Management Goal 5: Actively manage EWM to keep the population from negatively impacting the ecology or human use of the lake

Management Action:	Conduct hand-harvesting (includes DASH) to maintain a lowered EWM population in Little Spider Lake
Timeframe:	Ongoing
Facilitator:	Jim Allison
Description:	The objective of this action will be to target low-density areas of the lake with hand-harvesting, including Diver-Assisted Suction Harvest (DASH) techniques, to maintain a low EWM population in these areas. The proactive EWM management strategy that has occurred in Little Spider Lake since its detection has kept the EWM population at low levels. At these low levels, the EWM population is likely not causing measurable negative ecological impacts to the system nor diminishing the navigability, recreation, or aesthetics of the lake. The LSLA would like to continue on a proactive management approach to EWM to keep the population low within the lake, preferably with non-herbicide control options. In areas where the cost of hand-harvesting far exceeds the cost of herbicide treatment, the LSLA will evaluate the use of herbicides as a management approach. The 2021 stakeholder survey revealed that there is overwhelming support for this management program, with 87% of survey respondents indicating they completely or moderately support hand-harvesting of EWM in Little Spider Lake. Moving forward, the goal of the hand harvesting strategy in Little Spider Lake will likely be to manage specific sites at a lower density that imparts little impacts to the ecological function of the lake or to the sociological services the lake provides. Another goal of the hand harvesting strategy will be to target relatively new locations of EWM in hopes of inhibiting it from becoming established in more locations around the lake. Through implementing a coordinated hand harvesting management strategy, the LSLA will continue to learn about the utility of hand harvesting in Little Spider Lake as well as about the limitations of this technique in meeting management goals. For instance, the population of EWM in the west bay is currently too large to effectively manage with hand-harvesting. If the population continues to increase in density and navigation is hindered, herbicide options would be considered. During the winter following a late-season EWM mapping survey, a hand-harvesting strategy would be developed. The management and monitoring strategy would be formally outlined in an annual report that would be made available to LSLA members and Little Spider Lake riparians. Areas appliable for hand-harvesting include EWM mapped with point-based methods such as *single or few plants*, *clumps of plants*, and *small plant colonies*. Low-density and smaller areas of EWM mapped with polygon-based methods may also be applicable to a hand-harvesting strategy if sufficient effort can be implemented.

	If a Diver Assisted Suction Harvest (DASH) component is utilized, the LSLA and contracted firm would be responsible for the WDNR permit procedures. The contracted firm would be guided with GPS data from the consultant and would track their efforts (when, where, time spent, quantity removed) for post assessments. The hand-harvesting would occur from approximately mid-June to mid-September, but could be slightly extend earlier or later if climactic conditions allow. Generally conducting hand-harvesting earlier or later in the year can reduce the effectiveness of the strategy, as plants are more brittle and extraction of the roots more difficult. If a professional-based hand-harvesting method is chosen and WDNR funds are being used to offset the costs, a Late-Summer EWM Mapping Survey would take place following the hand-harvesting and be compared to the previous year for assessment. Hand-removal sites will be deemed successful if the level of EWM within the hand-removal areas were at least maintained at the point-based mapping level; for example, a site would be considered unsuccessful if it contained *single or few plants* (point-based mapping) prior to hand-harvesting and expanded to contain colonized EWM (polygons) following hand-harvesting.

Management Action:	Consider applicability of herbicide management in the West Bay if EWM populations reach approximately 10%
Timeframe:	Ongoing
Facilitator:	Board of Directors
Description:	The objective of this action will be to continually educate the board and lake group on what is considered a *best management practice* for herbicide management of EWM in the event that populations reach levels where this action would be considered. At this time, the LSLA feels the EWM populations are too low to warrant consideration of aquatic herbicides. The 2021 stakeholder survey revealed that slightly less than half (49%) of survey respondents indicating they completely or moderately support managing EWM with herbicides in Little Spider Lake. During the 2021 point-intercept survey, EWM was located at approximately 1.2% of littoral sampling locations. Looking at a subset of point-intercept sampling locations within the West Bay, that area contains EWM at approximately 7.1%. As discussed in the second management action under Goal 4, the LSLA will periodically monitor the aquatic plants in Little Spider Lake by applying the point-intercept survey method. Either using a subset of the whole-lake point-intercept data or just sampling those locations in the West Bay (N=56, Figure 5.0-1), the LSLA will continue to understand what the EWM population is within the West Bay. At this time, this part of the system contains the highest concentration of EWM and its semi-contained nature lends it to potentially be the most applicable

to future herbicide treatment. However, due to high boating and personal watercraft activity into and out of the West Bay, as well as prevailing water currents exiting the West Bay towards the outlet that leads to Verna Lake, the West Bay acts as a 'super-spreader' of EWM to other areas of the lake. Consequently, strict management of EWM in the West Bay is essential to slow its progress to other areas of the lake. Specifically, if the EWM population approaches 10%, as measured by a subset of the point-intercept survey, the development of a revised EWM management action using aquatic herbicides may be considered. In addition to active EWM management/control methods (e.g. herbicides, hand-harvesting, etc.), the LSLA board intends to inform its membership about the EWM trends other lakes have observed where they have not implemented any active management methods

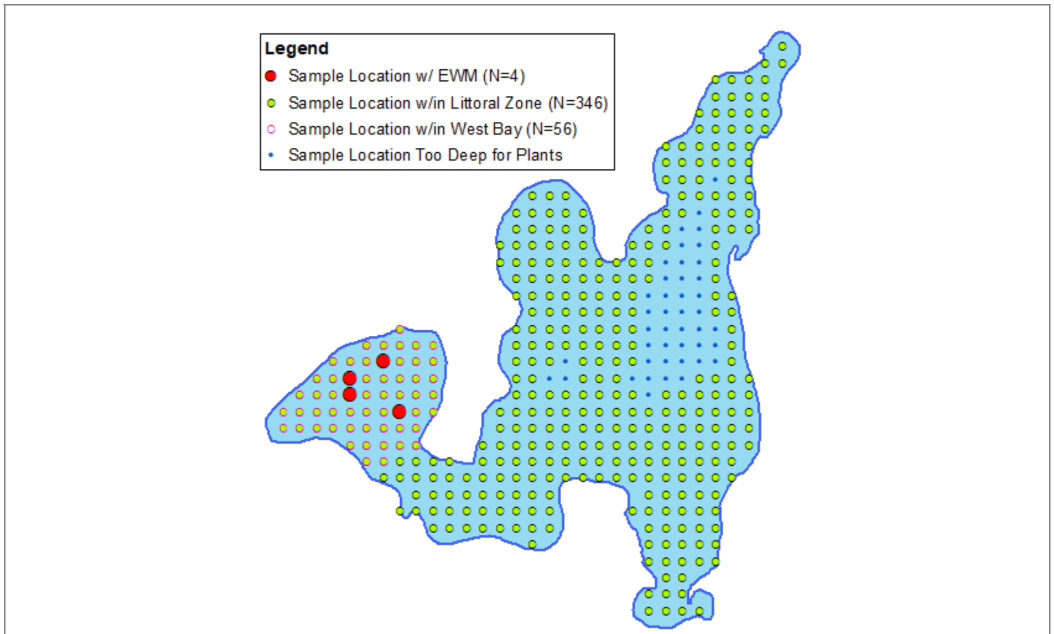


Figure 5.0-1. Point-intercept sampling locations with EWM in 2021. Lake-wide littoral EWM population = 1.2% (4/345). West Bay EWM population = 7.1% (4/56)

While some herbicide treatments have provided successful results in Wisconsin, the unpredictability of spot treatments state-wide has resulted in less favorability of this strategy with 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. Many lake groups have adopted herbicide strategies that involve herbicides with shorter exposure time requirements, such as ProcellaCOR™, or lengthen the exposure times by "containing" the herbicide in place with the use of barrier curtains. These and other evolved BMPs would be researched if the LSLA decides to consider herbicide use at a later date.

A

APPENDIX A

Public Participation Materials

Little Spider Lake Association

Comprehensive Management Planning Project

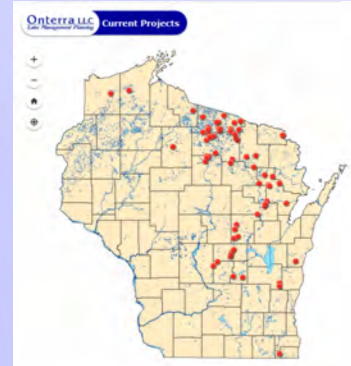
Kick-off Meeting
May 22, 2021

Eddie Heath
Onterra LLC
Lake Management Planning

LPL-1760-21

Presentation Outline

- Onterra, LLC
- Why Create a Management Plan?
- Elements of a Lake Management Planning Project
  - Data & Information
  - Planning Process



Onterra LLC
Lake Management Planning

Onterra, LLC

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

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Why create a lake management plan?

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

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Why create a lake management plan?

- WDNR recommends *Comprehensive Lake Management Plans* generally get updated every 10 years
- WDNR recommends lakes conducting active management update aspects of the plan every 5 years.
- Having a current and approved plan makes the sponsor eligible for WDNR grants that implement an action.
- Conducting large-scale management requires a current and approved plan.

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Management Planning Project Overview

Collect and compile information about Little Spider Lake

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

Create a realistic and implementable management plan

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

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

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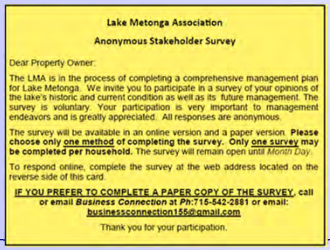
2.0 Stakeholder Participation

- General Attendance Meetings
  - Kick-off (Today!)
  - Wrap-Up (late-summer 2022)
- Planning Committee Meetings
  - Early Spring 2022
- Riparian Stakeholder Survey
  - All LSA members & Little Spider Lake Riparians
  - Summer 2021
- Review Process
  - Summer 2022



Lake Metonga Association

Anonymous Stakeholder Survey

Dear Property Owner:

The LMA is in the process of completing a comprehensive management plan for Lake Metonga. We invite you to participate in a survey of your opinions of the lake's historic and current condition as well as its future management. The survey is voluntary. Your participation is very important to management endeavors and is greatly appreciated. All responses are anonymous.

The survey will be available in an online version and a paper version. **Please choose only one method of completing the survey. Only one survey may be completed per household.** The survey will remain open until *Month Day*.

To respond online, complete the survey at the web address located on the reverse side of this card.

IF YOU PREFER TO COMPLETE A PAPER COPY OF THE SURVEY, call or email *Business Connection* at *Ph*:715-542-2881 or email: businessconnection155@gmail.com

Thank you for your participation.

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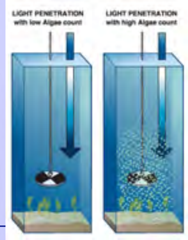
3.1 Water Quality Analysis

- Nutrient analysis
  - Lake trophic state (Eutrophication)
  - Limiting plant nutrient
- Trend Analysis
- Chemical characteristics
  - pH, alkalinity, calcium, color
- Supporting data for watershed modeling

↑ **Phosphorus**

↑ **Chlorophyll-*a***

↓ **Secchi Disk Transparency**



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3.1 Water Quality Analysis

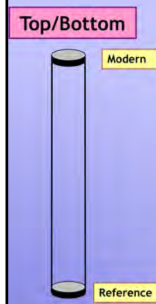
Table 1. Water Quality Sample Parameters and Timing

Parameter	Spring S	Spring B	June S	July S	July B	August S	Fall S	Fall B	Winter S	Winter B
Dissolved Phosphorus	●	●							●	●
Total Phosphorus	●♦	●	♦	●♦	●	♦	●	●	●	●
Total Nitrogen	●	●	■	●		■			●	●
Chlorophyll-a	●		♦	●♦		♦	●			
True Color	●			●						
Hardness	●									
Total Suspended Solids	●	●					●	●		
Laboratory Conductivity	●	●		●	●					
Laboratory pH	●	●		●	●					
Total Alkalinity	●	●		●	●					
Calcium	●									

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

- Professional Samples
  - Spring, July, Fall, Winter
- CLMN Volunteer
  - Spring, June, July, August
  - Add total nitrogen sample

3.2 Paleocore Collection & Analysis



Sediment core

Diatoms

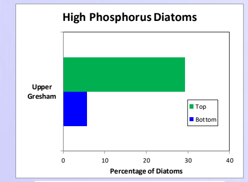
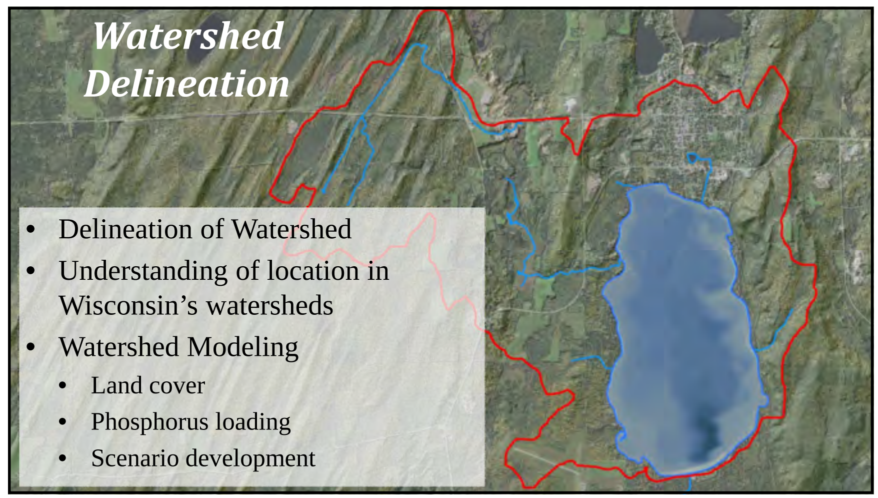


Table 3.3-1. Diatom inferred phosphorus concentrations in core samples (µg/L).

Lakes	Phosphorus
Upper Gresham Top	22
Upper Gresham Bottom	12

3.3 Watershed Assessment

- Geographic area within which all water drains to a common point

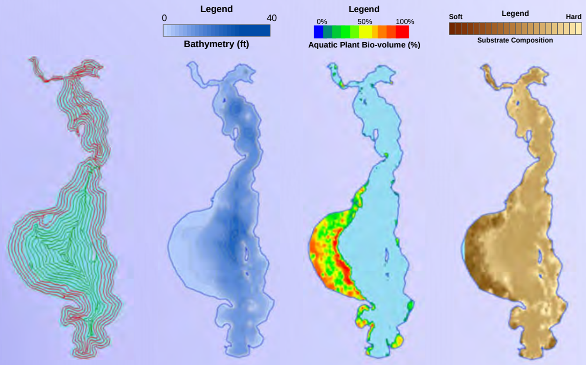


Watershed Delineation

- Delineation of Watershed
- Understanding of location in Wisconsin's watersheds
- Watershed Modeling
  - Land cover
  - Phosphorus loading
  - Scenario development

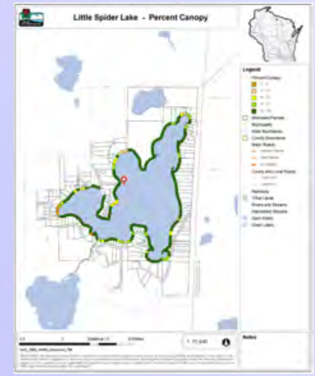
Acoustic Survey

- Systematically record multi-channel sonar data from entire lake
- Create models based upon processed data.



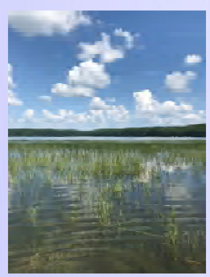
3.4 Shorelands & Shallows Assessment

- WDNR Conducted Survey in 2017
- Integrate summary into *Plan* and attach WDNR's report as Appendix



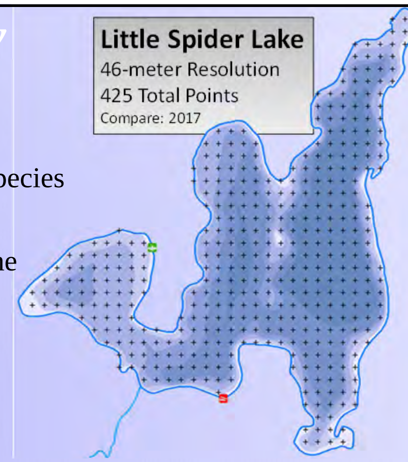
3.5 Aquatic Plants & 3.6 AIS

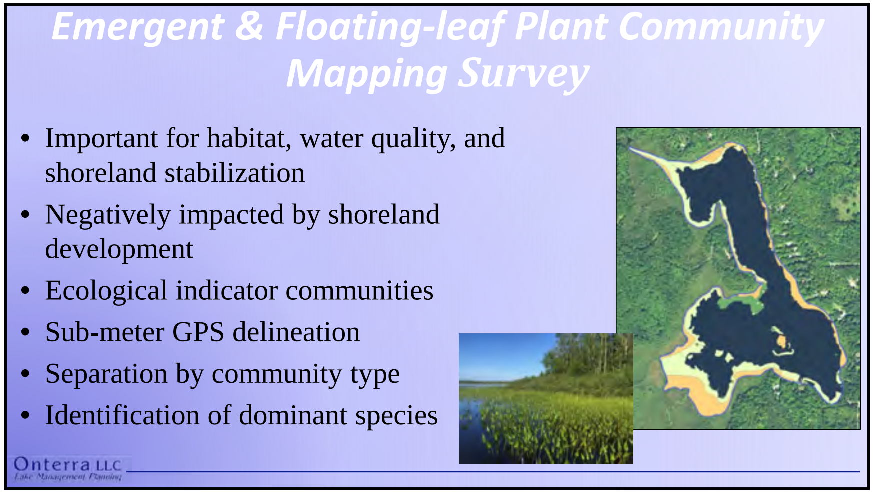
- Concerned with both native and non-native plants
- Multiple surveys used in assessment
  - Point-intercept survey
  - Emergent & Floating-leaf Community Mapping Survey
  - EWM Mapping Survey (2021 & 2022)



Point-Intercept Survey

- Grid-based survey
- Understand depth distribution
- Determine abundance of each species
- Compare to other lakes
- Compare the same lake over time




Emergent & Floating-leaf Plant Community Mapping Survey
• Important for habitat, water quality, and shoreland stabilization
• Negatively impacted by shoreland development
• Ecological indicator communities
• Sub-meter GPS delineation
• Separation by community type
• Identification of dominant species
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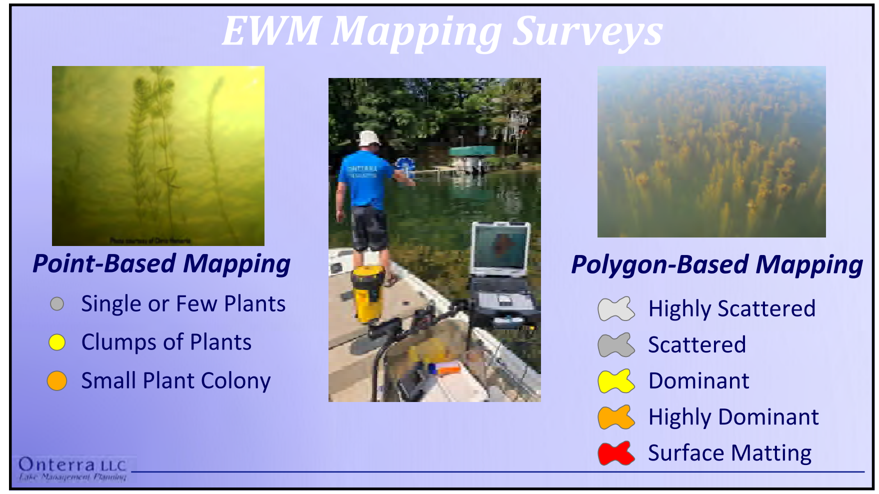
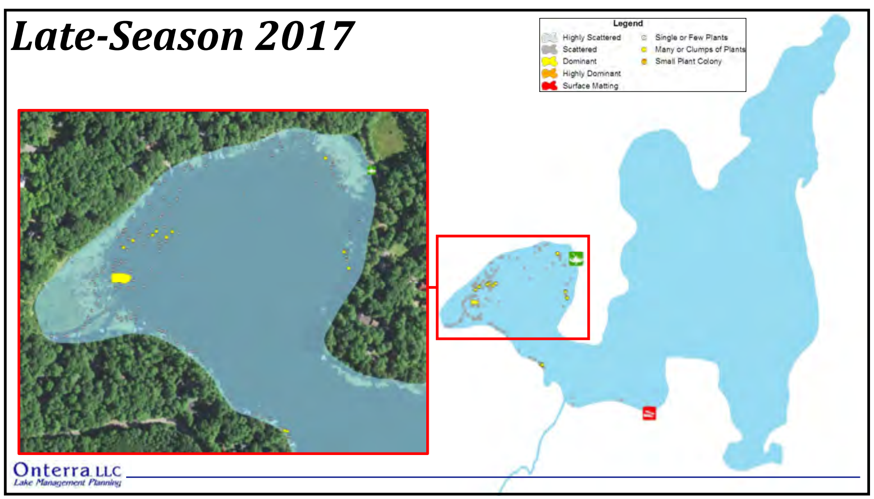

EWM Mapping Surveys
Point-Based Mapping
Single or Few Plants
Clumps of Plants
Small Plant Colony
Polygon-Based Mapping
Highly Scattered
Scattered
Dominant
Highly Dominant
Surface Matting
Onterra LLC
Lake Management Planning


Late-Season 2017
Legend
Highly Scattered
Scattered
Dominant
Highly Dominant
Surface Matting
Single or Few Plants
Many or Clumps of Plants
Small Plant Colony
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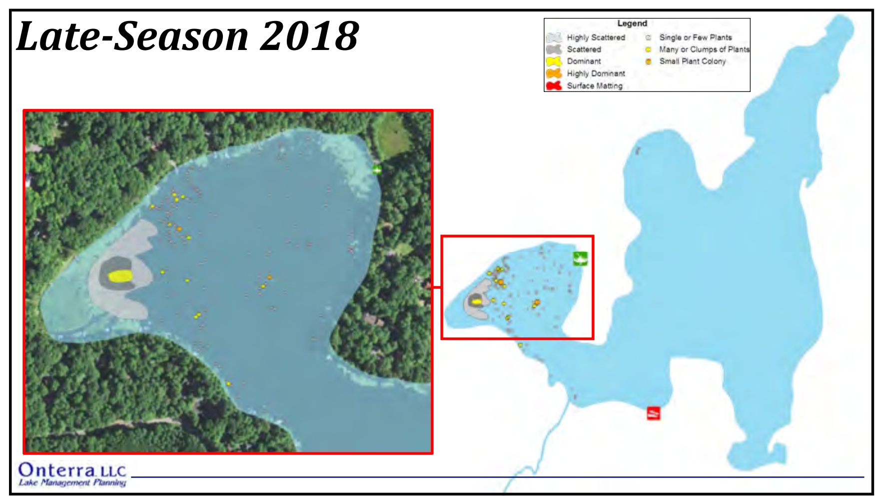
Late-Season 2018
Legend
Highly Scattered
Scattered
Dominant
Highly Dominant
Surface Matting
Single or Few Plants
Many or Clumps of Plants
Small Plant Colony
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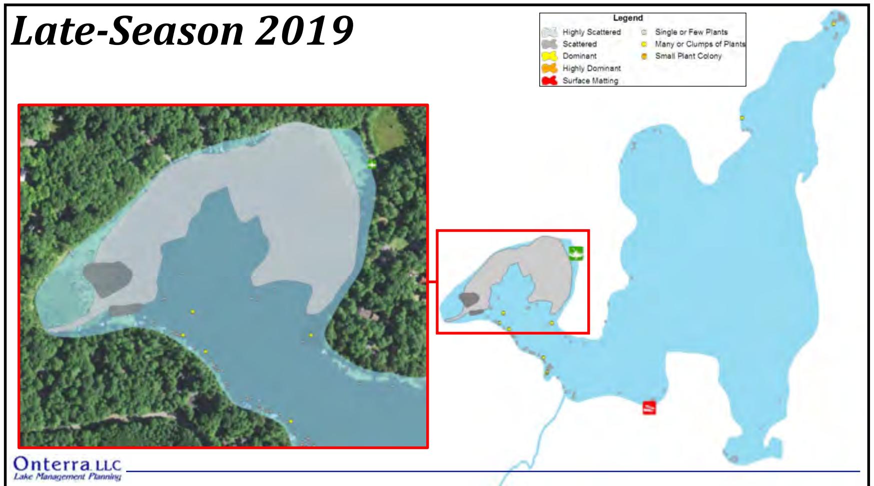
Late-Season 2019



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3.7 Fisheries Data Integration

- No fish sampling completed
- Assemble data from WDNR, GLIFWC, etc.
  - Harvest
  - Stocking
- Fish survey results summaries (if available)
- Use information in planning as applicable

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5.0 Implementation Plan

- Planning Committee Meetings
  - Become informed from the data collected
  - Discuss challenges of lake and lake group
  - Develop management goals
  - Identify management actions to reach goals
  - Assign timeframe and facilitator to each action

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Thank You

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Lake Management Planning

Little Spider Lake Association

Comprehensive Management Planning Project

Planning Meeting I
April 14, 2022

Eddie Heath
Onterra LLC
Lake Management Planning

LPL-1760-21

Why Create a Lake Management Plan?

