Aquatic Plant Community of

Lakes Riley, Susan, and Staring within the

Riley Purgatory Bluff Creek Watershed:

Annual Report for 2023.

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I. Introduction

Lakes Riley and Susan are small lakes connected by Riley Creek within the cities of Chanhassen and Eden Prairie, Minnesota in the Riley Creek Sub-watershed. Staring Lake, also in Eden Prairie, is within the Purgatory Creek Sub-watershed. These lakes are within the Riley Purgatory Bluff Creek Watershed District and are included in our aquatic vegetation research and monitoring efforts. Aquatic vegetation surveys were performed on these lakes from 2009 to 2023 and took place over various months between May and October. These surveys were conducted to evaluate the response of aquatic plant communities to lake management actions.

There were several goals of the project, but the initial purpose was to assess the native aquatic plant community response following the removal of common carp (*Cyprinus carpio*) from the lakes to improve water quality (e.g., Bajer et al. 2011, Bajer and Sorensen 2015, Sorensen and Bajer 2020). Carp were removed (by the Sorensen lab) from Lake Susan in winter 2009 and its plant community was surveyed in the spring and summers of 2009 through 2023. Carp were removed from Lake Riley in March 2010 and plant surveys were completed from 2011 through 2023. In Staring Lake, carp removal began in the winter of 2012 and concluded in 2015. In the summer of 2015 the carp population was reduced to approximately 10% of the pre-removal population. Aquatic plants were surveyed in Staring Lake in 2011 through 2023. Continuing these surveys on Staring Lake after carp removal allowed an assessment of the plant community response compared to the pre-removal surveys. Additional information on carp removal in these lakes is in Bajer et al. (2011), Bajer and Sorensen (2015), and Sorensen and Bajer (2020).

An additional goal of the project was to promote the recovery of native plants and control invasive macrophytes. The hypothesis was that removal of carp will lead to a decrease in uprooting of aquatic plants and an increase in water clarity. This will in turn increase the light available to aquatic plants, which will benefit both native and exotic species (Hanson and Butler, 1994). However, invasive species such as Eurasian watermilfoil (*Myriophyllum spicatum*) and curlyleaf pondweed (*Potamogeton crispus*) were already established in the lakes, and due to their naturally aggressive recruitment, there was concern these invasive species would expand at a faster rate than native species. Thus the problem was how to restore the native plants while containing invasive species.

Techniques to reduce the dominance of the invasive species and enhance native plant communities were evaluated. Transplanting native submersed plants took place in Lake Susan in 2009, 2010 and 2011. Early season endothall herbicide treatments were conducted to control curlyleaf pondweed in the spring of 2013, 2014, 2016, and 2017 in Lake Susan, and in 2013 through 2017 in Lake Riley. In 2016 Lake Susan underwent a partial half-lake treatment of curlyleaf pondweed instead of a whole lake treatment so as to evaluate the effect of herbicide on the native plant community; this was repeated in 2017. Lake Staring was for the first time treated with endothall in May 2017 to control curlyleaf pondweed. To control Eurasian watermilfoil in Lake Riley 2, 4-D herbicide treatments were applied in June of 2015 and 2016 and granular 2, 4-D and triclopyr treatments were assessed in 2017. To control a sparse population of Eurasian watermilfoil found in Staring Lake in September 2015 and again in August 2016 and 2017, a granular form of triclopyr herbicide was used for treatment and additional hand-pulling was also conducted by the district. In May of 2018, both Lake Riley and Lake Susan were treated to control curlyleaf pondweed with diquat (Tribune) and a surfactant (Cygnet plus). Staring Lake curlyleaf did not need treatment based on spring 2018 delineations. In 2019 no treatment of curlyleaf was made in any of the lakes and treatment of Eurasian watermilfoil in Lake Riley was also not needed in 2019 nor 2020 due to the effective treatments in 2017. Lake Riley was treated with diquat (Tribune) in May of 2020 to control curlyleaf pondweed but Staring and Susan were not treated. In 2021, only one plant survey was conducted on each lake in August. Lake Riley was treated with diquat (Tribune) in both 2021 and 2022 to control curlylead pondweed. Lake Riley was also treated with Procellacor in late August 2022 to control Eurasian watermilfoil. Lake Susan was treated with diquat (Tribune) in 2021 and 2022, to control curlyleaf pondweed. In 2022, Staring Lake was given a full lake low dose treatment with fluoridone to control both curlyleaf ponweed and Eurasian watermilfoil. In May of 2023, Lake Riley was treated with Diquat and Lake Susan was treated with Flumioxazin to control curlyleaf pondweed. Staring lake was not treated in 2023.

Although water clarity and quality improved in the lakes after carp removal, the response was not as great as initially antipated nor enough to remove impairments for nutrients and clarity. Therefore, Lake Riley was treated with Alum in spring 2016 to reduce internal loading and given a second treatment in spring 2020. Alum treatments have been under consideration for Lake Susan, but will not be applied until external loading is fully under control.

This report presents data and results from 2023 with prior data included from 2009 (Newman 2009), 2010 (Newman and Knopik 2011), 2011 (Knopik and Newman 2012), 2012 (JaKa et al. 2013), 2013 (JaKa et al. 2014), 2014 (JaKa and Newman 2015), 2015 (Dunne and Newman 2016), 2016 and 2017 (Newman 2018), 2018, 2019, 2020 (Olson and Newman 2019, 2020 and 2021) and 2022 (Weaver and Newman 2023). Additional data are given in Knopik (2014), JaKa (2015), Dunne (2017), Knopik and Newman (2018), and Dunne and Newman (2019). Our report examines the long term changes in plant communites with management actions and concludes with recommendations for further management of each of the lakes along with an overview of conclusions across lakes.

II. Methods

Plant communities were surveyed for frequency of occurrence and diversity by species (point intercept surveys) and curlyleaf pondweed turion densities to assess response to carp removal and monitor and develop approaches to enhance native plant communities while controlling invasive macrophytes. The goal of the herbicide treatments was not only to control the invasive curlyleaf pondweed and Eurasian watermilfoil, but also to determine whether the removal of curlyleaf and Eurasian watermilfoil will enhance the native plant community. Aquatic bathymetry and vegetation sonar data were collected using a Lowrance depth finder and BioBase software (Biobasemaps.com) to create bathymetry and lake vegetation maps. Biomass samples were also collected from approximately 40 randomly selected points from the point intercept survey points around Lake Riley, Lake Susan and Staring Lake during early spring, spring/summer and late summer in 2020 and in the previous years except

2018. There was no biomass data from 2021 due to Covid-19, and biomass was collected only in early summer and late summer in 2022.

Point Intercept Survey:

A point intercept survey approach (Madsen 1999) was used to define sampling points to assess the plant community in each lake. Using ArcMap GIS, survey points were generated following a systematic square grid. Grid spacing ranged from 40m to 60m to ensure at least 120 points within the littoral zone (≤4.6m depth) of each lake. The sampling points were loaded into either a Garmin GPS or a Lowrance HDS 7 fish finder and a boat was navigated to each sampling point. A weighted double headed rake (0.3m wide) attached to a rope was then tossed into the lake, allowed to sink and retrieved along the lake bottom for approximately three meters. The vegetation collected was identified and a semi-quantitative density rating (0 to 5) was visually estimated. Density ratings were given for the total amount of vegetation on the rake in addition to ratings given for each individual species on the rake. Frequency of occurrence was determined for each species within the littoral zone in addition to the overall frequency of native and invasive plants. Mean species richness was determined from the total number of taxa present at each site and total number of species found in each lake was also determined. Samples were taken in depths up to 5.5m to determine the maximum depth of rooted vegetation. ArcMap GIS and BioBase were used to generate maps to assist in visualizing taxa locations, depth of growth, and richness at sites.

Biomass Sampling:

Plant biomass (g dry/m^2) was sampled using methods described by Johnson and Newman (2011). A subset of at least forty littoral sampling sites were randomly selected from the point intercept survey points on each lake. At each site, all the plants in a 0.09m^2 area were collected with a long handled garden rake that was lowered to the lake bottom, rotated three times to ensure uprooting of all plants, and pulled to the surface (Johnson and Newman 2011). The samples were placed in plastic bags and taken to a lab where the plants were sorted by species and roots removed. The shoots were spun in a salad spinner to remove excess water and then weighed. The samples were then dried at 105˚C for >48 hr and re-weighed. Mean dry biomass was calculated for each species based on all samples taken within the littoral zone. Turions were removed from the dried curlyleaf biomass samples, counted and weighed to get an estimate of turion production. Sites that were sampled but found to have no plants were recorded as zeros and included in our lake or littoral wide biomass estimates. Biomass was sampled during each point intercept survey except no biomass was sampled in 2018 or 2021.

Curlyleaf Pondweed Turion Sampling:

Invasive curlyleaf pondweed is found in many lakes in Minnesota including Lakes Riley, Staring and Susan. Because curlyleaf pondweed often reproduces by forming over-wintering vegetative propagules called turions (Madsen and Crowell 2002), we assessed the turion bank in the sediment of Lakes Riley, Staring and Susan each fall. Following the approach used by Johnson et al. (2012), forty sampling sites in the littoral zone (≤ 4.6m depth) were randomly selected from the littoral zone point intercept sites at each lake. The coordinates were entered into a GPS and a boat was navigated to each point. At each point a petite ponar (225 cm^2 area, sample depth ~10 cm) was used to take a sediment sample; sampling depth and substrate type was noted. The sediment sample was then passed through a 1.0mm mesh sieve to remove fine sediment. Prior to 2018, the remaining samples were returned to the lab and turions were enumerated. Due to relatively low densities of turions in 2018 and subsequent years, turions were enumerated in the field. Turions that had sprouted in the field (plants or sprouts collected with turions attached) were counted, then discarded. The remaining turions were stored in transparent freezer bags, returned to the lab and placed in a dark refrigerator at 5 ˚C. Every 7 days the samples were examined for sprouting, and sprouted turions were counted and removed. After four weeks, the cold turions that had not sprouted were placed at room temperature (21 ˚C) under natural spectrum lighting for 12 hours per day. Samples continued to be examined every 7 days for another 4 weeks; sprouted turions were counted, recorded and then removed. Turion viability (proportion) was calculated as the ratio of the number of sprouted turions per site (including the turions that were field sprouted when collected) to the total number of turions collected per site. The number of turions collected at each site was expressed as the total number of turions per square meter and the number of viable turions/m^2. In 2020, turion sampling took place at Staring Lake, but not Lakes Riley nor Susan due to early winter conditions; zero turions were collected during sampling at Staring Lake in 2020. Turions were not collected in 2021 due to Covid-19.

Water Quality:

Several indicators of water quality were measured periodically on all lakes. Water temperature, dissolved oxygen and photosynthetically active radiation (PAR) readings were recorded in 0.5m depth intervals using a YSI ProODO electronic oxygen and temperature meter and a LI-COR 189 digital meter with LI-COR 192 quantum PAR sensor. Secchi depths were recorded to the nearest 0.1m.

Herbicide Treatments:

Early season (spring) endothall herbicide treatments were conducted in 2013, 2014 and 2016 and 2017 in Lake Susan and 2013-2017 in Lake Riley and in 2017 in Lake Staring. It has been shown that endothall can efficiently control curlyleaf pondweed at temperatures between 10-15 ˚C, when native plants should not be actively growing yet (Skogerboe and Getsinger 2002, Poovey et al. 2012). This method of timing can be effectively used to target curlyleaf pondweed with little collateral damage to the native plant community (Jones et al. 2012). Water temperatures would be closely monitored during the early parts of spring, once ice came off the study lakes. When water temperatures approached the treatment temperature threshold, the densest areas of curlyleaf were delineated and provided to the contracted herbicide applicator. Pretreatment point intercept surveys were conducted on all three lakes just prior to herbicide treatments. Post-treatment surveys were conducted at all lakes in June to correspond with typical peak curlyleaf abundance. Precise survey timing was coordinated with macrophyte growth each year. A third survey was conducted in August on all lakes corresponding with the timing of peak frequency of occurrence of native plants. Fall curlyleaf turion surveys were completed in October to monitor the turion densities in the sediments; this is essentially monitoring the seed bank for curlyleaf. Reduction of turions in the sediments is an important management strategy for reducing curlyleaf pondweed (Madsen and Crowell 2002, Crowell 2003).

In May of 2018, both Lake Riley and Lake Susan were treated for curlyleaf pondweed control with diquat (Tribune) and a surfactant (Cygnet Plus) following pre-treatment surveys conducted by James Johnson of Freshwater Scientific Services, LLC. The treatment area in Lake Riley was 15.7 acres (6.35 hectares) treated while 7.7 acres (3.1 hectares) were treated in Lake Susan. None of the lakes were treated for curlyleaf in 2019. In 2020, Lake Riley curlyleaf pondweed was treated with diquat (Tribune) with a treatment area of 16.0 acres (6.5 hectares). In 2021 and 2022, Lake Riley and Lake Susan were both treated with diquat (Tribune) to control curlyleaf pondweed. In 2021, the treatment area in Lake Riley was 22.3 acres (9.0 hectares) and in Lake Susan, 8.6 acres (3.5 hectares) were treated. In 2022, the treatment area in Lake Riley was 16.7 acres (6.8 hectares) and the treatment area in Lake Susan was 8.25 acres (3.3 hectares). To control curlyleaf pondweed and Eurasian watermilfoil in Staring Lake, a whole lake fluridone treatment 164 acres (66.4 hectares) was conducted in 2022. In 2023, Lake Riley was treated with diquat to control curlyleaf pondweed. The treatment area was 9 acres (3.6 hectares). In Lake Susan 5.35 acres (2.2 hectares) were treated with flumioxozin to control curlyleaf pondweed.

To control Eurasian watermilfoil a 2,4-D herbicide treatment was conducted on Lake Riley in the summers of 2015 and 2016. 2, 4-D is a systemic herbicide effective against dicot plants; it has been demonstrated to be effective in controlling Eurasian watermilfoil while having minimal impact on most native species since the majority of native plants are monocots (Parsons et al. 2001). Delineation of milfoil occurred in late May and the liquid herbicide was applied to designated areas in June. A pre-treatment survey occurred in June and an additional survey occurred in August to assess Eurasian watermilfoil and native macrophyte response. In 2017, Eurasian watermilfoil was controlled with a split application of 2,4-D (Sculpin G) to 10 acres (4.0 hectares) and granular triclopyr (Renovate OTF) to 10 acres (4.0 hectares). Granular formulations likely disperse less quickly than liquid applications. No Eurasian watermilfoil treatment was needed in 2018, 2019, 2020, or 2021. In 2022, Lake Riley was treated to control Eurasian watermilfoil using ProcellaCOR in late August after all sampling was completed. The treatment area was 8.1 acres (3.3 hectares).

A granular form of triclopyr (known as Renovate3®) was used to control a small population of Eurasian watermilfoil observed growing in Staring Lake in the fall of 2015 and again in late summer in 2016. The granules were placed at the locations of occurrence mapped by James Johnson of Freshwater Scientific Services, LLC. Similar to 2, 4-D, triclopyr is selective against Eurasian watermilfoil while having minimal adverse effects on other plant species (Poovey et al. 2004). No treatments were made in 2018, 2019, 2020, or 2021. A whole-lake fluridone treatment was conducted in 2022 with a long-exposure 3ppb target concentration to control both curlyleaf pondweed and Eurasian watermilfoil.

Alum Treatment:

A split dose hypolimnetic alum treatment was applied to Lake Riley in May 2016 and the second dose in June 2020 to control phoshorous, reduce algal growth and improve water clarity. When applied to the lake, alum creates an floc of aluminum hydroxide; this binds and sequesters phosphorous in the water column and in the sediment once the compound reaches the lake bottom. The improved water quality should aid in the expansion of the plant community. The plant surveys and water quality analysis are used to assess the alum treatment effectiveness.

Aquatic Bathymetry and Vegetation Mapping:

We collected sonar data using a Lowrance HDS 5 Gen 2 fish finder during all point intercept surveys in 2013 through 2017 and in 2018 through 2023 using a Lowrance HDS 7 fish finder. The HDS 5 and HDS 7 both recorded data onto an SD card while we navigated the boat to survey points. From the lab, we uploaded the sonar data to the BioBase servers at http://biobasemaps.com. After BioBase processed the sonar data, bathymetry and vegetation maps were available, along with a report generated for each lake containing plant coverage biovolume and bathymetry (i.e. average biovolume and percent area covered) for seasonal and year to year lake-wide comparisons.

Results by Lake:

Results are presented by lake; Lake Riley, Lake Staring and Lake Susan were sampled each of the project years, from 2011 to 2023, with results from the past years being reported but with an emphasis on results and findings from 2023. A general summary with overall conclusions and recommendations for future management will follow the results sections.

III. Lake Riley Results

Lake Riley (DOW ID 10-000200) is a eutrophic lake located about 2 km downstream of Lake Susan along the Chanhassen and Eden Prairie city boundary. Rice Lake Marsh lies along the Riley Creek between and Lake Susan and Lake Riley. Lake Riley has a surface area of about 300 acres (120 hectares) with a littoral zone of about 110 acres (45 hectares) and a maximum depth of about 15m (49ft) (MN DNR LakeFinder 2016).

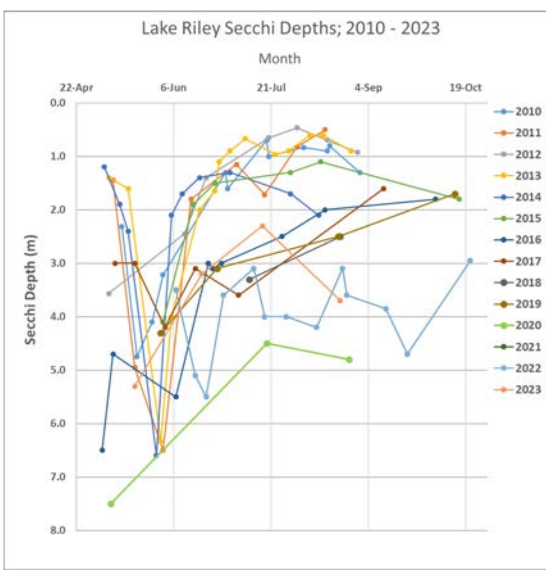
Carp were removed from Lake Riley in March 2010. A Lake Vegetation Management Plan was developed in winter 2013 and approved by the Riley Lake Association and the Minnesota DNR. To control curlyleaf pondweed, Lake Riley was treated with the herbicide endothall on 10 May 2013, 20 May 2014, 9 May 2015, 5 May 2016 and 3 May 2017 after water temperatures rose to between 10-15°C. Curlyleaf was delineated prior to treatment and herbicide was applied to approximately 20 acres (8.1 hectares) in 2013, 32 acres (13 hectares) in 2014, 20.1 acres (8.1 hectares) in 2015, 14 acres (5.7 hectares) in 2016 and 20 acres (8.1 hectares) in 2017. Diquat (Tribune) and a surfactant (Cygnet plus) was applied to 15.7 acres (6.35 hectares) in May 2018 to control curlyleaf pondweed. No curlyleaf treatment was conducted in 2019. A diquat (Tribune) treatment was applied to 16.0 acres (6.47 hectares) in May 2020 to control curlyleaf pondweed. In May of 2021, 2022, and 2023 a diquat (Tribune) treatment was applied to 22.3 acres (9.02 hectares), 16.7 acres (6.8 hectares), and 9 acres (3.6 hectares) respectively.

To control for Eurasian watermilfoil a 2, 4-D herbicide treatment occurred on 18 June 2015 and 21 June 2016. In 2015, it was applied to 35 acres (14.2 hectares) after delineation took place. In 2016, it was applied to 33 acres (13.4 hectares) after delineation took place. In June 2017, Eurasian watermilfoil was controlled with a split application of granular 2,4-d (Sculpin G) to 10 acres (4.0 hectares) and granular triclopyr (Renovate) to 10 acres (4.0 hectares). No Eurasian watermilfoil treatment was conducted in 2018, 2019, 2020, or 2021. In 2022, ProcellaCOR was used to treat 8.1 acres (3.3 hectares) in late August (after we were done sampling) to control Eurasian watermilfoil.

Additionally, hypolimnetic alum treatments occurred during 9 May 2016 and 11 June 2020 to decrease internal phosphorous loading and improve the water clarity. The 2020 treatment was the second and final dose conducted to further improve clarity and extend the life of the water quality improvement.

Water Quality:

Prior to the initial 2016 alum treatments, water clarity was typically low during summer months. Lake Riley Secchi depths were typically around 1m by the end of June or beginning of July before the first alum treatment occurred (Figure 1). Water clarity improved after the alum treatments in 2016 and was 2.8m in July. Spring and early summer water clarity remained high in 2017 through 2020, and Secchi depths were 1.9m or more through August. Water clarity in June-August 2016 to 2020, the prime native plant growth season, remained improved and more than 1.5m deeper than prior years during August. The 2020 season had the deepest Secchi depths recorded by the Newman lab for Lake Riley with Secchi depths > 4m all summer (Figure 1 & Figure 2). Secchi depths in 2021 also were >4m all summer, with a 6.3m average for May and a 5m average for June. In 2022 there was lower water clarity, with averages around 4m and 2023 also had lower water clarity with averages slightly lower than 2022, however late-season (July-August) Secchi depths remained > 2m. All three lakes surveyed had lower Secchi depth averages in 2023 than in years past. Dissolved oxygen and temperature profiles generally showed an anoxic hypolimnion below 5m in August but this has increased to 6-7m since 2020 (Figure 1).



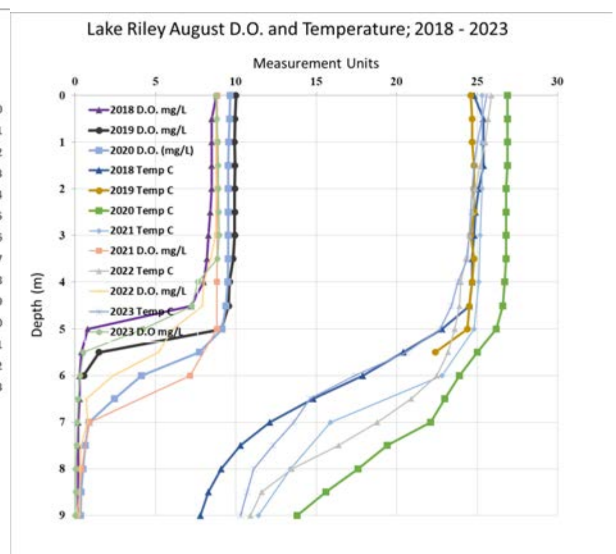


Figure 1. Secchi depths for Lake Riley 2010 through 2023 and dissolved oxygen (mg/L) and temperature (°C) profiles taken in August 2018 through 2023 (Newman lab data).

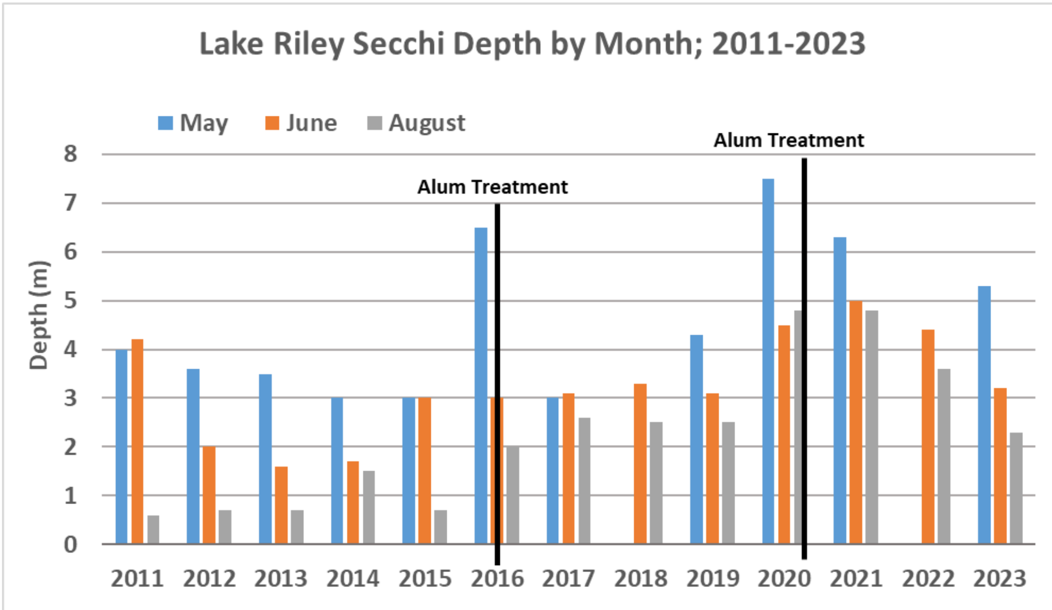


Figure 2. Mean monthly secchi depths for Lake Riley from 2011 through 2023 presented by month and year (Newman Lab and Riley Purgatory Bluff Creek Watershed District monitoring data).

