Aquatic Plant Community of
Lakes Lucy, Mitchell, Susan, Riley and Staring within the
Riley Purgatory Bluff Creek Watershed:
Final Report for 2015-2017

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I. Introduction

Lakes Lucy, Riley and Susan are small lakes connected by Riley Creek within the cities of Chanhassen and Eden Prairie, Minnesota in the Riley Creek Subwatershed. Lakes Mitchell and Staring, also in Eden Prairie, are within the Purgatory Creek Subwatershed. 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 between April and October during various years from 2009 through 2017. 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 main purpose was to assess the native aquatic plant community response following the removal of common carp (*Cyprinus carpio*) from the lakes. 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 2017. Carp were removed from Lake Lucy in January 2010 and plants were surveyed in 2010, 2011, 2012, 2015, and 2016. Carp were removed from Lake Riley in March 2010 and plant surveys were completed from 2011 through 2017. In Lake Staring, 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 Lake Staring in 2011 through 2017. Continuing these surveyson Lake Staring after carp removal allowed an assessment of the plant community response compared to the pre-removal surveys.

An additional goal of the project was to promote the recovery of native plants and control aquatic invasive macrophytes. The hypothesis is 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 natural aggressive recruitment, there was concern the invasive species would expand at a faster rate than native species. Thus the problem is 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, in 2013 through 2017 in Lake Riley, and in 2015 through 2017 in Lake Mitchell. Plant surveys were completed in 2013 through 2017 in Lake Mitchell. 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. To control Eurasian watermilfoil in Lake Riley a 2, 4-D herbicide treatment was applied in June of 2015 and 2016 and granular 2, 4-D and triclopyr were assessed in

2017. To control a sparse population of Eurasian watermilfoil found in Lake Staring in September 2015 and again in August 2016 and 2017, a granular form of triclopyr herbicide was used for these treatments and additional handpulling was also conducted by the district.

This final report presents data and results mainly from 2015-2017 with some 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), and 2015 (Dunne and Newman 2016) as well as from Knopik (2014), Knopik and Newman (in review) and Dunne (2017). It concludes with recommendations for further management of each of the lakes along with an overview of concuculsions across lakes.

II. Methods

Plant communities were surveyed for species occurrence and diversity (point intercept surveys), biomass, curlyleaf pondweed turion densities, and watermilfoil herbivore abundance to assess response to carp removal and monitor and develop approaches to enhance native plant communities while controlling invasive macrophytes. Plant species taxonomy and names follow what was published in Borman *et al.* 2014. In 2015, 2016 and 2017, early season, endothall herbicide treatments were employed to control curlyleaf pondweed in Lakes Riley, Susan, and Mitchell. A lake-wide 2, 4-D herbicide treatment was used on Lake Riley in June of 2015 and 2016 to control Eurasian watermilfoil and a combination of triclopyr and 2,4-D were used in 2017. Localized placement of granular triclopyr (Renovate3®) was used in Lake Staring in September of 2016 when isolated patches of Eurasian watermilfoil were found. 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 ciBioBase software (by Contour Innovations) to create bathymetry and lake vegetation maps.

Point Intercept Survey:

A point intercept survey approach modeled from the methods described by 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 a Garmin GPS 76 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 was 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 the samples were dried at 105˚C for >48 hr and 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.

Curlyleaf Pondweed Turion Sampling:

The invasive curlyleaf pondweed is found in many lakes in Minnesota including Lakes Lucy, Mitchell, Riley, Staring and Susan. One of the most common ways curlyleaf pondweed reproduces is by forming over-wintering vegetative propagules called turions (Madsen and Crowell 2002). To better understand the curlyleaf pondweed population dynamics in the lakes, we assessed the turion bank in the sediment of Lakes Mitchell, Riley, Staring and Susan. Turion sampling in Lake Susan began in October of 2010, sampling in Lakes Riley and Staring began in October of 2011, and sampling in Lake Mitchell began in October of 2013. 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. The remaining sample was returned to the lab and turions were enumerated. The turions that had sprouted in the field (plants or sprouts collected with turions attached) were discarded. The remaining turions were stored in transparent freezer bags 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 rate of sprouting of cold turions had declined. At this point the samples 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 and sprouted turions were removed and recorded. Turion viability (proportion) was calculated by taking the ratio of the number of sprouted turions per site (including the turions that were sprouted when collected) to the total number of turions collected per site. The total number of turions collected at each site was expressed as number of turions per square meter.

Milfoil Herbivore Abundance:

Surveys were conducted to evaluate the abundance of milfoil herbivores. The milfoil weevil, *Euhrychiopsis lecontei*, is a native weevil found in many lakes in North America. Much of the weevil's life cycle is dependent on the milfoil plant. Evidence suggests the milfoil weevil can be effective in controlling Eurasian watermilfoil (Newman 2004). Surveys were conducted on Lakes Ann, Lucy, Riley and Susan in 2011 and 2012, and continued in Lakes Riley and Susan in 2013 through 2016 to determine if milfoil weevils were present or abundant. Additionally, Lake Mitchell began to be surveyed in 2015 and continued in 2016. On Lake Susan, repeated surveys were conducted every four weeks to quantify and monitor the population throughout the summer in 2010 through 2016. Lake Riley was sampled every four weeks in the summers of 2012 through 2016. Lake Mitchell was sampled every four weeks in the summers of 2015 and 2016. To sample milfoil herbivores, transects perpendicular to the shoreline were predetermined and geographically spread around the lake. Three sampling points were established on each transect, one at a shallow depth (<0.75m), one at an intermediate depth (0.75 to 1.5m), and one at a deeper depth (>1.5m). At each sampling point the top 0.5m of eight stems of Eurasian watermilfoil were collected and placed in a sealable bag with water. In a lab, each sample was examined with a 3x magnifying lens, plant stems and meristems were counted, and all herbivores (lepidopterans and weevils) and weevil life stages (eggs, pupae, larvae, and adults) were counted and preserved in 80% ethanol.

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 LiCor LI-185 quantum sensor. Secchi depths were recorded to the nearest 0.1m.

Herbicide Treatments

To control curlyleaf pondweed, early season endothall herbicide treatments were conducted in the spring of 2013, 2014, 2016 and 2017 in Lake Susan and spring of 2013, 2014, 2015, 2016 and 2017 in Lake Riley and spring of 2015, 2016, and 2017 in Lake Mitchell and spring 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). Using this method of timing, we can effectively target curlyleaf pondweed with little collateral damage to the native plant community (Jones et al. 2012). During the early parts of spring when ice came off the study lakes we would begin to closely monitor water temperatures. Once water temperatures approached the treatment temperature threshold we then delineated the densest areas of curlyleaf and provided these areas to the contracted herbicide applicator. We conducted a pretreatment (point intercept and biomass) survey on all treatment lakes just prior to treatments. Post-treatment surveys were conducted at all lakes in June to correspond with typical peak curlyleaf abundance and biomass. Precise survey timing varied with growth each year. A third survey was conducted in August in all lakes corresponding with the timing of peak biomass of native plants. Fall turion surveys were completed in October to monitor the turion densities in the sediments, which is essentially the same as monitoring the seed bank for curlyleaf pondweed. Reducing turions in the sediments is an important management strategy to the reduction of 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 granular 2,4-d (Sculpin G) to 10 acres and granular triclopyr (Renovate OTF) to 10 acres. Granular formalations likely disperse less quickly than liquid applcations.

A granular form of triclopyr (known as Renovate3®) was used to control a small population of Eurasian watermilfoil observed growing in Lake Staring 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).

To evaluate the herbicide concentrations after treatment, herbicide residuals were collected on Lake Riley in 2015 for 2,4-D and in 2016 for endothall and 2,4-D and on

Lake Susan in 2016 for endothall and in Mitchell, Riley and Susan in 2017. Water samples were collected by University of Minnesota researchers and watershed district staff. Samples were collected four hours after application, a day after application, four days after application, and one week after application. Herbicide residual analysis was completed by Dr. Mike Netherland of the US Army Engineer Research and Development Center in Gainesville, Fl.

Alum Treatment

A hypolimnetic alum treatment was applied to Lake Riley in May 2016 to control algal growth and improve water clarity. When applied to the lake alum creates an aluminum hydroxide floc that binds and sequesters phosphorous in the water column and in the sediment once the compound reaches the lake bottom. Aquatic plant surveys occurred in May prior to the treatment, in June during peak curlyleaf growth, and in August during peak native plant growth and the abundance, rake ratings, and biomass were evaluated to assess if the improved water clarity had an effect on the plant community abundance, richness, and maximum depth of growth. Water quality metrics were also used to determine the overall success of the alum treatment.

Aquatic Bathymetry and Vegetation Mapping

We collected sonar data using a Lowrance HDS 5 Gen 2 Fish finder during point intercept surveys in 2013 through 2017. The HDS 5 recorded data onto an SD card while we navigated the boat to survey points. From the lab, we uploaded the sonar data to the ciBioBase servers. After ciBioBase processed the sonar data we then had access to bathymetry and vegetation maps as well as a report generated for each lake containing plant and water data such as average biovolume and percent area covered.

Results by Lake

Results are first presented by Lake. Lake Lucy was not sampled in 2017 but results from 2015 and 216 are presented. The other lakes were sampled each of the project years and these results are reported.

III. Lake Lucy Results

Lake Lucy (DOW ID 10-000700) is the headwaters of the Riley Creek Watershed. Lake Lucy has a surface area of about 36 hectares (87 acres), with about 35 hectares (86 acres) of littoral zone, and a maximum depth of 6.8m (22ft) (MN DNR LakeFinder 2016). The outlet of Lake Lucy goes directly into Lake Ann. In an attempt to improve water quality, common carp were removed from Lake Lucy in January 2010 (Bajer and Sorensen, personal communication). Plant assessments began in summer 2010 to quantify the response of the aquatic plant community to the carp removal and ended in 2012. In 2015 and 2016, Lake Lucy was surveyed twice in the summer to assess if plants have expanded after the carp removal.

Water Quality:

Water clarity in 2016 was consistent with observations from prior years (Figure 1). Secchi depths did not fall below 1m until August. Dissolved oxygen profiles taken during the summer show an anoxic hypolimnion starting at 2.5 to 3m (Figure 1).

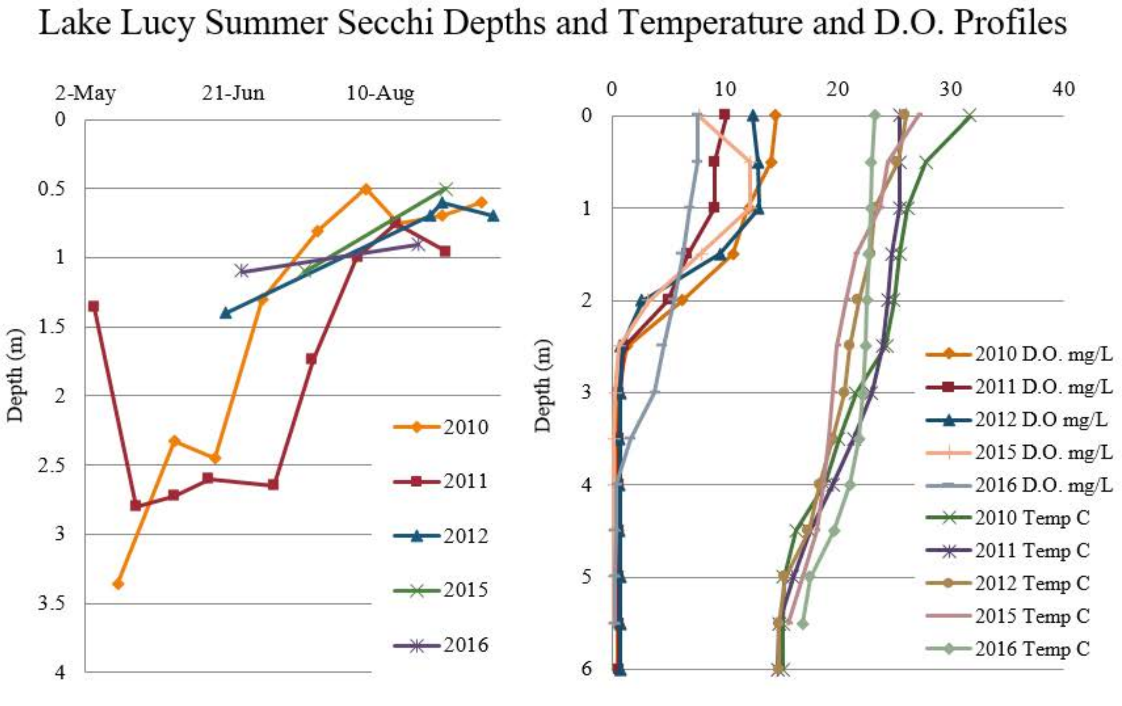


Figure 1. Secchi depths for Lake Lucy 2010 – 2012, 2015-2016 (Bajer and Sorensen unpublished data, personal communication) and dissolved oxygen (mg/L) and temperature (°C) profiles taken on 9 August 2010, 17 August 2011, 27 August 2012, 1 September 2015, and 23 August 2016.

Aquatic Vegetation Survey:

Point intercept surveys were previously conducted in Lake Lucy in June and August of 2010, 2011, and 2012. Surveys were conducted in July and September in 2015 and in June and August in 2016. Overall there was a moderately diverse plant community in Lake Lucy with 18 different aquatic plant species found during the surveys (Table 1). In 2016 only 12 different aquatic plant species were found. The maximum species richness per site in 2016 was 7 species per site in August (Figure 2). The greatest native plant coverage was noted in June 2010 when 69% of sites sampled shallower than 4.6m contained native plants (Table 2). In 2016, the native plant coverage was 53% of sites in June. This observation is consistent with 2015 surveys when 59% of sites contained plants in July (Table 2). The number of native submersed plants has remained consistent across survey years fluxuating at around 10 species found per survey (Table 2). Coontail (*Ceratophyllum demersum*) was the most frequently occurring species in all surveys conducted (Figure 3). Star duckweed (*Lemna trisulca*), white water lily (*Nymphaea odorata*), greater bladderwort (*Utricularia vulgaris*) and curlyleaf pondweed (*Potamogeton crispus*) were also observed at relatively high frequencies.

Coontail, chara (*Chara sp.*), white water lily, and yellow water lily had the highest biomass in Lake Lucy during the surveys (Figure 4). Biomass values appeared to be relatively stable throughout survey years of 2010 through 2012. However, in 2015 the biomass of most species showed a slight decline compared to previous August surveys. In 2016, most species increased in August biomass relative to 2015.

Overall, exotic species frequency and biomass has been declining. Eurasian watermilfoil was observed at less than 1% of sites during 2011 and 2012 surveys and it was not observed in 2015. However, in 2016 it was observed during both surveys at less than 5% of sites (Figure 3). Curlyleaf pondweed was present in over 40% of sites surveyed at 4.6m or shallower in June 2011. In June 2016 curlyleaf pondweed presence declined to less than 20% of sites surveyed (Figure 3 top). Also, curlyleaf pondweed had very little biomass present during all survey years (Figure 4), but the June survey in 2016 was too late to capture peak curlyleaf biomass.