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

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Management Plan and Grants

- WDNR recommends *Comprehensive Lake Management Plans* generally get updated every 10 years (implementation grants)
  - longer if a plan has been actively implemented and updated during its lifespan
- WDNR recommends lakes conducting active management update aspects of the plan every 5 years (AIS control grants)
  - longer if a plan has been actively implemented and updated during its lifespan and whole-lake PI survey is within 5 years

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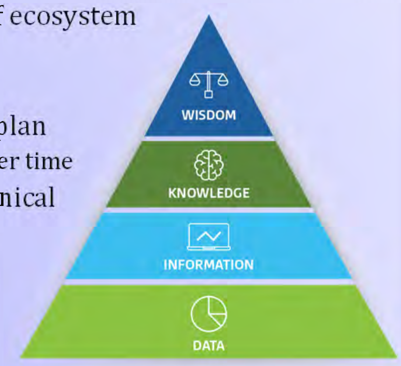
Lake Management Planning

Management Planning Project Overview

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



Management Planning Project Overview

Collect and compile information

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

Planning Meeting I
Data Sections

Create a realistic and implementable management plan

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

Planning Meeting II
Implementation Plan

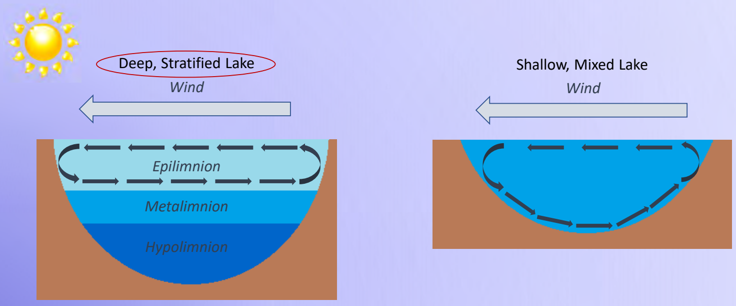
Comprehensive Management Plan ***Outline***

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

Plan Mtg I

Plan Meeting II

Wisconsin Lakes Classification



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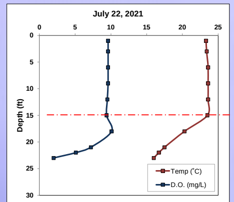
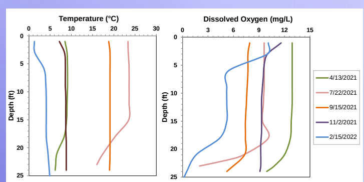
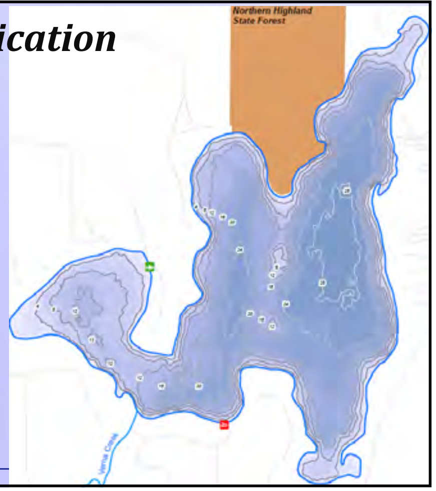
Stratification







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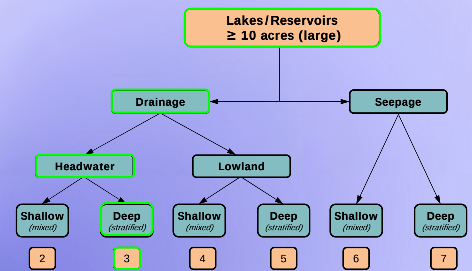
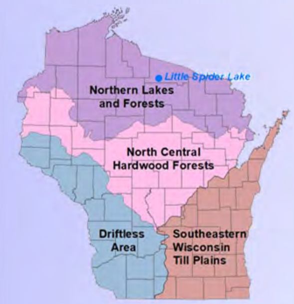
Natural Community Types

Categorization of lakes with similar features that influence water quality



Ecoregions

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



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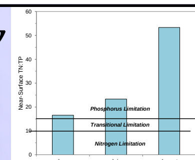
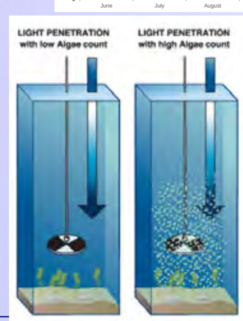
Introduction to Lake Water Quality

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

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

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





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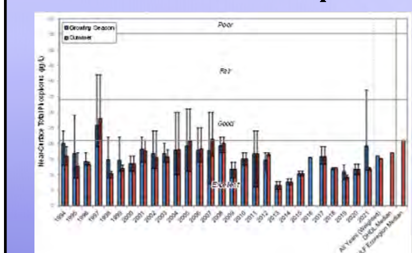
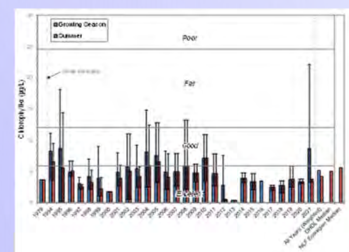
Little Spider Lake Water Quality

Near-Surface Total Phosphorus



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

Chlorophyll-a



- *Excellent* for Deep Headwater Drainage Lakes
- Similar to the Ecoregion Median

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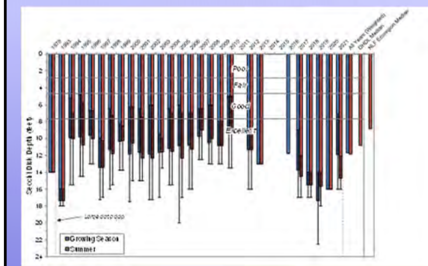
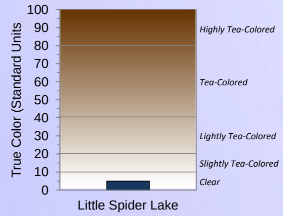
Lake Management Planning

Little Spider Lake Water Quality

Secchi Disk Transparency





- ***Excellent*** **for Deep Headwater Drainage Lakes**
- **Much lower (clearer) than the Ecoregion Median**
- **Minimally impacted by tanins**

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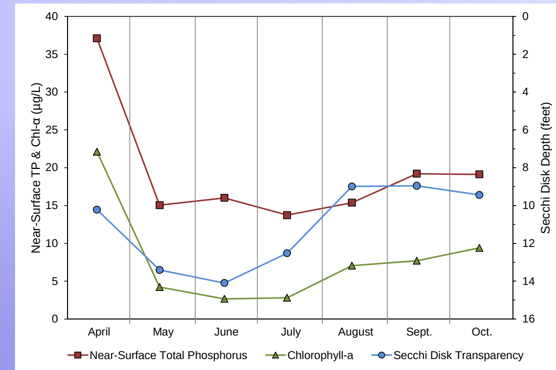
Little Spider Lake Water Quality



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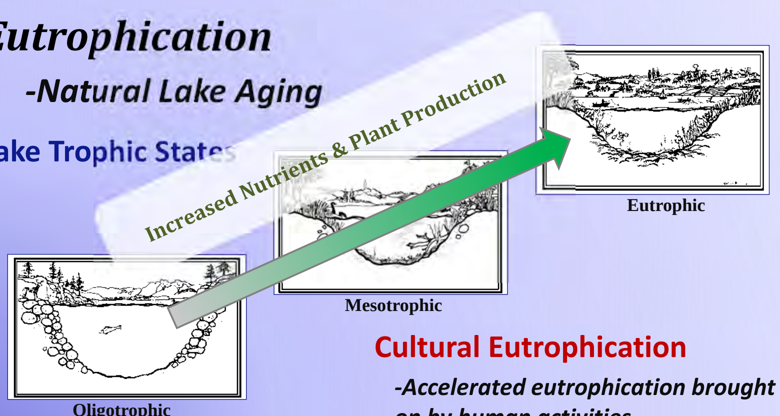
Eutrophication

-Natural Lake Aging

Lake Trophic States



Cultural Eutrophication

-Accelerated eutrophication brought on by human activities.

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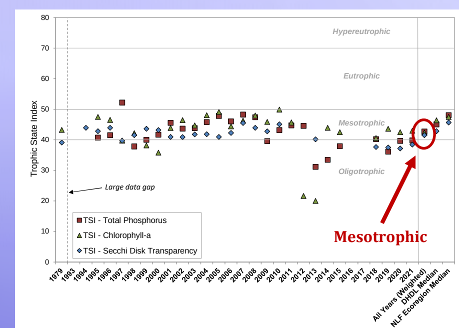
Little Spider Lake Water Quality



Trophic State Index

A method to relate the trophic parameters – phosphorus, chlorophyll-a, and Secchi transparency, and understand the trophic lake of a lake.

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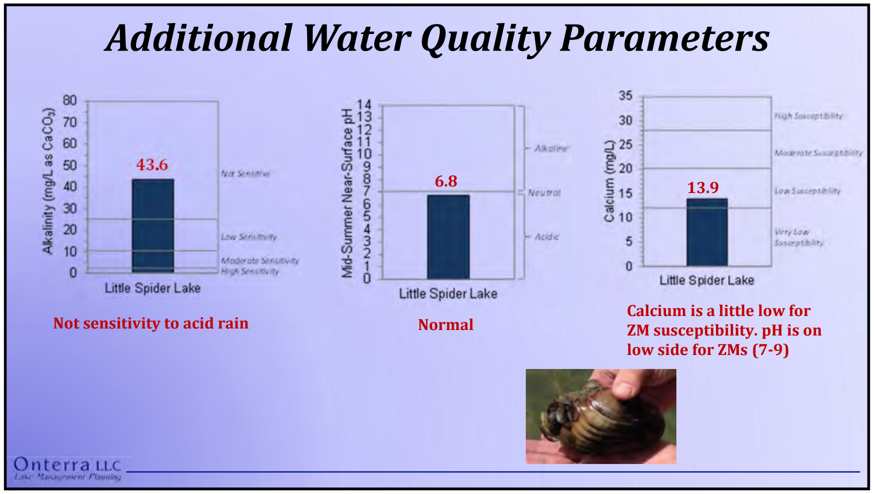
Additional Water Quality Parameters
Alkalinity (mg/L as $CaCO_3$)
43.6
Not Sensitive
Low Sensitivity
Moderate Sensitivity
High Sensitivity
Little Spider Lake
Not sensitivity to acid rain
Mid-Summer Near-Surface pH
6.8
Alkaline
Neutral
Acidic
Little Spider Lake
Normal
Calcium (mg/L)
13.9
High Susceptibility
Moderate Susceptibility
Low Susceptibility
Very Low Susceptibility
Little Spider Lake
Calcium is a little low for ZM susceptibility. pH is on low side for ZMs (7-9)
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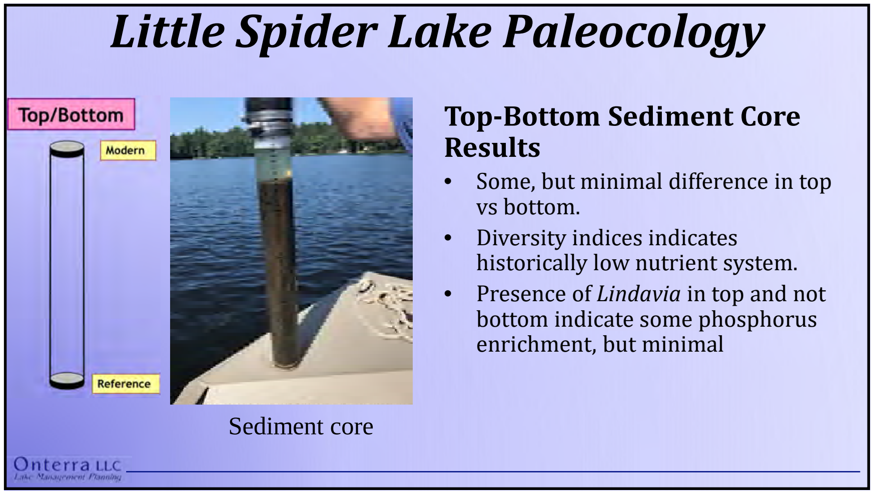
3.3 Paleoecology


Little Spider Lake Paleocology
Top/Bottom
Modern
Reference
Sediment core
Top-Bottom Sediment Core Results
• Some, but minimal difference in top vs bottom.
• Diversity indices indicates historically low nutrient system.
• Presence of *Lindavia* in top and not bottom indicate some phosphorus enrichment, but minimal
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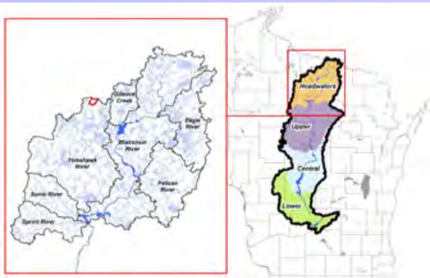
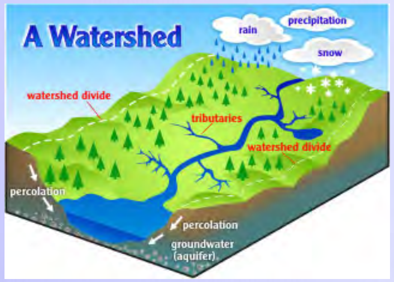
3.2 Watershed

Watershed

Geographic area within which all water drains to a common point

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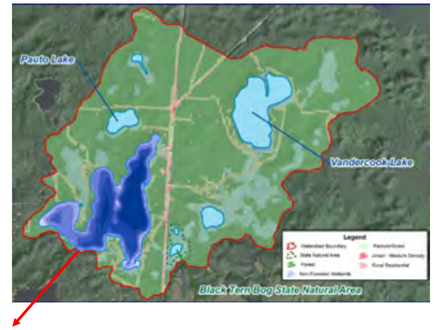
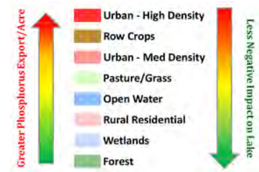
Little Spider Lake Watershed

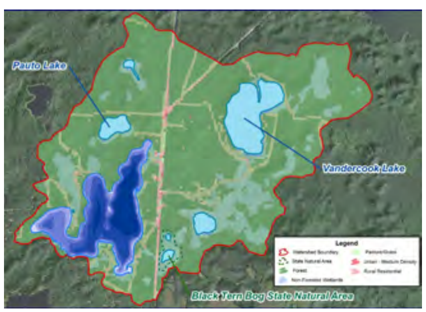


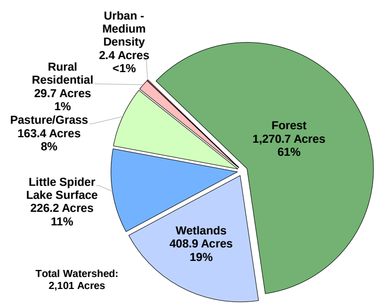
~2,100 acres (3.3 mi²)
WS:LA = 8:1
Residence Time: ~1.2 year

- Seepage lake nutrient sinks
- Black Tern Bog filter



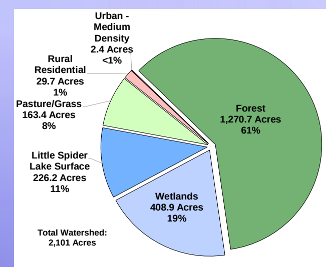
Little Spider Lake Watershed

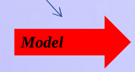


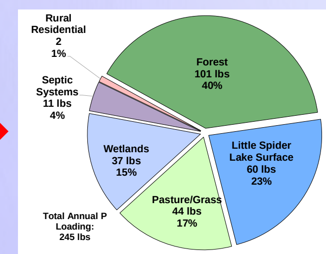


Watershed Modeling

Septic Info from Stakeholder Survey







Model over predicts amount of phosphorus entering lake, as parts of watershed are phosphorus sinks into groundwater

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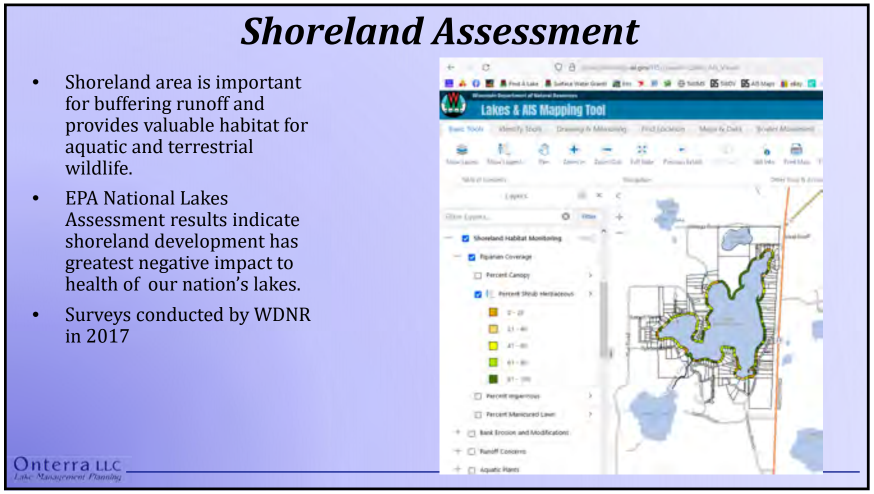
3.4 Shoreland Condition


Shoreland Assessment
• Shoreland area is important for buffering runoff and provides valuable habitat for aquatic and terrestrial wildlife.
• EPA National Lakes Assessment results indicate shoreland development has greatest negative impact to health of our nation's lakes.
• Surveys conducted by WDNR in 2017
Lakes & AIS Mapping Tool
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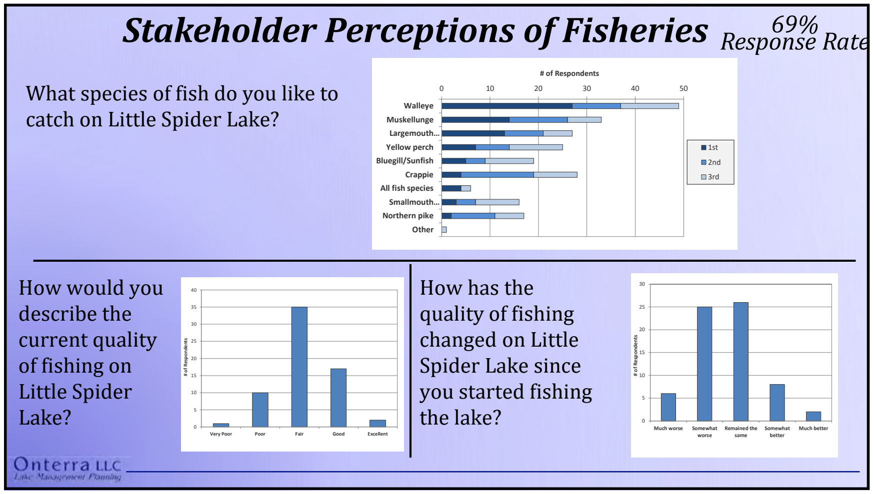
3.6 Fisheries Data Integration


Stakeholder Perceptions of Fisheries
69% Response Rate
What species of fish do you like to catch on Little Spider Lake?
# of Respondents
0
10
20
30
40
50
Walleye
Muskellunge
Largemouth...
Yellow perch
Bluegill/Sunfish
Crappie
All fish species
Smallmouth...
Northern pike
Other
1st
2nd
3rd
How would you describe the current quality of fishing on Little Spider Lake?
Very Poor
Poor
Fair
Good
Excellent
How has the quality of fishing changed on Little Spider Lake since you started fishing the lake?
Much worse
Somewhat worse
Remained the same
Somewhat better
Much better
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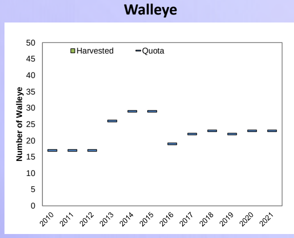
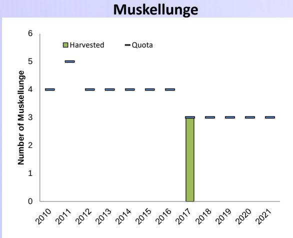
Fisheries Data

Walleye	Put-Grow-Take fishery Low density	Odd-year stocking at 10 extended growth fish/acre
Muskellunge	Class B – good fishing, but less than prime waters	Even-year stocking at 0.5 fingerlings/acre
Northern Pike	Present, but not managed for	
Bass	Largemouth are common	Large population can keep panfish populations in check
Panfish	Bluegill, pumpkinseed, black crappie and yellow perch	