Aquatic Vegetation Survey:

We conducted point intercept surveys on Lake Riley from 2011 through 2022. From 2011 to 2014, 13 species were observed in Lake Riley. Four additional species were recorded in 2015, and two additional species were recorded in 2016 bringing the total diversity to 19 species (Table 1). One more species, spiny-spored quillwort, was found in 2019. Unfortunately, despite the better water clarity only 10 species were found in 2017 (nine in the late summer survey) and 10 species were observed during both 2018 surveys (July and August), with eight species being native for these surveys. In 2019, 7-8 native species and 9-10 total species were found. In 2020, 7-10 native species and 9-12 total species were found. In 2021, surveys were only conduced in August, and 12 species were observed, with 10 species being native. In 2022, surveys were conducted in June and August. In June, 13 species were observed, 11 that were native. In August, 12 species were observed, 10 that were native. In May of 2023, 7 species were observed, and 5 species were native, in June, 11 species were observed, of which 9 were native, and in August, 11 species were observed, 9 were native.

The highest species richness per sample point from 2011 to 2021 was observed in a survey completed in August 2016 with six species at one site and a mean of 1.5 native species per point; this declined to one native species per point in 2017, similar to previous years. August of 2021 jumped back up to a mean of 1.5 submersed natives per point. In both June and August of 2022, the highest average of submersed natives per point was observed, with a mean of 1.7 for both months. In 2023 native richness declined slightly with a high of 1.3 natives per point in August. Throughout all survey years, most plants were in water < 2m deep. However, with the improved water clarity, in 2016 through 2023, some plants expanded to sites deeper than 4.0m and in 2023 plants were observed in sites up to 5.0m deep (Table 2).

Coontail, curlyleaf pondweed and Eurasian watermilfoil previously were the most frequently occurring species (Figure 3), with the exception of August when curlyleaf was typically not present due to its life cycle (Figures 3 and 4). In 2016, Canada waterweed surpassed curlyleaf occurrence in all surveys for the first time; native plant frequency of occurrence increased to over 80% of sampled points and Canada waterweed was observed at >40% of sites (Figure 4). However, abundant Canada waterweed did not persist and it declined to <10% frequency in 2020-2023. In 2021, 2022, and 2023 coontail was the most frequently occurring species, followed by bushy pondweed and Eurasian watermilfoil in 2021, curlyleaf pondweed and Eurasian watermilfoil in June of 2022, bushy pondweed and waterstargrass in August of 2022, curlyleaf pondweed and water stargrass in May of 2023, curlyleaf pondweed and chara in June of 2023, and water stargrass and bushy pondweed in August of 2023. Although some native taxa failed to increase in response to alum as they did in 2016, others managed to increase. Leafy pondweed reached its peak in 2018 at 10% in June. In 2021 and 2022, bushy pondweed increased to 32% in August of 2021 and 24.3% in June of 2022. Leafy pondweed was not observed in 2021, but was observed in small amounts in 2022. Floating-leaf and flat-stem pondweeds were sampled for the first time during 2020 (Figure 4).

From 2020 to 2023, coontail had the highest frequency of occurrence of all species. Coontail increased over this time, from 50% in May of 2020 to 80% in June of 2022 but decreased to 40% in 2023, the lowest frequency since 2014. Occurrence of chara has also been increasing since 2017. In 2019, chara had a frequency of 17% in June, and the highest frequency of chara was in June of 2023 at 24%. A few other native species have increased significantly in the past few years including bushy pondweed, long-leaf pondweed, small pondweed, and water stargrass. Water stargrass was first found in 2016 and found only at about 1% frequency until August of 2021, when it increased to 12%. It increased to 30% by August of 2022 and was 30% in August of 2023 as well. Long-leaf had its highest frequency in August of 2023 with 10% occurrence.

Eurasian watermilfoil and curlyleaf pondweed have both been problematic in Lake Riley. Prior to 2017, Eurasian watermilfoil was a dominant member of the plant community in the lake (Figure 3 & Figure 4). Eurasian watermilfoil was effectively controlled with the herbicide treatment in 2017, being reduced to 3% occurrence in late summer 2017 and 2018 compared to frequency of 20% or more in previous years of control (2015 and 2016). Eurasian watermilfoil frequency increased slightly in August of 2019 to 8% and further yet in August of 2020 to 10%. In August of 2021 frequency increased greatly to 30%, and slightly decreased in June and August of 2022 to 27% and 19%. Eurasian watermilfoil greatly decreased in 2023, with all three sampling months having less than 3% observed frequency.

In 2016, curlyleaf pondweed increased in frequency relative to previous treatment years but was subsequently reduced in 2017 with expanded control (Figure 3 & Figure 4). Despite a partial lake diquat treatment in 2018 for curlyleaf pondweed, without any treatment for control in 2019, curlyleaf pondweed frequency of occurrence in May and June increased sharply to 20% and 55%, respectively. Curlyleaf pondweed further increased in May of 2020 to 30% frequency of occurrence, however, it decreased in frequency to 25% during June (Figure 3 & Figure 4) after treatment. Frequency of curlyleaf pondweed increased slightly from June 2020 to June 2023, from 25% to 29% but has not expanded further. Periodic treatment of curlyleaf appears necessary to keep it in check.

Table 1. Aquatic plants found in surveys conducted in Lake Riley 2011 through 2023.

Common Name	Scientific Name	Abbreviation	Year First Observed
Submerged species			
Coontail	*Ceratophyllum demersum*	Cdem	2011
Muskgrass	*Chara spp.*	Char	2012
Canada waterweed	*Elodea canadensis*	Ecan	2011
Water stargrass	*Heteranthera dubia*[1]	Zdub	2016
Bushy Pondweed	*Najas flexilis*	Nfle	2011
Southern Naiad	*Najas guadalupensis*	Ngua	2015
Northern watermilfoil	*Myriophyllum sibericum*	Msib	2011
Eurasian watermilfoil	*Myriophyllum spicatum*	Mspi	2011
Curlyleaf pondweed	*Potamogeton crispus*	Pcri	2011
Leafy pondweed	*Potamogeton foliosus*	Pfol	2015
Long-leaf pondweed	*Potamogeton nodosus*	Pnod	2015
Small pondweed	*Potamogeton pusillus*	Ppus	2011
Flat-stem pondweed	*Potamogeton zosteriformis*	Pzos	2015
Sago pondweed	*Stuckenia pectinata*	Spec	2011
Water celery	*Vallisneria americana*	Vame	2016
Horned pondweed	*Zannichellia palustris*	Zpal	2011
Spiny-spored quillwort	*Isoetes echinospora*	Iech	2019
Floating-leaf Species			
Common duckweed	*Lemna minor*	Lmin	2014
White lily	*Nymphaea odorata*	Nodo	2011
Greater duckweed	*Spirodela polyrhiza*	Spol	2012

[1]*Heteranthera dubia* was formerly classified as *Zosterella dubia*

Table 2. Summary of point intercept surveys in Lake Riley from 2011 through 2023. Maximum depth of growth is based on the 95th percentile of points where plants were observed growing.

Survey Date	Maximum Depth of Plant Growth Observed (95%) (m)	% of Points with Native Taxa	Number of Submersed Natives	Average Secchi Depth (m)
June 2011	4.0	50%	6	4.1
August 2011	3.8	49%	7	0.6
May 2012	3.9	44%	8	3.6
June 2012	4.0	55%	9	2.0
August 2012	3.9	55%	9	0.7
May 2013	4.4	30%	3	3.1
June 2013	3.8	53%	6	2.2
August 2013	3.8	42%	9	0.7
May 2014	3.1	41%	5	3.0
June 2014	3.2	46%	11	1.7
August 2014	3.5	53%	9	2.1
April 2015	4.0	53%	7	4.1
June 2015	3.1	62%	8	1.7
August 2015	3.2	67%	12	1.1
May 2016	4.6	66%	5	5.5
June 2016	4.0	81%	6	3.0
August 2016	4.0	87%	14	1.5
May 2017	3.7	71%	3	4.2
June 2017	4.4	82%	4	4.2
September 2017	4.8	76%	7	1.9
July 2018	4.9	79%	6	2.8
August 2018	4.3	74%	6	2.5
May 2019	3.8	60%	6	4.3
June 2019	3.5	85%	8	3.1
August 2019	5.0	78%	7	2.5
May 2020	5.1	51%	6	7.5
July 2020	3.0	65%	6	4.5
August 2020	3.7	73%	9	4.8
August 2021	4.8	98%	8	4.7
June 2022	5.7	96%	10	4.4
August 2022	4.8	98%	9	3.6
May 2023	5.0	70%	5	5.3
June 2023	4.2	82%	8	3.2
August 2023	4.9	84%	8	2.3

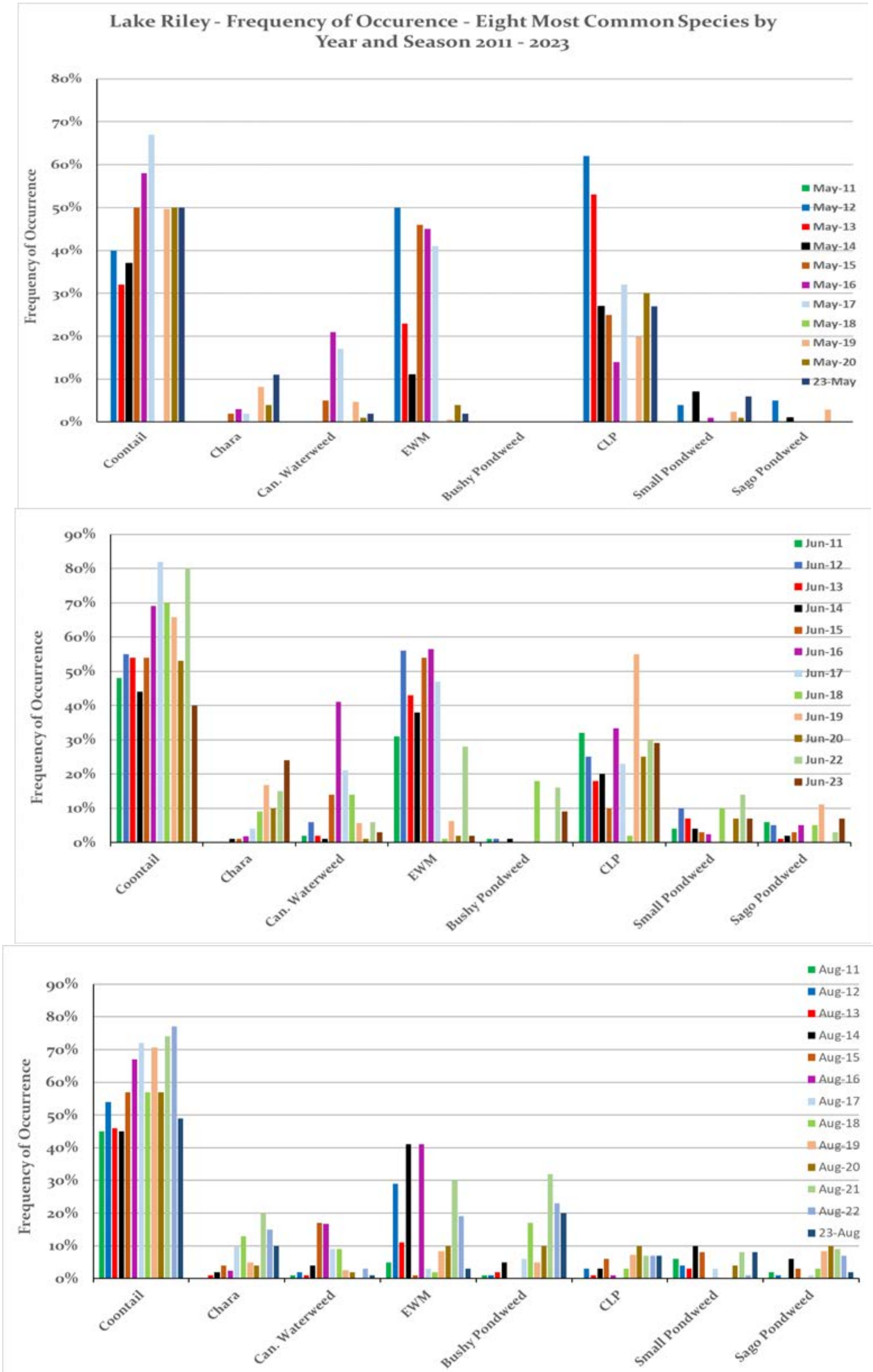
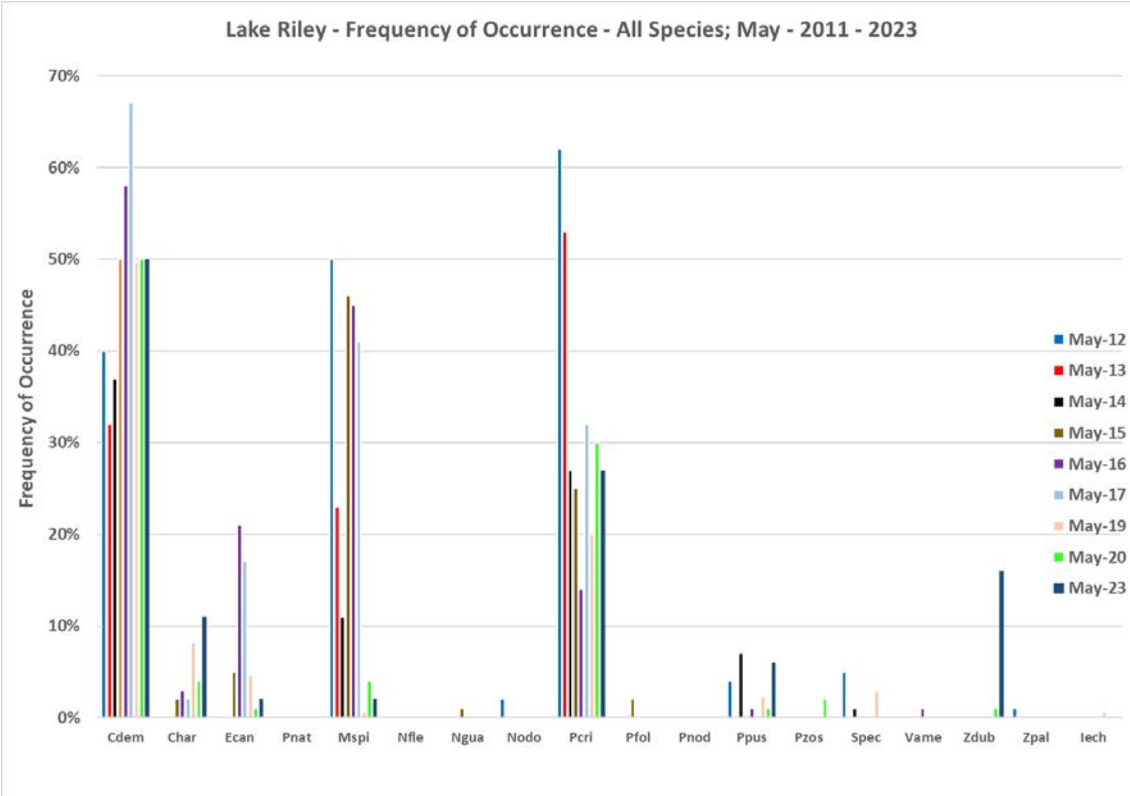
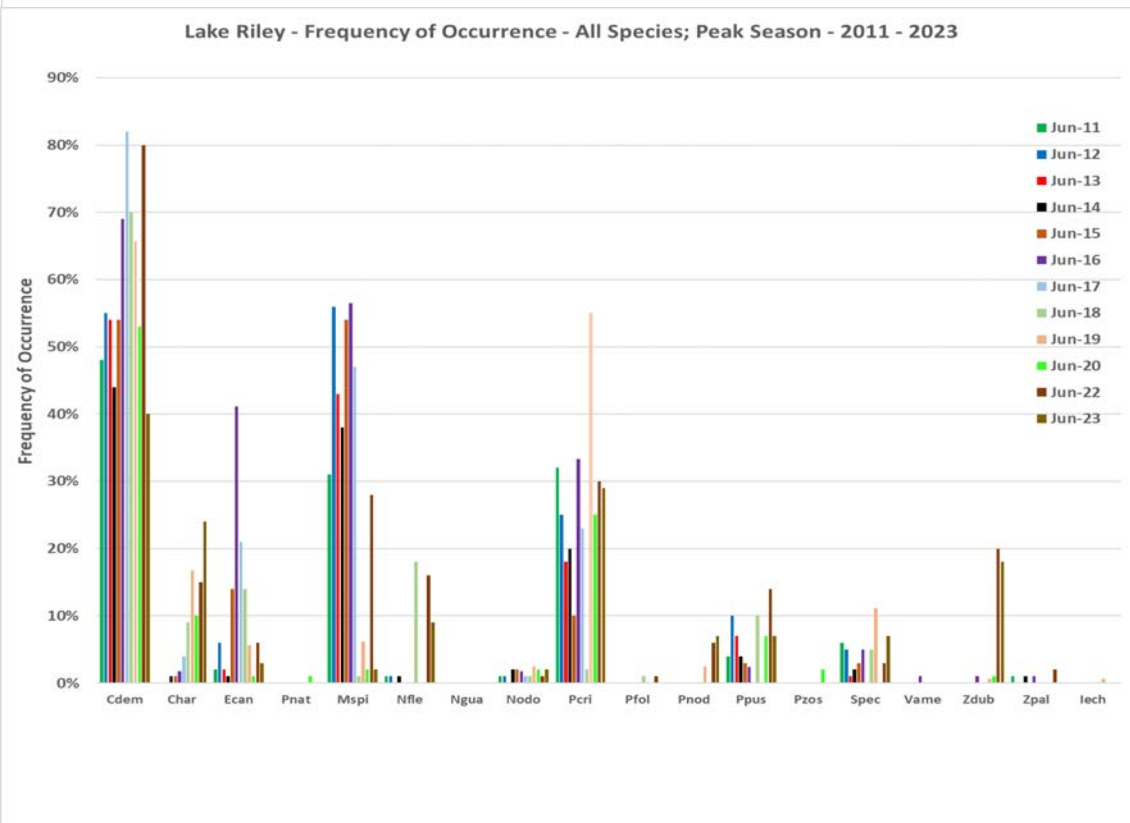


Figure 3. Frequency of occurrence of the eight most common plants from Lake Riley surveys May, June and August 2011 through 2023.


Lake Riley - Frequency of Occurrence - All Species; May - 2011 - 2023
70%
60%
50%
40%
30%
20%
10%
0%
Frequency of Occurrence
Cdem
Char
Ecan
Pnat
Mspi
Nfle
Ngua
Nodo
Pcri
Pfol
Pnod
Ppus
Pzos
Spec
Vame
Zdub
Zpal
Iech
May-12
May-13
May-14
May-15
May-16
May-17
May-19
May-20
May-23


Lake Riley - Frequency of Occurrence - All Species; Peak Season - 2011 - 2023
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Frequency of Occurrence
Cdem
Char
Ecan
Pnat
Mspi
Nfle
Ngua
Nodo
Pcri
Pfol
Pnod
Ppus
Pzos
Spec
Vame
Zdub
Zpal
Iech
Jun-11
Jun-12
Jun-13
Jun-14
Jun-15
Jun-16
Jun-17
Jun-18
Jun-19
Jun-20
Jun-22
Jun-23

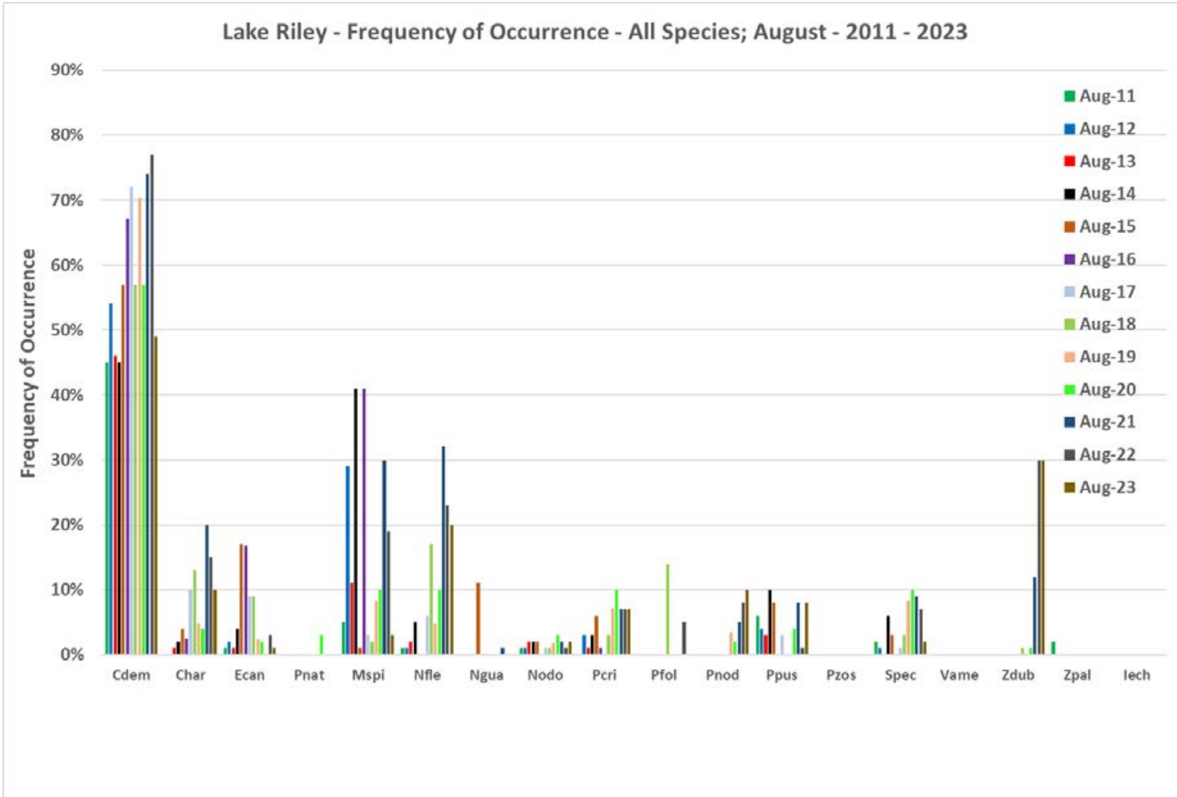


Figure 4. Frequency of occurrence of all plant taxa from Lake Riley surveys May, June and August 2011 through 2023. See Table 1 for plant abbreviations.

Curlyleaf Pondweed Herbicide Treatments:

Lake-wide early season endothall treatments took place in Lake Riley in the spring of 2013, 2014, 2015, 2016 and 2017. The total acreage treated in 2017 was 20 acres (8.1 hectares). The treatment in 2017 appeared to be more effective than the 2016 treatment, which was on a smaller area (14 acres) and ended with a lower dose than targeted. Treatment in 2018 used diquat (Tribune) and a surfactant (Cygnet plus) and was applied to 15.7 acres (6.35 hectares) total between the northern and western bays of the Lake Riley. No treatments took place in 2019. Diquat (Tribune) was applied to 16 acres (6.47 hectares) total between the northern and western bays in May of 2020, to 22.3 acres (9 hectares) in May 2021, and applied to 16.7 acres (6.8 hectares) in May 2022. Diquat was also applied to 9 acres (3.6 hectares) in 2023 (Figure 5).

