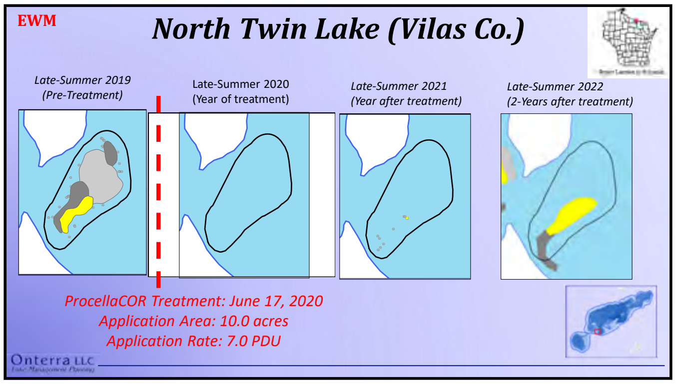

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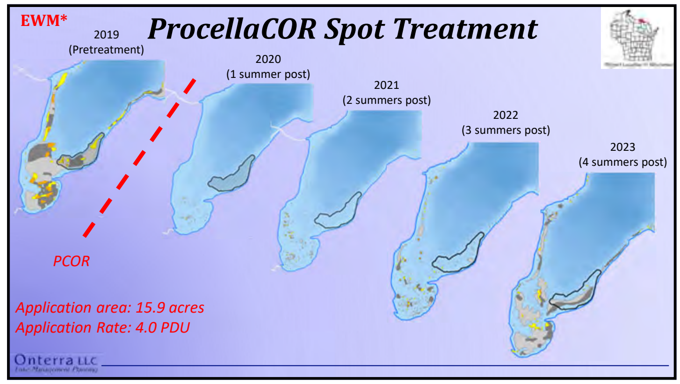

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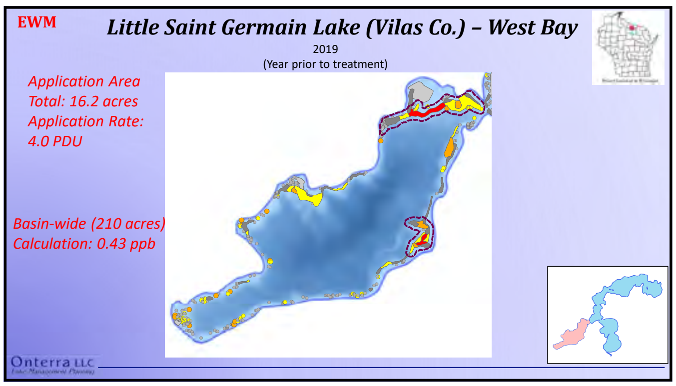

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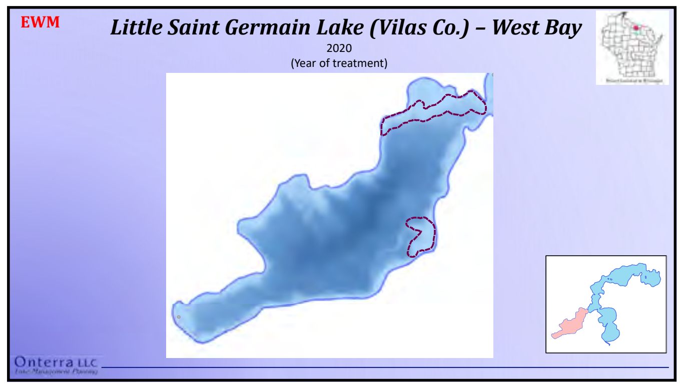

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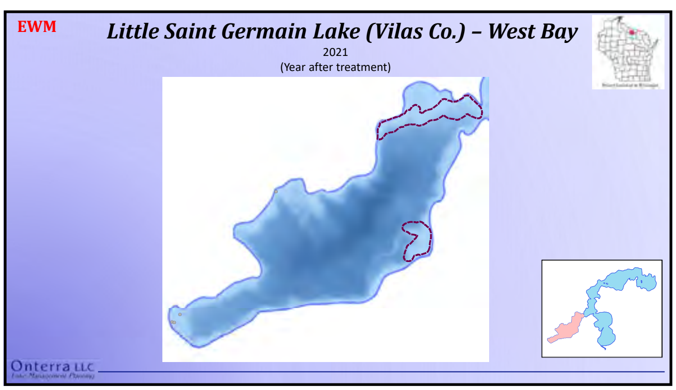

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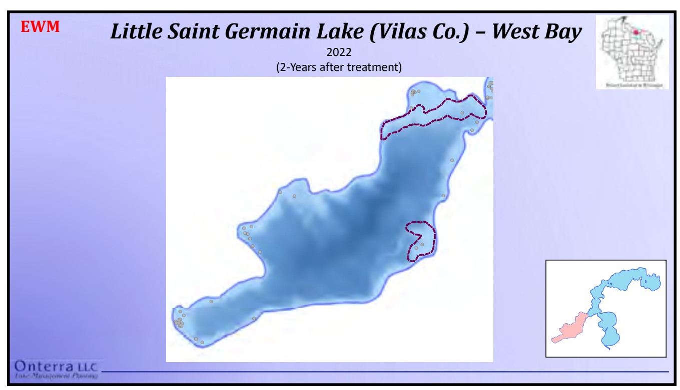

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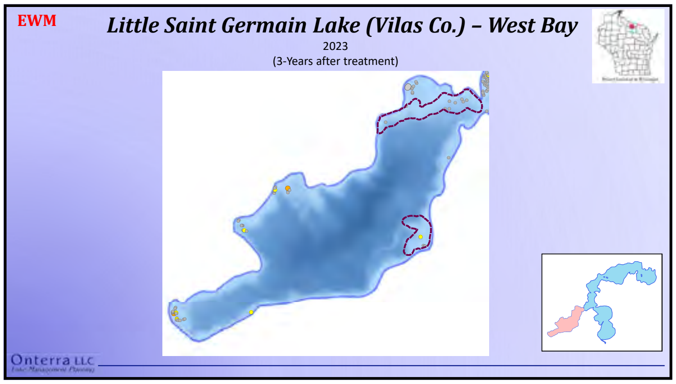

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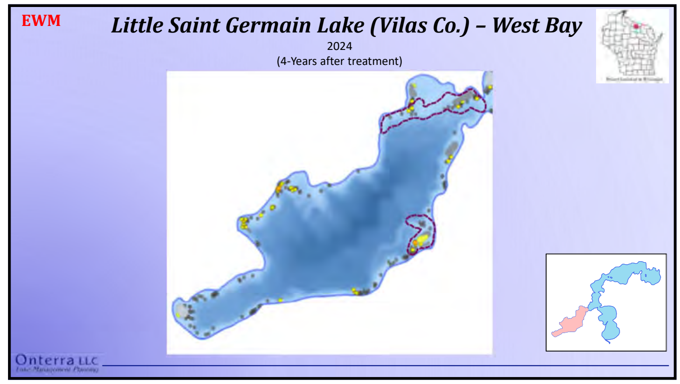

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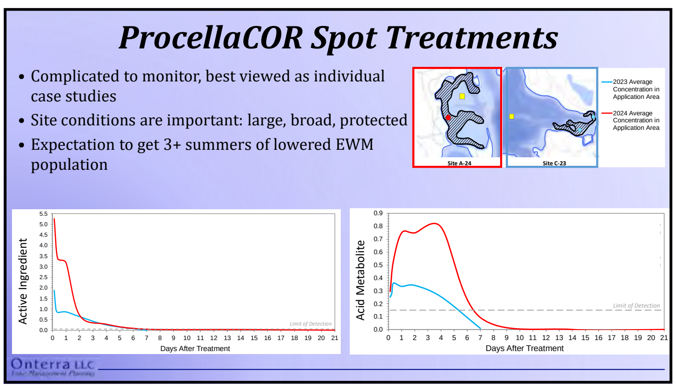

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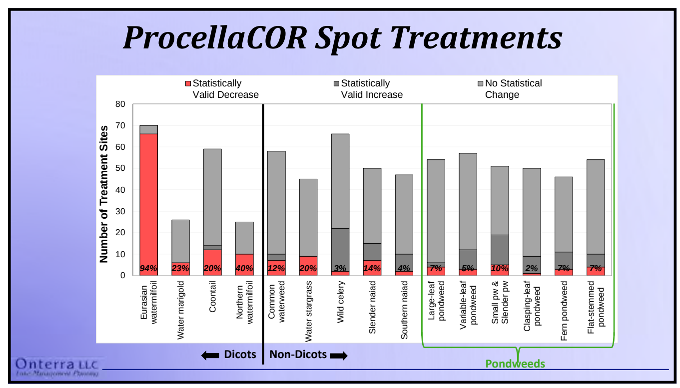

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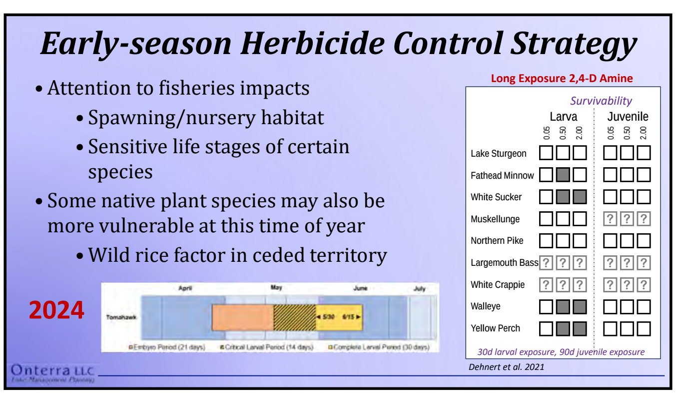

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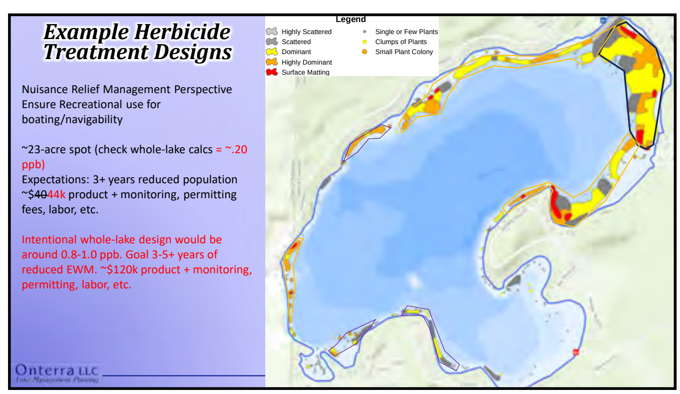

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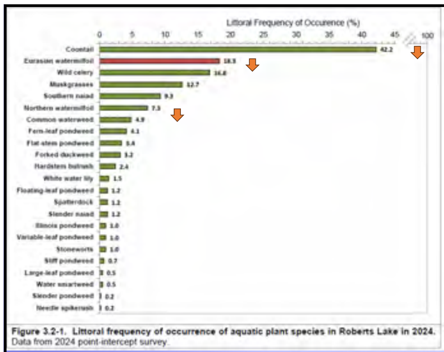

Susceptibility to ProcellaCOR

Coontail ~50% decrease
EWM ~100% decrease
Northern watermilfoil ~100% decrease

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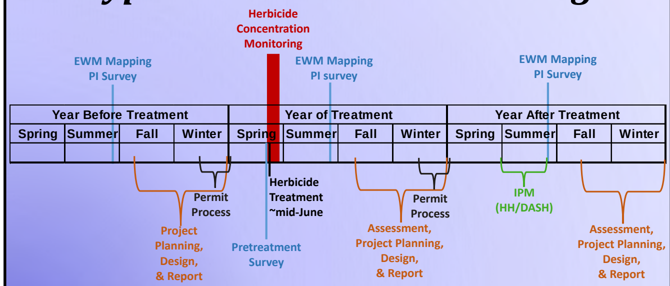
Typical Treatment Monitoring



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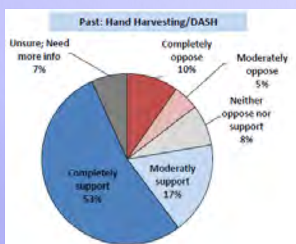
Stakeholder Survey Highlights

Question # 25. What is your level of support or opposition for the past hand harvesting / DASH to target EWM in Roberts Lake?



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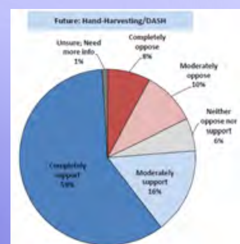
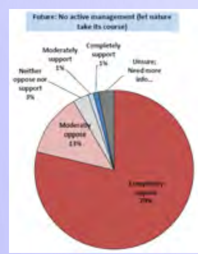
Stakeholder Survey Highlights

Question # 26. EWM can be managed in several ways. What is your level of support or opposition for future management strategies to target EWM in Roberts Lake?





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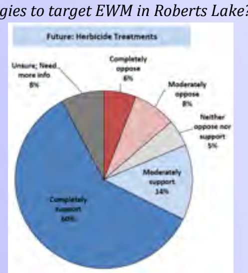
Stakeholder Survey Highlights

Question # 26. EWM can be managed in several ways. What is your level of support or opposition for future management strategies to target EWM in Roberts Lake?



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Planning Meeting II

Primary Objective: Create implementation plan framework

Steps to Achieve Objective:

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

Assignment for Planning Meeting II

1. Create list of challenges facing lake and lake group – keep for meeting
2. Review stakeholder survey results (Appendix B)
3. Send potential report section edits and questions to Todd

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Next Steps

- Conduct Planning Meeting 2
- Onterra write draft Implementation Plan, send to committee to approve
- Onterra compile *Official First Draft* and send to WDNR/other agency partners for review
- RLA complete 21-day public comment period
- Integrate comments into Final Plan
- RLA adopt Plan

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Thank You

Onterra LLC
Lake Management Planning

Todd Hanke: thanke@onterra-eco.com

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B

APPENDIX B

Stakeholder Survey Response Charts and Comments

Roberts Lake - Anonymous Stakeholder Survey

Surveys Distributed: *170*
Surveys Returned: *103*
Response Rate: *60.5*

Roberts Lake Property

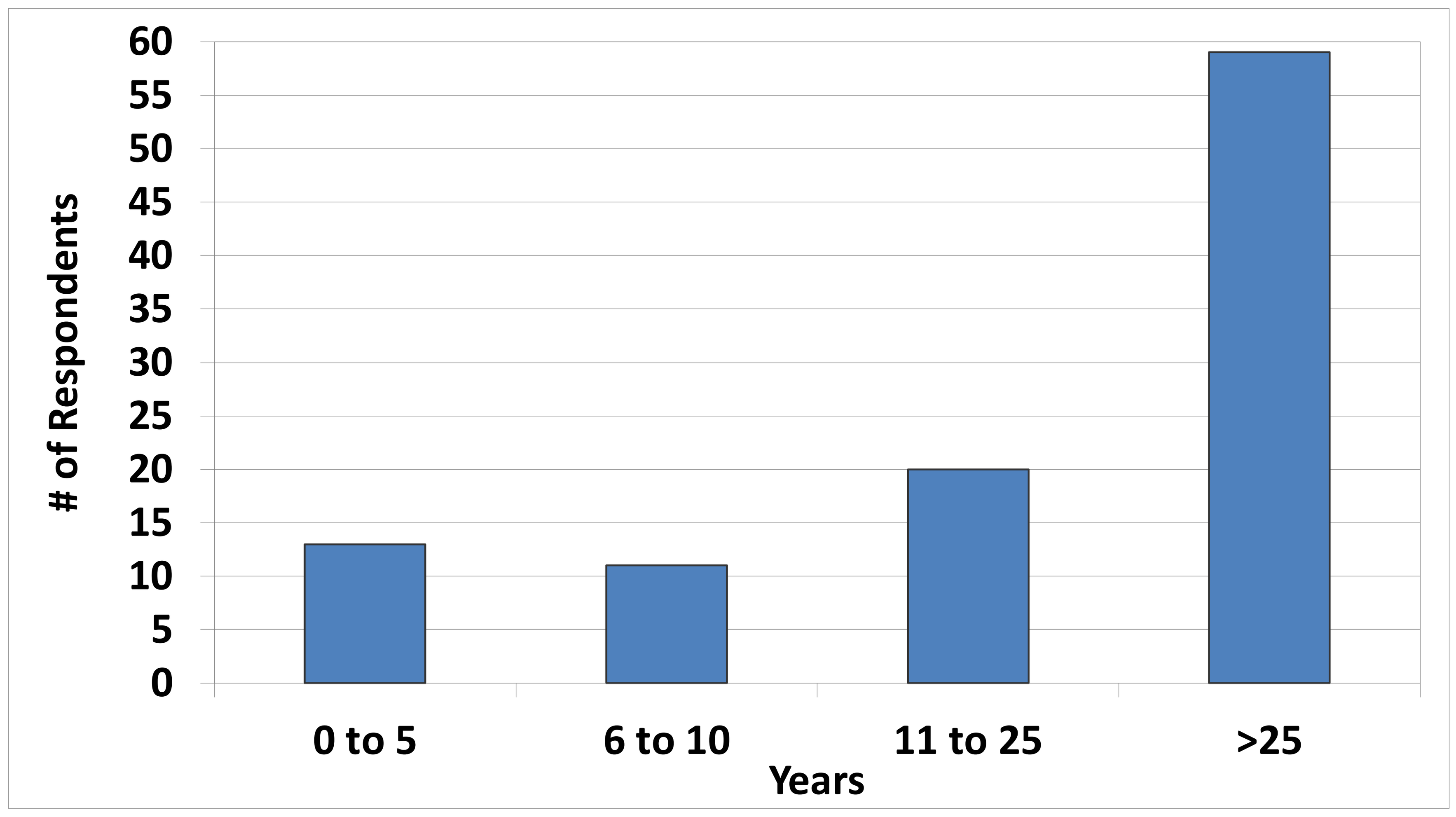
1. Is your property on the lake or off the lake? If you own more than one property, please refer to the property you have owned the longest.