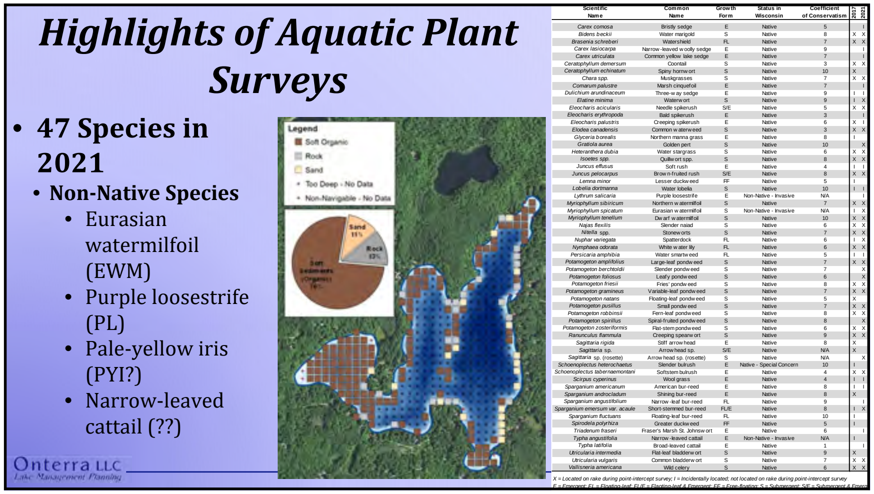
Spear Harvest – LDF Tribe





Aquatic Plant Surveys

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


Highlights of Aquatic Plant Surveys
• 47 Species in 2021
• Non-Native Species
• Eurasian watermilfoil (EWM)
• Purple loosestrife (PL)
• Pale-yellow iris (PYI?)
• Narrow-leaved cattail (??)
Legend
Soft Organic
Rock
Sand
Too Deep - No Data
Non-Navigable - No Data
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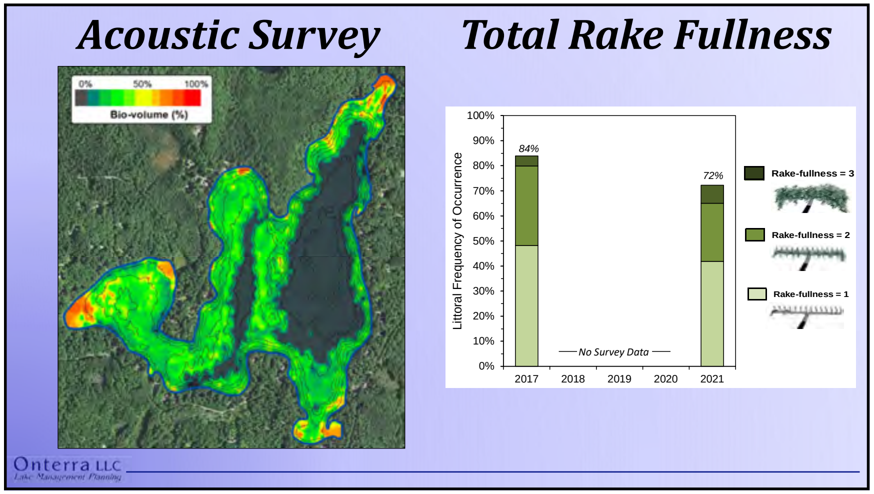
Acoustic Survey
Total Rake Fullness
0%
50%
100%
Bio-volume (%)
Littoral Frequency of Occurrence
84%
72%
No Survey Data
2017
2018
2019
2020
2021
Rake-fullness = 3
Rake-fullness = 2
Rake-fullness = 1
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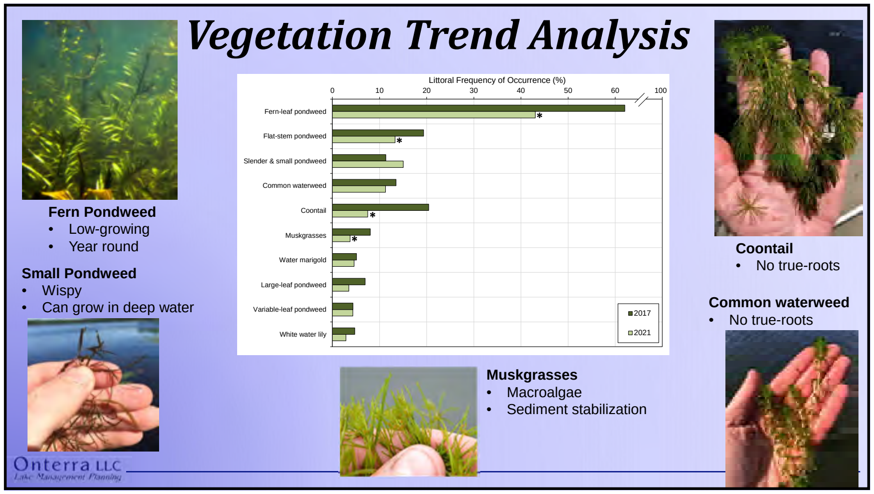
Vegetation Trend Analysis
Littoral Frequency of Occurrence (%)
Fern-leaf pondweed
Flat-stem pondweed
Slender & small pondweed
Common waterweed
Coontail
Muskgrasses
Water marigold
Large-leaf pondweed
Variable-leaf pondweed
White water lily
2017
2021
Fern Pondweed
• Low-growing
• Year round
Small Pondweed
• Wispy
• Can grow in deep water
Coontail
• No true-roots
Common waterweed
• No true-roots
Muskgrasses
• Macroalgae
• Sediment stabilization
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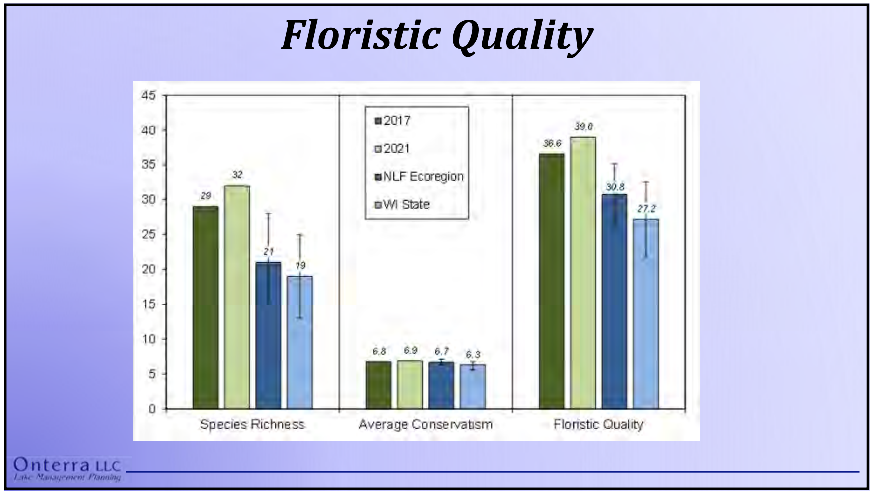
Floristic Quality
2017
2021
NLF Ecoregion
WI State
29
32
21
19
6.8
6.9
6.7
6.3
36.6
39.0
30.8
27.2
Species Richness
Average Conservatism
Floristic Quality
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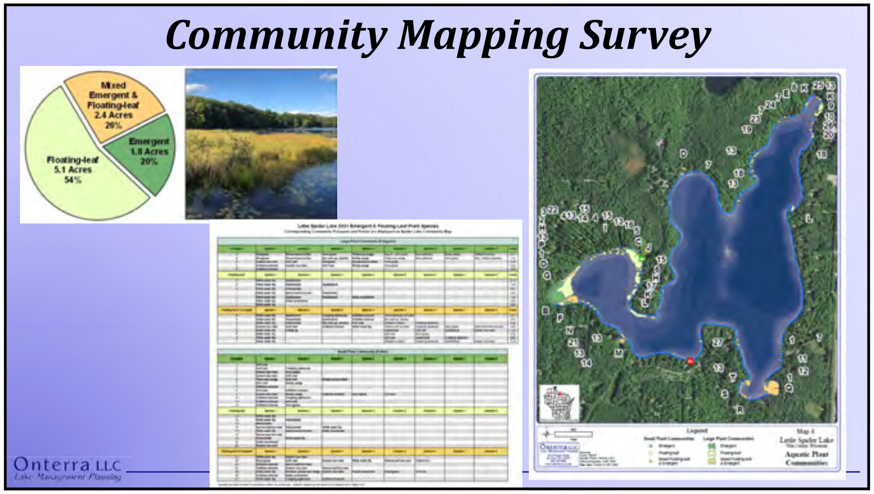
Community Mapping Survey
Mixed Emergent & Floating-leaf 2.4 Acres 26%
Emergent 1.8 Acres 20%
Floating-leaf 5.1 Acres 54%
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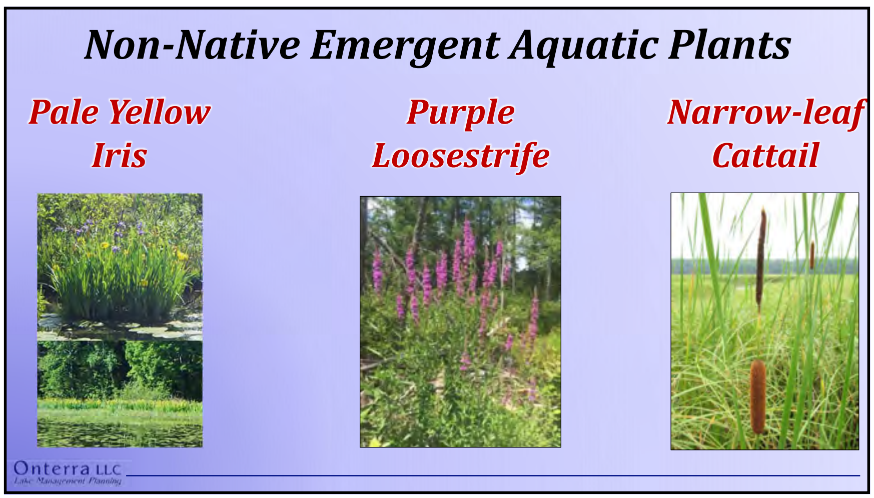
3.4 Aquatic
Invasive Species


Non-Native Emergent Aquatic Plants
Pale Yellow Iris
Purple Loosestrife
Narrow-leaf Cattail
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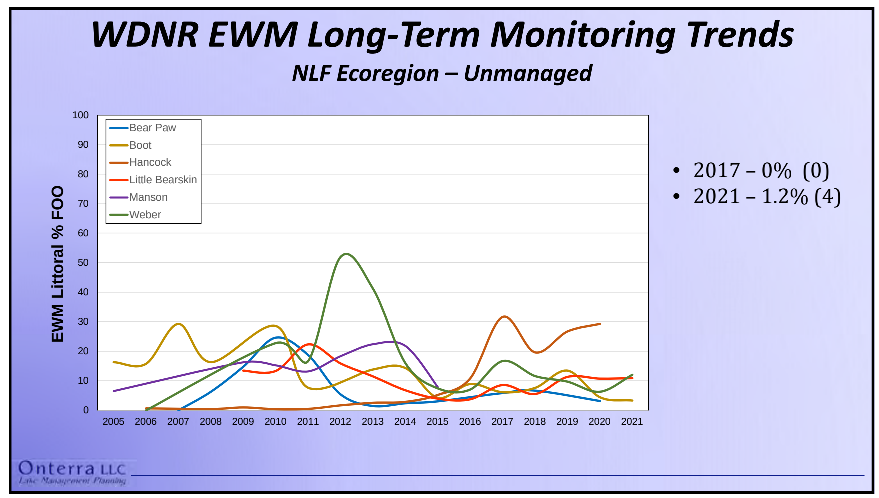
WDNR EWM Long-Term Monitoring Trends
NLF Ecoregion – Unmanaged
Bear Paw
Boot
Hancock
Little Bearskin
Manson
Weber
EWM Littoral % FOO
0
10
20
30
40
50
60
70
80
90
100
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
• 2017 – 0% (0)
• 2021 – 1.2% (4)
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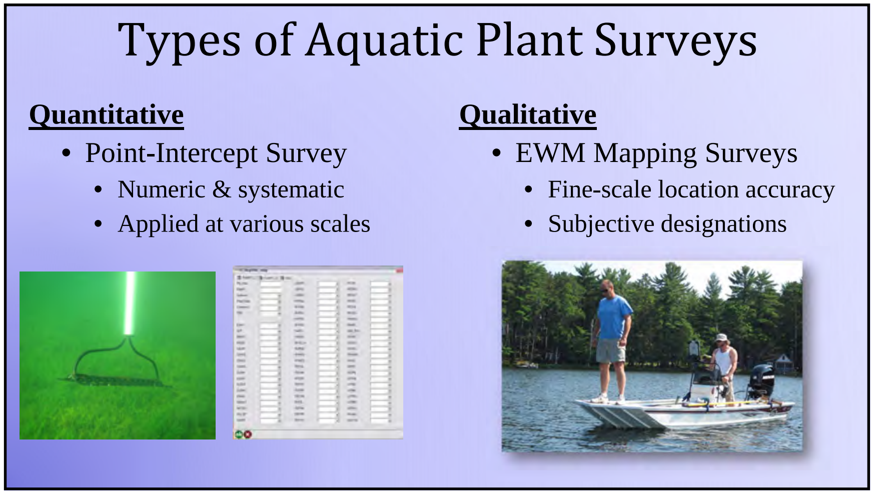
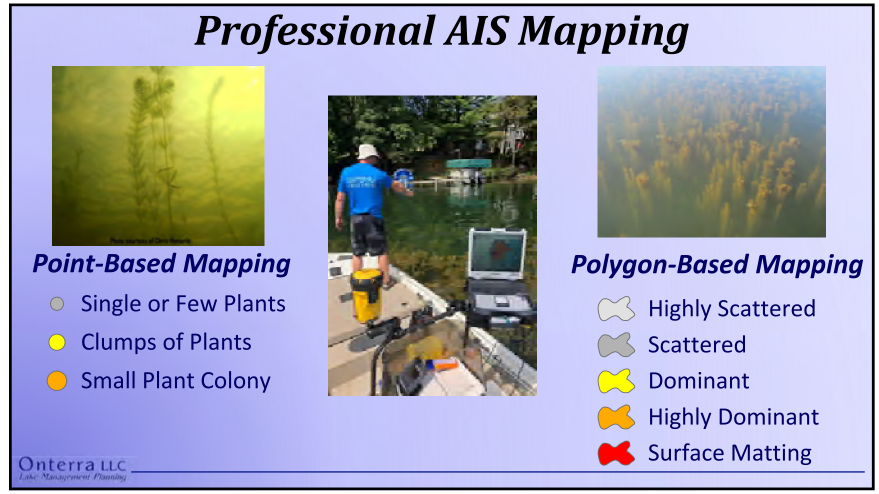

Types of Aquatic Plant Surveys
Quantitative
• Point-Intercept Survey
• Numeric & systematic
• Applied at various scales
Qualitative
• EWM Mapping Surveys
• Fine-scale location accuracy
• Subjective designations


Professional AIS Mapping
Point-Based Mapping
Single or Few Plants
Clumps of Plants
Small Plant Colony
Polygon-Based Mapping
Highly Scattered
Scattered
Dominant
Highly Dominant
Surface Matting
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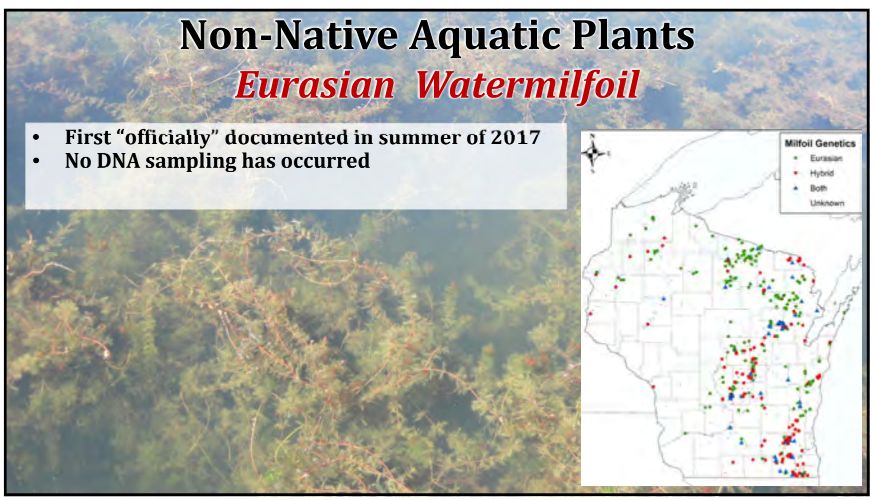
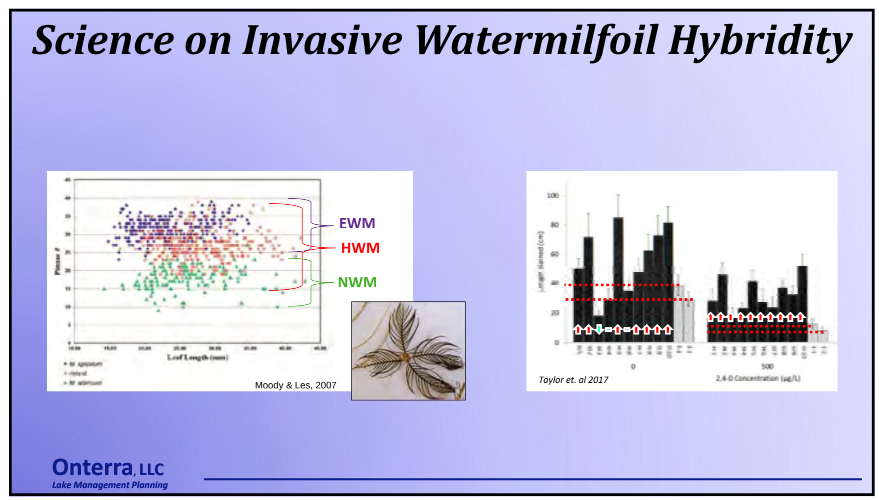

Non-Native Aquatic Plants
Eurasian Watermilfoil
• First "officially" documented in summer of 2017
• No DNA sampling has occurred
Milfoil Genetics
Eurasian
Hybrid
Both
Unknown


Science on Invasive Watermilfoil Hybridity
EWM
HWM
NWM
Moody & Les, 2007
Taylor et. al 2017
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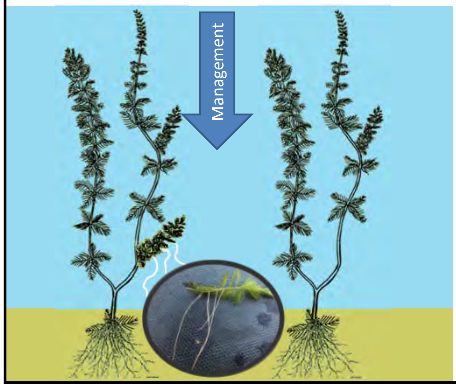
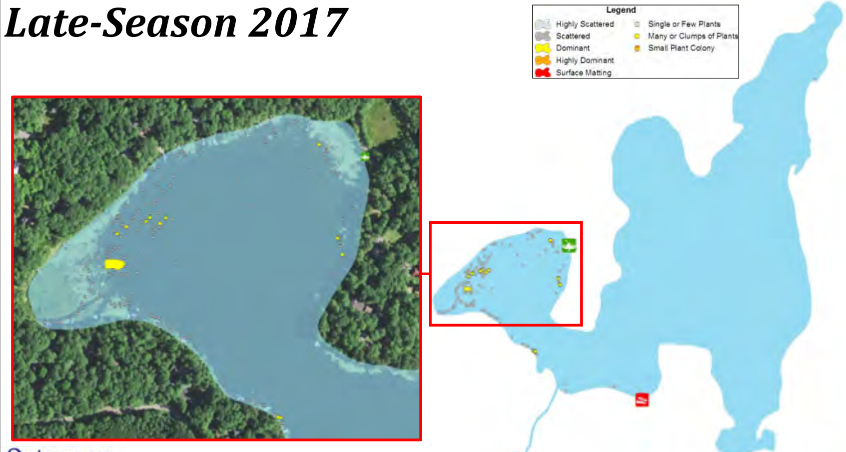
EWM Life-Cycle & Control Strategy Philosophy



- Strategy is straight-forward compared to those w/ seed or turion base
- Herbicide needs to translocate to root crown (*hard to kill with herbicides*)
- Hand-harvesting is analogous to single treatment (*extremely time intensive)*
- Winter drawdown can be effective if completely de-water and desiccate/freeze roots.

Late-Season 2017



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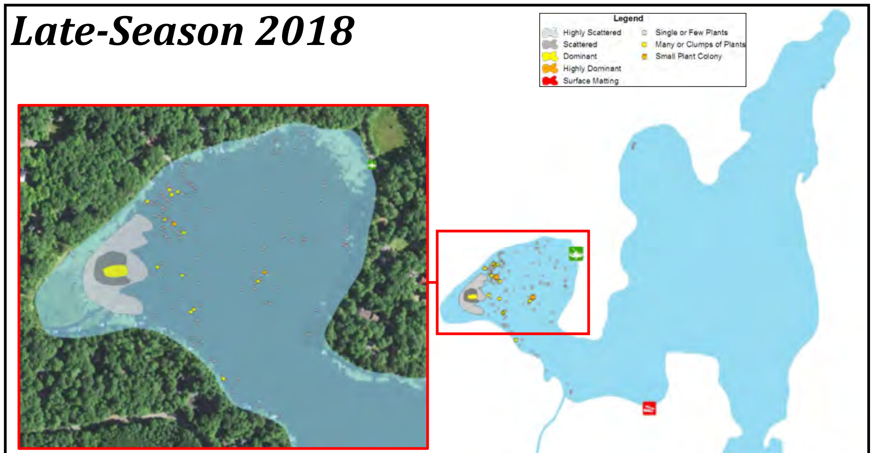
Late-Season 2018



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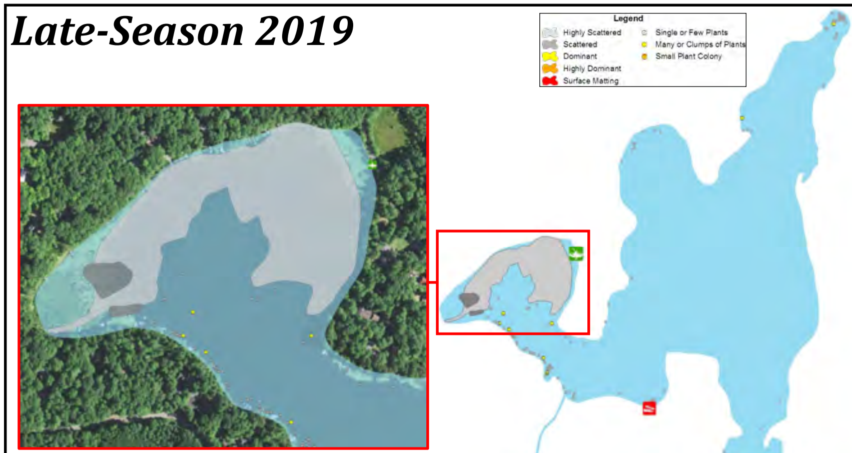
Late-Season 2019



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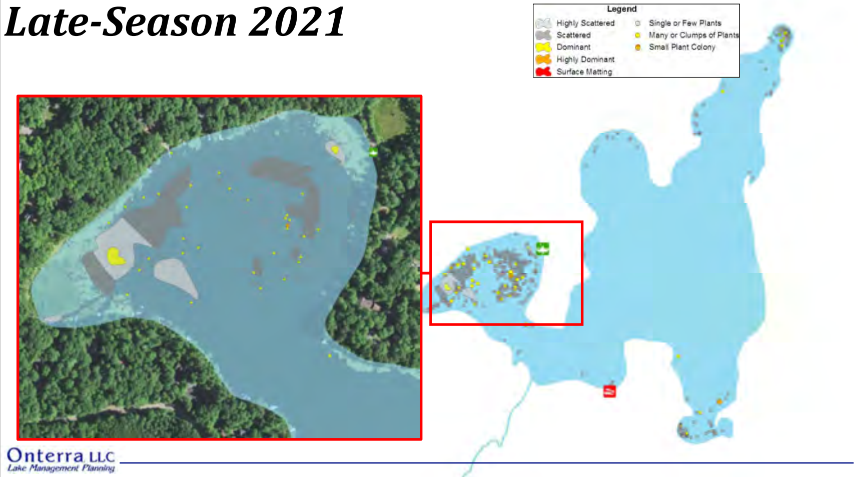
Late-Season 2021



Best Management Practices (BMPs)

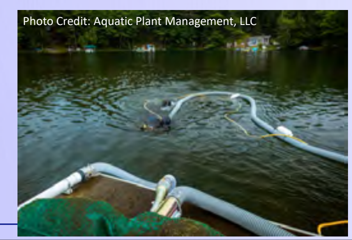
- **A "placeholder" term to represent the management option that is currently supported by that latest science and policy**
- **Definition evolves over time**
  - Pre 2010 - small spot treatments with granular products
  - Early 2010s - larger spot treatments with liquid products
  - Mid 2010s – whole-lake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

Integrated Pest Management Strategies (IPM)

- **Using a combination of methods that are more effective when applied collectively as part of defined strategy than when conducted separately**
  - Prevention
  - Biological control
  - Biomanipulation
  - Nutrient management
  - Habitat manipulation
  - Substantial modification of cultural practices
  - Pesticide application
  - Water level manipulation
  - Mechanical removal
  - Feasibility planning
  - Population monitoring

Hand-Harvesting

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



Herbicide Treatment

- **Introduces greater need for risk assessment discussion**
  - Known impacts of herbicides
  - Unknown impacts of herbicides
  - Public sentiment
- **How they work**
  - Concentration & Exposure Time (CET)
  - Herbicide dissipation
  - Spot vs whole-lake (whole-basin)
  - Herbicide formulation

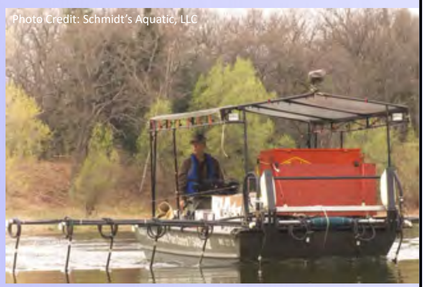


Photo Credit: Schmidt's Aquatic, LLC

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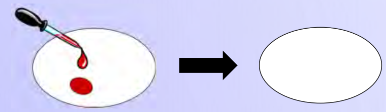
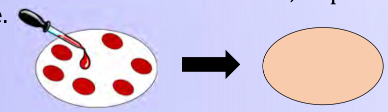
Ecological Definitions of Herbicide Treatment

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



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



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AIS Management Perspectives

1. **No Coordinated Active Management (Let Nature Take its Course)**
   - Focus on education of manual removal by property owners
2. **Reduce AIS Population on a lake-wide level (Population Management)**
   - Would likely rely on herbicide treatment (risk assessment)
   - Will not "eradicate" AIS
   - Set triggers (thresholds) of implementation and tolerance
3. **Minimize navigation and recreation impediment (Nuisance Control)**
   - May be accomplished through herbicide treatment, hand-harvesting, or mechanical harvesting

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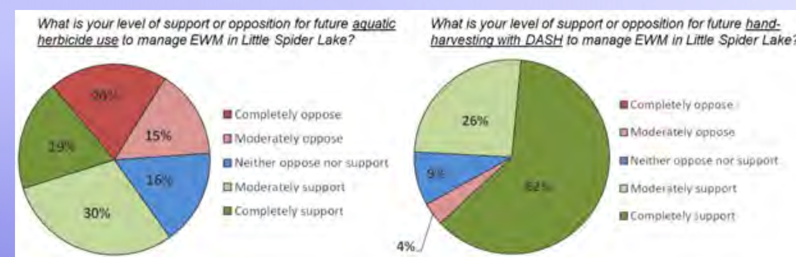
Stakeholder Perceptions of EWM Management

69% Response Rate



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4.0 Conclusions

Water Quality

- Overall "excellent" for Deep Headwater Drainage System
- Evidence exists that the water quality is only slightly more productive than pre-settlement.
- Interesting early-season dynamics (internal nutrients) and potential polymictic nature

Watershed

- Relatively small watershed, with likely nutrient sinks (bog wetlands)
- Shoreland protection and enhancement important to long-term health

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4.0 Conclusions

Aquatic Plants

- No real changes in aquatic plant populations from 2017 to 2021
- EWM population increasing, but may be stabilizing ??
- Development of AIS monitoring & management plans is necessary
  - Emergent AIS (PL, PYI, Cattail)
  - Eurasian watermilfoil

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Implementation Plan Development

Goal

- Reflects big picture
- Can be ambitious, but attainable

Action

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

- Management goals are statements, were as management actions are detailed.
- Typical Onterra APM Plans will have a 2-4 goals, with multiple actions under each goal.

