Crooked Lake Area Lakes

Oconto County, Wisconsin

2021 Aquatic Plant Studies Report

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1.0 INTRODUCTION

Crooked Lake, Oconto County, is an approximate 143-acre drainage lake with a reported maximum depth of 37 feet. Gilkey and Bass Lakes, 20 and 12 acres, respectively, are smaller drained lakes directly connected and flowing into to Crooked Lake. Gilkey Lake has a reported maximum depth of six feet and flows into Crooked Lake's northeast side, while Bass Lake has a reported maximum depth of 11 feet and is connected to Crooked Lake via a small channel on the lake's southeast side (Figure 1.0-1). Together they are all known as Crooked Lake Area Lakes. Two submergent non-native aquatic plants are known to exist in the Crooked Lake Area Lakes: Eurasian watermilfoil and curly-leaf pondweed.

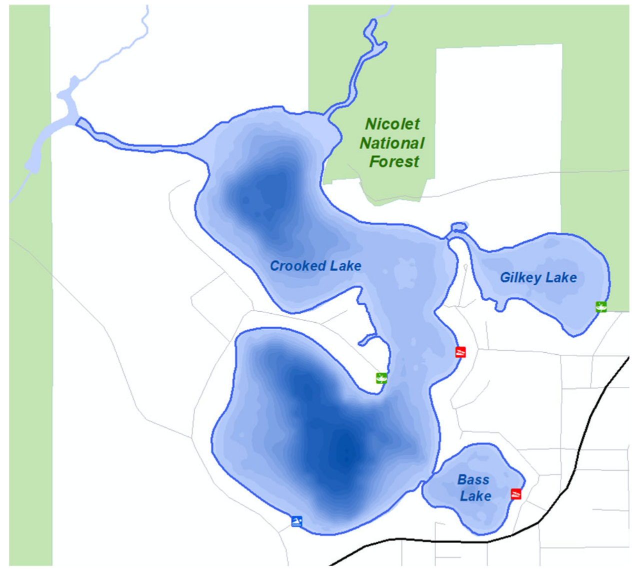


Figure 1.0-1. Crooked, Gilkey & Bass Lakes, Oconto County.

Eurasian watermilfoil (*Myriophyllum spicatum;* EWM) was first documented from Crooked, Gilkey, and Bass Lakes in 2002. Since 2003, the Crooked Lake Area Lakes Protection & Rehabilitation District (CLALPRD) has been actively managing the EWM population through strategically targeted herbicide applications and volunteer or professional based hand harvesting removal efforts.

Curly-leaf pondweed (*Potamogeton crispus,* CLP), another non-native exotic plant species commonly found in Wisconsin, was discovered within Crooked Lake in 2014. Limited hand-harvesting efforts were directed at the known CLP occurrences in 2014 through 2018 in an effort to maintain the low-density population in the lake and inhibit CLP from expanding in size or establishing elsewhere in the lake. Monitoring in 2018 indicated a modest population of CLP was present in similar locations as were documented in previous surveys.

1.1 2021 Aquatic Plant Monitoring & Management Strategy

The *Crooked Lake Area Lakes Comprehensive Management Plan* was finalized in December 2018. An important component of this process allowed the CLALPRD to objectively review their ongoing AIS management activities, outline appropriate thresholds of when specific control strategies warrant implementation, and establish measurable success criteria standards to monitor future control strategies. Within the management plan, the CLALPRD developed a goal to: *Control Existing and Prevent Further Aquatic Invasive Species Infestations within Crooked Lake Area Lakes.*

The CLALPRD has outlined a management action to *"conduct EWM population control using hand-harvesting and/or herbicide spot treatment."* Contracted hand-harvesting was employed from 2015-2018 on the Crooked Lake Area Lakes to maintain a low EWM population in the targeted areas. While seasonal EWM suppression has been observed from these efforts, the level of control is less than the CLALPRD believes justifies the high costs of this strategy.

The management plan outlines a process for which herbicide spot treatments would be directed to higher density (*dominant* or greater) EWM colonies to ensure the financial and ecological costs are commensurate with the magnitude of the population reduction. Herbicide spot treatments would also be reserved for instances where there is a higher likelihood of the treatment being effective. The CLALPRD ceased its hand-harvesting efforts and conducted a 2,4-D/endothall spot treatment in 2019. The spring 2019 herbicide treatment met control expectations for the *year-of-treatment* (2019) and *year-after-treatment* (2020).

The largest concentration of EWM mapped during the 2019 late-season mapping survey was located on the north end of Crooked Lake, approximately between the inlet and outlet. This population was too large and dense to manage with a hand harvesting strategy, as the amount of effort needed would be cost prohibitive to the CLALPRD. This site also met the trigger outlined in the management plan for considering herbicide treatment. By expanding a potential treatment to include the adjacent EWM occurrences in this area of the lake, a proposed treatment area of approximately 7.9 acres was constructed. It was anticipated than an herbicide that requires shorter concentration and exposure times (CET) would be necessary to meet control expectations in this site where water flow may impact herbicide dissipation. As discussed within the *2019 AIS Monitoring & Control Strategy Assessment Report*, the CLALPRD considered three herbicides that have been utilized in short CET scenarios, deciding on ProcellaCOR™. The upstream portion of this treatment site was treated at 5.0 product dosing units (PDU) per acre-feet, whereas the downstream portion was targeted at 3.0 PDU/acre-ft.

The efficacy of the 2020 herbicide treatment site was evaluated through qualitative and quantitative methods along with herbicide concentration monitoring following treatment. Monitoring conducted during the *year of treatment* (2020) indicated a high level of initial EWM control with no EWM detected within, or immediately adjacent to, the herbicide application area. Some native species exhibited statistically valid decreases in occurrence including white water lily, watershield, and common waterweed. Section 3.0 of this report discusses the *year-after-treatment* (2021) monitoring results from this site in an effort to understand if longer term EWM control or impacts to native species extended into the following year after the treatment occurred.

While curly-leaf pondweed (CLP) can cause great ecological and recreational impacts on some lakes, the CLP population can remain low on other lakes and does not cause these impacts. Following serval years of hand-harvesting, the CLALPRD opted to discontinue CLP management for a few years and then evaluate the population of this species. After a period of no management or monitoring in 2019 and 2021, the CLALPRD scheduled a June early season AIS survey in 2021. This survey will be valuable in understanding whether CLP has expanded into new areas around the Crooked Lake system and whether future active management should be considered for implementation.

The WDNR generally supports conducing a whole-lake point-intercept survey at least once every five years to meet WDNR planning requirements unless large-scale aquatic plant management is taking place and more frequent monitoring is requested for the specifically targeted areas. The CLALPRD committed to conducting whole-lake point-intercept surveys on all three lakes in 2021.

Aquatic plant management and monitoring activities for 2021 included an early-summer curly-leaf pondweed mapping survey, whole lake point intercept surveys, a sub-set point-intercept survey within the 2020 ProcellaCOR™ treatment site, and a late-summer EWM mapping survey. The results of all management and monitoring activities are summarized in the subsequent sections.

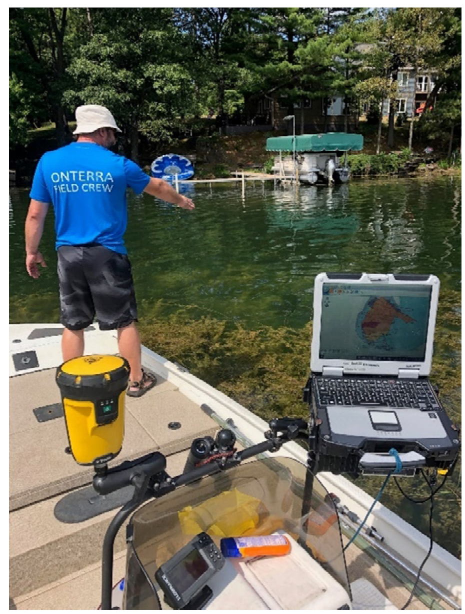
2.0 PRIMER ON AQUATIC PLANT DATA ANALYSIS & METHODOLOGY

It is important to note that three types of surveys are discussed in the subsequent materials: 1) whole lake point-intercept survey 2) sub-sample point-intercept survey and 3) EWM mapping survey.

The point-intercept survey provides a standardized way to gain quantitative information about a lake's aquatic plant population through visiting predetermined locations and using a rake sampler to identify all the plants at each location. The point-intercept survey can be applied at various scales. As a part of the current project, a sub sample point-intercept survey over the spring 2020 herbicide treatment areas was conducted before and after the treatment. This form of data will be discussed in Section 4.0.

The point-intercept survey is most commonly applied at the whole-lake scale. According to the *Crooked Lake Areas Lakes Comprehensive Management Plan (December 2018)*, whole-lake point-intercept surveys would be completed at 3-5-year intervals. The whole-lake point-intercept survey has been conducted on the Crooked Lake Area Lakes in 2011 and 2016. This project included a whole-lake point-intercept survey in 2021 consistent with the 5-year interval between surveys (Section 3.0).

While the point-intercept survey is a valuable tool to understand the overall plant population of a lake, it does not offer a full account (census) of where a particular species exists in the lake. During the EWM mapping survey, the entire littoral area of the lake is surveyed through visual observations from the boat (Photography 2.0-1). Field crews supplemented the visual survey by deploying a submersible camera along with periodically doing rake tows. The EWM population is mapped using sub-meter GPS technology by using either 1) point-based or 2) area-based methodologies. Large colonies >40 feet in diameter are mapped using polygons (areas) and are qualitatively attributed a density rating based upon a five-tiered scale from *highly scattered* to *surface matting*. Point-based techniques were applied to AIS locations that were considered as *small plant colonies* (<40 feet in diameter), *clumps of plants*, or *single or few plants*.



Photograph 2.0-1. EWM mapping survey on Big Hills Lake, Waushara County. Photo credit Onterra.

Overall, each survey has its strengths and weaknesses, which is why both are utilized in different ways as part of this project. A whole-lake point-intercept survey, sub-sample point-intercept survey within a 2020 herbicide management site, and CLP and EWM mapping surveys occurred in 2021 on Crooked Lake which are discussed within the subsequent sections of this report.

Aquatic Plants Primer

Native aquatic plants are an important element in every healthy aquatic ecosystem, providing food and habitat to wildlife, improving water quality, and stabilizing bottom sediments. Because most aquatic plants are rooted in place and are unable to relocate in wake of environmental alterations, they are often the first community to indicate that changes may be occurring within the system. Aquatic plant communities can respond in a variety of ways; there may be increases or declines in the occurrences of some species, or a complete loss. Or, certain growth forms, such as emergent and floating-leaf communities may disappear from certain areas of the waterbody. With periodic monitoring and proper analysis, these changes are relatively easy to detect and provide relevant information for making management decisions.

The point-intercept method as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) have been conducted on the Crooked Lake Area Lakes in 2011, 2016, and 2021. Table 2.0-1 displays the point-intercept survey spacing and total number of sampling points for each of the waterbodies. At each point-intercept location within the *littoral zone*, information regarding the depth, substrate type (soft sediment, sand, or rock), and the plant species sampled along with their relative abundance on the sampling rake was recorded.

Table 2.0-1. Crooked Lake Area Lakes point-intercept resolutions.

Lake	Distance Between Sampling Points (meters)	Number of Sampling Locations
Crooked	40	403
Gilkey	30	89
Bass	30	59

A pole-mounted rake was used to collect the plant samples, depth, and sediment information at point locations of 15 feet or less. A rake head tied to a rope (rope rake) was used at sites greater than 15 feet. Depth information was collected using graduated marks on the pole of the rake (at depths < 15 ft) or using an onboard sonar unit (at depths > 15 feet). Also, when a rope rake was used, information regarding substrate type was not collected due to the inability of the sampler to accurately "feel" the bottom with this sampling device. At each point that is sampled the surveyor records a total rake fullness (TRF) value ranging from 0-3 as a somewhat subjective indication of plant biomass (Figure 2.0-1). The point-intercept survey produces a great deal of information about a lake's aquatic vegetation and overall health. These data are analyzed and presented in numerous ways; each is discussed in more detail the following section.

Figure 2.0-1. Total rake fullness (TRF) ratings.

Species List

The species list is simply a list of all of the aquatic plant species, both native and non-native, that were located during the surveys completed in the Crooked Lake Area Lakes in the 2021 point-intercept surveys. The list also contains each species' scientific name, common name, status in Wisconsin, and coefficient of conservatism. The latter is discussed in more detail below. Changes in this list over time, whether it is differences in total species present, gains and losses of individual species, or changes in growth forms that are present, can be an early indicator of changes in the ecosystem.

Frequency of Occurrence

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

Frequency of occurrence describes how often a certain aquatic plant species is found within a lake. Obviously, all of the plants cannot be counted in a lake, so samples are collected from pre-determined areas. In the case of the whole-lake point-intercept surveys that have been completed; plant samples were collected from plots laid out on a grid that covered the lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. The occurrence of aquatic plant species is displayed as the *littoral frequency of occurrence*. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are within the maximum depth of plant growth (littoral zone), and is displayed as a percentage.

Relative frequency of occurrence uses the littoral frequency for occurrence for each species compared to the sum of the littoral frequency of occurrence from all species. These values are presented in percentages and if all of the values were added up, they would equal 100%. For example, if water lily had a relative frequency of 0.1 and we described that value as a percentage, it would mean that water lily made up 10% of the population.

Floristic Quality Assessment

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

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

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

The Crooked Lake Area Lakes falls within the Northern Lakes and Forests (NLF) *ecoregion* (Figure 2.0-2), and the floristic quality of its aquatic plant community will be compared to other lakes within this ecoregion as well as the entire State of Wisconsin. Ecoregions are areas related by similar climate, physiography, hydrology, vegetation and wildlife potential. Comparing ecosystems within the same ecoregion is sounder than comparing systems within manmade boundaries such as counties, towns, or states. Ecoregional and state-wide medians were calculated from whole-lake point-intercept surveys conducted on 392 lakes throughout Wisconsin by Onterra and WDNR ecologists.

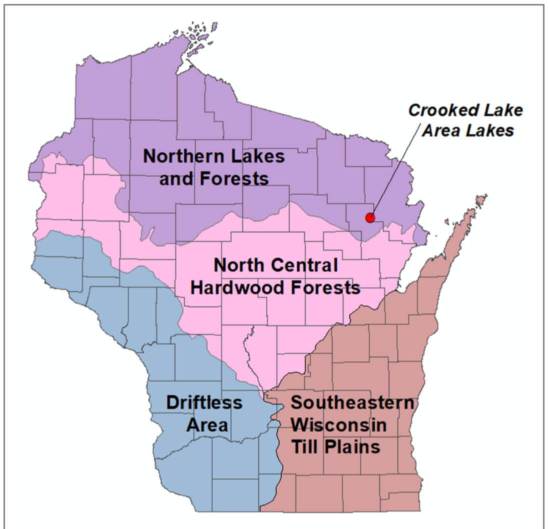


Figure 2.0-2. Location of Crooked Lake Area Lakes within the ecoregions of Wisconsin. After Nichols 1999.

Species Diversity

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

An aquatic system with high species diversity is more stable than a system with a low diversity. This is analogous to a diverse financial portfolio in that a diverse aquatic plant community can withstand environmental fluctuations much like a diverse portfolio can handle economic fluctuations. Some managers believe a lake with a diverse plant community is also better suited to compete against exotic infestations than a lake with a lower diversity. However, in a recent study of 1,100 Minnesota lakes, researchers concluded that more diverse communities were not more resistant or resilient to invaders (Muthukrishnan et al. 2018).

The diversity of a lake's aquatic plant community is determined using the Simpson's Diversity Index (1-D):

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

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

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from the Crooked Lake Area Lakes is compared to data collected by Onterra and the WDNR Science Services on 212 lakes within the Northern Lakes and Forests (lakes only, does not include flowages) Ecoregion and on 392 lakes throughout Wisconsin.

3.0 2021 WHOLE-LAKE POINT INTERCEPT SURVEY RESULTS

3.1 Entire System (Crooked Lake Area Lakes)

Whole-lake point-intercept surveys have been completed on the Crooked Lake Area Lakes in 2011, 2016, and 2021. An additional year of point-intercept surveys occurred on Bass Lake in 2014 as an aspect of whole-lake treatment monitoring. This report will highlight the 2021 point-intercept survey results from each of the waterbodies in the system and will integrate comparisons to the previous surveys throughout the section (Table 3.1-1).

Table 3.1-1. Aquatic plant species located in 2021 point-intercept surveys in the Crooked Lake Area Lakes.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2021 Crooked	2021 Gilkey	2021 Bass
Emergent	*Comarum palustre*	Marsh cinquefoil	8	I		
	Dulichium arundinaceum	Three-way sedge	9	I	I	
	Eleocharis robbinsii	Robbins' spikerush	10	X	X	
	Iris spp. (sterile)	Iris spp. (sterile)	N/A		I	
	Pontederia cordata	Pickerelweed	9	X	I	I
	Schoenoplectus acutus	Hardstem bulrush	5	I		
	Schoenoplectus tabernaemontani	Softstem bulrush	4	X	I	
	Typha spp.	Cattail spp.	N/A	I	I	I
FL	*Brasenia schreberi*	Watershield	7	X	X	X
	Nuphar variegata	Spatterdock	6	X	X	X
	Nymphaea odorata	White water lily	6	X	X	X
	Sparganium fluctuans	Floating-leaf bur-reed	10	I		
Submergent	*Chara spp.*	Muskgrasses	7	X	X	X
	Elodea canadensis	Common waterweed	3	X	X	X
	Isoetes spp.	Quillwort spp.	8	X		
	Myriophyllum spicatum	Eurasian watermilfoil	N/A	I	X	X
	Myriophyllum tenellum	Dwarf watermilfoil	10	I	I	
	Najas flexilis	Slender naiad	6	X	X	X
	Najas gracillima	Northern naiad	7	X		
	Najas guadalupensis	Southern naiad	7	X	X	X
	Nitella spp.	Stoneworts	7	X		
	Potamogeton amplifolius	Large-leaf pondweed	7	X	X	X
	Potamogeton crispus	Curly-leaf pondweed	N/A	X		
	Potamogeton gramineus	Variable-leaf pondweed	7	X	X	X
	Potamogeton illinoensis	Illinois pondweed	6	X	X	X
	Potamogeton natans	Floating-leaf pondweed	5	X	X	
	Potamogeton praelongus	White-stem pondweed	8	X	X	X
	Potamogeton pusillus	Small pondweed	7	X		X
	Potamogeton richardsonii	Clasping-leaf pondweed	5			X
	Potamogeton robbinsii	Fern-leaf pondweed	8	X	X	X
	Potamogeton strictifolius	Stiff pondweed	8	X	I	X
	Potamogeton zosteriformis	Flat-stem pondweed	6	X	X	X
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	N/A	X		
	Stuckenia pectinata	Sago pondweed	3	X		
	Utricularia gibba	Creeping bladderwort	9	X		X
	Utricularia intermedia	Flat-leaf bladderwort	9	X		I
	Utricularia minor	Small bladderwort	10	I		
	Utricularia vulgaris	Common bladderwort	7	X		
	Vallisneria americana	Wild celery	6	X		
S/E	*Eleocharis acicularis*	Needle spikerush	5	X	I	
	Juncus pelocarpus	Brown-fruited rush	8	X		
	Sagittaria cristata	Crested arrowhead	9		X	
	Schoenoplectus subterminalis	Water bulrush	9	X	X	X

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

A total of 43 aquatic plant species were identified in the Crooked Lake Area Lakes during the 2021 point-intercept survey. Of these 43 species, two non-native species were documented during the 2021 survey including Eurasian watermilfoil and curly-leaf pondweed. More information about these invasive species can be found in Sections 4.0 and 5.0.