Answer Options	Response Percent	Response Count
On the lake	100.0%	103
Off the lake	0.0%	0
	answered question	103
	skipped question	0

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

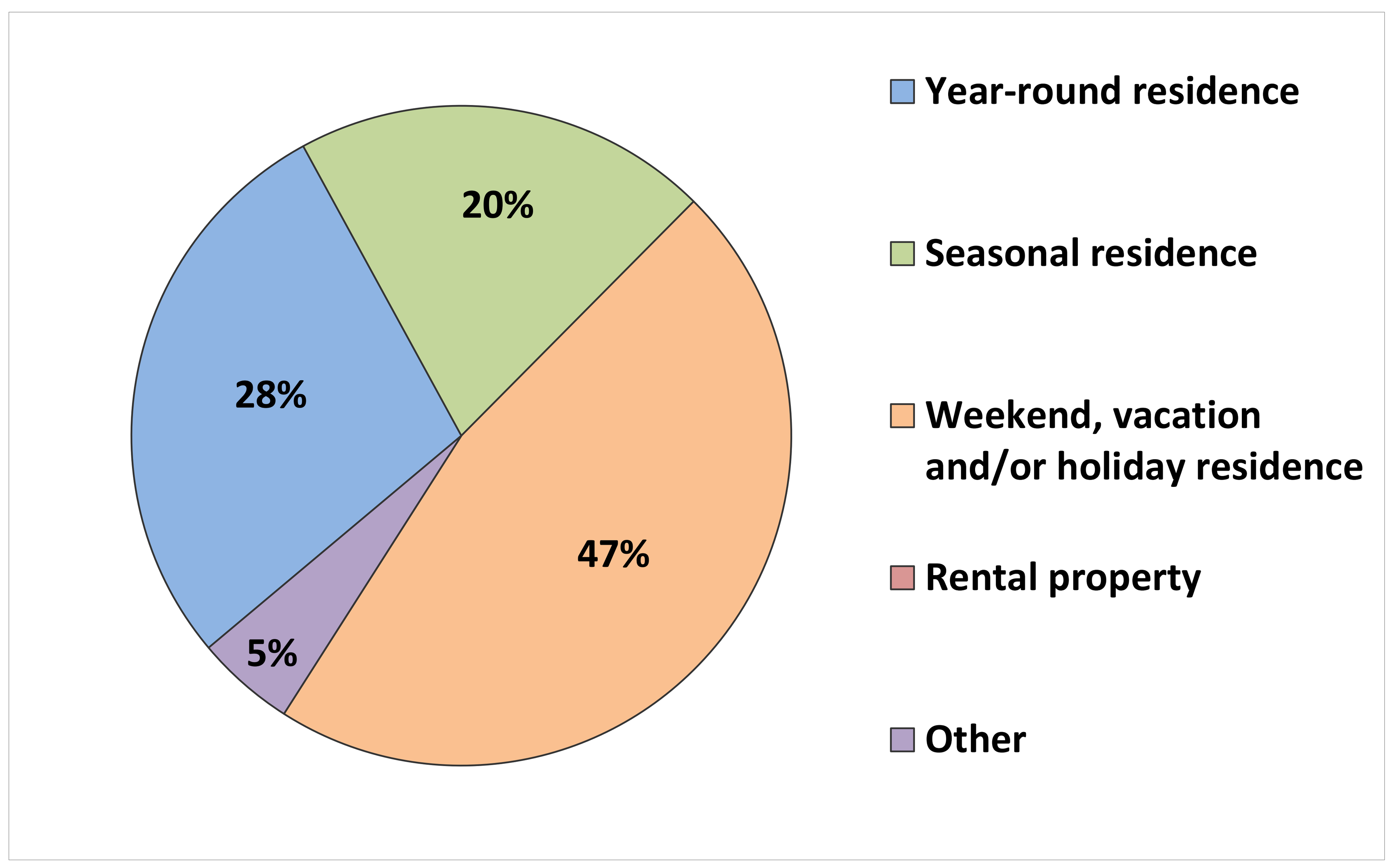
Answer Options	Response Count
	103
answered question	103
skipped question	0

Category (# of years)	Responses	% Response
0 to 5	13	13%
6 to 10	11	11%
11 to 25	20	19%
>25	59	57%



3. How is your property on or near Roberts Lake used?

Answer Options	Response Percent	Response Count
Year-round residence	28.2%	29
Seasonal residence	20.4%	21
Weekend, vacation and/or holiday residence	46.6%	48
Rental property	0.0%	0
Other	4.9%	5
	answered question	103
	skipped question	0

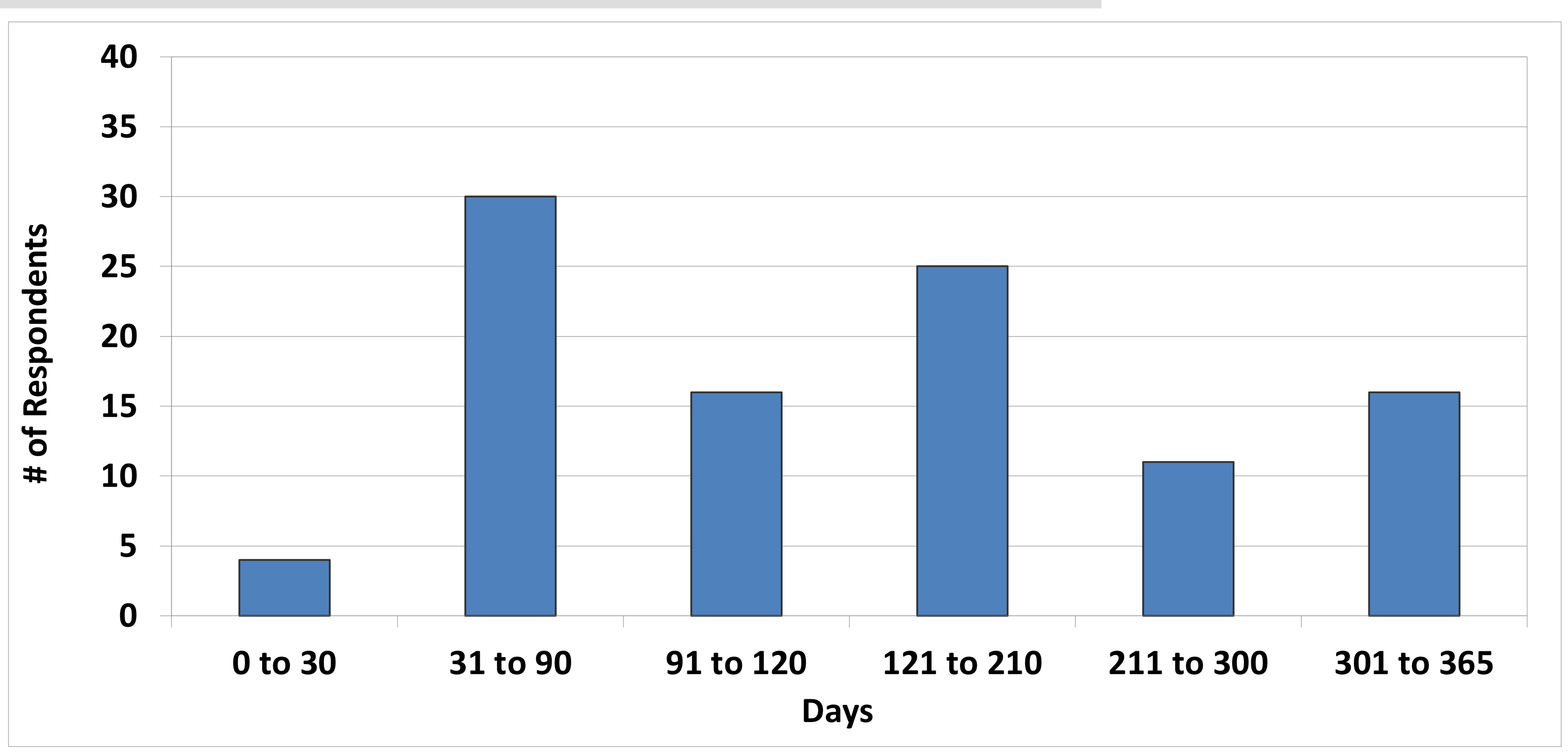


Number	"Other" responses
1	Some week days, weekends, year-round.
2	Keep cottage open for year round use. Primarily weekend and holiday use. Boating in summer and snow skiing in winter at Brule Mt.
3	We use the cottage about half the time year round.
4	seasonal residence and rental
5	As a second home used year round

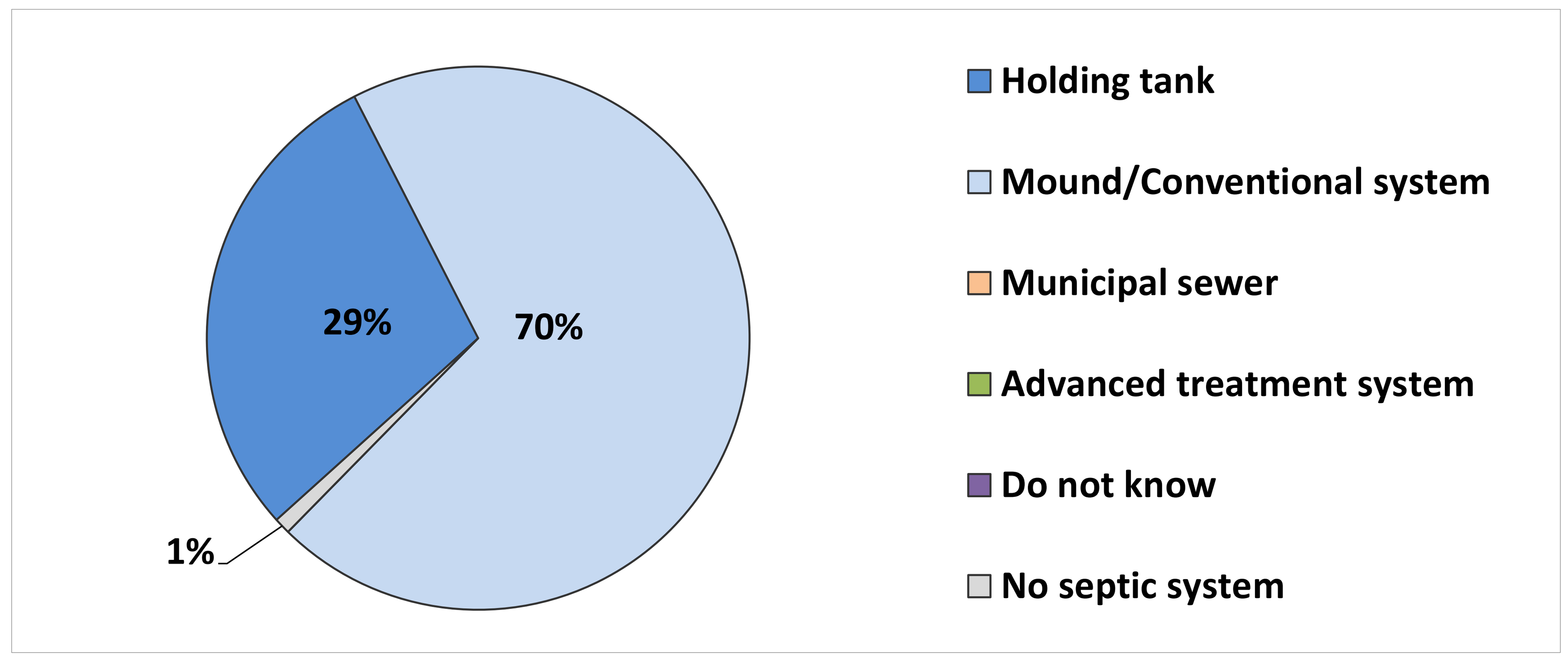
4. Considering the past three years, how many days each year is your property used by you or others?

	Response Count
answered question	102
skipped question	1

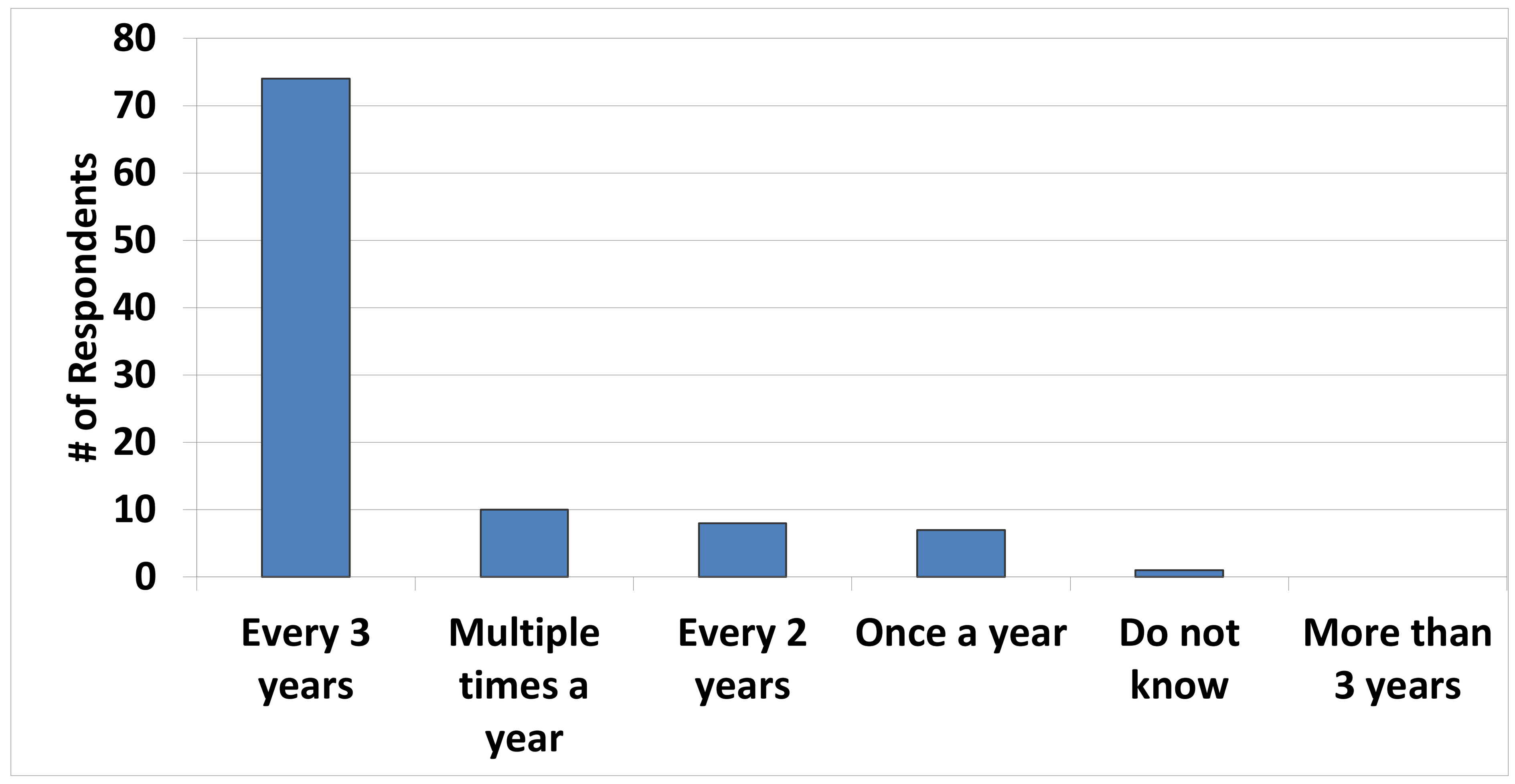
Category (# of days)	Responses	%
0 to 30	4	4%
31 to 90	30	29%
91 to 120	16	16%
121 to 210	25	25%
211 to 300	11	11%
301 to 365	16	16%



5. What type of septic system does your property have?		
Answer Options	**Response Percent**	**Response Count**
Holding tank	29.1%	30
Mound/Conventional system	69.9%	72
Municipal sewer	0.0%	0
Advanced treatment system	0.0%	0
Do not know	0.0%	0
No septic system	1.0%	1
	answered question	103
	skipped question	0

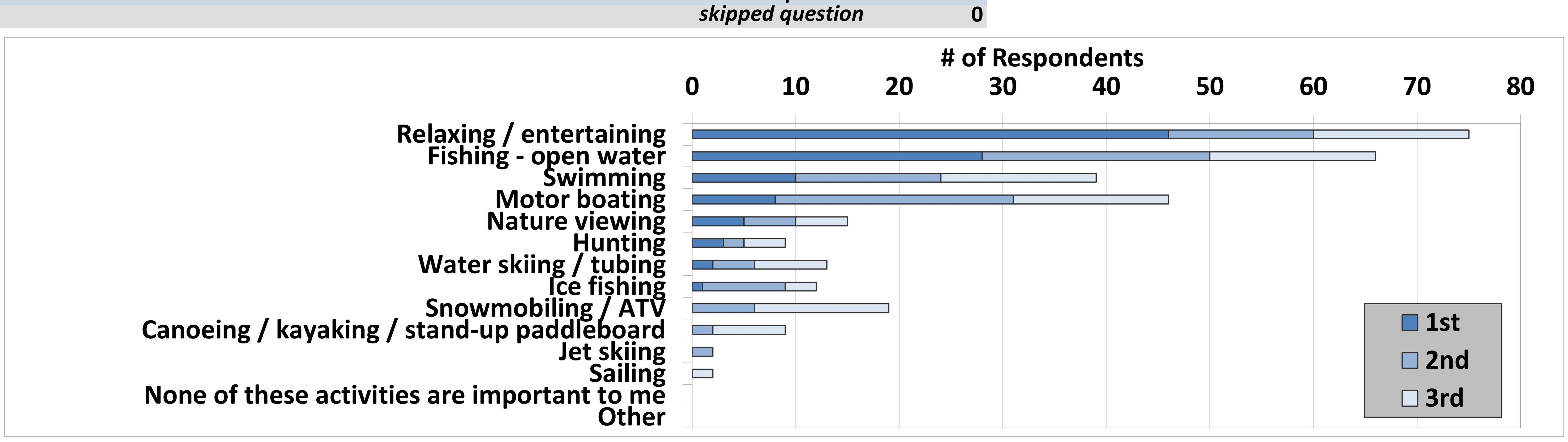


6. How often is the septic system on your property pumped or inspected?		
Answer Options	**Response Percent**	**Response Count**
Every 3 years	74.0%	74
Multiple times a year	10.0%	10
Every 2 years	8.0%	8
Once a year	7.0%	7
Do not know	1.0%	1
More than 3 years	0.0%	0
	answered question	100
	skipped question	3



<u>Recreational Activity on Roberts Lake</u>

7. Please rank up to three activities that are important reasons for owning your property on or near Roberts Lake, with the 1st being most important.					
Answer Options	**1st**	**2nd**	**3rd**	**Rating Average**	**Response Count**
Relaxing / entertaining	46	14	15	1.59	75
Fishing - open water	28	22	16	1.82	66
Swimming	10	14	15	2.13	39
Motor boating	8	23	15	2.15	46
Nature viewing	5	5	5	2	15
Hunting	3	2	4	2.11	9
Water skiing / tubing	2	4	7	2.38	13
Ice fishing	1	8	3	2.17	12
Snowmobiling / ATV	0	6	13	2.68	19
Canoeing / kayaking / stand-up paddleboard	0	2	7	2.78	9
Jet skiing	0	2	0	2	2
Sailing	0	0	2	3	2
None of these activities are important to me	0	0	0	0	0
Other	0	0	0	0	0
				answered question	103
				skipped question	0



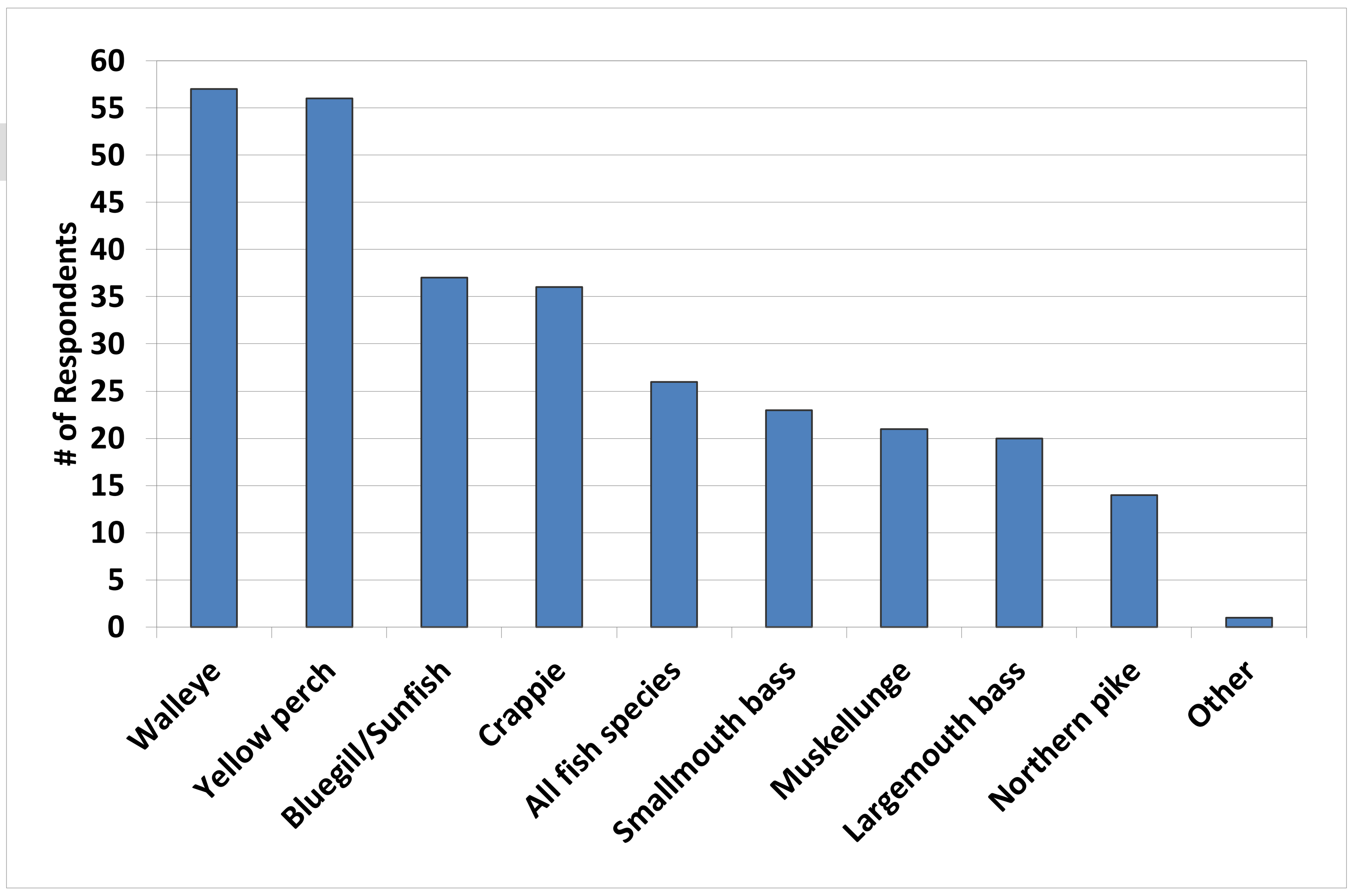
8. Have you personally fished on Roberts Lake in the past three years?