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Planning Meeting II

Primary Objective: Create implementation plan framework

Steps to Achieve Objective:

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

Assignment for Planning Meeting II

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

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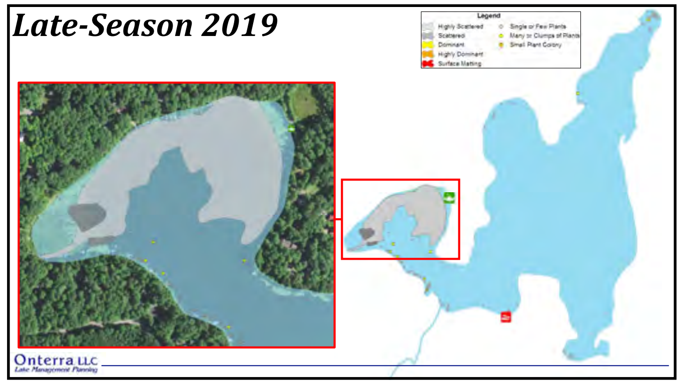
Little Spider Lake Association
Comprehensive Management Planning Project
Planning Meeting II
May 20, 2022
Eddie Heath
Onterra LLC
Lake Management Planning
LPL-1760-21


Late-Season 2019
Legend
Onterra LLC
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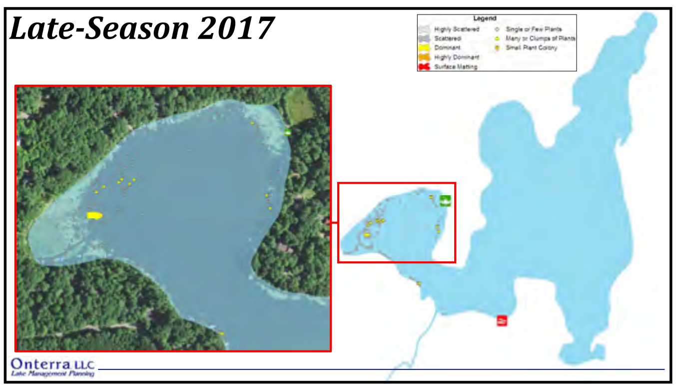
Late-Season 2017
Legend
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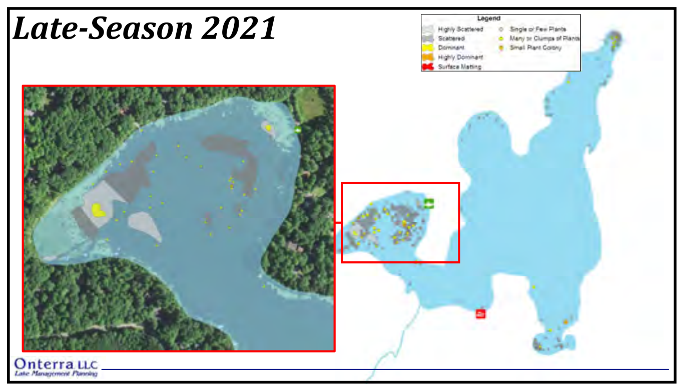
Late-Season 2021
Legend
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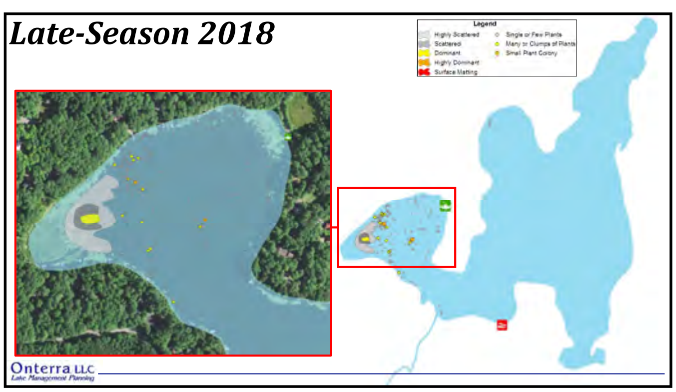
Late-Season 2018
Legend
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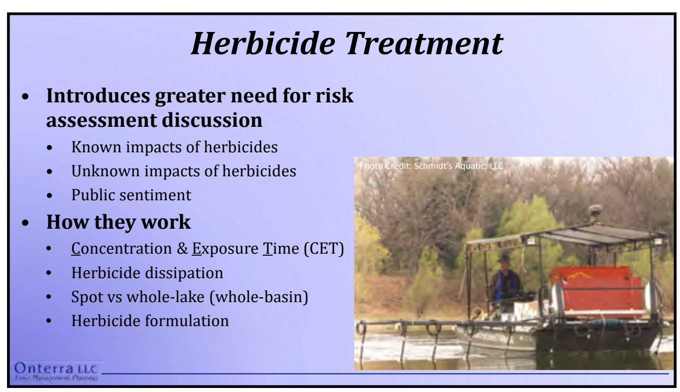
Herbicide Treatment
• Introduces greater need for risk assessment discussion
• Known impacts of herbicides
• Unknown impacts of herbicides
• Public sentiment
• How they work
• Concentration & Exposure Time (CET)
• Herbicide dissipation
• Spot vs whole-lake (whole-basin)
• Herbicide formulation
Photo Credit: Schmidt's Aquatic LLC
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Herbicide Treatment on Lake Metonga

- Tracer Dye (Rhodamine WT)
- A-15 (south) ~ 3 acres
- B-15 (north) ~ 5 acres

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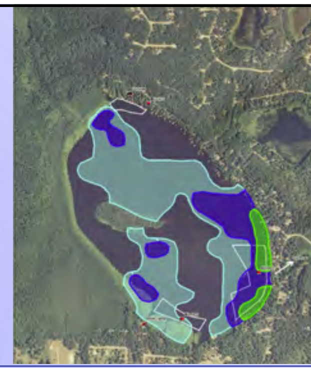
6 HAT

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

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



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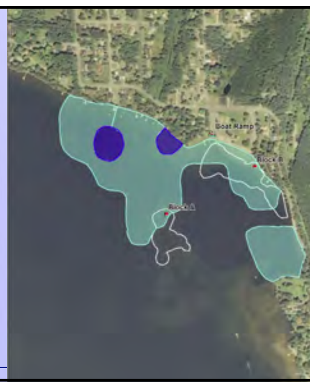
5 HAT

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

2,4-D CET needed for EWM control based upon published studies:
sustained 4.0 ppm for 12 hours
sustained 2.0 ppm for 24 hours



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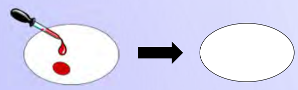
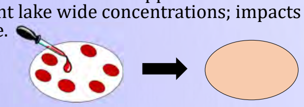
Ecological Definitions of Herbicide Treatment

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



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



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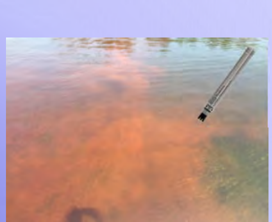
Herbicide Treatment on Loon Lake

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



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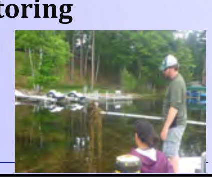
Treatment Monitoring

- **Qualitative Target Plant Monitoring**
  - Comparative pre/post EWM mapping surveys
- **Quantitative Aquatic Plant Monitoring**
  - Comparative pre/post sub-sample point-intercept surveys
- **Herbicide Concentration Monitoring**
  - Volunteer-based in situ water testing



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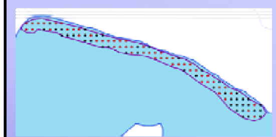
Sub-Sample Point-Intercept Survey



- Presence-Absence data produces frequency of occurrence
- Comparisons made using Chi-square statistical analysis

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Lake Management Planning

Onterra Projects

2019-2021

- 34 Treatments, 14 Lakes
- Application Rate 3.0-8.0 PDU/acre-ft
- Almost all highly effective
  - Less effective: Kettle Moraine, Boulder
- Emerging suite of sensitive native plant species
  - NWM, Bidens, Coontail, dicots

Lake Name	County	Target	Site	Acres	PDU/ acre-foot	Treatment Date
North Twin	Vilas	EWM	B-19	14.3	8.0	6/17/2019
		EWM	C-20	10.0	7.0	6/17/2020
South Twin	Vilas	EWM	X-21	5.4	4.5	6/9/2021
		EWM	Y-21	22.5	4.0	6/9/2021
		EWM	Z-21	30.1	4.0	6/9/2021
Kawaguesaga	Oneida	EWM	K1-19	4.3	4.0	7/16/2019
		EWM	K2-19		4.0	7/16/2019
		EWM	K3-19		5.0	7/16/2019
		EWM	E-20	15.2	3.5	6/30/2020
		EWM	F-20	12.9	5.0	6/30/2020
		EWM	P-21	3.6	3.5	6/22/2021
		EWM	Q-21	3.3	3.5	6/22/2021
		EWM	R-21	3.4	3.5	6/22/2021
Minocqua	Oneida	EWM*	M1-19	9.3	3.5	6/8/2019
		EWM*	M2-19		3.5	6/8/2019
		EWM*	B-20	17.7	4.5	6/15/2020
		EWM*	C-20	10.2	4.5	6/15/2020
		EWM*	D-20	12.8	3.0	6/15/2020
		EWM*	G-20	7.4	5.0	6/30/2020
		EWM*	O-21	13.4	4.0	6/22/2021
Berry	Oconto-Menominee	HWM	A-20	10.0	4.0	6/12/2020
Crooked	Oconto	EWM	A-20	7.9	3.0/5.0	7/6/2020
Little Saint Germain	Vilas	EWM	A-20	11.1	4.0	6/12/2020
		EWM	C-20	5.1	4.0	6/12/2020
		EWM	D-20	15.9	3.0	6/12/2020
Long	Vilas	EWM*	B-20	15.9	4.0	6/17/2020
[Big] Silver	Waushara	HWM	A-20	11.6	3.5	6/8/2020
Hatch	Waupaca	EWM?	A-21	3.0	4.0	6/17/2021
Kettle Moraine	Fond du Lac	EWM	A-21	10.0	4.0	6/10/2021
Boulder	Oconto	EWM	A-21	1.4	5.0	6/18/2021
		EWM	B-21	1.0	5.0	6/18/2021
Silver	Forest	EWM	A-21	15.0	3.0	6/23/2021
Grass (Cloverleaf Lakes)	Shawano	HWM	A-21	3.5	4.0	6/22/2021
		HWM	B-21	3.3	3.5	6/22/2021

*Presumably EWM although HWM has been documented from system

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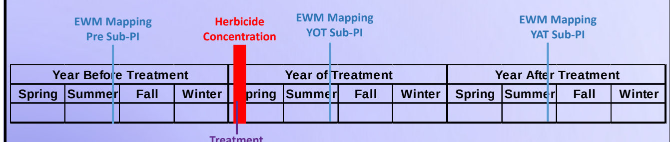
Typical Herbicide Monitoring



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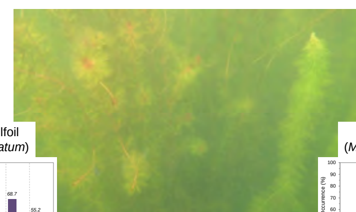
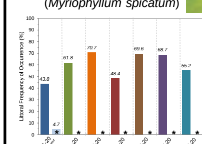
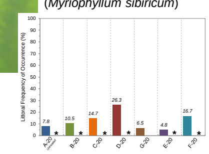
Minoc-Kawa 2020 Combined



Eurasian watermilfoil
(*Myriophyllum spicatum*)



Northern watermilfoil
(*Myriophyllum sibiricum*)



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Florpyrauxifen-benzyl (ProcellaCOR™)

- New class of synthetic auxin hormone mimics
  - Much different binding affinity than other auxins
  - Use at PPB rate vs PPM
- Short contact exposure time (CET) requirement
- Short environmental fate of ae, acid metabolite ??
  - Half life 1-6 days (photolysis, higher rates in clear water)
  - High Koc (soil/organic binding affinity)
- Currently formulated for spot treatments, but manufacturer working towards whole-lake use patterns
- Detailed information on field applications is limited

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Lake Management Planning

Sub-Sample PI Survey – Pre to YOT

Pretreatment to Year of Treatment

		Berry Eastern Basin	North Twin C-20	LSG A-20	LSG C-20	LSG D-20	LongV B-20	Big Silver A-20	Minoc B-20	Minoc C-20	Minoc D-20	South Twin Y-21	South Twin Z-21	Crooked A-20	Minoc G-20	Kawa E-20	Kawa F-20	Minoc O-21	Kawa P-21	Kawa Q-21	Kawa R-21	Grass A -21	Grass B -21	SilverF A-21	Kettle Moraine A-21
Myriophyllum spicatum	Eurasian watermilfoil	↓↓↓	↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓	↓↓↓	↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓	↓↓↓
Bidens beckii	Water marigold	-	ns	↓	ns	-	ns	ns	↓	-	↓	-	-	-	ns	ns	-	↓↓	ns	ns	ns	-	-	-	-
Brasenia schreberi	Watershield	ns	-	-	-	-	-	-	-	-	-	-	-	↓	-	ns	-	-	-	ns	ns	-	ns	-	ns
Ceratophyllum demersum	Coontail	ns	ns	↓↓↓	ns	↓↓	ns	ns	↓↓↓	↓↓↓	↓↓	↑↑	ns	ns	ns	↓	ns	ns	ns	ns	ns	ns	ns	ns	↓↓↓
Charophytes	Muskgrasses & Stoneworts	ns	ns	↓↓	↓	ns	ns	ns	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	↓
Eleocharis acicularis	Needle spikerush	ns	-	ns	ns	-	ns	-	ns	ns	ns	ns	-	ns	ns	ns	ns	↓↓↓	-	ns	-	-	-	ns	ns
Elodea canadensis	Common waterweed	-	ns	ns	ns	ns	ns	↑	↓	↓	↓↓↓	ns	-	↓	ns	ns	ns	↑↑	ns	ns	ns	ns	↓	ns	↓↓↓
Heteranthera dubia	Water stargrass	-	ns	ns	ns	ns	ns	↓↓↓	↓↓	ns	-	ns	ns	-	ns	ns	ns	ns	ns	ns	ns	-	ns	-	-
Isoetes spp.	Quillwort spp.	ns	-	ns	ns	ns	ns	-	-	-	-	-	-	-	ns	ns	ns	ns	-	-	-	-	-	-	-
Lemna trisulca	Forked duckweed	-	-	-	-	↑	-	-	ns	ns	↑↑	-	-	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
Myriophyllum sibiricum	Northern watermilfoil	-	-	↓↓	ns	ns	ns	-	↓↓	↓↓	↓↓↓	-	-	-	ns	↓	↓↓↓	↓↓	↓↓	-	ns	-	-	-	-
Myriophyllum tenellum	Dwarf watermilfoil	ns	-	-	ns	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Najas flexilis	Slender naiad	ns	ns	-	ns	ns	ns	ns	ns	-	-	ns	ns	ns	-	ns	ns	↓	-	-	-	ns	ns	↑↑↑	-
Najas guadalupensis	Southern naiad	↑↑	-	ns	ns	ns	ns	ns	ns	↓	ns	-	-	↑↑↑	ns	↑↑↑	↑	ns	ns	ns	ns	ns	ns	↓↓↓	ns
Nuphar variegata	Spatterdock	-	-	ns	-	ns	-	-	-	-	-	-	-	ns	-	-	-	-	-	ns	ns	ns	ns	-	ns
Nymphaea odorata	White water lily	ns	-	-	-	ns	-	ns	-	-	-	-	-	↓	ns	-	-	ns	-	ns	-	-	ns	-	ns
Potamogeton amplifolius	Large-leaf pondweed	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	↑	ns	ns	ns	ns	ns	ns	ns	ns
Potamogeton gramineus	Variable-leaf pondweed	ns	ns	ns	ns	ns	↑	ns	ns	ns	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Potamogeton illinoensis	Illinois pondweed	↑	-	↓	-	-	-	ns	ns	-	ns	-	-	-	-	-	-	ns	-	-	-	-	ns	ns	ns
Potamogeton natans	Floating-leaf pondweed	ns	-	-	-	-	-	ns	-	-	-	-	-	↑	-	-	-	-	-	-	-	-	ns	-	-
Potamogeton praelongus	White-stem pondweed	ns	ns	↓	-	ns	ns	ns	↑↑	ns	ns	↑	ns	ns	ns	-	ns	ns	-	ns	ns	-	-	-	-
P. pusillus & P. berchtoldii	Small pw & Slender pw	ns	↑↑	↓	ns	↓	-	ns	ns	↓↓	↓	ns	↑	↑	ns	ns	ns	↑	ns	ns	-	-	-	ns	-
Potamogeton richardsonii	Clasping-leaf pondweed	ns	ns	ns	↑	ns	↓↓	-	ns	ns	ns	↑	↑↑	-	↑	ns	↑	ns	ns	ns	ns	ns	ns	↑	-
Potamogeton robbinsii	Fern-leaf pondweed	ns	-	ns	ns	↑↑	ns	-	↓↓	ns	ns	↑↑	ns	ns	↑	↑	ns	ns	ns	↑	ns	-	-	ns	-
Potamogeton strictifolius	Stiff pondweed	ns	-	-	-	↑	-	ns	ns	-	-	-	-	↑	-	-	-	ns	-	-	ns	-	-	-	ns
Potamogeton zosteriformis	Flat-stem pondweed	ns	ns	ns	-	ns	-	↑↑↑	ns	ns	ns	↓	↑	ns	ns	ns	ns	ns	ns	ns	ns	ns	↓↓	-	ns
Ranunculus aquatilis	White water crowfoot	ns	ns	ns	-	-	-	ns	↓	ns	ns	-	-	-	ns	ns	↓↓	↓	ns	ns	ns	-	-	-	-
Stuckenia pectinata	Sago pondweed	-	-	-	-	-	-	ns	-	-	-	-	-	-	-	-	-	-	-	-	ns	ns	ns	-	ns
Vallisneria americana	Wild celery	ns	ns	ns	ns	↓	ns	ns	ns	ns	ns	ns	ns	ns	↑↑	↑↑↑	↑	ns	↑↑	ns	↑↑	ns	ns	ns	-

- Table displays species that exhbited a frequency of occurrence of at least above 2% in any one survey. Less commonly encountered species displayed in list in sheet 2.
- Table splits to separate survey timing schemes
- Arrow Represents statistically valid direction of change, ↑ = $p<0.05$, ↑↑ = $p<0.01$, ↑↑↑ = $p<0.001$

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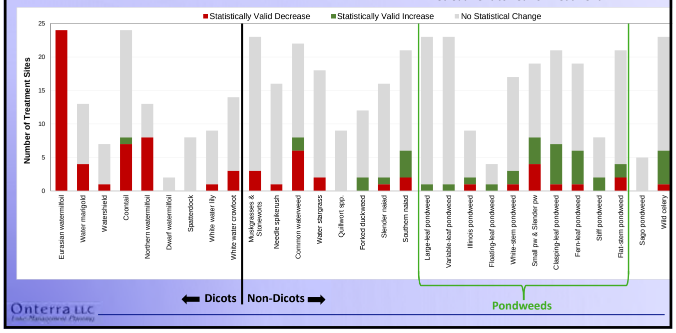
Lake Management Planning

Sub-Sample PI Survey – Pre to YOT

Pretreatment to Year of Treatment



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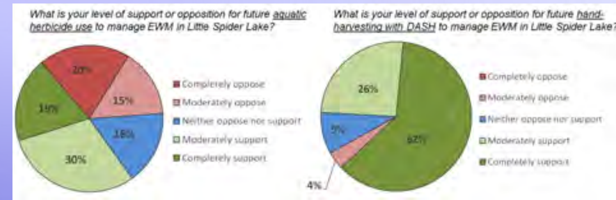
Stakeholder Perceptions of EWM Management

69% Response Rate



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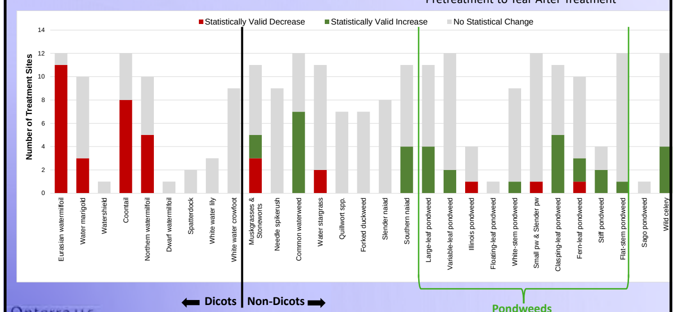
Sub-Sample PI Survey – Pre to YAT

Pretreatment to Year After Treatment



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5.0 Implementation Plan

AIS Management Perspectives

1. **No Coordinated Active Management (Let Nature Take its Course)**
   - Focus on education of manual removal by property owners
2. **Reduce AIS Population on a lake-wide level (Population Management)**
   - Would likely rely on herbicide treatment (risk assessment)
   - Will not "eradicate" AIS
   - Set triggers (thresholds) of implementation and tolerance
3. **Minimize navigation and recreation impediment (Nuisance Control)**
   - May be accomplished through herbicide treatment, hand-harvesting, or mechanical harvesting

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Implementation Plan Development

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

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

- Management goals are statements, were as management actions are detailed.
- Typical Onterra APM Plans will have a 2-4 goals, with multiple actions under each goal.