Two native aquatic plant species located during these studies, northern naiad and robbins' spikerush (Photograph 3.1-1), are listed as special concern by the WDNR Natural Heritage Inventory Program due to "a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors" (Wisconsin Natural Heritage Program 2021). Both of these plants require high-quality conditions to survive, and their presence in Crooked Lake Area Lakes is indicative of high-quality environmental conditions.

Robbins' spikerush (*Eleocharis robbinsii*)

Northern naiad (*Najas gracillima*)

Photograph 3.1-1. Native plant species listed as special concern in Wisconsin. Photograph credit Onterra.

Lakes in Wisconsin vary in their morphometry, water chemistry, water clarity, substrate composition, and management, all of which influence aquatic plant community composition. Like terrestrial plants, aquatic plants vary in their preference for a particular substrate type; some species are usually only found growing in soft sediments, others only found in course substrates like sand, while some are more generalists and can be found growing in either. Lakes with varying types of substrates generally support a higher number of aquatic plant species because of the different habitat types that are available. During the whole-lake point-intercept surveys completed on the Crooked Lakes Area Lakes in 2021, substrate data were also recorded at each sampling location in one of three general categories: soft/organic sediments, sand, or rock/gravel.

The individual lakes within the chain vary somewhat in their proportion of these three substrate types. The littoral zones of Bass and Gilkey Lakes are largely comprised of soft/organic sediments (98%), while Crooked Lakes has a larger proportion of harder substrates such as sand (Figure 3.1-1). No occurrences of rock substrate were sampled in 2021.

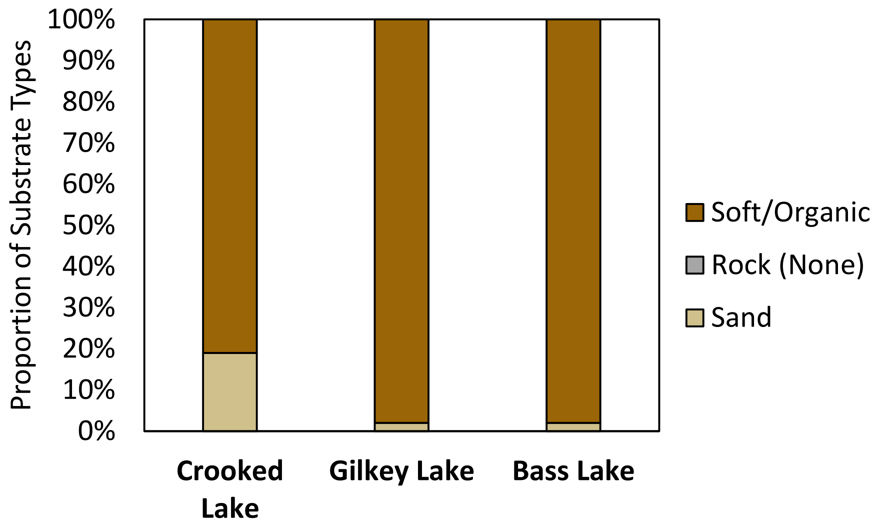


Figure 3.1-1. Crooked Lake Area Lakes proportion of substrate types. Represents proportion of substrate types in water ≤ 15 feet deep. Created using data collected during the 2021 whole-lake point-intercept surveys.

The calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. The native aquatic plant species located on the rake during the point-intercept surveys in 2021 and their conservatism values were used to calculate the FQI for each waterbody within the system.

Using the species richness and average conservatism to calculate the Floristic Quality Index for Crooked Lake Area Lakes revealed a high value for Crooked Lake (Figure 3.1-2). The FQI of Gilkey and Bass Lakes are slightly below the ecoregion median but slightly above the state median. A comparison of these metrics to previous surveys on a lake-by-lake basis are discussed below within each waterbody's individual report section.

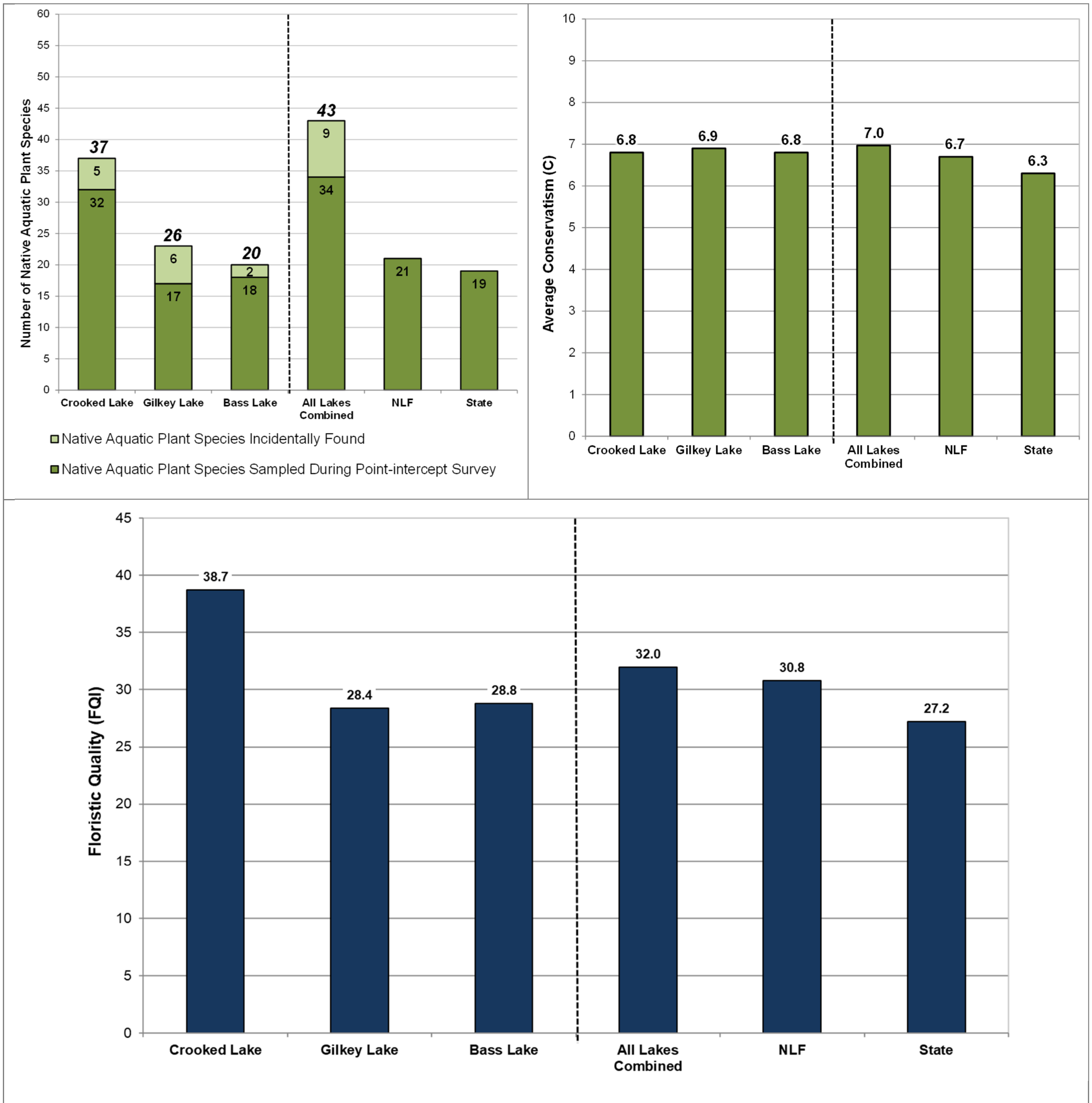


Figure 3.1-2. Species richness (upper left frame) average coefficient of conservatism (upper right frame) and floristic quality index (FQI) in the Crooked Lake Area Lakes. Created using data from 2021 point-intercept surveys.

3.2 Crooked Lake

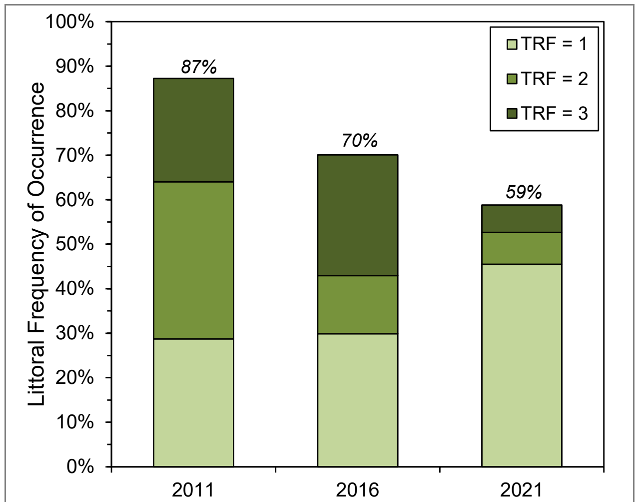


Figure 3.2-1. Total rake fullness (TRF) of Crooked Lake. Created using data from 2011-2021 point-intercept survey.

Total rake fullness (TRF) values from the 2021 point-intercept survey are displayed on Figure 3.2-1 and Figure 3.2-2. These data represent the aquatic plant biomass at each sampling location and does not differentiate between native or non-native vegetation.

The point-intercept survey data indicate that there was a decrease in the amount of sampling locations containing aquatic vegetation in 2021 compared to 2011. The overall density of aquatic vegetation at sampling points has also reduced over this time period, with most sampling locations being rated a TRF=1 in 2021 compared to higher proportions of TRF=2 and TRF=3 in prior years. Aquatic plants were found growing out to a maximum depth of 16 feet in all years, indicating that plants are becoming sparser across all depths. On most lakes, changes in overall aquatic plant abundance can be linked to decreases in water clarity.

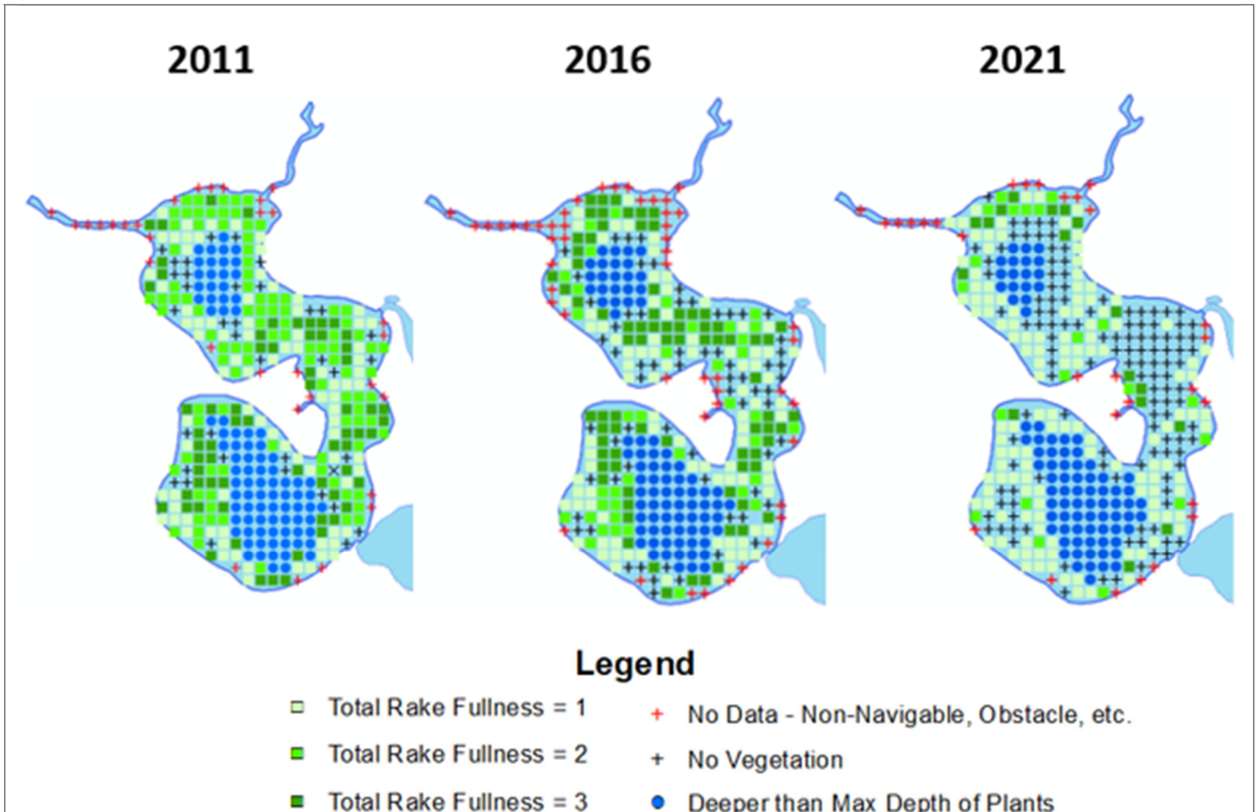


Figure 3.2-2. Crooked Lake aquatic plant distribution in 2011, 2016, and 2021. Created using data from Onterra 2011, 2016, and 2021 point-intercept surveys.

Table 3.2-1 shows the herbicide management history of the Crooked Lake Area Lakes during this timeframe, as aquatic plants can be influenced by these actions. While claims of changes in aquatic plant occurrence have been related to recent herbicide treatment strategies (2019-2020), the aquatic plant changes observed in Crooked Lake have been occurring since 2011. Since 2011, the herbicide treatments within Crooked Lake have been relatively small and likely only impacted aquatic plants within their targeted application area with the exception of the 2020 ProcellaCOR™ treatment. This herbicide likely had the potential to impact the entire northern basin of Crooked Lake. Robust aquatic plant monitoring occurred in association with this treatment and are reported on in Section 2.2

Table 3.2-1. Crooked Lake Area Lakes EWM herbicide management history (2011-2021).

	Treatment Acres	Herbicide Product	Dosing Strategy	Bass	Crooked	Gilkey
2011	3.8	2,4-D granular ester	200 lbs/acre	X	X	X
2012	14.1	2,4-D granular amine	2.5-3.0 ppm	X	X	-
2013	2.7	2,4-D granular amine	4.0 ppm	-	X	X
2014	13.3	2,4-D liquid amine	0.375 ppm ae lake-wide	X	-	-
2015	2.4	2,4-D liquid amine + endothall liquid	4.0 ppm ae + 1.5 ppm ai	-	X	-
2016	-	-	-	-	-	-
2017	-	-	-	-	-	-
2018	-	-	-	-	-	-
2019	2.0	2,4-D liquid amine + endothall liquid	1.5 ppm ae + 3.6 ppm ai	-	X	-
2020	7.9	florpyrauxifen-benzyl	5.0/3.0 PDU	-	X	-
2021	-	-	-	-	-	-

X = herbicide treatment occurred

An increase in precipitation bringing in more nutrients and staining compounds (tanic acids) can decrease water clarity in systems like the Crooked Lake Area Lakes. With the exception of 2012, Crooked Lake water clarity values have always fallen within the *excellent* category for deep headwater drainage lakes (Figure 3.2-3). The average summer water clarity from 2011 to 2021 is 9.2 feet while from 2000 to 2010 is 10.7 feet, indicating water clarity has decreased by 1.5 feet during the last decade compared to the previous.

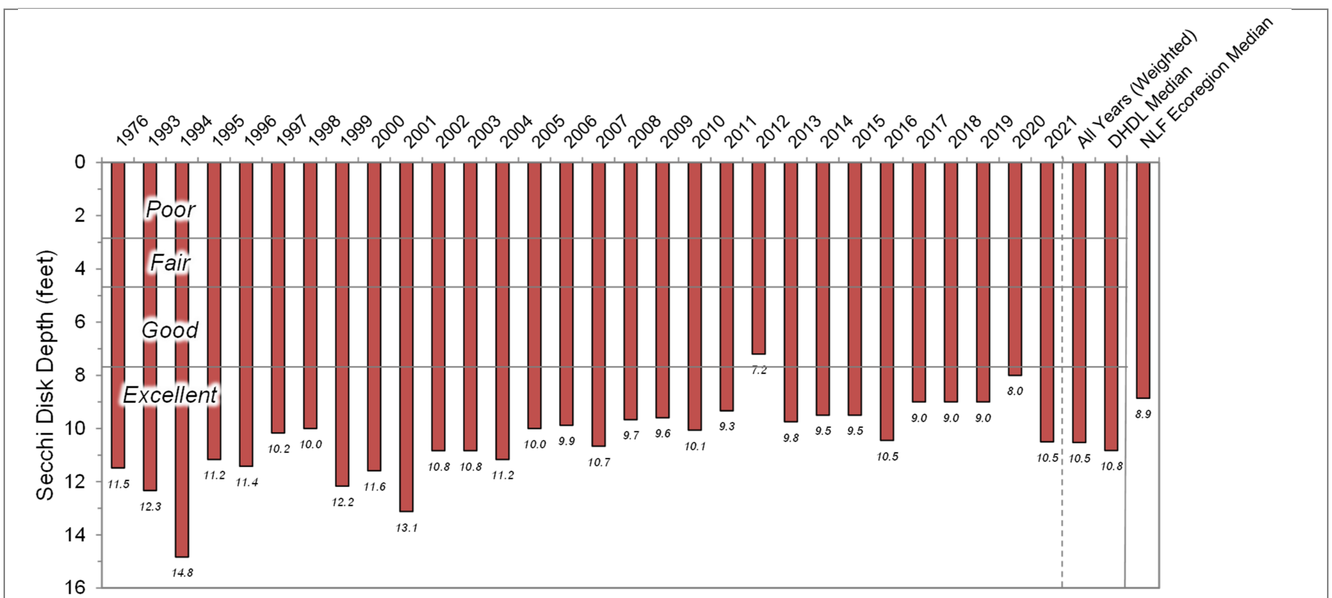


Figure 3.2-3. Crooked Lake summer average Secchi disk depths. DHDL = Deep headwater drainage Lakes, NLF = Northern Lakes and Forests Ecoregion

The magnitude nor longevity of the water clarity change has not been sufficient to impact the maximum depth of aquatic plant growth during the years of survey, as this remained constant at 16 feet in all Crooked Lake point-intercept surveys. It is possible that aquatic plant growth may have extended out deeper than 16 feet prior to 2011. Further, certain aquatic plant species have different wavelength and intensity requirements, which slight changes could impact their populations if they are growing in stressful conditions. Low growing vegetation, such as fern-leaf pondweed, would likely experience declines in this situation due to its inability to increase its water column height and take in enough sunlight. As zebra mussels become increasingly more established in Crooked Lake, water clarity increases are likely and may cause increases in aquatic plant abundance.