Answer Options	Response Percent	Response Count
Yes	92.2%	94
No	7.8%	8
	answered question	102
	skipped question	1

9. What species of fish do you try to catch on Roberts Lake?

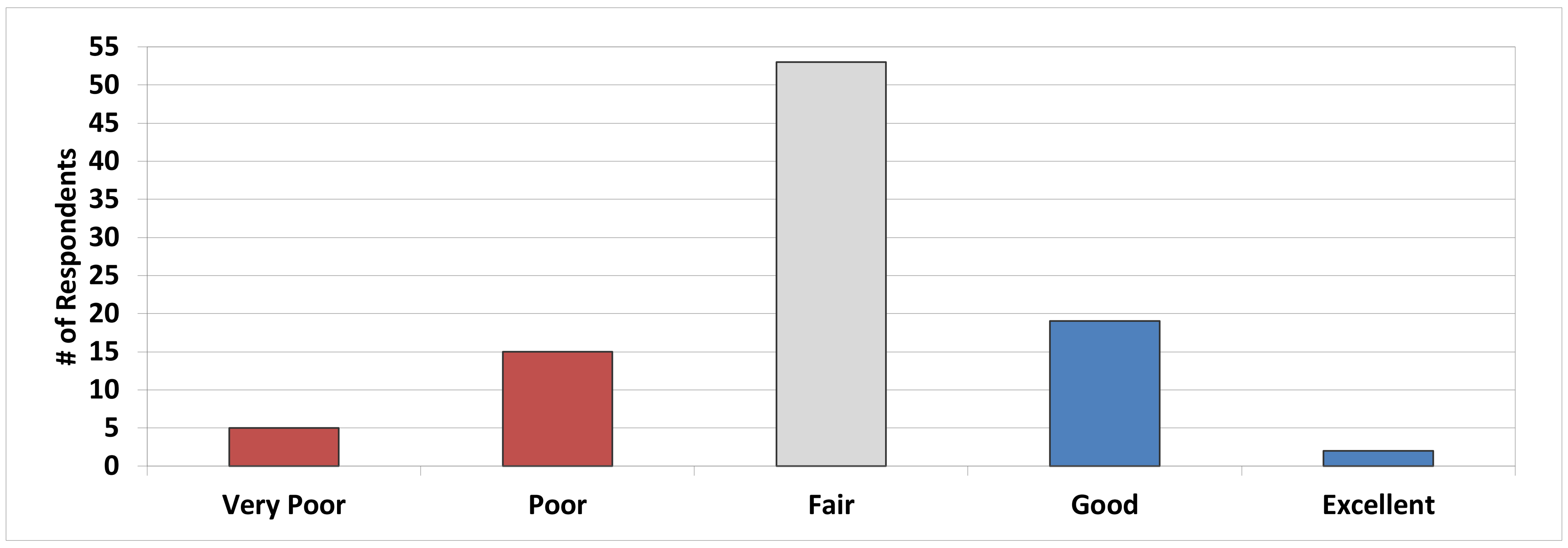
Answer Options	Response Percent	Response Count
Walleye	61.3%	57
Yellow perch	60.2%	56
Bluegill/Sunfish	39.8%	37
Crappie	38.7%	36
All fish species	28.0%	26
Smallmouth bass	24.7%	23
Muskellunge	22.6%	21
Largemouth bass	21.5%	20
Northern pike	15.1%	14
Other	1.1%	1
	answered question	93
	skipped question	10

Number	"Other" responses
1	Anything that will bite a piece of a cold hot dog :)



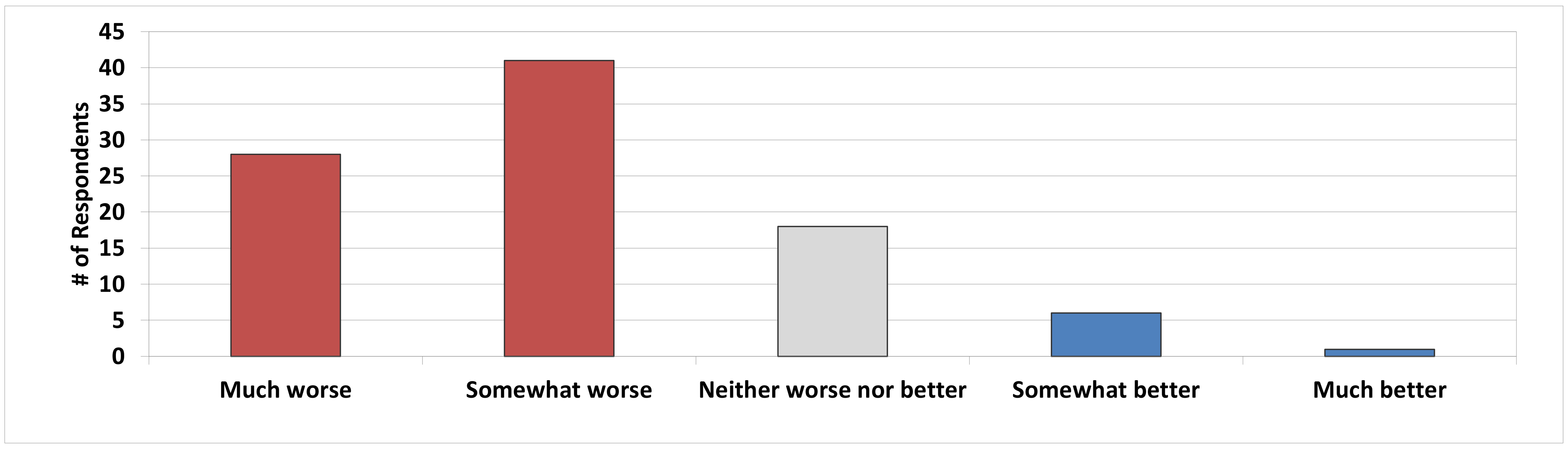
10. How would you describe the current quality of fishing on Roberts Lake?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	5	15	53	19	2	94
					answered question	94
					skipped question	9



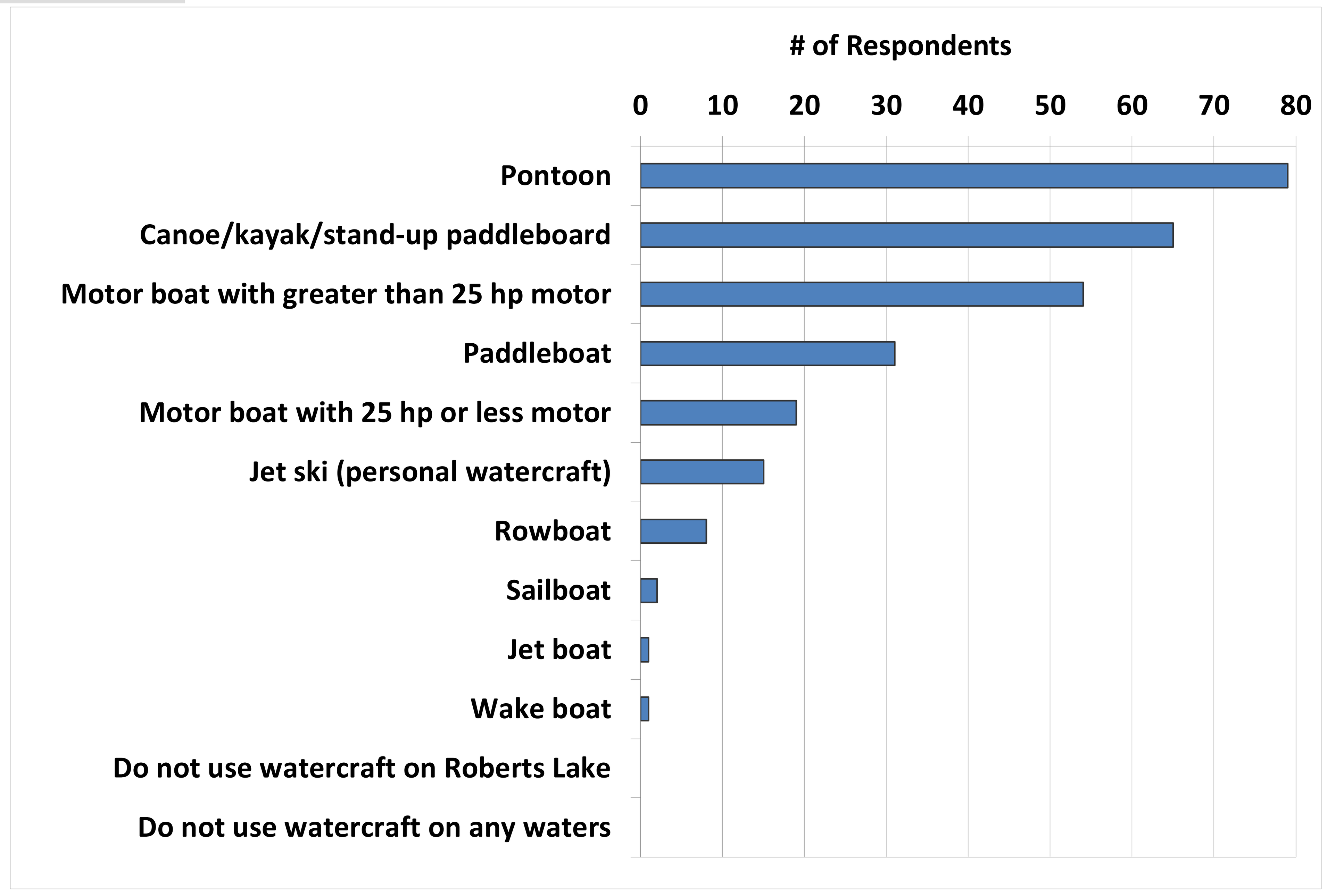
11. How has the quality of fishing changed on Roberts Lake since you have started fishing the lake?

Answer Options	Much worse	Somewhat worse	Neither worse nor better	Somewhat better	Much better	Response Count
	28	41	18	6	1	94
					answered question	94
					skipped question	9



12. What types of watercraft do you currently use on Roberts Lake?

Answer Options	Response Percent	Response Count
Pontoon	77.5%	79
Canoe/kayak/stand-up paddleboard	63.7%	65
Motor boat with greater than 25 hp motor	52.9%	54
Paddleboat	30.4%	31
Motor boat with 25 hp or less motor	18.6%	19
Jet ski (personal watercraft)	14.7%	15
Rowboat	7.8%	8
Sailboat	2.0%	2
Jet boat	1.0%	1
Wake boat	1.0%	1
Do not use watercraft on Roberts Lake	0.0%	0
Do not use watercraft on any waters	0.0%	0
	answered question	102
	skipped question	1

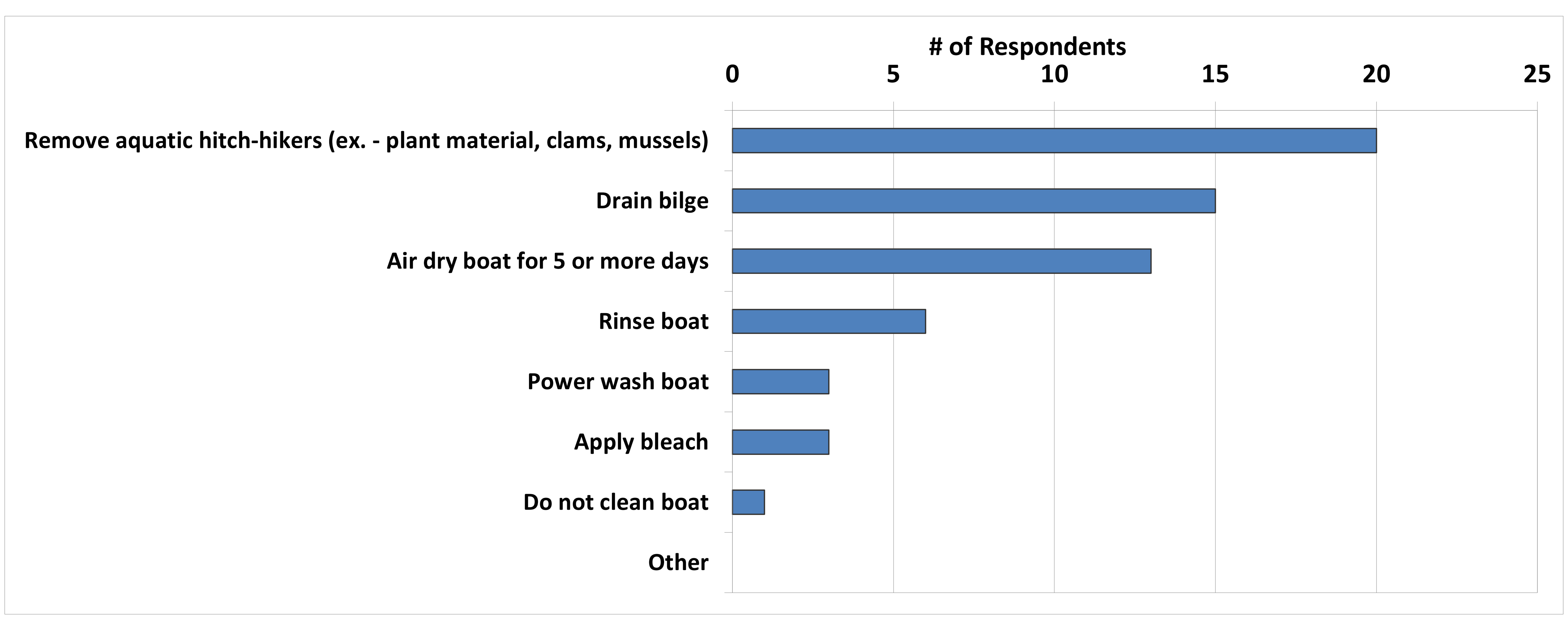


13. Do you use your watercraft on waters other than Roberts Lake?

Answer Options	Response Percent	Response Count
Yes	20.6%	21
No	79.4%	81
	answered question	102
	skipped question	1

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

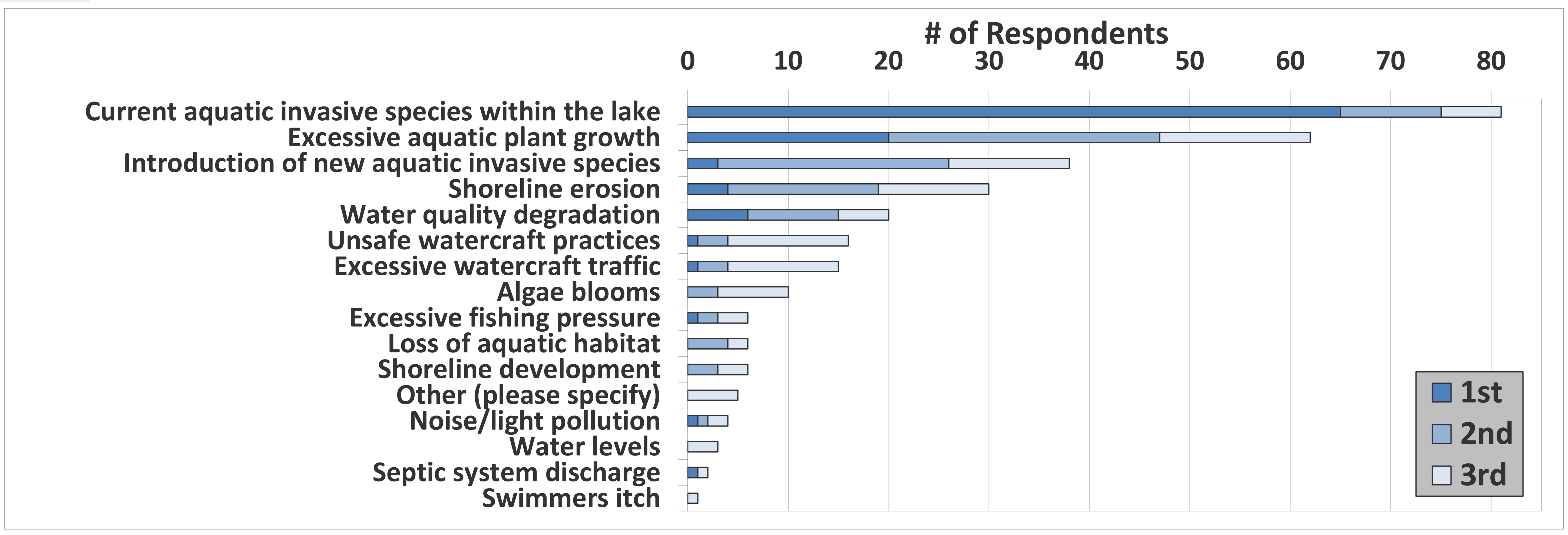
Answer Options	Response Percent	Response Count
Remove aquatic hitch-hikers (ex. - plant material, clams, mussels)	90.9%	20
Drain bilge	68.2%	15
Air dry boat for 5 or more days	59.1%	13
Rinse boat	27.3%	6
Power wash boat	13.6%	3
Apply bleach	13.6%	3
Do not clean boat	4.6%	1
Other	0.0%	0
	answered question	22
	skipped question	81



15. From the list below, please rank your top three concerns regarding Roberts Lake, with the 1st being your top concern.