Aquatic Bathymetry and Vegetation Maps

Plants at Lake Lucy were dense in the western and northern areas of the lake during all surveys in 2015 and 2016 (Figure 5). Percent coverage ranged from approximately 40% to almost 70% of the surveyed area depending on the time year between 2015 and 2016 (Table 3).

Table 1. Aquatic plants found in surveys conducted in Lake Lucy 2010 through 2012, and 2015 and 2016.

Common Name	Scientific Name	Abbreviation	Year First Observed
Emergent			
Cattail	*Typha spp.*	Typh	2010
Submerged species			
Coontail	*Ceratophyllum demersum*	Cdem	2010
Chara	*Chara spp.*	Char	2010
Canada waterweed	*Elodea canadensis*	Ecan	2010
Water stargrass	*Heteranthera dubia*[1]	Zdub	2010
Eurasian watermilfoil	*Myriophyllum spicatum*	Mspi	2011
Northern watermilfoil	*Myriophyllum sibiricum*	Msib	2010
Curlyleaf pondweed	*Potamogeton crispus*	Pcri	2010
Narrow leaf pondweed	*Potamogeton pusillus*	Ppus	2011
Flat-stem pondweed	*Potamogeton zosteriformis*	Pzos	2012
Sago pondweed	*Stuckenia pectinata*	Spec	2010
Greater bladderwort	*Utricularia vulgaris*	Uvul	2010
Floating-leaf Species			
Star duckweed	*Lemna trisulca*	Ltri	2010
Lesser duckweed	*Lemna minor*	Lmin	2012
White water lily	*Nymphaea odorata*	Nodo	2010
Yellow water lily	*Nuphar variegata*	Nvar	2010
Greater duckweed	*Spirodela polyrrhiza*	Spol	2010
Watermeal	*Wolffia columbiana*	Wcol	2010

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

Table 2. Summary of Lake Lucy aquatic plant survey data from survey years 2010, 2011, 2012, 2015, and 2016. 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 Submersed Native Taxa	Number of Submersed Natives	Average Secchi Depth (m)
June 2010	4.3	69%	11	2.3
August 2010	4.5	63%	10	0.7
June 2011	4.5	61%	13	2.6
August 2011	4.6	64%	13	0.8
June 2012	4.5	56%	12	1.4
August 2012	4.3	48%	11	0.7
July 2015	4.2	59%	8	1.1
September 2015	4.1	57%	8	0.5
June 2016	4.3	53%	9	1.1
September 2016	3.8	48%	10	0.9

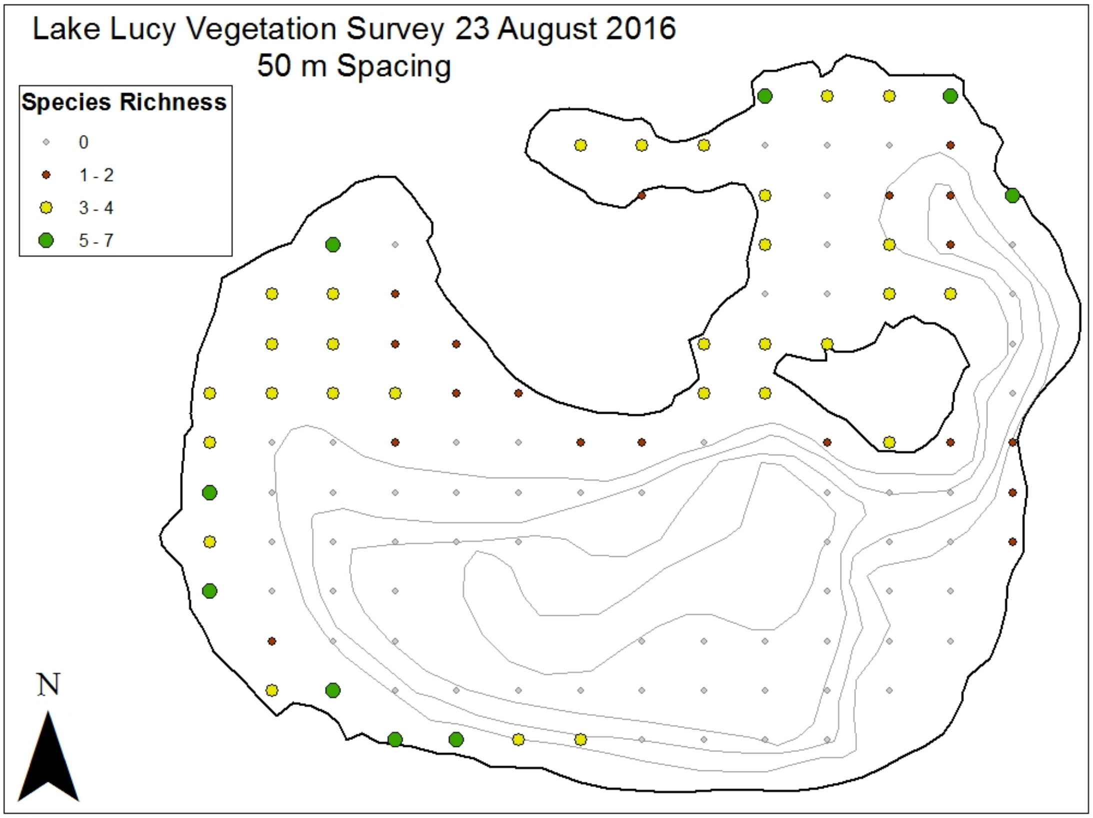


Figure 2. The number of aquatic plant species present at each site surveyed in Lake Lucy, 23 August 2016.

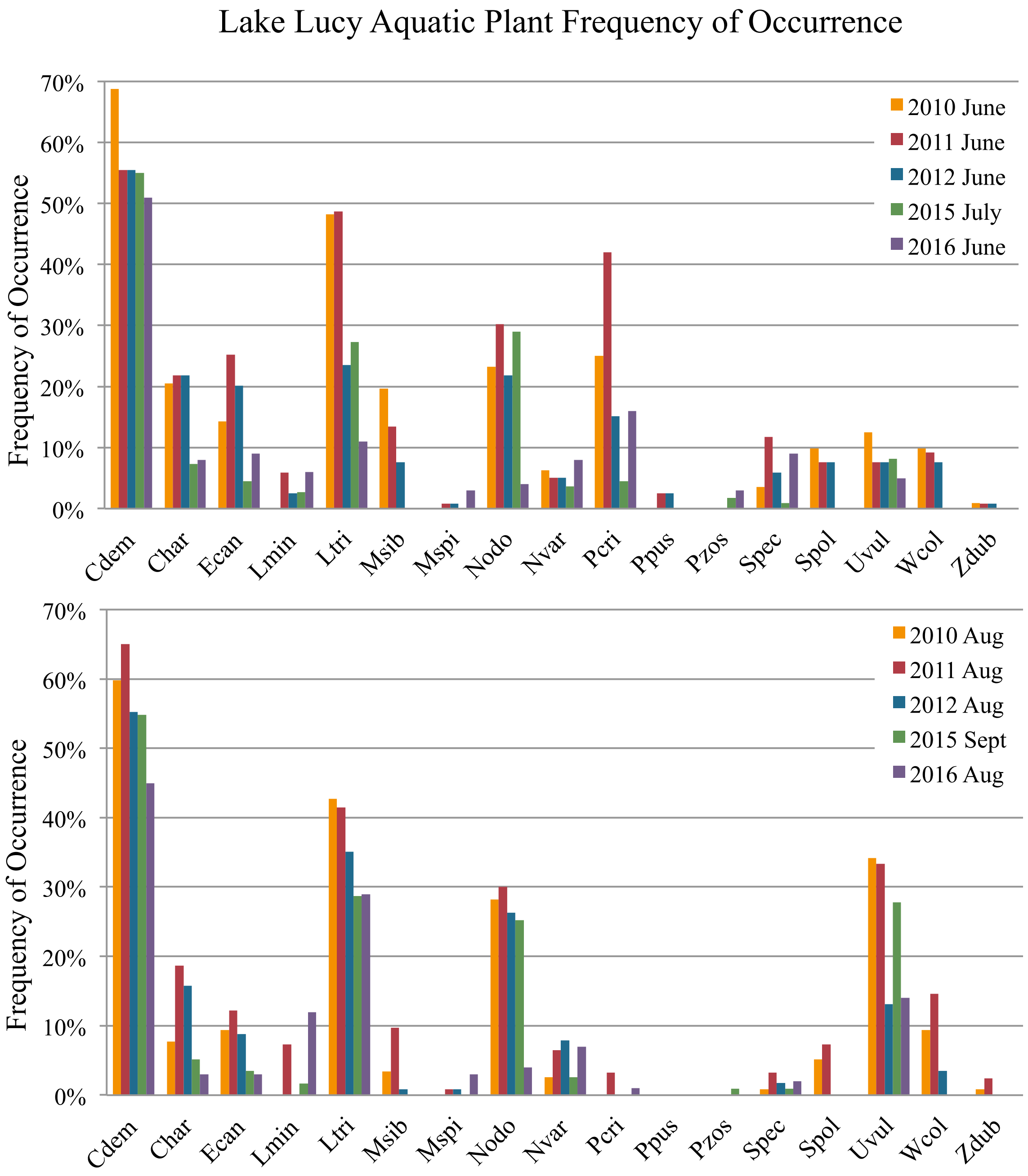


Figure 3. Frequency of occurrence for the most commonly occurring species in Lake Lucy found in surveys June 2010 through 2012, July 2015, and June 2016 and in August 2010 through 2012, September 2015, and August 2016. See Table 1 for abbreviations.

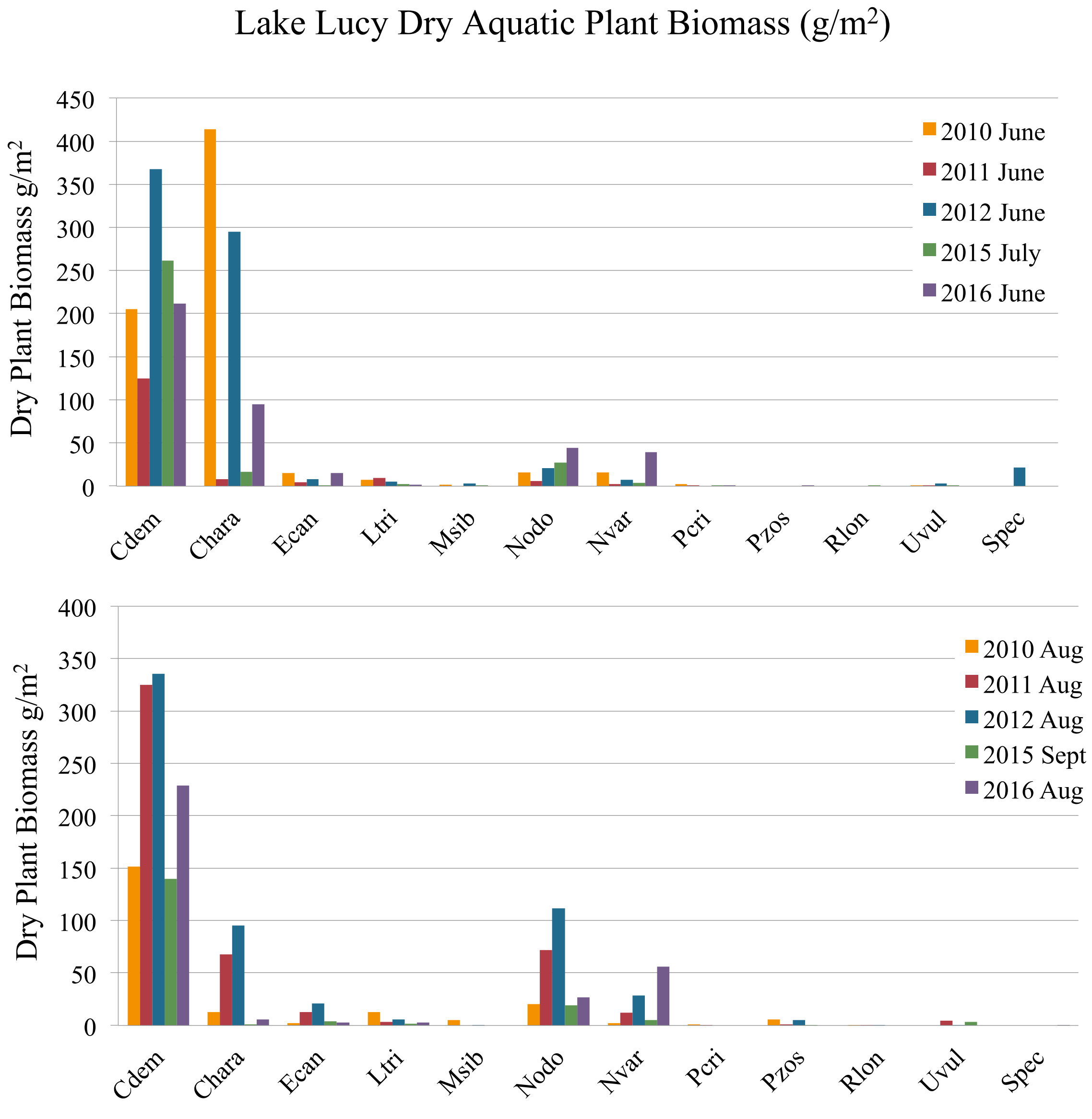


Figure 4. Dry aquatic plant biomass (g dry/m^2) in Lake Lucy from surveys in June 2010 through 2012, July 2015, and June 2016 and in August 2010 through 2012, September 2015, and August 2016. See Table 1 for abbreviations.