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Planning Meeting II

Primary Objective: Create implementation plan framework

Steps to Achieve Objective:

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

Assignment for Planning Meeting II

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

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Thank You

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Challenges Discussion

- Aquatic plants
  - Continued monitoring
  - Education
    - Importance
    - Native plant pledge/guidance
- AIS
  - Periodic monitoring
  - Eurasian watermilfoil
    - Continued HH/DASH
    - Trigger for considering herbicide management
  - Emergent AIS (purple loosestrife, pale-yellow iris)
  - Education
    - EWM LTT
    - Keep up to date on BMPs, risks
  - Containment & Protection
    - Signage
    - CBCW

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Challenges Discussion

- Shoreland health
  - Healthy Lakes Grants!!!
  - Concern for wake boats
  - Education
    - Connection to WQ
    - Links to WDNR survey data
- Fisheries & Ecosystem health
  - Encourage more dialogue with WDNR fisheries program
    - Appointed liaison
    - Mgmt goals
    - Fish stocking (LSLA funded?)
    - Natural reproduction
    - Fish sticks (state lands)
    - Research potential (creel survey)
  - Education
    - SHS results to membership
- Organizational capacity
  - Communication abilities
  - Partners matrix
- Recreation
  - Watercraft safety/guidelines/courtesy code
    - Powerloading & erosion
  - Improper Wake boat usage, signage at entrance
  - Water level monitoring
- Conservation & General Education
  - Loon program
  - Toxic tackle
  - Wildlife issues
  - AIS ID, Inspections
  - Lawn/fertilizers/Natural Veg
  - Shoreline destruction (beavers)
  - Noise & Light pollution

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B

APPENDIX B

Stakeholder Survey Response Charts and Comments

Little Spider Lake - Anonymous Stakeholder Survey

Surveys Distributed: *121*
Surveys Returned: *84*
Response Rate: *69%*

Little Spider Lake Property

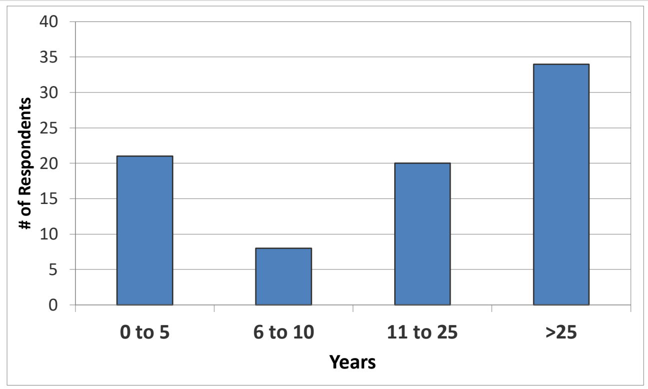
1. Is your property on the lake or off the lake?

Answer Options	Response Percent	Response Count
On the lake	99%	82
Off the lake	1%	1
	answered question	**83**
	skipped question	**1**

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

Answer Options	Response Count
	83
answered question	**83**
skipped question	**1**

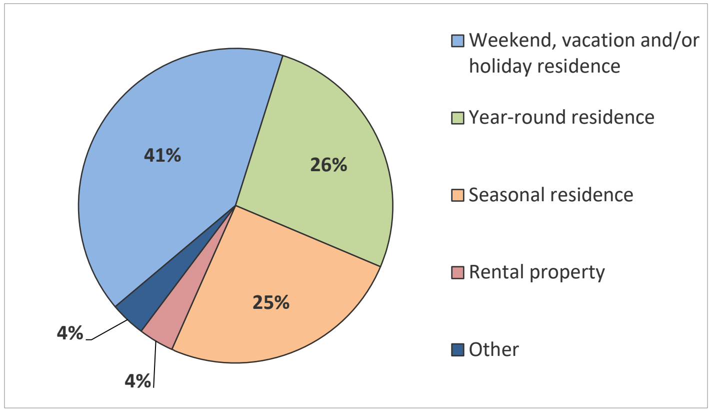
Category (# of years)	Responses	% Response
0 to 5	**21**	**25%**
6 to 10	**8**	**10%**
11 to 25	**20**	**24%**
>25	**34**	**41%**



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

Answer Options	Response Percent	Response Count
Weekend, vacation and/or holiday residence	41%	34
Year-round residence	27%	22
Seasonal residence	25%	21
Rental property	4%	3
Other	4%	3
answered question		**83**
skipped question		**1**

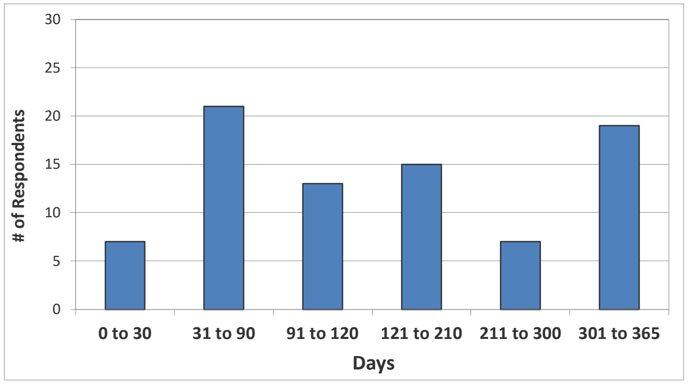
Number	Other
1	7 month then Some Week ends
2	Vacant land, not currently used.
3	Family cabin that is used about 5 months in total thru out the year



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

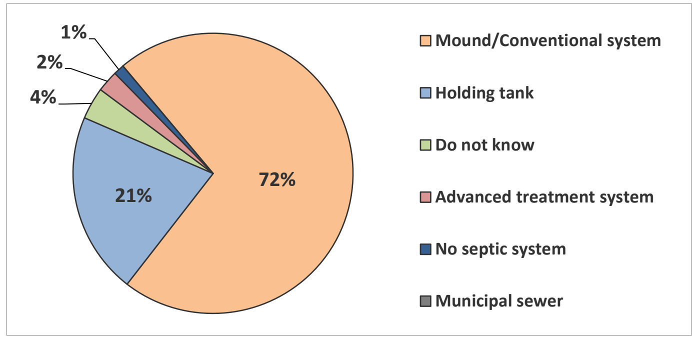
	Response Count
answered question	**82**
skipped question	**2**

Category (# of days)	Responses	%
0 to 30	**7**	**9%**
31 to 90	**21**	**26%**
91 to 120	**13**	**16%**
121 to 210	**15**	**18%**
211 to 300	**7**	**9%**
301 to 365	**19**	**23%**



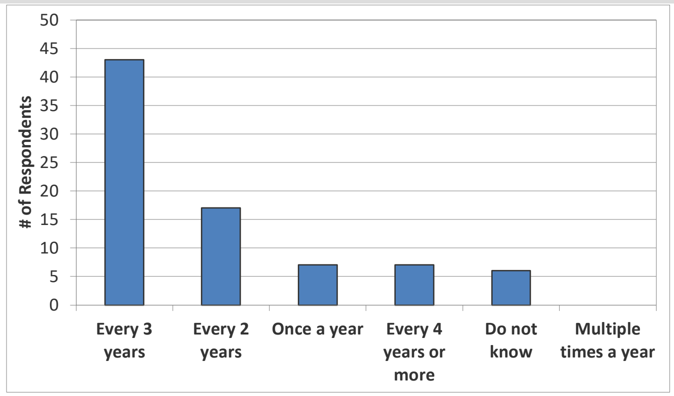
5. What type of septic system does your property have?

Answer Options	Response Percent	Response Count
Mound/Conventional system	72%	58
Holding tank	21%	17
Do not know	4%	3
Advanced treatment system	2%	2
No septic system	1%	1
Municipal sewer	0%	0
	answered question	**81**
	skipped question	**3**



6. How often is the septic system on your property pumped?

Answer Options	Response Percent	Response Count
Every 3 years	54%	43
Every 2 years	21%	17
Once a year	9%	7
Every 4 years or more	9%	7
Do not know	8%	6
Multiple times a year	0%	0
	answered question	**80**
	skipped question	**4**

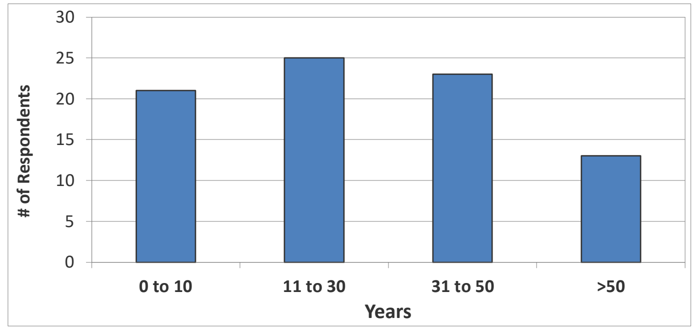


Recreational Activity on Little Spider Lake

7. How many years ago did you first visit Little Spider Lake?

Answer Options	Response Count
answered question	82
skipped question	2

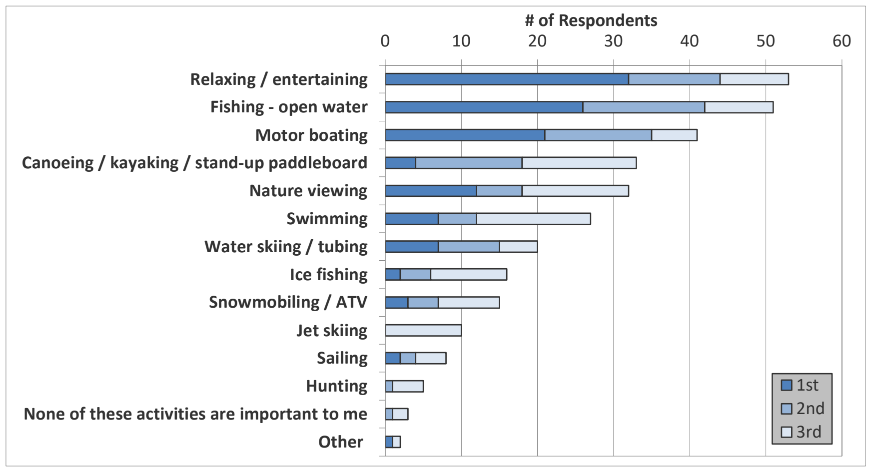
Category (# of years)	Response Percent	Response Count
0 to 10	26%	21
11 to 30	30%	25
31 to 50	28%	23
>50	16%	13



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

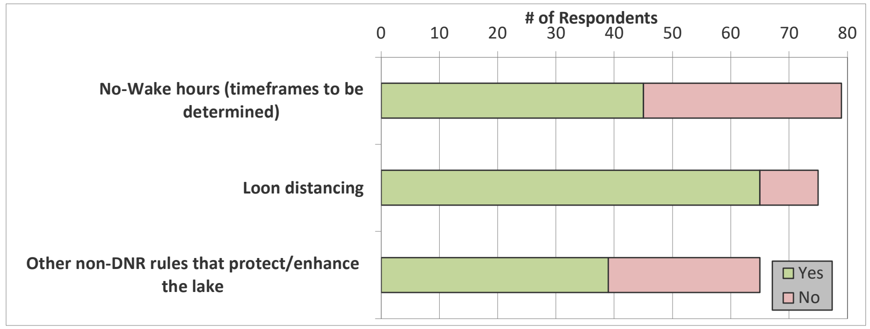
Answer Options	1st	2nd	3rd	Response Count
Relaxing / entertaining	32	12	9	53
Fishing - open water	26	16	9	51
Motor boating	21	14	6	41
Canoeing / kayaking / stand-up paddleboard	4	14	15	33
Nature viewing	12	6	14	32
Swimming	7	5	15	27
Water skiing / tubing	7	8	5	20
Ice fishing	2	4	10	16
Snowmobiling / ATV	3	4	8	15
Jet skiing	0	0	10	10
Sailing	2	2	4	8
Hunting	0	1	4	5
None of these activities are important to me	0	1	2	3
Other	1	0	1	2
			answered question	**82**
			skipped question	**2**

Number	"Other" responses
1	Cross country skiing in winter
2	Income



9. Would you support the establishment of new 'lake rules' and signage at the boat launch for:

Answer Options	Yes	No	Response Count
No-Wake hours (timeframes to be determined)	45	34	79
Loon distancing	65	10	75
Other non-DNR rules that protect/enhance the lake	39	26	65
		answered question	**80**
		skipped question	**4**



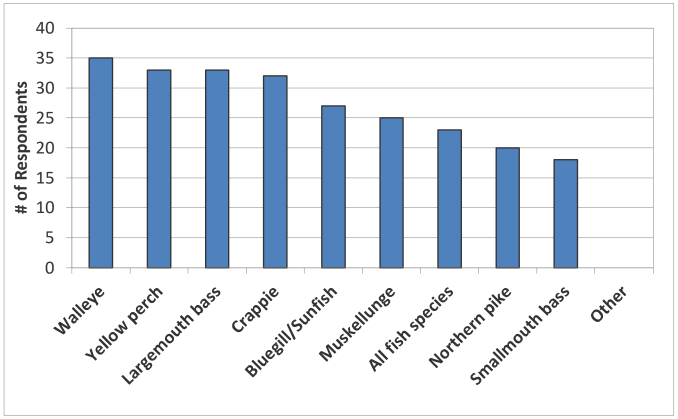
Number	"Other" responses
1	No wake boats in bays
2	No surf wake boats / wake surfing
3	No wake-making boats, maintaining distance from shore
4	NO Wake Boats
5	No wake boats/protect erosion from happening
6	How close to the shores you can drive fast. Eroding the shorelines
7	Staying 50 fee from all residence and buoys
8	No wake withend 200 feet of boat landing
9	No wake boats
10	No wake area in the west bay
11	Speed limit near shore
12	dam to keep the lake level higher
13	Not sure. I do not have enough information to make a choice
14	No parking at or around boat launch, no power loading
15	No power boat launching, need a sign that is more visible
16	Fish size and slot limits if applicable.
17	The more rules the more need to enforce. Prefer dealing with each case individually as needed
18	It all depends on what non-DNR rules are being considered
19	Something regarding boat cleaning

10. Have you personally fished on Little Spider Lake in the past three years?

Answer Options	Response Percent	Response Count
Yes	82%	67
No	18%	15
	answered question	**82**
	skipped question	**2**

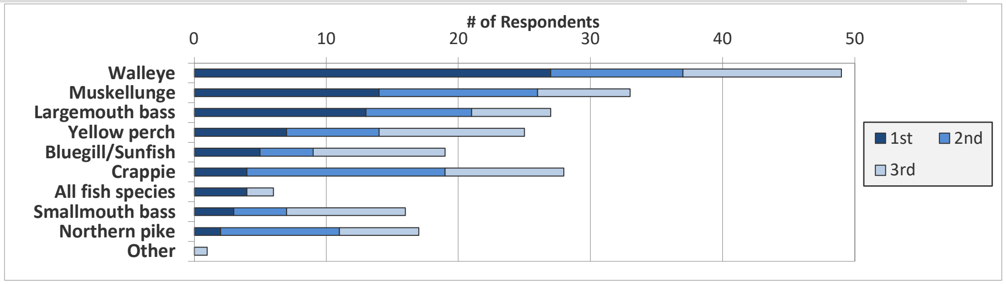
11. What species of fish do you try to catch on Little Spider Lake?

Answer Options	Response Percent	Response Count
Walleye	51%	35
Yellow perch	49%	33
Largemouth bass	49%	33
Crappie	47%	32
Bluegill/Sunfish	40%	27
Muskellunge	37%	25
All fish species	34%	23
Northern pike	29%	20
Smallmouth bass	26%	18
Other	0%	0
	answered question	**68**
	skipped question	**16**



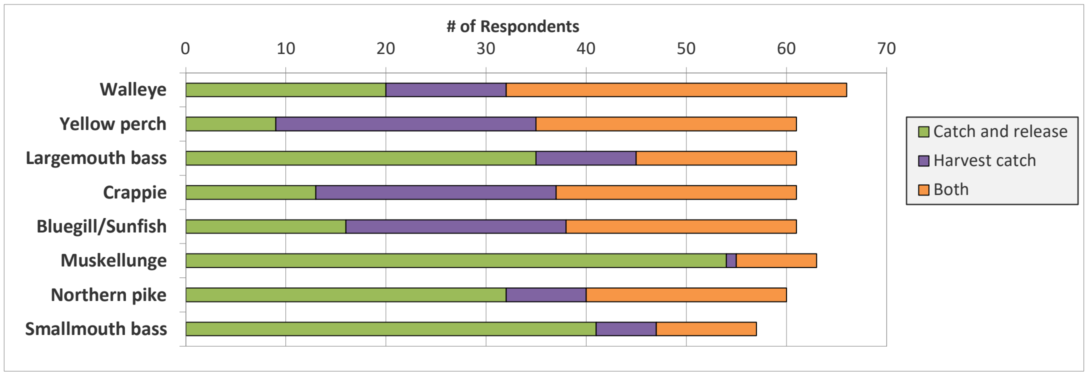
12. From the list below, please rank your top three favorite priorities for catching fish in Little Spider Lake. Please select as the 1st being your top fish species to catch.

Answer Options	1st	2nd	3rd	Response Count
Walleye	27	10	12	49
Muskellunge	14	12	7	33
Largemouth bass	13	8	6	27
Yellow perch	7	7	11	25
Bluegill/Sunfish	5	4	10	19
Crappie	4	15	9	28
All fish species	4	0	2	6
Smallmouth bass	3	4	9	16
Northern pike	2	9	6	17
Other	0	0	1	1
			answered question	**67**
			skipped question	**17**



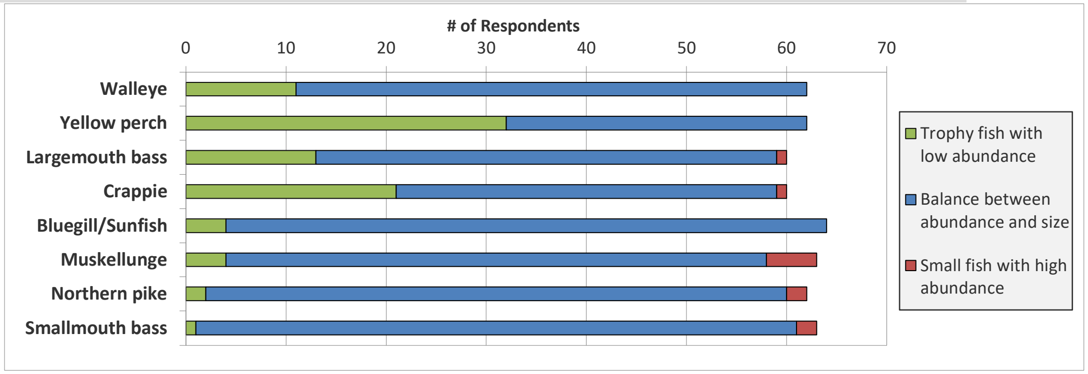
13. When fishing Little Spider Lake in the future, would you like to practice catch and release, harvest your catch, or both?

Answer Options	Catch and release	Harvest catch	Both	Response Count
Walleye	20	12	34	66
Yellow perch	9	26	26	61
Largemouth bass	35	10	16	61
Crappie	13	24	24	61
Bluegill/Sunfish	16	22	23	61
Muskellunge	54	1	8	63
Northern pike	32	8	20	60
Smallmouth bass	41	6	10	57
			answered question	**67**
			skipped question	**17**



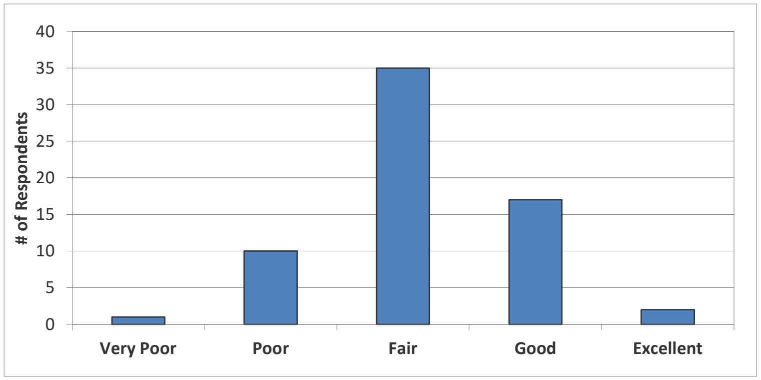
14. When fishing Little Spider Lake in the future, what kind of fishing opportunities would you like to experience?

Answer Options	Trophy fish with low abundance	Balance between abundance and size	Small fish with high abundance	Response Count
Walleye	11	51	0	62
Yellow perch	32	30	0	62
Largemouth bass	13	46	1	60
Crappie	21	38	1	60
Bluegill/Sunfish	4	60	0	64
Muskellunge	4	54	5	63
Northern pike	2	58	2	62
Smallmouth bass	1	60	2	63
			answered question	**66**
			skipped question	**18**



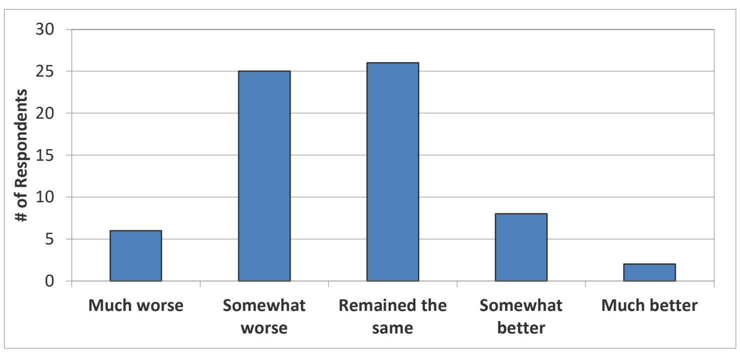
15. How would you describe the current quality of fishing on Little Spider Lake?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	1	10	35	17	2	65
					answered question	**65**
					skipped question	**19**



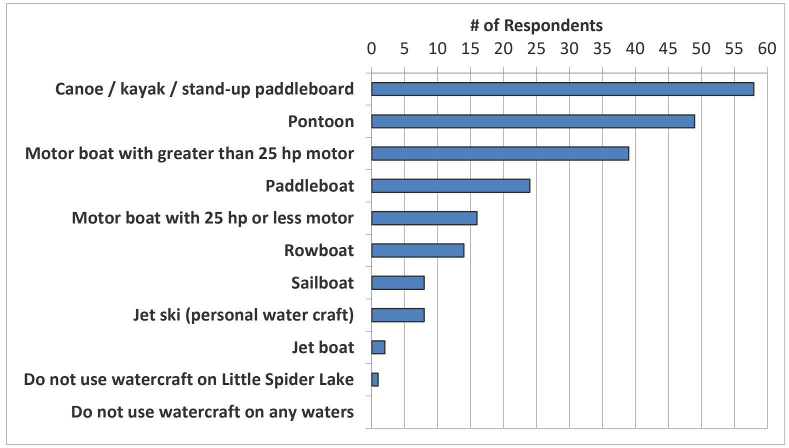
16. How has the quality of fishing changed on Little Spider Lake since you have started fishing the lake?

Answer Options	Much worse	Somewhat worse	Remained the same	Somewhat better	Much better	Response Count
	6	25	26	8	2	67
					answered question	**67**
					skipped question	**17**



17. What types of watercraft do you currently use on Little Spider Lake?

Answer Options	Response Percent	Response Count
Canoe / kayak / stand-up paddleboard	70%	58
Pontoon	59%	49
Motor boat with greater than 25 hp motor	47%	39
Paddleboat	29%	24
Motor boat with 25 hp or less motor	19%	16
Rowboat	17%	14
Sailboat	10%	8
Jet ski (personal water craft)	10%	8
Jet boat	2%	2
Do not use watercraft on Little Spider Lake	1%	1
Do not use watercraft on any waters	0%	0
	answered question	83
	skipped question	1

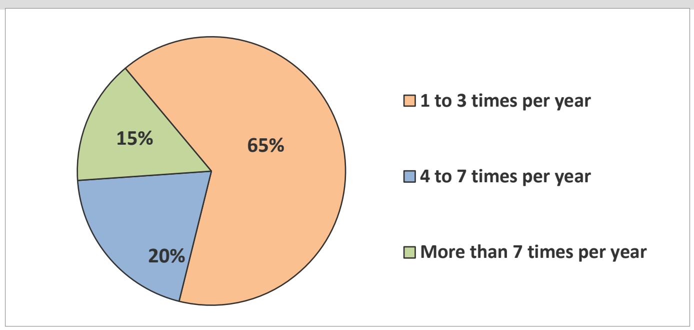


18. Do you use your watercraft on waters other than Little Spider Lake?

Answer Options	Response Percent	Response Count
Yes	23%	19
No	77%	64
	answered question	83
	skipped question	1

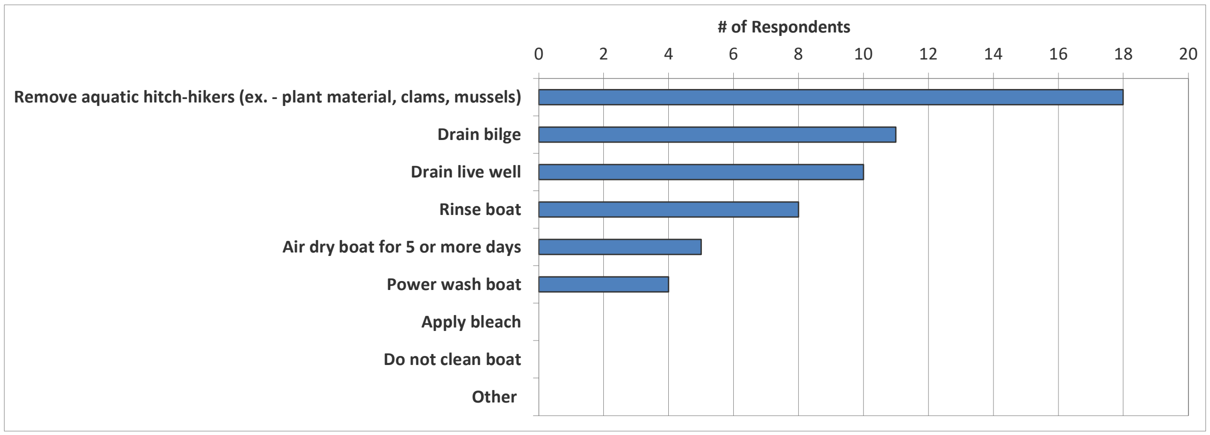
19. If "Yes", how frequently do you take your boat to other waters?