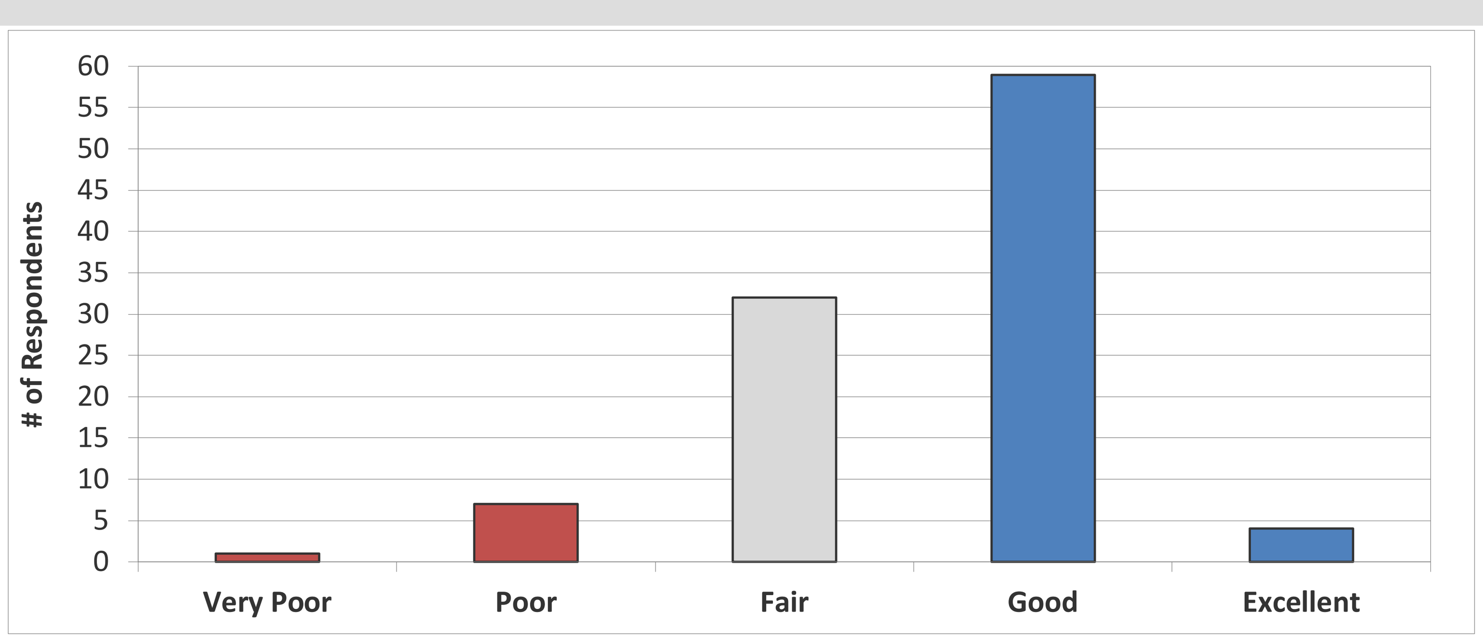
Answer Options	1st	2nd	3rd	Response Count
Current aquatic invasive species within the lake	65	10	6	81
Excessive aquatic plant growth	20	27	15	62
Introduction of new aquatic invasive species	3	23	12	38
Shoreline erosion	4	15	11	30
Water quality degradation	6	9	5	20
Unsafe watercraft practices	1	3	12	16
Excessive watercraft traffic	1	3	11	15
Algae blooms	0	3	7	10
Excessive fishing pressure	1	2	3	6
Loss of aquatic habitat	0	4	2	6
Shoreline development	0	3	3	6
Other (please specify)	0	0	5	5
Noise/light pollution	1	1	2	4
Water levels	0	0	3	3
Septic system discharge	1	0	1	2
Swimmers itch	0	0	1	1
			answered question	103
			skipped question	

Number	"Other" responses
1	Wake boats disrupting the lake
2	jet skis
3	Need to increase the rusty crab populat
4	Wakeboats
5	Milfoil overtaking entire lake.
6	will not let me check more than one
7	Muskrats eroding shoreline
8	Wakeboat use



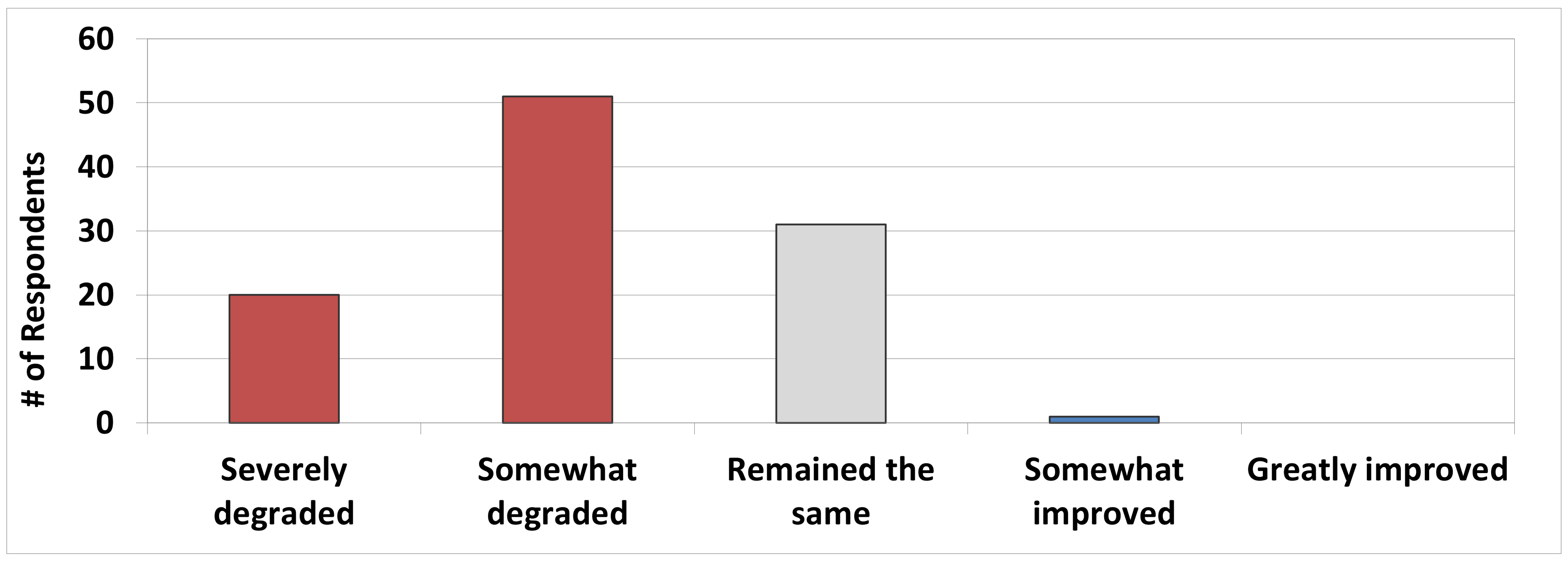
16. How would you describe the overall current water quality of Roberts Lake?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	1	7	32	59	4	103
					answered question	103
					skipped question	0



17. How has the overall water quality changed in Roberts Lake since you first visited the lake?

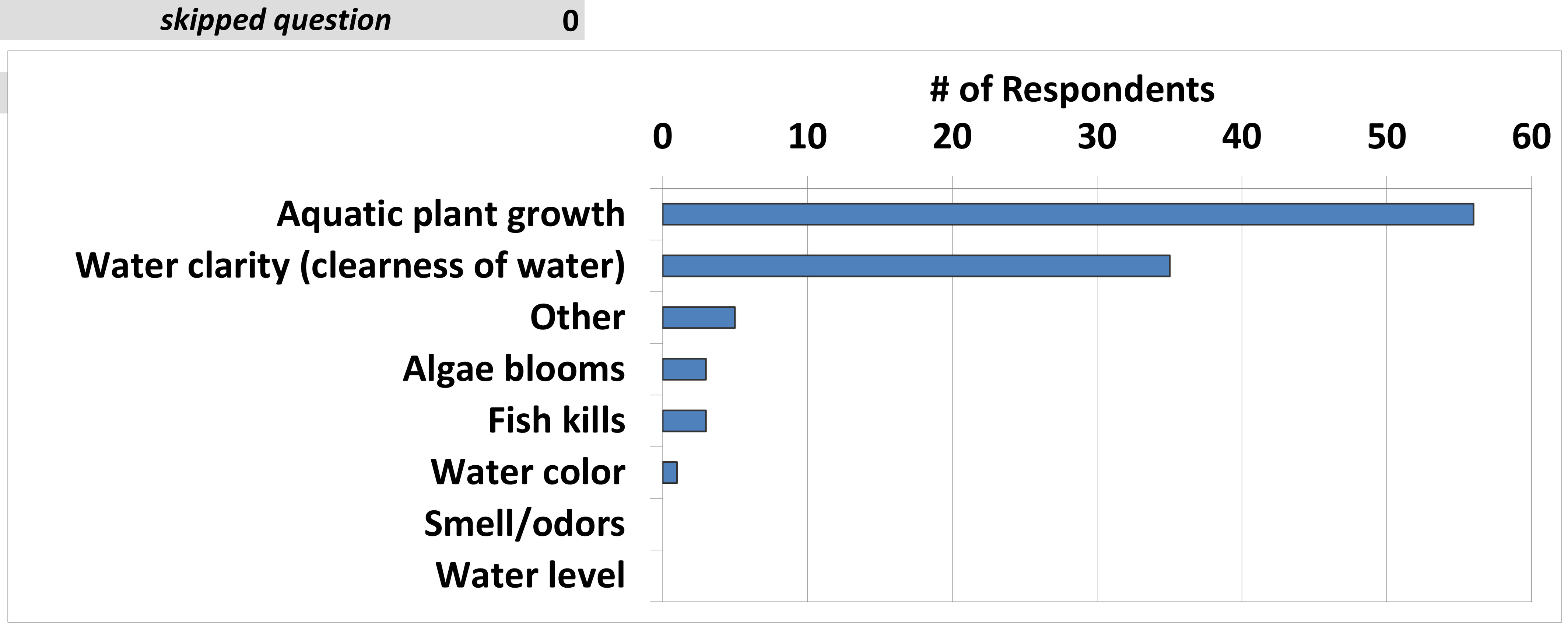
Answer Options	Severely degraded	Somewhat degraded	Remained the same	Somewhat improved	Greatly improved	Response Count
	20	51	31	1	0	103
					answered question	103
					skipped question	0



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

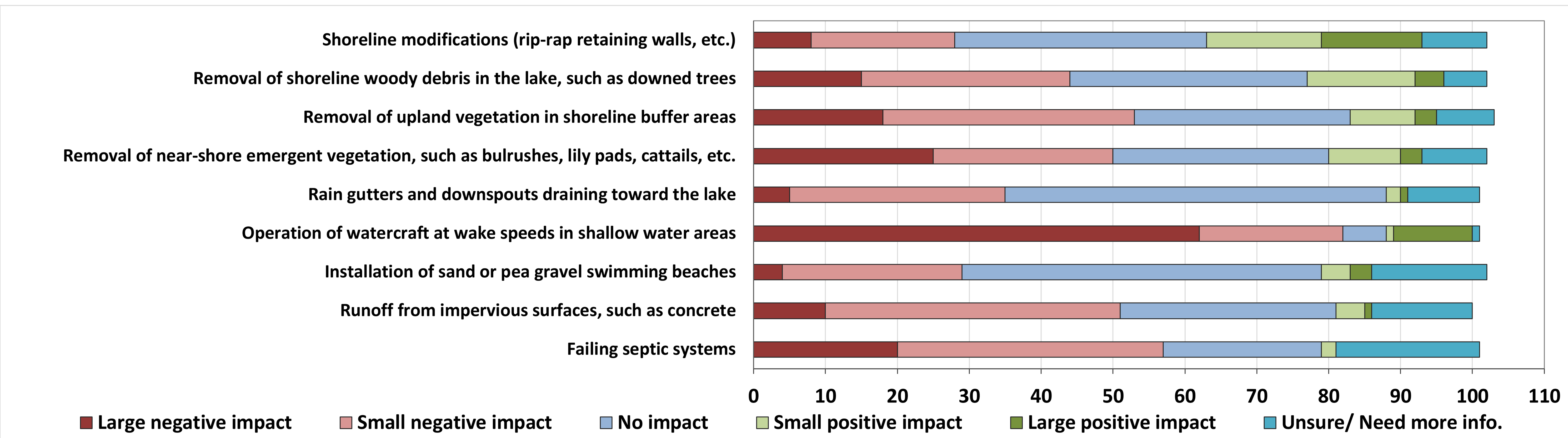
Answer Options	Response Percent	Response Count
Aquatic plant growth	54.4%	56
Water clarity (clearness of water)	34.0%	35
Other	4.9%	5
Algae blooms	2.9%	3
Fish kills	2.9%	3
Water color	1.0%	1
Smell/odors	0.0%	0
Water level	0.0%	0
	answered question	103
	skipped question	0

Number	"Other" responses
1	Invasive species
2	Invasive plants
3	After busy weekends weeds piling up on shoreline & dirty water
4	Excessive milfoil growth.
5	Invasive Species



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

Answer Options	Large negative impact	Small negative impact	No impact	Small positive impact	Large positive impact	Unsure/ Need more info.	Response Count
Failing septic systems	20	37	22	2	0	20	101
Runoff from impervious surfaces, such as concrete	10	41	30	4	1	14	100
Installation of sand or pea gravel swimming beaches	4	25	50	4	3	16	102
Operation of watercraft at wake speeds in shallow water areas	62	20	6	1	11	1	101
Rain gutters and downspouts draining toward the lake	5	30	53	2	1	10	101
Removal of near-shore emergent vegetation, such as bulrushes, lily pads, cattails, etc.	25	25	30	10	3	9	102
Removal of upland vegetation in shoreline buffer areas	18	35	30	9	3	8	103
Removal of shoreline woody debris in the lake, such as downed trees	15	29	33	15	4	6	102
Shoreline modifications (rip-rap retaining walls, etc.)	8	20	35	16	14	9	102
						answered question	**103**
						skipped question	**0**



20. Before reading the statement above, had you ever heard of aquatic invasive species?

Answer Options	Response Percent	Response Count
Yes	98.1%	101
No	1.9%	2
	answered question	**103**
	skipped question	**0**

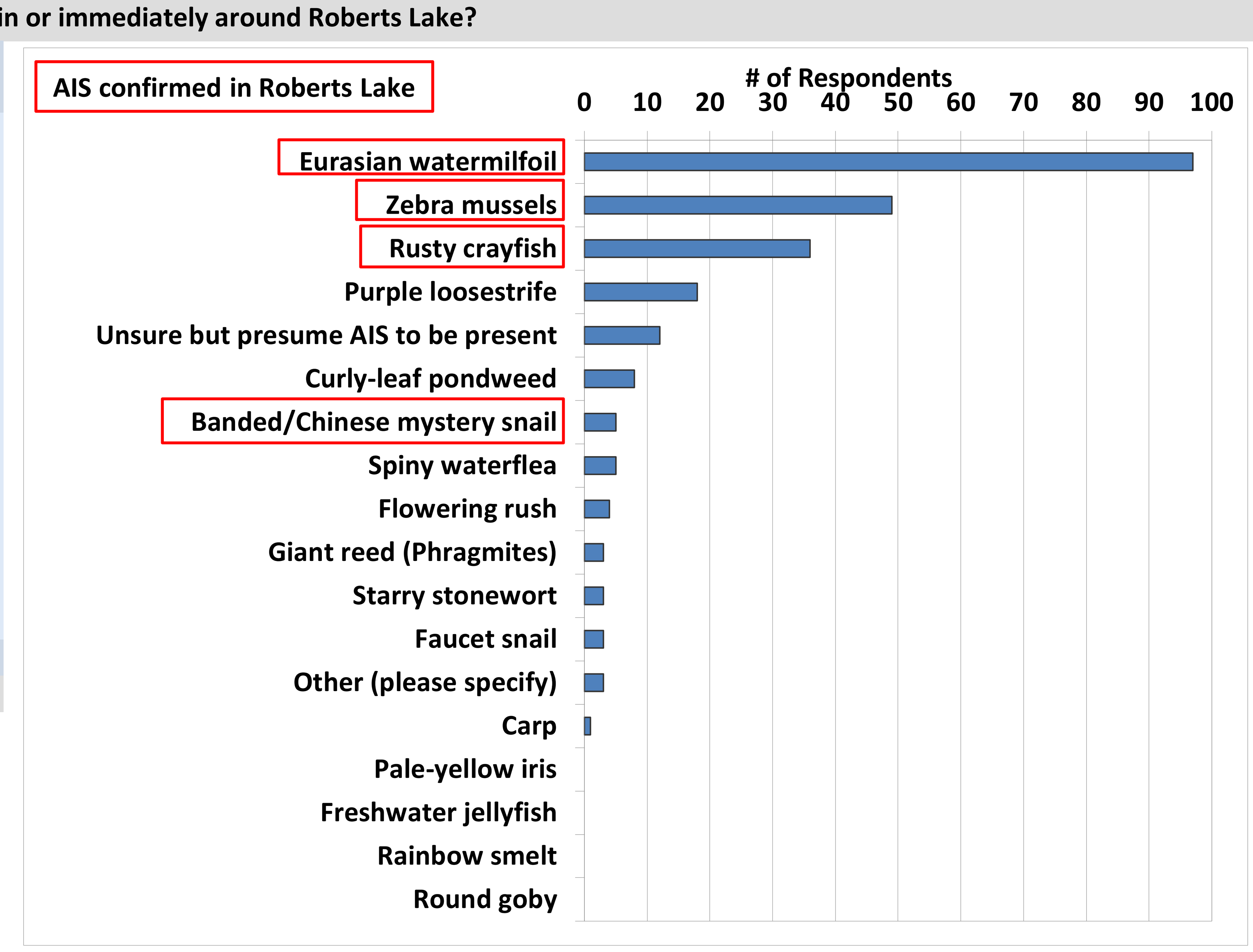
21. Do you believe aquatic invasive species are present within Roberts Lake?

Answer Options	Response Percent	Response Count
Yes	98.0%	99
No	2.0%	2
	answered question	**101**
	skipped question	**2**

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

Answer Options	Response Percent	Response Count
Eurasian watermilfoil	99.0%	97
Zebra mussels	50.0%	49
Rusty crayfish	36.7%	36
Purple loosestrife	18.4%	18
Unsure but presume AIS to be present	12.2%	12
Curly-leaf pondweed	8.2%	8
Banded/Chinese mystery snail	5.1%	5
Spiny waterflea	5.1%	5
Flowering rush	4.1%	4
Giant reed (Phragmites)	3.1%	3
Starry stonewort	3.1%	3
Faucet snail	3.1%	3
Other (please specify)	3.1%	3
Carp	1.0%	1
Pale-yellow iris	0.0%	0
Freshwater jellyfish	0.0%	0
Rainbow smelt	0.0%	0
Round goby	0.0%	0
	answered question	**98**
	skipped question	**5**

Number	"Other" responses
1	Hydrilla
2	can't recall the name of the invasive plant, mussels
3	Possible various invasive snails

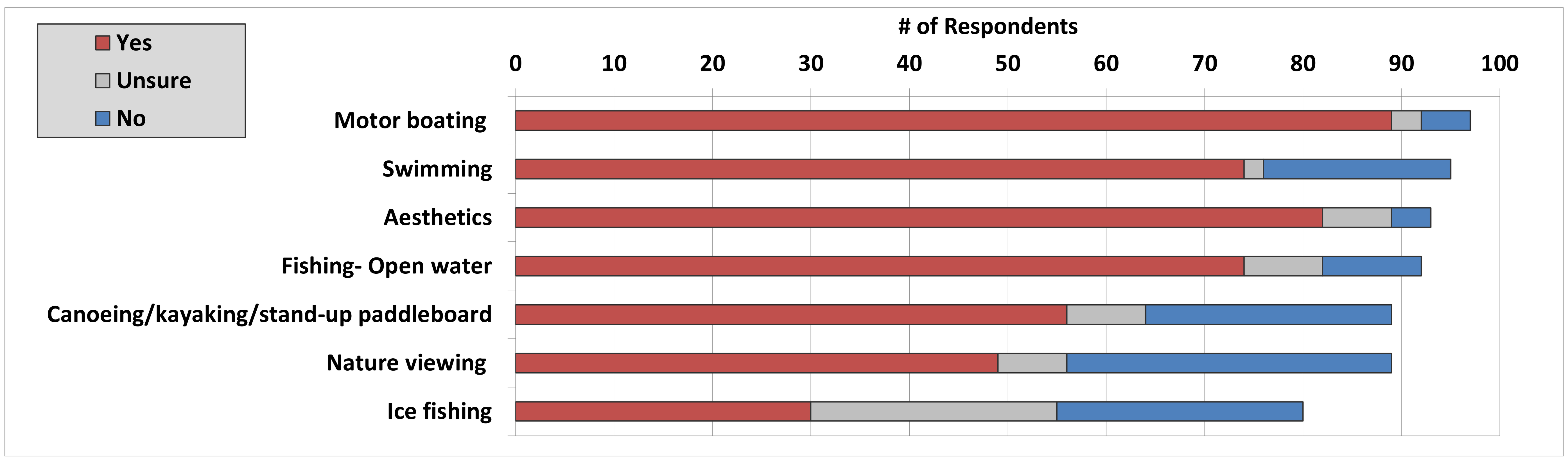


23. Can you identify Eurasian watermilfoil?

Answer Options	Response Percent	Response Count
Yes	88.8%	87
No	11.2%	11
	answered question	98
	skipped question	5