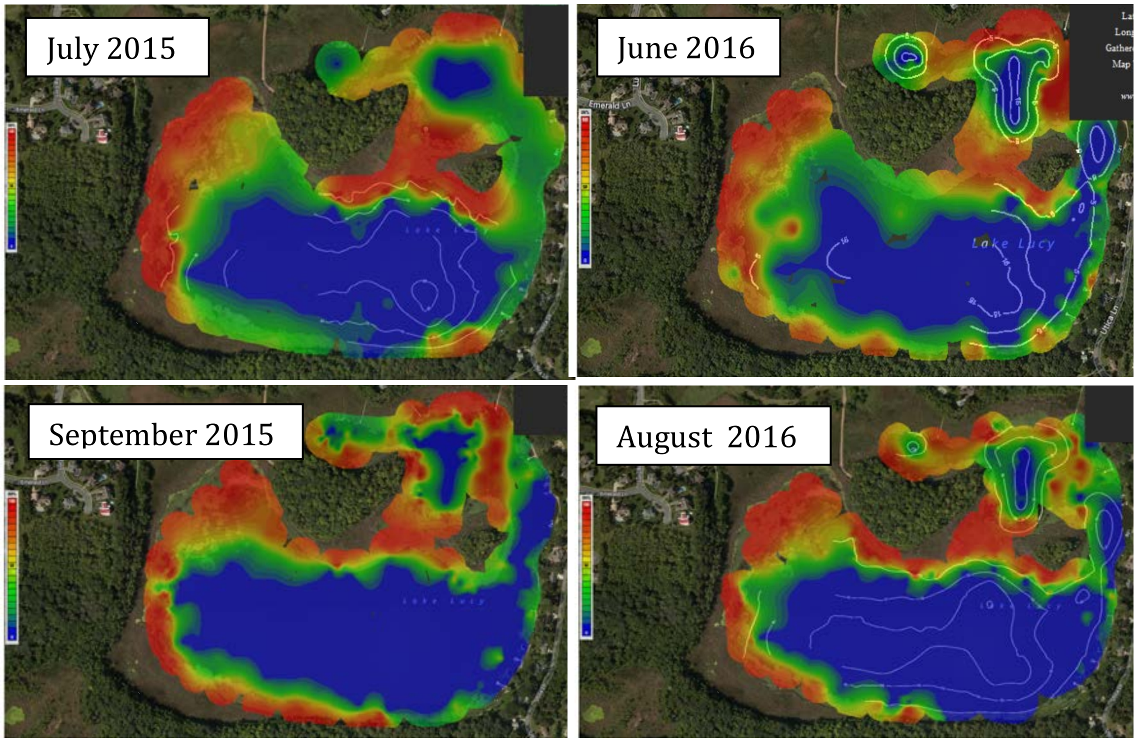


Figure 5. Aquatic bathymetry and vegetation maps of Lake Lucy. Data collected during point intercept aquatic vegetation surveys on: 15 July 2015, 1 September 2015, 24 June 2016, and 23 August 2016. Contour lines are 5ft intervals. Color legend represents percent biovolume (refers to the percentage of 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 3. Lake-wide percent area covered (PAC) and average biovolume (BV) for surveys in 2015 and 2016 in Lake Lucy. Values coincide with maps in Figure 5. 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
July 2015	43.2%	58.2%
September 2015	46.8%	57.0%
June 2016	67.9%	50.9%
August 2016	48.5%	48.8%

Recommendations for Lake Lucy:

A slight decrease in the species richness of the aquatic plant community of Lake Lucy appears to have occurred between the 2012 and 2015 gap in sampling period. In 2016, the plant community richness and abundance was closer to 2010 through 2012 levels. Exotic species curlyleaf pondweed and Eurasian watermilfoil are still present at low abundances and the plant community is still relatively healthy. Lakeshore homeowners are currently controlling curlyleaf with local herbicide applications so lake-wide treatments are not recommended at this time. If curlyleaf pondweed increases dramatically in the future, Lake Lucy could possibly benefit from a lake-wide early season endothall herbicide treatment. Lake Lucy could be surveyed every few years to assess status. Otherwise, it may only need to be monitored if lake users notice and report concerns.

VI. Mitchell Lake Results

Mitchell Lake (DOW ID 27-007000) is within the city limits of Eden Prairie, Minnesota and is classified as a "Natural Environment Lake" by the Minnesota Department of Natural Resources. Mitchell Lake has a surface area of about 46 hectares (114 acres), with a littoral zone area of about 44 hectares (109 acres), and a maximum depth of about 5.8m (19ft) (MN DNR LakeFinder 2016).

Surveys conducted on Mitchell Lake in 2013 and 2014 were used as a reference for a Master's research project conducted by Jonathan JaKa, a University of Minnesota graduate student. Mitchell Lake was chosen as a reference lake because there were no curlyleaf pondweed treatments planned for 2013 or 2014 and curlyleaf had been present at high frequencies and densities. In 2015, 2016 and 2017, Mitchell Lake was treated with an early season endothall herbicide treatments. Therefore, aquatic vegetation surveys and water quality monitoring continued in 2015 -2017 so as to monitor the effects of herbicide treatment on the aquatic plant community.

Water Quality:

Secchi depths were better in 2017 with Secchi depth staying at or above 1m. The Secchi depth in 2016 declined to less than 0.5m by mid-August, similar to 2015 (Figure 6). Mid-summer dissolved oxygen and temperature profiles showed some dissolved oxygen to the lake bottom in 2013 but an anoxic hypolimnion beginning at depths of 2.5m to 3.5m appeared in 2014-2017 (Figure 6).

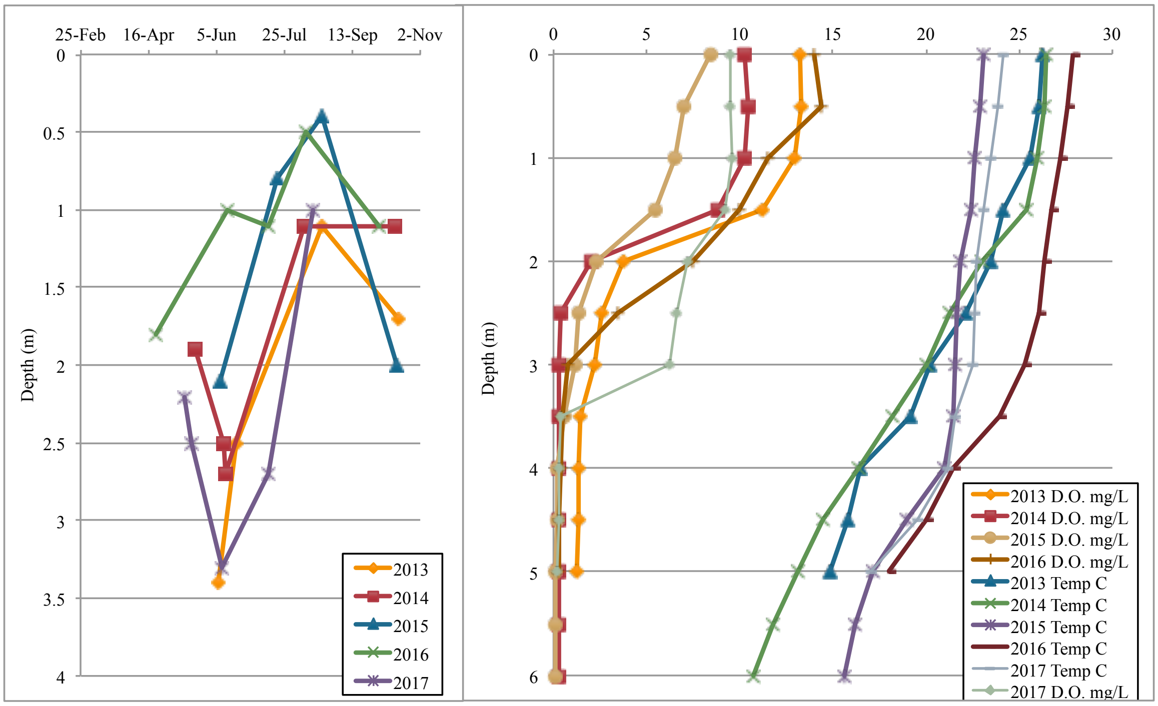


Figure 6. Secchi depths for Mitchell Lake and dissolved oxygen (mg/L) and temperature (°C) profiles taken on 22 August 2013, 8 August 2014, 21 August 2015, 10 August 2016 and 15 August 2017.

Milfoil Weevil Population

Monitoring for the weevil population began in 2015 in Lake Mitchell and continued in 2016 ands 2017. No weevils of any life stage were found during the three surveys conducted in June, July and August of 2016 or in 2017.

Aquatic Vegetation Survey:

Aquatic vegetation surveys were conducted in early and late June and once in August of 2013, in May, June and August of 2014, and in late April, June, and August of 2015, 2016 and 2017. Overall there was a fairly diverse aquatic plant community in Mitchell Lake with 21 different species observed over the three survey years (Table 4). In 2017, 13 species were observed throughout the three sampling dates. Native species richness per sampling site (1.3/point) was similar to 2016, which was lower when compared to when sampling began in 2013. The highest richness was observed in August 2013 when one site contained 10 species per site and several sites contained between 7 and 9 species. The August frequency of occurrence for natives decreased from 82% of sites in 2013 to 49% of sampled sites in 2016 but increased to 62% in 2017 (Figure 7) and the August maximum depth of growth had been decreasing from about 3.0m in 2013 and 2014 to about 2.0m in 2015 and 2016 but returned to 2.9 m in 2017 (Table 5); maximum depth of growth varies with August Secchi.

Table 4. Aquatic plants found in surveys conducted in Mitchell Lake 2013 through 2016.

Common Name	Scientific Name	Abbreviation	Year First Observed
Emergent Species			
Cattail	*Typha spp.*	Typh	2013
Submerged Species			
Coontail	*Ceratophyllum demersum*	Cdem	2013
Muskgrass	*Chara spp.*	Char	2013
Canada waterweed	*Elodea canadensis*	Ecan	2013
Water stargrass	*Heteranthera dubia*[1]	Zdub	2013
Northern watermilfoil	*Myriophyllum sibiricum*	Msib	2013
Eurasian watermilfoil	*Myriophyllum spicatum*	Mspi	2013
Bushy pondweed	*Najas flexilis*	Nfle	2013
Stoneworts	*Nitella spp.*	Nite	2015
Curlyleaf pondweed	*Potamogeton crispus*	Pcri	2013
Illinois pondweed	*Potamogeton illinoensis*	Pill	2015
Leafy pondweed	*Potamogeton foliosus*	Pfol	2015
Narrow leaf pondweed	*Potamogeton pusillus*	Ppus	2013
Flat-stem pondweed	*Potamogeton zosteriformis*	Pzos	2013
White water buttercup	*Ranunculus aquatilis*	Rlon	2013
Sago pondweed	*Stuckenia pectinata*	Spec	2013
Greater bladderwort	*Utricularia vulgaris*	Uvul	2013
Wild celery	*Vallisineria americana*	Vame	2015
Northern wild rice	*Zizania palustris*	Zpal	2015
Floating-leaf species			
Lesser duckweed	*Lemna minor*	Lmin	2013
Star duckweed	*Lemna trisulca*	Ltri	2013
American lotus	*Nelumbo lutea*	Nlut	2013
White water lily	*Nymphaea odorata*	Nodo	2013
Yellow water lily	*Nuphar variegata*	Nvar	2013
Great duckweed	*Spriodela polyrrhiza*	Spol	2013

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

Table 5. Summary of aquatic plant surveys on Lake Mitchell from 2013 through 2017. 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 Submersed Native Taxa	Number of Submersed Natives	Average Secchi Depth (m)
Early June 2013	3.6	76%	8	3.4
Late June 2013	3.8	83%	9	2.5
August 2013	3.3	82%	13	1.1
May 2014	3.2	70%	11	1.9
June 2014	3.3	79%	12	2.6
August 2014	2.9	72%	12	1.1
April 2015	3.5	73%	8	2.5
June 2015	2.9	70%	9	2.1
August 2015	2.3	59%	6	0.5
April 2016	3.8	76%	7	1.8
June 2016	2.7	61%	10	1.0
August 2016	1.8	49%	11	0.5
May 2017	4.0	44%	8	2.7
June 2017	4.0	54%	8	2.7
August 2017	2.9	62%	9	0.9

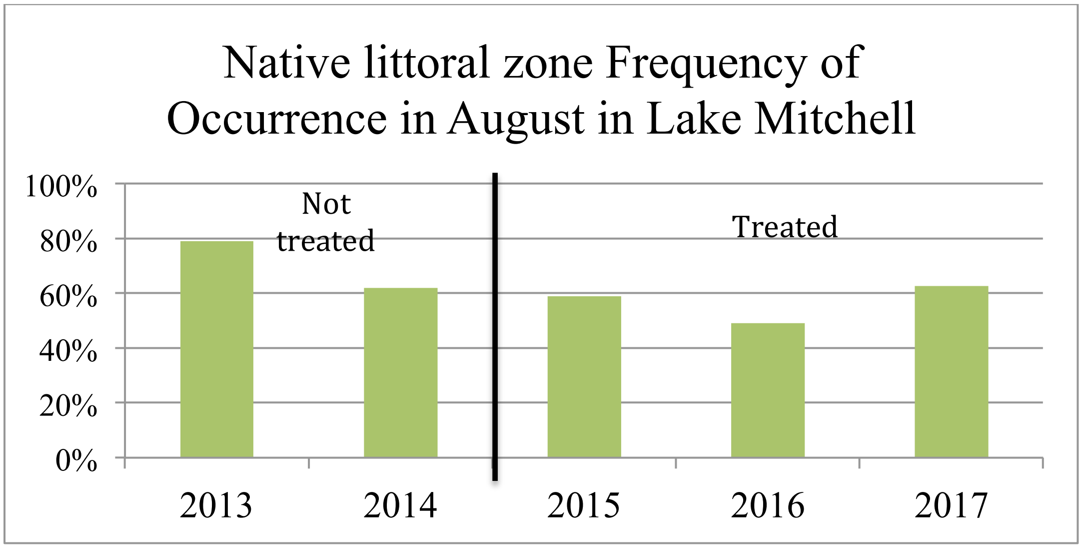


Figure 7. Mean total native aquatic plant frequency in Mitchell Lake August 2013 through 2017. The vertical line represents the beginning of herbicide treatment and divides pre- and post- treatment years.

Overall the most dominant species in frequency was coontail (Figure 8). Additionally, curlyleaf pondweed occurred quite frequently in the spring and early summer as well and was the most frequently occurring species in April/May 2016 and

2017 (Figure 8). Other commonly occurring species include: star duckweed (*Lemna trisulca*), white water lily (*N. odorata*), narrow leaf pondweed (*P. pusillus*), flat-stem pondweed (*P. zosteriformis*) and northern watermilfoil (*M. sibiricum*), all of which were observed in at least 5% of sites surveyed in the littoral zone.