Figure 3.2-4 shows the eight-most abundant plant species from Crooked Lake. Fern pondweed, muskgrasses, and stoneworts are all low-growing species that provide valuable sediment stabilization and year-round habitat for aquatic life. Species growing higher in the water column, such as variable pondweed, flat-stem pondweed, and large-leaf pondweed are more often sought by fish species as habitat and refugia. Largely non-rooted species like common waterweed and southern naiad are often found growing entangled on taller vegetation and were the primary focus of previous mechanical harvesting use on the system. These data indicate that the largest changes in aquatic plant populations over this time period occurred from southern naiad, fern-leaf pondweed, flat-stem pondweed, and large-leaf pondweed.

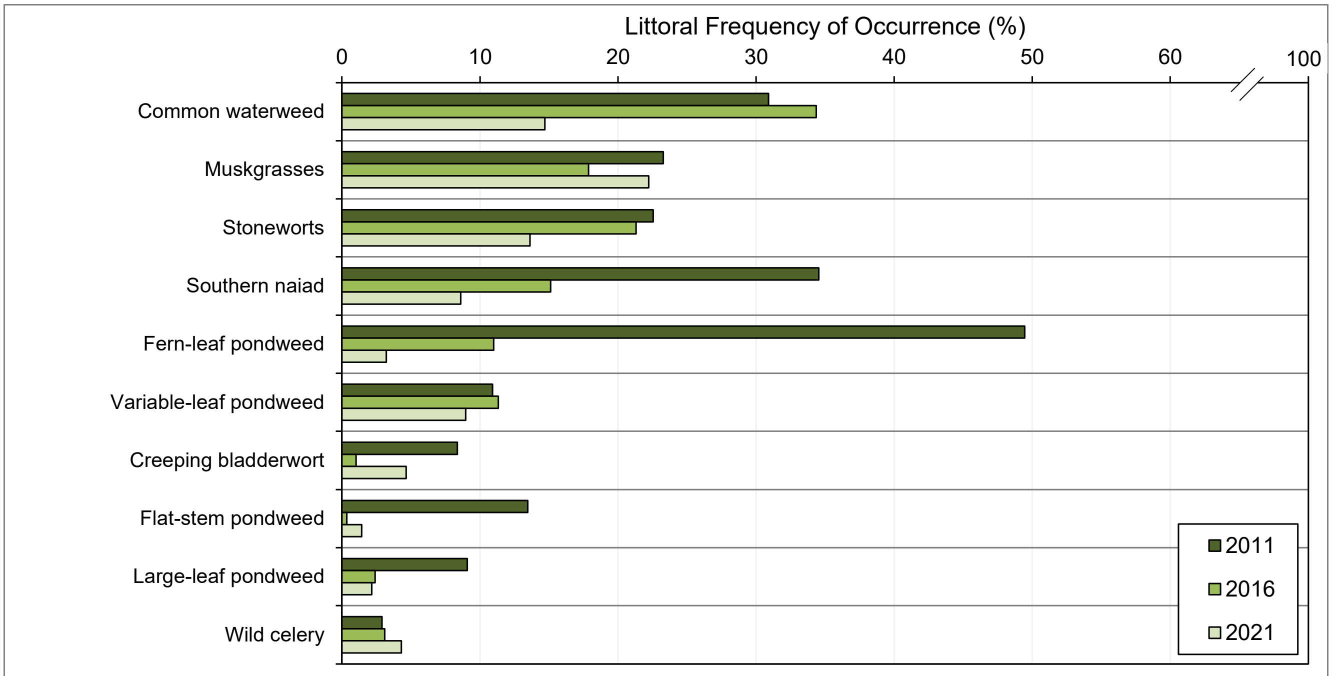


Figure 3.2-4. Littoral frequency of occurrence of most abundant plants in Crooked Lake.

A Chi-Square Test was utilized to determine if changes in the littoral occurrence between surveys are statistically valid ($\alpha = 0.05$). The littoral occurrences of all species recorded in 2011, 2016, and 2021 in Crooked Lake can be found in a table in Appendix A. Aquatic plant species of interest will be discussed below.

Muskgrasses, a group of macroalgae (non-vascular aquatic plants), was the most frequently encountered aquatic plant species in Crooked Lake in 2021 with a littoral occurrence of 22% (Figure 3.2-4). The littoral occurrence of muskgrasses in Crooked Lake has not been statistically different between the 2011 and 2016 surveys (Figure 3.2-5). Stoneworts, another group of macroalgae, are also found in Crooked Lake at similar population levels to muskgrasses. This taxonomic growing showed some population reduction between 2016 and 2021.

Muskgrasses (*Chara* spp.)

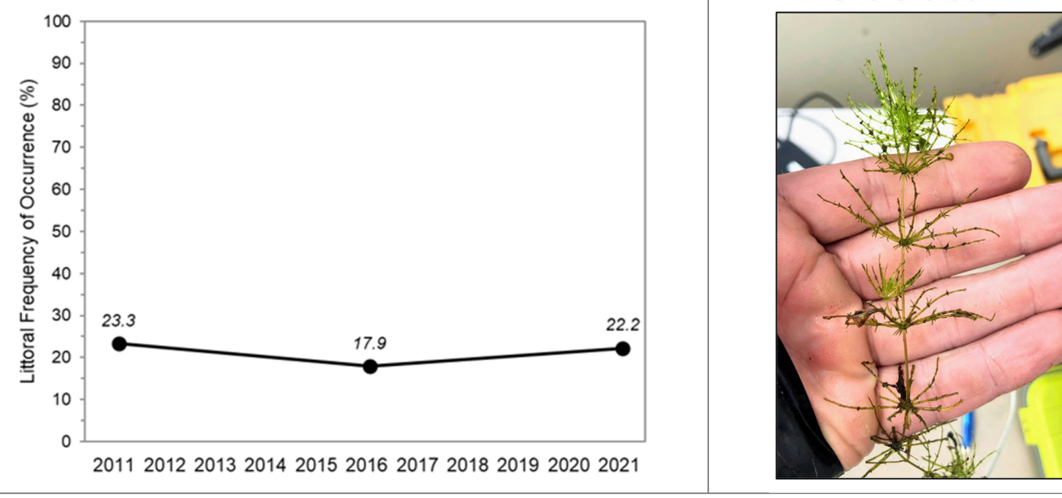


Figure 3.2-5. Littoral frequency of occurrence of Charophytes in Crooked Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square α = 0.05).

Common waterweed was the second-most frequently encountered aquatic plant in Crooked Lake in 2021 with a littoral occurrence of nearly 15% (Figure 3.2-4). Common waterweed can be found in many waterbodies across Wisconsin, obtains much of its nutrients directly from the water, and provides valuable structural habitat.

Common Waterweed (*Elodea canadensis*)

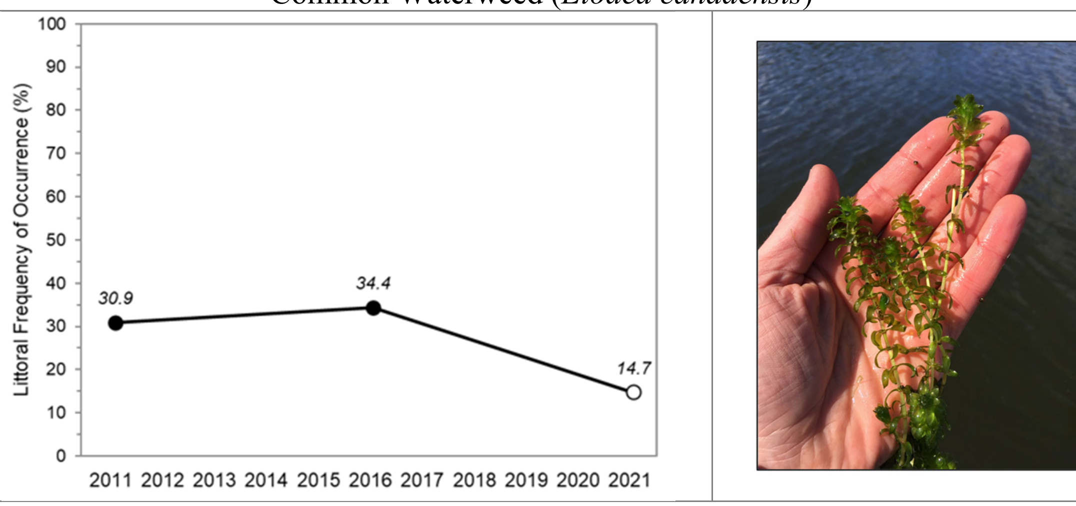


Figure 3.2-6. Littoral frequency of occurrence of common waterweed in Crooked Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square α = 0.05).

Common waterweed was the most frequently encountered species in the 2016 survey, but its occurrence has declined over this period (Figure 3.2-6). Common waterweed has declined from an occurrence of 31% in 2011, to 34% in 2016, and 15% in 2021, representing a statistically valid reduction in occurrence of 53% over this period. The declining trend in common waterweed occurrence has also been observed on other northern Wisconsin lakes over this period, indicating the decline of common waterweed in Crooked Lake is likely related to regional changes in environmental factors and not factors specifically isolated to this system.

Fern-leaf pondweed was one of the least abundant aquatic plants in Crooked Lake in 2021 with a littoral occurrence of 3% after being the most common species in 2011 (Figure 3.2-4). As its name indicates, this plant resembles a terrestrial fern frond in appearance (Figure 3.2-7) and is often a dominant species in plant communities of northern Wisconsin lakes. Fern-leaf pondweed is generally found low-growing in thick beds over soft substrates where it stabilizes bottom sediments and provides a dense network of structural habitat for aquatic wildlife.

Fern-leaf Pondweed (*Potamogeton robbinsii*)

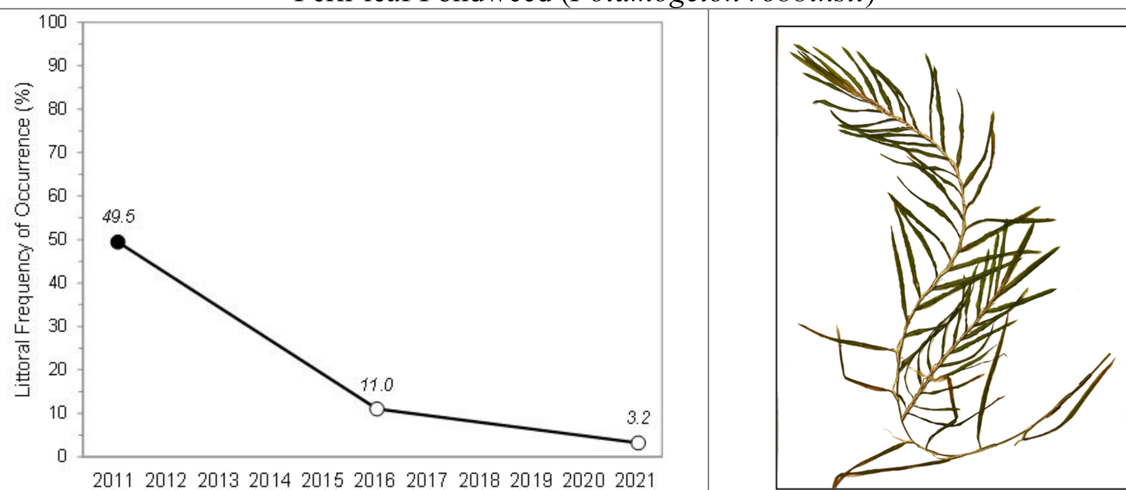


Figure 3.2-7. Littoral frequency of occurrence of fern-leaf pondweed in Crooked Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square α = 0.05).

Southern naiad, although native to North America, has in some lakes been observed exhibiting aggressive growth in recent years. While southern naiad provides shelter for smaller fish and invertebrates and is a food source for some duck species, it can dislodge from sediments and form surface mats that interfere with navigation, recreation, and aesthetics. The rapid population growth of southern naiad in some northern Wisconsin lakes has some ecologists questioning whether this species was historically present in these waterbodies or if it represents a recent introduction, likely via watercraft. The rapid decline in the southern naiad population in Crooked Lake lends some support to this theory as it aligns with the 'boom-bust concept' in invasive species ecology (Figure 3.2-8). This concept presents the idea that invasive species undergo an initial outbreak (boom phase) where their population grows rapidly before declining to a smaller population size (bust or collapse phase) (Strayer et al. 2017). Otherwise, if southern naiad is naturally occurring in Crooked Lake, some change in environmental conditions around 2011 resulted in a rapid decrease in its abundance and has maintained a lower occurrence through 2021. The ability of this species to rapidly increase and decrease in occurrence in northern Wisconsin lakes warrants further study.

Southern naiad (*Najas guadalupensis*)

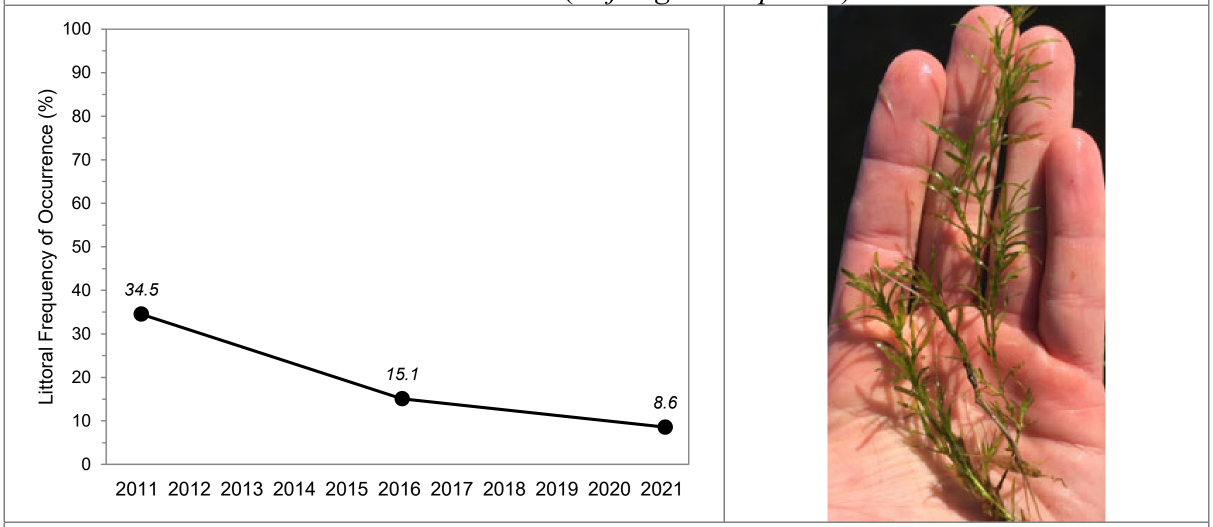


Figure 3.2-8. Littoral frequency of occurrence of fern-leaf pondweed in Crooked Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square α = 0.05).

The calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. The native aquatic plant species located on the rake during the point-intercept surveys from 2011, 2016, and 2021 and their conservatism values were used to calculate the FQI for each year (Figure 3.2-9). Native species richness, or the number of native plant species recorded on the rake, has increased over the course of the three surveys from 25 in 2011 to 32 in 2021. Species richness in 2021 exceeds both the 75th percentile for lakes in the Northern Lakes and Forests (NLF) and throughout Wisconsin.

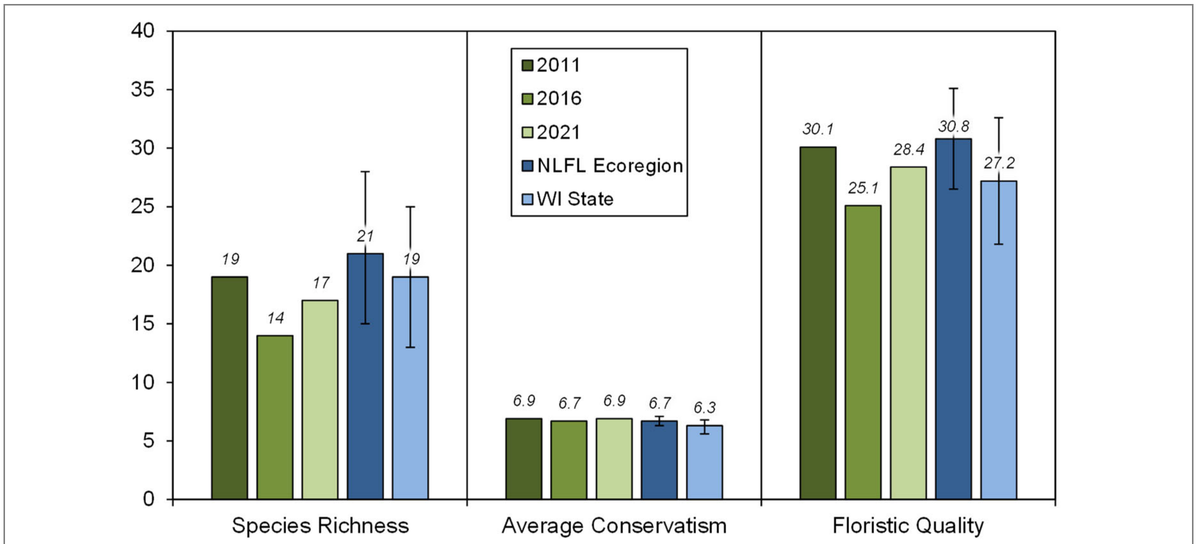


Figure 3.2-9. Crooked Lake native aquatic plant species richness, average conservationism, and floristic quality. Includes native aquatic plant species physically encountered on the rake during the point-intercept survey and does not include incidentally-located species.

Average species conservatism in Crooked Lake has remained relatively the same from 6.8 in 2011 and 2021 to 6.9 in 2016 (Figure 3.2-9). These conservatism values fall above the median values for lakes in the NLF ecoregion and the state. In other words, Crooked Lake has a higher number of environmentally sensitive aquatic plant species. Using the species richness and average conservatism to calculate the Floristic Quality Index for Crooked Lake yields high values for all years (Figure 3.2-9). Floristic quality has increased over the course of the surveys, and the value in 2021 of 38.5 exceeds the 75th percentile values for lakes in the ecoregion and the state. This analysis indicates that Crooked Lake harbors a high-quality plant community comprised of a number of species considered sensitive to environmental disturbance.

While a method for characterizing diversity values of fair, poor, etc. does not exist, lakes within the same ecoregion may be compared to provide an idea of how Crooked Lake's diversity values rank. Using data collected by Onterra, quartiles were calculated for 212 lakes within the NLFL Ecoregion (Figure 3.2-10). Using the data collected from the whole-lake point-intercept surveys, Crooked Lake's aquatic plant species diversity has fluctuated over the course of the 2011, 2016, and 2021 surveys. In 2021, Simpson's diversity was above the 75th percentile at 0.91.