24. Has the Eurasian watermilfoil population ever had a negative impact on your enjoyment of Roberts Lake?

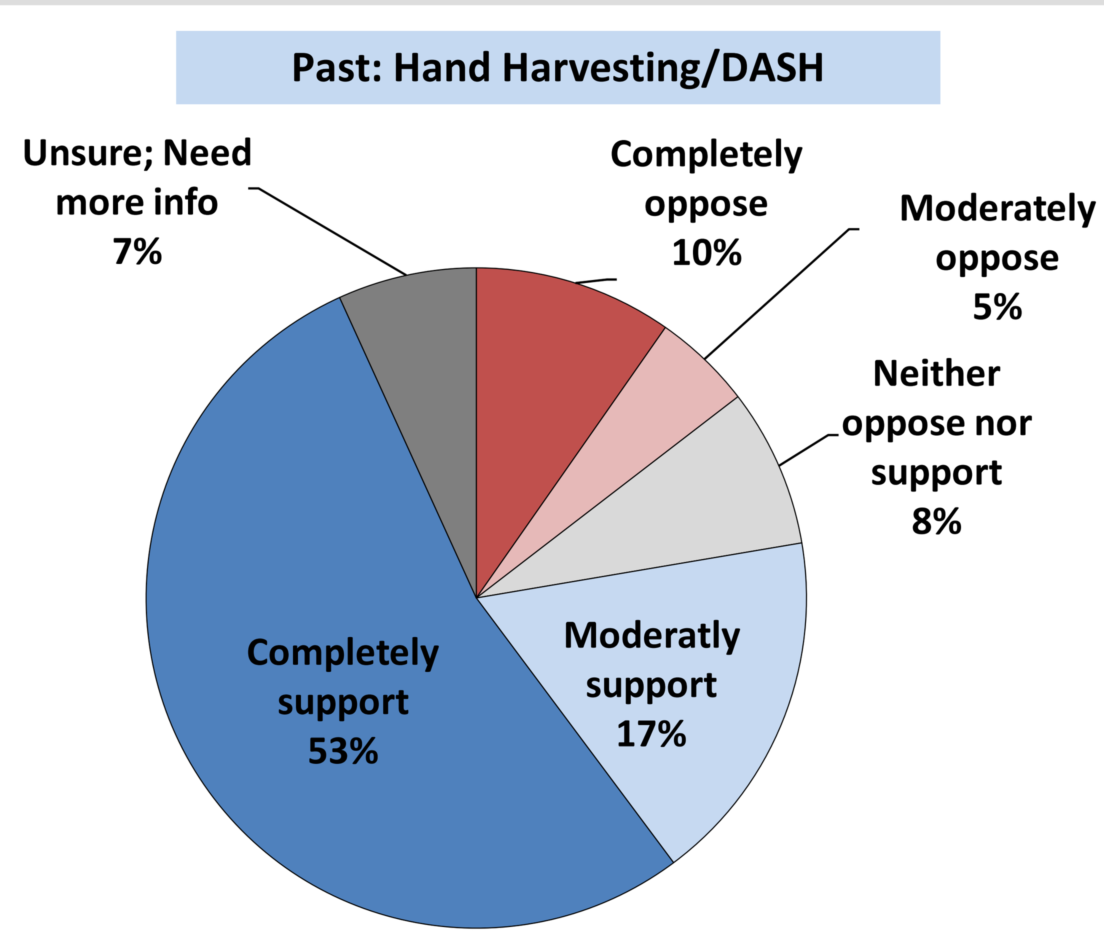
Answer Options	Yes	Unsure	No	Total	Weighted Average
Motor boating	89	3	5	97	1.13
Swimming	74	2	19	95	1.42
Aesthetics	82	7	4	93	1.16
Fishing- Open water	74	8	10	92	1.30
Canoeing/kayaking/stand-up paddleboard	56	8	25	89	1.65
Nature viewing	49	7	33	89	1.82
Ice fishing	30	25	25	80	1.94
Other (please specify)				5	
			answered question		98
			skipped question		5



Number	"Other" responses
1	2024 was first year it was by my dock. Had good size patch that I had to get through with my fishing boat when leaving the dock. Mid season the impeller went on my fishing boat motor. Never happened before in 20 years on the lake.
2	Excessive weed growth
3	can't comment for sure
4	The uprooted aquatic vegetation is resulting in sedimentation of fish spawning areas and shallow areas and shallows near shore
5	Property Value

25. Eurasian watermilfoil has been managed with manual removal methods which includes traditional hand-harvesting and the use of Diver Assisted Suction Harvesting (DASH) equipment. What is your level of support or opposition for the past hand-harvesting/DASH (Diver Assisted Suction Harvesting) to target Eurasian watermilfoil in Roberts Lake? Please circle one number for each control technique.

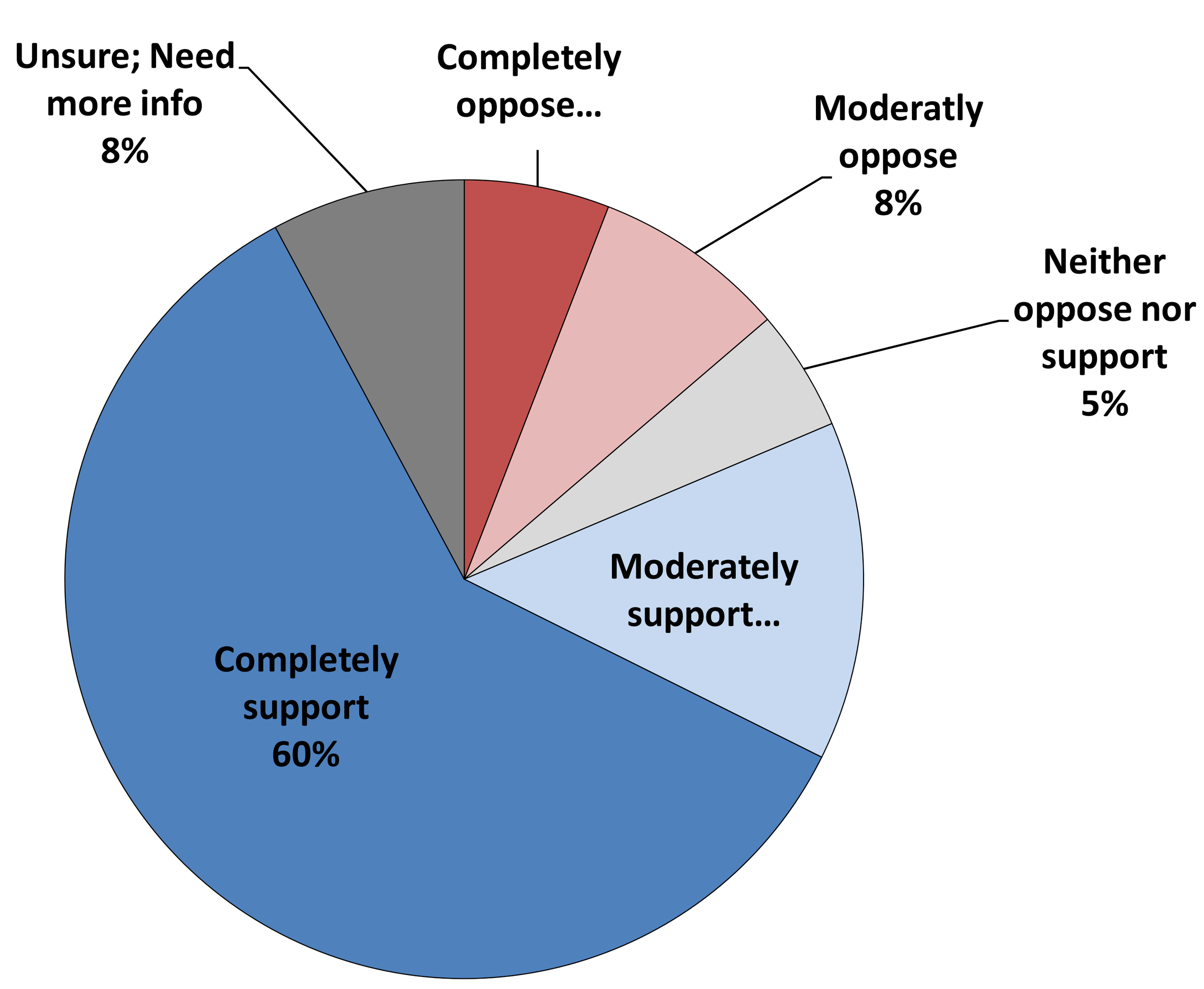
Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Unsure; Need more info	Rating Average	Response Count
Hand-havesting/DASH	10	5	8	18	55	7	4.2	103
							answered question	103
							skipped question	0



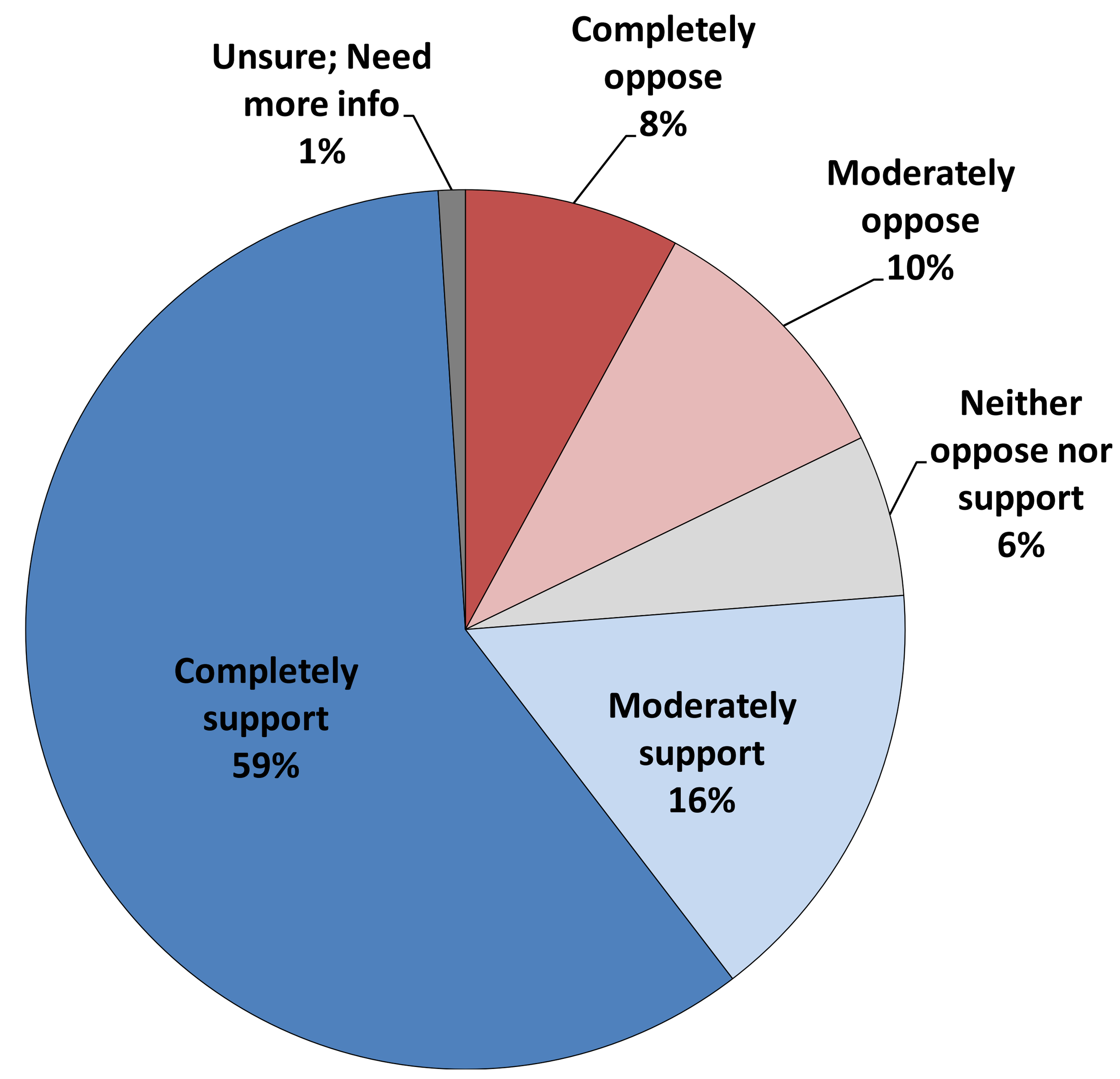
26. EWM can be managed in several ways. What is your level of support or opposition for future management strategies to target Eurasian watermilfoil in Roberts Lake?

Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Unsure; Need more info	Rating Average	Response Count
Herbicide treatments	6	8	5	14	61	8	4.37	102
Hand-harvesting/ DASH	8	10	6	16	60	1	4.12	101
Mechanical harvesting (Weed cutter)	16	19	4	17	35	9	3.63	100
No active management	74	12	3	1	1	3	1.43	94
							answered question	**103**
							skipped question	**0**

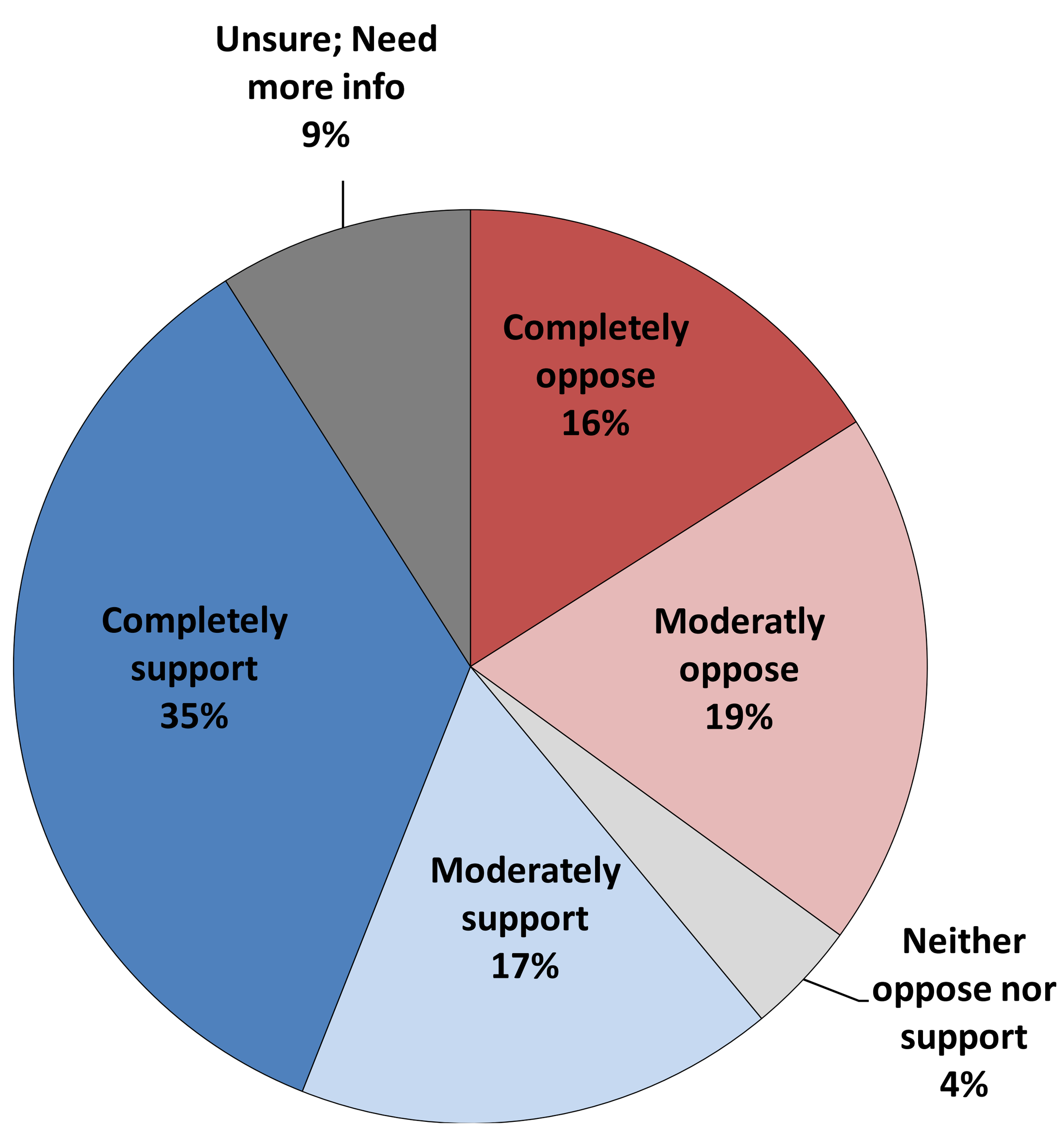
Future: Herbicide Treatments



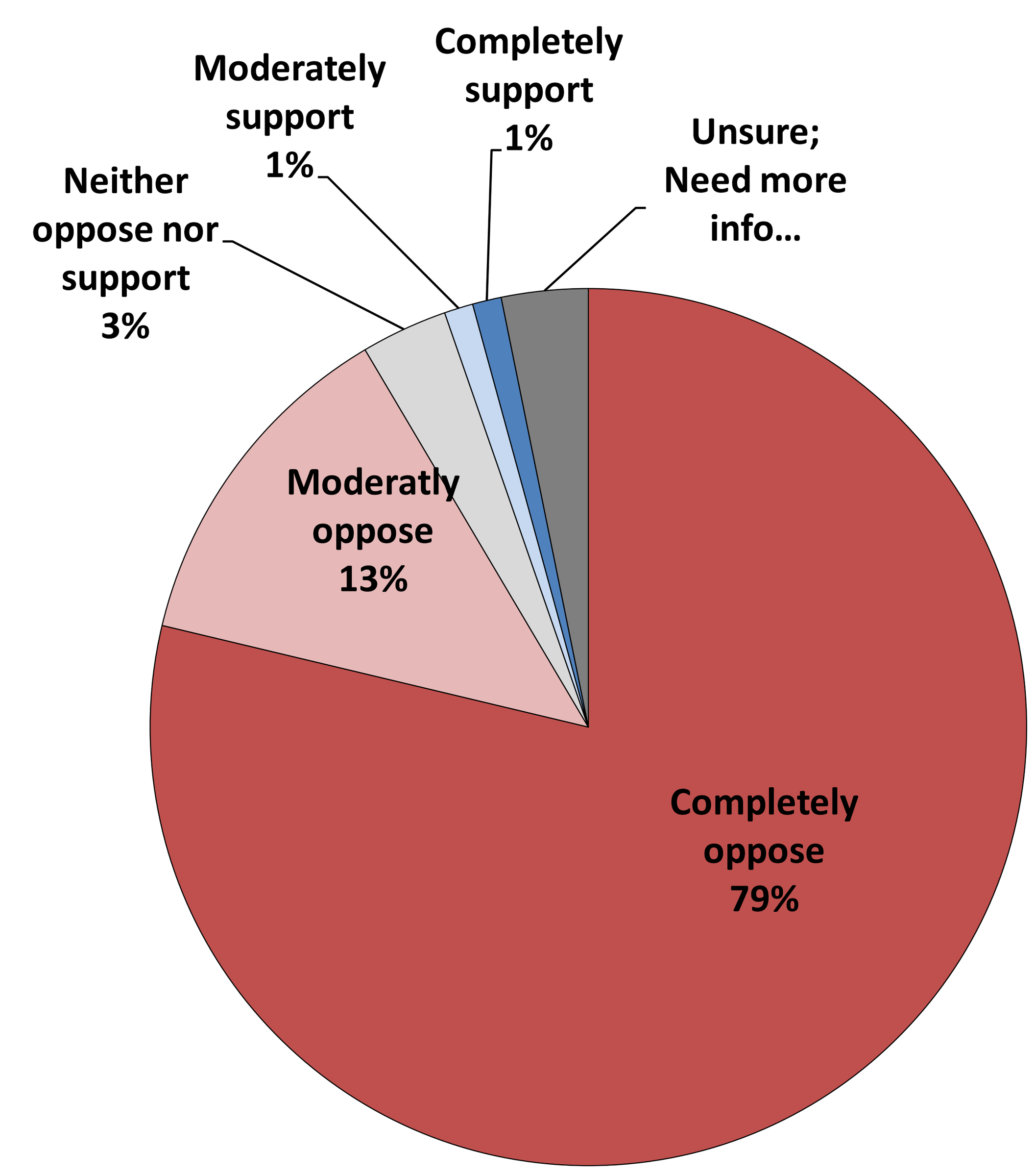
Future: Hand-Harvesting/DASH



Future: Mechanical Harvesting

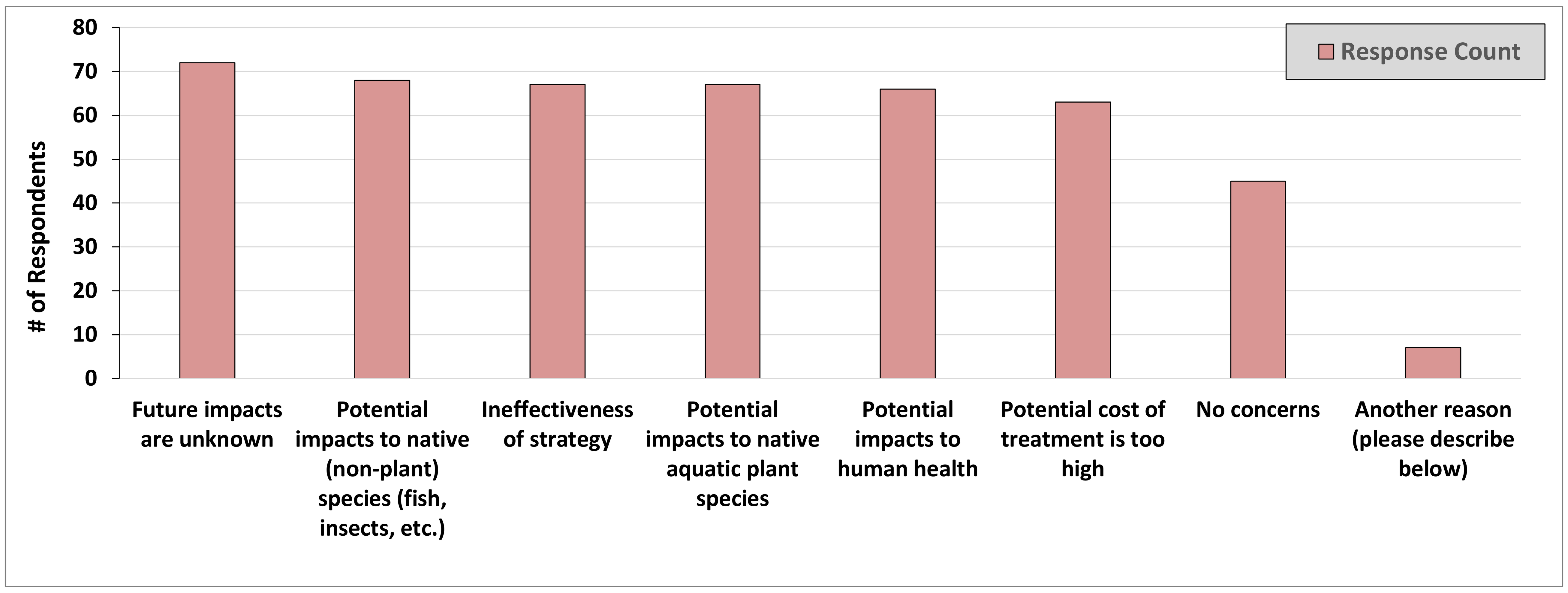


Future: No active management (let nature take its course)



27. What concerns, if any, do you have for the future use of aquatic herbicides, hand harvesting/DASH (Diver Assisted Suction Harvesting) and/or mechanical harvesting to target Eurasian watermilfoil in Roberts Lake?