Answer Options	Response Percent	Response Count
1 to 3 times per year	65%	13
4 to 7 times per year	20%	4
More than 7 times per year	15%	3
	answered question	20
	skipped question	64



20. What is your typical cleaning routine after using your watercraft on waters other than Little Spider Lake?

Answer Options	Response Percent	Response Count
Remove aquatic hitch-hikers (ex. - plant material, clams, mussels)	95%	18
Drain bilge	58%	11
Drain live well	53%	10
Rinse boat	42%	8
Air dry boat for 5 or more days	26%	5
Power wash boat	21%	4
Apply bleach	0%	0
Do not clean boat	0%	0
Other	0%	0
	answered question	19
	skipped question	65

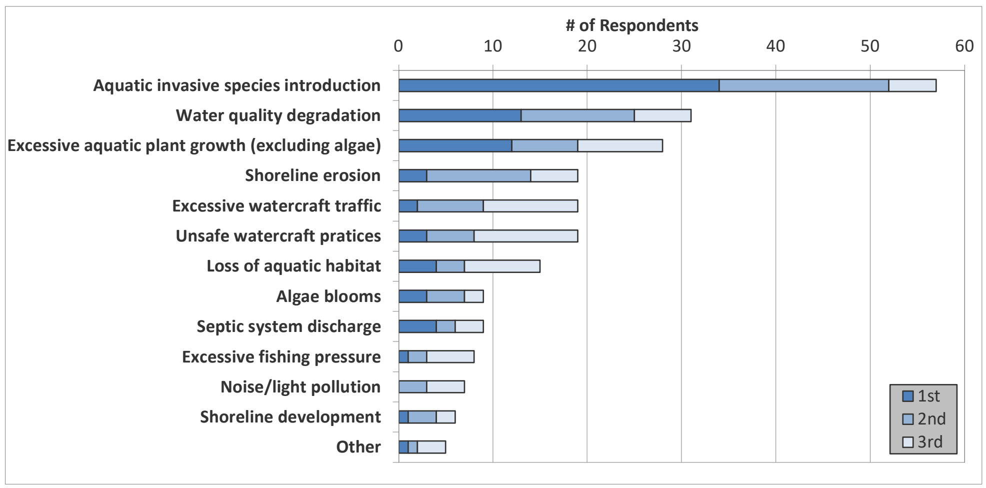


Little Spider Lake Current and Historic Condition, Health and Management

21. From the list below, please rank your top three concerns regarding Little Spider Lake, with 1 being your greatest concern.

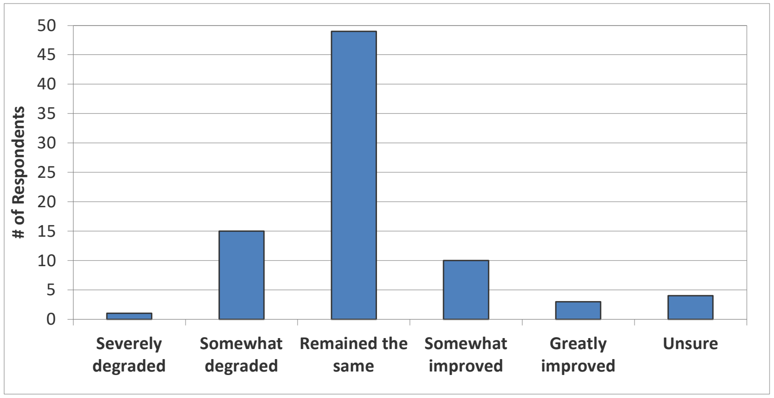
Answer Options	1st	2nd	3rd	Response Count
Aquatic invasive species introduction	34	18	5	57
Water quality degradation	13	12	6	31
Excessive aquatic plant growth (excluding algae)	12	7	9	28
Shoreline erosion	3	11	5	19
Excessive watercraft traffic	2	7	10	19
Unsafe watercraft pratices	3	5	11	19
Loss of aquatic habitat	4	3	8	15
Algae blooms	3	4	2	9
Septic system discharge	4	2	3	9
Excessive fishing pressure	1	2	5	8
Noise/light pollution	0	3	4	7
Shoreline development	1	3	2	6
Other	1	1	3	5
			answered question	81
			skipped question	3

Number	"Other" responses
1	Excessive watercraft traffic by uneducated boaters, coming too close to shore, raising high wakes at slow speeds. Not following laws already in place.
2	Oversize/wakesurf boats
3	Failure to follow state boating laws!
4	Use of fireworks over the water
5	everything else listed as well
6	Property Fertilization/Ice Fisherman Pressure

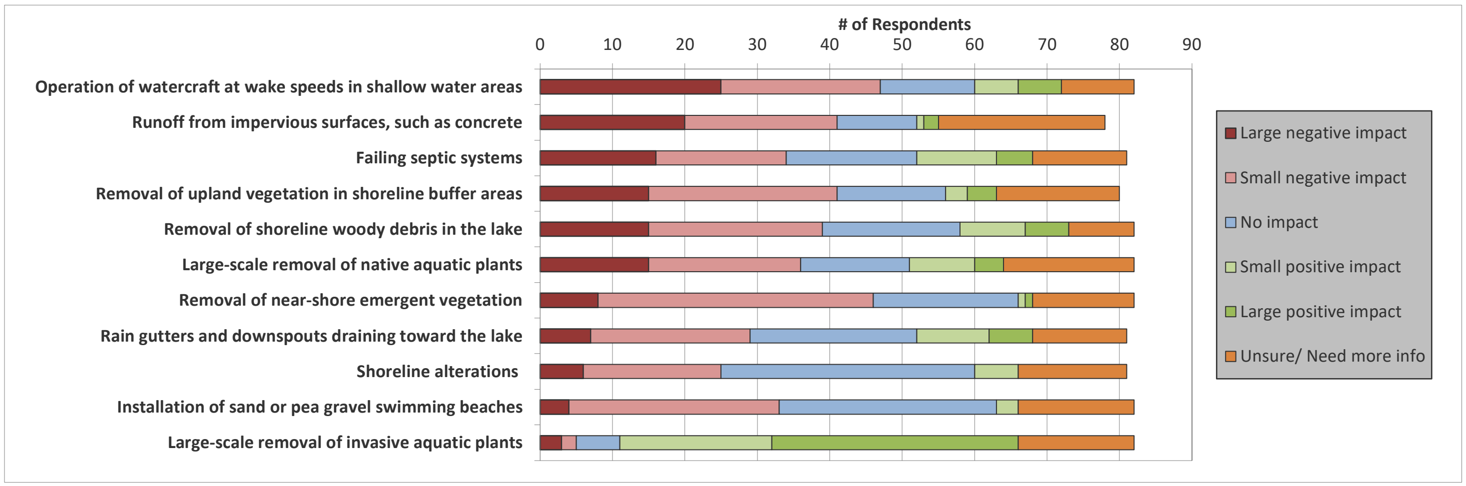


22. How has the overall water quality changed in Little Spider Lake since you first visited the lake?

Answer Options	Severely degraded	Somewhat degraded	Remained the same	Somewhat improved	Greatly improved	Unsure	Response Count
	1	15	49	10	3	4	82
						answered question	**82**
						skipped question	**2**

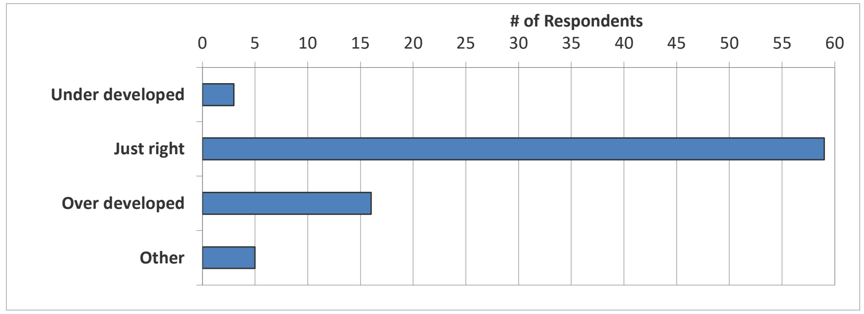


23. Using the following scale, what impact, if any, do you believe each of the following practices have on the water quality of Little Spider Lake?							
Answer Options	**Large negative impact**	**Small negative impact**	**No impact**	**Small positive impact**	**Large positive impact**	**Unsure/ Need more info**	**Response Count**
Operation of watercraft at wake speeds in shallow water areas	25	22	13	6	6	10	82
Failing septic systems	20	21	11	1	2	23	78
Removal of near-shore emergent vegetation, such as bulrushes, lily pads, cattails, etc	16	18	18	11	5	13	81
Removal of upland vegetation in shoreline buffer areas	15	26	15	3	4	17	80
Removal of shoreline woody debris in the lake, such as downed trees	15	24	19	9	6	9	82
Large-scale removal of native aquatic plants	15	21	15	9	4	18	82
Runoff from impervious surfaces, such as concrete	8	38	20	1	1	14	82
Shoreline alterations (rip-rap retaining walls, etc.)	7	22	23	10	6	13	81
Installation of sand or pea gravel swimming beaches	6	19	35	6	0	15	81
Rain gutters and downspouts draining toward the lake	4	29	30	3	0	16	82
Large-scale removal of invasive aquatic plants	3	2	6	21	34	16	82
						answered question	**82**
						skipped question	**2**



24. Which of the following descriptions do you believe most accurately describes the development of the Little Spider Lake shoreline?

Answer Options	Response Percent	Response Count
Under developed	4%	3
Just right	71%	59
Over developed	19%	16
Other	6%	5
	answered question	**83**
	skipped question	**1**



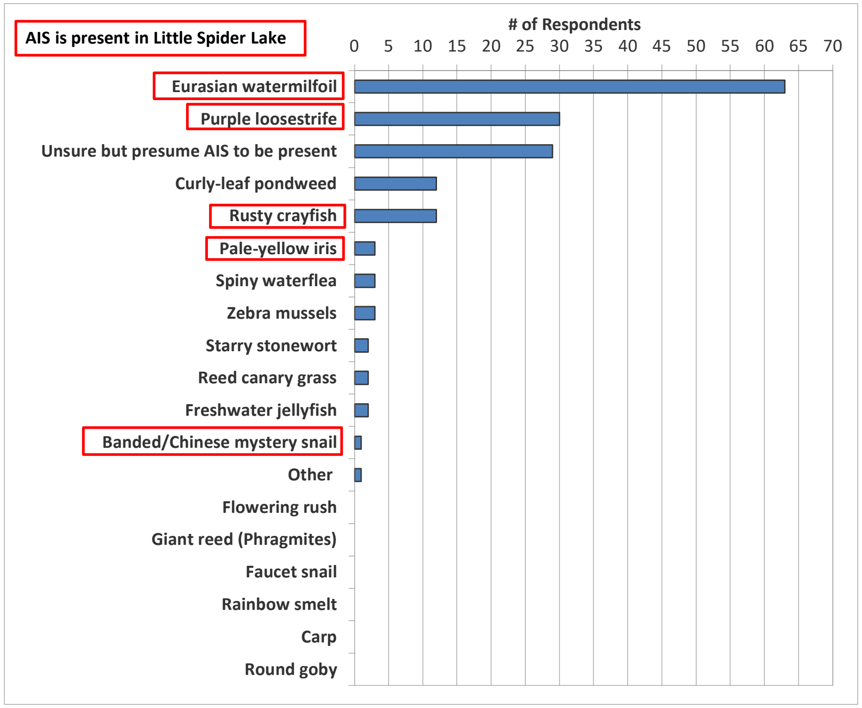
Number	"Other" responses
1	?
2	In recent years
3	Don’t like the clear cutting that seems to be occurring
4	slightly over developed
5	Depends on location.

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

Answer Options	Response Percent	Response Count
Yes	98%	81
No	2%	2
	answered question	**83**
	skipped question	**1**

26. Which aquatic invasive species do you believe are present in or immediately around Little Spider Lake?

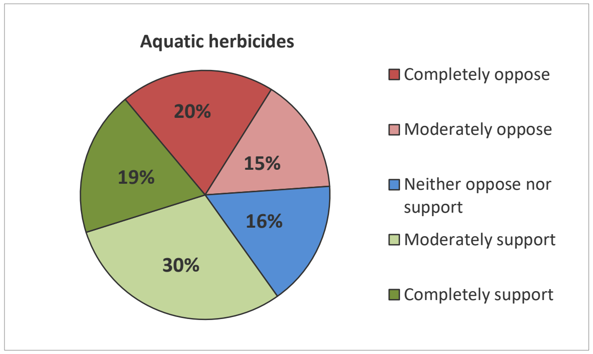
Answer Options	Response Percent	Response Count
Eurasian watermilfoil	83%	63
Purple loosestrife	39%	30
Unsure but presume AIS to be present	38%	29
Curly-leaf pondweed	16%	12
Rusty crayfish	16%	12
Pale-yellow iris	4%	3
Spiny waterflea	4%	3
Zebra mussels	4%	3
Starry stonewort	3%	2
Reed canary grass	3%	2
Freshwater jellyfish	3%	2
Banded/Chinese mystery snail	1%	1
Other	1%	1
Flowering rush	0%	0
Giant reed (Phragmites)	0%	0
Faucet snail	0%	0
Rainbow smelt	0%	0
Carp	0%	0
Round goby	0%	0
	answered question	76
	skipped question	8

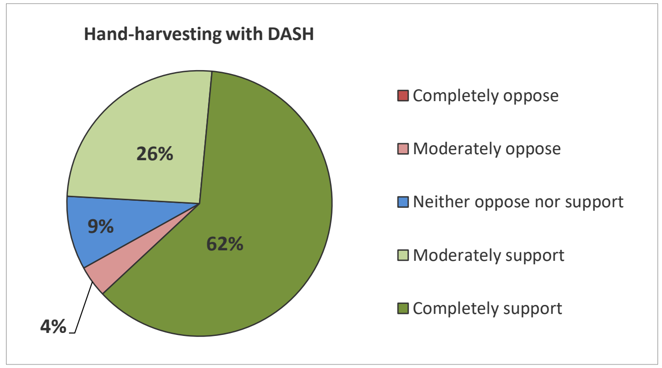


Number	"Other" responses
1	I know there are more but I cannot name them

27. What is your level of support or opposition for future aquatic herbicide use of aquatic herbicides and hand-harvesting with DASH (Diver Assisted Suction Harvesting) to manage Eurasian watermilfoil in Little Spider Lake?

Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Response Count
Aquatic herbicides	16	12	13	24	15	80
Hand-harvesting with DASH	0	3	7	20	48	78
					answered question	**82**
					skipped question	**2**

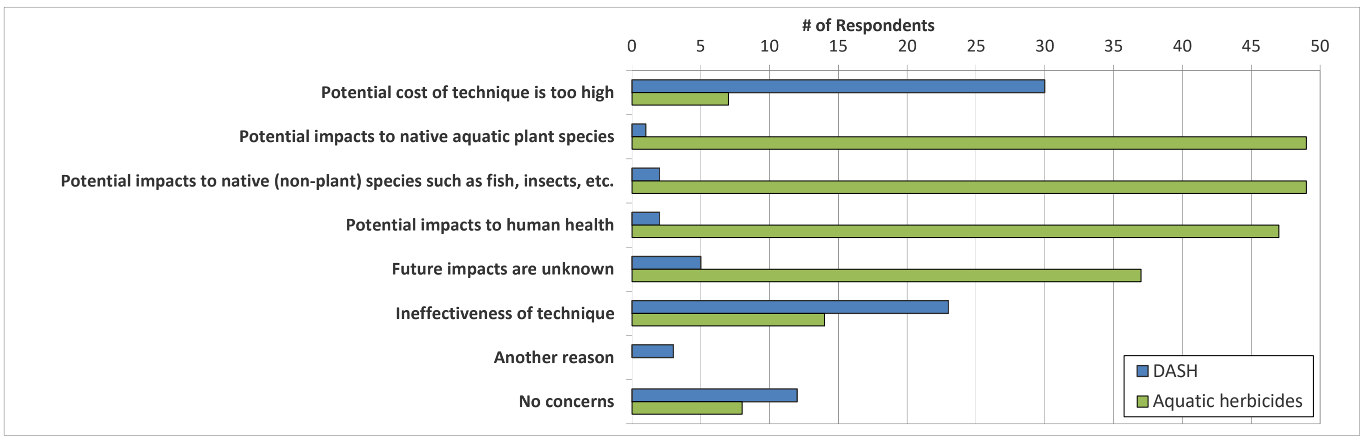




28. What concerns, if any, do you have for the future use of aquatic herbicides and/or hand-harvesting with DASH to target Eurasian watermilfoil in Little Spider Lake?

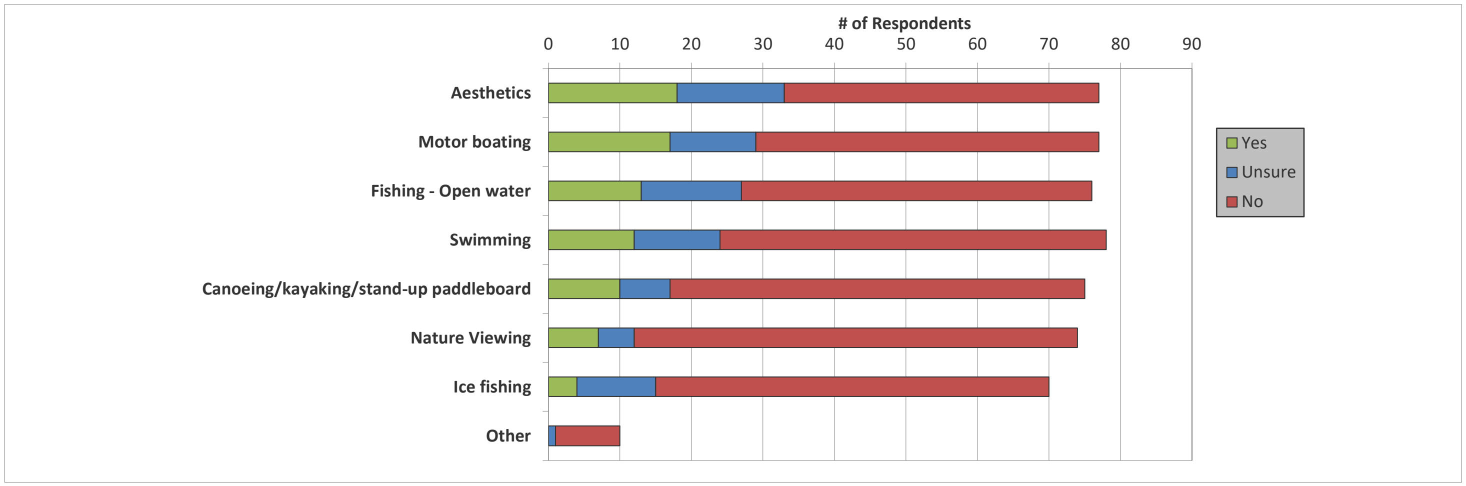
Answer Options	Aquatic herbicides	DASH	Response Count
Potential cost of technique is too high	7	30	37
Potential impacts to native aquatic plant species	49	1	50
Potential impacts to native (non-plant) species such as fish, insects, etc	49	2	51
Potential impacts to human health	47	2	49
Future impacts are unknown	37	5	42
Ineffectiveness of technique	14	23	37
Another reason	0	3	3
No concerns	8	12	20
		answered question	**73**
		skipped question	**11**

Number	"Other" responses
1	more careful management
2	Herbicides hurt fishery.
3	unsure of question
4	Would the chemicals be safe?
5	cost of either would be worth considering
6	Whatever we do….just make damn sure we know what we are doing…before we commit time and money to the project!!! I believe our lake is pretty good….and do NOT…want to cause making things worse…because someone has an unproven agenda…
7	Concern with DASH is the propagating of invasive weeds to other areas of the lake
8	Potential to spread AIS to other areas of the lake.



29. Has the Eurasian watermilfoil population ever had a negative impact on your enjoyment of Little Spider Lake?

Answer Options	No	Unsure	Yes	Response Count
Aesthetics	44	15	18	78
Motor boating	48	12	17	76
Fishing - Open water	49	14	13	70
Swimming	54	12	12	77
Canoeing/kayaking/stand-up paddleboard	58	7	10	75
Nature Viewing	62	5	7	74
Ice fishing	55	11	4	77
Other	9	1	0	10
			answered question	80
			skipped question	4



Number	"Other" responses
1	Makes me anxious when I'm on the water. Am I doing something to compound the problem?

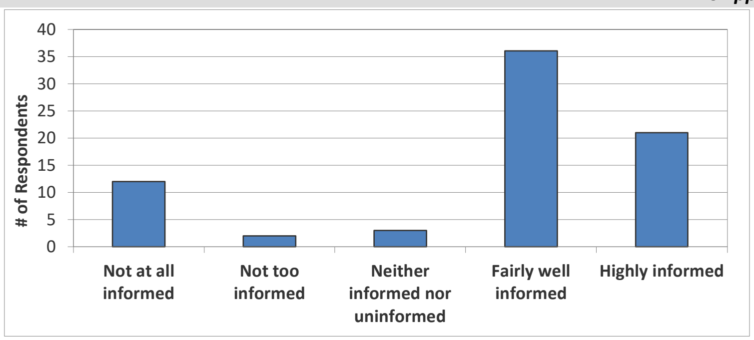
Little Spider Lake Association (LSLA)

30. What is your membership status with the LSLA?

Answer Options	Response Percent	Response Count
Current member	90%	73
Former member	2%	2
Never been a member	7%	6
	answered question	**81**
	skipped question	**3**

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

Answer Options	Not at all informed	Not too informed	Neither informed nor uninformed	Fairly well informed	Highly informed	Response Count
	12	2	3	36	21	74
					answered question	**74**
					skipped question	**10**



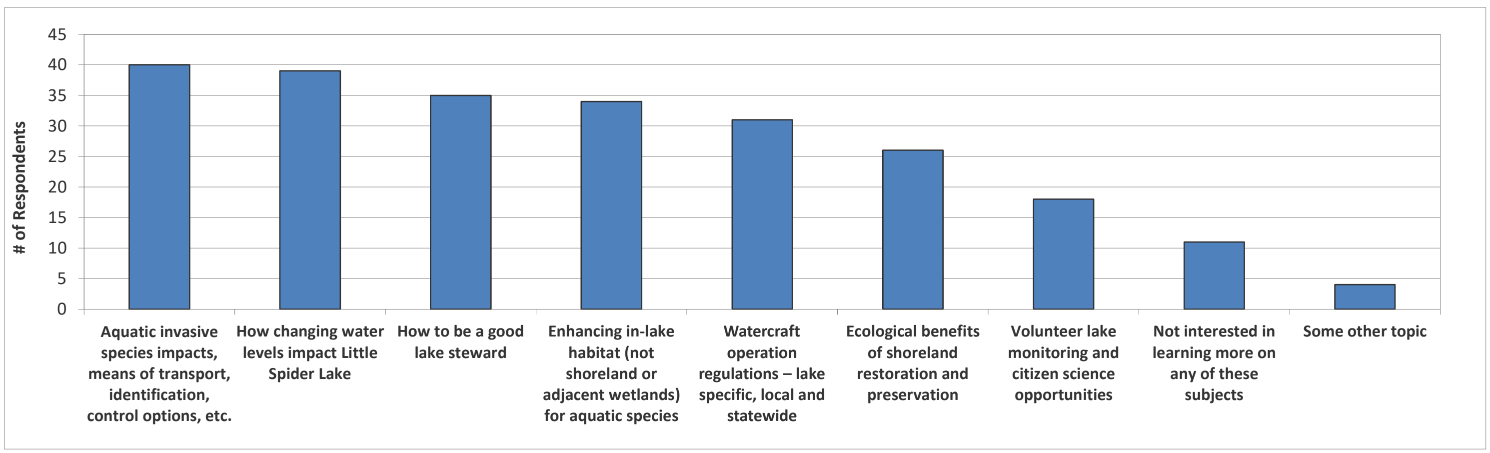
32. Would you support expanding LSLA membership to include residences within ½ mile of Little Spider Lake to increase annual dues contributions?