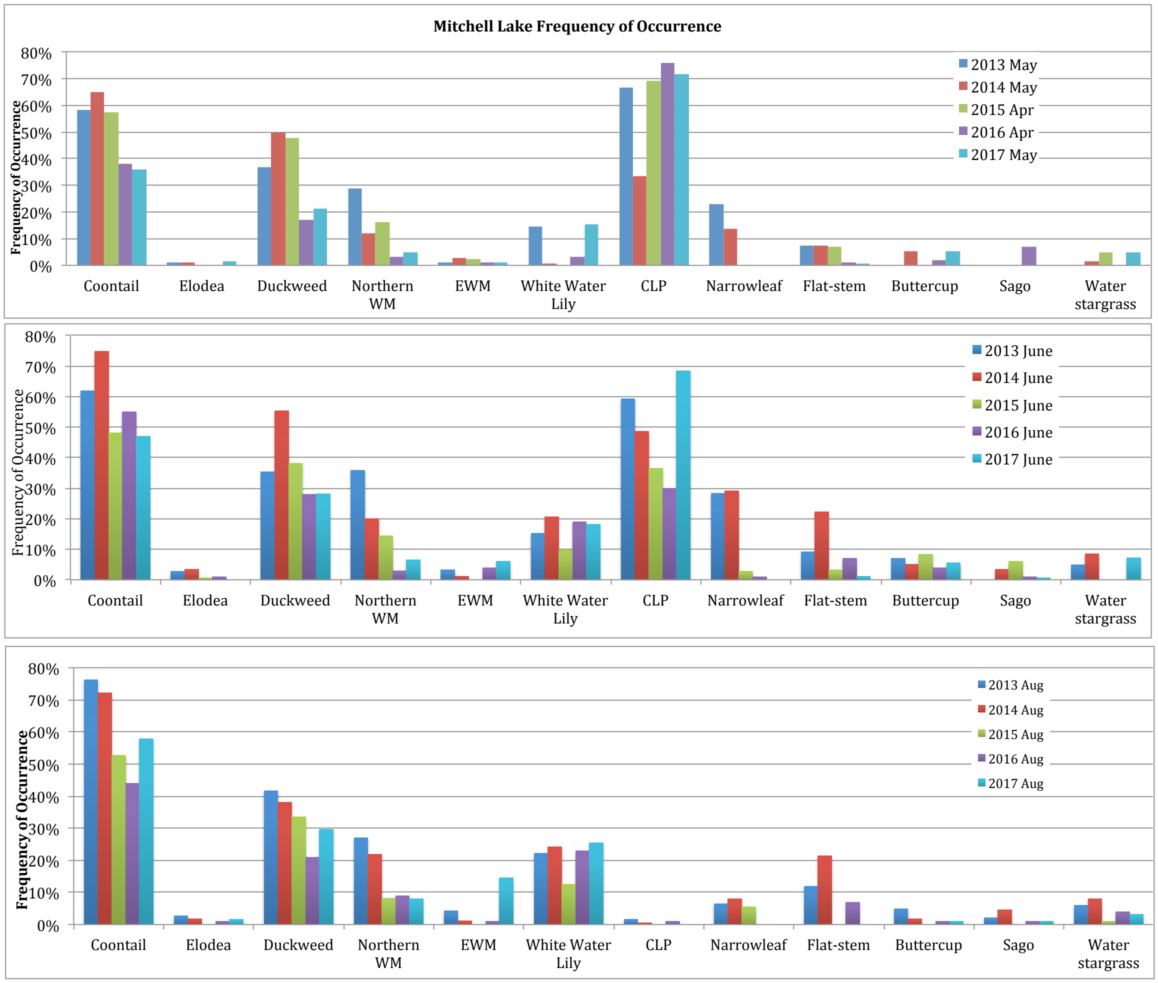


Figure 8. Frequency of occurrence for some of the most commonly occurring species in Mitchell Lake found in surveys from May, June and August 2013 through 2017. See Table 4 for abbreviations.

Coontail made up the large majority of the biomass sampled in Mitchell Lake although it has been declining since sampling started in 2013 (Figure 9). Curlyleaf pondweed typically had the second highest biomass in the spring and early summer when it reached its peak biomass. Other native plants with higher plant biomass in the summer were northern watermilfoil, star duckweed, narrow leaf pondweed and white water lily (Figure 9). Coontail made up the majority of a significant ($p \leq 0.05$) decline in mean total native plant biomass from August 2013 to August 2014 (Figure 12), but many other species declined as well. Desite the decrease observed in native aquatic plant frequency of occurrence in 2016, the August mean total native plant biomass increased compared to 2015 (Figure 10). In 2017 native frequency increased to 60%, but biomass declined to levls similar to 2015.

Eurasian watermilfoil and curlyleaf pondweed were both present in Mitchell Lake. Curlyleaf pondweed has reached nuisance levels in the spring and early summer. In 2016, the early season treatment took place with better effects on the peak season curlyleaf biomass compared to the 2015 treatment (Figure 11). The 2016 treatment appeared to moderately effect the density of curlyleaf in the treatment areas (Figure 12). Eurasian watermilfoil did not appear to be present at high frequencies. We hypothezied that the taxon we are calling northern watermilfoil (based on leaflet count) may be a hybrid of Eurasian watermilfoil and northern watermilfoil, but genetic analyses by Thum in 2017 indicated no hybrids present and only northern and Eurasian in the lake.

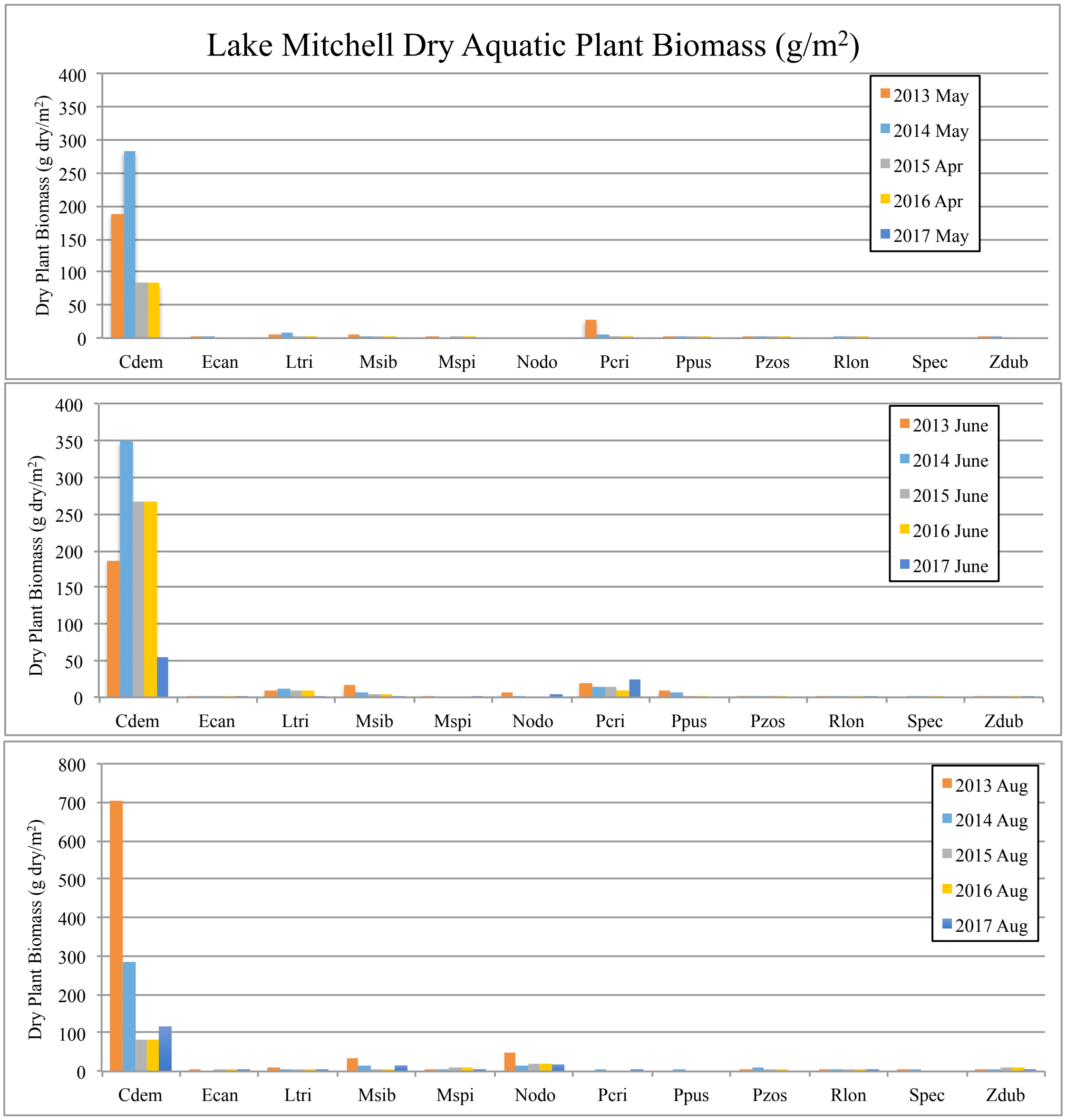


Figure 9. Dry plant biomass (g dry/m^2) for some of the most commonly occurring species in Mitchell Lake found in surveys May, June and August 2013 through 2017. See Table 4 for abbreviations.

Curlyleaf Pondweed Treatment

An early season endothall treatment was conducted in 2015, 2016 and 2017. The area that was treated was 16 acres in 2015 and 12.7 acres in 2016 and 9.8 acres in 2017. In 2015, the reduction in peak season curlyleaf frequency of occurrence and biomass was less than the reductions seen in the first year of treatment in Lakes Riley and Susan. Greater reductions in the population were observed in 2016 and curlyleaf inceased in 2017. Curlyleaf pondweed frequency of occurrence at peak season was 59% in 2013 and 49% in 2014 prior to treatment, 37% in 2015 and 30% in 2016 after the treatments occurred (Figure 10). The average, peak season littoral-wide biomass in 2013 was 20.2 g dry/m^2, 14.0 g dry/m^2 in 2014, 14.3 g dry/m^2 in 2015, and 0.9g dry/m^2 in 2016 (Figure 11). Both frequency (Figure 10) and biomass (Figure 11) increased in 2017 with the somewhat reduced treatment area. Native plant biomass in August has mirrored curlyleaf biomass in June (compare Figures 11 and 12); native plant biomass declined in 2017 (Fig. 12) despite the higher frequency (Figure 7) relative to previous years.

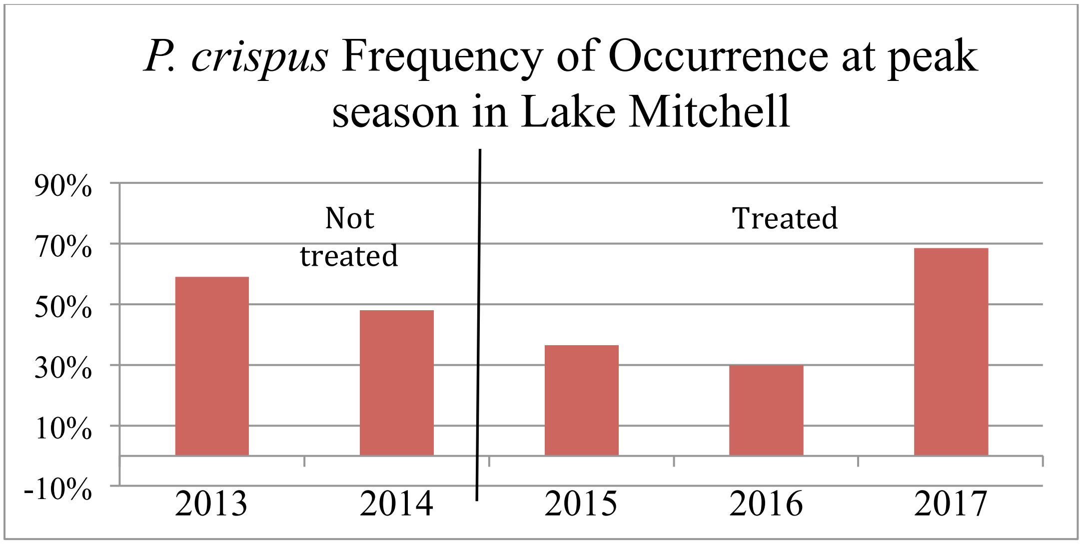


Figure 10. Mean total curlyleaf pondweed frequency Mitchell Lake from 2013 through 2017. The vertical line represents the beginning of herbicide treatment and divides pre- and post- treatment years.

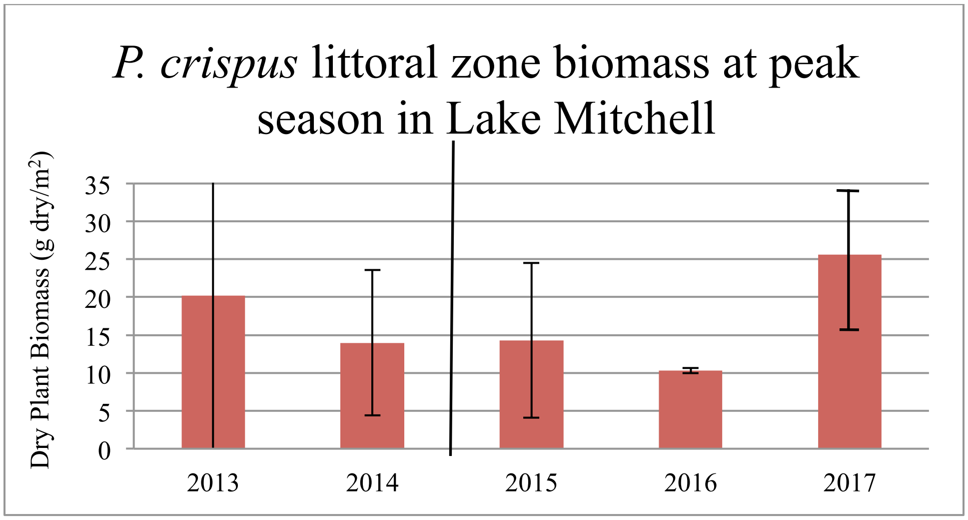


Figure 11. Mean total curlyleaf pondweed frequency Mitchell Lake from 2013 through 2017. The vertical line represents the beginning of herbicide treatment and divides pre- and post- treatment years.

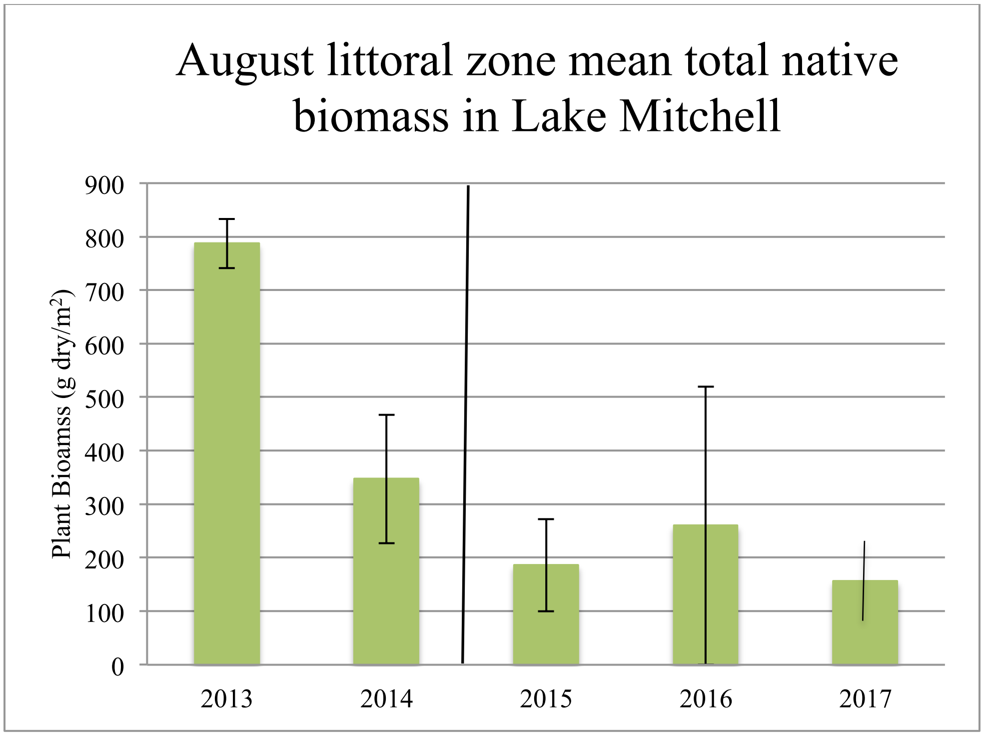


Figure 12. Native plant dry biomass (± SE) in Lake Mitchell, August 2013 to August 2017.