Curlyleaf pondweed was observed in over 60% of sites sampled in the littoral zone in 2012. Since then, curlyleaf pondweed has been controlled to less than 25-30% of sites sampled in the littoral zone in June post-treatment surveys (Figure 6). The diquat treatment in 2018 was quite effective and reduced the frequency of curlyleaf, to < 3% occurrence (Figure 6). Without treatment in 2019, curlyleaf pondweed increased substantially to a peak of 55% frequency of occurrence in June. Treatment was necessary in 2020, but was fairly effective. Peak season curleyleaf pondweed was reduced to 25% frequency of occurrence, less than half that of 2019 peak season. After treatments in 2021, 2022, and 2023, peak season frequency was around 30%. Continued control in different areas appears necessary, but can keep curlyleaf pondweed occurrence to ≤ 30%.

Lack of treatment results in occurrence ≥ 50%. Native plants responded positively to curlyleaf control and have generally increased with curlyleaf control (Figure 7).

Turion densities in the sediments declined significantly ($p \leq 0.05$) from a peak of 132 turions/m^2 in 2012 to 3 turions/m^2 in 2017 and 12 in 2018 (Table 3). Despite the high frequency of occurrence of curlyleaf pondweed in 2019, turions densities remained low at 9 turions/m^2. After no turion sampling in 2020 or 2021, turion density was sampled again in 2022 and 2023, and remained low again at 8 turions/ m^2 in 2022 and increased slightly to 25 turions /m^2 in 2023, well below the abundance prior to the start of invasive control (Table 3; Figure 6). Turions were not sampled during 2020 due to early winter weather, and not sampled in 2021 due to Covid-19. Overall, regular herbicide treatments have kept curlyleaf coverage < 30% (Figure 6).

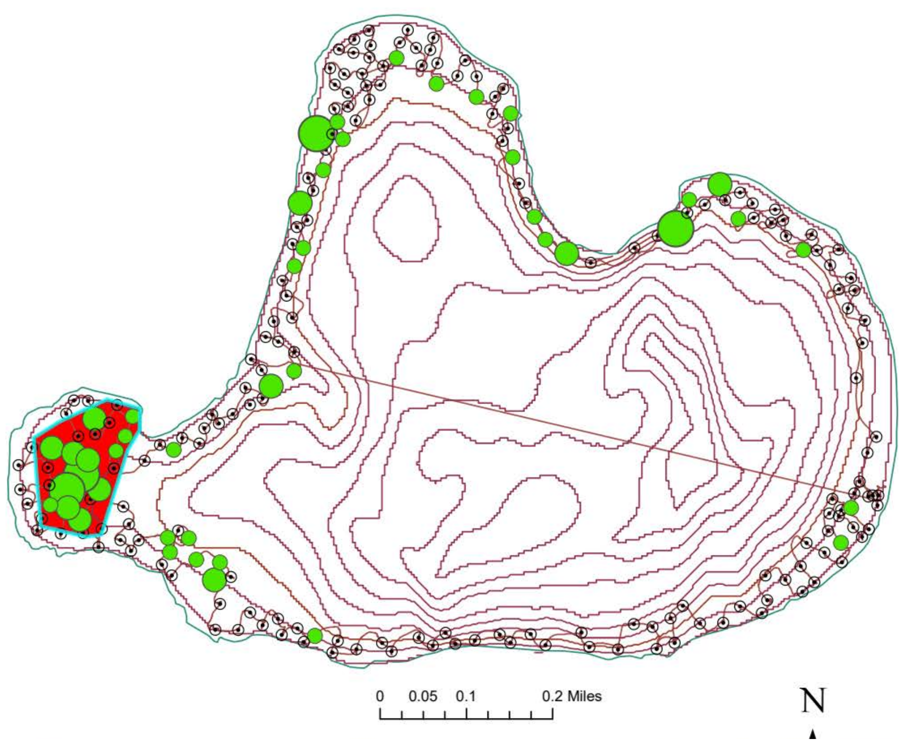
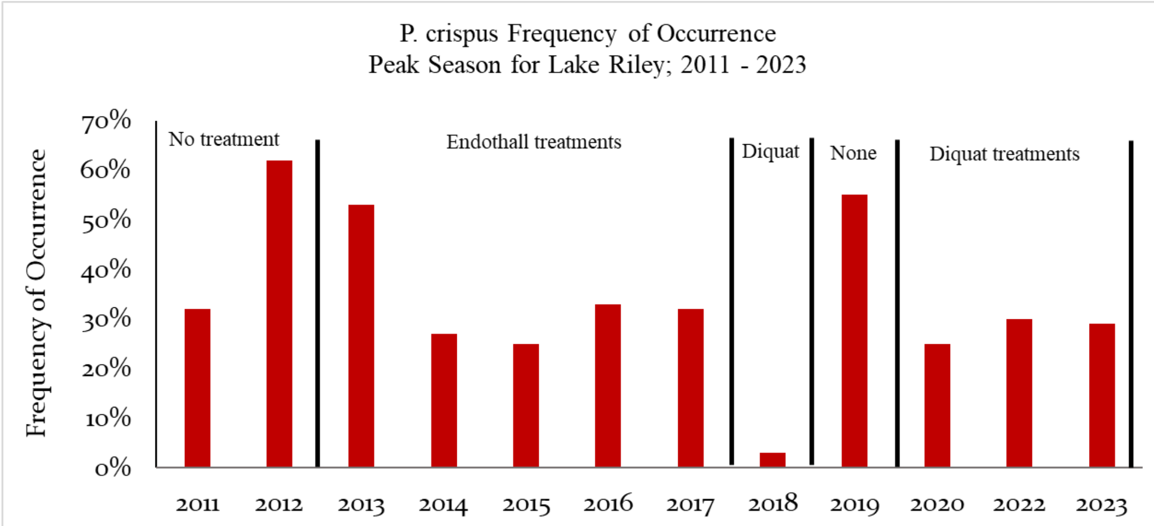


Figure 5. Curlyleaf pondweed diquat treatment block for May 2023 (red box) and curlyleaf relative density at locations from the delineation (green dots – larger dots size represents greater relative frequency of occurrence). In total, 9 acres (3.6 ha) were treated with diquat (Tribune) herbicide.



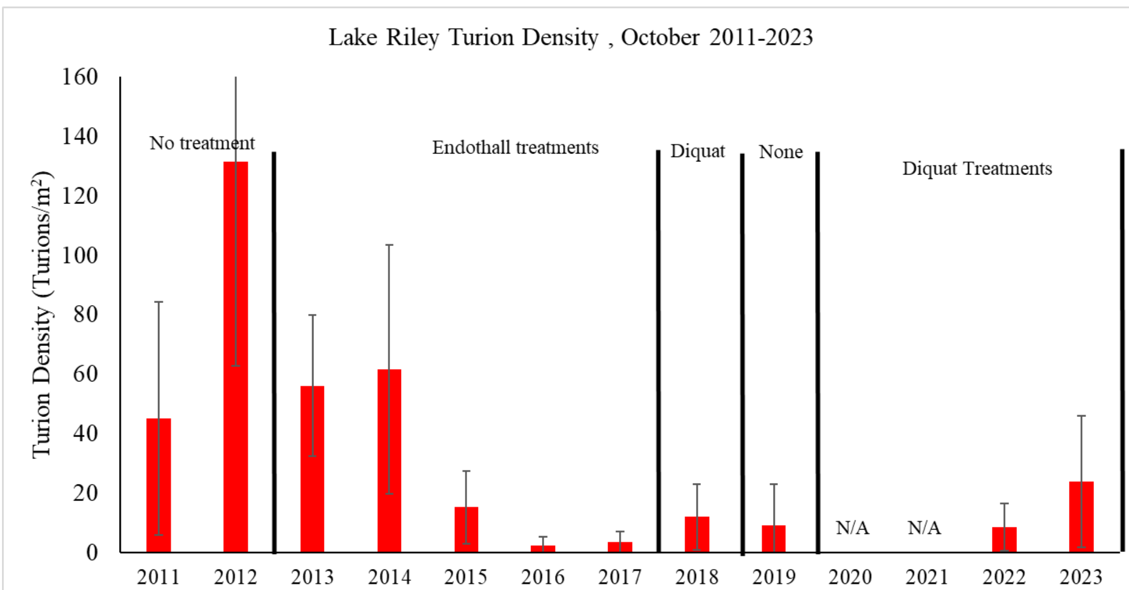
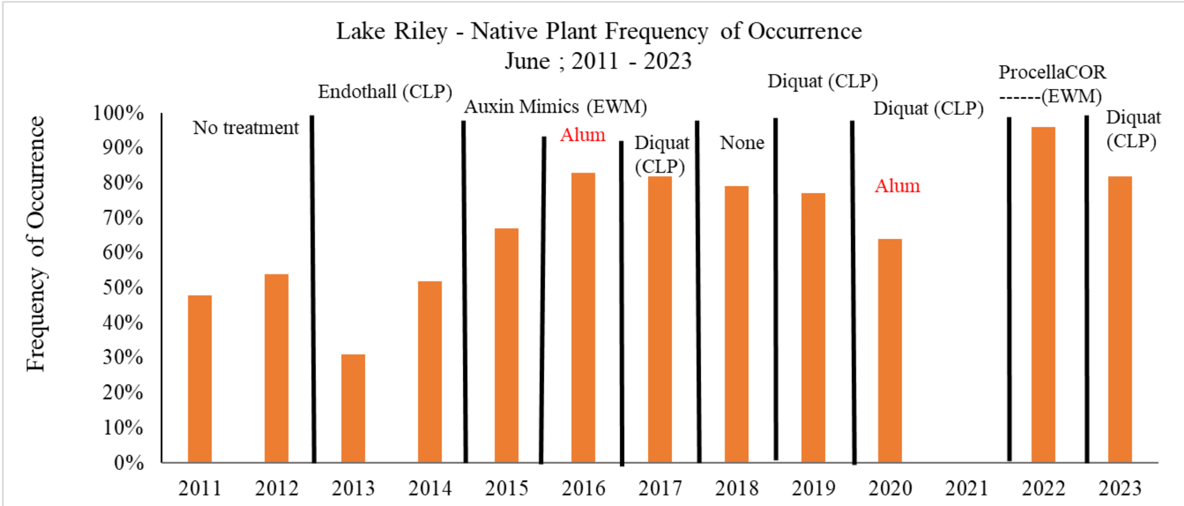


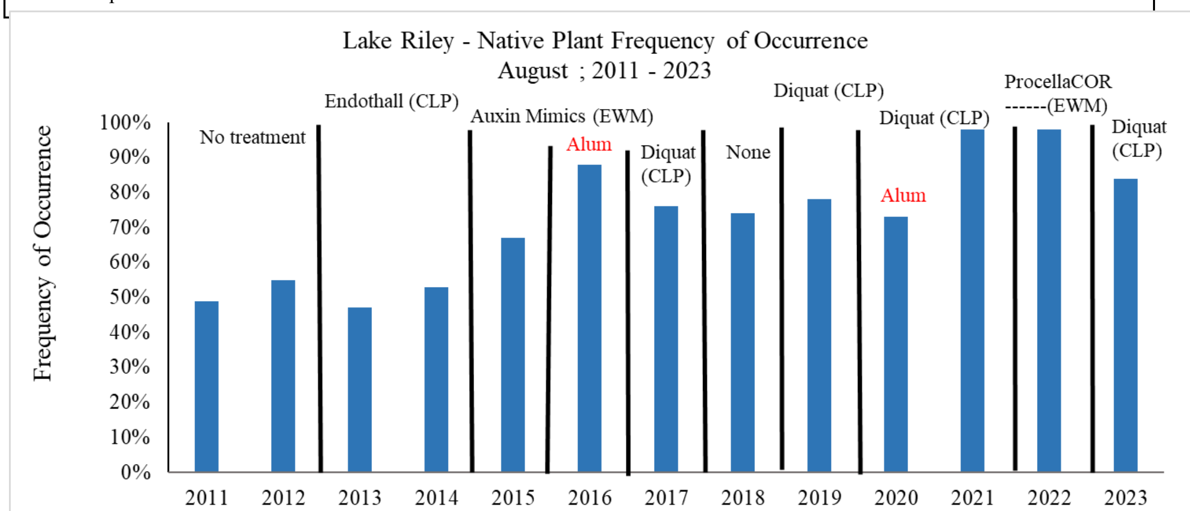
Figure 6. Peak frequency of occurrence of curlyleaf pondweed (May or June survey) and sediment turion density in Lake Riley 2011 through 2023. The vertical line represents the beginning of herbicide treatment and divides pre- and post- treatment years. Turion sampling did not take place in 2020 or 2021.

Table 3. Sediment turion density and viability from surveys conducted October 2011 through 2023 in Lake Riley. Note: Declines from 2012 to 2016 are significant ($p \leq 0.05$). Turion sampling did not occur in 2020 or 2021 (N/A).

Date	Turions/m^2	Viability	Viable Turion Density
Oct-2011	45	96%	43
Oct-2012	132	99%	131
Oct-2013	56	71%	40
Oct-2014	61	33%	20
Oct-2015	14	44%	6
Oct-2016	2	100%	2
Oct-2017	3	100%	3
Oct-2018	12	61%	5
Oct-2019	9	100%	9
Oct-2020	N/A	N/A	N/A
Oct-2021	N/A	N/A	N/A
Oct-2022	8	50%	4
Oct-2023	25	91%	24



#Native Species	6	9	6	11	8	6	4	6	8	6	N/A	10	9



#Native Species	7	9	9	9	12	14	7	6	7	9	8	9	9

Figure 7. Native plant frequency of occurrence in the littoral zone in June and August in Lake Riley 2011 through 2023. Below the graphs are the number of submerged native species observed each year. The vertical lines represent the beginning of herbicide treatments and divides pre- and post- herbicide treatment years.

Eurasian Watermilfoil Herbicide Treatment:

Eurasian watermilfoil was treated in 2015, 2016, 2017, and 2022 on Lake Riley. In 2016, 33 acres (13.4 hectares) were treated with 2, 4-d herbicide at targeted concentration within the treatment areas of 2.0 mg/L. In 2015 and 2016, August Eurasian watermilfoil frequency of occurrence decreased (Figure 8) compared to the pre-treatment June surveys. However, August frequency of occurrence and reductions were variable throughout the survey years.

In 2017, a slightly smaller area of 20 acres (8.1 hectares) was treated with granular herbicides; 10 acres (4.0 hectares) with triclopyr as Renovate OTF (2.5 ppm target) and 10 acres (hectares) with 2,4-d as Sculpin G at 4ppm. The combination of a granular treatment at a higher dose effectively controlled Eurasian watermilfoil lake-wide, with only several scattered plants in treated areas and a few small patches remaining in one untreated area. Lake-wide, milfoil frequency was reduced to 3% (Figure 9) through these treatments. However, native plants also appeared affected (Figure 3). Coontail declined 10% in frequency and both muskgrass and Canada waterweed decreased relative to both June and the previous year. The failure of native plants to continue to increase or sustain frequency of occurrence levels attained in 2016 did not appear due to water clarity; June and August Secchi depths were 3.5 and 3.0 m in 2016 and 2017 respectively compared to 1.2-1.9m in 2013-2015. Furthermore, five native taxa present in 2016 did not appear in 2017.

Genetic analysis by the Thum lab in 2018 based on watermilfoil samples from September 2017 revealed no hybrid watermilfoil – only pure Eurasian watermilfoil was found and it was the widespread Eurasian genotype (Newman and Thum 2019). It was difficult to find milfoil plants after the treatment and the treatment did not appear to shift the population towards hybrid in the following years.

Aggressive milfoil control was avoided in 2018 through early August 2022 to see if the native plant assemeblage would continue to recover. Eurasian watermilfoil frequency remained low (<10% Figure 8) and August native plant frequency remained above 72% through 2020. Species richness per sample increased somewhat and has remained at 10 the past two years. A new species, spiny-spored quillwort (*Isoetes echinospora*), was found during sampling in 2019. Without treatment, frequency of Eurasian watermilfoil in August of 2021 was around 30%, slightly lower in June 2022 and decreased to 3% in August of 2023 without any treatment.

After 4 years without aggressive milfoil control, a new treatment was used in August 2022. In late August of 2022, 8.1 acres (3.3 hectares) were treated with ProcellaCOR. Although Eurasian watermilfoil had declined to <20% occurrence prior to treatment in August, the treatment seemed to be effective as frequency of Eurasian watermilfoil was below 3% in all summer months of 2023.

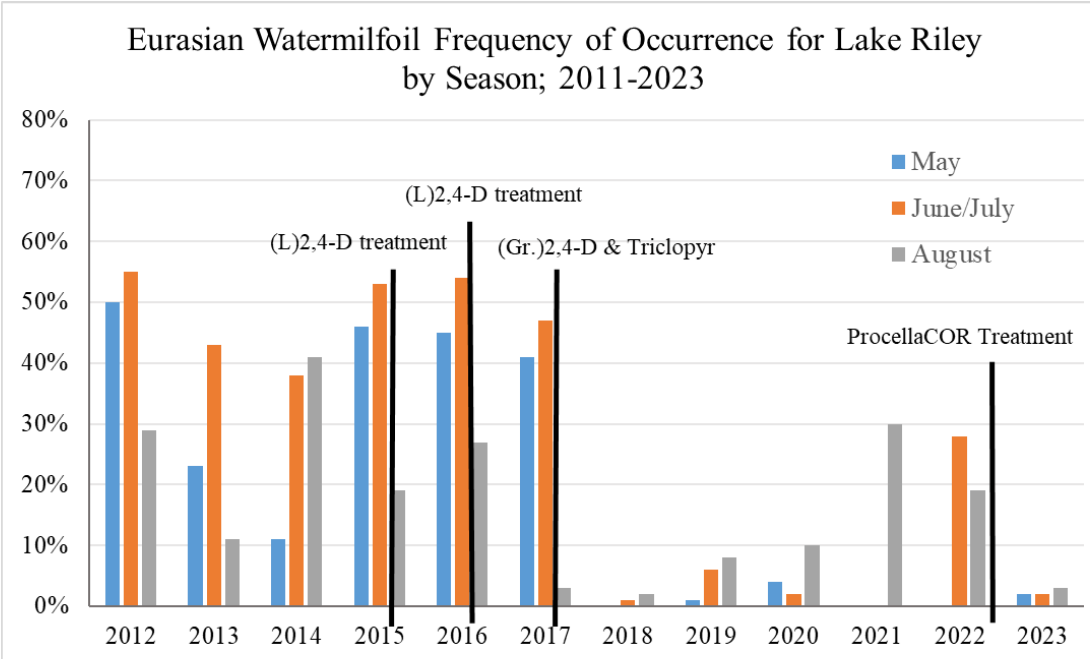


Figure 8. Frequency of occurrence of Eurasian watermilfoil in Lake Riley from 2011 through 2023. The vertical line represents the beginning of herbicide treatments and divides pre- and post-treatment sampling periods. L indicates liquid and Gr indicates granular formulations of these herbicides.

Alum Treatment:

On May 9th and 10th 2016 and June 11th 2020, Lake Riley received hypolimnetic alum treatments. Alum treatments improve the water clarity by binding phosphorous in the water column and in the sediment. Reducing phosphorous prevents the wide-spread growth of planktonic algae in the water column, increasing the clarity and thus the light penetration in the lake. Aquatic plants have been demonstrated to expand and increase in richness and abundance as a result of the improved clarity. As indicated above, water clarity increased significantly in 2016 through 2022 and good clarity was sustained during the June-August native plant growing season these years (Table 2). The average Secchi depth from June and August of 2021 was the deepest recorded by the Newman lab at 5m and 4.8m. Native aquatic plants occurred at 67% of sampled littoral points in August of 2015, pre-treatment. Post-treatment, native aquatic plants occurred at 88% and 73% of sampled points in August of 2016 and 2020, respectively (Figure 7). Post-treatment in 2020, native plant frequency was 96% in June of 2022, and 98% in August of 2022 (Figure 7). Native aquatic plant abundance had been increasing since curlyleaf management began in 2013 but the 2016 increase was the largest yearly increase since monitoring began in 2011. However, native plants failed to persist through 2017, possibly due to non-target impacts from the herbicide treatment. Submersed native plants made a modest recovery from four species in June of 2017 to six species in August of 2018, seven in 2019, nine in 2020, 10 in June of 2022, and 8 in June of 2023 (Table 2).

Zebra mussels were discovered in Lake Riley during the fall of 2018, which may have future implications for water clarity. Continued monitoring will determine if native plants will further increase if current water clarity persists or improves.

Biomass:

Coontail has been the predominant species within Lake Riley with a peak biomass that occurred during August of 2016 at 985 g/m^2 (Table 4). Coontail had the highest biomass until August of 2023, when chara increased to 126 g/m^2 and the peak coontail biomass during the 2023 season (August) was significantly lower at 99.3 g/m^2. Eurasian watermilfoil had a peak biomass during June 2015 at 52.1 g/m^2. However, subsequent herbicide treatments during 2015, 2016, 2017, and 2022 were effective as biomass of Eurasian watermilfoil decreased to 0.001 g/m^2. Biomass was not sampled in 2018 or 2021. Eurasian watermilfoil was not detected during biomass sampling in June of 2023 but was detected during May and August sampling at 0.6 g/m^2 0.01 g/m^2, respectively. In June of 2019, curlyleaf pondweed had the second highest biomass at 25.8 g/m while while in August, muskgrass was the second highest at 103.7 g/m^2. In June of 2020, curlyleaf pondweed had the second highest biomass at 21.1 g/m^2 while sago pondweed had the second highest biomass in August at 7.5 g/m^2. In June and August of 2022, chara had the second highest biomass at 56.6 g/m^2 and 54 g/m^2 respectively (Table 4). Overall, native plant biomass in 2023 (45-357 g/m^2) was much higher than invasive biomass (0.5-17.2 g/m^2). After the alum treatment in 2020, native biomass in 2020 was somewhat lower than in the years immediately following the initial alum treatment in 2016, but increased greatly in 2022. These numbers decreased in May and June of 2023, but August 2023 native biomass increased greatly (Table 4).

Table 4. Average dry plant biomass within the littoral from 2011 through 2023 in Lake Riley. Biomass data was not collected in 2021. All data presented in g-dry/m^2.