Answer Options	Response Percent	Response Count
Yes	58%	44
No	42%	32
	answered question	**76**
	skipped question	**8**

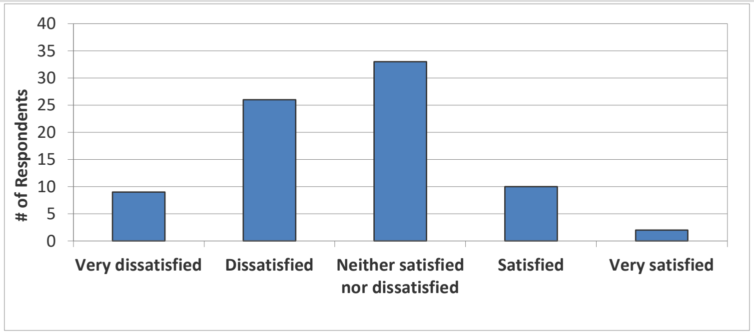
33. Stakeholder education is an important component of every lake management planning effort. Which of these subjects would you like to learn more about?

Answer Options	Response Percent	Response Count
Aquatic invasive species impacts, means of transport, identification, control options, etc	52%	40
How changing water levels impact Little Spider Lake	51%	39
How to be a good lake steward	45%	35
Enhancing in-lake habitat (not shoreland or adjacent wetlands) for aquatic species	44%	34
Watercraft operation regulations – lake specific, local and statewide	40%	31
Ecological benefits of shoreland restoration and preservation	34%	26
Volunteer lake monitoring and citizen science opportunities	23%	18
Not interested in learning more on any of these subjects	14%	11
Some other topic	5%	4
	answered question	77
	skipped question	7

Number	Other
1	Would love to offer safe boating lessons for all LSLA members, their guests, any renters of said porperties,and anyone who uses the ramp, needing to pre-qualify for ramp usage, to have a LSLA safe boating permit sticker posted on their windshield to prove they are a safe boater. Way too many boaters come to LS Lake and don't know the first thing about boater safety and shoreline wake control laws.
2	Impact of fertilizers, impact of pumping water from lake for personal use
3	Having information available online to read as time allows is good enough for us
4	Fishing controls to help the fishery to rebound, mature and develop, such controls as catch and release only for a limited season.



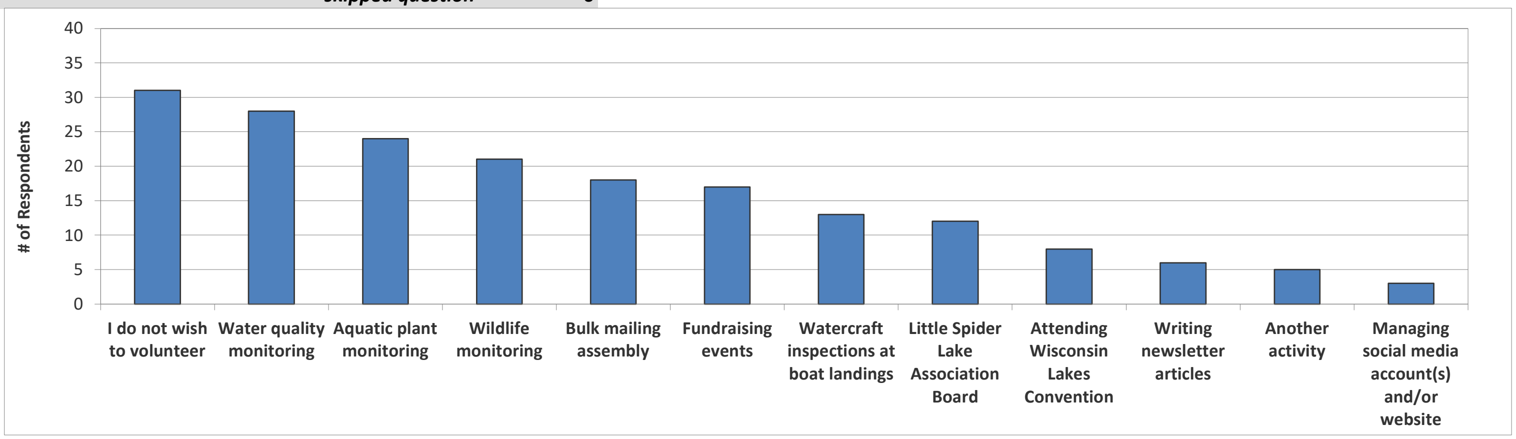
34. How satisfied are you that non-riparian visitors to the lake adequately respect lake ecology when engaged in recreational activity? E.g.: boating etiquette, clean boats, abiding by fishing regulations, etc.						
Answer Options	**Very dissatisfied**	**Dissatisfied**	**Neither satisfied nor dissatisfied**	**Satisfied**	**Very satisfied**	**Response Count**
	9	26	33	10	2	80
					answered question	**80**
					skipped question	**4**



35. The effective management of Little Spider Lake will require the cooperative efforts of numerous volunteers. Please select the activities you would be willing to participate in if the Little Spider Lake requires additional assistance.

Answer Options	Response Percent	Response Count
I do not wish to volunteer	40%	31
Water quality monitoring	36%	28
Aquatic plant monitoring	31%	24
Wildlife monitoring	27%	21
Bulk mailing assembly	23%	18
Fundraising events	22%	17
Watercraft inspections at boat landings	17%	13
Little Spider Lake Association Board	15%	12
Attending Wisconsin Lakes Convention	10%	8
Writing newsletter articles	8%	6
Another activity	6%	5
Managing social media account(s) and/or wet	4%	3
	answered question	**78**
	skipped question	**6**

Number	Another Activity
1	Boater Education, only if all those who launch a boat are included, i.e., non-stakeholders/riparians who use the ramp free of charge but do not donate to the safety, upkeep, or beautification of the lake.
2	Get rid of some of the bluegill population
3	Social gatherings
4	Lake clean up day
5	Insufficient time at the lake to be a helpful volunteer



36. Please feel free to provide written comments concerning Little Spider Lake, its current and/or historic condition and its management.

Answer Options	Response Count
	37
answered question	**37**
skipped question	**47**

Number	Category	Response Text
1	Wake boats/ Shoreline erosion	High-speed boating close to shore by water skiers, wake boats and jet skis is a major concern due to large wakes eroding the shoreline and the impact on aquatic plants under the water surface.
2		Boat/motor size limits, DNR activity on the lake, Collaboration with other lake association, Installation of shoreline satellite dishes, Process of fishery development
3		It seems there are more wave runners using excessive, repetitive speeds in the bays which tears up the lake bottom & contributes to erosion!
4		Need wake boats out of all bays.
5		I feel that ski boats over the years have gotten closer and closer to shore. I fear the wake is damaging our shorelines.
6		I have been a property owner on Little Spider Lake for 62 years. The biggest problem, I feel, and always have, is speed boats in the shallow waters and now the practice of slow speed wake boarding. That tears up the bottom and , at the very least, clouds up the water.
7		Biggest concern the damage to shorelines by excessive speeds too close to shorelines - not monitered.
8		Having been on the lake for 50 years, we don't believe that watercraft are a problem, but we are much more concerned about people clearing their lots, runoff from various sources etc., shoreline management and invasive species of all sorts. Also over all water level is falling again but can't really control that.
9		Over the last ten years the lake has seen a much larger rental population present. With this has come more and bigger boats with boaters not caring what the effect to our shorelines and bays they are causing. We are now seeing wake boats entering the picture causing damage to piers and shoreline. This lake is to small for these they destroy the weed beds and spawning grounds.
10		I am very concerned about the increase in the number of motor boats on the lake and the use of wave/wake boats. This lake is too small for fast motorized boats.
11		Have lived on lake full time 30 years. Please do not limit hours of skiing on lake. WE HAVE TO WORK! ESPECIALLY WHEN IT IS TOURIST TIME, WE HAVE TO WORK! Sometimes it means skiing in the early evening. Also, why did you not allow a slalom ski course to be set up? We never used it but could not see the harm in having it.
12	Aquatic Plants	People need to be aware that by cutting invasive milfoil plants to make their shoreline more aesthetic causes it to spread to other areas of the lake and should be made to stop or be fined by the LSLA.
13		This lake is very nice but there is great concern by users over the years that the bays and shallow areas are filling in with weeds! Turning into bogs!
14		Read an article in the Lakeland Times on August 20th about a new product to control EWM. The new product which is called Pro-cellaCor which has been approved by the EPA which attacks EWM and is highly selective treatment. Would like to know more about this product.
15	Fishing	We want the quality of the lake to be enjoyable for many years to come and to be a great fishing lake
16		Fishing is important to us. Way too many small fish and increasing. Even though there is a good population of sizeable LMB, there are way too many small ones. The pan fishing is declining due to too many stunted fish, no sizeable ones. I have caught many 38"- 44" muskies with many follows on LSL. The last 4 years has been very poor. I do see an increase in off lake pressure and guide pressure. Walleyes stay small, used to caught 18", now 12". I caught, photo, release everything but stunted fish.
17	General Comments	I'm grateful for the association members who devote time and effort for the care and betterment of Little Spider.
18		I think it is important to remember that we do not want or need the Big Brother DNR hanging out on our lake with alot of involvement. Lets keep this in house so to speak
19		I've enjoyed Little Spider Lake for many years and hope that it remains a gem in the Northwoods for years to come. Thank you to all the folks that volunteer their time and talents to keep our lake great!

20	General Comments	I am very happy with the historic condition of this lake for the past 13 years. Now that I have lived on this lake for the past 1.5 years, I am very happy with the current condition as well. That being said, I am concerned about the future condition and hope that it remains similar to the current condition for my children.
21		Grateful for the LSLA Board. Might be willing to participate more at some point (read: when retired). Would like to invest more early than play catch up later.
22		Any opportunities for participating in citizen science and/or monitoring wildlife and plants sound great!
23		Board Members do a great job in working toward keeping Little Spider Lake a beautiful lake for all to enjoy.
24		All in all it's been very pleasant. Thanks
25		none
26		Too many "rules" and biased view point of what privately owned properties "must" look like are a very real turn off and an imposition of personal preferences!
27		We are new to having property on the lake and so far happy with LSLA.
28		I appreciate the efforts to improve the lake
29		Very concerned regarding overuse of lake by visitors and renters.
30		It is a great lake.
31		?? Its columnarus desease ?? or iron bacteria in water
32		Since this is a shared family vacation home, challenging to participate but we try when asked. Comment the LSLA team for all that you do.
33		The email address greatlittlespiderlake@gmail.com doesn't seem to be monitored very well.
34		Our visits to our property on the lake are unfortunately infrequent. We appreciate the efforts of the Lake Association Officers in their concern for the quality of life on the lake.
35		To investigate or initiate additional measure to increase our revenues to fund programs to secure the future of our lake. Fund drive such as selling LSLA tee shirts or sweaters to create additional funds. Possibility of having a lock box at the boat landing for non stakeholders to donate. Just thinking out of the box.
36		Glad for your interest and information.
37		I'm curious as to what impact, if any, the lake association can have in changing attitudes and/or behaviors of lake residents and visitors since the association has no enforcement powers and posting signs at the landing has had virtually no effect on behaviors.

C

APPENDIX C

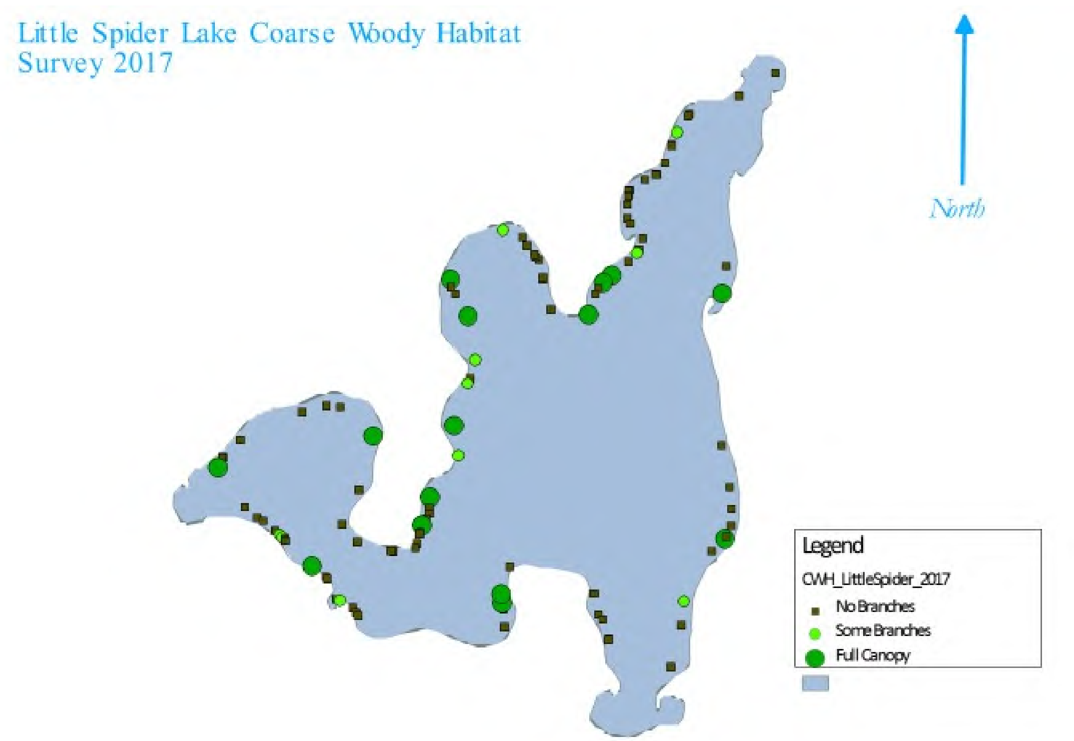
Water Quality Data

	Secchi (feet)				Chlorophyll-*a* (µg/L)				Total Phosphorus (µg/L)			
	Growing Season		Summer		Growing Season		Summer		Growing Season		Summer	
Year	Count	Mean	Count	Mean	Count	Mean	Count	Mean	Count	Mean	Count	Mean
1979	1	14.0	1	14.0	1	3.6	1	3.6				
Data Gap												
1993	4	17.4	4	17.4	0		0					
1994	11	9.9	9	10.6	4	8.2	2	6.5	6	22.0	2.0	16.0
1995	9	9.8	6	10.8	4	8.7	3	5.6	4	16.8	3.0	12.7
1996	12	9.6	8	10.0	5	4.8	3	5.1	5	14.2	3.0	13.3
1997	11	13.5	9	13.4	3	3.0	2	2.5	4	25.8	3.0	28.0
1998	13	11.3	8	11.8	4	4.2	3	3.3	5	14.8	3.0	10.3
1999	5	10.4	3	10.3	4	3.9	3	2.2	5	14.6	3.0	12.0
2000	8	11.8	5	10.6	2	0.8	2	0.8	2	13.5	2.0	13.5
2001	11	11.6	6	12.3	4	4.9	3	3.9	5	18.2	3.0	17.7
2002	12	11.9	8	12.3	7	5.7	6	5.0	9	17.2	6.0	15.5
2003	10	11.7	5	11.6	4	5.4	3	4.2	4	16.8	3.0	15.7
2004	10	11.2	5	11.6	4	8.1	3	5.9	6	17.8	3.0	18.0
2005	7	10.9	3	12.3	4	7.5	3	6.6	5	19.2	3.0	20.7
2006	5	10.8	4	11.3	5	4.9	4	4.1	5	17.8	4.0	18.3
2007	4	9.8	3	9.0	3	5.0	3	5.0	4	17.8	3.0	21.3
2008	4	10.5	4	10.5	3	5.9	3	5.9	4	19.3	4.0	19.3
2009	3	10.8	3	10.8	3	3.2	3	3.2	3	11.7	3.0	11.7
2010	2	9.3	2	9.3	2	7.1	2	7.1	2	15.0	2.0	15.0
2011	0		0		3	4.7	3	4.7	3	16.7	3.0	16.7
2012	3	11.3	3	11.3	3	2.8	2	0.4	3	14.7	2.0	16.5
2013	1	13.0	1	13.0	2	0.2	2	0.2	2	6.5	2.0	6.5
2014	0		0		3	3.9	3	3.9	3	7.6	3.0	7.6
2015	0		0		2	3.4	2	3.4	2	10.4	2.0	10.4
2016	1	11.8	0		1	3.4	0		1	15.5	0.0	
2017	4	13.8	2	14.5	3	2.5	3	2.5	3	15.8	3.0	15.8
2018	4	15.5	4	15.5	3	2.8	3	2.8	3	7.9	2.0	6.1
2019	4	17.4	3	15.7	4	3.7	3	3.8	5	8.8	3.0	6.1
2020	3	16.0	3	16.0	2	3.2	2	3.2	2	10.8	2.0	10.8
2021	4	11.9	2	16.0	3	10.3	1	3.3	3	21.5	1.0	11.4
All Years (Weighted)		11.7		12.1		5.0		4.0		16.0		14.8
SHDL Median				5.6				7.5				29.0
NLF Ecoregion Median				8.9				5.6				21.0

D

APPENDIX D

2017 WDNR Lake Assessment Report pages 9-15



Although Little Spider still has appreciable CWH, it has much less CWH than undeveloped lakes as well as comparable developed lakes. One study surveyed 16 northern lakes and found significantly more CWH in undeveloped lakes (mean of 888 logs/mile of shoreline) than in developed lakes. Within developed lakes, CWH densities were much lower at cabin-occupied sites (mean of 91 logs/mile of shoreline) than forested sites (mean of 606 logs/mile of shoreline). These losses of CWH will affect littoral communities in developed north temperate lakes for about two centuries. [11]

Abundant coarse woody habitat is important for supporting productive fisheries in lakes. A study on neighboring Little Rock Lake in 2006 revealed that after removing over 75% of the coarse woody habitat, largemouth bass consumed less fish, ate more terrestrial prey, and grew more slowly relative to the populations with more woody habitat available to them. [12] Yellow perch declined to extremely low densities as a consequence of predation due to loss of habitat with the removal of wood. In contrast, perch in the reference basin reproduced successfully in consecutive years. Relative to undeveloped

[11] Christensen, D., Herwig, B., Schindler, D., & Carpenter, S. (1996). Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. [Article]. *Ecological Applications, 6*(4), 1143-1149.
[12] Sass, G., Kitchell, J., Carpenter, S., Hrabik, T., Marburg, A., & Turner, M. (2006). Fish community and food web responses to a whole-lake removal of coarse woody habitat. [Article]. *Fisheries, 31*(7), 321-330.

lakes, largemouth bass in highly developed lakes take 1.5 growing seasons longer to reach a harvestable size. [13]

Shoreline Assessment: According to the EPA, forty-five percent of lakes sampled within the Upper Midwest show moderate to high levels of lakeshore human disturbances. Subsequently, lakes with poor lakeshore habitats in general have poor overall biological conditions and are three times more likely to be impaired.[14] Over time, an accumulation of subtle ecological changes may result in irreversible ecosystem degradation, species loss, and invasive species establishment. Characterizing riparian and in-lake habitats identifies habitats to protect, those at risk of invasive species invasions, and potential restoration sites. Furthermore, this data allows informed management decision making and provides baseline information to evaluate change over time.

Little Spider Lake consists of 135 parcels, most of which are privately owned. Lake-wide, 63% of the riparian area (35 ft. inland from shore) is covered by a shrub/herbaceous layer. Approximately 16% of the riparian area is covered by duff which is naturally occurring and does not present runoff or erosion concerns, while another 17% is manicured lawn which does pose a risk to runoff. Only 4% of the riparian area was categorized as impervious. These numbers are represented visually by parcel on maps created by WI DNR which are available online.[15] For convenience, four of these maps are displayed at the end of this document.

Since Wisconsin now allows 100 foot frontage lake parcels, and each parcel (or each 100 ft.) is allowed a 35 ft. viewing corridor through the Riparian Buffer Zone (Vilas County Shoreland Zoning Ordinance), 65% native vegetation remaining in the Riparian Buffer Zone is the lake-wide standard target. This rate does not reflect a biological or ecological best practice. Approximately 79% of the riparian area around Little Spider Lake is either native vegetation or natural duff. While these numbers represent a fairly healthy shoreline overall, individual properties still have opportunities for improvement.

One study shows that from 1937-1999 housing around lakes in northern Wisconsin has increased by 353%. Habitat loss reached up to 15% in some of these areas. The Northern Highlands exhibited the most pronounced trend of increasing disturbed land area over time, and two of the six townships studied had more than half of their land within a 1/3mile disturbance zone of houses in 1999.[16]

Little Spider Lake also has 157 docks, 45 boat lifts, and 18 swim rafts throughout its 4.6 miles of shoreline. This equals about 34 docks per mile. We see evidence that an increase in docks and other shading structures may also have an adverse impact on the

[13] Gaeta, J., Guarascio, M., Sass, G., & Carpenter, S. (2011). Lakeshore residential development and growth of largemouth bass (Micropterus salmoides): a cross-lakes comparison. [Article]. *Ecology of Freshwater Fish, 20*(1), 92-101.
[14] https://www.epa.gov/sites/production/files/2013-11/documents/nla_newlowres_fullrpt.pdf
[15] https://dnrmaps.wi.gov/H5/?viewer=Lakes_AIS_Viewer
[16] Gonzalez-Abraham, C., Radeloff, V., Hawbaker, T., Hammer, R., Stewart, S., & Clayton, M. (2007). Patterns of houses and habitat loss from 1937 to 1999 in northern Wisconsin, USA. [Article]. Ecological Applications, 17(7), 2011-2023.

sunfish population with catch rates going down where piers are shading out aquatic plant growth.[17] A study in neighboring Minnesota showed that in lakes with development similar to Little Spider, the percentage of shoreline frontage impacted by dock structures was 19.7%.[18] As docks become more complex with build-outs or boatlifts, these numbers increase.

Recommendations

Recommendations for parcel owners on Little Spider Lake are based on the goals listed at the beginning of this report:

1. gain baseline information
2. share information with the lake association
3. work with them to protect high quality areas and improve disturbed areas

- Collaborate with UW Extension Lakes on their "Healthy Lakes" projects in areas that have less than 65% native vegetation or where erosion is occurring. There are five practices, all of which can be covered under grant funding, that are designed to help property owners restore and improve your lakeshore property. These include native plantings, water diversion, rock infiltration, "fish sticks", and rain garden installation.[19]
- In addition to improving individual properties, Little Spider Lake can also maintain its coarse woody habitat by encouraging property owners to leave wood where it falls.
- Monitor for invasive species. AIS monitoring should occur every few years. This could be accomplished through volunteers and help from coordinating an AIS Monitoring program through the Vilas County Land & Water Conservation Department.
- Implement a Clean Boats Clean Waters (CBCW) campaign. Help with coordinating a campaign is available through the Vilas County Land & Water Conservation Department.

Acknowledgements

Volunteers are the source of the majority of Wisconsin's lake water quality data, and their dedication is greatly appreciated.