There was a significant decrease in turion density between 2014 and after treatment in 2015 (Table 6). Sediment surveys for curlyleaf pondweed turions were conducted in Mitchell Lake on 17 October 2013, 14 October 2014, 14 October 2015, 3 October 2016 and October 2017. Prior to 2015 the turion densities were higher than peak turion densities at both Lakes Riley and Susan, which had lake-wide mean densities of 128 turions/m^2 and 87 turions/m^2 respectively in fall 2012 before spring herbicide treatments. In 2013 the Lake Mitchell turion density was 191 turions/m^2, and 173 turions/m^2 in 2014. After treatment in 2015, the turion density significantly decreased to 14 turions/m^2. After treatment in 2016, the turion density increased to 27 turions/m^2, but the increase was not significant (Table 6). Although treatments appeared less effective in 2017, turion density and viablility decreased and the lowest total (13/m^2) and viable turion density (5/m^2) was found (Table 6).

Table 6. Results from sediment turion surveys at Mitchell Lake conducted October 2013 through 2017.

Pcri	Turions/m^2	Viability	Viable turion density
Oct-2013	191	77%	147
Oct-2014	173	45%	78
Oct-2015	14	80%	11
Oct-2016	27	64%	18
Oct-2017	13	49%	5

Aquatic Bathymetry and Vegetation Maps

Plants at Mitchell Lake were dense in much of the lake to depths of 3m and less (Figure 13). Percent coverage ranged from about 65% to almost 95% of the surveyed area depending on year and the time of year between 2013 and 2017 (Table 7). In 2017, the August percent area covered increased from 60% in 2016 to 70% in 2017 an improvement compared to the 2015 August coverage of 52% (Table 7). The loss of curlyleaf between June and August 2017 is evident from the heat map (Figure 13).

Figure 13

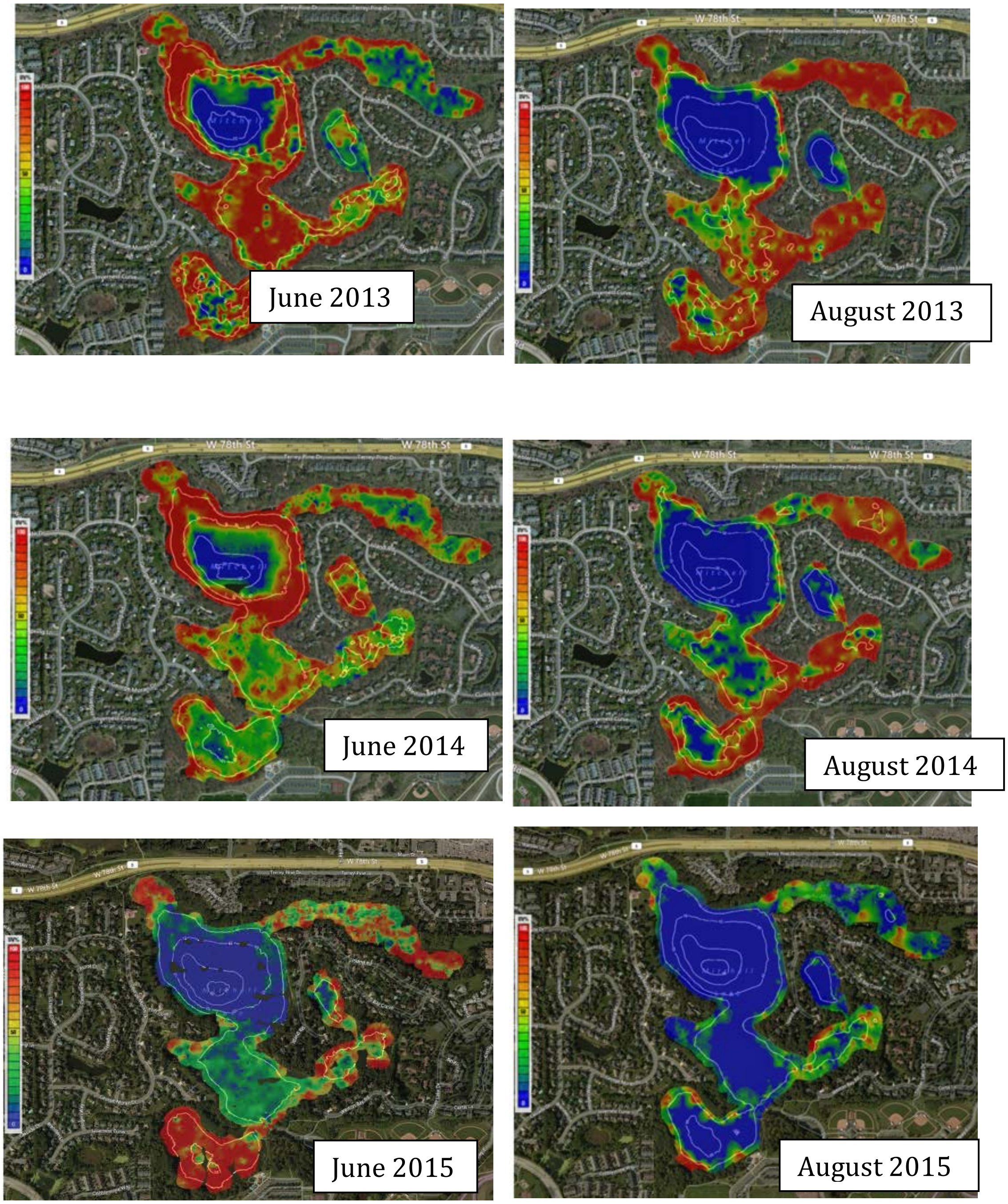

June 2013
August 2013
June 2014
August 2014
June 2015
August 2015

Fig 13 Continued

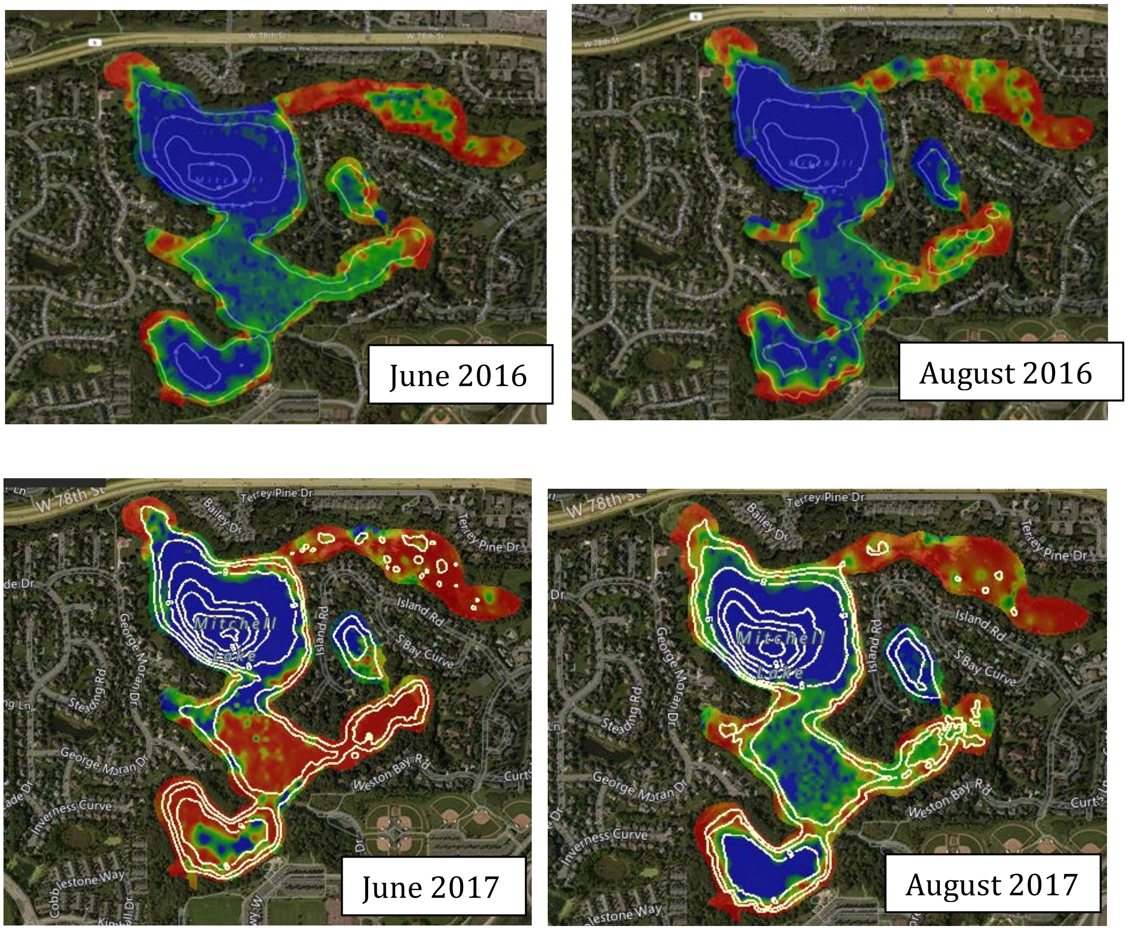


Figure 13. Aquatic bathymetry and vegetation maps of Mitchell Lake. Data collected during point intercept aquatic vegetation surveys on: 13 June 2013, 20 August 2013, 12 June 2014, 8 August 2014, 10 June 2015, 20 August 2015, 13 June 2016, 10 August 2016, 8 June 2017 and 14 August 2017. Contour lines 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 7. Lake-wide percent area covered (PAC) and average biovolume (BV) for surveys in 2013 through 2017 in Mitchell Lake. Values coincide with maps in Figure 13. 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	89.4%	66.6%
August 2013	75.1%	68.2%
May 2014	79.6%	21.3%
June 2014	94.4%	60.7%
August 2014	70.1%	58.8%
June 2015	82.7%	58.6%
August 2015	52.0%	52.1%
May 2016	87.8%	58.4%
June 2016	69.3%	40.5%
August 2016	62.0%	45.3%
June 2017	70.3%	70.6%
August 2017	72.5%	53.5%

Recommendations for Mitchell Lake:

The native plant community in Mitchell Lake should continue to be monitored in case of further declines. Another year of early season curlyleaf treatment will be useful to manage the population, probably in areas not treated in 2017. However, due to the complex shoreline and limits to application areas, whole-lake reductions in curlyleaf may not be as apparent as in other treated lakes. Although Mitchell Lake is a "Natural Environment Lake", the Minnesota DNR may grant another variance if early season endothall treatments were likely to maintain or enhance the native plant community. Because Eurasian watermilfoil is relatively low in abundance, Mitchell may benefit from another early season endothall treatment similar to 2016 and 2017 and coordination with harvesting efforts should continue. .

V. 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 120 hectares (300 acres) with a littoral zone of about 45 hectares (110 acres) and a maximum depth of about 15m (49ft). 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 in 2013, 32 acres in 2014, 20.1 acres in 2015, 14 acres in 2016 and 20 acres in 2017. 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 after delineation took place. In 2016, it was applied to 33 acres 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 and granular triclopyr (Renovate) to 10 acres. Additionally, a hypolimnetic alum treatment occurred during the week of 9 May 2016 to decrease internal phosphorous loading and improve the water clarity.

Water Quality:

Prior to the 2016 alum treatment, 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 alum treatment occurred (Figure 14). In 2016, in the beginning of July the Secchi depth was recorded at 2.8m. By October of 2016, the Secchi depth was just below 2.0m, similar to the 2015 observation. Spring and early summer water clarity remained high in 2017, and Secchi depths were 1.9m or more through August. Water clarity in June-August 2016 and 2017, prime native plant growth season, was more than 1.5 m deeper than prior years. Dissolved oxygen and temperature profiles generally show an anoxic hypolimnion below 5m in August (Figure 14).

Aquatic Vegetation Survey:

We conducted point intercept surveys on Lake Riley from 2011 through 2017. 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 8). Unfortunately, only 10 species were found in 2017 (9 in the late summer survey) despite the better water clarity. The highest species richness per site was observed in a survey completed in August 2016 with 6 species at one site and a mean of 1.5 natives species per point; this declined to 1 native species per point in 2017, similar to previous years. Throughout all survey years, most plants were in water < 2m deep. However, in 2016 and 2017 some plants expanded to sites deeper than 4.0m (Table 9).

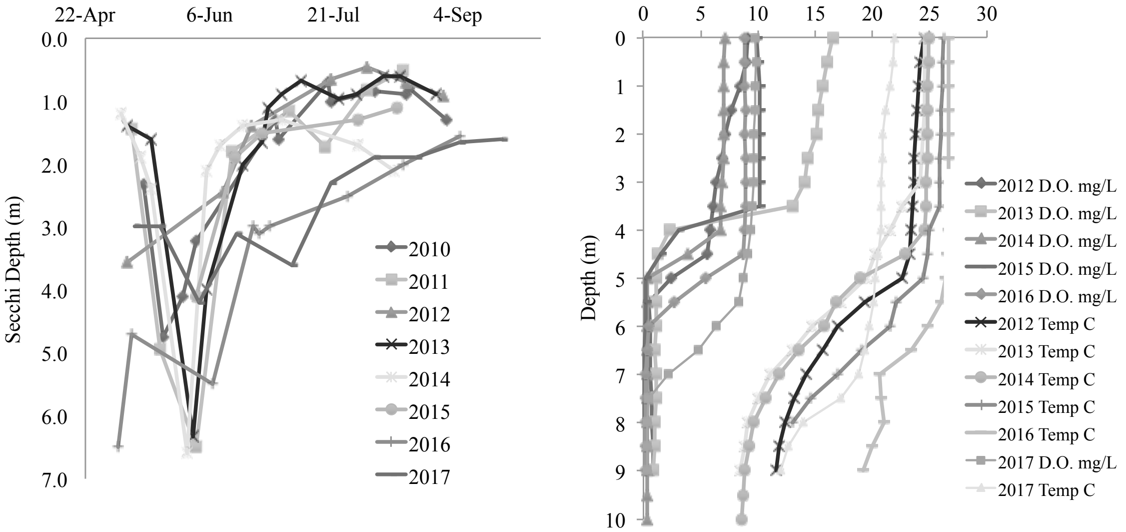


Figure 14. Secchi depths for Lake Riley 2010 through 2017 (Bajer and Sorensen unpublished data, RPBCWD, and Newman Lab) and dissolved oxygen (mg/L) and temperature (°C) profiles taken in August 2012 through 2017.