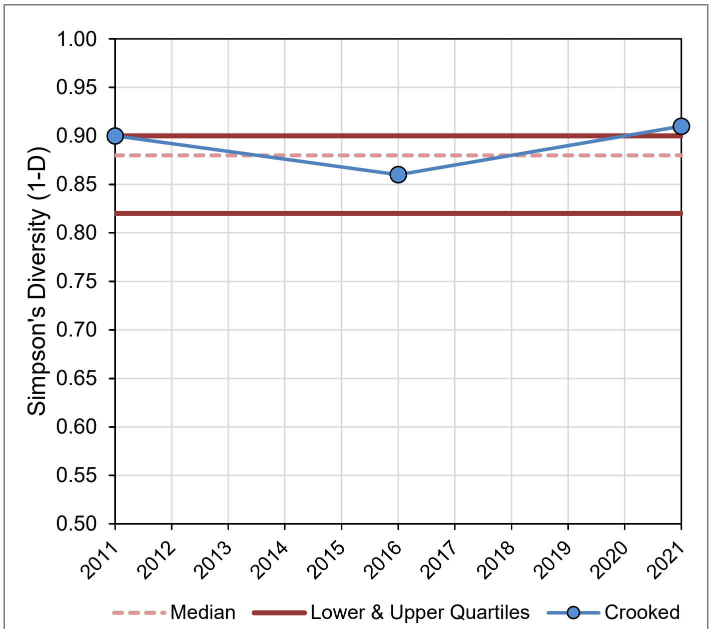


Figure 3.2-10. Crooked Lake Simpson's Diversity Index. Created using data from whole lake-lake point intercept surveys.

One way to visualize the diversity of Crooked Lake's plant community is to examine the relative frequency of occurrence of aquatic plant species (Figure 3.2-11). Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. For example, while muskgrasses was found at 22% of the littoral sampling locations in Crooked Lake in 2021 (littoral occurrence), its relative frequency of occurrence was 19%. Explained another way, if 100 plants were randomly sampled from Crooked Lake in 2021, 19 of them would have been muskgrasses, 12 common waterweed, 11 stoneworts, etc. Diversity has increased in Crooked Lake primarily due to the decline in occurrence of fern-leaf pondweed and southern naiad, which together comprised nearly 40% of the plant community in 2011. In 2021, these species comprised 11% of the community, yielding a more even distribution amongst species and higher diversity.

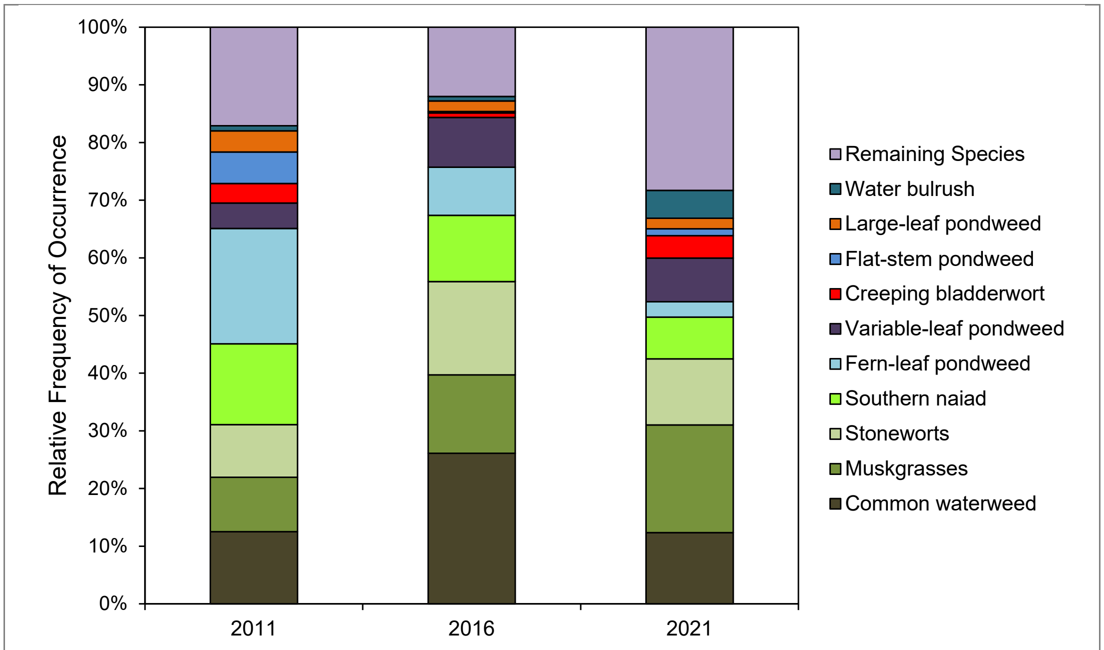


Figure 3.2-11. Relative frequency of occurrence of aquatic vegetation in Crooked Lake. Created using data from whole-lake point-intercept surveys.

3.3 Gilkey Lake

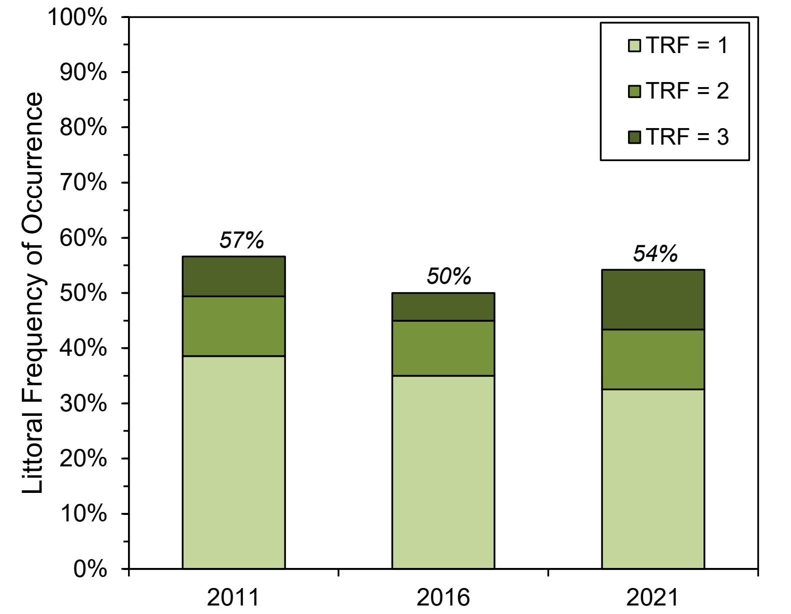


Figure 3.3-1. Total rake fullness (TRF) of Gilkey Lake. Created using data from 2011-2021 point-intercept survey.

The Gilkey Lake portion of the project area is the second largest body of the water in the system at approximately 21 acres. Total rake fullness values from the 2021 point-intercept survey are displayed on Figure 3.3-1 and Figure 3.3-2. These data represent the aquatic plant biomass at each sampling location and does not differentiate between native or non-native vegetation.

The point-intercept survey data indicate the amount of sampling locations containing aquatic vegetation in 2021 compared to 2011 has remained relatively the same. Aquatic plants were found growing out to a maximum depth of 6 feet in all years. The fluctuation in aquatic plant abundance in Crooked Lake does not seem to be occurring in Gilkey Lake.

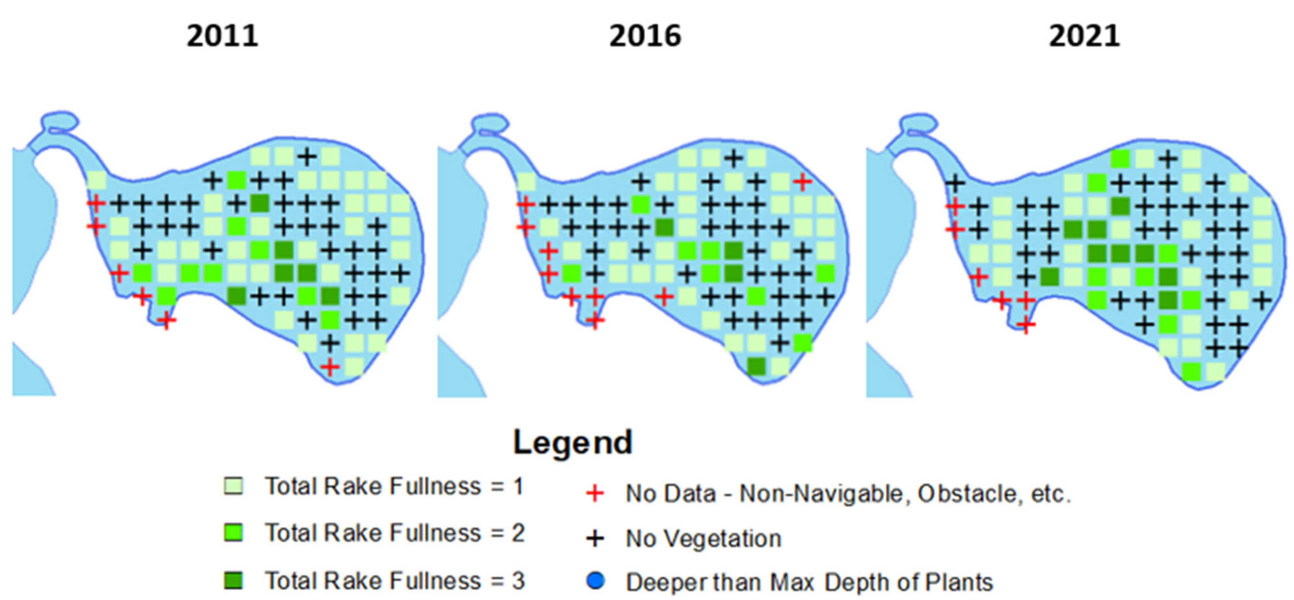


Figure 3.3-2. Gilkey Lake aquatic plant distribution in 2011, 2016, and 2021. Created using data from Onterra 2011, 2016, and 2021 point-intercept surveys.

Of the 32 species that have been recorded in Gilkey Lake since 2011, 18 were physically encountered on the rake during the 2021 point-intercept survey (Table 3.1-1). Figure 3.3-3 shows the eight-most abundant plant species from Crooked Lake. Of these 18 species, white-stem pondweed, large-leaf pondweed, white water lily, and variable-leaf pondweed were the most frequently encountered. The littoral occurrences of all species recorded in 2011, 2016, and 2021 in Crooked Lake can be found in a table in Appendix A. Aquatic plant species of interest will be discussed below.

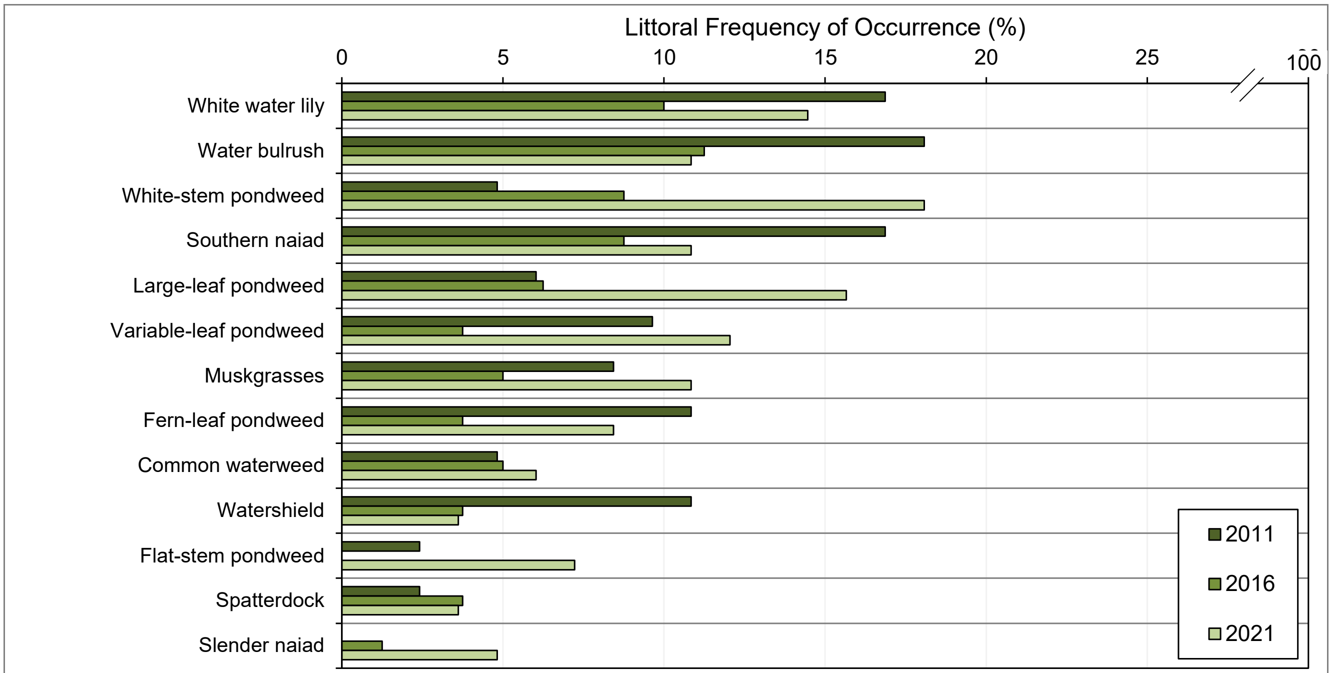


Figure 3.3-3. Littoral frequency of occurrence of most abundant plants in Gilkey Lake.

White-stem pondweed was the most frequently encountered aquatic plant species in Gilkey Lake in 2021 with a littoral occurrence of 18% (Figure 3.3-3). The fruit of white-stem pondweed are produced later in summer, which serve as a source of food for migratory waterfowl. The littoral occurrence of white-stem pondweed in Gilkey Lake has not been statistically different between the 2011 and 2021 surveys (Figure 3.3-4).

White-stem pondweed (*Potamogeton praelongus*)

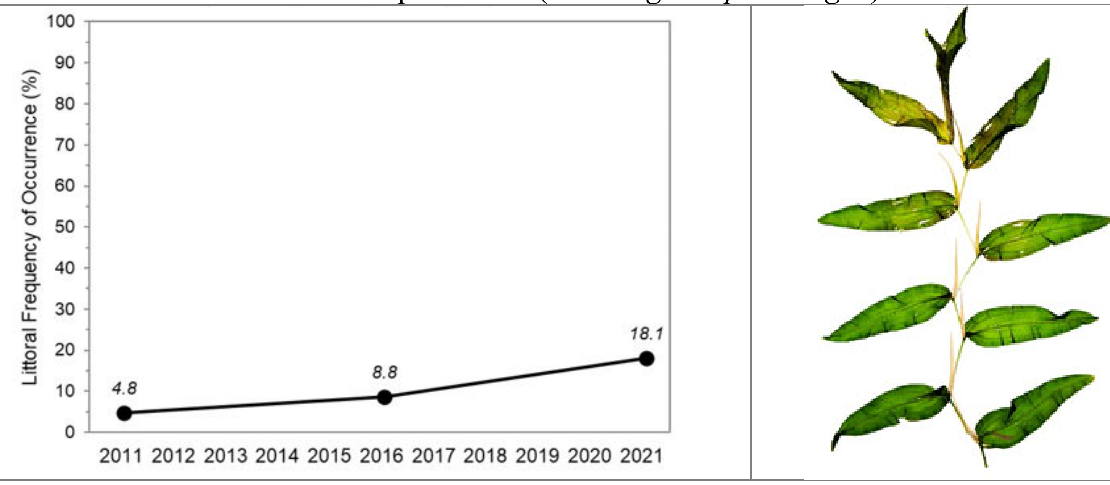


Figure 3.3-4. Littoral frequency of occurrence of white-stem pondweed in Gilkey Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square $\alpha = 0.05$).

Large-leaf pondweed was the second-most frequently encountered aquatic plant in Gilkey Lake in 2021 with a littoral occurrence of nearly 16% (Figure 3.3-3). Large-leaf pondweed can be found in many waterbodies across Wisconsin and provides valuable structural habitat for fish. Large-leaf pondweed has increased from an occurrence of 6% in 2011 and 2016, to 16% in 2021 representing a statistically valid increase in occurrence of 160% over this entire period (Figure 3.3-5).

Large-leaf pondweed (*Potamogeton amplifolius*)

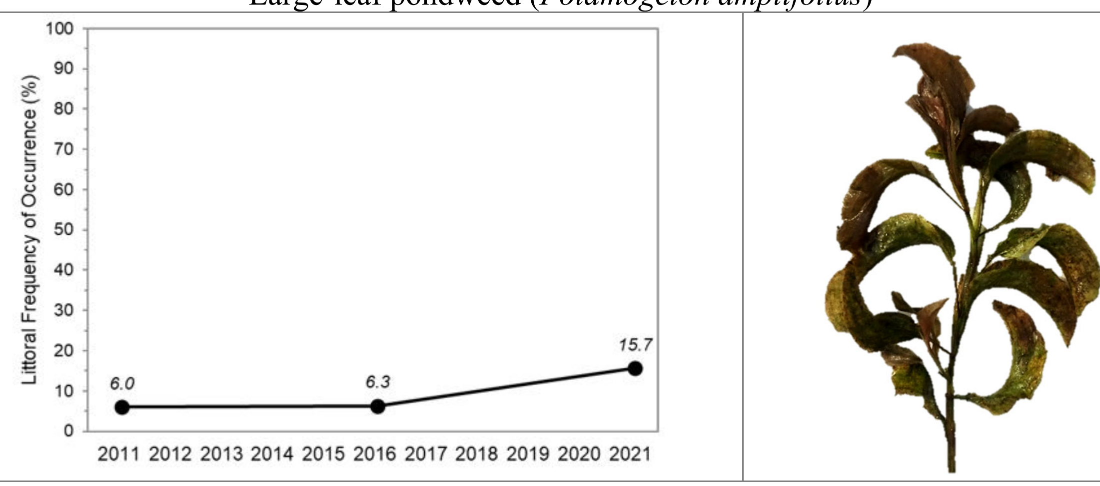


Figure 3.3-5. Littoral frequency of occurrence of large-leaf pondweed in Gilkey Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square $\alpha = 0.05$).

White water lily was the third most abundant aquatic plant in Gilkey Lake in 2021 with a littoral occurrence of 15% (Figure 3.3-3). White water lily was one of the most frequently encountered species in the 2011 survey with an occurrence of 17%, and has remained relatively the same with an occurrence of 15% in 2021 (Figure 3.3-6).