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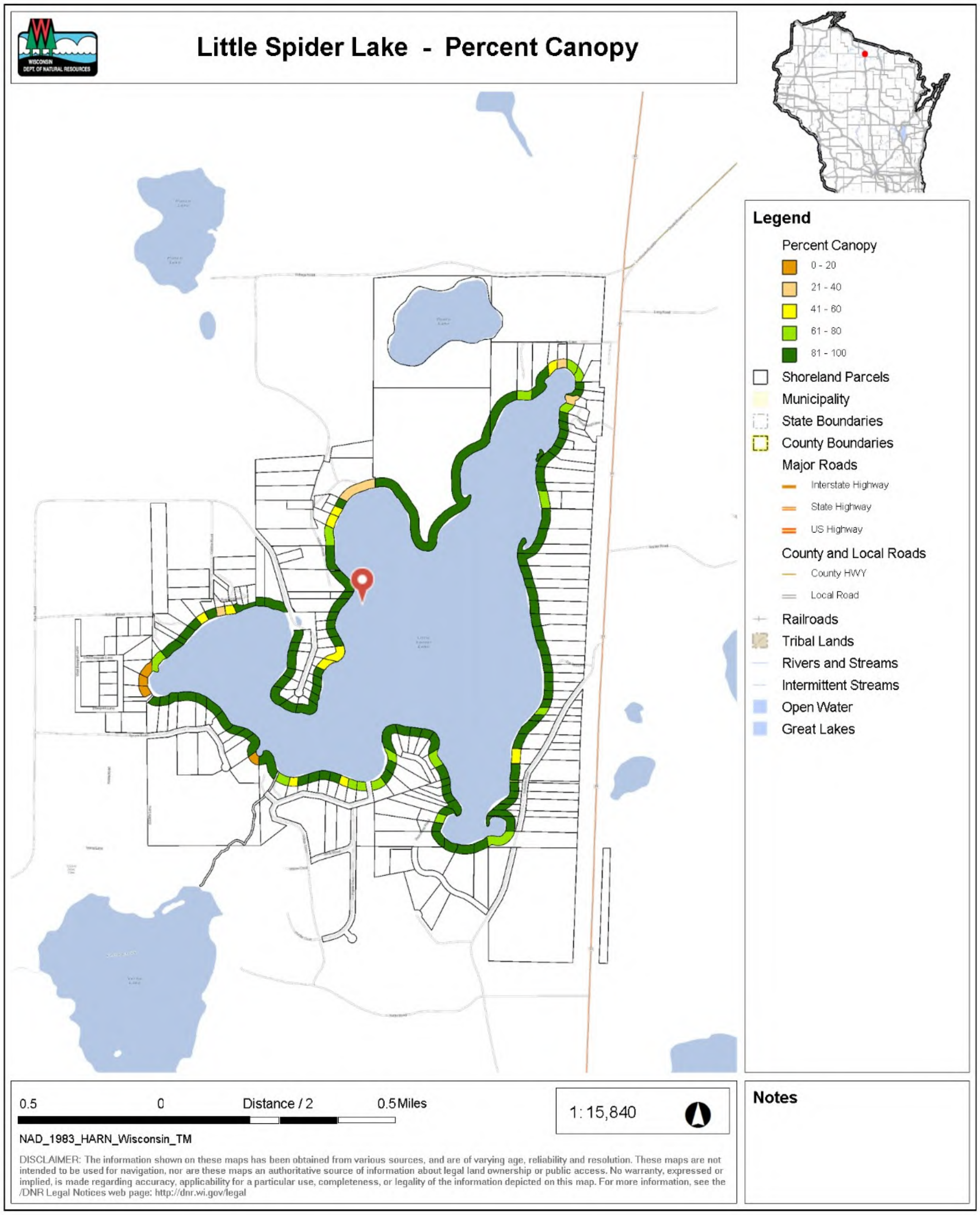
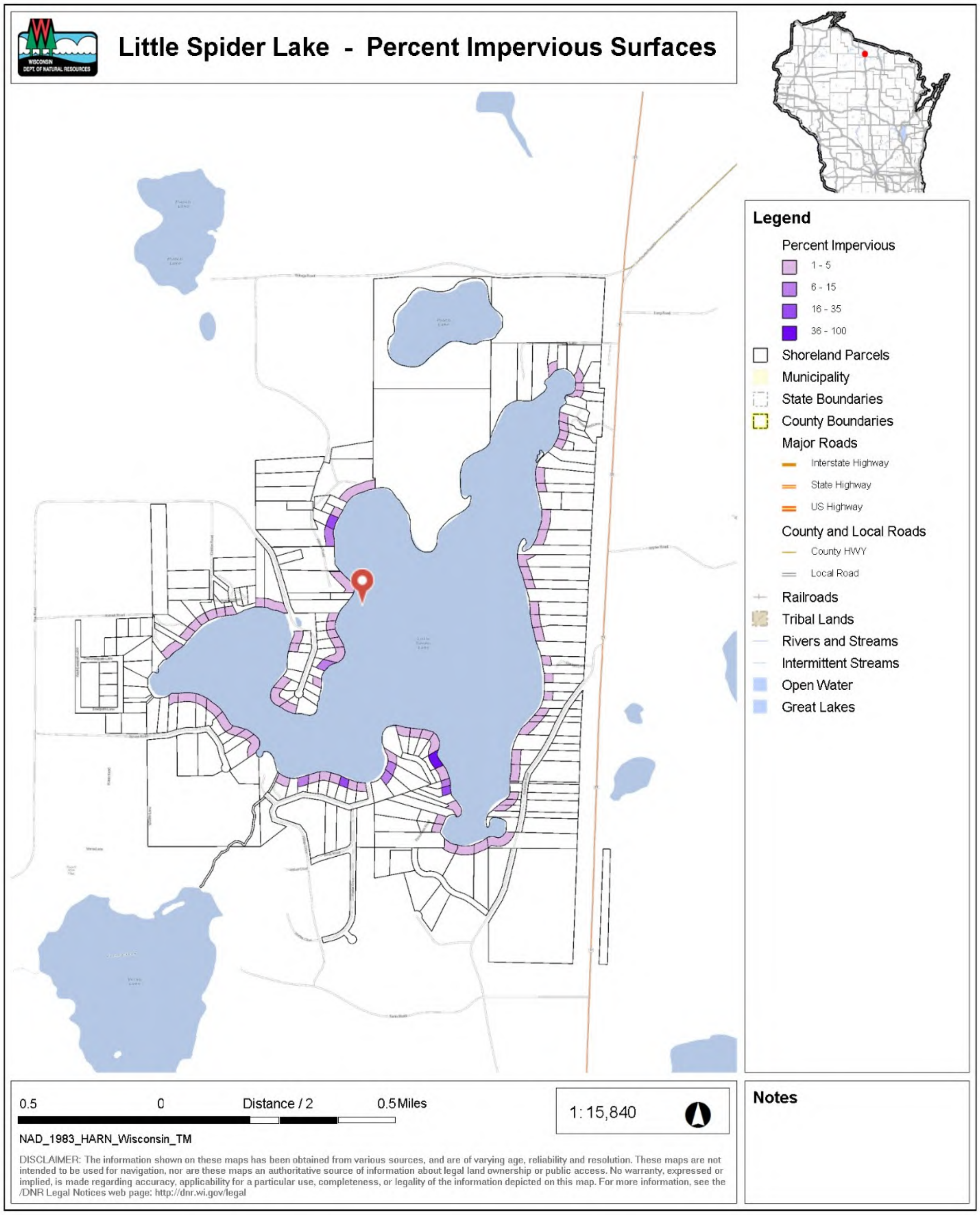
[17] https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/ecology/shoreland/background/pier_shading_jefferson_cty_final_report_2005.pdf

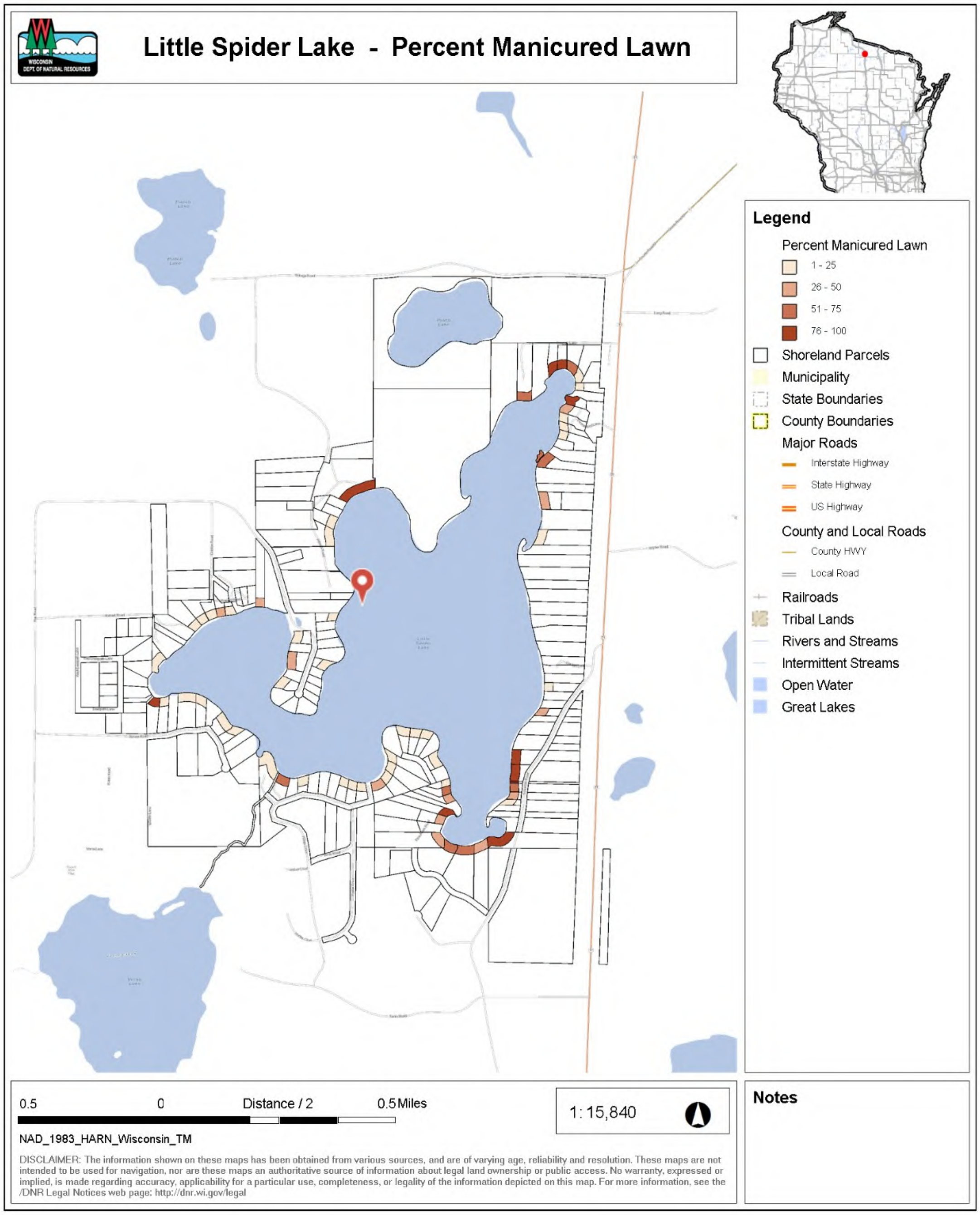
[18] Radomski, P., Bergquist, L., Duval, M., & Williquett, A. (2010). Potential Impacts of Docks on Littoral Habitats in Minnesota Lakes. [Article]. *Fisheries, 35*(10), 489-495.

[19] https://healthylakeswi.com/

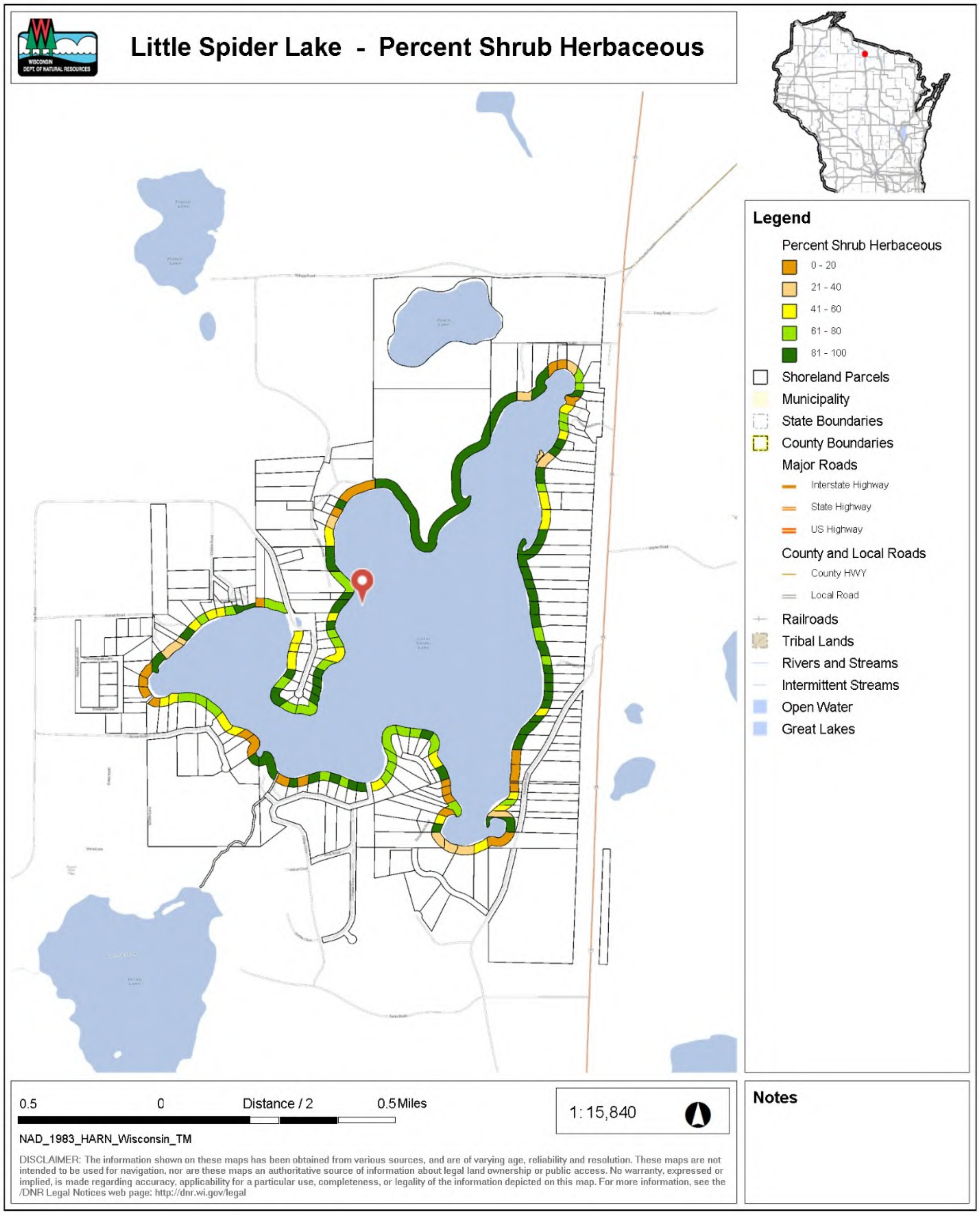


Little Spider Lake - Percent Canopy
Legend
Percent Canopy
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Shoreland Parcels
Municipality
State Boundaries
County Boundaries
Major Roads
Interstate Highway
State Highway
US Highway
County and Local Roads
County HWY
Local Road
Railroads
Tribal Lands
Rivers and Streams
Intermittent Streams
Open Water
Great Lakes
0.5
0
Distance / 2
0.5 Miles
NAD_1983_HARN_Wisconsin_TM
1: 15,840
Notes
DISCLAIMER: The information shown on these maps has been obtained from various sources, and are of varying age, reliability and resolution. These maps are not intended to be used for navigation, nor are these maps an authoritative source of information about legal land ownership or public access. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map. For more information, see the /DNR Legal Notices web page: http://dnr.wi.gov/legal


WISCONSIN DEPT OF NATURAL RESOURCES
Little Spider Lake - Percent Impervious Surfaces
Legend
Percent Impervious
1 - 5
6 - 15
16 - 35
36 - 100
Shoreland Parcels
Municipality
State Boundaries
County Boundaries
Major Roads
Interstate Highway
State Highway
US Highway
County and Local Roads
County HWY
Local Road
Railroads
Tribal Lands
Rivers and Streams
Intermittent Streams
Open Water
Great Lakes
0.5
0
Distance / 2
0.5 Miles
NAD_1983_HARN_Wisconsin_TM
1: 15,840
Notes
DISCLAIMER: The information shown on these maps has been obtained from various sources, and are of varying age, reliability and resolution. These maps are not intended to be used for navigation, nor are these maps an authoritative source of information about legal land ownership or public access. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map. For more information, see the /DNR Legal Notices web page: http://dnr.wi.gov/legal



Little Spider Lake - Percent Manicured Lawn
WISCONSIN DEPT OF NATURAL RESOURCES
Legend
Percent Manicured Lawn
1 - 25
26 - 50
51 - 75
76 - 100
Shoreland Parcels
Municipality
State Boundaries
County Boundaries
Major Roads
Interstate Highway
State Highway
US Highway
County and Local Roads
County HWY
Local Road
Railroads
Tribal Lands
Rivers and Streams
Intermittent Streams
Open Water
Great Lakes
0.5
0
Distance / 2
0.5 Miles
1: 15,840
NAD_1983_HARN_Wisconsin_TM
DISCLAIMER: The information shown on these maps has been obtained from various sources, and are of varying age, reliability and resolution. These maps are not intended to be used for navigation, nor are these maps an authoritative source of information about legal land ownership or public access. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map. For more information, see the /DNR Legal Notices web page: http://dnr.wi.gov/legal
Notes



Little Spider Lake - Percent Shrub Herbaceous
WISCONSIN DEPT OF NATURAL RESOURCES
Legend
Percent Shrub Herbaceous
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
Shoreland Parcels
Municipality
State Boundaries
County Boundaries
Major Roads
Interstate Highway
State Highway
US Highway
County and Local Roads
County HWY
Local Road
Railroads
Tribal Lands
Rivers and Streams
Intermittent Streams
Open Water
Great Lakes
0.5
0
Distance / 2
0.5 Miles
1: 15,840
NAD_1983_HARN_Wisconsin_TM
DISCLAIMER: The information shown on these maps has been obtained from various sources, and are of varying age, reliability and resolution. These maps are not intended to be used for navigation, nor are these maps an authoritative source of information about legal land ownership or public access. No warranty, expressed or implied, is made regarding accuracy, applicability for a particular use, completeness, or legality of the information depicted on this map. For more information, see the /DNR Legal Notices web page: http://dnr.wi.gov/legal
Notes

E

APPENDIX E

Point-Intercept Aquatic Macrophyte Survey Data

Little Spider Lake

	Scientific Name	Common Name	LFOO (%) 2017	LFOO (%) 2021	2017-2021 % Change	2017-2021 Direction
Dicots	*Ceratophyllum demersum*	Coontail	20.4	7.5	-63.2	▼
	Bidens beckii	Water marigold	5.1	4.6	-9.5	▼
	Nymphaea odorata	White water lily	4.7	2.9	-39.1	▼
	Myriophyllum tenellum	Dwarf watermilfoil	0.4	2.6	612.7	▲
	Myriophyllum sibiricum	Northern watermilfoil	2.6	1.2	-54.7	▼
	Ranunculus flammula	Creeping spearwort	0.4	1.4	296.0	▲
	Myriophyllum spicatum	Eurasian watermilfoil	0.0	1.2		▲
	Utricularia vulgaris	Common bladderwort	1.1	0.6	-47.2	▼
	Brasenia schreberi	Watershield	0.7	0.3	-60.4	▼
	Utricularia intermedia	Flat-leaf bladderwort	1.1	0.0	-100.0	▼
	Nuphar variegata	Spatterdock	0.0	0.3		▲
	Ceratophyllum echinatum	Spiny hornwort	0.4	0.0	-100.0	▼
Non-dicots	*Potamogeton robbinsii*	Fern-leaf pondweed	62.0	43.1	-30.6	▼
	Potamogeton zosteriformis	Flat-stem pondweed	19.3	13.3	-31.3	▼
	Potamogeton berchtoldii & P. pusillus	Slender & small pondweed	11.3	15.0	32.8	▲
	Elodea canadensis	Common waterweed	13.5	11.3	-16.5	▼
	Potamogeton pusillus	Small pondweed	11.3	7.8	-31.0	▼
	Potamogeton berchtoldii	Slender pondweed	0.0	7.2		▲
	Chara spp.	Muskgrasses	8.0	3.8	-53.2	▼
	Potamogeton amplifolius	Large-leaf pondweed	6.9	3.5	-50.0	▼
	Potamogeton gramineus	Variable-leaf pondweed	4.4	4.3	-1.0	▼
	Eleocharis acicularis	Needle spikerush	2.6	1.7	-32.1	▼
	Najas flexilis	Slender naiad	1.5	2.0	38.6	▲
	Nitella spp.	Stoneworts	0.7	1.7	137.6	▲
	Vallisneria americana	Wild celery	0.7	1.4	98.0	▲
	Juncus pelocarpus	Brown-fruited rush	0.4	1.2	216.8	▲
	Potamogeton friesii	Fries' pondweed	0.4	0.9	137.6	▲
	Heteranthera dubia	Water stargrass	1.1	0.3	-73.6	▼
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	0.0	0.6		▲
	Gratiola aurea	Golden pert	0.0	0.6		▲
	Elatine minima	Waterwort	0.0	0.6		▲
	Schoenoplectus tabernaemontani	Softstem bulrush	0.4	0.3	-20.8	▼
	Potamogeton natans	Floating-leaf pondweed	1.1	0.0	-100.0	▼
	Isoetes spp.	Quillwort spp.	0.4	0.3	-20.8	▼
	Sparganium emersum var. acaule	Short-stemmed bur-reed	0.0	0.3		▲
	Potamogeton spirillus	Spiral-fruited pondweed	0.0	0.3		▲
	Potamogeton foliosus	Leafy pondweed	0.0	0.3		▲
	Fissidens spp. & Fontinalis spp.	Aquatic Moss	0.0	0.3		▲
	Sagittaria sp.	Arrowhead sp.	0.4	0.0	-100.0	▼
	Sparganium androcladum	Shining bur-reed	0.4	0.0	-100.0	▼
	Sagittaria rigida	Stiff arrowhead	0.4	0.0	-100.0	▼
	Eleocharis palustris	Creeping spikerush	0.4	0.0	-100.0	▼

▲ or ▼ = Change Statistically Valid (Chi-square; α = 0.05)
▲ or ▼ = Change Not Statistically Valid (Chi-square; α = 0.05)

F

APPENDIX F

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)**

chemical curtains or adjuvants (weighting or sticking agents) may also help to maintain adequate CET, however more research is needed in this area.

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

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

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

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

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

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

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

Diquat

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

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

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

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

Toxicology

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

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

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

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

Species Susceptibility

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

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

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

Flumioxazin

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

Species Susceptibility

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

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

Carfentrazone-ethyl

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

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

Species Susceptibility

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

S.3.3.2. Submersed, Relatively Slow-Acting Herbicides

2,4-D

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

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

<u>Toxicology</u>

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

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

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

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

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

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

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

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

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

Species Susceptibility

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

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

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

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

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

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

Fluridone

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

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

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

Toxicology

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

Species Susceptibility

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

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

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

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

Endothall

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

Dipotassium salt formulations

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

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

Dimethylalkylamine salt formulations

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

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

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.

<u>Species Susceptibility</u>

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

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

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

Florpyrauxifen-benzyl

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

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

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

Species Susceptibility

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

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

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

S.3.3.3. Emergent and Wetland Herbicides

Glyphosate

Registration and Formulations

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

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

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

Species Susceptibility

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

Imazapyr

Registration and Formulations

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

Mode of Action and Degradation

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

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

Toxicology

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

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

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

Species Susceptibility

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

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

S.3.3.4. Herbicides Used for Submersed and Emergent Plants

Triclopyr

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

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

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

Species susceptibility

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

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

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

Penoxsulam

Registration and Formulations

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

Mode of Action and Degradation

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

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

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

Toxicology

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

Species Susceptibility

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

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

S.3.4. Physical Removal Techniques

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

S.3.4.1. Manual and Mechanical Cutting

Manual and Mechanical Cutting

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

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

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

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

<u>Ecological Impacts of Manual and Mechanical Cutting</u>

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).

<u>Ecological Impacts of Benthic Barriers</u>

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

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

S.3.4.4. Dredging

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

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

<u>Ecological effects of Dredging</u>

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

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

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

S.3.4.5. Drawdown

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

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

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

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

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

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

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

Species Susceptibility to Water-level Drawdown

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

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

S.3.5.Biological Control

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

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

Purple loosestrife beetles

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

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

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

Milfoil weevils

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

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

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

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

Grass carp – not allowed in Wisconsin

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

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