Answer Options	Aquatic herbicide	Hand-havesting/ DASH	Mechanical harvesting	Rating average	Response Count
Future impacts are unknown	64	5	3	1.15	72
Potential impacts to native (non-plant) species (fish, insects, etc.)	61	3	4	1.16	68
Ineffectiveness of strategy	14	32	21	2.10	67
Potential impacts to native aquatic plant species	49	5	13	1.46	67
Potential impacts to human health	64	1	1	1.05	66
Potential cost of treatment is too high	29	20	14	1.76	63
No concerns	15	16	14	1.98	45
Another reason (please describe below)					7
				answered question	**99**
				skipped question	**4**



Number	"Other" responses
1	I believe Aquatic Herbicide in certain areas is needed along with dash services. I believe further education on herbicides is coming to understand its effect on the lake.
2	All actions should follow sound biological recommendations
3	liabilities with the use of herbicides. Hand harvest and mechanical harvesting during the growing season has only lead to spreading invasive plants..
4	need info on effectiveness of mechanical harvesting
5	unsure of the impacts doing any of these
6	Aquatic herbicide is likely the only truly effective method.
7	Not enough information on what involved with all these procedures and the effectiveness of each procedure.

Roberts Lake Association (RLA)

28. From what source(s) do you draw the majority of your information for each of the three listed aquatic plant management techniques?

Answer Options	Aquatic herbicide	Hand-havesting/ DASH	Mechanical harvesting	Response Count
WI DNR website/preesentations/publicationsn	47	6	2	58
Scientific literature	27	1	3	33
RLA newsletter articles/RLA facebook page	46	12	3	66
Other lake association communications (excluding RLA)	41	8	5	59
Personal communications with friends, family, or community me	50	4	9	67
First-hand observation of management techniques and their effi	28	9	9	49
Web search and/or social media	36	4	7	50
Other (please specify)				4
			answered question	**99**
			skipped question	**4**

Number	"Other" responses
1	prior significant personal involvement in attempts to control.
2	Most info comes from Onterra through RLA for all three.
3	headings are missing from this section-no idea how to respond
4	I do not fully understand how to answer this question due to the format

29. Before receiving this mailing, had you ever heard of the Roberts Lake Association?

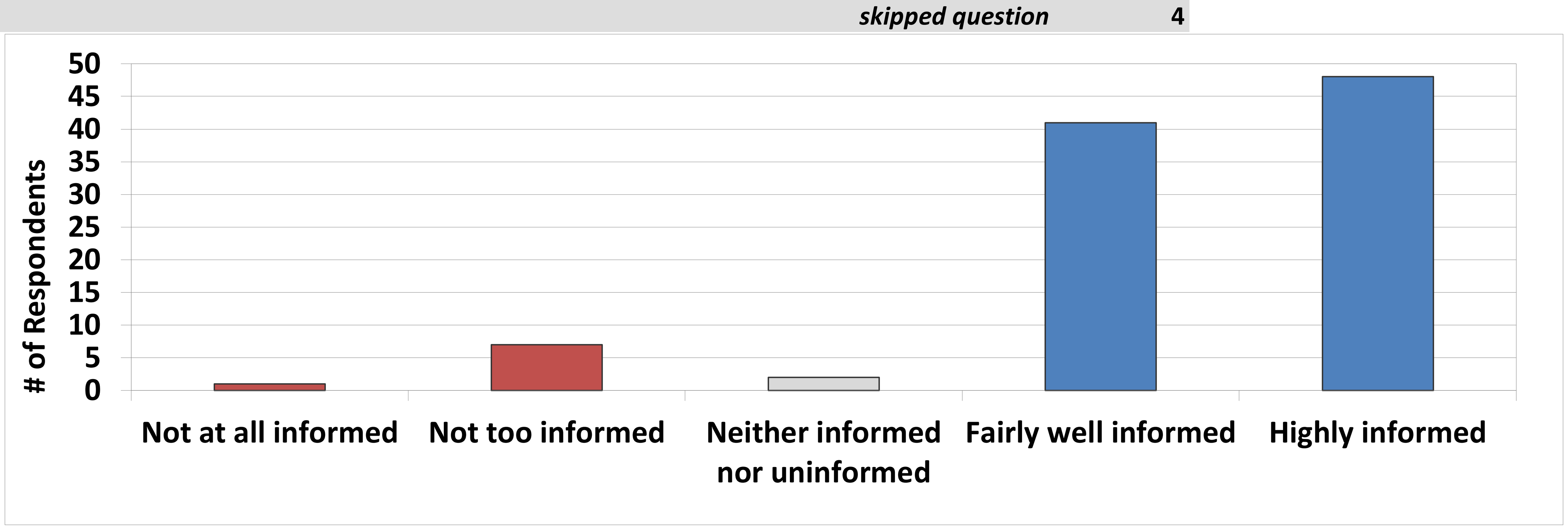
Answer Options	Response Percent	Response Count
Yes	100.0%	103
No	0.0%	0
	answered question	**103**
	skipped question	**0**

30. What is your membership status with the Roberts Lake Association?

Answer Options	Response Percent	Response Count
Current member	87.4%	90
Former member	8.7%	9
Never been a member	3.9%	4
answered question		103
skipped question		0

31. How informed has (or had) the RLA kept you regarding issues with Roberts Lake and its management?

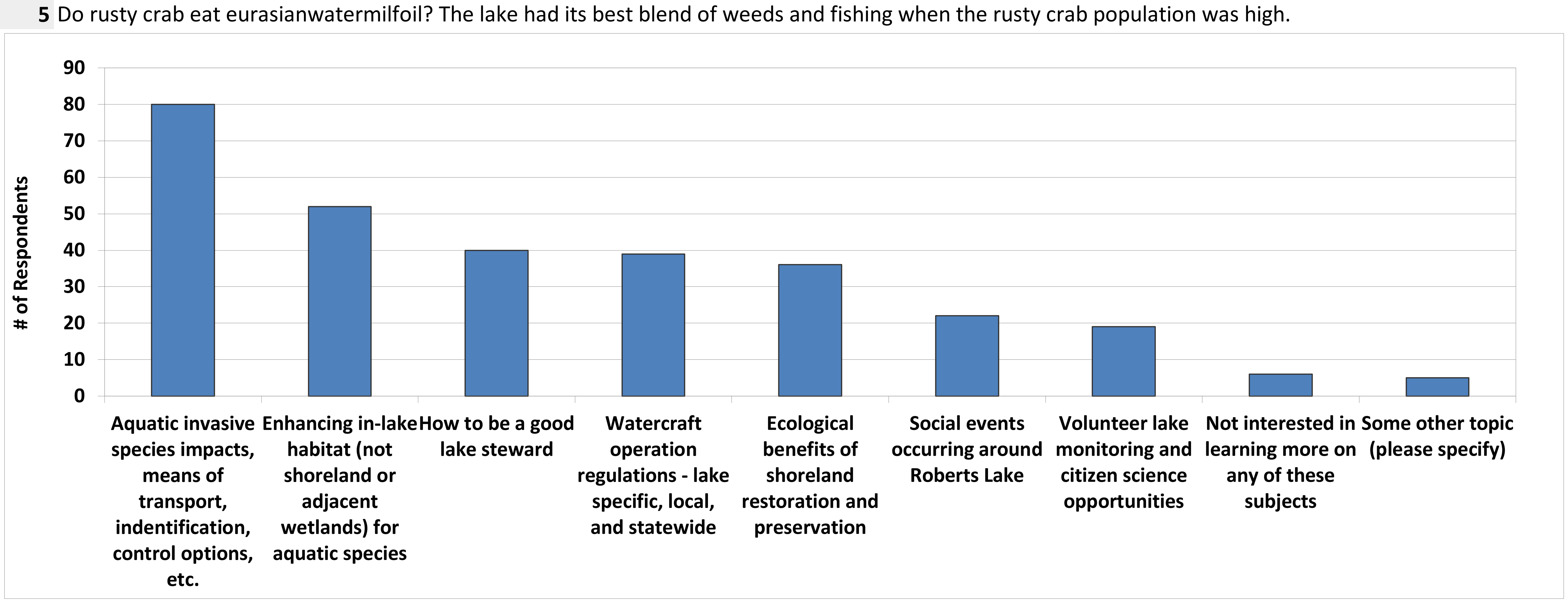
Answer Options	Not at all informed	Not too informed	Neither informed nor uninformed	Fairly well informed	Highly informed	Response Count
	1	7	2	41	48	99
					answered question	99
					skipped question	4



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

Answer Options	Response Percent	Response Count
Aquatic invasive species impacts, means of transport, indentification, control options, etc.	82.5%	80
Enhancing in-lake habitat (not shoreland or adjacent wetlands) for aquatic species	53.6%	52
How to be a good lake steward	41.2%	40
Watercraft operation regulations - lake specific, local, and statewide	40.2%	39
Ecological benefits of shoreland restoration and preservation	37.1%	36
Social events occurring around Roberts Lake	22.7%	22
Volunteer lake monitoring and citizen science opportunities	19.6%	19
Not interested in learning more on any of these subjects	6.2%	6
Some other topic (please specify)	5.2%	5
answered question		97
skipped question		6

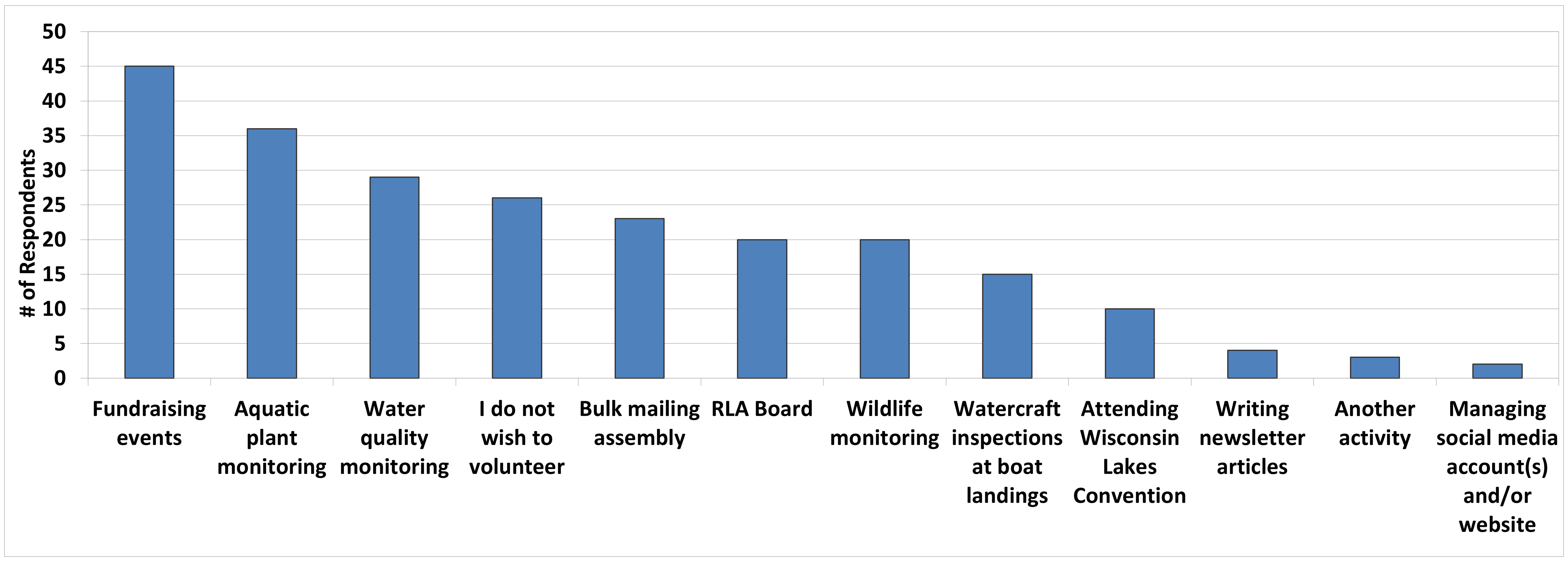
Number	"Some other topic" responses
1	No wake-boats allowed on Roberts Lake.
2	Use of non herbicide (like EWM beetle) to fight EWM.
3	reliable wake boat specifics
4	Environmental impacts of water craft on birds during nesting and rearing young (i.e. loons)
5	Do rusty crab eat eurasianwatermilfoil? The lake had its best blend of weeds and fishing when the rusty crab population was high.



33. Please note that because this survey is anonymous, your answer to this question will not be regarded as a commitment to participate, but instead will be used to gauge potential participation of stakeholders in the RLA.The effective management of Roberts Lake will require the cooperative efforts of numerous volunteers. Please select the activities you would be willing to participate in if the Roberts Lake Association requires additional assistance.

Answer Options	Response Percent	Response Count
Fundraising events	45.9%	45
Aquatic plant monitoring	36.7%	36
Water quality monitoring	29.6%	29
I do not wish to volunteer	26.5%	26
Bulk mailing assembly	23.5%	23
RLA Board	20.4%	20
Wildlife monitoring	20.4%	20
Watercraft inspections at boat landings	15.3%	15
Attending Wisconsin Lakes Convention	10.2%	10
Writing newsletter articles	4.1%	4
Another activity	3.1%	3
Managing social media account(s) and/or website	2.0%	2
answered question		98
skipped question		5

Number	"Another activity" responses
1	I am currently on the board.
2	To old!
3	The upper leadership needs to be replaced before I would consider volunteering again. The current officer and board are to clickie.



34. Please feel free to provide comments concerning Roberts Lake, its current and/or historic condition, and its management.

Answer Options	Response Count
	46
answered question	46
skipped question	57

Number	Response Text
1	I have been coming up to Roberts Lake since I was born in 1964 because my grandfather had a cottage on Roberts Lake, who my uncle now owns. We felt very blessed to buy our own cottage on Roberts Lake in 2013. It is so sad to me to see the degradation of the lake since I was a child--VERY SAD !!! One of the things I loved about the lake was the water clarity and no weeds. Now our shore is COVERED in weeds. We are no longer even able to swim off of our dock.
2	I'm concerned that there is movement toward a "6 flags Wabeno" attitude in use of the lake as opposed to appreciation and preservation of the natural environment
3	Hoping RLA can address EWM soon as it has significantly increased over the past year. It wasn't prevalent at all just 2 years ago. (our lakefront). Overall lake clarity is good but we want to see it be maintained and improved in the future.
4	It is very important to maintain the lake. We have lived on the lake for many years and have enjoyed it greatly. We have a large problem with Eurasian Water Milfoil and it is starting to take over the lake. I am disappointed in the amount of hoops that the DNR makes us jump through to control this issue. It is very obvious that the problem on our lake is going to require herbicides to control our issue, We have done the hand harvesting and DASH harvesting and the problem continues to grow. We will have to endure this problem for at least another year before we will be able to treat this issue with the herbicides and for another year the problem will continue to grow costing our association more money to treat.

5	Keeping the lake clean and free of invasive weeds are important to me. I know how the fishing was 30 years ago and support the efforts to increasing the Walleye, perch and Musky populations back to what they were. I know the crayfish are invasive, but also think the were a good food source for fish.
6	Thank you for the work you are doing to try to address the concerns of the lake and surrounding properties.
7	We have owned property on the lake since 1951. In recent years we are concerned about the lawn/fertilizer runoff into the lake, excessive weed growth and size of the fish population (smaller pan fish, hardly any perch, etc.) The natural shoreline is disappearing with groomed lawns that need to be fertilized to "look nice". We have enjoyed the lake all these years as a great get-away from the city. Children and grandchildren love coming to "the lake" each summer for a week's vacation.
8	Put a limit back on the smallmouth bass. Leave no limit on largemouth bass. That was what was decided at your fish management meeting and was not implemented as such by the dent. I catch plenty of walleye if you actually do some work and know what the hell your doing
9	Check check and recheck that who ever is applying herbicide does it correctly. Told fishery can be protected if applied correctly. Very skeptical about any herbicides used on on lake.
10	None
11	Dying weeds floating into our shore cause trouble with getting our boats off the dock.
12	I believe the majority of Lake association members are on the sandy side of the lake. I am in the muck area that is full of invasive weed species. For us in this area we get little information and have seen very little efforts to remedy the problem. My lake access has diminished to almost unusable. RIDICULOUS! Studies have been done and they know the problem areas and should address the issues, rather than looking at additional studies. In addition, the lake association gives out scholarships - this is not a benevolent organization but one that is supposed to focus on the lake.
13	Great Team! Let's continue to work together to take care of our lake.
14	Our family has had a Shack on the lake for over 70 years. As a child growing up on the lake I have witnessed many varying lake conditions. As a young boy I remember many years when the native aquatic vegetation was so congested that major potions of the lake were unusable for fishing, boating, swimming and other activities. There were also algae blooms some years that made the water a solid green color with the texture of paint. Swimmers itch has always been a part of most area lakes including Roberts. Rusty crayfish were also a major problem for awhile. Smallmouth bass did not exist in the lake and catching a northern was a rarity. Over fishing decimated the walleye and perch populations through the years and Im guessing someone stocked northern, which made the musky, walleye and perch populations plummet. There was a time when the lakes' walleye strain was so coveted that the WDNR would harvest the roe for their hatcheries. There was a good population of musky too, with occasional 50+" fish caught. Largemouth bass have always been present but in the last several decades their numbers increased as did the bluegill populations. There has always been a high concentration of crappies but now, over fishing is having a negative impact on fish size. Motor trolling was never allowed on most inland lakes and that too is having an adverse affect on the walleye and musky populations. Growing up a great portion of the lake was undeveloped and wild. I remember hunting ducks on several places on the lake as a boy. I never thought the entire lake shore would look like it does today. Thank goodness for wetlands. The RLA, WDNR and the Mole Lake Tribe has done a good job in recent years of managing the largemouth bass and northern populations but those fish species will rebound if their efforts are curtailed and motor trolling, generous fish limits, wake boats and sedimentation of fish spawning areas will decimated the walleye population. As a Roberts Lake riparian land owner I have contributed to the development of the Lake shore so I have no right to preach but I would suggest that RLA purchase the remaining undeveloped shore land adjoining the outlet. Currently it cannot be developed but that will change. As a Grandparent I'm concerned about herbicides in the water but trust that due diligence will prove it safe for use in managing the eurasian milfoil.
15	fertilizer run-off from beautiful lawns needs to be curtailed
16	The lake has changed since I bought my property in 1986. Some of that is understandable and some of it is negative change due to things that may have been able to be controlled. The fishing quality is surely not what it had been. This year especially, there are weeds where there have not been weeds before and my understanding is that much of that is invasive. I concede that the weather this year helped the vegetation, both native and invasive to grow. The water is not as clear as it has been in years past. We need to be good stewards of the lake and do what is necessary to preserve the quality for future generations. That means addressing the invasive species as well as the wake boat situation causing significant erosion of the shoreline and general motoring in areas that contain Eurasian milfoil. Our shoreline needs to be rebuilt as a result of wake boats and ice damage. Shorelines should be able to be restored to natural conditions with appropriate materials. This will prevent erosion and provide fish habitat. The Eurasian milfoil needs to be controlled in and of itself in order to preserve the quality of life on Roberts Lake. I'm not sure how much runoff and septic leaching is contributing to the quality of the water, but it should be addressed. We only use our property 30-45 days a year, but thoroughly enjoy our time up there with children, grandchildren and friends.
17	EWM has really gotten to become quite a problem.
18	Only major concern is the spreading milfoil infestation.
19	I do NOT believe we should continue to spend money on putting walleye in the lake. The lake does not appear to have sufficient areas for breeding and natural reproduction of walleye. The money spent could be used to better manage the aquatic invasive species that are in Roberts Lake.