	Coontail	Chara	Canada waterweed	Spiny-spored qullwort	Star duckweed	Bushy pondweed	Southern naiad	Eurasian watermilfoil	White water lily	Curlyleaf pondweed	Small pondweed	Variable pondweed	Leafy pondweed	Sago pondweed	Water stargrass	Water celery	Horned pondweed	Long-leaf Pondweed	Curlyleaf turions	Natives	Invasives
Jun-11	26.6		0.04					9.6		8.1	0.5			0.1			0.03		30.0	27.5	45.1
Aug-11	56.8		0.1					36.9			0.2									57.0	36.9
May-12	69.7		0.4					52.0		120.1	0.3			1					1.5	71.4	172.1
Jun-12	173.4		0.6					124.1	0.9	2.8	2.1	3.9		3.4					0.1	184.4	130
Aug-12	199.6	0.03	0.4					25.1	15.5	0.4	0.2								6.1	215.9	25.5
May-13	19.8		1					0.3		7.3									0.2	20.7	7.6
Jun-13	39.0							22.7		0.7	0.2								0.9	39.1	23.3
Aug-13	66.2		0.06			0.1		1.0		0.02									0.7	66.6	1.0
May-14	60.6	0.7	0.1					0.8		2.0	0.01									61.4	2.8
Jun-14	60.0		0.1					22.7		2.8	0.02			0.3					6.2	60.4	25.4
Aug-14	117.7		0.5					43.2	3.0		0.7			0.04						122.0	165.2
May-15	62.5	0.3	0.09					3.7		0.7	0.04									63.0	4.4
Jun-15	237.0	17.6	3.1					52.1		5.9	0.1			0.05	0.01				0.004	258.0	58.0
Aug-15	397.5	0.1	17.6				2.4	6.9					12.8	0.2					0.03	430.6	7.1
May-16	290.0	0.1	7.5					23.0		0.3						0.02			0.1	297.6	23.3
Jun-16	360.7	0.1	6.6					13.3		27.5	0.05								1.8	367.5	2.1
Aug-16	985.2	6.2	53.6			0.1		22.6		0.1	0.2			2.1						1047	22.7
Jun-17	128.1	140.6	4.2					29.1		2.3										273.0	31.3
Sep-17	367.6	20.8	3.7		0.02			0.04	1.5	0.2										393.7	1.3
May-19	103.6	0.6	0.1	0.2	0.03					2.1	0.03								0.01	104.6	2.1
Jun-19	185.4	0.5	0.5					0.04		25.8				1.8	0.06				2.9	188.2	28.7
Aug-19	258.9	103.7							4.7					1.9					0.9	369.2	0.9
May-20	81.7									0.8									0.08	81.7	0.9
Jun-20	158.2	3.3								11.7	1.9			2.6					0.05	166.0	11.8
Aug-20	173.5	0.7	0.01					0.1						4.3	0.04				0.1	178.6	0.2
Jun-22	181.2	56.6	0.2			0.3		5.9		1.1	0.01		0.03	0.8	0.99			1.9	0.06	242.0	7.0
Aug-22	399.6	54	16.5			17		28.2	2.6	2.5			0.03	15.5	37.9			30.7	0.04	571.5	30.7
May-23	33.7	5.0	0			0.01		0.6		16.4	0				4.82				0.2	43.5	17.2
Jun-23	8.7	19.3	0.7			6.1				0.3				0.6	15.4			1.1	0.15	52.0	0.5
Aug-23	99.3	126.1				11		0.01		0.8				0.9	87.8			13	0.05	338.1	0.9

Aquatic bathymetry and vegetation maps:

Plant coverage and biovolume increased in 2015 and 2016. The effects of the milfoil treatment in 2017 are clear in both the maps and the coverage and biovolume estimates (Figure 9). Coverage declined to <50% in September 2017 and biovolume was relatively low at 19%. Biovolume in August 2018 was 34%, lower than most prior years at this time (Table 5). The lower value is likely due to milfoil control in 2017 and also reduced coontail abundance throughout 2018 (Figure 4 & Figure 5). Biovolume increased during 2019, however this was likely due to to increased coontail abundance. Biovolume decreased slightly in 2020 likely due to curelyleaf pondweed control in 2020. Biovolume stayed about the same between 2020 and 2023, but coverage increased, suggesting a more diverse plant community.

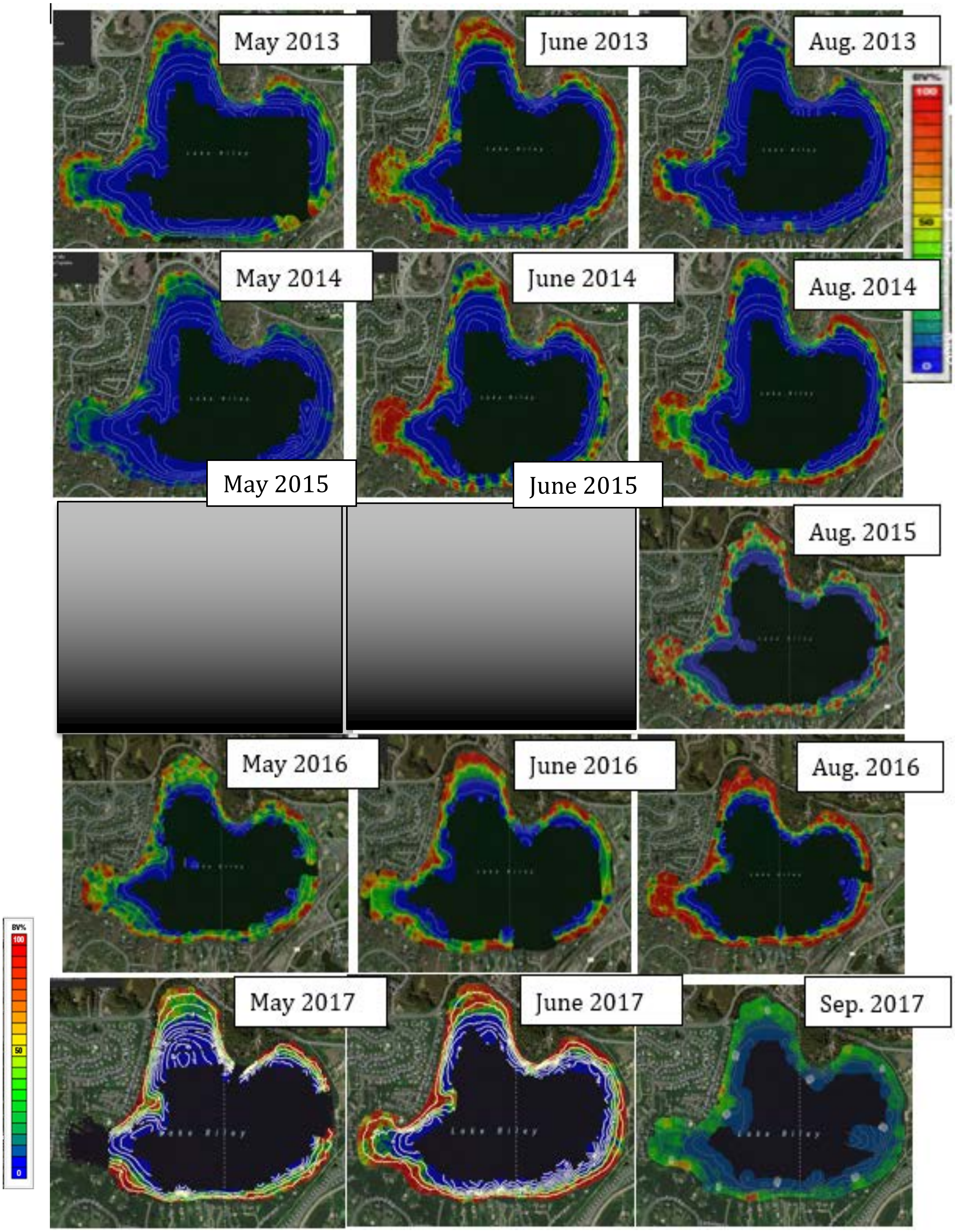

May 2013
June 2013
Aug. 2013
BV%
100
50
0
May 2014
June 2014
Aug. 2014
May 2015
June 2015
Aug. 2015
May 2016
June 2016
Aug. 2016
BV%
100
50
0
May 2017
June 2017
Sep. 2017

Figure 9 Continued

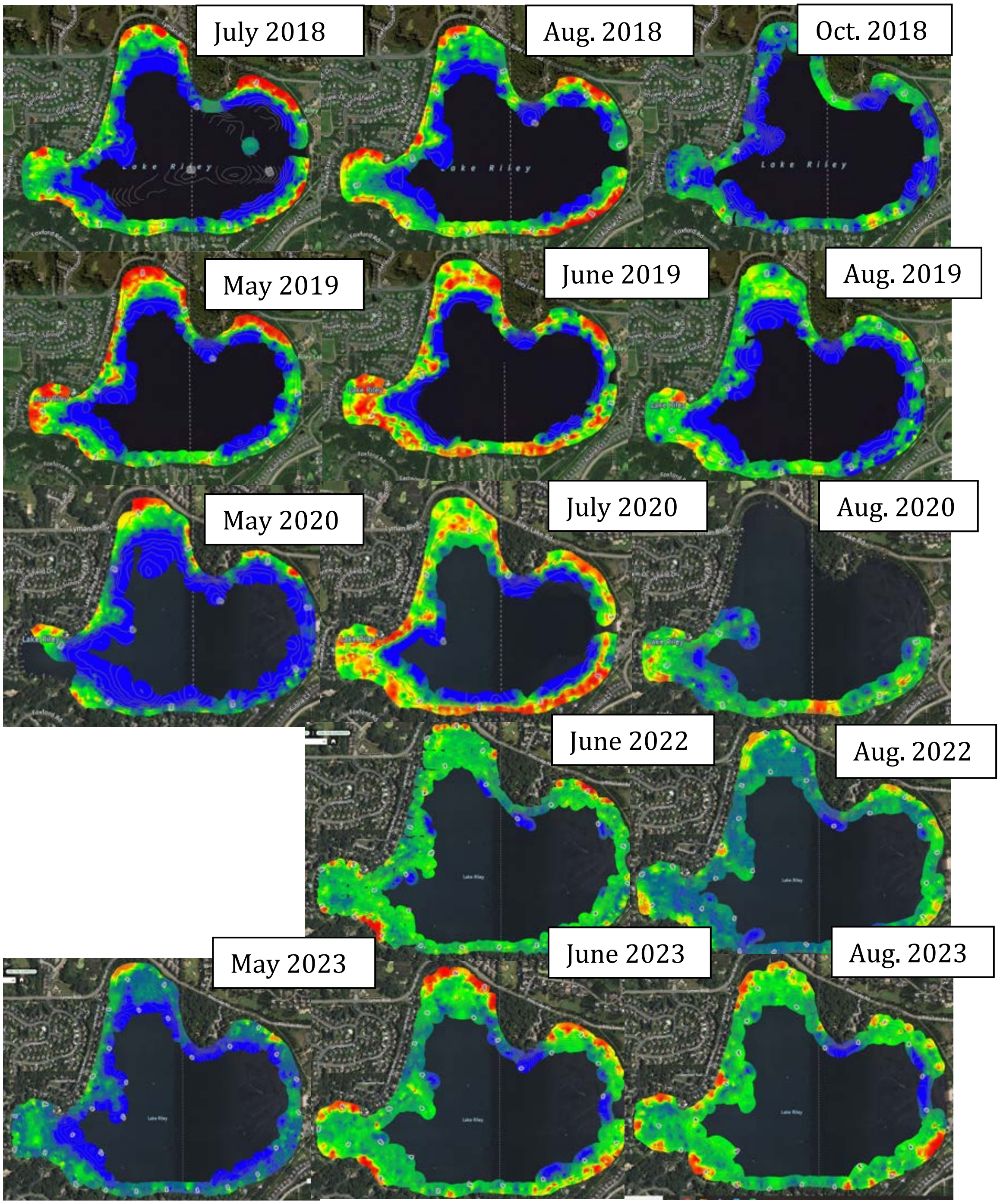


Figure 9. Aquatic bathymetry and vegetation maps of Lake Riley based on processing by Biobase. Data collected during point intercept aquatic vegetation surveys by the Newman lab on: 8 May 2013, 18 June 2013, 14 August 2013, 16 May 2014, 18 June 2014, 12 August 2014, 13 August 2015, 4 May 2016, 9 June 2016, 5 August 2016, 10 May 2017, 5 June 2017, 6 September 2017, 11 July 2018, 22 August 2018, 24 October 2018, 25 May

2019, 26 June 2019, 21 August 2019, 8 May 2020, 2 July, 25 August 2020, 21 June 2022, 22 August 2022, 18 May 2023, 19 June 2022, and 22 August 2023. Equipment failure corrupted data in May and June 2015, and recording issues interfered with August 2020 data collection. Contour lines are 5ft intervals. Color legend represents percent biovolume (refers to the percentage of the water column taken up by vegetation when vegetation exists) with blue representing no vegetation present and red representing 100% of the water column being taken up by vegetation.

Table 5. Lake Riley lake-wide percent area cover (PAC) and average biovolume (BV) for 2013 - 2020 and 2022-2023. No data were collected in 2021. Values coincide with maps in Figure 10. PAC refers to the overall surface area that vegetation is growing in the surveyed area. Average BV refers to the percentage of the water column taken up by plants when plants exist; areas that have no plants are not factored into this calculation. *August 2020 data incomplete due to recording failure.

Date	PAC	Average BV
May 2013	49.2%	36.6%
June 2013	60.2%	53.2%
August 2013	25.6%	38.5%
May 2014	24.6%	15.4%
June 2014	50.3%	55.9%
August 2014	47.6%	47.7%
August 2015	68.3%	62.7%
May 2016	70.5%	49.9%
June 2016	74.8%	66.5%
August 2016	75.5%	37.8%
May 2017	58.2%	37.8%
June 2017	60.9%	51.0%
September 2017	46.6%	18.9%
July 2018	80.8%	31.9%
August 2018	73.2%	33.6%
October 2018	60.5%	16.0%
May 2019	66.8%	38.6%
June 2019	58.1%	45.7%
August 2019	61.4%	24.6%
May 2020	33.6%	27.9%
July 2020	69.9%	43.7%
*August 2020	84.7%	24.4%
June 2022	94.6%	24.3%
August 2022	86.8%	17.2%
May 2023	54.1%	12.5%
June 2023	85.1%	24.2%
August 2023	86.4%	23.1%

Recommendations for Lake Riley:

Native plants positively responded to the combined control of curlyleaf pondweed and Eurasian watermilfoil in addition to the improved water clarity due to the alum treatment and prior removal of common carp. With the removal of common carp in 2010, both native and invasive plants increased in frequency and biomass from 2011-2014 resulting in the need for invasive plant control. Water clarity improved in May and June with carp removal (Secchi >2m) but remained low in July and August (often <1m) which continued to limit native plant abundance. An alum treatment was needed to maintain good summer long water clarity.

Significant increases in both frequency of occurrence and biomass of natives were observed in 2016 after alum treatment. Improved water clarity appeared to enhance the recovery of the native plant community and expansion of native plants in water deeper than 2.5m. Unfortunately, the positive response did not persist through 2017, most likely due to direct or indirect effects of the milfoil treatments, which did, however, greatly reduce Eurasian watermilfoil. The lack of treatment in 2018 and 2019 did not further harm the native community, but the native community only incrementally improved. Although peak native frequency of occurrence in 2020 was close to that of 2018, the number of native species was only slightly higher than 2019. It appears that the second alum treatment in spring of 2020 further improved native plant recovery, with native frequency of occurrence being greater than 85% in August of 2022 and 2023. Water clarity also improved from 2020 to 2021. The was curlyleaf pondweed herbicidal control completed in May of 2021, 2022, and 2023 did not appear to have any negative or positive effects on native plants, consistent with past research (Jones et al. 2012).

Eurasian watermilfoil had been present at nuisance levels and the 2015 and 2016 herbicide treatments to control it appeared to reduce the August frequency of occurrence. The use of granular herbicides at slightly higher doses in 2017 was aimed at getting better exposure to the herbicide. Lake-wide reduction in Eurasian watermilfoil indicates the treatments were quite effective and Eurasian watermilfoil had remained suppressed at < 11% of sites and barely detectible biomass from the 2017 treatment to 2020. In 2021, Eurasian watermilfoil appeared at around 30% of sampled sites. This number decreased slightly during 2022 to <20%. The 2022 treatment with ProcellaCOR occurred after sampling in August and but appears extremely effective, as Eurasian watermilfoil frequency decreased to less than 3% in all summer months of 2023. However, as this was a lakewide decline other factors may have resulted in the low watermilfoil abundance and biomass. With this low frequency, treatment should not be needed in 2024. Genetic testing of plants collected in September 2017 revealed no hybrid watermilfoil and indicated that all plants remaining after treatment were Eurasian watermilfoil. This indicates that herbicide tolerant hybrids are not currently a concern in Lake Riley (Larue et al. 2013).

It is not certain that the auxin mimic treatments had an effect on native plants but the reduction in coontail and Canada waterweed in 2017 is consistent with other studies (e.g.. Nault et al. 2012, 2014) as is the failure of wild celery to continue to increase. Treatments were deferred in 2018 through 2020 to see if the native plants would recover. Good water clarity (Secchi > 3.5-4m) has been sustained since 2016 and was further improved with the second alum dose in 2020. The native plants are rebounding toward 2016 levels. Eurasian watermilfoil remained at low frequency of occurrence 2018 through 2020; this break in treatment may have assisted with native plant recovery along with clarity improvments from alum treatment in 2020. The break in treatment was the most likely cause of increased levels of invasives in Lake Riley, however, native species have been improving in frequency since the 2020 alum treatment. Milfoil weevils were present in 2012-2015 and may be worth considering if native plants expand and sunfish densities are not too high.

Curlyleaf pondweed appeared to be reduced from the 6 consecutive years of treatment based on frequency of occurrence and turion densities. The 2016 increase in frequency of occurrence warranted continued treatment in 2017; this treatment was very effective controlling curlyleaf and keeping turion densities very low, despite fewer acres having been treated. The spring 2018 treatment with diquat (Tribune) with a surfactant (Cygnet plus) in the northern and western bays appeared to have fewer detrimental effects on native species than later summer milfoil treatments. Native species promotion appears to be occurring, likely in part due to the 2018 treatment not being overly aggressive. Delineations in spring 2019 suggested that a curlyleaf treatment was not warranted, however, frequency of occurrence peaked at over 50% in 2019, so treatment was necessary in 2020. Curlyleaf peaked at 30% frequency of occurrence in 2020, less than half of 2019's peak, likely due to the early season, partial-lake diquat treatment. There was no plant survey completed during peak curlyleaf pondweed season in 2021, but after a diquat treatment in May, August densities were lower than in 2020. In 2022 and 2023 there were diquat treatments, but peak season frequency was 30% for both years. A spring delineation in 2024 will be helpful in determining next steps for controlling curlyleaf pondweed in Lake Riley. Keeping Eurasian watermilfoil and curlyleaf pondweed at or below 20% and 30% frequency appears a feasible management target.

If invasive species remain in check and good clarity persists, the native plants should have more space and light, less competition from the invasive species and ideally be able to establish and continue expanding in 2024 with improved clarity from the alum treatment. If recovery of the native plant community does not progress in 2024, planting or transplanting could be considered to jump-start the recovery, but the presence of propagules in the seed bank suggests natural recruitment should be sufficient. After consistent presence of 10-12 native taxa with higher Secchi depths it is likely that these numbers could represent a relatively stable native community in Lake Riley, however, it will be important to continue assessment frequency in peak summer months to compare to previous results. Although it is unfortunate that Lake Riley now has zebra mussels, this development may further improve water clarity. (https://www.dnr.state.mn.us/invasives/ais/infested.html).

IV. Staring Lake Results

Staring Lake is a eutrophic lake in the Purgatory Creek Watershed. The lake has an area of about 164 acres (66 hectares), with a maximum depth of 4.9m (16ft) (MN DNR LakeFinder 2016). Until 2015, Staring Lake had a large population of carp (Bajer and Sorensen 2012) and had been turbid and algae-dominated with low water clarity. Efforts began in 2012 to reduce the carp population and a substantial, but still only partial, removal occurred in winter 2014 (Bajer and Sorensen, personal communication).

In 2015, the carp were further reduced to approximately 10% of the original 2011 population prior to removal. Carp were still at low abundance as of 2023. Increases in native and exotic plant diversity, frequency of occurrence, and biomass occurred in the 2015 and 2016 surveys relative to previous years. Additionally, in 2015 the later summer water clarity improved somewhat relative to previous years (Figure 10). However, in 2016 and 2017 the summer Secchi depth did not further improve and may have constrained native plant expansion. Secchi depth slightly improved in 2018 through 2023 over 2017 measurements, which may be due to an expanded plant community and may have aided further plant expansion. Increases in curlyleaf pondweed and particularly Eursaian waterfmilfoil over the past several years necessitated control in 2022 with a whole-lake fluridone treatment (3 ppb target and bump) initated in May. No treatment was conducted in 2023.

Water quality:

Secchi depths increased during the summer following carp removal in 2015. There was a slight decrease in late summer Secchi depth in 2016 relative to 2015 with July and August Secchi depths of 0.8m and 0.6m respectively (Figure 10 & Figure 11). Early season water clarity increased from 2018 to 2023, remaining above 2.6m in June of 2023. August clarity is lower than early season, but slowly increased from 2011 to 2019, peaking at 1m. There was a slight decrease to 0.8m in 2020 and 2021, and average August clarity in 2023 was around 0.6m. Average Secchi depth increased in May, June, and August from 2020 to 2021 with June clarity improving from 1.6m to 2.5m from 2020 to 2021. From 2022 to 2023, the average Secchi depth in June decreased from 2.7m to 2.2m. In August of 2021, the average Secchi depth was 0.9m. In August of 2022, this decreased to 0.5m and slightly increased in August of 2023 to 0.6. Improvements to water clarity, prior to the decline in 2022, may have supported the plant expansion or may have been due to the expanded plant cover. The decrease in August 2022 was likely due to the decrease in plant coverage due to the fluridone treatment. The response in coming years will reveal if water clarity will improve or further decline, likely in step with changes in the plant community.

Dissolved oxygen profiles show that an anoxic hypolimnion may exist from below 2.5m to 4m during the summer depending on the year (Figure 10). The years 2019 through 2023 illustrate the lack of dissolved oxygen in the hypolimnion, likely due to stratification.

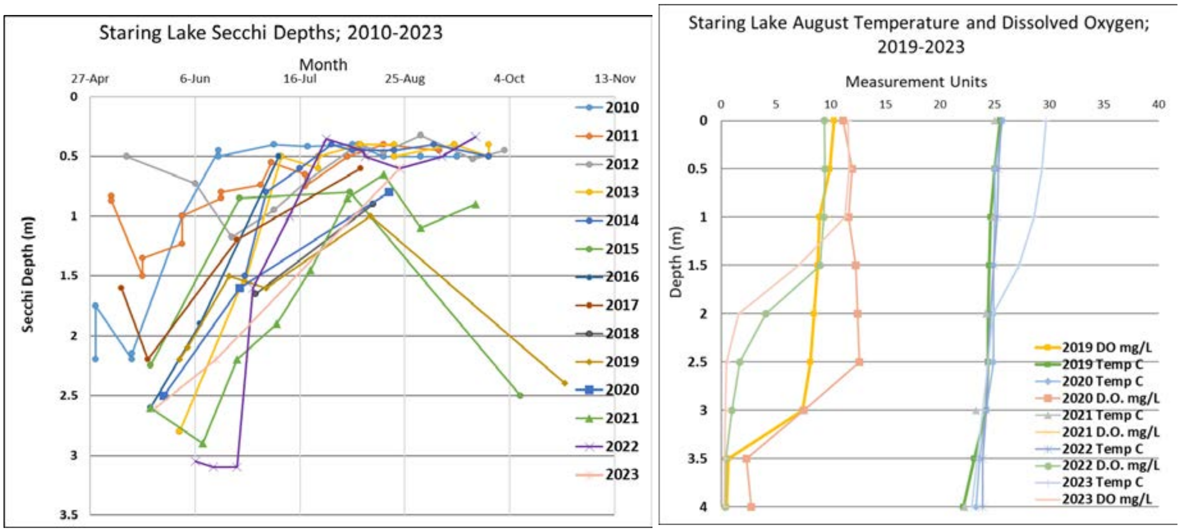


Figure 10. Secchi depths for Staring Lake 2010 through 2023 (Bajer and Sorensen unpublished data, and Newman lab's data) and dissolved oxygen (mg/L) and temperature (°C) profiles taken in August 2019 through 2023 (Newman lab's data).

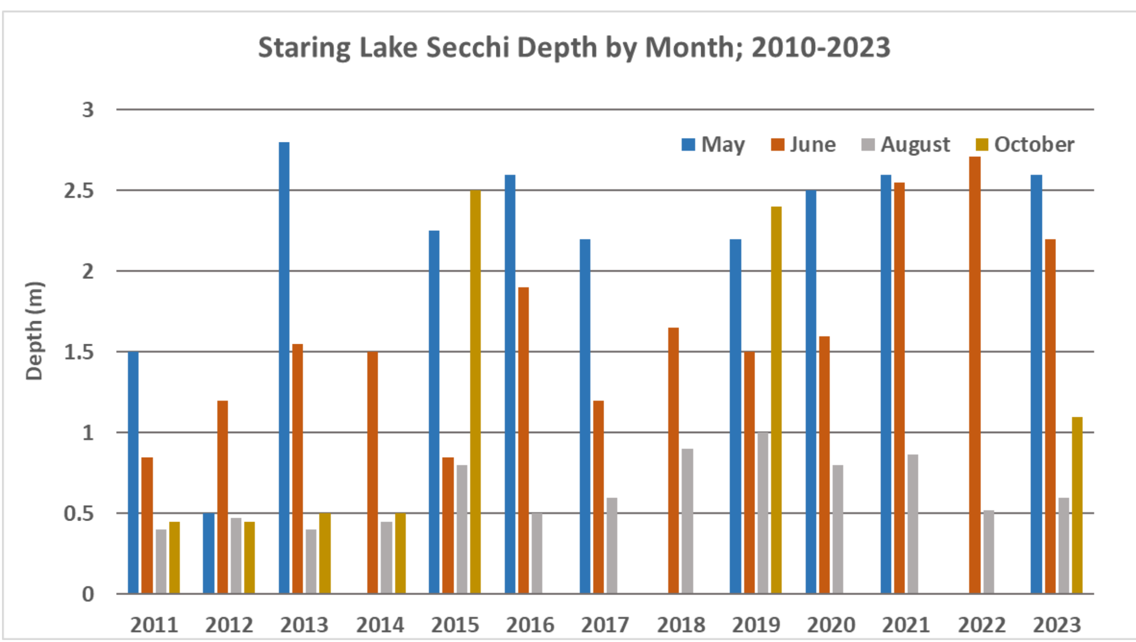


Figure 11. Mean Secchi depths for Staring Lake 2010 through 2023 presented by month and year (Newman Lab and Riley Purgatory Bluff Creek Watershed District monitoring data).