White water lily (*Nymphaea odorata*)

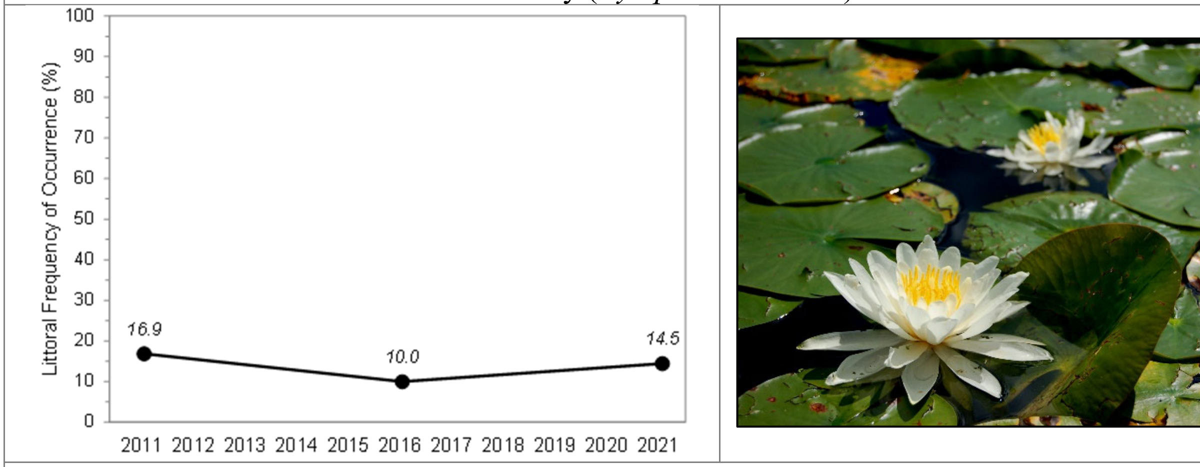


Figure 3.3-6. Littoral frequency of occurrence of white water lily in Gilkey Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square α = 0.05).

The calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. The native aquatic plant species located on the rake during the point-intercept surveys from 2011, 2016, and 2021 and their conservatism values were used to calculate the FQI for each year (Figure 3.3-7). Native species richness, or the number of native plant species recorded on the rake, has decreased over the course of the three surveys from 19 in 2011 to 17 in 2021. Species richness in 2021 is below both the 75th percentile for lakes in the Northern Lakes and Forests (NLF) and throughout Wisconsin.

Average species conservatism in Gilkey Lake has remained the same from 6.8 in 2011 and 2021 (Figure 3.3-7). These conservatism values fall at or above the median values for lakes in the NLF ecoregion and the state. In other words, Gilkey Lake has an average number of environmentally sensitive aquatic plant species. Using the species richness and average conservatism to calculate the Floristic Quality Index for Gilkey Lake yields average values for all years (Figure 3.3-7). Floristic quality has decreased slightly over the course of the surveys, and the value in 2021 of 28.4 falls between the ecoregion and the state averages. This analysis indicates that Gilkey Lake harbors an average quality plant community comprised of a number of species considered sensitive to environmental disturbance.

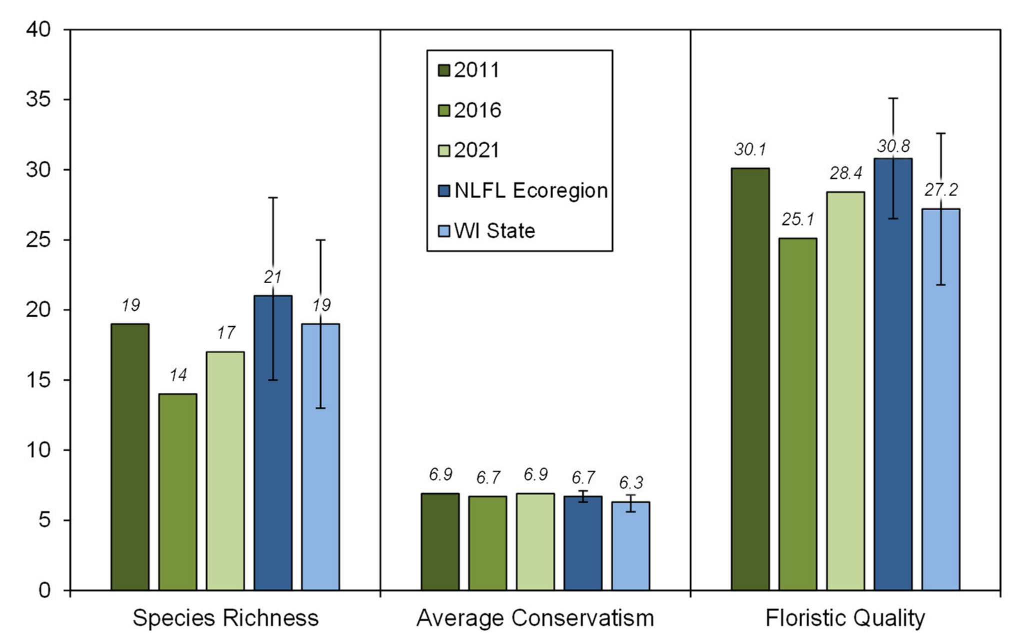


Figure 3.3-7. Gilkey Lake native aquatic plant species richness, average conservationism, and floristic quality. Includes native aquatic plant species physically encountered on the rake during the point-intercept survey and does not include incidentally-located species.

While a method for characterizing diversity values of fair, poor, etc. does not exist, lakes within the same ecoregion may be compared to provide an idea of how Gilkey Lake's diversity values rank. Using data collected by Onterra, quartiles were calculated for 212 lakes within the NLFL Ecoregion (Figure 3.3-8). Using the data collected from the whole-lake point-intercept surveys, Gilkey Lake's aquatic plant species diversity has fluctuated slightly over the course of the 2011, 2016, and 2021 surveys. In 2021, Simpson's diversity was above the 75th percentile at 0.92.

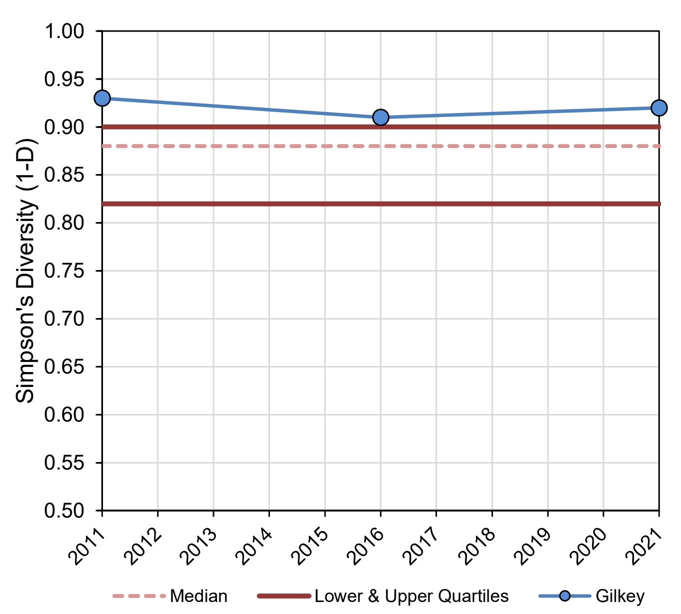


Figure 3.3-8. Gilkey Lake Simpson's Diversity Index. Created using data from whole lake-lake point intercept surveys.

One way to visualize the diversity of Gilkey Lake's plant community is to examine the relative frequency of occurrence of aquatic plant species (Figure 3.3-9). Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. For example, while white-stem pondweed was found at 18% of the littoral sampling locations in Gilkey Lake in 2021 (littoral occurrence), its relative frequency of occurrence was 13%. Explained another way, if 100 plants were randomly sampled from Gilkey Lake in 2021, 13 of them would have been white-stem pondweed, 11 large-leaf pondweed, 10 white water lily, etc. Diversity has remained relatively the same in Gilkey Lake since the first survey in 2011.

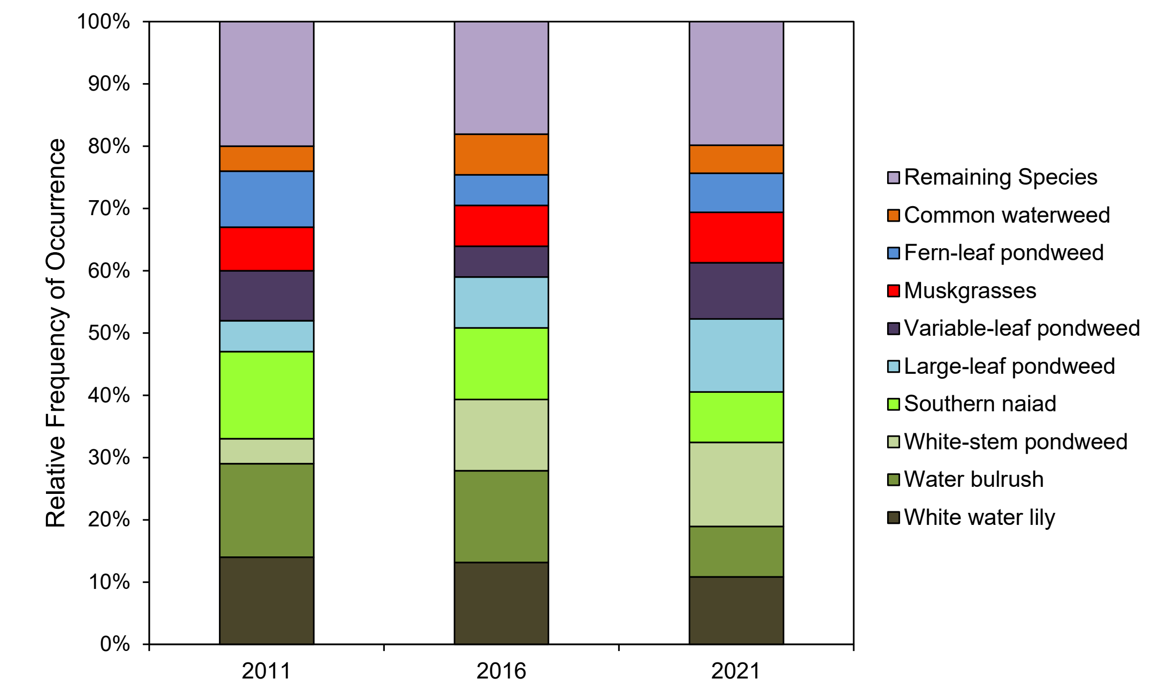


Figure 3.3-9. Relative frequency of occurrence of aquatic vegetation in Gilkey Lake. Created using data from whole-lake point-intercept surveys.

3.4 Bass Lake

The Bass Lake portion of the project area is the smallest body of the water in the system at approximately 13 acres. Total rake fullness values from the 2021 point-intercept survey are displayed on Figure 3.4-1 and Figure 3.4-2. These data represent the aquatic plant biomass at each sampling location and does not differentiate between native or non-native vegetation.

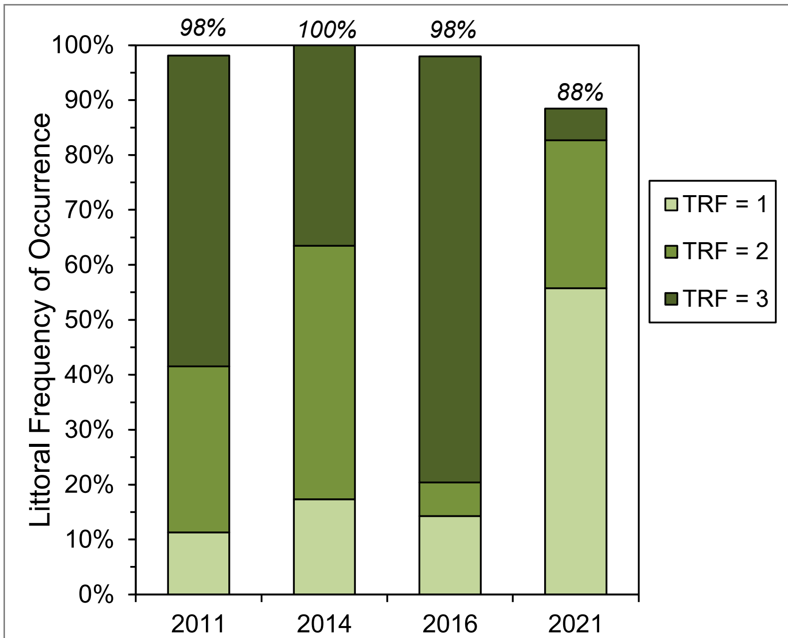


Figure 3.4-1. Total rake fullness (TRF) of Bass Lake. Created using data from 2011-2021 point-intercept survey.

The point-intercept survey data indicate the amount of sampling locations containing aquatic vegetation in 2021 had declined slightly compared to previous years. Herbicide treatments have not taken place on Bass Lake since spring of 2014.

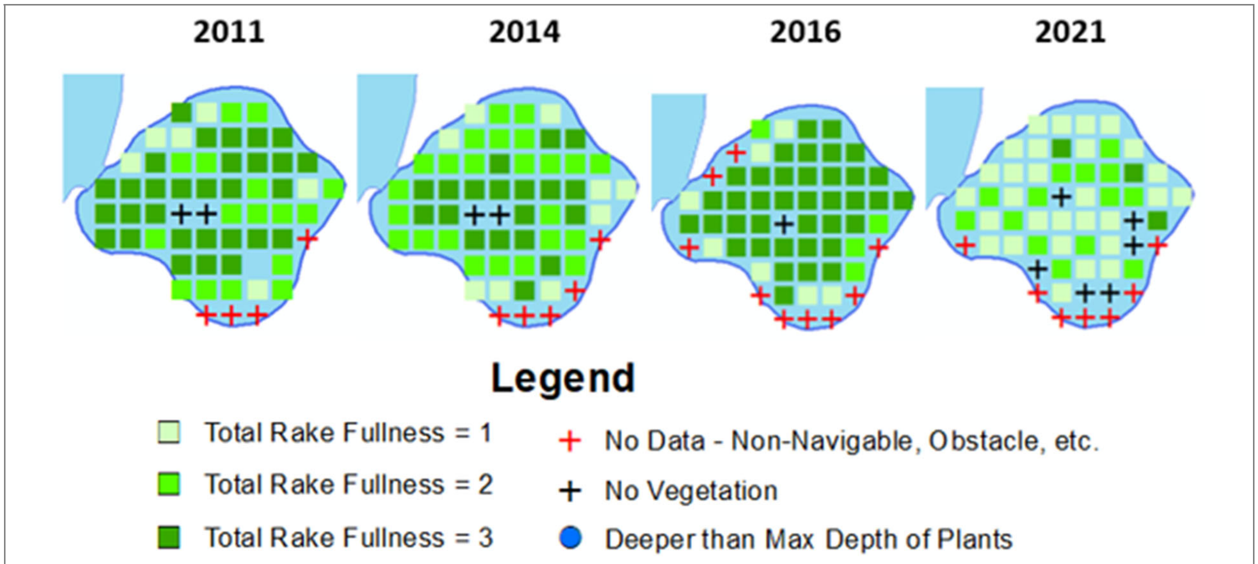


Figure 3.4-2. Bass Lake aquatic plant distribution in 2011, 2014, 2016, and 2021. Created using data from Onterra 2011, 2016, and 2021 point-intercept surveys.

Of the 37 species that have been recorded in Bass Lake since 2011, 19 were physically encountered on the rake during the 2021 point-intercept survey (Table 3.1-1). Figure 3.4-3 shows the most abundant plant species from Bass Lake. Of these 19 species, southern naiad, common waterweed, creeping bladderwort, and fern-leaf pondweed were the most frequently encountered. The littoral occurrences of all species recorded in 2011, 2104, 2016, and 2021 in Bass Lake can be found in a table in Appendix A. Aquatic plant species of interest will be discussed below.

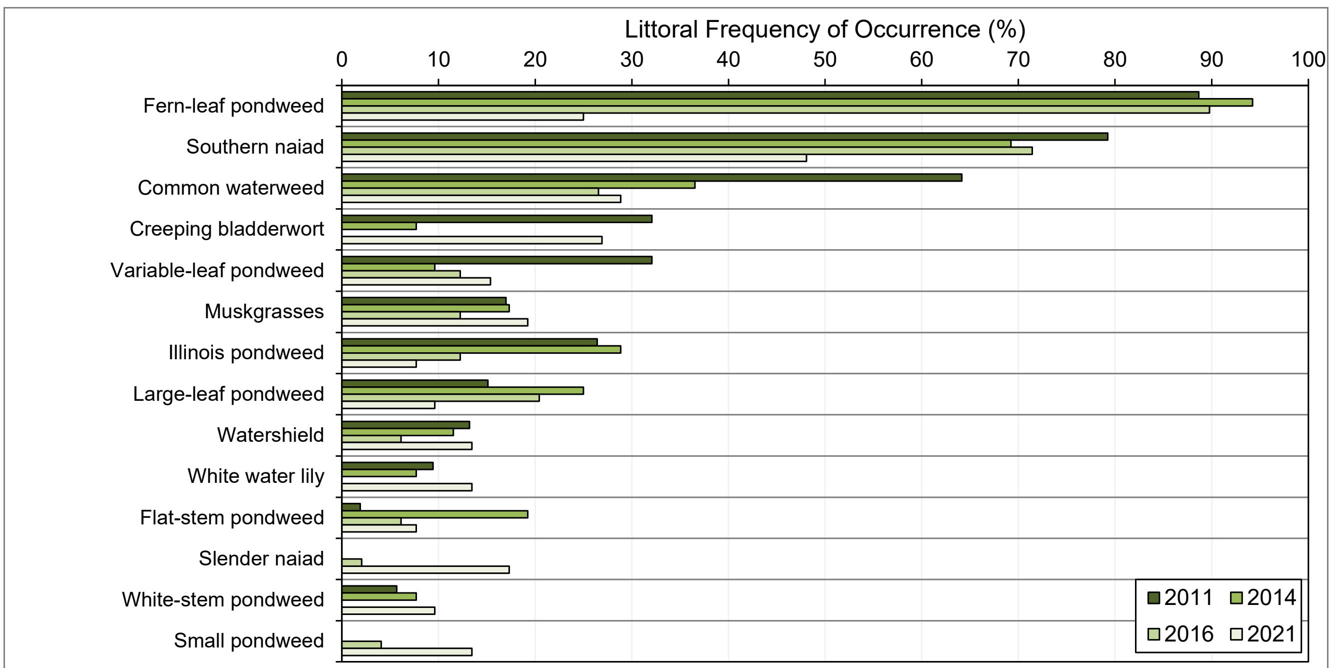


Figure 3.4-3. Littoral frequency of occurrence of most abundant plants in Bass Lake.

Southern naiad was the most frequently encountered aquatic plant species in Bass Lake in 2021 with a littoral occurrence of 48% (Figure 3.4-3). The littoral occurrence of southern naiad in Bass Lake exhibited a statistically valid decrease between the 2016 and 2021 surveys (Figure 3.4-4), similar to the decline discussed previously for Crooked Lake, proper.