20	I think the RLA board has done an exceptional job at communicating and taking care of issues head on and quickly. Such as the topics of EMF and wake boats. Both of which should stay top of the list for the environmental integrity of the lake. Thanks for all of your hard work and please keep the lines of communication strong. I also like the idea of actively seeking volunteers for various causes.
21	We are so glad that the RLA is taking aggressive action to manage EWM. Thank you, Brett.
22	Eurasian Milfoil is probably the most daunting issue facing our lake in the 60 years I've been on the lake. The increased boat traffic on the lake over the past 20 years has surely stirred up the undisturbed sediments dormant for hundreds of years. That and the increase of dwellings on the lake importing lawns that require fertilizers to thrive. As a child the lake bottom in front of our cottage was mostly stone and rock. It's now sandy and mucky. So it's obvious runoff has effected the lake significantly in the last 60 years. If we could return the lake to its condition in 1963 when I first set eyes on it, our lake association will need to police and educate new owners that boats that create massive wakes are not welcome and green lawns belong in a city environment.
23	Not sure that removing the mature bass population will have a great impact on future walleye population? Northern pike yes, but as Musky population declined bluegill population exploded, this also is a negative impact on an overall quality fish population. Many great fishing lakes have a good population of musky, walleye, larger bass, and perch, as Roberts once did.
24	If the watercraft that has a high potential to disrupt the lakes normal state need to be banned so be it
25	I am very concerned about the future of our lake. The area around our dock at *Address Removed* has been overrun with milfoil in a matter of a year. Stuck in motors, impacting swimming, and a terrible impact on fishing. We had great fishing right off our dock, and now you can't even fish. Looking forward to seeing more about what we can do in 2025 to start addressing before it's too late and the lake quality becomes terrible. Appreciate all you are doing to address this challenge- Thanks, *Name Removed*
26	I absolutely love Roberts lake. I have been on the lake with my parents since I was four years old and we currently have a place On the lake now! I never thought I would be able to be on the lake! I have been on Roberts lake for 58 years! I wonder who is trying to change the names of the bays. We only had one bay and one Cove. That's it. I don't believe you can just change these names. I do appreciate the concern of the conditions of the lake I would like it to be there for a long, long time for the next generations to love like I do! Roberts Lake is my dream come true! I also want to thank whoever is tackling this big job.
27	I choose not to volunteer and left the association because I feel the RLA focuses on the preferences and needs of just a select few residents/property owners on Roberts Lake. I feel the RLA is not interested in the views/concerns of the other property owners.
28	Been seeing a fair amount of litter washing up on shorelines lately.
29	The Walleye population degraded after continuous spearing by the Native Americans. Their own spearing records attest to it by the decreased numbers per year. You can't take out Mature Females with thousands of eggs before they spawn and not reduce future populations. Nobody wants to admit this especially the Native Americans. The Lake ecosystem has not been the same since then.
30	As responses indicate, Eurasian Milfoil is clearly the most pressing issue facing Roberts Lake. Its rapid spread rate is nothing short of alarming. From what I've read and been told, aquatic herbicide is the only technique that gets effective results. Thank you for undertaking this effort!
31	Something has to be done immediately about this invasive weed problem.
32	Roberts Lake continues to be the best all-around lake in Forest County and among the best in northern Wisconsin. I have been a full-time resident of Roberts Lake for twenty-seven years and a property owner for fifty plus years. Our lake association is one of the greatest reasons that our lake is considered one of the greatest lakes. With the power boats, etc. of today, the jet ski/water ski hours remain a top priority to continue. Our previous association officers were responsible for the Freedom Town Board adopting this ordinance. I hope we can continue to recruit all property owners to take an active role in our association.
33	I would like something done to the dam put a lift gate in so the level could be drawn down over winter. This would prevent damage to the shore from ice shift in real cold weather. Start draw down Dec. 1st and put the lift gate back March 15.
34	I think the weed situation is getting a lot worse and a plan needs to be developed to control the weeds progression. From my research it appears once the weed is here it's here to stay and the best scenario is I keep its spread under control.
35	to many wake boat and jet ski
36	Over 50 years on the lake. Never saw milfoil like today.
37	Good lake association. Need to get all our neighbors to join the association. Person invites might work best.
38	Please help RL to return to a healthy level again! It's sad to see how it has declined in the last years. Big speed boats need to be banned all together! Talk about shoreline erosion and weed dispersion much caused by deep motors and high speed watercraft!
39	Feel that to do nothing the last two years with regard to the EWM issue was a mistake! EWM is now everywhere and will be much more difficult and expensive to deal with as a result of this decision.

40	Not happy with current fish management removal of fish species that my grandkids can actually catch "bass and northern" for walleyes which are hard to catch and can't keep enough to be worth while while partnering with native tribe who's interest is in more fish to spear why bother to take kids out for fish they seldom catch left with catching panfish off dock disappointed there wasn't a survey of lake members before this was implemented weed growth a major problem soon boats will be circling middle of lake bays weed choked on lake 63 years never had weeds off dock now they are closing in on swimming area
41	The millfoil issue has exploded this year. I am very concerned about developing an effective management plan soon.
42	Hopefully this survey will be a positive step in controlling and eradicating a very serious problem.
43	Our shorelines are being destroyed with roads constructed to the lake, native vegetation removed, unsightly rock and gravel put in its place, excavating, permanent pier/deck installation on shoreline and all these solar lights have ruined the evening star gazing
44	The amount of EWM has become a major issue and threatens the traditional use of the lake. I've seen significant growth of EWM colonies in just the last few years. Extreme measures shoud be taken to eliminate the plant colonies and the spread through fragmentation. We need to knock down to plants using an effective herbacide and reuce the spread by banning wake boats, and even consider making the entire lake a No Wake Lake for a few years until we get the EWM under control.
45	Need younger people to get involved and help manage the lake
46	Aquacide is a great source for EVM and needs to be considered ASAP. Evidence from other lakes has shown no I'll effects.The EVM has exploded over the past 3 years and will soon affect property values if not eliminated. Extreme heavy weed accumulation in all shallow areas has affected 80% of the shoreline, eliminating fishing except in deeper waters. As an open water fisherman, fishing is harder to catch or simply enjoy the sport, especially in the past 2 years. The RLA has plenty of funds to clean up our lake.

C

APPENDIX C

Aquatic Plant Data

Roberts Lake Point-Intercept
Survey Matrix

Scientific Name	Common Name	LFOO (%)	
		2015	2024
Ceratophyllum demersum	Coontail	38.9	42.2
Najas guadalupensis	Southern naiad	37.8	9.3
Elodea canadensis	Common waterweed	38.7	4.9
Vallisneria americana	Wild celery	16.9	16.8
Myriophyllum sibiricum	Northern watermilfoil	28.6	7.3
Chara spp.	Muskgrasses	15.8	12.7
Myriophyllum spicatum	Eurasian watermilfoil	0.0	18.3
Lemna trisulca	Forked duckweed	13.2	3.2
Potamogeton zosteriformis	Flat-stem pondweed	6.8	3.4
Potamogeton robbinsii	Fern-leaf pondweed	0.2	4.1
Schoenoplectus acutus	Hardstem bulrush	2.4	2.4
Potamogeton illinoensis	Illinois pondweed	3.6	1.0
Najas flexilis	Slender naiad	1.7	1.2
Nymphaea odorata	White water lily	1.1	1.5
Nitella spp.	Stoneworts	1.7	1.0
Potamogeton natans	Floating-leaf pondweed	1.1	1.2
Nuphar variegata	Spatterdock	1.1	1.2
Potamogeton amplifolius	Large-leaf pondweed	1.9	0.5
Potamogeton strictifolius	Stiff pondweed	1.3	0.7
Potamogeton pusillus	Small pondweed	2.4	0.0
Potamogeton gramineus	Variable-leaf pondweed	0.2	1.0
Potamogeton berchtoldii	Slender pondweed	1.3	0.2
Heteranthera dubia	Water stargrass	1.7	0.0
Persicaria amphibia	Water smartweed	0.2	0.5
Potamogeton amplifolius x praelongus	Large-leaf x White-stem pondwe	0.6	0.0
Eleocharis acicularis	Needle spikerush	0.2	0.2
Fissidens spp. & Fontinalis spp.	Aquatic Moss	0.2	0.0

Compiled by Onterra

Coontail (*Ceratophyllum demersum*) Native

FLORA of WISCONSIN: https://wisflora.herbarium.wisc.edu/taxa/index.php?taxon=3082

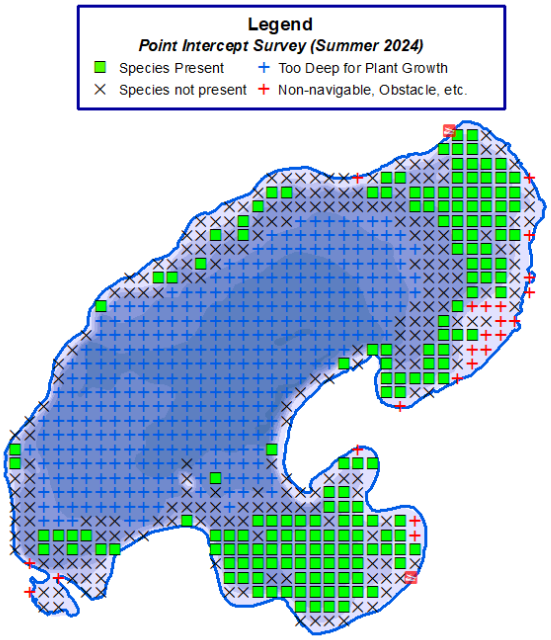


Photo Credit: Onterra

- Coontail has whorls of leaves which fork into two to three segments, providing surface area for invertebrate habitat.
- Does not produce true roots and is often found growing entangled amongst other aquatic plants or matted at the surface.
- Coontail has a high tolerance for low-light conditions which allows this plant to become more abundant in eutrophic waterbodies with higher nutrients and low water clarity.

Eurasian watermilfoil (*Myriophyllum spicatum*) Exotic

FLORA of WISCONSIN: https://wisflora.herbarium.wisc.edu/taxa/index.php?taxon=4313

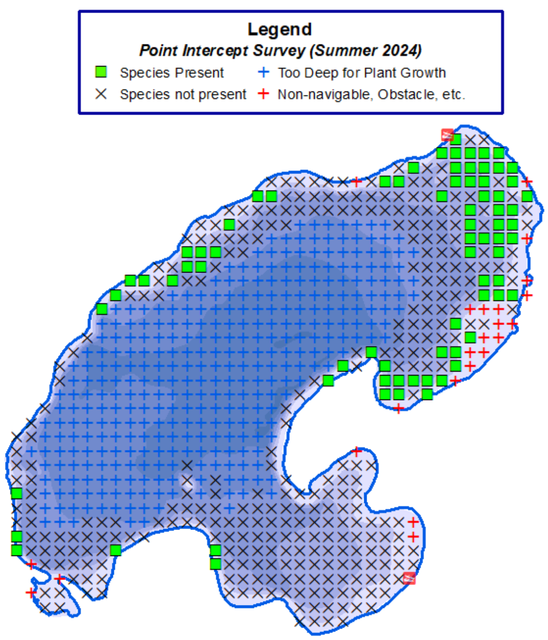


Photo Credit: Onterra

- A common and problematic invasive species in Wisconsin. Most developed lakes in Wisconsin have been exposed to this plant and some have even experienced change in its aquatic environment due to this plant.
- It can be identified by its slender shape when held out of water, the leaves are in whorls of around four, and each leaf has 24 or more leaflets (12 on each side of a leaf). There are some native milfoil plants in Wisconsin, but they are more likely to hold their bushy shape when pulled out of the water and have less leaflets on each of their leaves.

Wild Celery (*Vallisneria americana*) Native

FLORA of WISCONSIN: https://wisflora.herbarium.wisc.edu/taxa/index.php?taxon=5329

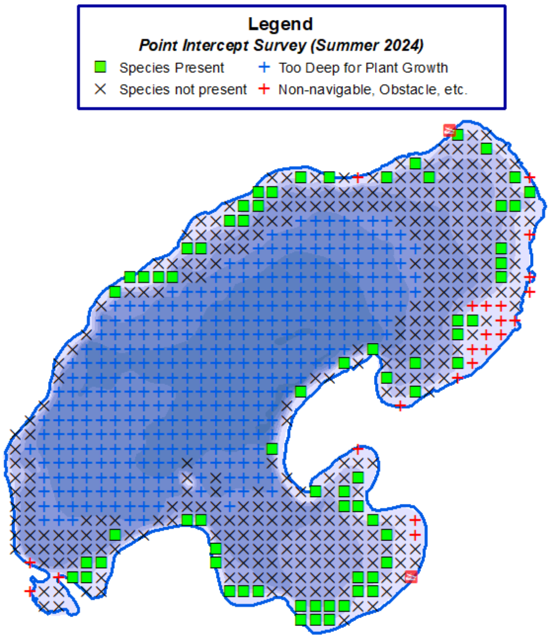


Photo Credit: Onterra

- Wild Celery has long ribbon-like leaves that tend to sway with the current and projects a singular small white flower to the surface from a spiraling stalk.
- Prefers to grow over harder substrates and is tolerant of low-light conditions.

Muskgrasses (*Chara)* Native

FLORA of WISCONSIN: https://wisflora.herbarium.wisc.edu/taxa/index.php?taxon=22150

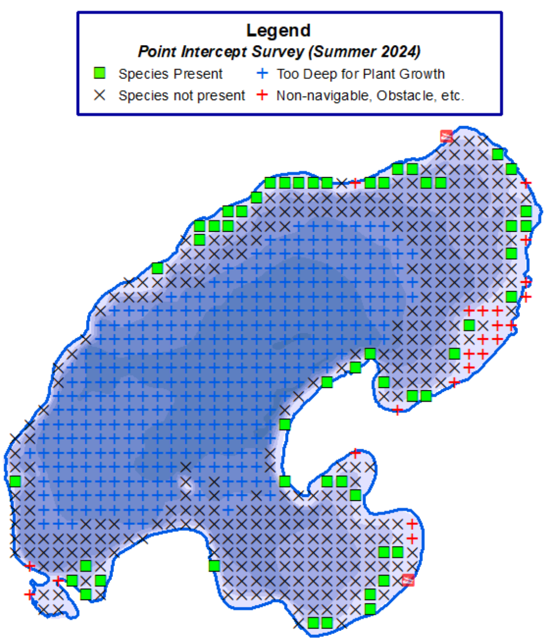


Photo Credit: Onterra

- These groups of plants grow unrooted and generally and low along the bottom of the water column and can provide dense coverage. Their large beds help stabilize bottom sediments
- Muskgrasses require lakes with good water clarity
- Muskgrasses are easily distinguished from stoneworts by the skunk like smell that muskgrasses have.

Southern naiad (*Najas guadalupensis*) Native

FLORA of WISCONSIN: https://wisflora.herbarium.wisc.edu/taxa/index.php?taxon=4321

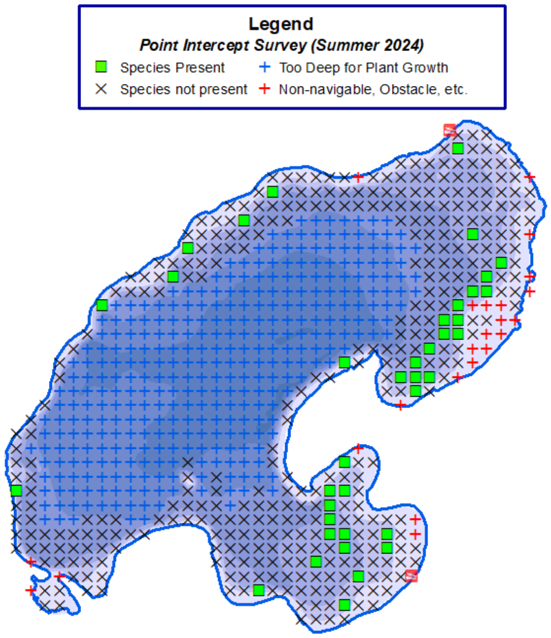


Photo Credit: Onterra

- Southern naiad grows in a variety of conditions. It can grow in sand or muck and shallow or deep water. Dense colonies of this plant can form
- The rapid population growth of southern naiad in some northern Wisconsin lakes has some ecologists questioning whether this species was historically present in these waterbodies or if it represents a recent introduction, likely via watercraft.

Northern watermilfoil (Myriophyllum sibiricum) Native

FLORA of WISCONSIN: https://wisflora.herbarium.wisc.edu/taxa/index.php?taxon=4312

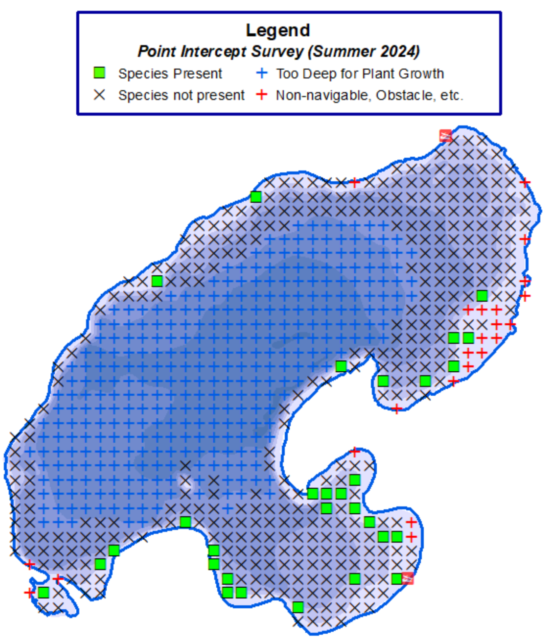


Photo Credit: Onterra

- Northern watermilfoil is arguably the most similar native species to the invasive Eurasian watermilfoil. These two plants can hybridize with one another.
- Northern watermilfoil also has less leaflets on its leaves (5-10 pairs) than Eurasian watermilfoil (12-16 pairs).
- Northern watermilfoil can be distinguished from the invasive Eurasian watermilfoil in that northern watermilfoil has more whorls of leaves per length of stem which appears as a bushier plant than Eurasian watermilfoil.