Aquatic Vegetation Survey:

Point intercept surveys were conducted in Staring Lake in June and August 2011, 2012, 2013, 2014 and 2018. In 2015 surveys were conducted in May, June, August, and October. By 2015 a total of 15 submersed and 4 floating leaf taxa were found. In 2016, 2017, 2019, and 2020 surveys occurred in May, June, and August. In 2021, only one survey was conducted in August. In 2022, surveys were completed in June and August and in 2023, surveys were completed in May, June, and August. Native plants increased throughout Staring Lake after carp removal, from < 15% in 2011-2013 to >40% in 2015 and > 50% in 2016-2022 (Figure 12). Native plant coverage decreased to > 25% in August 2023. This decrease is likely a direct result of the whole-lake treatment in late 2022. Submersed plant species increased from 4 in 2011 to 11 in 2016. No additional new species were observed in 2016-2020, but a total 19 species were observed through 2023 (Table 6). The maximum species richness per site was observed in the August 2015 survey with one site having 5 species; in 2016 the maximum species richness at one site was 4 species. Species richness decreased in 2017, with only 3 submersed taxa found in August. In June and August of 2018 submersed native taxa increased to 7 and 4, was similar in 2019 at 5 and 7, in 2020 was 3 and 8, respectively, in 2022 5 submersed native taxa were found in both June and August and in 2023 13 total species were found throughout the year, with 12 total natives and 8 submersed natives. (Table 7).

Curlyleaf pondweed was generally the most frequently occurring species in June each year until 2017 (Figure 13). In 2016, curlyleaf frequency increased to over 65%, almost doubling in occurrence within one year. This led to an herbicide treatment in spring 2017. Peak curlyleaf occurrence has remained ≤26% since 2017, through 2023 with no herbicide treatment except fluridone in 2022. In 2023, curlyleaf pondweed wad found at 20% of points in peak season. White and yellow water lilies were previously two of the most commonly occurring native species in Staring Lake, likely due to that fact that they are floating leaf species and less impacted by poor water clarity. In 2016, Canada waterweed, coontail, and chara all increased in frequency (Figure 13). With poorer water clarity in 2017, Canada waterweed and chara declined but coontail continued to increase. Coontail, Canada waterweed and sago pondweed had the highest frequencies of occurrence for native submersed plants in 2018 and 2019, with coontail being most common. In 2020, coontail, sago pondweed and small pondweed were common, with coontail being most common (Figure 13). Coontail increased to over 60% occurrence in May and August 2020 and June and August 2022. In 2023, after the fluridone treatment, coontail abundance decreased to less than 30% in all three sampling months. White water lily, sago pondweed, and star duckweed were all found at the highest frequency in 2023 since sampling started in 2011, with frequencies of 12%, 13%, and 6% respectively.

Since the water clarity improvement in 2015, the maximum depth of species growth increased from about 1.4m to at least 2.5m for every survey in 2015 through 2017 and was 3.4m or over in 2018 through 2022. In 2023, maximum depth of growth was over 3.8m in May but decreased to 2.1m in August (Table 7).

Table 6. Aquatic plants found in surveys conducted in Staring Lake 2011 through 2023.

Common Name	Scientific Name	Abbreviation	Year First Observed
Submerged species			
Coontail	*Ceratophyllum demersum*	Cdem	2011
Muskgrass	*Chara spp.*	Char	2011
Canada waterweed	*Elodea canadensis*	Ecan	2013
Water stargrass	*Heteranthera dubia*[1]	Zdub	2016
Eurasian watermilfoil	*Myriophyllum spicatum*	Mspi	2015
Bushy Pondweed	*Najas flexilis*	Nfle	2014
Southern waternymph	*Najas guadalupensis*	Ngua	2014
Brittle Naiad	*Najas minor*	Nmin	2015
Curlyleaf pondweed	*Potamogeton crispus*	Pcri	2011
Long-leaf pondweed	*Potamogeton nodosus*	Pnod	2015
Small pondweed	*Potamogeton pusillus*	Ppus	2011
Flat-stemmed pondweed	*Potamogeton zosteriformis*	Pzos	2015
Sago pondweed	*Stuckenia pectinata*	Spec	2011
Greater bladderwort	*Utricularia vulgaris*	Uvul	2015
Horned pondweed	*Zannichellia palustris*	Zpal	2011
Floating-leaf Species			
Common duckweed	*Lemna minor*	Lmin	2014
Star duckweed	*Lemna trisulca*	Ltri	2014
Yellow water lily	*Nuphar variegata*	Nvar	2011
White water lily	*Nymphaea odorata*	Nodo	2011

[1]*Heteranthera dubia* was formerly called *Zosterella dubia*.

Table 7. Summary of point intercept surveys in Staring Lake from 2011 through 2023. Maximum depth of growth is based on the 95th percentile of points where plants were observed growing.

Survey Date	Maximum Depth of Plant Growth Observed (95%) (m)	% of Points with Native Taxa	Number of Submersed Natives	Average Secchi Depth (m)
June 2011	1.6	6%	3	1.0
August 2011	1.3	4%	1	0.5
June 2012	1.3	2%	1	1.0
August 2012	1.0	2%	0	0.4
June 2013	1.3	10%	6	1.5
August 2013	1.5	7%	6	0.4
June 2014	3.3	20%	11	1.5
August 2014	1.3	16%	11	0.5
May 2015	3.0	24%	8	2.3
June 2015	2.6	43%	8	0.8
August 2015	2.6	44%	9	0.8
October 2015	2.0	46%	9	2.5
May 2016	3.6	46%	7	2.6
June 2016	3.0	67%	10	1.9
August 2016	2.6	44%	7	0.5
May 2017	3.4	35%	5	1.9
June 2017	3.4	49%	4	1.2
August 2017	2.9	43%	3	0.6
June 2018	4.4	66%	7	1.4
August 2018	3.5	55%	4	0.9
May 2019	3.6	54%	4	2.2
June 2019	2.9	66%	5	1.5
August 2019	3.8	67%	7	1.0
May 2020	4.8	74%	5	2.5
June 2020	3.5	58%	3	1.6
August 2020	3.4	67%	8	0.8
August 2021	3.5	94%	3	0.9
June 2022	4.2	89%	5	2.7
August 2022	4.4	68%	5	0.5
May 2023	3.8	35%	4	2.6
June 2023	2.7	38%	6	2.2
August 2023	2.1	25%	5	0.6

Curlyleaf Pondweed Turion Surveys:

Fall sediment turion surveys were conducted in October of 2011 through 2023 for Staring Lake. In 2021, there was no turion survey conducted. Until 2015, no turions were found in the sediments of Staring Lake in fall despite production of some turions in the spring (Table 8). With the increase in curlyleaf frequency and abundance in 2015, increased turion production was observed and turions were found in the sediment in fall. The density of turions in 2015 was 30 turions/m^2, with 91% viable. In 2016, the density of curlyleaf turions decreased to 18 turions/m^2, with 56% viable. After herbicide treatment in 2017 the density dropped to 1 turion/m^2 with 100% viability. Turion densities remained low in 2018 at 4 turions/m^2 with 50% viability, 2019 at 2 turnions/m^2 with 100% viability, and turions were not observed during fall sediment turion surveys in 2020 or 2022 (Table 8). In 2023 the density was 3 turnions/m^2 or 2 viable turnions/m^2. Low turion densities are likely a legacy result of the 2017 treatment, the 2022 full lake fluoridone treatment, and low subsequent occurrence of curlyleaf in Staring Lake.

Curlyleaf Pondweed Herbicide Treatment:

The expanding curlyleaf and increasing turion density found in 2016 led to an early season endothall treatment in 2017. Curlyleaf was delineated in the north western 1/3 of the lake (40 acres – 16.2 hectares) and treatment was conducted on 5 May. The treatment was effective at controlling curlyleaf. Curlyeaf decreased from 52% occurrence in May to < 20% in June 2017 after control, much lower that the June occurrence of 65% in 2016 (Figure 14). Furthermore, most of the plants found in June 2017 were dead or dying and sparse; most occurrences were of single or few plants (all 1s and 2s on a relative 5 pt. scale). Curlyleaf frequency of occurrence was < 14% in June of 2018 and dropped to < 2% in August of 2018 and <26% in June of 2019 while not being found during sampling in August of 2019, with no treatments during those years. Although curlyleaf pondweed frequency of occurrence did increase to 26% in June 2019, this was well below the peaks in 2015 and 2016. Curlyleaf pondweed was not found in the August survey in 2021. Frequencies of occurrence in May and June of 2023 were 16% and 20%, respectively. The low level in 2022 and 2023 is likely due to the whole-lake treatment with fluoridone in 2022. Turion production since 2017 has almost been eliminated and fall turion densities have been low to non-detectible since (Table 8).

Table 8. Results from sediment turion surveys conducted October 2011 through 2023 in Staring Lake.

Date	Turions/m^2	Viability	Viable Turion Density
Oct-2011	0	0%	0
Oct-2012	0	0%	0
Oct-2013	0	0%	0
Oct-2014	0	0%	0
Oct-2015	30	91%	27
Oct-2016	19	56%	11
Oct-2017	1	100%	1
Oct-2018	4	50%	2
Oct-2019	2	100%	2
Oct-2020	0	N/A	0
Oct-2021	N/A	N/A	N/A
Oct-2022	0	N/A	0
Oct-2023	3	66%	2

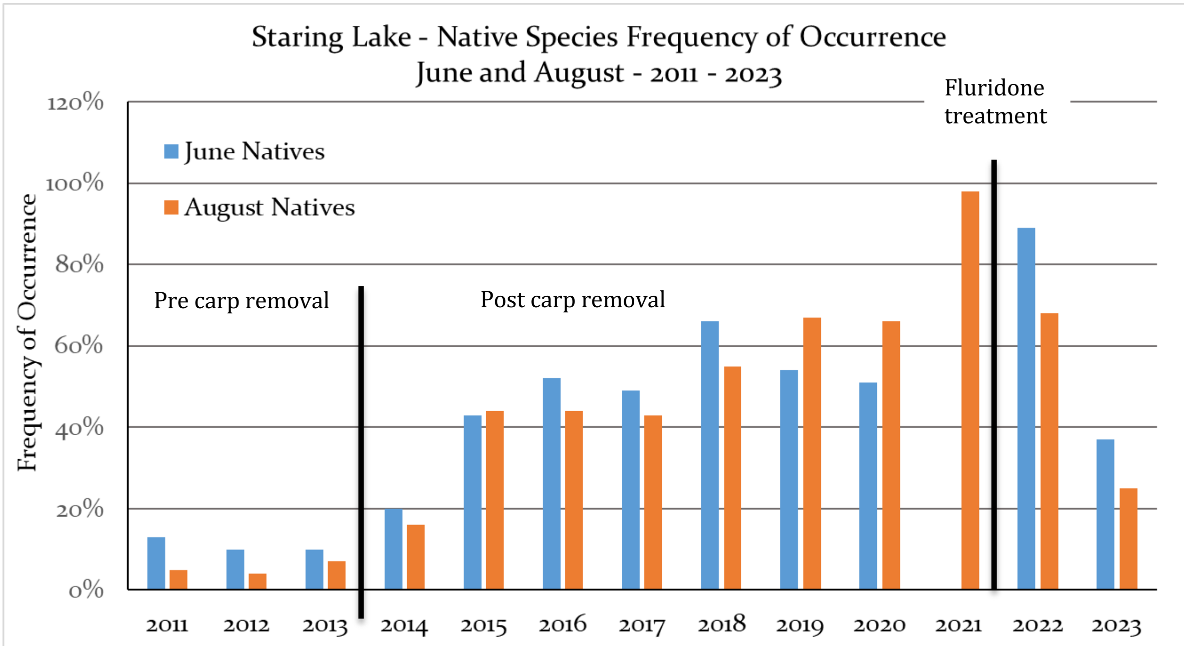


Figure 12. The frequency of occurrence of native aquatic plants in Staring Lake, June and August, 2011 through 2023.

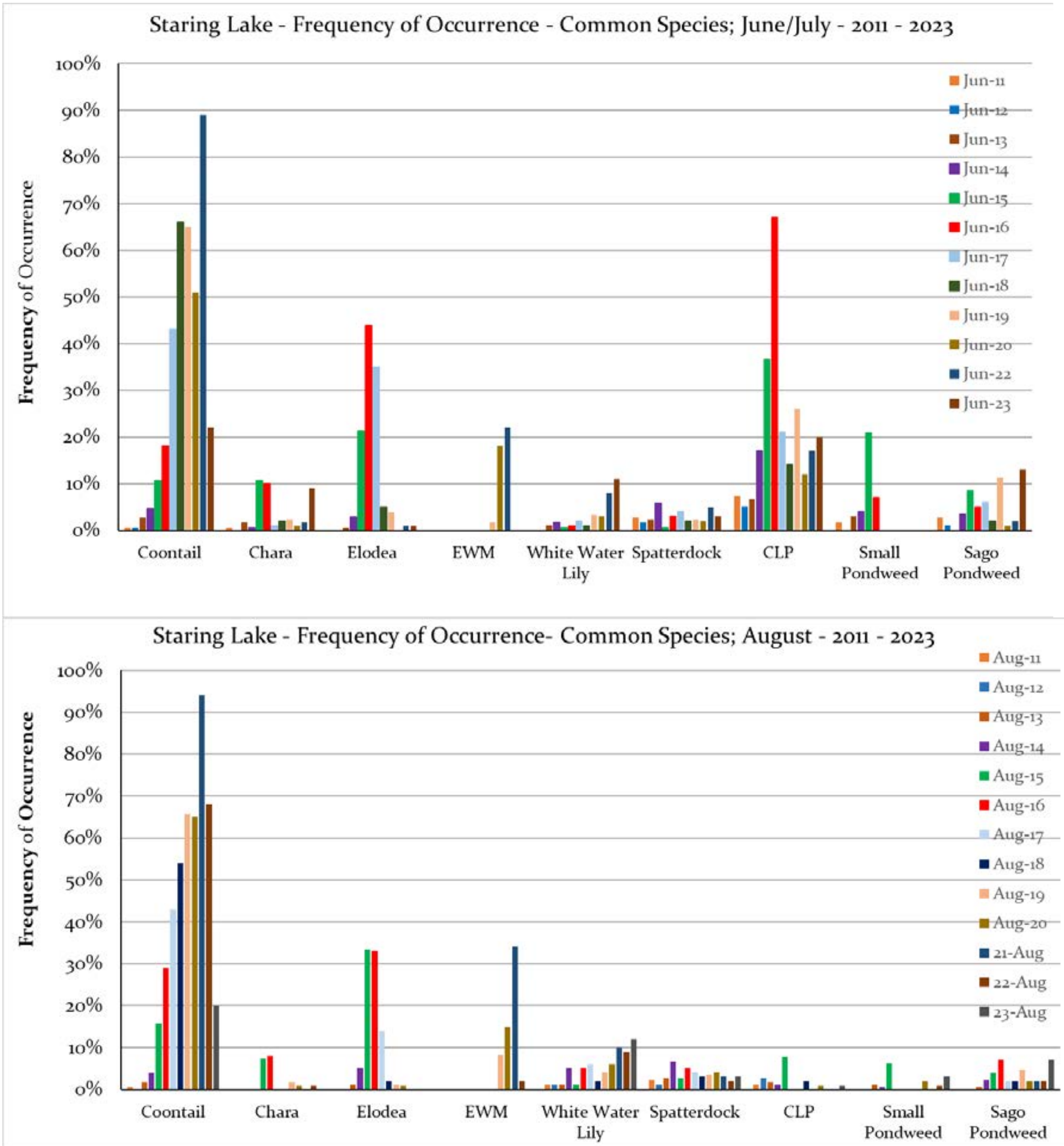


Figure 13. Frequency of occurrence of the most commonly occurring species in Staring Lake surveys in June and August 2011 through 2023. Eurasian watermilfoil = EWM and CLP is curlyleaf pondweed. Plant species are given in Table 6.

Eurasian Watermilfoil Herbicide Treatment:

In September of 2015 and August of 2016, Eurasian watermilfoil was observed in small patches in Staring Lake. In October of 2015 and September of 2016, efforts by the watershed district with assistance from James Johnson of Freshwater Services, LLC, occurred to manually pull milfoil. Following these treatments an herbicide application consisting of granular Triclopyr (known as Renovate3®) took place to control the remaining plants. Monitoring for the species has continued and milfoil has only recently expanded enough to be detected in our point intercept surveys in 2019 and 2020 (Figure 14). Eurasian watermilfoil was detected during our August 2019 point-intercept at a peak frequency of occurrence at 8% and in June 2020 point-intercept at a frequency of occurrence of 18%. Frequency increased from 2020 to 2021, to 34% in August of 2021. A whole lake fluridone treatment was conducted in summer 2022 (May through July) to control both curlyleaf pondweed and Eurasian watermilfoil. Eurasian watermilfoil decreased to 22% occurrence in June of 2022, 2% in August of 2022, and was not detected in any survey in 2023, indicating successful control. Examination of Eurasian plants by the Thum Lab indicated that all are pure Eurasian watermilfoil (n=8), the same genotype found in Riley (Newman and Thum 2019), and no hybrids have been found.

Biomass:

As of 2022, coontail had been the most commonly occurring species within Staring Lake with a peak average biomass that occurred during August 2019 at 1094.2 g/m^2 (Table 9). In June 2020 and 2022 coontail had a biomass of 425 and 258.3 g/m^2. In 2023, there was a large decrease in all biomass, but especially for coontail (<10g/m^2) with white water lily exceeding biomass of coontail at 13.1 g/m^2. Biomass for the second most commonly occurring species for 2019 was white water lily in June at 28.8 g/m^2 and Eurasian watermilfoil in August of 2020 at 171.6 g/m^2. Between May 2015 and August 2016 chara, Canada waterweed and curlyleaf pondweed had the highest biomasses (Table 9). Eurasian watermilfoil appeared in biomass sampling in June of 2019 at 1.4 g/m^2, but was only 0.7 g/m^2 in August of 2019. Eurasian watermilfoil appeared in 2022 during June and August at 10.6 g/m^2 and 0.1 g/m^2, repectively, but none was found in 2023. Curlyleaf pondweed biomass peaked in May of 2016 at 93.7 g/m^2, however, the May 2017 endothall treatment for curlyleaf pondweed appeared to be effective as the highest biomass since has only reached 12.5 g/m^2 (Table 9). The decline in Canada waterweed from peak abudance in 2015-2016 to rare in subsequent years was also observed in Riley and Susan and reflects the cyclical occurrence of the species.

Overall peak native biomass in 2019 was much higher than invasive biomass at 1129.8 g/m^2 versus 8.4 g/m^2. Native biomass decreased from 2019 to 2023 to <20 g/m^2 in 2023. In June of 2022 peak native biomass was 259.6 Peak invasive biomass increased from 1.1 g/m^2 in 2019 to 78.4 g/m^2 in 2020. This number decreased to a historical low of 0.04 g/m^2 in August of 2022 and 0 g/m^2 in August of 2023. In 2023, the highest native biomass was in August at 20.3 g/m^2. This decrease is likely due to treatment in 2022, but should bounce back in the following years.

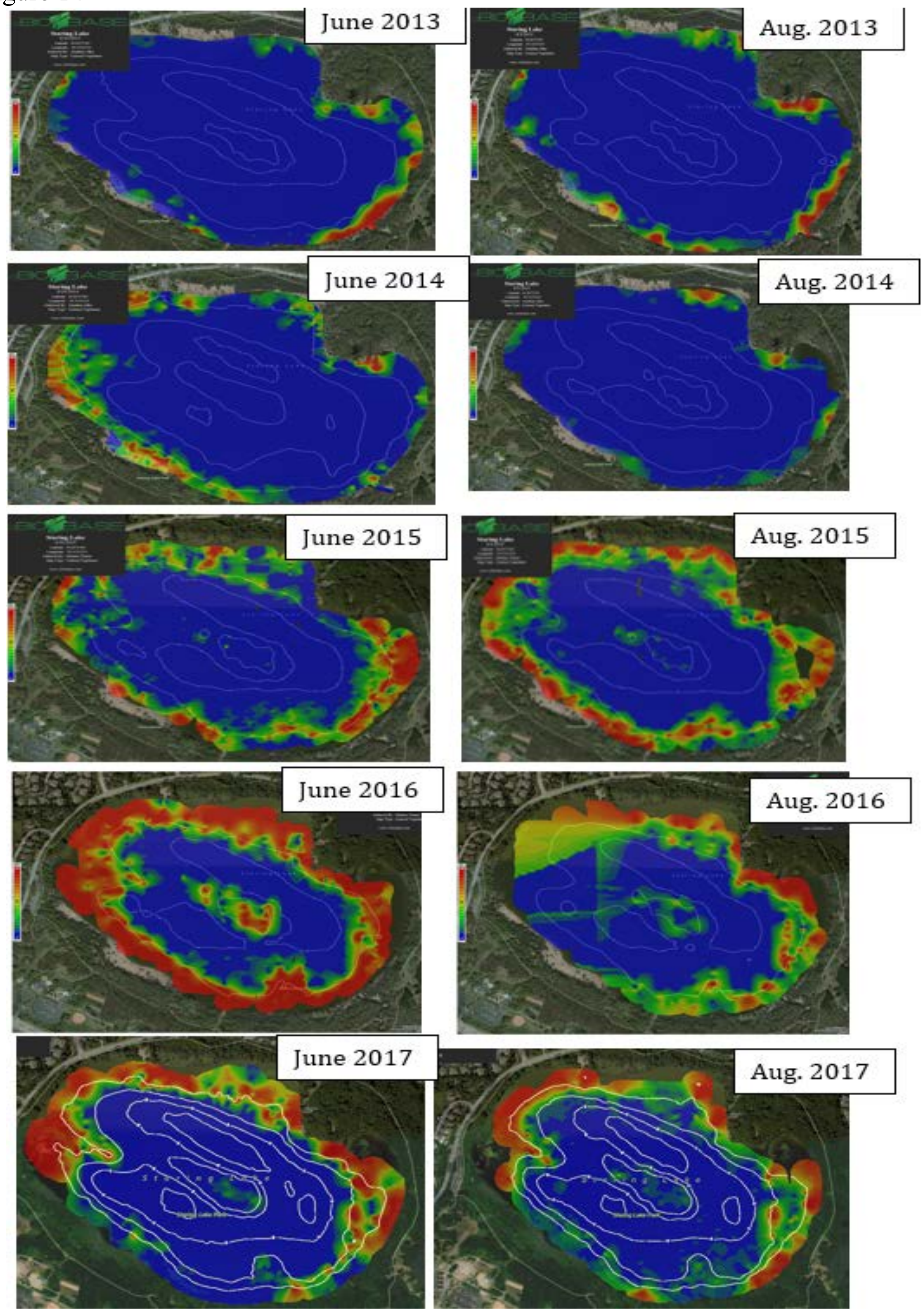
Table 9. Average biomass results from 2011 through 2023 in Staring Lake. All data presented in g/m^2.