Coontail, curlyleaf pondweed and Eurasian watermilfoil were typically the most frequently occurring species (Figure 15), with the exception of August when curlyleaf was typically not present due to its life cycle (Figure 16). In 2016, Canada waterweed surpassed curlyleaf occurrence in all surveys for the first time. In 2016, native plant frequency of occurrence increased to over 80% of sampled points. White waterlily and Canada waterweed were observed in August 2016 at their highest frequencies of occurrence since surveys began (Figure 16). However, these trends did not persist in 2017, particularly in later summer when coontail, and Canada waterweed, declined from peaks in June and most other taxa failed to increase in as they did in 2016 (Figure 15). Eursian watermilfoil was effectively controlled with the herbicide treatment in 2017, being reduced to 3% occurrence in late summer compared to frequency of 20% or more in previous years of control (2015 and 2015).

Coontail, Eurasian watermilfoil, and Canada waterweed were the most dominant species in biomass (Figure 17). Coontail continued to make up the vast majority of the native aquatic plant biomass in Lake Riley, with very little contribution of other native plants to total lake-wide native plant biomass. Biomass of most plants was much lower in 2017 than 2016 and in particular in late summer after milfoil herbicide treatments (Figures 17 and 23).

Eurasian watermilfoil and curlyleaf pondweed have both been problematic in Lake Riley. Eurasian watermilfoil was a dominant member of the plant community in the lake (Figures 15 and 17), but was reduced significantly in 2017. In 2016, curlyleaf pondweed increased in frequency and biomass relative to previous treatment years but was subsequently reduced in 2017 with expanded control (Figures 15, 17, 20 and 21).

Table 8. Aquatic plants found in surveys conducted in Lake Riley 2011 through 2017.

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
Narrow leaf pondweed	*Potamogeton pusillus*	Ppus	2011
Flat-stem pondweed	*Potamogeton zosteriformis*	Pzos	2015
Sago pondweed	*Stuckenia pectinata*	Spec	2011
Wild celery	*Vallseneria americana*	Vame	2016
Horned pondweed	*Zannichellia palustris*	Zpal	2011
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 formerally classified as *Zosterella dubia*

Table 9. Summary of point intercept surveys in Lake Riley from 2011 through 2017. 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 Submersed 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
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	1.8
May 2017	3.7	71%	3	4.2
June 2017	4.4	82%	4	4.2
September 2017	4.8	76%	7	1.6

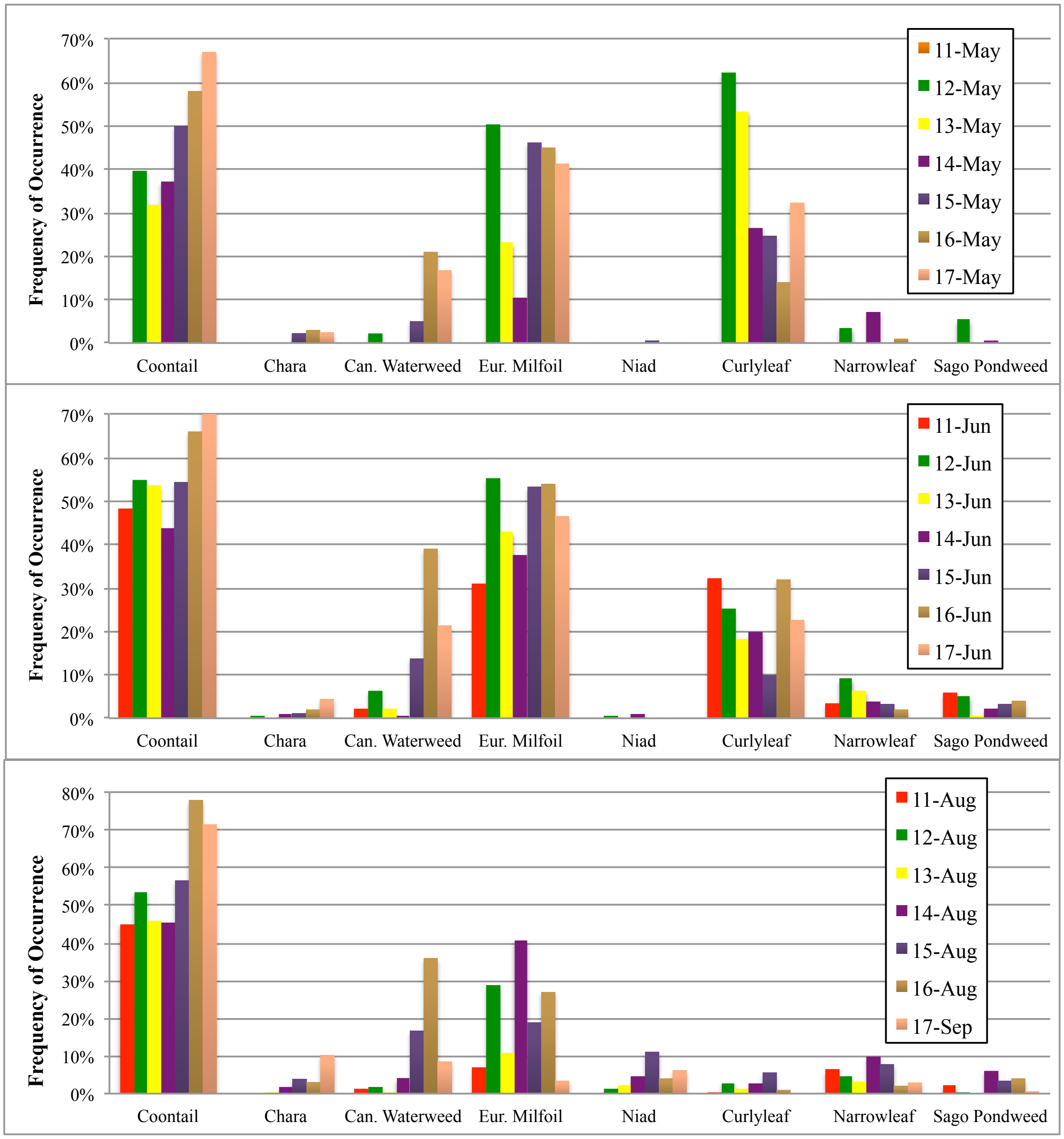


Figure 15. Frequency of occurrence of the 8 most common plants from Lake Riley surveys May, June and August 2011 through 2017.

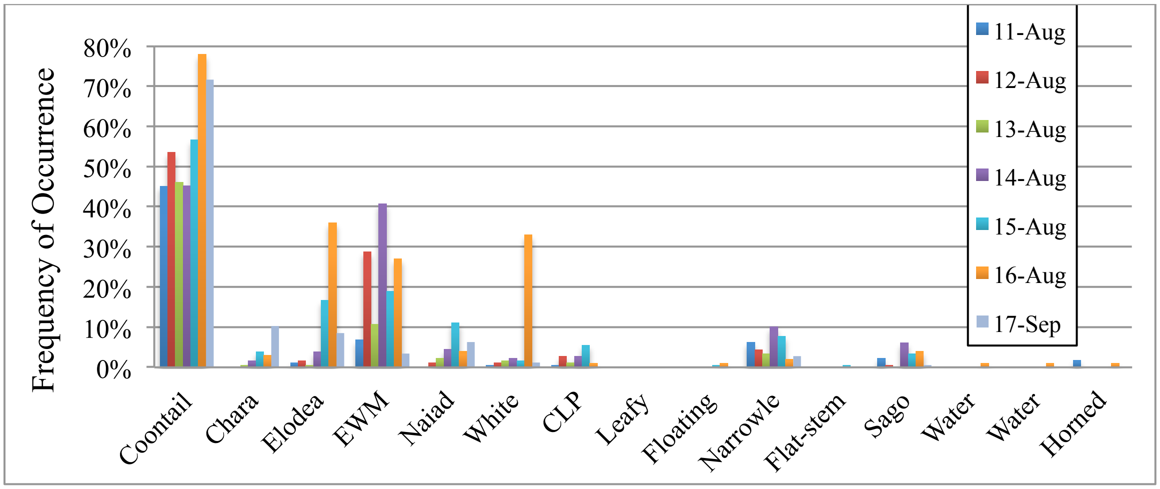


Figure 16. Frequency of occurrence of all plants from Lake Riley surveys in August 2011 through 2017.

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 (Figure 18). 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.

There was no significant difference in 2016 curlyleaf frequency of occurrence and biomass relative to 2015 or 2017. Curlyleaf pondweed was observed in over 60% of sites sampled in the littoral zone in 2012. Curlyleaf pondweed has been controlled to less than 25% of sites sampled in the littoral zone in all June post-treatment surveys apart from 2016 where it was observed at 30% of sampled sites (Figure 20). The increase in 2016 was likely due to the decrease in total area treated and the plant occurring in low densities throughout the littoral zone. The larger treatment area and higher dose in 2017 reduced the frequency (Figure 20) and particularly the biomass (Figure 21) of curlyleaf. At its peak in 2012, we observed a littoral-wide average biomass of about 120 g dry/m^2. Curlyleaf biomass values declined significantly ($p \leq 0.05$) to under 5 g dry/m^2 in 2013 through 2015 and 2017 (Figure 21). As noted above the increase in 2016 to 27.4g dry/m^2 was likely due to the decrease in the treatment area. Turion densities in the sediments declined significantly ($p \leq 0.05$) from a peak of 132 turions/m^2 to 2 turions/m^2 in 2016 and 2017 (Table 10) and turion production has been controlled by herbicide treatments. Native aquatic plants did not increase significantly in biomass or frequency between the years of 2012 to 2014 with initial curlyleaf treatment but did show increases in frequency and biomass in 2015 and 2016 that remained in 2017 (Figures 22 and 23).

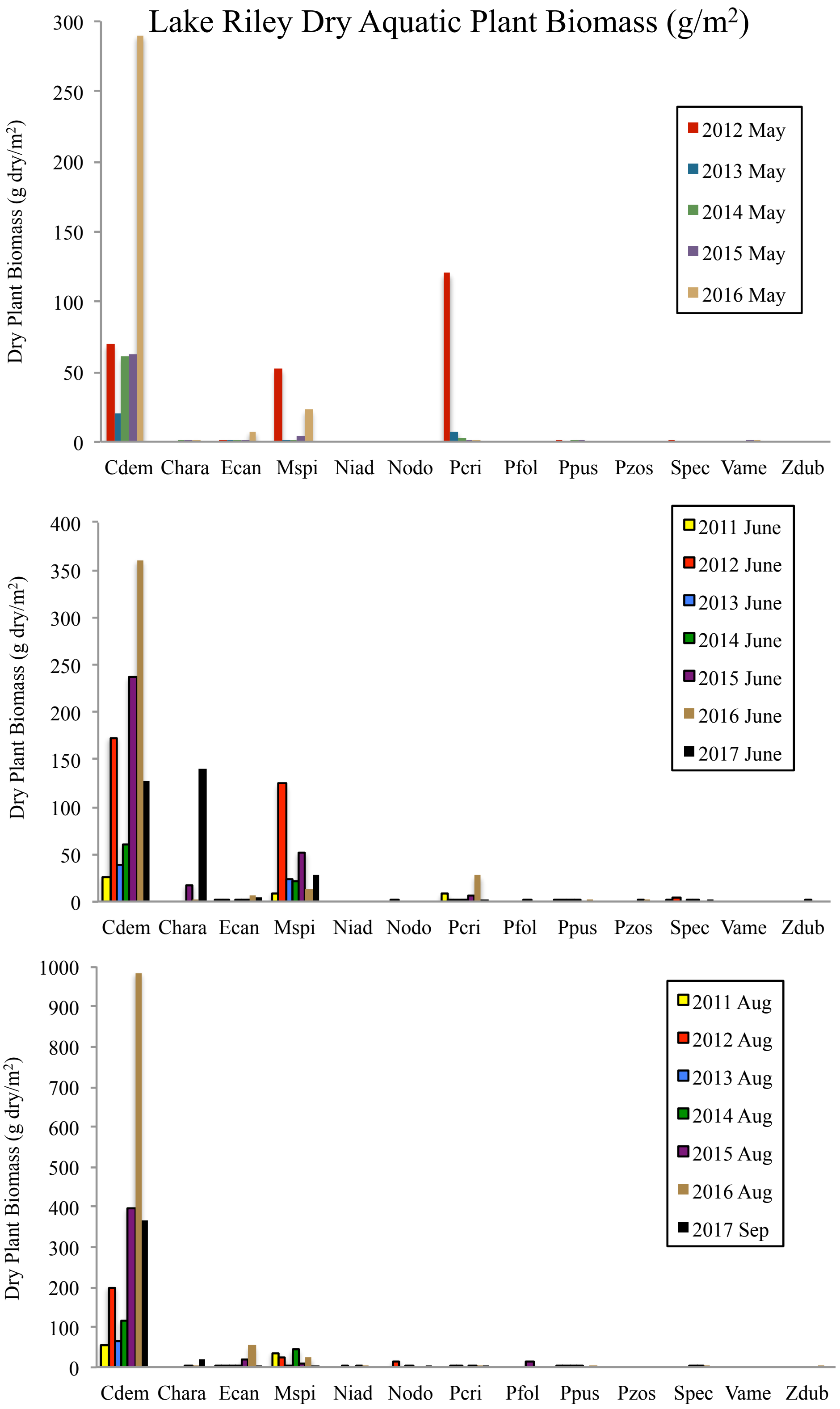


Figure 17. Dry aquatic plant biomass (g dry/m^2) for Lake Riley surveys May, June and August 2011 through 2017. Biomass was not sampled in May 2017. See Table 8 for abbreviations.