Southern naiad (*Najas guadalupensis*)

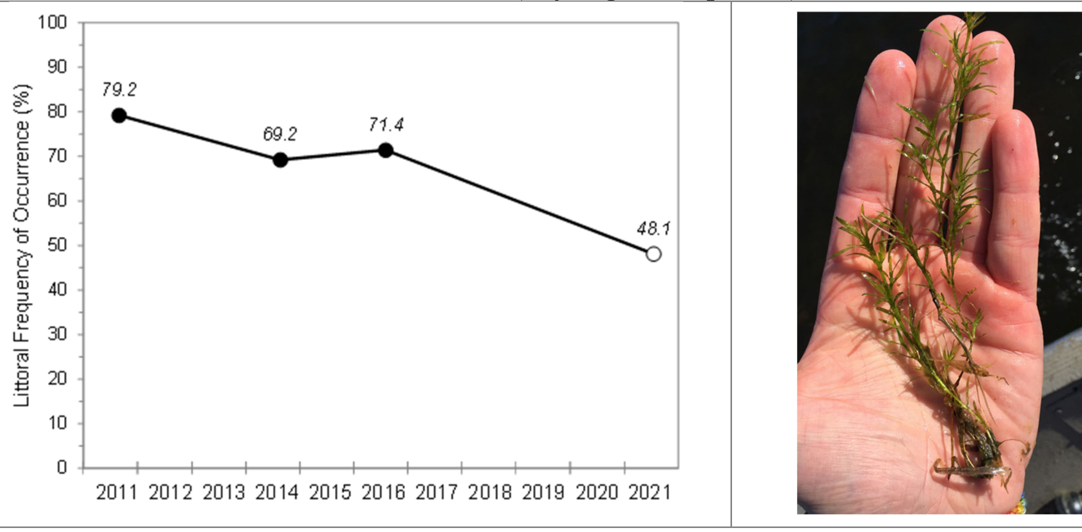


Figure 3.4-4. Littoral frequency of occurrence of southern naiad in Bass Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square $\alpha = 0.05$).

Common waterweed was the second-most frequently encountered aquatic plant in Bass Lake in 2021 with a littoral occurrence of nearly 29% (Figure 3.4-3). Common waterweed has overall decreased from an occurrence of 64% in 2011 to 29% in 2021 representing a statistically valid decrease in occurrence of 55% over this period (Figure 3.4-5). Declines of this species have also been observed in Crooked Lake, proper.

Common Waterweed (*Elodea canadensis*)

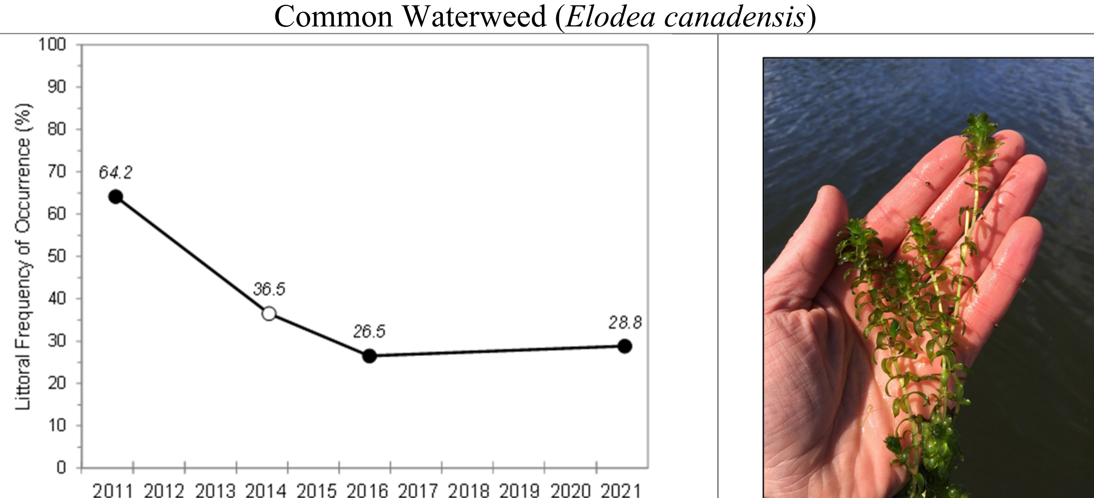


Figure 3.4-5. Littoral frequency of occurrence of common waterweed in Bass Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square $\alpha = 0.05$).

Fern-leaf pondweed was the fourth most abundant aquatic plant in Bass Lake in 2021 with a littoral occurrence of 25% (Figure 3.4-3). Fern-leaf pondweed was one of the most frequently encountered species in the 2011, 2014, and 2016 surveys with an occurrence of 89%, 94%, and 90% respectively. Between the 2016 and 2021 surveys a statistically significant decline of 72% was observed (Figure 3.4-6). Fern pondweed populations also drastically declined in Crooked Lake, proper. However, the declines in Crooked Lake have been consistent since 2011 and more recent (between 2016-2021) in Bass Lake.

Fern-leaf Pondweed (*Potamogeton robbinsii*)

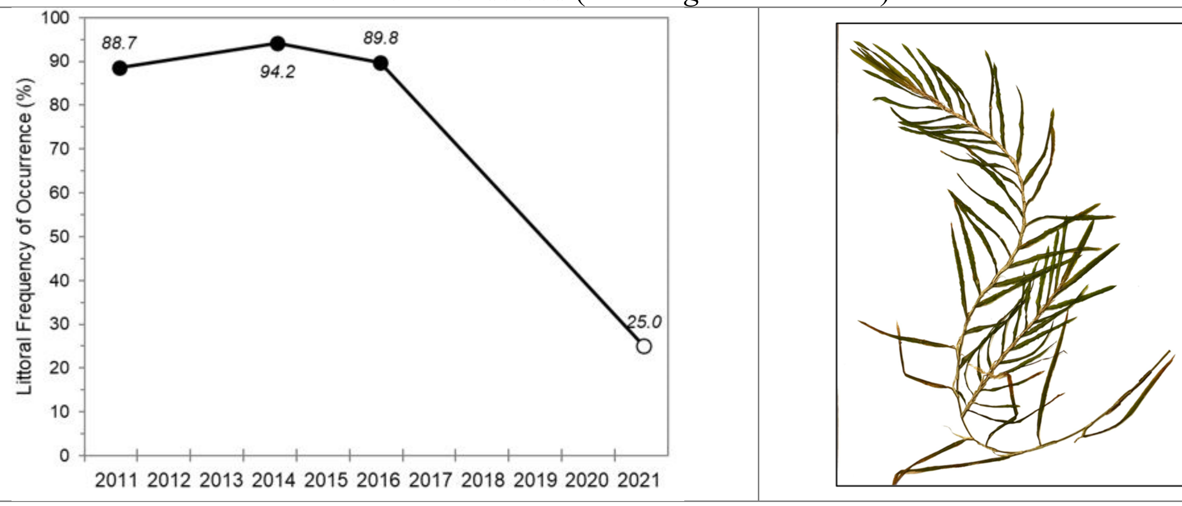


Figure 3.4-6. Littoral frequency of occurrence of fern-leaf pondweed in Bass Lake. Closed circle denotes no statistical difference in occurrence from previous survey; open circle denotes statistically valid change in occurrence from previous survey (Chi-square α = 0.05).

The calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. The native aquatic plant species located on the rake during the point-intercept surveys from 2011, 2014, 2016, and 2021 and their conservatism values were used to calculate the FQI for each year (Figure 3.4-7). Native species richness, or the number of native plant species recorded on the rake, has remained relatively the same over the course of the four surveys from 20 in 2011 to 18 in 2021. Species richness in 2021 falls between the averages for lakes in the Northern Lakes and Forests (NLF) and throughout Wisconsin.

Average species conservatism in Bass Lake has remained relatively the same from 7.0 in 2011 and 6.8 in 2021 (Figure 3.4-7). These conservatism values fall above the median values for lakes in the NLF ecoregion and the state. In other words, Bass Lake has an above average amount of environmentally sensitive aquatic plant species. Using the species richness and average conservatism to calculate the Floristic Quality Index for Bass Lake yields average values for all years (Figure 3.4-7). Floristic quality has decreased slightly over the course of the surveys, and the value in 2021 of 28.8 falls between the ecoregion and the state averages. This analysis indicates that Bass Lake harbors an average quality plant community comprised of a number of species considered sensitive to environmental disturbance.

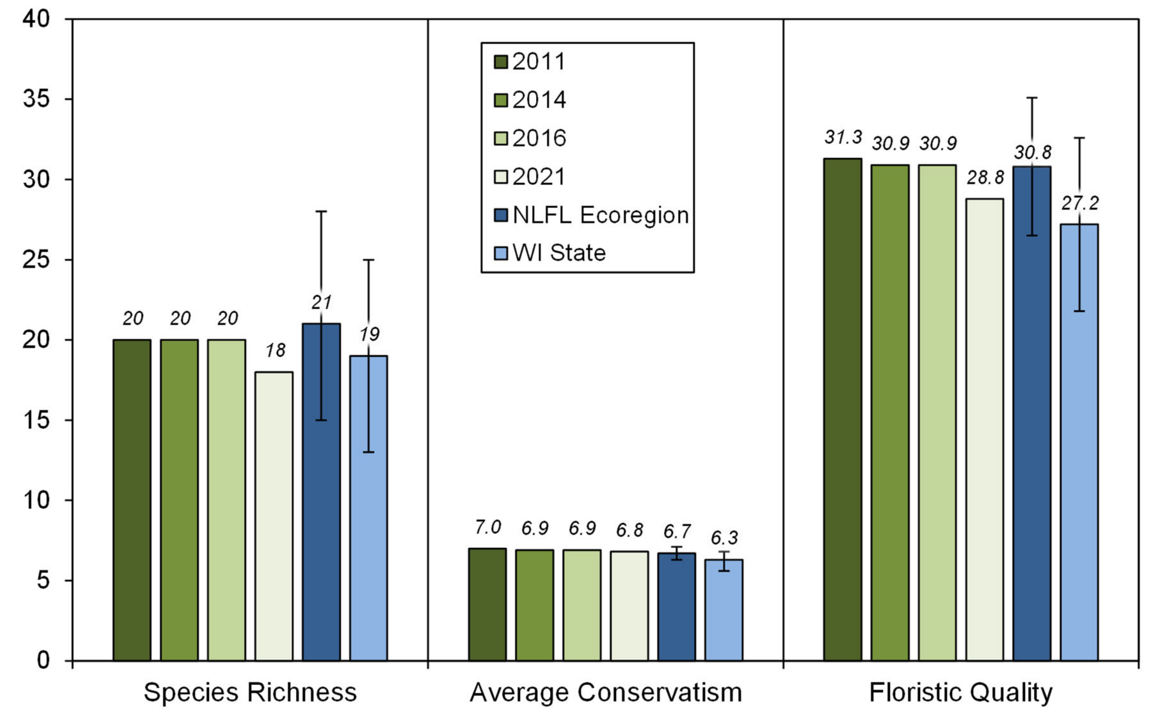


Figure 3.4-7. Bass Lake native aquatic plant species richness, average conservationism, and floristic quality. Includes native aquatic plant species physically encountered on the rake during the point-intercept survey and does not include incidentally-located species.

While a method for characterizing diversity values of fair, poor, etc. does not exist, lakes within the same ecoregion may be compared to provide an idea of how Bass Lake's diversity values rank. Using data collected by Onterra, quartiles were calculated for 212 lakes within the NLFL Ecoregion (Figure 3.4-8). Using the data collected from the whole-lake point-intercept surveys, Bass Lake's aquatic plant species diversity has fluctuated over the course of the 2011, 2014, 2016, and 2021 surveys. In 2021, Simpson's diversity was above the 75th percentile at 0.92.

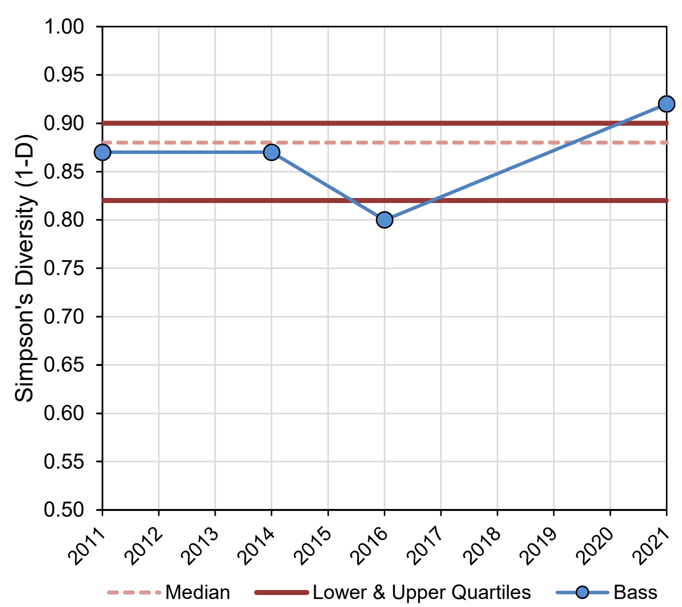


Figure 3.4-8. Bass Lake Simpson's Diversity Index. Created using data from whole lake-lake point intercept surveys.

One way to visualize the diversity of Bass Lake's plant community is to examine the relative frequency of occurrence of aquatic plant species (Figure 3.4-9). Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. For example, while southern naiad was found at 48% of the littoral sampling locations in Bass Lake in 2021 (littoral occurrence), its relative frequency of occurrence was 17%. Explained another way, if 100 plants were randomly sampled from Bass Lake in 2021, 17 of them would have been southern naiad, 10 common waterweed, nine creeping bladderwort, etc. Diversity has fluctuated in Bass Lake since the first survey in 2011. It should be noted the decrease in fern-leaf pondweed has resulted in a more even relative frequency of plants in 2021.

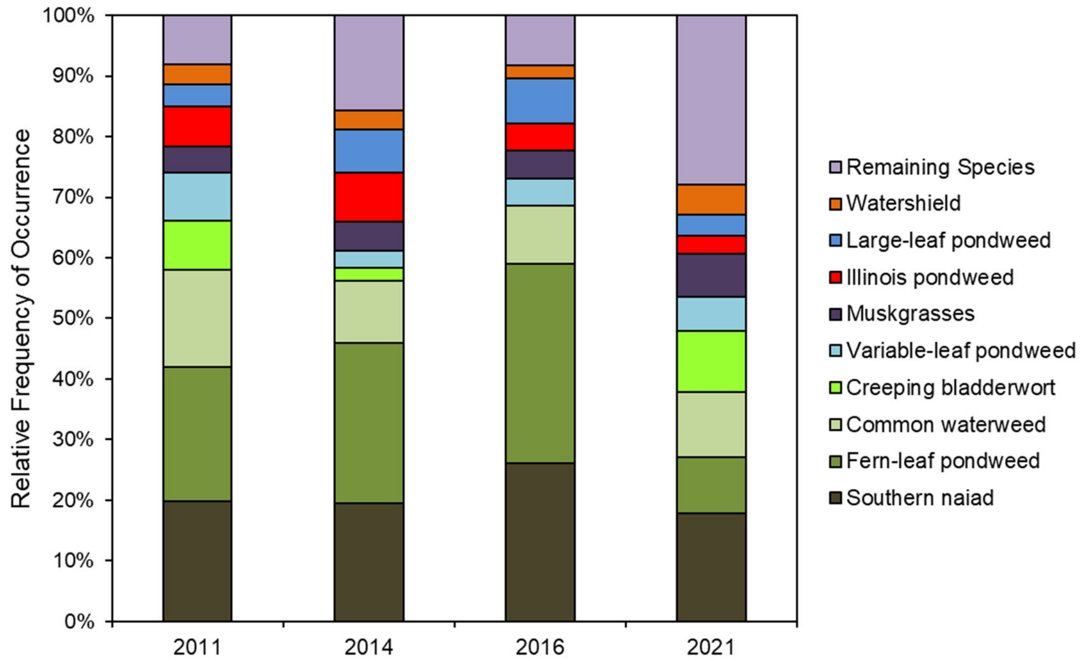


Figure 3.4-9. Relative frequency of occurrence of aquatic vegetation in Bass Lake. Created using data from whole-lake point-intercept surveys.

4.0 2020 PROCELLACOR™ *YEAR-AFTER-TREATMENT* MONITORING

Quantitative Monitoring: Sub-sample point-intercept Survey

A pretreatment sub-sample point-intercept survey was completed on June 19, 2020 (Figure 4.0-1). The same sub-sample point-intercept survey was replicated on September 9, 2020 (*year of treatment*) and on September 3, 2021 (*year after treatment*) in order to understand the efficacy and selectivity of the ProcellaCOR™ herbicide treatment on Crooked Lake. Figure 4.0-1 displays the location of the sub-set sampling locations that are included in the following analysis. This dataset was intended to specifically monitor the EWM and native plant population dynamics during the pre and post treatment timeframe within the area where herbicide was directly applied.

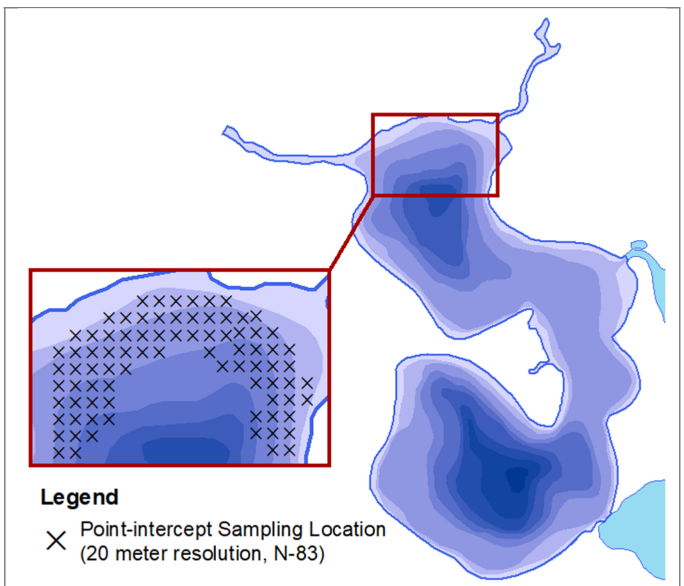


Figure 4.0-1. Sub Point-Intercept Survey Sampling Locations in Crooked Lake. (20-meter spacing, N=83)

Figure 4.0-1 investigates the aquatic plant data at the treatment site in 2020-2021. These data indicate a high level of EWM control, with no EWM being located from the application area one year post treatment compared to a 17.5% littoral frequency of occurrence documented pre-treatment. Fluctuations in the native aquatic plant community were observed, for both the dicot and non-dicot species.