	Coontail	Chara	Canada waterweed	Bushy pondweed	Southern naiad	Eurasian watermilfoil	White water lily	Spatterdock	Curlyleaf pondweed	Small pondweed	Sago pondweed	Water stargrass	Brittle naiad	Horned pondweed	Long-leaf pondweed	Curlyleaf turions	Natives	Invasives
Jun-11		0.6							0.7	0.02							0.6	0.7
Jun-12									3.7									3.7
Aug-12									0.5									0.5
Jun-13									1.3	0.07							0.07	1.3
Jun-14		0.04	0.2						2.9	0.4		0.05				0.3	0.6	3.2
Aug-14	0.09		0.07	0.2							2.1						2.4	
May-15		0.06	0.2					0.07	8.4		0.6						0.9	8.4
Jun-15		60.5	2.7	0.04					80.3	7.2	0.7					9.7	71.2	90.0
Aug-15	9.1	6.9	22.2	2.4	0.4				0.05	0.4	1.9					0.003	43.2	0.05
Oct-15	1.1	61.3	19.7		0.01				4.3	0.01		0.02	6.9			0.3	82.1	11.5
May-16	0.5	120.3	53.4						93.7	0.1		0.005				5.2	174.4	98.9
Jun-16	2.6	78.2	93.4						60.4	0.2	0.004	0.06				5.2	174.4	65.6
Aug-16	57.3	14.4	544.0						0.02	0.2		0.04				0.71	615.4	0.02
Jun-17	10.9		9.3				0.2	0.03	0.1		0.001						20.5	0.1
Aug-17	9.1	0.01	1.7				1.4	0.3									12.5	
May-19	245.9	0.1	0.002						3.0		0.1					0.03	246.1	3.1
Jun-19	299.0	2.3	0.5			1.4	4.6		6.5		1.7					0.5	308.2	8.4
Aug-19	1094.2	0.5		6.3		0.7	28.8						0.4				1130	1.1
May-20	256.4	8.2	0.03			7.3			2.3								264.6	9.6
Jun-20	425.9	38.2	0.3			47.3			5.1							0.8	464.4	53.2
Aug-20	227.3		0.06			78.4											227.4	78.4
Jun-22	258.3	0.74				10.6	0.58		0.13			0.001		0			259.6	10.7
Aug-22	67.7	0.12				0.04	8.7					0.001			0		76.53	0.04
May-23	5.4	0.003					1.3		0.3								6.7	0.3
Jun-23	2.8	0.1					13.1	0.8	4.7		2.5	0.02			0.02	0.01	19.2	4.7
Aug-23	9.5						7.3			0.03	2.9	0.02			0.5		20.3	0

Aquatic Bathymetry and Vegetation Mapping:

Prior to 2015, plants were generally restricted to depths shallower than 2m (Table 7?), percent area covered was usually <20%, and mean biovolume 35% or less (Table 10). In 2015, plants started to colonize in water deeper than 2.0m, the percent area covered increased in August and October to just under 50% and the mean biovolume was approximately 65% (Table 10). In 2016, plants were observed at depths up to 3.6m with no major differences in percent area covered or mean biovolume and in 2017 plants were observed to 3.4 m with similar biovolume and coverage to 2016 (Table 10 & Figure 14). The treatment in 2017 appeared to control plants (curlyleaf) along the southern shore outside of the treatment block as indicated by the June BioBase survey but August coverage and biovolume were similar to 2016 (Table 10). August of 2019 had a slightly higher biovolume than August of 2017 and 2018 and the southern treatment area started to be recolonized by native macrophytes. May and June of 2020 had a higher percent area covered than 2019, although only June of 2020 had a higher mean biovolume. May, June, and August 2023 had lower percent cover and biovolume than previous years, likely due to the whole lake treatment started in 2022 (Table 10 and Figure 14).

Figure 14


June 2013
Aug. 2013
June 2014
Aug. 2014
June 2015
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June 2016
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June 2017
Aug. 2017

Figure 14 Continued

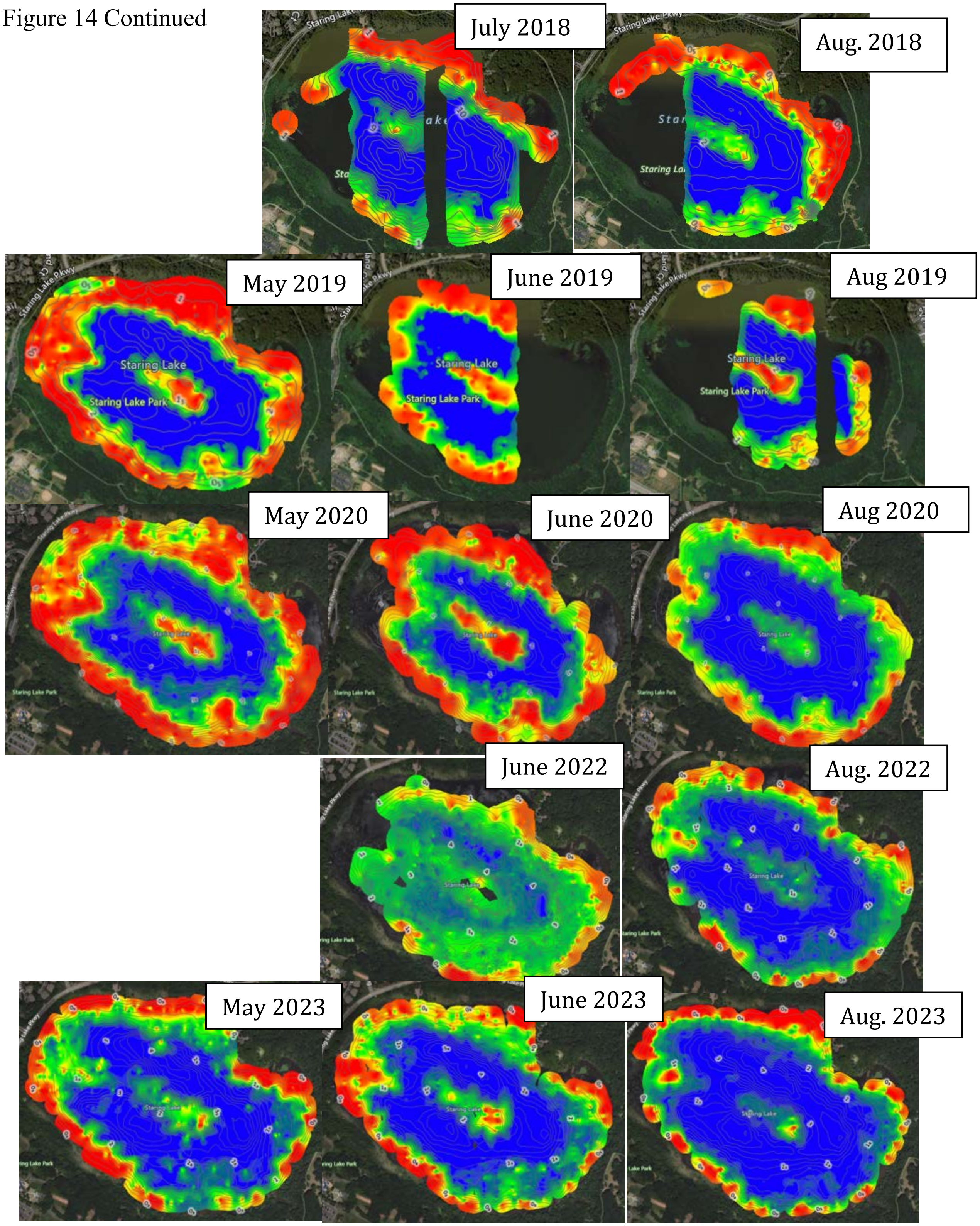


Figure 14. Aquatic bathymetry and vegetation maps of Staring Lake. Sonar data collected during point intercept aquatic vegetation surveys by Newman lab on: 10 June 2013, 5 August 2013, 25 June 2014, 5 August 2014, 23 June 2015, 4 August 2015, 8 June 2016, 8

August 2016, 20 June 2017, 8 August 2017, July 2018, August 2018, 4 June 2019 (represents May), 20 June 2019, 8 August 2019, 29 May 2020, 23 June 2020, 19 August 2020, 10 June 2022, 8 August 2022, 22 May 2023, 14 June 2023, and 23 August 2023. Contour lines are 5ft intervals. Color legend represents percent biovolume (refers to the percentage of the water column taken up by vegetation when vegetation exists) with blue representing no vegetation present and red representing 100% of the water column being taken up by vegetation. Maps for 2018 and 2019 are incomplete likely due to high abundance of coontail, which formed mats and caused the sonar to lose readings.

Table 10. Lake-wide percent area cover (PAC) and average biovolume (BV) for Staring Lake. Values coincide with maps in Figure 14. PAC refers to the overall surface area that vegetation is growing in the surveyed area. Average BV refers to the percentage of the water column taken up by plants when plants exist; areas that have no plants are not factored into this calculation.

Date	PAC	Average BV
June 2013	12.5%	31.0%
August 2013	15.1%	31.6%
June 2014	23.2%	34.8%
August 2014	9.3%	21.8%
May 2015	21.9%	63.2%
June 2015	36.4%	54.9%
August 2015	47.1%	62.7%
October 2015	49.7%	65.1%
May 2016	64.5%	69.9%
June 2016	64.5%	63.7%
August 2016	50.4%	39.8%
June 2017	39.9%	51.7%
August 2017	50.2%	36.2%
July 2018	65.5%	48.1%
August 2018	61.0%	48.5%
May 2019	67.3%	61.5%
June 2019	61.1%	51.5%
August 2019	62.6%	50.7%
May 2020	71.8%	57.4%
June 2020	74.6%	57.0%
August 2020	57.9%	42.6%
June 2022	94.4%	27.6%
August 2022	51.9%	33.7%
May 2023	32.6%	43.1%
June 2023	37.4%	37.8%
August 2023	31.9%	33.3%

Recommendations for Staring Lake:

By 2015 carp were reduced to a density that allowed for the establishment of macrophytes. Exotic species should continue to be monitored as curlyleaf pondweed continues to be problematic early in the summer and Eurasian watermilfoil recurred in 2016 after a 2015 rapid response to control it. Eurasian watermilfoil increased from not being detected in aquatic vegetation nor biomass surveys prior to 2019 to a peak frequency of occurrence of 34% in August of 2021 and an average biomass 78.4 g/m^2 in 2020. In response to this rapid increase, a full lake fluoridone treatment occurred in spring 2022. After this treatment, no Eurasian watermilfoil was observed in 2023. This fluridone treatment also decreased coontail, allowing room for other native species to expand. Curlyleaf pondweed also appears to have been controlled with these treatments, as there were no turions found in October of 2022 and there was a low density in 2023. Curlyleaf pondweed frequency of occurrence doubled from June 2014 to June 2015 and doubled again from June 2015 to June 2016 warranting an early season herbicide treatment in 2017. The treatment, in the northwest 1/3 of the lake was effective, more or less lake-wide. Spring aquatic vegetation assessments conducted in spring 2018 -2020 and 2023 found that treatment was not necessary for these years. Our sampling verified that curlyleaf density was moderate in mid-June 2019 at 26% frequency of occurrence, was similar in May 2020 at 25%, 12% in June 2020, 17% in June of 2022, and 20% in June of 2023.

Although coontail decreased and other native species increased in frequency in 2023, close monitoring during plant surveys will be important to inform future treatment decisions. The whole lake fluoridone treatment also greatly lowered Eurasian watermilfoil levels to zero in 2023, but full assessment of treatment effectiveness will occur in following years. Brittle naiad (*Najas minor*) was not observed 2016 through 2018, despite occurring at several points in 2015. Brittle naiad was observered again at very low frequency of occurrence during August of 2019 at 1%, in 2020 at 2%, and in August of 2022 at 1%. It was only detected in biomass sampling in 2015 and 2019 at $6.9g/m^2$ and $0.4g/m^2$, respectively. Brittle naiad was not observed in 2023. Brittle naiad monitoring via seasonal aquatic vegetation surveys will be crucial to ensure it does not expand to become problematic.

To track lake health parameters, continued, aquatic vegetation surveys should continue. This will allow for consistent monitoring of the plant community and to track exotic species expansion. Continued control of the carp population is necessary to maintain the clear water state; control efforts for curlyleaf pondweed and Eurasian watermilfoil will be futile if carp populations reach high abundances again within the coming years as the lake will likely return to a turbid, low macrophyte abundance state. The continued expansion of maximum depth of occurrence is a good sign if native plants can remain abundant in shallower water. The 2022 treatment was effective in controlling Eurasian watermilfoil, helped contain coontail, and should allow a positive responsed by desirable natives, if clarity can be maintained. Although there was a decrease in overall plant abundance and coverage, individual native taxa with previous low numbers did increase in 2023, and will likely expand further in future years. If clarity continues to improve but additional native taxa do not establish and expand, a seedbank assessment (similar to that for Lake Riley) should be conducted before stocking or transplanting is considered. Alum treatments could be considered pending an assessment of internal and external nutrient loading and it will be essential to continue to monitor and control carp in Staring Lake as further increases in carp abundance would likely revert the lake to pre-2015 conditions.

V. Lake Susan Results

Lake Susan (DOW ID 10-001300) is a small kettle lake within the Chanhassen city limits. Lake Susan is located downstream about two kilometers southeast of Lake Ann and upstream from Rice Marsh Lake and Lake Riley. Lake Susan covers about 93 acres (38 hectares), with approximately 75 acres (30 hectares) of littoral zone and a maximum depth of about 5.2m (17ft) (MN DNR LakeFinder 2016). Carp removal occurred in the winter of 2009 (Bajer and Sorensen 2015). Following successful carp removal, aquatic plant transplanting experiments began in the summer of 2009 and ended in the summer of 2011 (Knopik and Newman 2018). Lake Susan was treated with the herbicide endothall to control curlyleaf in May 2013, 2014, 2016 and 2017. In 2016 and 2017, a half-lake treatment was applied rather than a lake-wide treatment that was used in 2013 and 2014. The half-lake treatment was conducted so as to evaluate the effect of the herbicide on the native plant community by comparing response in the treated half and the untreated half of Lake Susan. In the spring of 2018, treatment took place along the eastern littoral zone, the south side of the lake and the western littoral zone (7.73 acres, 3.13 ha total). However, in 2018, diquat (Tribune) and a surfactant (Cygnet plus) were utilized instead of endothall as in previous treatments. No treatments took place during the summer of 2019 nor 2020. In spring 2021 and 2022, diquat (Tribune) treatments took place. In 2021, 8.6 acres (3.5 hectares) were treated, and in 2022, 8.25 acres (3.3 hectares) were treated. In 2023, 5.35 acres (1.4 hectares) were treated with flumioxazin.

Water Quality:

Water clarity improved in the spring in Lake Susan after carp removal, but usually declined to 1m or less by early summer, which is rather low during most of the prime native aquatic plant growing season (Figure 15). May water clarity increased from 2019 to 2021, peaking at 3.6m (Figure 16). While water clarity declined slightly to under 1.75m in June from 2020 to 2022 from over 2m in June 2019, it exceeded that of both 2017 and 2018. August clarity has ranged between 0.5 and 0.75m during that time. In 2023, May Secchi was 4.4m and August was at 0.9m both higher than in previous years (Figure 16). Dissolved oxygen profiles show that by July there was often an anoxic hypolimnion beginning at 3.5m and deeper (Figure 15); this can contribute to internal loading of phosphorous in the summer.

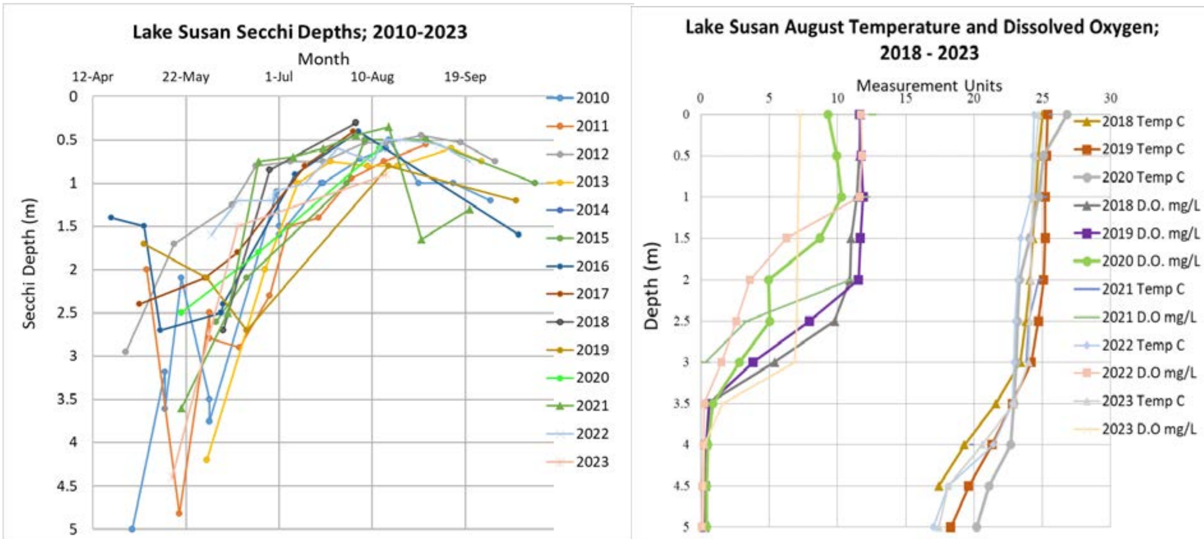


Figure 15. Secchi depths for Lake Susan 2010 through 2023 (Bajer and Sorensen unpublished data, personal communication and Newman lab's data) and dissolved oxygen (mg/L) and temperature (°C) profiles taken in August 2018 through 2023 (Newman lab's data).

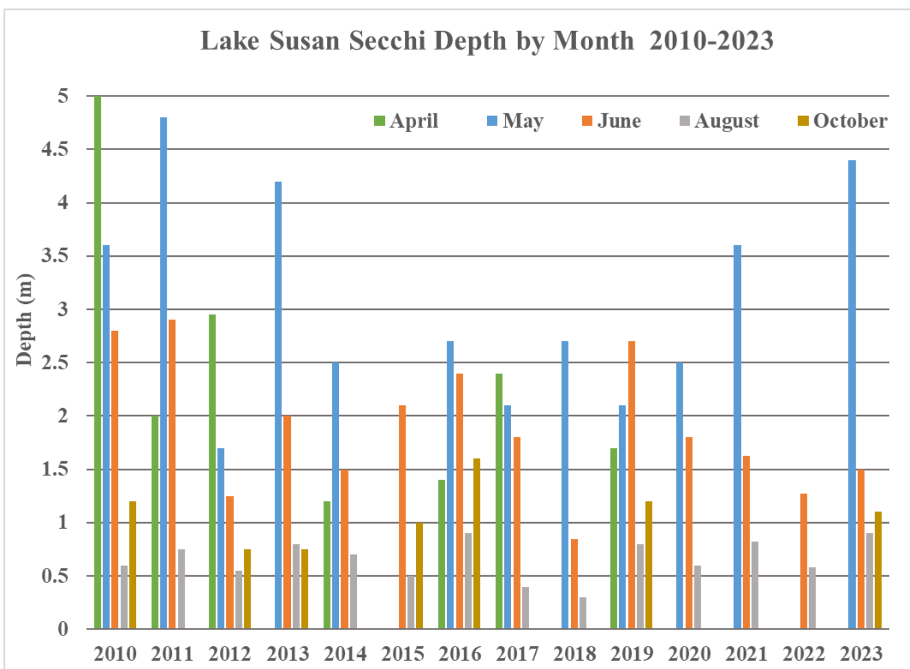


Figure 16. Mean Secchi depths for Lake Susan 2010 through 2023 presented by month and year (Newman Lab and Riley Purgatory Bluff Creek Watershed District monitoring data).

Aquatic Vegetation Survey:

Macrophytes have been sampled in Lake Susan since 2009. Twenty three different species (including transplanted species) have been found in Lake Susan from 2009 to 2020 (Table 11). Lake Susan had relatively low to moderate plant diversity, but increased from 9 native taxa in 2009 (Newman 2009) to 16 native taxa that were found in 2014. However, the higher diversity did not persist. The highest species richness per site in 2016 occurred in August with one site containing 4 different species, although most sites had one to two species. Species richness was lower in 2017 through 2019 with a maximum of 6-7 submersed native species. Submersed native species further decreased in 2020 and ended at 3 submersed native taxa. In August of 2021 and 2022 only three submersed native taxa were present, but in June of 2022, 5 species were observed. In 2023, 2 submersed natives were found in May, 3 in June, and 7 in August (Table 12). Overall, the maximum depth of growth of observed has been variable; in 2015 and 2016 the depths decreased to shallower than 3m but expanded to > 3m in 2017 and > 5m in the spring of 2018. The 2018 summer maximum depth of growth decreased to 1.8m and only 3 submersed natives were found (Table 12). The maximum depth of growth increased to 3.5m in 2019 and likely played part in the native community expansion to 11 taxa. In May of 2020, the maximum depth of growth increased to 4.1m, however, submersed native species were not able to expand and decreased to a low of 3 unique taxa in June and August. In June of 2022, the maximum depth of growth was also >4m, and 5 submersed natives were observed, but this number dropped to three in August, and maximum depth of growth also decreased to less than 2m. In 2023, May maximum depth of growth was 3.1 and decreased to 1.5 in August.

Coontail has been the most frequently occurring native species since 2010, and has also generally been the most frequently occurring species overall, with curlyleaf pondweed exceeding these numbers only a few times (Figure 17). White water lily and yellow water lily are often found at frequencies second to coontail. From 2010 to 2015, small pondweed and sago pondweed were commonly found, then numbers decreased. After three years of not observing small pondweed, it was found at 7% frequency in June of 2022. Sago pondweed has been observed at lower numbers, and was not found in 2018 or 2021, but was found at a frequency of 7% in June of 2022, 9% in August 2022, and 3% in 2023. Many other native species including elodea, bushy pondweed, leafy pondweed, and small pondweed were observed in recent years after periods of no observations or very low frequencies. Long leaf pondweed was found for the first time since 2019 at 1% in August of 2023.

Transplanted species (muskgrass, northern watermilfoil, flatstem ponweed, bushy ponweed, water celery and water stargrass) have been observed (in low frequencies) in surveys as some species have expanded, particularly bushy pondweed; in 2017, it and water stargrass were both found in surveys. Both were observed in June of 2018, but water stargrass was not collected on any samples during the August 2018 survey. Water stargrass was, however, again collected during sampling during June and August point-intercepts during 2019 as well as the August 2020 survey (Figure 17). Water stargrass was observed in 2021 and 2023. Bushy pondweed was observed in 2019, but not 2020 or 2021. It appeared again at a low frequency in 2022 and 2023. The invasive Eurasian watermilfoil declined in frequency since 2011 and was not observed on any rake tosses during the aquatic vegetation surveys of 2018 through 2023. Brittle naiad was detected for the first time in 2019 (Table 11) and was also observed in August of 2021, but not found in any rake samples during point-intercept surveying. Chara was observed in 2017 through 2021, with the exception of 2018. Chara was not observed in 2022 but was observed in June of 2023.