D

APPENDIX D

Strategic Analysis of Aquatic Plant Management in Wisconsin (June 2019). Extracted Supplemental Chapters:

- 3.3 Herbicide Treatment
- 3.4 Physical Removal
- 3.5 Biological Control

WDNR Herbicide Fact Sheets:

- Florpyrauxifen-benzyl (ProcellaCOR)
- Fluridone
- 2,4-D

FLORPYRAUXIFEN-BENZYL CHEMICAL FACT SHEET

Formulations

Florpyrauxifen-benzyl is a relatively new herbicide that was first registered with the U.S. EPA in 2017. The active ingredient is 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester, also identified as florpyrauxifen-benzyl. Florpyrauxifen-benzyl is labeled for control of submerged, floating and emergent aquatic plants using surface, subsurface or foliar application in slow-moving and quiescent waters. Commercial formulations approved for aquatic use in Wisconsin include ProcellaCOR™*.

Aquatic Use and Considerations

Florpyrauxifen-benzyl is a systemic herbicide (i.e., it moves throughout the plant tissue). It is a WSSA Group 4 herbicide, meaning that the mechanism of action is by mimicking the plant growth hormone auxin and causing excessive elongation of plant cells, ultimately killing the plant. Affected plants may show atypical growth patterns (e.g., large and/or twisted leaves, stem elongation), and leaf and shoot tissue may become fragile. While initial effects will become apparent within a few days after treatment, it will take two to three weeks for the full plant decomposition process to occur. Florpyrauxifen-benzyl should be applied to plants that are actively growing; mature plants may require a higher concentration of herbicide and a longer contact time compared to smaller, less established plants.

It is important to note that repeated use of herbicides in the same WSSA group (i.e., with the same mechanism of action) can lead to herbicide-resistant plants, even in aquatic environments. In order to reduce the risk of developing resistant genotypes, avoid using the same type of herbicides year after year, and utilize effective integrated pest management strategies as part of any long-term control program.

Florpyrauxifen-benzyl has relatively short contact exposure time (CET) requirements (typically 12 to 24 hours). The short CET may be advantageous for localized treatments of submersed aquatic plants, however, the target species efficacy compared to the size of the treatment area is not yet known. In some Wisconsin lakes impacts to target and non-target plants have been observed in areas beyond the targeted treatment areas, and research is ongoing to better understand the herbicide's dissipation and degradation patterns across various lake types.

Florpyrauxifen-benzyl is labeled for control of invasive Eurasian watermilfoil (*Myriophyllum spicatum*), hybrid watermilfoil (*M. spicatum x sibiricum*) and yellow floating heart (*Nymphoides peltata*)†. Native species listed on the product label as susceptible to florpyrauxifen-benzyl include coontail (*Ceratophyllum demersum*), variable-leaf watermilfoil (*Myriophyllum heterophyllum*), watershield (*Brasenia schreberi*), pickerelweed (*Pontederia cordata*) and American lotus (*Nelumbo lutea*)†.

Preliminary results from pre- and post-treatment monitoring conducted on a subset of Wisconsin lakes observed negative impacts to dicot species such as northern watermilfoil (*Myriophyllum sibiricum*), white water crowfoot (*Ranunculus aquatilis*), water marigold (*Bidens beckii*), & coontail following treatment.

* Product names are provided solely for your reference and should not be considered exhaustive nor endorsements.

† May vary by formulation, application rate, and/or product. Every product label must be carefully reviewed and followed by the user.

Post-Treatment Water Use Restrictions

There are no drinking water or recreational use restrictions, including swimming and fishing, and no restrictions on irrigating turf. There is a short waiting period (dependent on application rate) for other non-agricultural irrigation purposes. Treated water should not be used for livestock drinking water or for agricultural irrigation without analytical monitoring to confirm dissipation[†].

Herbicide Degradation, Persistence and Trace Contaminants

Florpyrauxifen-benzyl is short-lived, with a half-life (the time it takes for half of the active ingredient to degrade) of four to six days in aerobic aquatic environments and two days in anaerobic aquatic environments. Florpyrauxifen-benzyl in water is subject to rapid breakdown by light (photolysis), with a reported photolytic half-life of approximately two hours in surface water when exposed to sunlight. In addition, the herbicide can convert partially to an acid form via breakdown by water (hydrolysis) at high pH (greater than 9) and higher water temperatures (greater than 25°C). Microbial activity in the water and sediment can also enhance degradation.

Florpyrauxifen-benzyl breaks down into five major degradation products. These materials are generally more persistent in water than the active herbicide (with a half-life of up to three weeks), but four of the five products are minor metabolites detected at less than 5% of applied active ingredient.

Florpyrauxifen-benzyl has a high soil adsorption coefficient (KOC) and low volatility, which allows for rapid plant uptake resulting in short exposure time requirements. Florpyrauxifen-benzyl degrades quickly (two to 15 days) in sediment. Few studies have yet been completed for groundwater, but based on known environmental properties, florpyrauxifen-benzyl is not expected to be associated with potential environmental impacts in groundwater.

Impacts on Fish and Other Aquatic Organisms

Florpyrauxifen-benzyl is practically nontoxic to freshwater fish and invertebrates, birds, bees, reptiles, amphibians and mammals. Florpyrauxifen-benzyl will temporarily bioaccumulate (the process by which chemicals in the environment or in a food source are taken up by plants or animals) in freshwater organisms but is expelled and/or metabolized within one to three days after exposure to high (greater than 150 parts per billion) concentrations.

Human Health

There are no risks of concern to human health since no adverse short- or long-term effects, including a lack of carcinogenicity or mutagenicity, were observed in the submitted toxicological studies for florpyrauxifen-benzyl regardless of the route of exposure. Drinking water exposures to florpyrauxifen-benzyl also do not pose a significant human health risk. Additionally, there is no hazard concern for metabolites and/or degradants of florpyrauxifen-benzyl that may be found in drinking water, plants and livestock.

For Additional Information

U.S. Environmental Protection Agency (EPA)
Office of Pesticide Programs
epa.gov/pesticides

Wisconsin Department of Agriculture, Trade, and Consumer Protection
datcp.wi.gov/Pages/Programs_Services/ACMOverview.aspx

Wisconsin Department of Natural Resources
608-266-2621
dnr.wi.gov/lakes/plants

National Pesticide Information Center
1-800-858-7378
npic.orst.edu

Washington State Department of Ecology. 2017.
fortress.wa.gov/ecy/publications/documents/1710020.pdf

January 2012

2,4-D Chemical Fact Sheet

Formulations

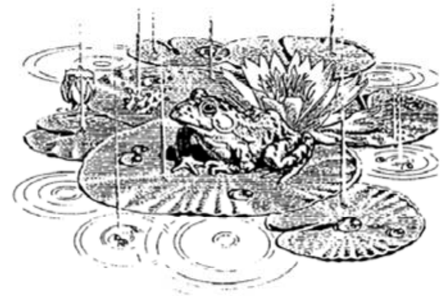
2,4-D is an herbicide that is widely used as a household weed-killer, agricultural herbicide, and aquatic herbicide. It has been in use since 1946, and was registered with the EPA in 1986 and re-reviewed in 2005. The active ingredient is 2,4-dichloro-phenoxyacetic acid. There are two types of 2,4-D used as aquatic herbicides: dimethyl amine salt and butoxyethyl ester. Both liquid and slow-release granular formulations are available. 2,4-D is sold under the trade names Aqua-Kleen, Weedar 64 and Navigate (product names are provided solely for your reference and should not be considered endorsements nor exhaustive).

Aquatic Use and Considerations

2,4-D is a widely-used herbicide that affects plant cell growth and division. It affects primarily broad-leaf plants. When the treatment occurs, the 2,4-D is absorbed into the plant and moved to the roots, stems, and leaves. Plants begin to die in a few days to a week following treatment, but can take several weeks to decompose. Treatments should be made when plants are growing.

For many years, 2,4-D has been used primarily in small-scale spot treatments. Recently, some studies have found that 2,4-D moves quickly through the water and mixes throughout the waterbody, regardless of where it is applied. Accordingly, 2,4-D has been used in Wisconsin experimentally for whole-lake treatments.

2,4-D is effective at treating the invasive Eurasian watermilfoil (*Myriophyllum spicatum*). Desirable native species that may be affected include native milfoils, coontail (*Ceratophyllum demersum*), naiads (*Najas* spp.), elodea (*Elodea canadensis*) and duckweeds (*Lemna* spp.). Lilies (*Nymphaea* spp. and *Nuphar* spp.) and bladderworts (Utricularia spp.) also can be affected.



Post-Treatment Water Use Restrictions

There are no restrictions on eating fish from treated water bodies, human drinking water or pet/livestock drinking water. Following the last registration review in 2005, the ester products require a 24-hour waiting period for swimming. Depending on the type of waterbody treated and the type of plant being watered, irrigation restrictions may apply for up to 30 days. Certain plants, such as tomatoes and peppers and newly seeded lawn, should not be watered with treated water until the concentration is less than 5 parts per billion (ppb).

Herbicide Degradation, Persistence and Trace Contaminants

The half-life of 2,4-D (the time it takes for half of the active ingredient to degrade) ranges from 12.9 to 40 days depending on water conditions. In anaerobic lab conditions, the half-life has been measured up to 333 days. After treatment, the 2,4-D concentration in the water is reduced primarily through microbial activity, off-site movement by water, or adsorption to small particles in silty water. It is slower to degrade in cold or acidic water, and appears to be slower to degrade in lakes that have not been treated with 2,4-D previously.

There are several degradation products from 2,4-D: 1,2,4-benzenetriol, 2,4-dichlorophenol, 2,4-dichloroanisole, chlorohydroquinone (CHQ), 4-chlorophenol and volatile organics.

Impacts on Fish and Other Aquatic Organisms

Toxicity of aquatic 2,4-D products vary depending on whether the formulation is an amine or an ester 2,4-D. The ester formulations are toxic to fish and some important invertebrates such as water fleas (*Daphnia*) and midges at application rates; the amine formulations are not toxic to fish or invertebrates at application rates. Loss of habitat following treatment may cause reductions in populations of invertebrates with either formulation, as with any herbicide treatment. These organisms only recolonize the treated areas as vegetation becomes re-established.

Available data indicate 2,4-D does not accumulate at significant levels in the bodies of fish that have been tested. Although fish that are exposed to 2,4-D will take up some of the chemical, the small amounts that accumulate are eliminated after exposure to 2,4-D ceases.

On an acute basis, 2,4-D is considered moderately to practically nontoxic to birds. 2,4-D is not toxic to amphibians at application rates; effects on reptiles are unknown. Studies have shown some endocrine disruption in amphibians at rates used in lake applications, and DNR is currently funding a study to investigate endocrine disruption in fish at application rates.

As with all chemical herbicide applications it is very important to read and follow all label instructions to prevent adverse environmental impacts.

Human Health

Adverse health effects can be produced by acute and chronic exposure to 2,4-D. Those who mix or apply 2,4-D need to protect their skin and eyes from contact with 2,4-D products to minimize irritation, and avoid inhaling the spray. In its consideration of exposure risks, the EPA believes no significant risks will occur to recreational users of water treated with 2,4-D.

Concerns have been raised about exposure to 2,4-D and elevated cancer risk. Some (but not all) epidemiological studies have found 2,4-D associated with a slight increase in risk of non-Hodgkin's lymphoma in high exposure populations (farmers and herbicide applicators). The studies show only a possible association that may be caused by other factors, and do not show that 2,4-D causes cancer. The EPA determined in 2005 that there is not sufficient evidence to classify 2,4-D as a human carcinogen.

The other chronic health concern with 2,4-D is the potential for endocrine disruption. There is some evidence that 2,4-D may have estrogenic activities, and that two of the break-down products of 2,4-D (4-chlorophenol and 2,4-dichloroanisole) may affect male reproductive development. The extent and implications of this are not clear and it is an area of ongoing research.

For Additional Information

Environmental Protection Agency
Office of Pesticide Programs
www.epa.gov/pesticides

Wisconsin Department of Agriculture, Trade, and Consumer Protection
http://datcp.wi.gov/Plants/Pesticides/

Wisconsin Department of Natural Resources
608-266-2621
http://dnr.wi.gov/lakes/plants/

Wisconsin Department of Health Services
http://www.dhs.wisconsin.gov/

National Pesticide Information Center
1-800-858-7378
http://npic.orst.edu/

January 2012

Fluridone Chemical Fact Sheet

Formulations

Fluridone is an aquatic herbicide that was initially registered with the EPA in 1986. The active ingredient is 1-methyl-3-phenyl-5-3-(trifluoromethyl)phenyl|-41H|-pyridinone. Both liquid and slow-release granular formulations are available. Fluridone is sold under the brand names Avast!, Sonar, and Whitecap (product names are provided solely for your reference and should not be considered endorsements).

Aquatic Use and Considerations

Fluridone is an herbicide that stops the plant from making a protective pigment that keeps chlorophyll from breaking down in the sun. Treated plants will turn white or pink at the growing tips after a week and will die in one to two months after treatment as it is unable to make food for itself. It is only effective if plants are growing at the time of treatment.

Fluridone is used at very low concentrations, but a very long contact time is required (45-90 days). If the fluridone is removed before the plants die, they will once again be able to produce chlorophyll and grow.

Fluridone moves rapidly through water, so it is usually applied as a whole-lake treatment to an entire waterbody or basin. There are pellet slow-release formulations that may be used as spot treatments, but the efficacy of this is undetermined. Fluridone has been applied to rivers through a drip system to maintain the concentration for the required contact time.

Plants vary in their susceptibility to fluridone, so typically some species will not be affected even though the entire waterbody is treated.

Plants have been shown to develop resistance to repeated fluridone use, so it is recommended to rotate herbicides with different modes of action when using fluridone as a control.

Fluridone is effective at treating the invasive Eurasian watermilfoil (*Myriophyllum spicatum*). It also is commonly used for control of invasive hydrilla (*Hydrilla verticillata*) and water hyacinth (*Eichhornia crassipes*), neither of which are present in Wisconsin yet. Desirable native species that are usually affected at concentrations used to treat the invasives include native milfoils, coontail (*Ceratophyllum demersum*), naiads (*Najas* spp.), elodea (*Elodea canadensis*) and duckweeds (*Lemna* spp.). Lilies (*Nymphaea* spp. and *Nuphar* spp.) and bladderworts (Utricularia spp.) also can be affected.

Post-Treatment Water Use Restrictions

There are no restrictions on swimming, eating fish from treated water bodies, human drinking water or pet/livestock drinking water. Depending on the type of waterbody treated and the type of plant being watered, irrigation restrictions may apply for up to 30 days. Certain plants, such as tomatoes and peppers and newly seeded lawn, should not be watered with treated water until the concentration is less than 5 parts per billion (ppb).

Herbicide Degradation, Persistence and Trace Contaminants

The half-life of fluridone (the time it takes for half of the active ingredient to degrade) ranges from 4 to 97 days depending on water conditions. After treatment, the fluridone concentration in the water is reduced through dilution due to water movement, uptake by plants, adsorption to the sediments, and break down from light and microbial action.

There are two major degradation products from fluridone: n-methyl formamide (NMF) and 3-trifluoromethyl benzoic acid. NMF has not been detected in studies of field conditions, including those at the maximum label rate.

Fluridone residues in sediments reach a maximum in one to four weeks after treatment and decline in four months to a year depending on environmental conditions. Fluridone adsorbs to clay and soils with high organic matter, especially in pellet form, and can reduce the concentration of fluridone in the water. Adsorption to the sediments is reversible; fluridone gradually dissipates back into the water where it is subject to chemical breakdown.

Impacts on Fish and Other Aquatic Organisms

Fluridone does not appear to have any apparent short-term or long-term effects on fish at application rates.

Fish exposed to water treated with fluridone absorb fluridone into their tissues. Residues of fluridone in fish decrease as the herbicide disappears from the water. The EPA has established a tolerance for fluridone residues in fish of 0.5 parts per million (ppm).

Studies on Fluridone's effects on aquatic invertebrates (i.e. midge and water flea) have shown increased mortality at label application rates.

Studies on birds indicate that fluridone would not pose an acute or chronic risk to birds. No studies have been conducted on amphibians or reptiles.

Human Health

The risk of acute exposure to fluridone would be primarily to chemical applicators. The acute toxicity risk from oral and inhalation routes is minimal. Concentrated fluridone may cause some eye or skin irritation. No personal protective equipment is required on the label to mix or apply fluridone.

Fluridone does not show evidence of causing birth defects, reproductive toxicity, or genetic mutations in mammals tested. It is not considered to be carcinogenic nor does it impair immune or endocrine function.

There is some evidence that the degradation product NMF causes birth defects. However, since NMF has only been detected in the lab and not following actual fluridone treatments, the manufacturer and EPA have indicated that fluridone use should not result in NMF concentrations that would adversely affect the health of water users. In the re-registration assessment that is currently underway for fluridone, the EPA has requested additional studies on both NMF and 3-trifluoromethyl benzoic acid.

For Additional Information

Environmental Protection Agency
Office of Pesticide Programs
www.epa.gov/pesticides

Wisconsin Department of Agriculture, Trade, and Consumer Protection
http://datcp.wi.gov/Plants/Pesticides/

Wisconsin Department of Natural Resources
608-266-2621
http://dnr.wi.gov/lakes/plants/

Wisconsin Department of Health Services
http://www.dhs.wisconsin.gov/

National Pesticide Information Center
1-800-858-7378
http://npic.orst.edu/

Hamelink, J.L., D.R. Buckler, F.L. Mayer, D.U. Palawski, and H.O. Sanders. 1986. Toxicity of Fluridone to Aquatic Invertebrates and Fish. Environmental Toxicology and Chemistry 5:87-94.

Fluridone ecological risk assessment by the Bureau of Land Management, Reno Nevada: http://www.blm.gov/pgdata/etc/medialib/blm/wo/Planning_and_Renewable_Resources/veis.Par.91082.File.tmp/Fluridone%20Ecological%20Risk%20Assessment.pdf

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

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

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

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S.3.3. Herbicide Treatment

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Diquat

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

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

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

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

Toxicology

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

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

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

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

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

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

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

Flumioxazin

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

Species Susceptibility

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

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

Carfentrazone-ethyl

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

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

Species Susceptibility

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

S.3.3.2. Submersed, Relatively Slow-Acting Herbicides

2,4-D

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

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

Toxicology

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

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

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

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

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

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

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

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

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

<u>Species Susceptibility</u>

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

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

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

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

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

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

Fluridone

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

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

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

Toxicology

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

Species Susceptibility

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

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

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

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

Endothall

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

Dipotassium salt formulations

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

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

Dimethylalkylamine salt formulations

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

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

Species Susceptibility

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

Dipotassium salt formulations

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

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

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

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

Dimethylalkylamine salt formulations

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

Imazamox

Registration and Formulations

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

Mode of Action and Degradation

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

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

Toxicology

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

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

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

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

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

Species Susceptibility

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

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

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

Florpyrauxifen-benzyl

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

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

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

Species Susceptibility

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

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

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

S.3.3.3. Emergent and Wetland Herbicides

Glyphosate

Registration and Formulations

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

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

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

Species Susceptibility

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

Imazapyr

Registration and Formulations

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

Mode of Action and Degradation

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

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

Toxicology

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

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

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

Species Susceptibility

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

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

S.3.3.4. Herbicides Used for Submersed and Emergent Plants

Triclopyr

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

Species susceptibility

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

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

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

Penoxsulam

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

Species Susceptibility

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

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

S.3.4. Physical Removal Techniques

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

S.3.4.1. Manual and Mechanical Cutting

Manual and Mechanical Cutting

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

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

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

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

Ecological Impacts of Manual and Mechanical Cutting

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

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

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

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

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

Ecological Impacts of Hand-Pulling and DASH

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

S.3.4.3. Benthic Barriers

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

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

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

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

Ecological Impacts of Benthic Barriers

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

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

S.3.4.4. Dredging

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

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

Ecological effects of Dredging

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

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

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

S.3.4.5. Drawdown

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

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

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

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

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

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

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

Species Susceptibility to Water-level Drawdown

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

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

S.3.5.Biological Control

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

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

Purple loosestrife beetles

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

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

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

Milfoil weevils

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

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

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

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

Grass carp – not allowed in Wisconsin

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

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