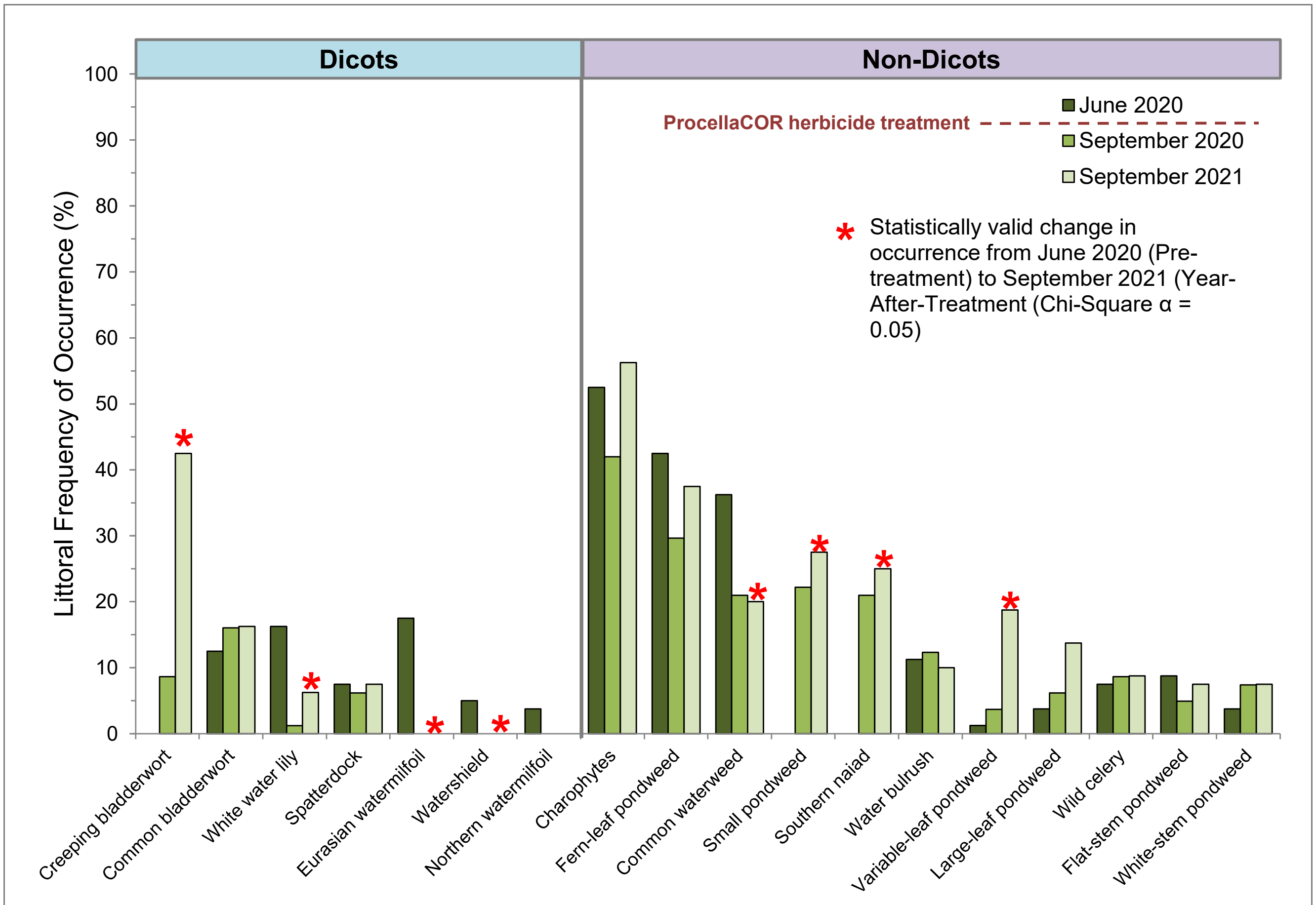


Figure 4.0-1. Littoral frequency of occurrence of aquatic plants before (June 2020) and after (Sept 2020, Sept 2021) a ProcellaCOR spot-treatment in Crooked Lake. Statistical differences based upon Chi-square (α = 0.05). n=81. All sampling locations are located within the herbicide application area.

White water lily (*Nymphaea odorata*), muskgrasses (*Chara* spp.), watershield (*Brasenia schreberi*), and common waterweed (*Elodea canadensis*) exhibited statistically valid declines in occurrence between the pre- and post-treatment surveys (Figure 4.0-1). The floating-leaf aquatic plant species, white-water lily and watershield, have shown susceptibility to ProcellaCOR™ in treatments of other lakes but typically rebound rather quickly. Northern watermilfoil (*Myriophyllum sibiricum*) is also known to be highly susceptible to ProcellaCOR™ treatments, likely because of its close genetic relationship to EWM. Northern watermilfoil was located at three sampling locations during the pretreatment survey (3.8%) and was not sampled, or visually seen, within the treatment area during either post treatment survey (0%).

Creeping bladderwort (*Utricularia gibba*), small pondweed (*Potamogeton pusillus*), stoneworts (*Nitella* spp.), southern naiad (*Najas guadalupensis*), variable-leaf pondweed (*Potamogeton gramineus*), and large-leaf pondweed (*Potamogeton amplifolius*) all exhibited a statistically valid increases in occurrence between the pre- and post-treatment surveys (Figure 4.0-1). Please note that the population increases may be solely a function of survey timing, such that the pretreatment survey was conducted early in the year (mid-June) when many plants are at lower populations compared to the late-summer post treatment survey. That being said, the treatment clearly did not cause population declines or this would have been apparent in the data. Several other native species that were present within the treatment site did not exhibit a statistical change in occurrence between the two surveys.

Several native aquatic plant species were documented in the September 2020 (post treatment) survey that were not present during the June 2020 (pretreatment) survey. Of these, creeping bladderwort (43% occurrence) and small pondweed (28% occurrence) were found in the largest abundance. These data suggest that some native species may have been dormant at the time of the June survey and only began actively growing later in the growing season, potentially after the herbicide treatment took place.

Aside from the direct impact of the herbicide, there are a few factors that could have resulted in the changes observed. The timing of the pre-treatment survey is meant to take place late enough such that most native species have begun growing; however, it is believed that some species such as naiads and wild celery begin to grow a bit later in the growing season and may be under-represented in the June survey. Therefore, any increases in occurrence between the two surveys cannot be solely attributed to some kind of competitive release as plants compete in a site newly devoid of EWM after the herbicide treatment, but potentially also from continued population expansion between the time of the June and late-summer replication of the survey during the same growing season.

Qualitative Monitoring: Late-Summer EWM Mapping Survey

A qualitative assessment of the 2020 herbicide treatment includes comparing the 2019 Late-Season EWM Mapping Survey (*year before treatment*) to the 2021 Late-Season EWM Mapping Survey (*year after treatment*) mapping results. Prior to treatment, the 2019 Late-Season EWM Mapping Survey indicated large contiguous colonies of EWM in the target area as displayed on the left frame of Figure 2.2-4 below.

Onterra staff completed a Late-Season EWM Mapping Survey on September 3, 2021. Crews surveyed the entire littoral area of the Crooked Lake Area Lakes from the bow of the survey boat. The results of the survey are displayed on Map 1. No colonized areas of EWM that required area-based mapping techniques were located within Crooked Lake. No EWM was observed within the 2020 treatment area. Within Crooked Lake, only a handful of isolated *single or few plant* or *clump of plants* occurrences were mapped. In Bass Lake, the EWM population consisted of numerous *single or few plant* occurrences or *clumps of plants*. Two *small plant colonies* and a colonized area of *scattered* were also mapped within the lake. The EWM population in Gilkey Lake consisted of numerous *single or few plants* and a couple of *clumps of plants* on the southeast end of the lake.

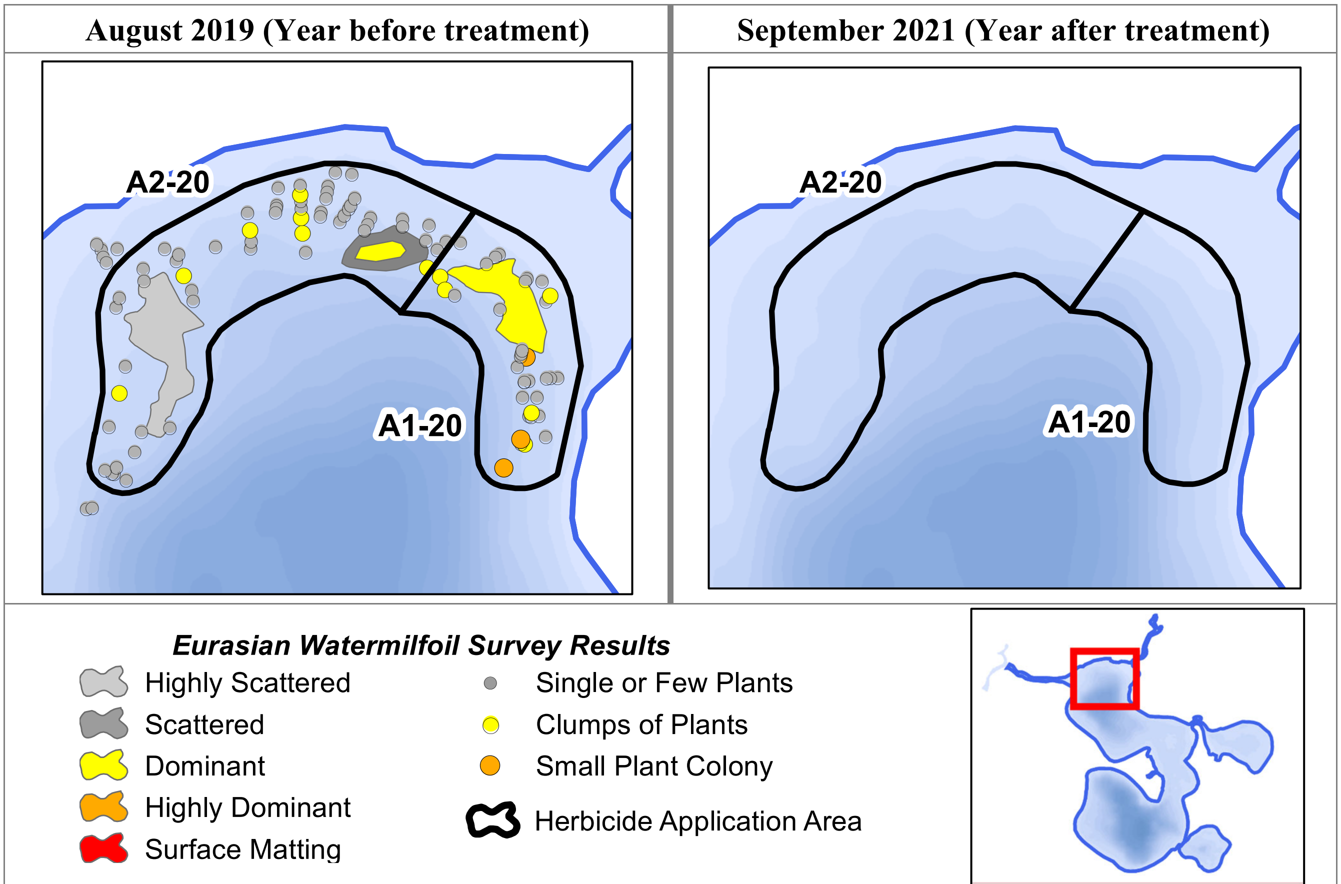


Figure 4.0-2. EWM Mapping Survey Results from before (August 2019) and one year after (September 2021) treatment. ProcellaCOR™ treatment occurred on July 6, 2020.

5.0 CURLY-LEAF PONDWEED MAPPING SURVEY

In some lakes, mostly in northern Wisconsin, CLP appears to integrate itself within the community without becoming a nuisance or causing measurable impacts the lake ecosystem. Many groups resist commencing an herbicide control strategy for CLP, as it often consists of multiple annual treatments (5 or more) of the same areas which can have large financial and ecological costs. The CLP population was last monitored in 2018 which showed a relatively low population. Periodically conducting population estimates, as occurred in June 2021, will be important for the district to determine whether active management may be warranted or if continued periodic monitoring is appropriate.

Photograph 5.0-1. Curly-leaf pondweed. Photograph credit Onterra.

On June 11, 2021, Onterra ecologists completed the Early-Summer CLP Mapping Survey on the Crooked Lake Area Lakes. Curly-leaf pondweed (Photograph 5.0-1) is at or near its peak growth in early summer before naturally senescing (dying back) in mid-summer, making early summer the most probable time to locate this species.

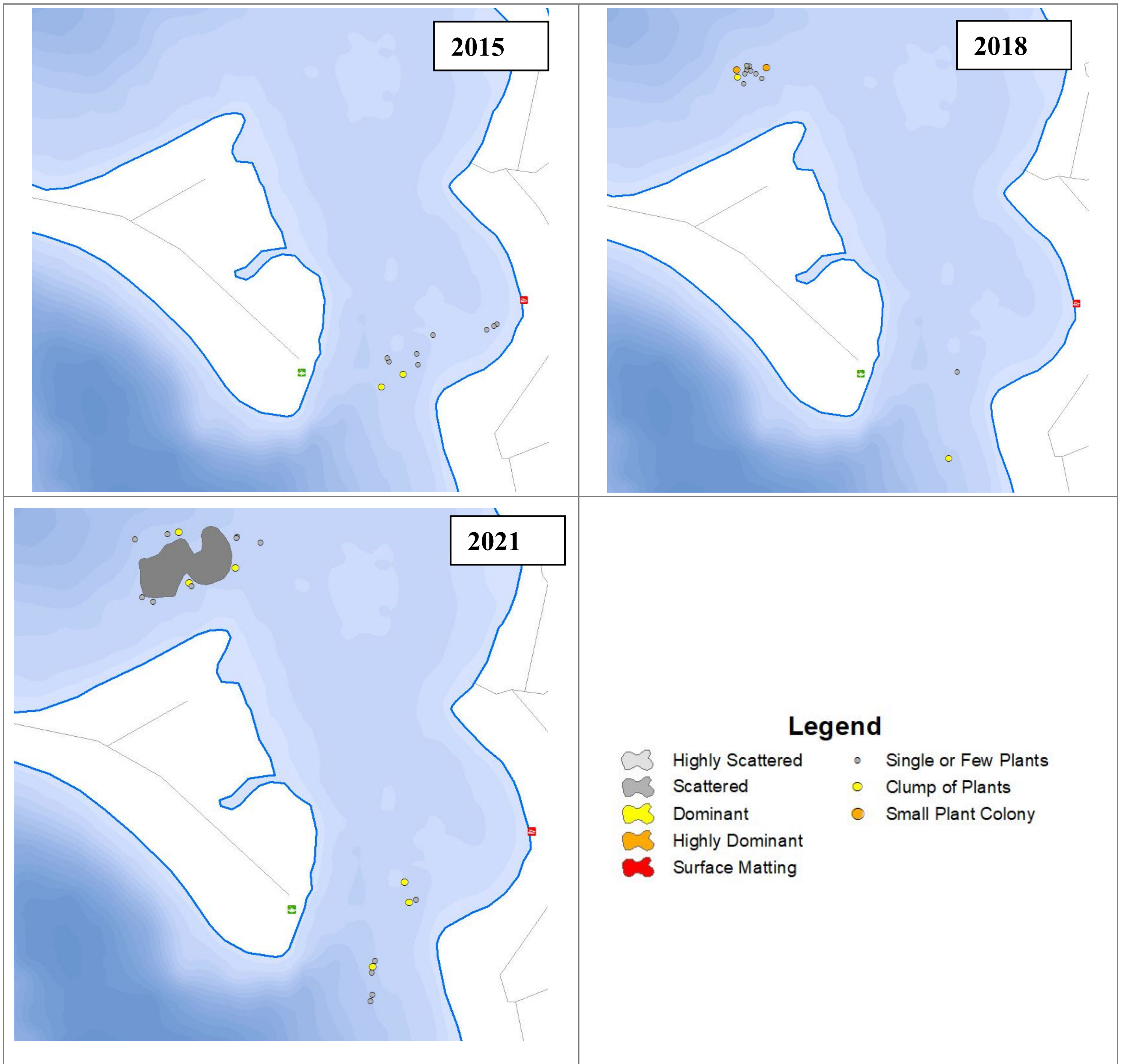


Figure 5.0-1. CLP Mapping Survey Results from 2015, 2018, and 2021 in Crooked Lake.

During the June 2021 survey, Onterra ecologists located several CLP occurrences in the approximate area in which it was documented in 2015 in the central portion of Crooked Lake (Figure 5.0-1). One *single or few plants* occurrence was found near the boat landing on Bass Lake (Map 2). No CLP was recorded in Gilkey Lake. Compared to the 2015 survey, when CLP was also mapped throughout the

Crooked Lake Area Lakes, the population appears to inhabit approximately the same footprint (Figure 5.0-1).

6.0 CONCLUSIONS & DISCUSSION

The 2021 project on the Crooked Area Lakes was intended to fulfil the following main objectives:

- Understand the overall aquatic plant population within the system (Section 3.0)
- Understand the overall EWM population within the system (Section 4.0).
- Investigate the results of the 2020 herbicide management program in the context of the *year after treatment* (Section 4.0)
- Understand the overall CLP population within the system (Section 5.0)

Overall Aquatic Plant Population

The whole-lake point-intercept surveys located a similar number of aquatic plant species within the Crooked Lake Area Lakes compared with previous surveys. More species were found in the Crooked Lake Area Lakes compared with other lakes in the state and with other lakes in this Northern Lakes and Forests Ecoregion. The Crooked Lake Area Lakes contain a wide range of habitats, including sandy shoals, sediment-rich bays (Bass Lake), and riverine areas. Different aquatic plant species favor these habits and results in the high species richness.

The point-intercept surveys confirm anecdotal reports of a decreased aquatic plant community compared to previously. A notable reduction in the overall vegetation of Crooked Lake and Bass Lake was documented, while the aquatic plant population of Gilkey Lake has been largely constant over time. The aquatic plant declines were first observed between 2011 and 2016, with many species declining even further between 2016 and 2021. This trend in reduced aquatic plant population in the last decade has been a concern by district members.

As a part of this project, an effort was made to better understand the driving forces of these changes. It is known that aquatic plant communities are highly dynamic, and populations of individual species have the capacity to fluctuate, sometimes greatly, in their occurrence from year to year and over longer periods of time. These fluctuations can be driven by a combination of natural factors including variations in temperature, ice and snow cover (winter light availability), nutrient availability, water levels and flow, water clarity, length of the growing season, herbivory, disease, and competition. Adding to the complexity of factors which affect aquatic plant community dynamics, human-related disturbances such as the application of herbicides for non-native plant management, mechanical harvesting, watercraft use, and pollution runoff also affect aquatic plant community composition.

This report investigated the herbicide treatment history and failed to find a straight-forward connection with the decrease in aquatic plant biomass. The primary species declining over this time period are those that are relatively resilient to the herbicides used. Also, the timing of their decline does not align directly with when herbicides were applied. Herbicide treatments in 2018 and 2020 produced higher EWM control and would have had the capacity for higher non-native collateral impacts. These treatments, particularly the recent 2020 ProcellaCOR™ treatment, have had a robust aquatic plant monitoring program component. This monitoring yielded some impacts to some specific native plant species, but they were not the species driving the changes that many residents and lake users have noticed.