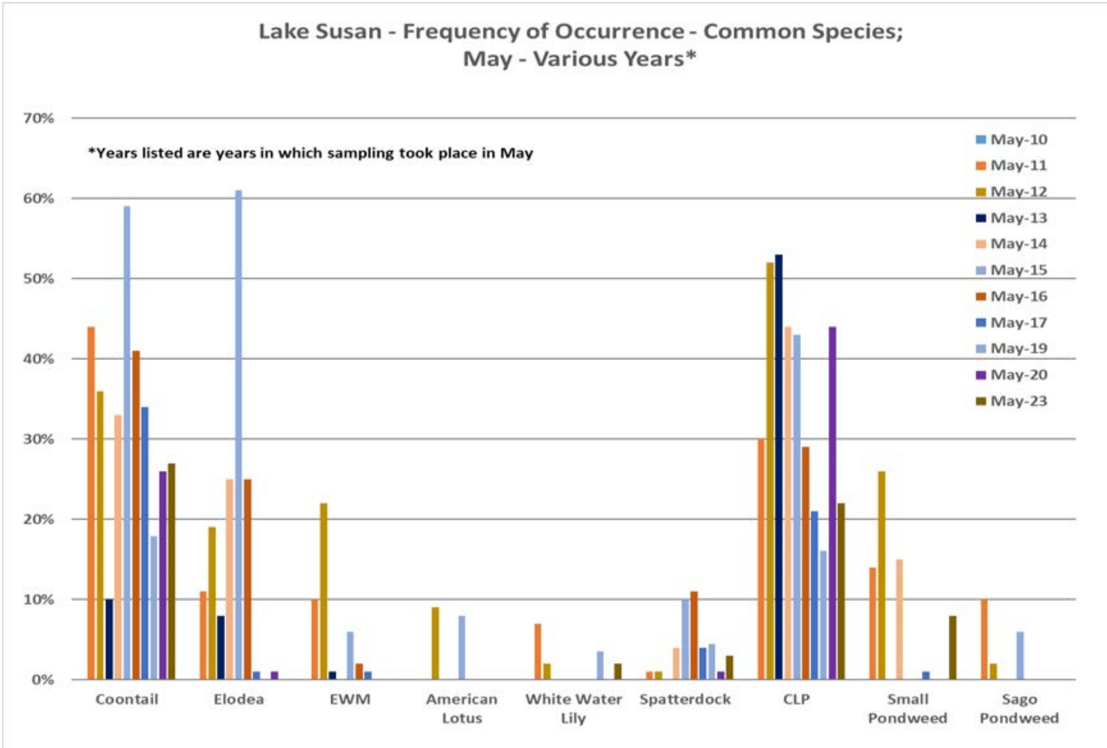
Table 11. Aquatic plants found in surveys conducted in Lake Susan 2009 through 2023. *These species were transplanted in Lake Susan and have been observed in surveys. **These species were transplanted in Lake Susan and have not been observed in surveys.

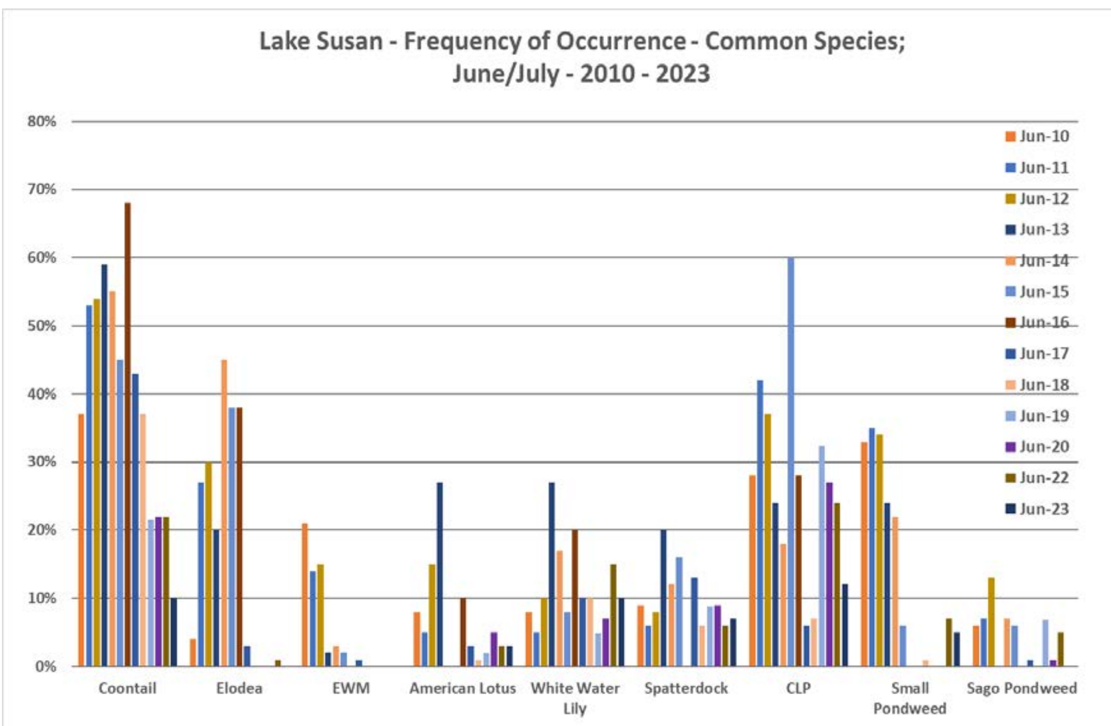
Common Name	Scientific Name	Abbreviation	Year First Observed
Emergent species			
Cattail	*Typha spp.*	Typh	2010
Hardstem bulrush	*Scirpus acuts*	Sacu	2010
Submerged species			
Coontail	*Ceratophyllum demersum*	Cdem	2009
*Muskgrass	*Chara spp.*	Chara	2011
Canada waterweed	*Elodea canadensis*	Ecan	2009
**Northern watermilfoil	*Myriophyllum sibiricum*	Msib	2011
Eurasian watermilfoil	*Myriophyllum spicatum*	Mspi	2009
*Bushy pondweed	*Najas flexilis*	Nfle	2011
Curlyleaf pondweed	*Potamogeton crispus*	Pcri	2009
Leafy pondweed	*Potamogeton foliosus*	Pfol	2013
Long-leaf pondweed	*Potamogeton nodosus*	Pnod	2012
Small pondweed	*Potamogeton pusillus*	Ppus	2009
*Flat-stem pondweed	*Potamogeton zosteriformis*	Pzos	2014
White water buttercup	*Ranunculus longirostris*	Rlon	2015
Sago pondweed	*Stuckenia pectinata*	Spec	2009
*American water celery	*Vallisneria americana*	Vame	2011
Horned pondweed	*Zannichellia palustris*	Zpal	2013
*Water stargrass	*Zosterella dubia*	Zdub	2011
Brittle naiad	*Najas minor*	Nmin	2019
Floating-leaf Species			
Lesser duckweed	*Lemna minor*	Lmin	2011
Star duckweed	*Lemna trisulca*	Ltri	2011
American lotus	*Nelumbo lutea*	Nlut	2010
White lily	*Nymphaea odorata*	Nodo	2009
Yellow lily	*Nuphar variegata*	Nvar	2009

[1]*Heteranthera dubia* was formerly classified as *Zosterella dubia*.

Table 12. Summary of point intercept surveys in Lake Susan from 2011 through 2023. Maximum depth of growth is based on the 95th percentile of points where plants were observed growing.

Survey Date	Maximum Depth of Plant Growth Observed (95%) (m)	% of Points with Native Taxa	Number of Submersed Natives	Average Secchi Depth (m)
June 2009	3.7	52%	5	1.0
August 2009	3.5	45%	4	0.6
June 2010	4.8	65%	9	2.7
August 2010	3.1	57%	9	0.7
May 2011	5.0	32%	8	3.4
June 2011	2.4	40%	9	2.6
August 2011	3.5	38%	10	0.9
May 2012	4.0	30%	9	1.7
June 2012	3.6	33%	9	1.0
August 2012	2.0	26%	10	0.5
May 2013	3.9	12%	4	4.2
June 2013	1.8	25%	8	2.0
August 2013	3.0	27%	11	0.8
May 2014	3.6	28%	7	2.4
June 2014	3.0	32%	12	2.1
August 2014	2.9	30%	16	0.8
May 2015	2.7	39%	10	N/A
June 2015	3.2	25%	10	2.4
August 2015	2.3	35%	9	0.8
May 2016	2.8	21%	5	1.9
June 2016	2.6	33%	10	2.5
August 2016	2.4	28%	10	0.4
May 2017	3.1	36%	3	2.2
June 2017	3.3	47%	7	1.8
August 2017	3.1	37%	6	0.4
June 2018	5.0	40%	5	2.5
August 2018	1.8	26%	3	0.5
May 2019	2.9	21%	2	2.1
June 2019	2.8	33%	5	2.7
August 2019	3.5	38%	7	0.8
May 2020	4.1	33%	3	2.5
June 2020	2.5	30%	3	1.8
August 2020	2.8	35%	3	0.6
August 2021	1.4	24%	3	0.8
June 2022	4.8	36%	5	1.3
August 2022	1.9	36%	3	0.6
May 2023	3.1	36%	2	4.4
June 2023	2.9	21%	3	1.5
August 2023	1.5	25%	7	0.9


Lake Susan - Frequency of Occurrence - Common Species;
May - Various Years*
*Years listed are years in which sampling took place in May
70%
60%
50%
40%
30%
20%
10%
0%
May-10
May-11
May-12
May-13
May-14
May-15
May-16
May-17
May-19
May-20
May-23
Coontail
Elodea
EWM
American Lotus
White Water Lily
Spatterdock
CLP
Small Pondweed
Sago Pondweed


Lake Susan - Frequency of Occurrence - Common Species;
June/July - 2010 - 2023
80%
70%
60%
50%
40%
30%
20%
10%
0%
Jun-10
Jun-11
Jun-12
Jun-13
Jun-14
Jun-15
Jun-16
Jun-17
Jun-18
Jun-19
Jun-20
Jun-22
Jun-23
Coontail
Elodea
EWM
American Lotus
White Water Lily
Spatterdock
CLP
Small Pondweed
Sago Pondweed

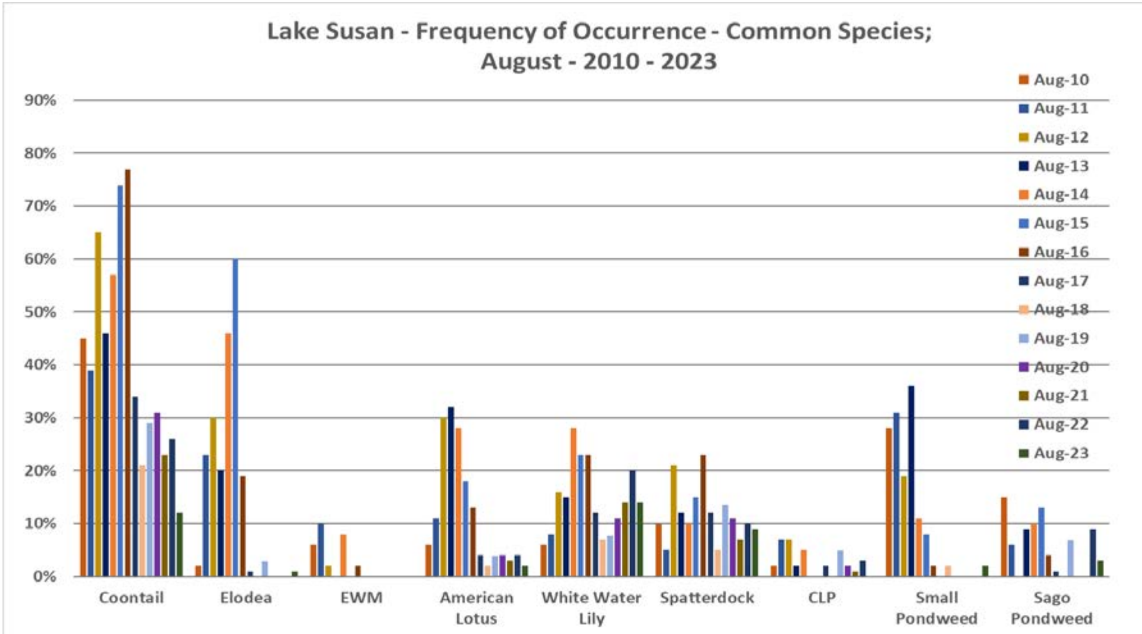


Figure 17. Frequency of occurrence for the most commonly occurring species in Lake Susan surveys May 2011 to 2023, various years, and June and August 2010 through 2023.

Curlyleaf Pondweed Herbicide Treatments:

Lake-wide early season endothall herbicide treatments took place in Lake Susan in the spring of 2013, and 2014. During the herbicide treatment years of 2013 and 2014, curlyleaf pondweed declined significantly ($p \leq 0.05$) in frequency of occurrence (Figure 18), and turion density in the sediments (Table 13). Curlyleaf pondweed declined to less than 10% of sites sampled in the littoral zone in 2014 post-treatment (June). In 2015, without treatment, the peak season frequency of occurrence increased.. Although curlyleaf frequency increased in 2015 the native plant frequency of occurrence remained similar to 2014 observations.

In 2016, due to the increases observed in 2015, Lake Susan was given another endothall treatment. Unlike 2013 and 2014, the treatment was not lake-wide but was concentrated on the eastern side of the lake to evaluate the effect of the herbicide application on the native plant community by directly comparing the plant communities of the western, untreated side of the lake against the plant communities in the eastern, treated side of the lake. There was no distinct pattern in the native plant community response to the herbicide treatment between the untreated and treated sides of Lake Susan.

With the half lake treatment in 2017, the curlyleaf frequency of occurrence and relative abundance decreased in the treatment area in June relative to May 2017 survey results. In the untreated area, the June survey indicated no decrease in frequency and abundance in June relative to May indicating that the treatment was relatively successful at controlling curlyleaf. In 2018 unlike previous years, diquat was selected for application; the application area included most of the western, southern and eastern littoral zones. The 2018 diquat treatment appeared to be effective. However, with no treatment in 2019, curlyeaf pondweed increased and turions also increased. Turion densities were low in 2018 at 9 turions/m^2 with a viability of 92% but increased in 2019 to 38 turions/m^2 at 90% viability (Table 13).

After curlyleaf pondweed frequency increased in 2020, a diquat (Tribune) treatment was executed on 8.64 acres of Lake Susan in May of 2021and another diquat treatment was completed in May of 2022 and covered 8.25 acres. In 2023, Flumioxazin was used. Lake-wide curlyleaf pondweed frequency has decreased from 2020 levels of 44% in May and 27% in June to 24% in June of 2022 and 22% in May of 2023 and 12% in June of 2023 (Figure 18).

In May of 2023, 5.35 acres (2.2 hectares) in Lake Susan were treated with flumioxazin to control curlyleaf pondweed (Figure 19). A high-density grid of plant point-intercept sampling points (20m grid) was created both in the treatment grid and in a control grid on the far end of the lake to improve resolution for assessing response to treatment. The treatment was successful, as the frequency of occurrence of curlyleaf pondweed in the treatment grid decreased from 38% percentage occurrence pre-treatment to 7.1% post treatment. This decrease is much larger than in the control grid, where curlyleaf pondweed occurrence only decreased 7%. Frequency of occurrence of curlyleaf pondweed was 34% in May and 27% in June. Apart from curlyleaf pondweed, all other plants in the treatment and control grids were sampled. Native plants were sampled in order to determine if there were any residual effects of the herbicide. Native plant frequency of occurrence decreased slightly in both the treatment and control grids. In the treatment grid, native frequency decreased from 42% pre-treatment to 38% post-treatment. In the control grid, native frequency decreased from 49% to 44%. Lakewide, curlyleaf decreased from 22% in May to 12% in June.

Native frequency of occurrence has decreased since sampling on Lake Susan started in response to herbicide treatments, invasive species, and other factors, but has stayed relatively constant in recent years (Figure 20). Turions were not sampled in 2020 or 2021. In fall 2022, turion density was 35 turions/m^2 at 89% viability. Turion density decreased in 2023 to 20 turions/m^2 and viability was 87%.

Table 13. Results from turion surveys conducted October 2011 through October 2023 in Lake Susan. Turion sampling was not conducted in 2020 or 2021.

Date	Turions/m^2	Viability	Viable Turion Density
Oct-2010	24	90%	22
Oct-2011	51	98%	50
Oct-2012	87	98%	85
Oct-2013	18	65%	12
Oct-2014	8	67%	5
Oct-2015	11	99%	11
Oct-2016	30	77%	23
Oct-2017	18	94%	15
Oct-2018	9	92%	8
Oct-2019	38	90%	36
Oct-2020	N/A	N/A	N/A
Oct-2021	N/A	N/A	N/A
Oct-2022	35	89%	29
Oct-2023	20	87%	18

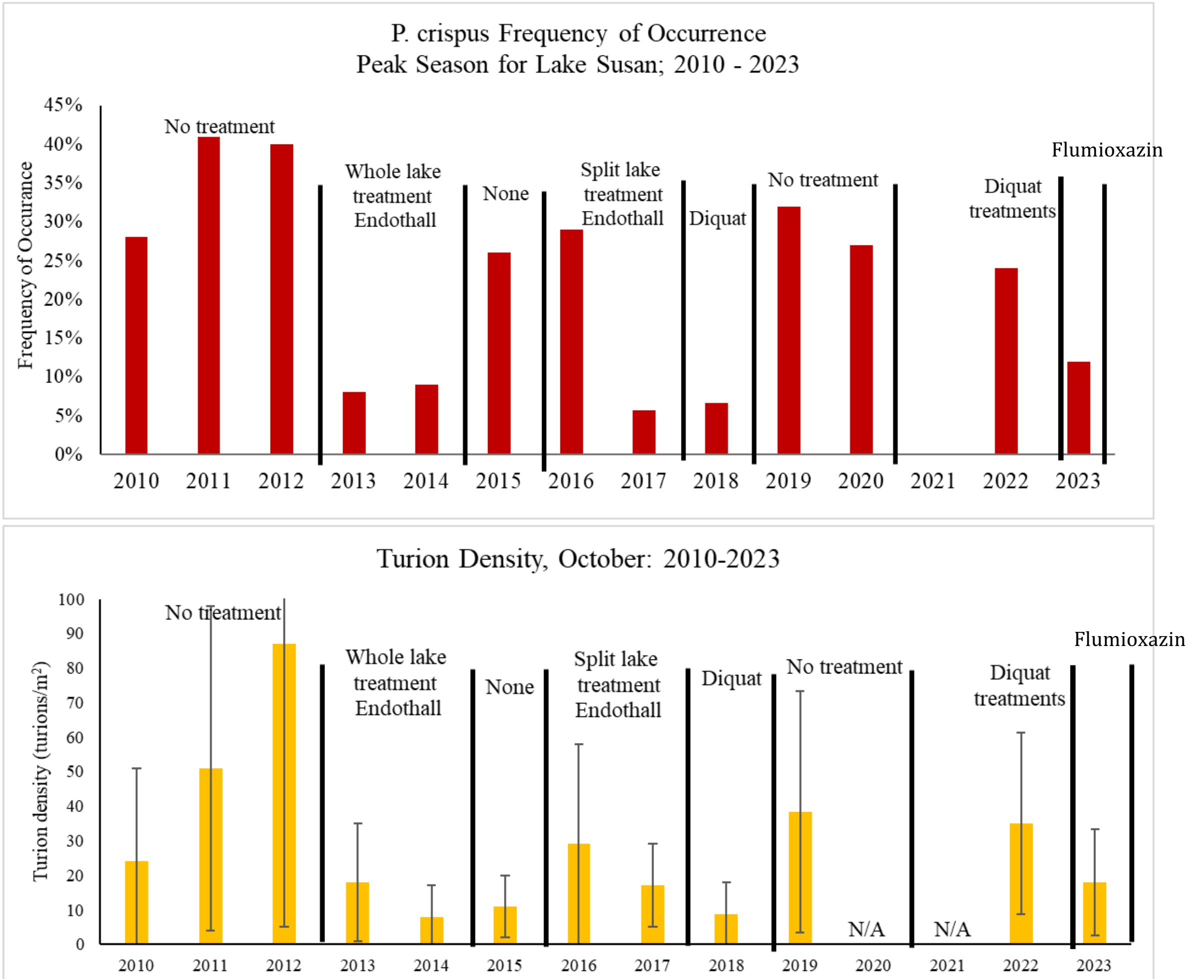


Figure 18. Curlyleaf pondweed peak season (June) frequency of occurrence and fall turion density in Lake Susan 2009 through 2023. The vertical lines represent the treatment years of 2013 and 2014, split treatments in 2016-2017, and partial lake diquat treatments in 2018, 2021 and 2022. Flumioxizin was used in 2023. Note: Post-treatment declines were significant ($p \leq 0.05$) in 2013-2014. Turion sampling was not conducted in 2020 or 2021 nor was a peak curleaf survey conducted in 2021.

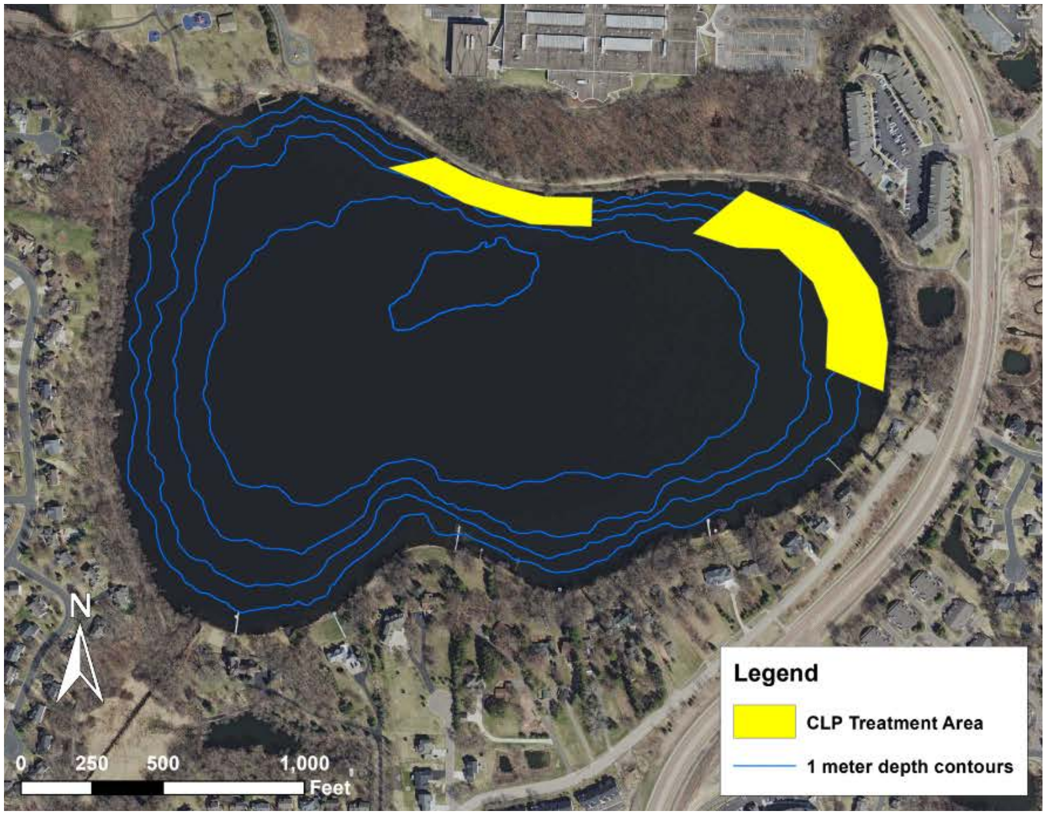
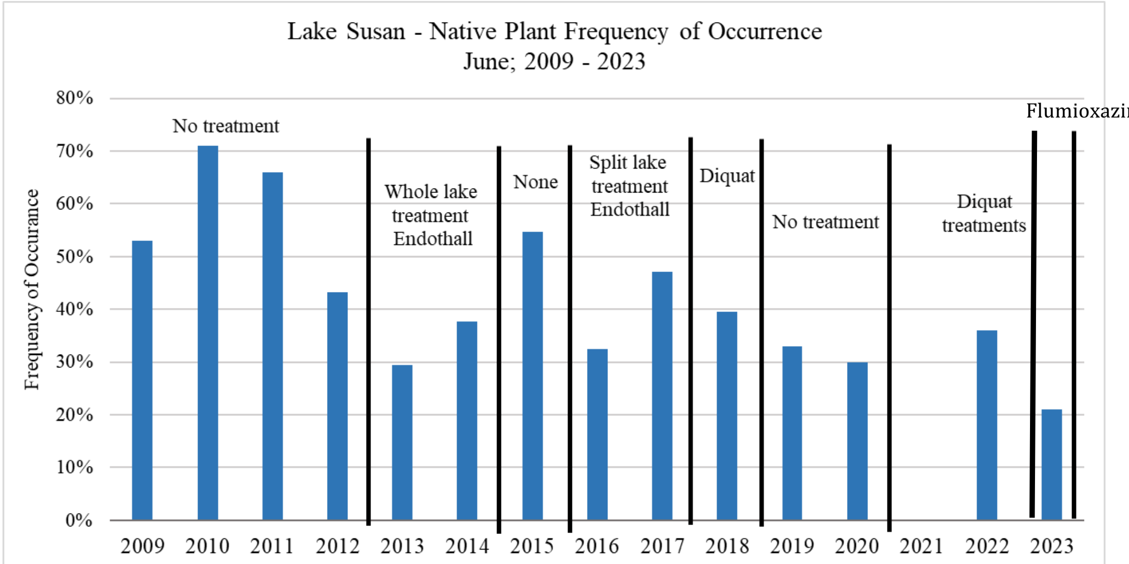


Figure 19. Curlyleaf pondweed diquat treatment blocks for May of 2023 (yellow boxes). In total, 5.35 acres were treated with Flumioxazin.