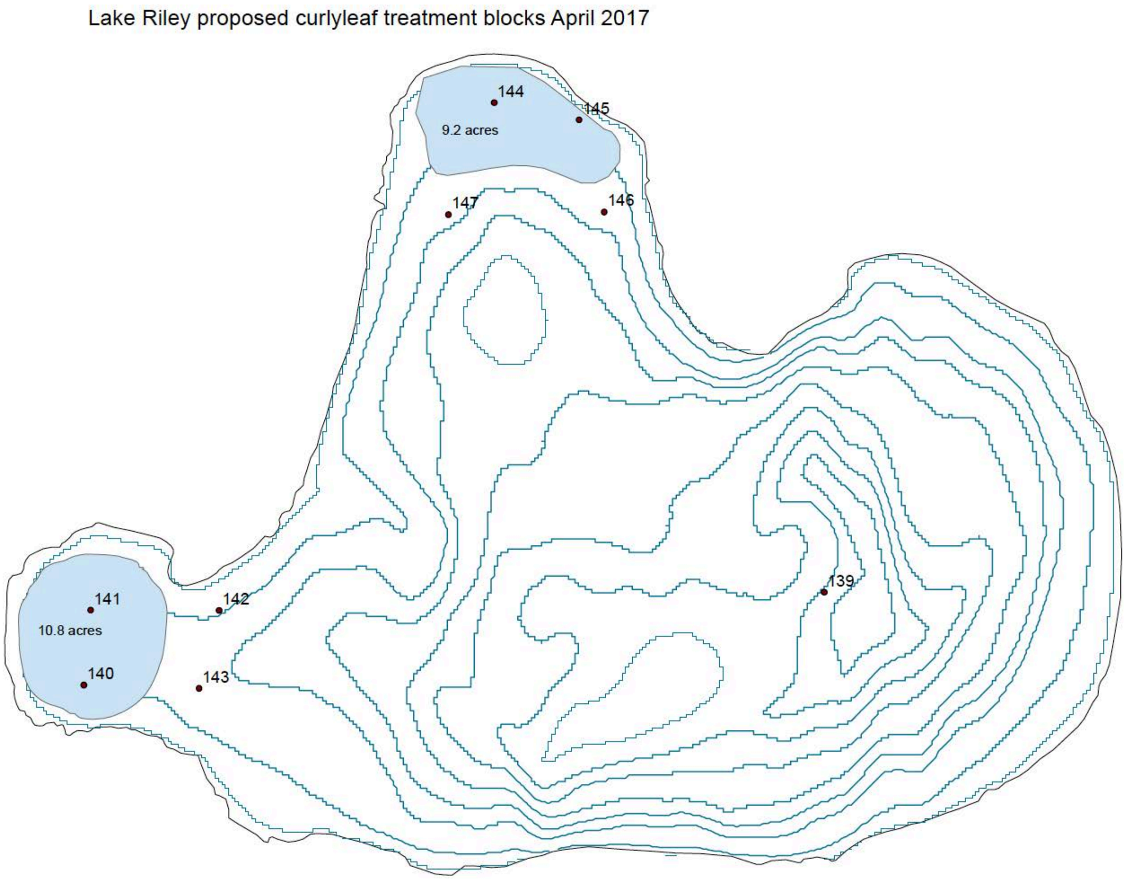


Figure 18. Curlyleaf pondweed treatment blocks in 2017. Acreage treated is given for each block and herbicide residue sampling stations are indicated (points 139-147).

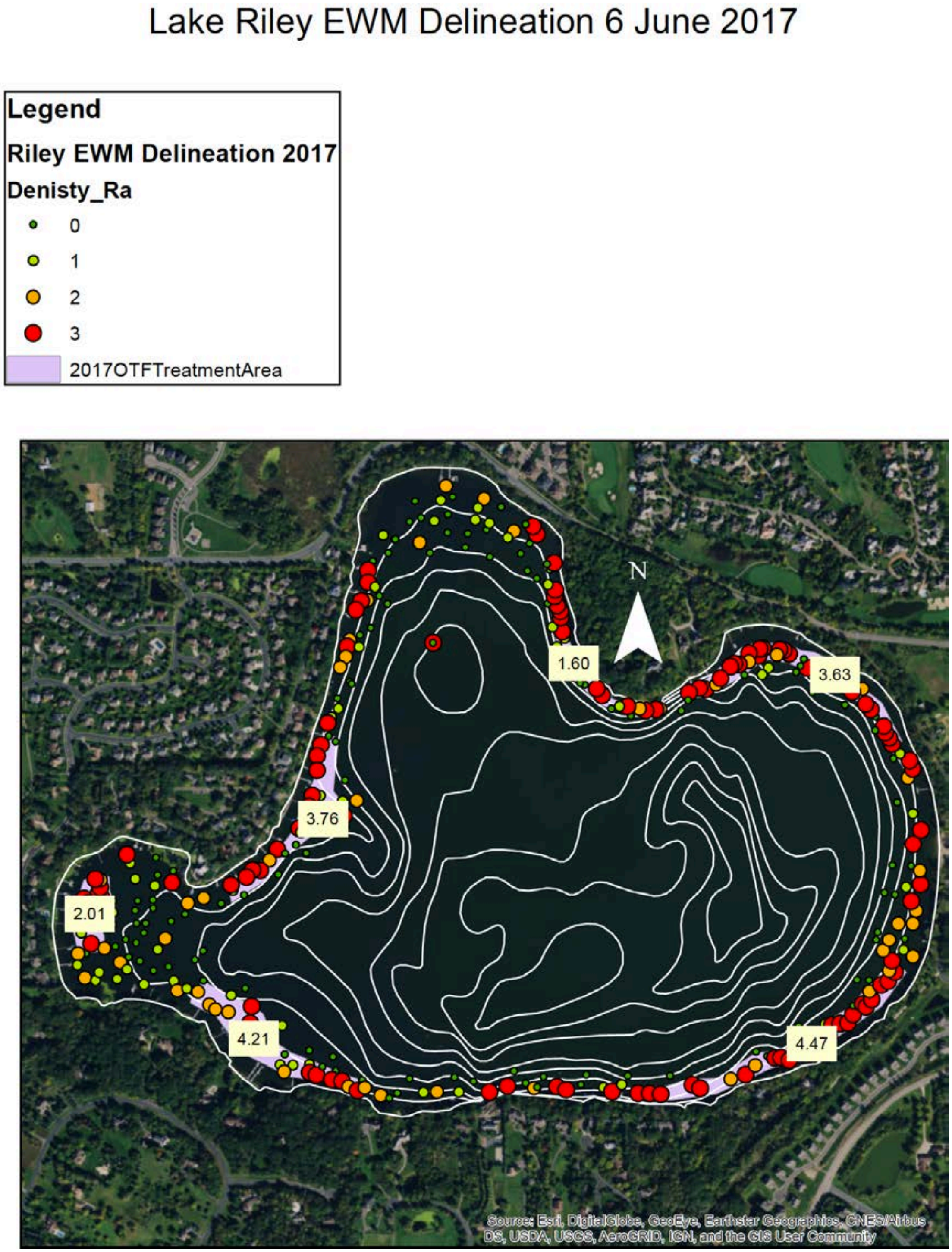


Figure 19. Eurasian watermilfoil June 2017 relative abundance and delineated treatment block (purple) with acreage in yellow boxes. The three plots on the east were treated with Renovate OTF and the three in the west with Sculpin G.

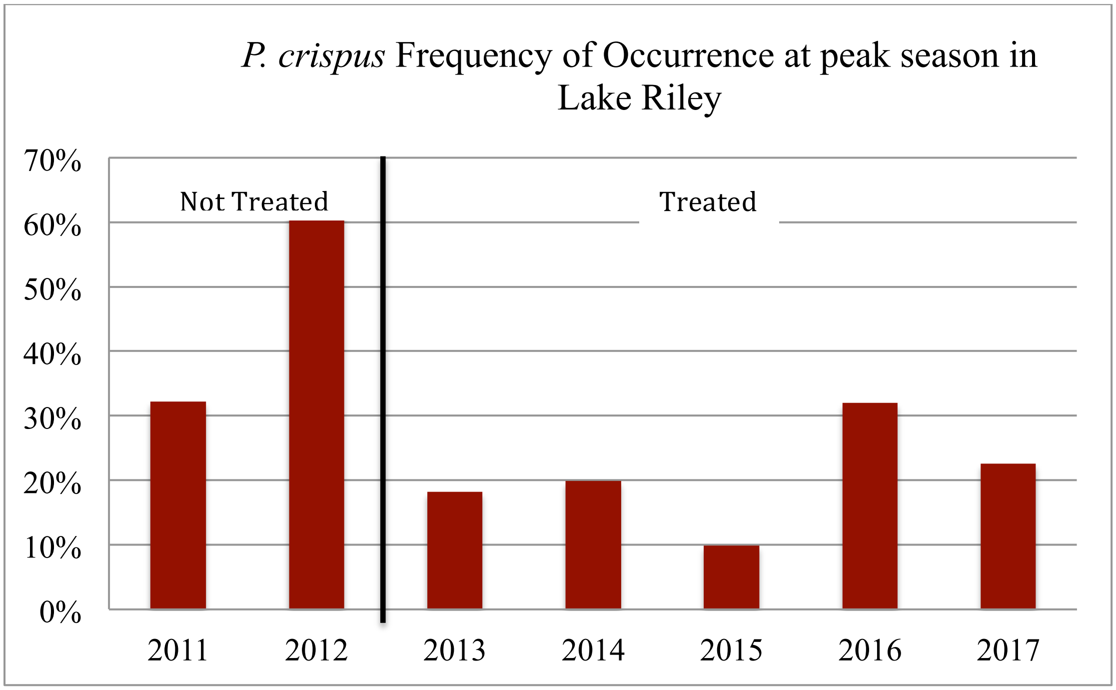


Figure 20. Peak frequency of occurrence of curlyleaf pondweed in Lake Riley. The vertical line represents the beginning of herbicide treatment and divides pre- and post-treatment years. Post-treatment declines are significant ($p \leq 0.05$).

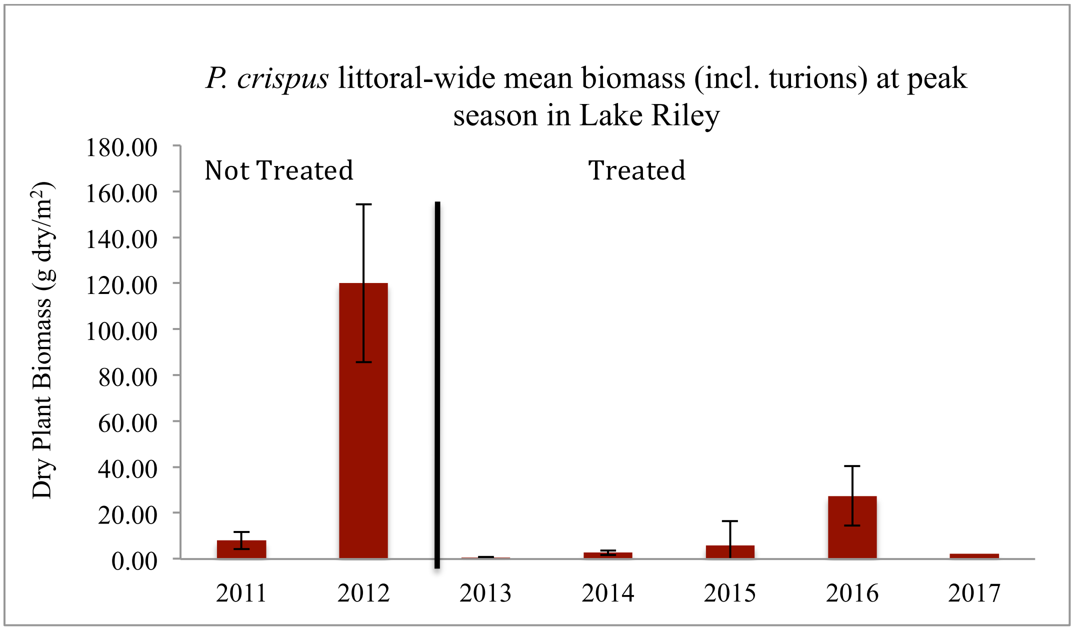


Figure 21. Peak biomass (g dry/m^2) of curlyleaf pondweed in Lake Riley. The vertical line represents the beginning of herbicide treatments and divides pre- and post- treatment years. Post-treatment declines are significant ($p \leq 0.05$).

Table 10. Results from sediment turion surveys conducted October 2011 through 2017 in Lake Riley. Note: Declines from 2012 to 2016 are significant ($p \leq 0.05$).

Pcri	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

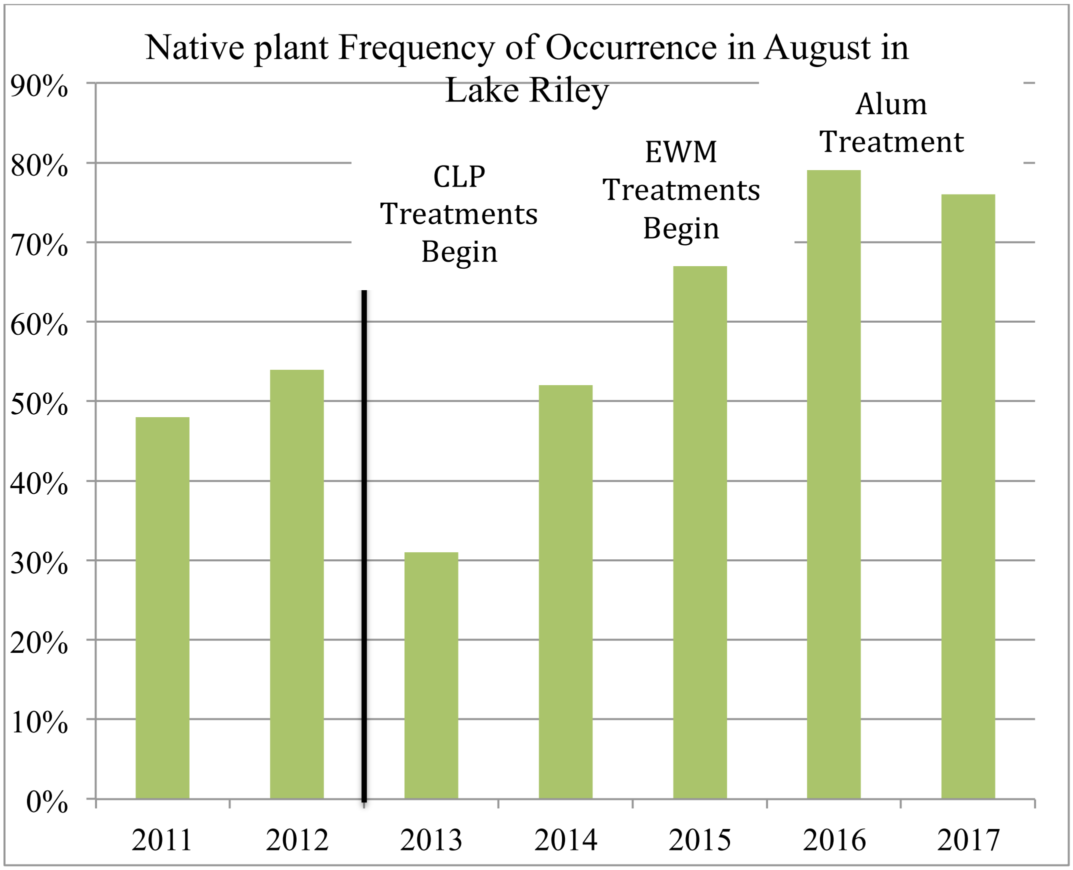


Figure 22. Native plant frequency of occurrence in the littoral zone in August in Lake Riley 2011 through 2017.