The aquatic plant reductions observed in the Crooked Area Lakes have also been observed in other nearby systems, suggesting these changes are likely being driven by regional changes in environmental conditions. On most lakes, changes in overall aquatic plant abundance can be linked to decreases in water clarity or changes in water flow. Small reductions in water clarity may have occurred during this time period, but it is unclear if this is the primary driver of the aquatic plant reductions. As zebra mussels become increasingly more established in Crooked Lake, water clarity increases are likely and may cause increases in aquatic plant abundance. Continued monitoring of the plant community will reveal if these trends represent longer-term cycles in these plant populations.

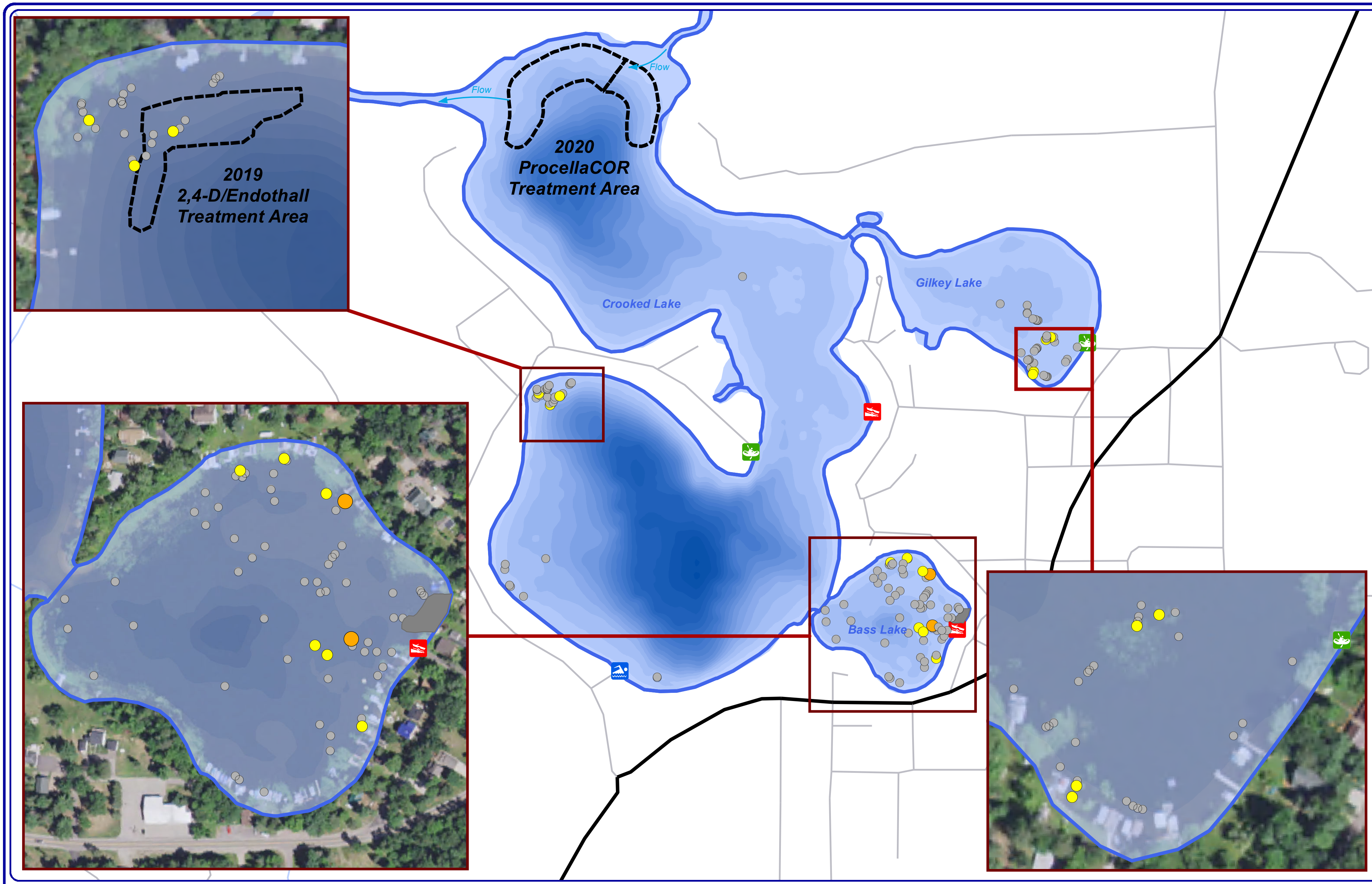
Eurasian Watermilfoil Population and Past Management Activities

The 2020 herbicide treatment continues to show promising results during the *year-after-treatment* with reductions in EWM demonstrated through comparative mapping surveys and point-intercept sub-sampling surveys. As discussed above, comparing native plant populations *before the treatment* to the *year of the treatment* and *year after the treatment* indicated that native plant populations were largely unimpacted by the herbicide management actions outside of a few sensitive dicot species such as northern watermilfoil and some floating-leaf species (white water lily, watershield). The primary aquatic plant species of fisheries interest, such as the tall-growing pondweeds, were not shown to be impacted by the herbicide treatment.

The EWM population in Crooked, Bass, and Gilkey Lakes in late-summer 2021 is considered to be very low. At these levels, herbicide management is not warranted in 2021. A hand harvesting effort could be helpful in keeping the pressure on the EWM population and limit any re-growth or re-establishment in the lake. The CLALPRD would consider the costs of a coordinated hand harvesting effort in relation to the expectations associated with this technique in deciding whether to pursue this option.

Curly-Leaf Pondweed Population

The 2021 CLP survey showed a modest population with a scattered density colony delineated in the same approximate location as has been documented in the past. Despite management not occurring in recent years, the CLP population continues to be well below levels impacting navigation and recreation of the lake, or the ecological function of the system. At the current population, an herbicide management strategy would not be warranted. The CLALPRD could consider a hand-harvesting effort in the future as this strategy has relatively minimal negative ecological consequences of enacting. However, hiring professional contractors to hand-harvesting CLP is extremely expensive and it is unclear to many lake groups whether the effort towards CLP is effective. Continued CLP monitoring at a defined interval, perhaps every 3 years, will be valuable in understanding whether this species has expanded into new areas around the Crooked Lake Area Lakes and whether future active management should be considered for implementation.



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Sources:
Roads and Hydro: WDNR
Bathymetry: Onterra, 2016
Orthophoto: NAIP, 2020
Aquatic Plants: Onterra, 2021
Map Date: September 23, 2021 - EJH
File Name: Crooked_EWM_PB_Sept20.mxd

Project Location in Wisconsin

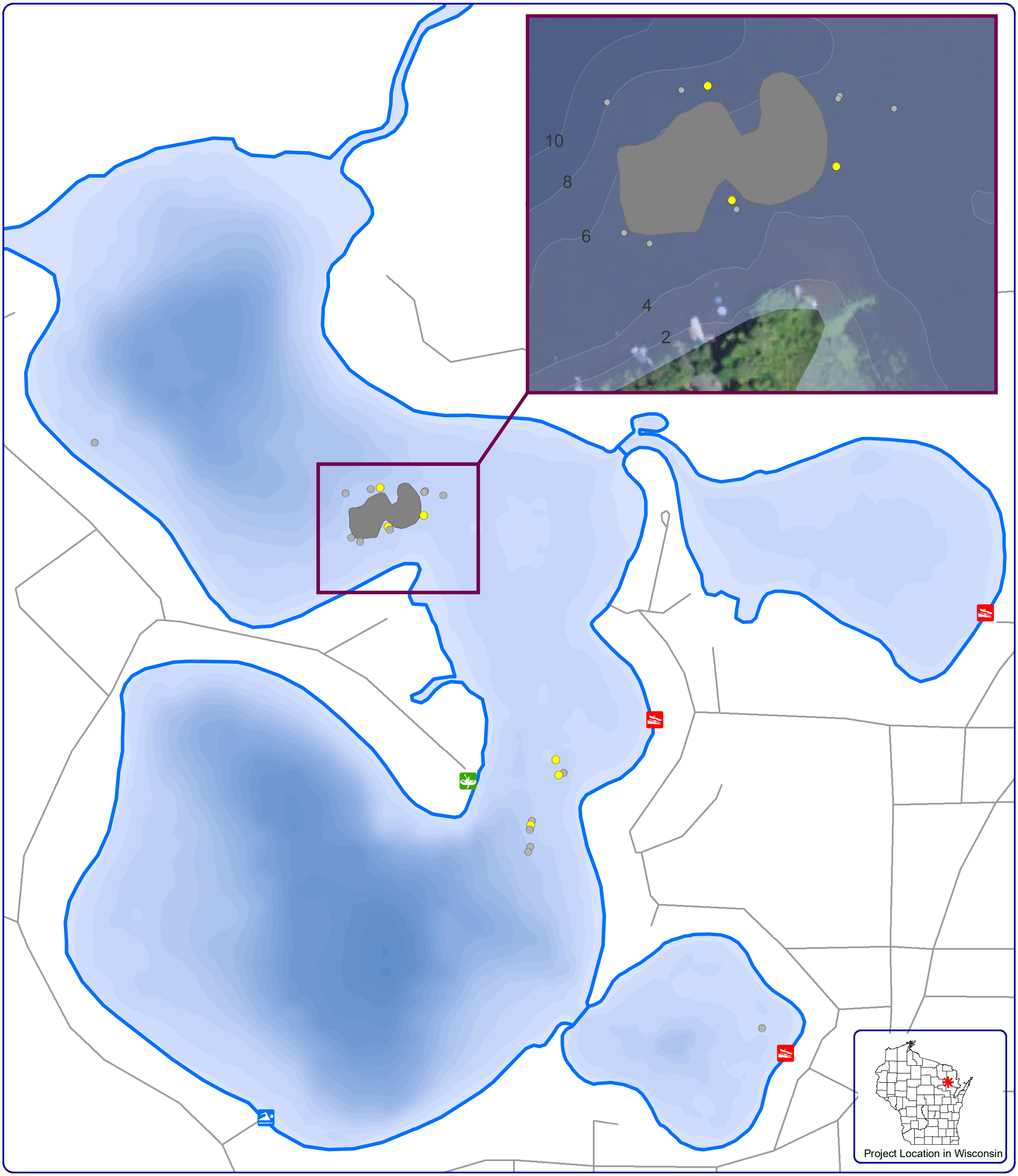
Legend

EWM Survey: September 3, 2021

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

Map 1
Crooked Lake
Oconto County, Wisconsin

2021 Late-Season EWM Survey Results



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Feet

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Sources:
Roads & Hydro: WDNR
Bathymetry: Onterra, 2016;
Orthophotograph: NAIP, 2020
Aquatic Plants: Onterra, 2021
Map Date: June 17, 2021 - EJH

Legend
CLP Survey: June 11, 2021

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

Map 2
Crooked Lake
Oconto, Wisconsin
June 2021 CLP Survey Results

A

APPENDIX A

Crooked Lake Area Lakes Point-Intercept Survey Results

- **Crooked Lake**
- **Bass Lake**
- **Gilkey Lake**

	Scientific Name	Common Name	LFOO (%)		
			2011	2016	2021
Dicots	*Utricularia gibba*	Creeping bladderwort	8.4	1.0	4.7
	Nymphaea odorata	White water lily	5.1	1.7	3.2
	Nuphar variegata	Spatterdock	2.9	0.3	4.3
	Utricularia vulgaris	Common bladderwort	5.5	0.3	0.7
	Utricularia intermedia	Flat-leaf bladderwort	1.8	0.3	1.8
	Brasenia schreberi	Watershield	3.6	0.0	0.7
	Myriophyllum spicatum	Eurasian watermilfoil	2.5	0.0	0.0
	Ceratophyllum demersum	Coontail	1.5	0.3	0.0
	Myriophyllum tenellum	Dwarf watermilfoil	0.4	0.7	0.0
Non-dicots	*Elodea canadensis*	Common waterweed	30.9	34.4	14.7
	Chara spp.	Muskgrasses	23.3	17.9	22.2
	Nitella spp.	Stoneworts	22.5	21.3	13.6
	Najas guadalupensis	Southern naiad	34.5	15.1	8.6
	Potamogeton robbinsii	Fern-leaf pondweed	49.5	11.0	3.2
	Potamogeton gramineus	Variable-leaf pondweed	10.9	11.3	9.0
	Potamogeton zosteriformis	Flat-stem pondweed	13.5	0.3	1.4
	Potamogeton amplifolius	Large-leaf pondweed	9.1	2.4	2.2
	Vallisneria americana	Wild celery	2.9	3.1	4.3
	Schoenoplectus subterminalis	Water bulrush	2.2	1.0	5.7
	Potamogeton strictifolius	Stiff pondweed	8.0	1.0	1.8
	Potamogeton pusillus	Small pondweed	2.2	0.7	3.6
	Najas flexilis	Slender naiad	0.0	1.7	3.6
	Potamogeton illinoensis	Illinois pondweed	1.8	2.4	1.4
	Eleocharis acicularis	Needle spikerush	0.7	1.4	1.8
	Potamogeton praelongus	White-stem pondweed	0.7	0.3	1.1
	Potamogeton natans	Floating-leaf pondweed	1.8	0.0	0.4
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	0.4	0.3	0.7
	Stuckenia pectinata	Sago pondweed	0.0	0.0	0.7
	Schoenoplectus tabernaemontani	Softstem bulrush	0.0	0.0	0.7
	Pontederia cordata	Pickerelweed	0.0	0.0	0.7
	Juncus pelocarpus	Brown-fruited rush	0.4	0.3	0.4
	Potamogeton crispus	Curly-leaf pondweed	0.0	0.0	0.4
	Najas gracillima	Northern naiad	0.0	0.0	0.4
	Isoetes spp.	Quillwort spp.	0.0	0.0	0.4
	Fissidens spp. & Fontinalis spp.	Aquatic Moss	0.0	0.0	0.4
	Eleocharis robbinsii	Robbins' spikerush	0.0	0.0	0.4
	Potamogeton foliosus	Leafy pondweed	0.0	0.3	0.0
	Potamogeton epihydrus	Ribbon-leaf pondweed	0.0	0.3	0.0

	Scientific Name	Common Name	LFOO (%)			
			2011	2014	2016	2021
Dicots	*Utricularia gibba*	Creeping bladderwort	32.1	7.7	0.0	26.9
	Brasenia schreberi	Watershield	13.2	11.5	6.1	13.5
	Nymphaea odorata	White water lily	9.4	7.7	0.0	13.5
	Nuphar variegata	Spatterdock	3.8	7.7	0.0	1.9
	Myriophyllum spicatum	Eurasian watermilfoil	0.0	0.0	0.0	5.8
	Utricularia vulgaris	Common bladderwort	1.9	1.9	0.0	0.0
	Utricularia intermedia	Flat-leaf bladderwort	0.0	1.9	0.0	0.0
Non-dicots	*Potamogeton robbinsii*	Fern-leaf pondweed	88.7	94.2	89.8	25.0
	Najas guadalupensis	Southern naiad	79.2	69.2	71.4	48.1
	Elodea canadensis	Common waterweed	64.2	36.5	26.5	28.8
	Potamogeton gramineus	Variable-leaf pondweed	32.1	9.6	12.2	15.4
	Chara spp.	Muskgrasses	17.0	17.3	12.2	19.2
	Potamogeton illinoensis	Illinois pondweed	26.4	28.8	12.2	7.7
	Potamogeton amplifolius	Large-leaf pondweed	15.1	25.0	20.4	9.6
	Potamogeton zosteriformis	Flat-stem pondweed	1.9	19.2	6.1	7.7
	Najas flexilis	Slender naiad	0.0	0.0	2.0	17.3
	Potamogeton praelongus	White-stem pondweed	5.7	7.7	0.0	9.6
	Potamogeton pusillus	Small pondweed	0.0	0.0	4.1	13.5
	Potamogeton richardsonii	Clasping-leaf pondweed	0.0	0.0	0.0	11.5
	Potamogeton strictifolius	Stiff pondweed	3.8	3.8	0.0	1.9
	Vallisneria americana	Wild celery	5.7	0.0	4.1	0.0
	Potamogeton natans	Floating-leaf pondweed	3.8	3.8	2.0	0.0
	Schoenoplectus subterminalis	Water bulrush	0.0	0.0	0.0	3.8
	Pontederia cordata	Pickerelweed	1.9	3.8	0.0	0.0
	Nitella spp.	Stoneworts	0.0	3.8	0.0	0.0
	Fissidens spp. & Fontinalis spp.	Aquatic Moss	0.0	0.0	0.0	1.9
	Sparganium emersum var. acaule	Short-stemmed bur-reed	1.9	0.0	0.0	0.0
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	0.0	0.0	2.0	0.0
	Potamogeton crispus	Curly-leaf pondweed	0.0	0.0	2.0	0.0
	Lemna trisulca	Forked duckweed	0.0	1.9	0.0	0.0
	Calla palustris	Water arum	1.9	0.0	0.0	0.0

	Scientific Name	Common Name	LFOO (%)		
			2011	2016	2021
Dicots	*Nymphaea odorata*	White water lily	16.9	10.0	14.5
	Brasenia schreberi	Watershield	10.8	3.8	3.6
	Nuphar variegata	Spatterdock	2.4	3.8	3.6
	Utricularia vulgaris	Common bladderwort	3.6	0.0	0.0
	Myriophyllum spicatum	Eurasian watermilfoil	0.0	1.3	1.2
	Utricularia gibba	Creeping bladderwort	1.2	0.0	0.0
	Myriophyllum tenellum	Dwarf watermilfoil	1.2	0.0	0.0
Non-dicots	*Schoenoplectus subterminalis*	Water bulrush	18.1	11.3	10.8
	Potamogeton praelongus	White-stem pondweed	4.8	8.8	18.1
	Najas guadalupensis	Southern naiad	16.9	8.8	10.8
	Potamogeton amplifolius	Large-leaf pondweed	6.0	6.3	15.7
	Potamogeton gramineus	Variable-leaf pondweed	9.6	3.8	12.0
	Chara spp.	Muskgrasses	8.4	5.0	10.8
	Potamogeton robbinsii	Fern-leaf pondweed	10.8	3.8	8.4
	Elodea canadensis	Common waterweed	4.8	5.0	6.0
	Potamogeton zosteriformis	Flat-stem pondweed	2.4	0.0	7.2
	Najas flexilis	Slender naiad	0.0	1.3	4.8
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	7.2	2.5	0.0
	Sagittaria cristata	Crested arrowhead	0.0	0.0	4.8
	Potamogeton natans	Floating-leaf pondweed	2.4	0.0	2.4
	Potamogeton illinoensis	Illinois pondweed	0.0	3.8	1.2
	Eleocharis robbinsii	Robbins' spikerush	0.0	0.0	1.2
	Sagittaria latifolia	Common arrowhead	1.2	0.0	0.0
	Potamogeton strictifolius	Stiff pondweed	1.2	0.0	0.0
	Potamogeton pusillus	Small pondweed	0.0	1.3	0.0
	Pontederia cordata	Pickerelweed	1.2	0.0	0.0