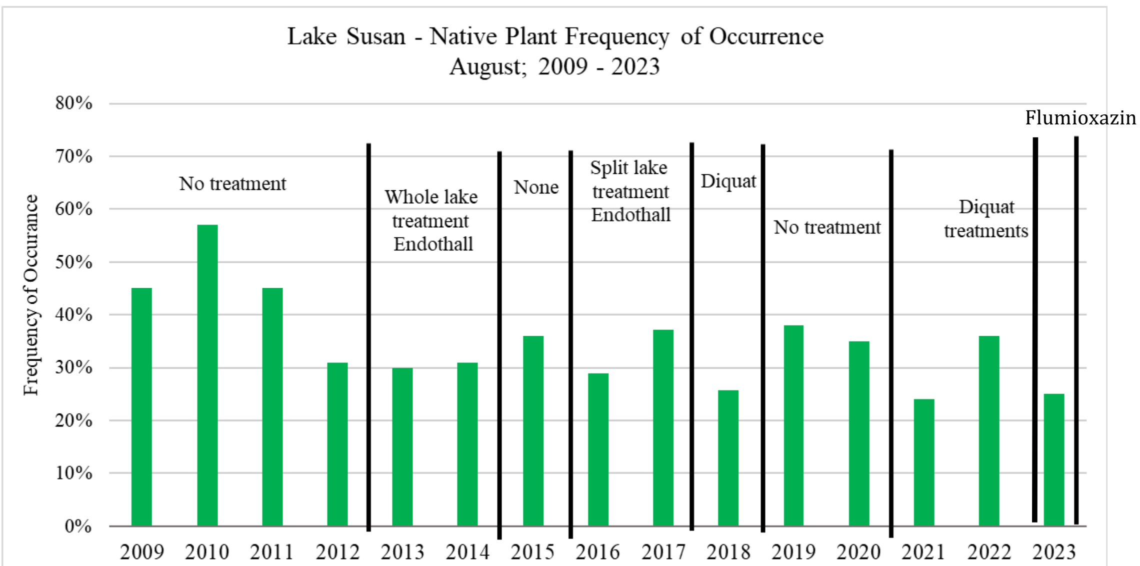


Figure 20. The frequency of occurrence of native aquatic plant species in Lake Susan, June and August 2009 through 2023.

Biomass:

Historically, coontail has been the predominant species within Lake Susan with a peak biomass that occurred during August of 2022 at 212.3 g/m^2 (Table 14). However, during August of 2019 chara was the taxa with the highest biomass at 360.2 g/m^2 followed by coontail at 201.6 g/m^2 and sago pondweed at 40.0 g/m^2. In June of 2022, white water lily had the highest biomass of 61.5 g/m^2, followed by yellow water lily at 40.3 g/m^2 and coontail at 63.7g/m^2. In 2023, coontail had the highest biomass in all three months. Eurasian watermilfoil had a peak biomass during June 2017 at 29.0 g/m^2; it appears to be in check partly due to herbivores as biomass and point-intercept sampling in 2018 through 2023 did not find any Eurasian watermilfoil.

Despite whole-lake endothall treatments in 2013 and 2014, split-lake endothall treatments in 2016 and 2017, and 2018 diquat treatment to control curlyleaf, there was a fairly large increase in curlyleaf biomass during June of 2019 after no treatment. During June of 2019, curlyleaf pondweed biomass peaked at 96.2 g/m^2 in June, which was higher than the previous measured maximum in May 2012 of 50.0 g/m^2. In May of 2020, curlyleaf pondweed had a biomass of 86.1 g/m^2, slightly less than the June peak in 2019. However, in June of 2020, curlyleaf pondweed biomass more than doubled that of the 2019 peak to a new maximum of 249.6 g/m^2. This new maximum biomass of curlyleaf pondweed also more than doubled that of native coontail in June of 2019 and 2020 at at 96.1 g/m^2 and 107.9 g/m^2, respectively (Table 14). After treatment in 2021, 2022, and 2023, curlyleaf pondweed biomass decreased greatly, with no biomass recorded in August of 2021, and 3.9 g/m^2 in June of 2022, 0.005g/m^2 in August of 2022, and 1.1 g/m^2 in June of 2023.

Table 14. Average biomass (all littoral sites sampled) results from 2011 through 2023 in Lake Susan. All data presented in g/m^2.

	Coontail	Chara	Canada waterweed	Star duckweed	Bushy pondweed	Southern naiad	Eurasian watermilfoil	White water lily	Spatterdock	American Lotus	Curlyleaf pondweed	Small pondweed	Flat-stem pondweed	Long-leaf pondweed	Floating-leaf pondweed	Sago pondweed	Water stargrass	White water buttercup	Brittle naiad	Horned pondweed	Leafy pondweed	Curlyleaf turions	Natives	Invasives
May-11	35.3		0.4				2.7	0.2			2.6	0.1											36.0	5.3
Jun-11	59.5		12.5				1.0		11.7		19.3	2.0				0.1							85.8	20.3
Aug-11	73.6		73.2				1.4		10.7	1.3	1.0	28.0											186.9	2.4
May-12	59.8		18.0				1.1		2.4	1.5	50.0	2.8				0.3							84.7	51.1
Jun-12	29.6		6.3				0.9		15.1	15.8	5.9	5.5				1.1							73.5	6.9
Aug-12	2.8		5.1	0.03			0.4		4.6	27.7	0.1	5.8											47.9	0.5
May-13	1.2		0.1								6.5											4.6	1.3	6.5
Jun-13	1.4		0.4	0.01			0.01	1.2	0.6		0.2	0.3										0.4	3.8	0.2
Aug-13	25.1		1.6					5.3	9.5	25.6	0.2	5.8				0.1						0.2	73.0	0.2
May-14	22.9		1.7		0.01						2.3	0.2						0.01					24.7	1.3
Jun-14	23.1		15.5		0.1			1.1	5.8	1.2	1.0	0.1				0.1				0.1		1.4	47.1	1.0
Aug-14	52.5		49.2	0.01	0.2			3.9	3.8	14		0.3	0.02			0.7				0.06			124.8	
May-15	10.7		1.2	0.01	0.3				0.2		1.0	0.01											12.3	1.0
Jun-15	5.2		13.6	0.001	0.05		0.07	3.4	7.9		29.6	0.3				0.09						2.9	30.5	32.6
Aug-15	63.7	0.2	39.8			1.8	0.6	2.9	9.6	1.0	0.001	1.2				0.2						0.2	120.5	0.8
May-16	21.1		2.4	0.02	0.5				0.3		2.00	0.02											24.3	2.0
Jun-16	67.2		21.1	0.001			3.3	0.2	3.0		16.6	0.03										1.9	91.5	21.7
Aug-16	71.6		0.8		0.1				4.7		0.01												77.2	0.01
Jun-17	107.4	30.0	0.02				29.0	2.5	47.4		0.3					0.3							236.1	29.3
Aug-17	152.6	11.1	0.2		22.9			11.8	22.5	2.4	0.02			0.001		0.1							71.2	0.02
May-19	96.6			0.02				0.2	1.5		10.3											0.004	98.3	10.3
Jun-19	96.1			0.5				1.1	13.6	3.9	96.2			0.6		8.6						3.8	124.5	100.0
Aug-19	201.6	360.2	4.2	1.3	0.1			17.8	39.6	5.3	3.2				3.2	40.0	0.05		0.04			0.4	673.5	2.6
May-20	79.9	2.6							0.3		86.1											0.1	82.8	86.2
Jun-20	107.9	3.5						30.4	7.3	7.8	249.6					0.2						8.4	157.1	258.0
Aug-20	212.3		0.8					10.9	1.1	1.0						3.3			0.1			0.4	229.4	0.5
Jun-22	63.7	0.002		0.69	0.01			61.5	40.3		3.89					1.8	0					2.3	170.3	3.9
Aug-22	33.3			0.002				26.4	5.0		0.01					0.5					0.1	1.4	66.7	0.01
May-23	18.3			0.003				0.02	0.3		0.3	0.01										0.1	18.6	0.4
Jun-23	107.1	0.01		0.01				1.1	7.2		1.1					0.2						1.3	115.6	2.5
Aug-23	20.9				0.01			9.6	1.4			3.2				0.3	0.2					0.04	35.7	0.04

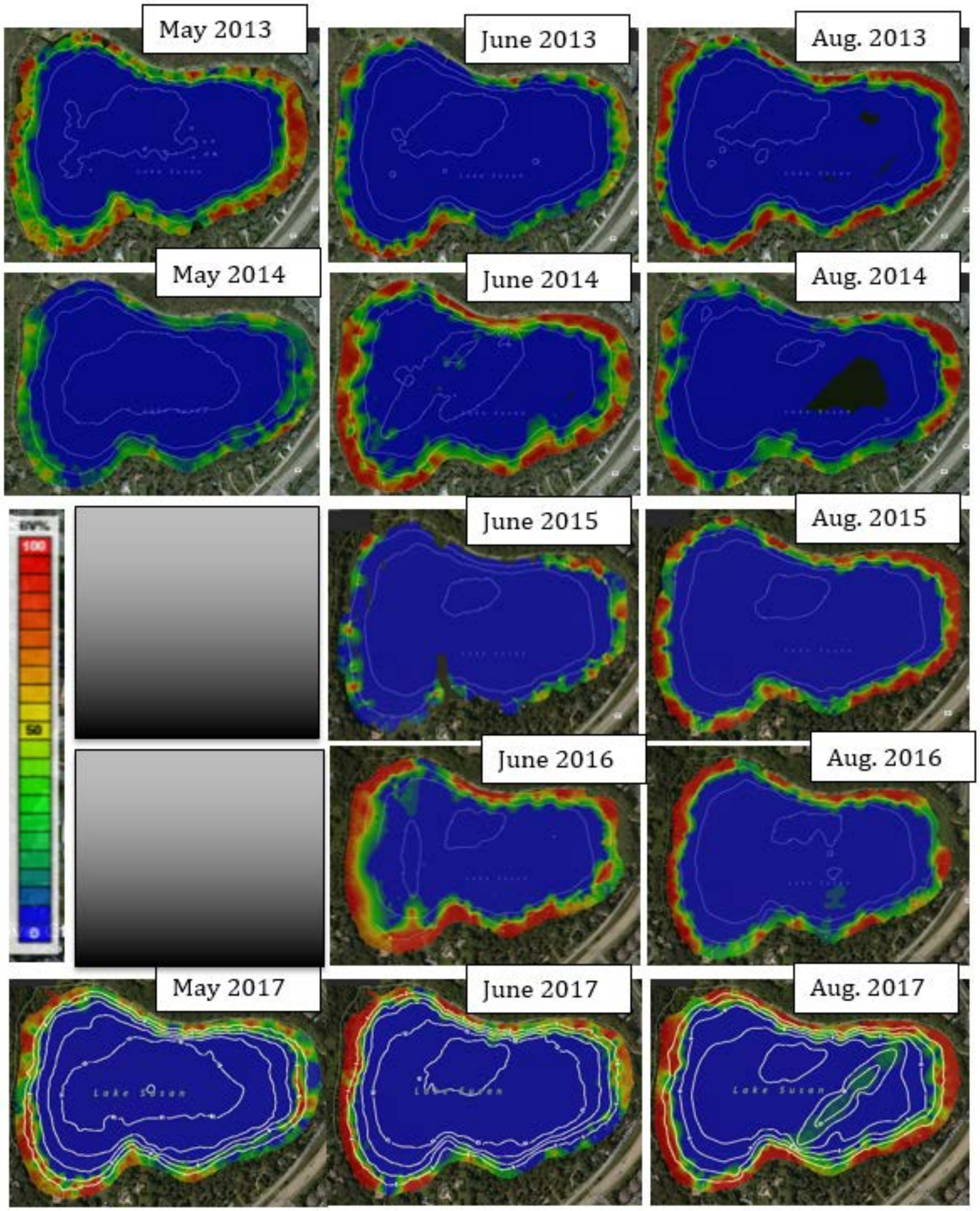
Aquatic Bathymetry and Vegetation Mapping:

Plant coverage between 2013 to 2023 has ranged from 6.6% to almost 65% while biovolume ranged from 21% to 68% (Table 15); the highest biovolume was generally in water < 2m deep (Figure 21). Plants were distributed around the lake, but rarely in water deeper than 3m. Mean biovolume ranged from 21% in May 2014 to 68% in June 2015

(Table 15). Coverage and biovolume in 2017 and 2018 was similar to previous years. Improvements in water clarity expanded plant coverage beyond to 3.5m and percent area coverage over 50% in August of 2019, although biovolume was lower than previous years. Plant coverage decreased in 2020 with August being half of what was measured in August of 2019. Average biovolume increased slightly in 2020, with June and August both being 10% higher than values for corresponding 2019 months while May was only slightly higher. Numbers in 2023 were very similar to those of recent years, with a slight decrease in PAC in June of 2023.

Table 15. Lake-wide percent area cover (PAC) and average biovolume (BV) for data collected in 2013 through 2023 in Lake Susan. Values coincide with maps in Figure 21. PAC refers to the overall surface area that vegetation is growing in the surveyed area. Average BV refers to the percentage of the water column taken up by plants when plants exist; areas that have no plants are not factored into this calculation.

Date	PAC	Average BV
May 2013	33.7%	46.3%
June 2013	17.9%	35.8%
August 2013	22.5%	56.1%
May 2014	23.6%	20.6%
June 2014	38.6%	47.5%
August 2014	23.8%	37.8%
June 2015	6.6%	68.3%
August 2015	19.0%	55.3%
June 2016	37.7%	50.4%
August 2016	28%	46.5%
May 2017	27.7%	43.5%
June 2017	23.8%	51.9%
August 2017	39.4%	49.8%
June 2018	26.2%	41.6%
August 2018	45.8%	31.8%
October 2018	22.8%	26.4%
May 2019	32.2%	46.3%
June 2019	64.7%	34.7%
August 2019	51.0%	25.6%
May 2020	33.3%	47.9%
June 2020	38.5%	44.9%
August 2020	24.9%	37.1%
June 2022	26.3%	41.9%
August 2022	29.9%	35.3%
May 2023	31.4%	33.0%
June 2023	17.1%	37.4%
August 2023	23.7%	33.8%


May 2013
June 2013
Aug. 2013
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100
50

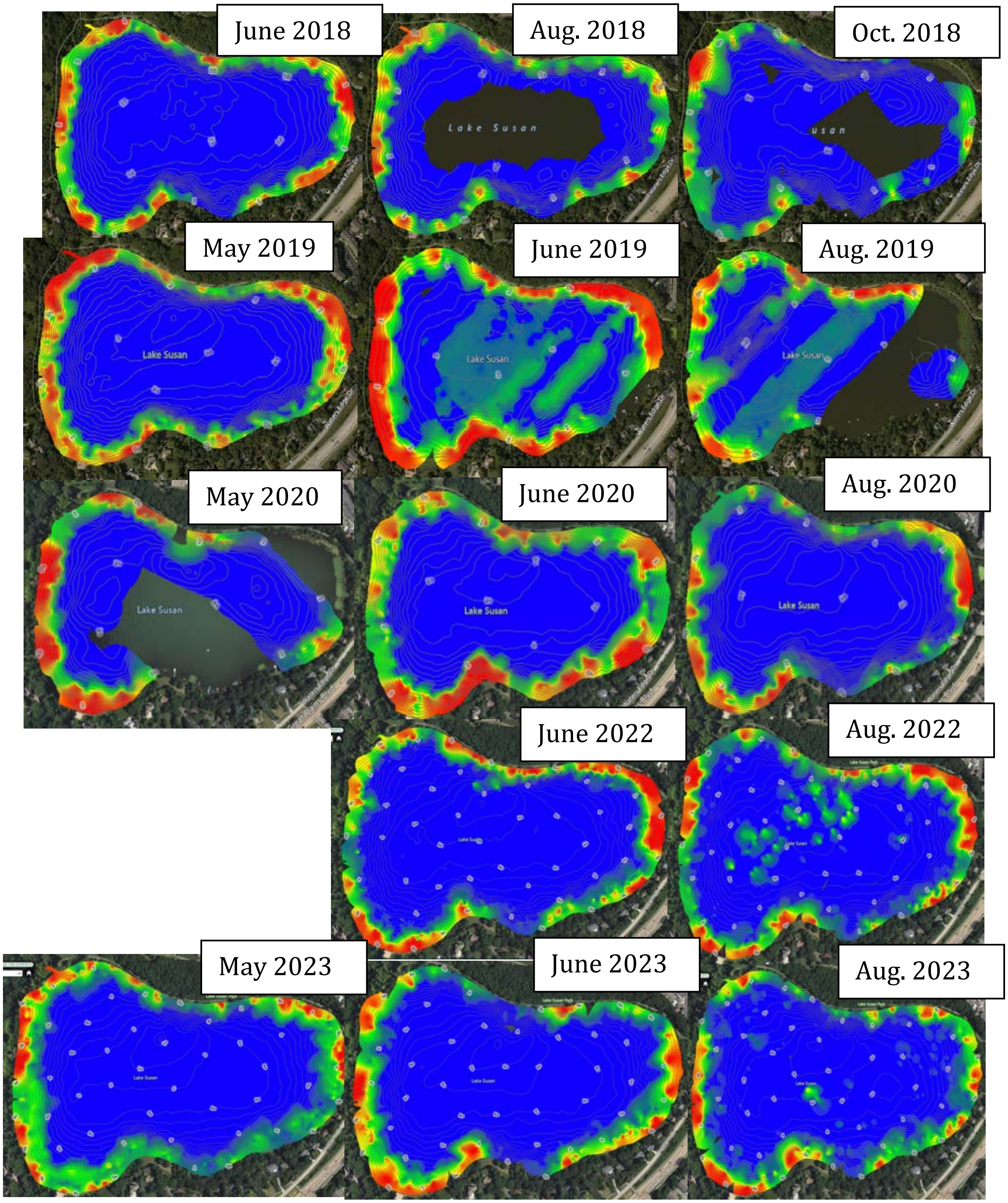

Figure 21. Aquatic bathymetry and vegetation maps of Lake Susan. Data collected during point intercept aquatic vegetation surveys by Newman lab on: 6 May 2013, 7 June 2013, 12 August 2013, 13 May 2014, 17 June 2014, 6 August 2014, June 26 2015, August 7 2015, June 6 2016, August 3 2016, 4 May 2017, 12 June 2017, 1 August 2017, 27 June 2018, 3 August 2018, 20 October 2018, 23 May 2019, 17 June 2019, 17 August 2019, 18

May 2020, 18 June 2020, 13 August 2020, 28 June 2022, 15 August 2022, 16 May 2023, 13 June 2023, and 16 August 2023. Color legend represents percent biovolume (the percentage of the water column taken up by vegetation when vegetation exists) with blue representing no vegetation present and red representing 100% of the water column being taken up by vegetation (Newman lab's data).

Lake Susan Recommendations:

Curlyleaf pondweed had been contained with regular treatment but lack of treatment in 2019 and 2020 allowed curlyleaf to increase and turion densities to remain somewhat elevated at 38 (2020) and 35 (2022) turions/m^2, but still much lower than densities in 2011 and 2012. No turion or peak season curlyleaf sampling was conducted in 2021. Diquat treatments occurred in May of 2021 and 2022, but curlyleaf frequency still remained above 20% in May of 2023. The flumioxazin treatment in 2023 was a bit more effective at reducing June frequency and fall turion density. Viable turion density in fall 2023 was just below 20/m^2 so a spring delineation in 2024 will be needed to inform treatment.

Historically the expansion of native plants in Lake Susan has been limited by water clarity. Although water clarity improved in 2019 and the native plant community appeared to be expanding, this trend did not continue in 2020. In 2021 there was higher water clarity, but this was short-lived, and clarity went back down in 2022. Clarity was high in May of 2023 but decreased significantly in following months. Some of the transplanted species have remained established since 2014; bushy pondweed and water stargrass had expanded enough to remain in lake wide surveys in 2014, and also 2017 through 2019. In 2020 and 2021, bushy pondweed was not observed, but was observed in 2022 and 2023. Water stargrass was found in 2014, 2015, and 2017-2023. Chara was observed in 2017 and 2019-2023. It was not observed in 2018 or 2022. However, when observed, these plants have been found at very low frequency of occurrence. Wild celery was observed in summer 2018 but not found in surveys from 2019 to 2023. The decrease in Canada waterweed since a peak in 2015 and its disappearance in 2020 along with an increase in coontail is concerning.

With the limited water clarity of Lake Susan, an alum treatment to bolster clarity and reduce internal nutrient loading may be beneficial. A plan for an alum treatment should be considered for 2024 or 2025. If alum treatments occur in the future, herbicide applications will likely be needed to control the expansion of curlyleaf. An LVMP should be developed prior to or during the alum treatment. If transplanted taxa remain in the lake, they should respond favorably to improved water clarity. If they are not found in future surveys or within a year of improved water clarity, additional transplanting into deeper water should be considered. An assessment of the sediment seedbank would be useful before any further transplanting is considered.

Summary:

Overall, native plant communities improved in the lakes of the Riley Purgatory Bluff Creek Watershed District following carp removal. An expansion of submersed plants followed carp removal in the three lakes that were assessed (Riley, Staring and Susan). However, management of invasive curlyleaf pondweed and Eurasian watermilfoil has been needed and one or both increased to levels requiring management in all three lakes. Both species tolerate low-light conditions and are able to grow early in the season. As a result, the exotic species can outcompete natives and be abundant in nuisance levels. Brittle naiad will also need to be closely monitored in Staring Lake and Lake Susan in the future, although it appears to be limited in occurrence to late summer and early fall.

Properly dosed herbicide treatments have been effective at controlling these invasives and should continue as needed. Ideally, the populations of invasive species will be reduced to the extent that treatment will not need to occur each year and the lack of need to treat Eurasian watermilfoil in Riley from 2018-2023 and curlyleaf pondweed in Staring from 2018-2023 is encouraging. For Lake Riley, a spring delineation should be conducted in 2024 to determine if curlyleaf pondweed treatment is needed. Eurasian watermilfoil should be assessed in June but treatment is likely not needed. The whole-lake fluridone treatment in Staring Lake should provide several years of control of curlyleaf and Eurasian watermilfoil and the main concern will be the response of native plants and water clarity in 2024 and beyond. Lake Susan may require a curlyleaf pondweed treatment in 2024. Spring delination surveys for curlyleaf pondweed should be conducted in each lake after iceout to determine if treatment is needed. Similar surveys for milfoil should be conducted June in Lake Riley and Staring Lake and Lake Susan should be closely monitored for appearance of milfoil and brittle niad.

In many lakes, actions to further enhance summer water clarity are likely needed for the development of healthy native plant communities; these communities will be more resilient to exotic macrophyte proliferation and will provide habitat for aquatic life. Improvements to the native plant community should also help maintain and promote improved clarity. An alum treatment in Lake Susan in 2024 or future years would be helpful and continued monitoring of the response of Lake Riley and Hyland Lake to alum treatments will allow assessment of the response of native plants. A nutrient loading analysis for Staring Lake would be useful to assess the need for futher water quality improvement strategies and the long term stability with plant management. Continued actions to monitor and contain the carp populations in Lake Riley, Lake Susan and Staring Lake will be important. Carp still do not appear to be a current issue in Lakes Riley and Susan, but continued vigilance in Staring Lake is still needed.

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