Eurasian Watermilfoil Herbicide Treatment:

Eurasian watermilfoil was treated in 2015, 2016, and 2017 on Lake Riley. In 2016 33 acres was treated with 2, 4-d herbicide at targeted concentration within the treatment areas of 2.0 mg/L. The results of the herbicide residue monitoring indicated that the desired concentration of herbicide was reached in some of the treatment areas, but not all, leading to a treatment average below the desired concentration of 2.0 mg/L. The average residual concentration taken four hours after treatment in each treatment area was 1.04 mg/L, and four days later residuals were at background levels apart from one location where the concentration was at 0.33 mg/L.

In 2015 and 2016, August Eurasian watermilfoil frequency of occurrence (Figure 24) as well as biomass in decreased compared to the pre-treatment June surveys. However, August frequency of occurrence has been variable throughout the survey years and the reductions were variable.

In 2017, a slightly smaller area (20 acres) was treated with granular herbicides; 10 acres with triclopyr as Renovate OTF (2.5 ppm target) and 10 acres with 2,4-d as Sculpin G at 4ppm (Figure 19). The combination of granular treatment and higher dose effectively controlled the Euarsian watermilfoil lakewide, with only a few scatter plants in treated areas and a few small patches remaining in one untreated area. Lakewide, milfoil frequency was reduced to 3% (Figure 24) and biomass to 0.04 g/m^2 (Figure 25). However, native plants also appeared affected. Coontail declined 10% in frequency and to <400 g/m^2 and both muskgrass and Canada waterweed decreased relative to June and the previous year. Overall native biomass was < half of its 2016 level and similar to 2015 prior to water clarity improvements (Figure 23). The failure of native plants to continue to increase or even sustain levels attained in 2016 did not appear due to water clarity; June-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. Aggressive milfoil control should be avoided in 2018 to see if the native plants will continue to recover.

Genetic analysis by the Thum lab in 2018 based on samples from September 2017 revealed no hybrids – only pure Eruasian watermilfoil was found. It was difficult to find mifoil plants after the treatment but at least the treated did not appear to shift the population towards hybrid.

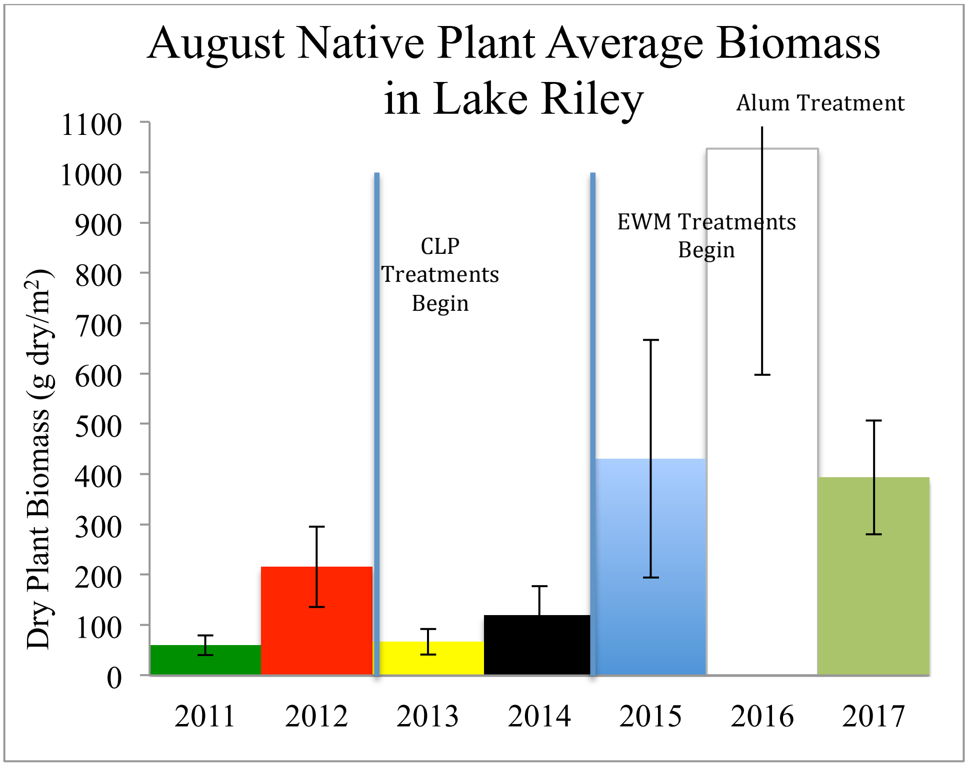


Figure 23. Mean total native plant biomass in the littoral zone in August in Lake Riley 2011 through 2017. Management activities are given above the year of initiation.

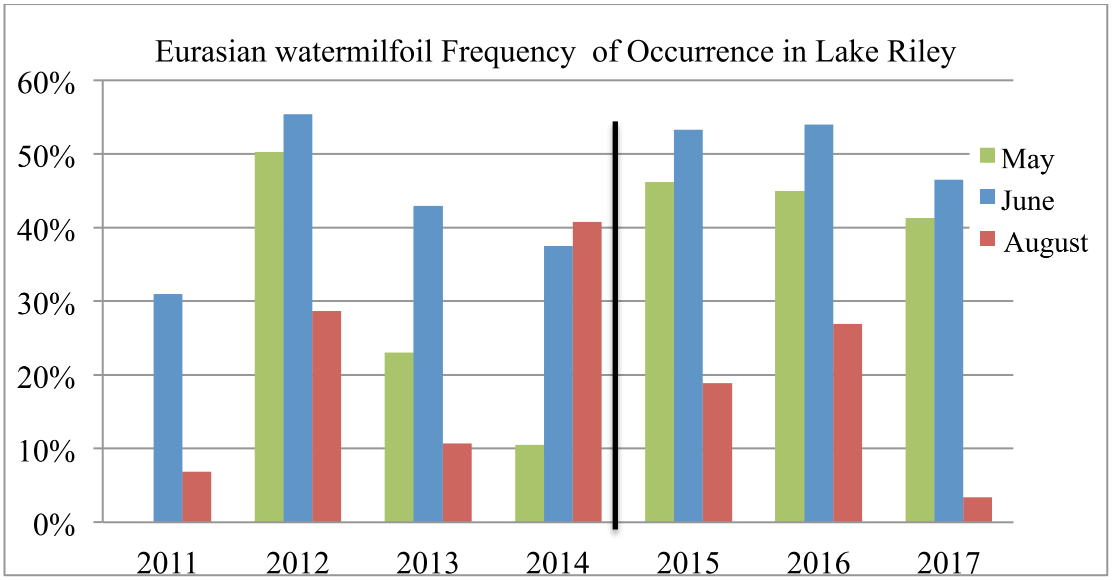


Figure 24. Frequency of occurrence of Eurasian watermilfoil in Lake Riley from 2011 to 2017. The vertical line represents the beginning of herbicide treatments and divides pre- and post-treatment sampling periods.

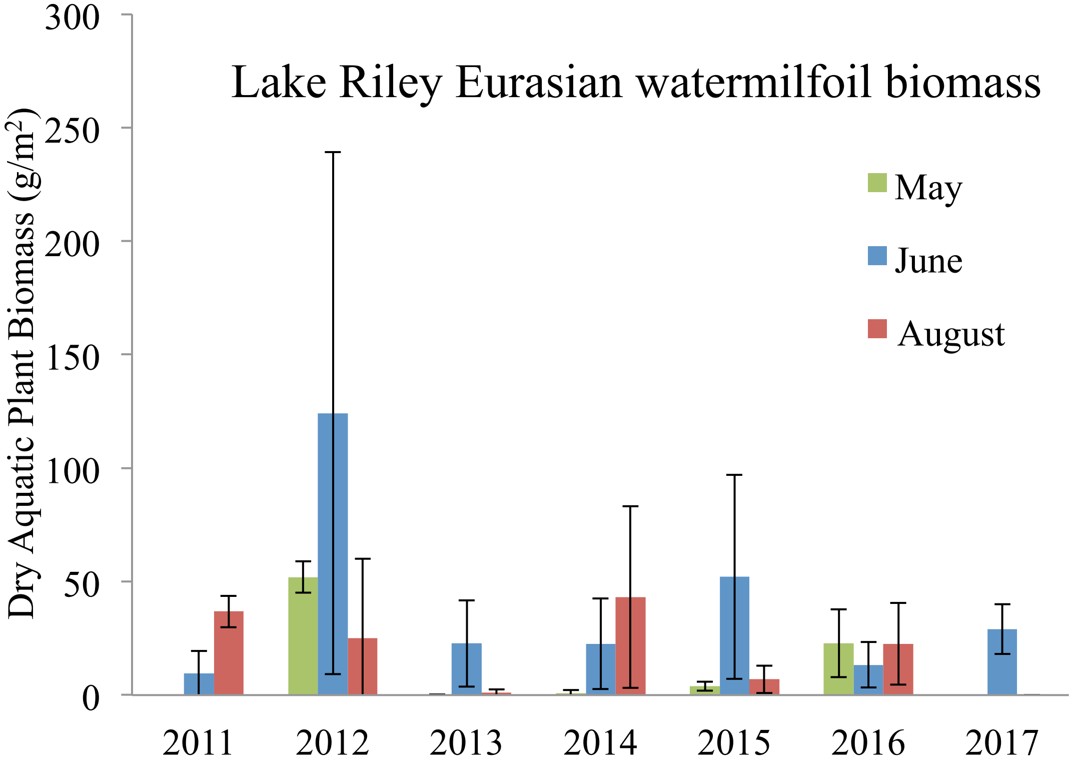


Figure 25. Eurasian watermilfoil biomass (g dry/m^2 ± 1 SE) in Lake Riley May, June and August 2011-2017. Biomass was not sampled in May 2017 and was very low (0.04 ± 0.03) in August (early September)2017. Biomass was significantly reduced after treatment in 2017.

Alum Treatment

On May 9th and 10th 2016, Lake Riley underwent a hypolimnetic alum treatment. 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 and 2017 and good clarlity was sustained during the June-August native plant growing season. In 2016, native aquatic plant biomass more than doubled compared to 2015 values and is significant when compared to surveys prior to 2015 ($p \leq 0.05$) (Figure 23). Native aquatic plants occurred at 67% of sampled littoral points in August of 2015 and at 83% of sampled points in August of 2016 (Figure 22). Native aquatic plant abundance has been increasing since curlyleaf management began in 2013 but the 2016 increase is the largest yearly increase since monitoring began in 2011. However, the native plants failed to persist through 2017, possibly due to non-target impacts from the herbicide treatment. Continued monitoring will determine if native plants can recover if water clarity improvements persist.

Milfoil Herbivore Population:

We began monitoring the milfoil herbivore population in 2011 and the maximum density of weevils was observed on 27 August 2014 at 0.68 weevils per stem (Table 11). The maximum density in 2016 occurred in July at 0.11 weevils per stem and no weevils were found in 2017 (Table 11). It is possible that abundant sunfish may be decreasing the weevil population in Lake Riley and the extensive chemical control intiated in 2015 may also be having an effect (see Havel et al. 2017). The weevil population does not appear to be persistently abundant enough to control Eurasian watermilfoil and has been decreasing since 2015.

Table 11. Results of Eurasian watermilfoil herbivore population surveys in Lake Riley 2011 through 2016. No weevils were found in surveys in 2017. Values are lake-wide means for weevil populations expressed as total weevils in all life stages per stem.

Sampling Date	Weevils/Stem
2011	
19 July	0.20
2012	
18 June	0.02
9 July	0.38
8 August	0.48
2013	
5 June	0.15
27 June	0.08
29 July	0.00
27 August	0.00
2014	
5 June	0.06
2 July	0.04
30 July	0.11
27 August	0.68
2015	
1 June	0.09
29 July	0.12
31 August	0.27
2016	
2 June	0.05
26 July	0.11
22 August	0.02

Seedbank Assessment

In spring 2016 sediment cores were collected from 1m depth around Lake Riley and returned to the laboratory for presence and viability of propagules as part of Melaney Dunne's MS thesis (Dunne 2017). The sediment was exposed to several light treatments and also a treatment with giberllic acid to induce germination and followed for 4 months.

Additional details and results for nearby Lake Ann are given in Dunne (2017) but the Riley results, particularly of maximum (induced) germination are informative and suggest that seedbank studies should be conducted during any future attempts to restore native plant communities.

Seventeen species sprouted from the sediment, including curlyleaf pondweed (Table 12a). In addition to plants already known from Lake Riley, two taxa germinated that were first seen in Riley in 2015, floating leaf (*Potamogeton nodosus*) and flat stem pondweeds (*Potamogeton zosteriformis*) and two that were first seen later in 2016 with the incrased water clarity (water stargrass (*Heteranthera dubia*) and wild celery (*Vallisneria americana*). Two taxa that have not yet been reported from Riley were also found to germinate: Richardson's pondweed (*Potamogeton richardsonii*) and Robbins' pondweed (*Potamogeton robinsii*) (Dunne 2017), indicating that there may be the potential for these plants to recruit if in-lake conditions become suitable. These results indicate a viable seedbank remains in Riley and we should see more desirable species recruit if water clarity can be sustained and carp remain low, obviating the need to attempt transplantation.

Table 12a. Total number of propagules germinating from Lake Riley sediment for the maximum germination, high clarity, and low clarity treatments based on 3.0L of collected sediment per treatment. From Dunne (2017).

Species	Species Abbreviation	***Treatment Type*** Maximum Germination	High clarity	Low clarity
Ceratophyllum demersum	Cdem	10	8	3
Chara spp.	Char	62	40	49
Elodea canadensis	Ecan	3	5	1
Heteranthera dubia	Hdub	1	1	0
Lemna minor	Lmin	1	2	0
Lemna trisulca	Ltri	0	0	0
Myriophyllum spicatum	Mspi	1	1	0
Najas guadalupensis	Ngua	1	0	0
Nyphar varigaeta	Nvar	1	0	0
Potamogeton crispus	Pcri	95	26	46
Potamogeton pusillus	Ppus	13	8	5
Potamogeton nodosus	Pnod	9	1	3
Potamogeton robinsii	Prob	1	1	0
Potamogeton zosteriformis	Pzos	4	3	3
Ranunculus longirostris	Rlon	9	0	0
Stuckenia pectinata	Spec	39	4	1
Vallisneria americana	Vame	3	20	22

Aquatic Bathymetry and Vegetation Maps

Abundant plant growth was restricted to areas < 2m deep (Figure 25). In these areas, biovolume can approach 100%, but drops to near zero in deeper areas. Overall plant cover in the littoral was thus not high (usually ≤ 50%) and mean biovolume was 62% or less (Table 12b). In 2016, most growth continued at depths of 2.5m or less but in some regions, such as the southwest bay and east shoreline, abundant growth expanded to 3.5 to 4.0m (Figure 25).

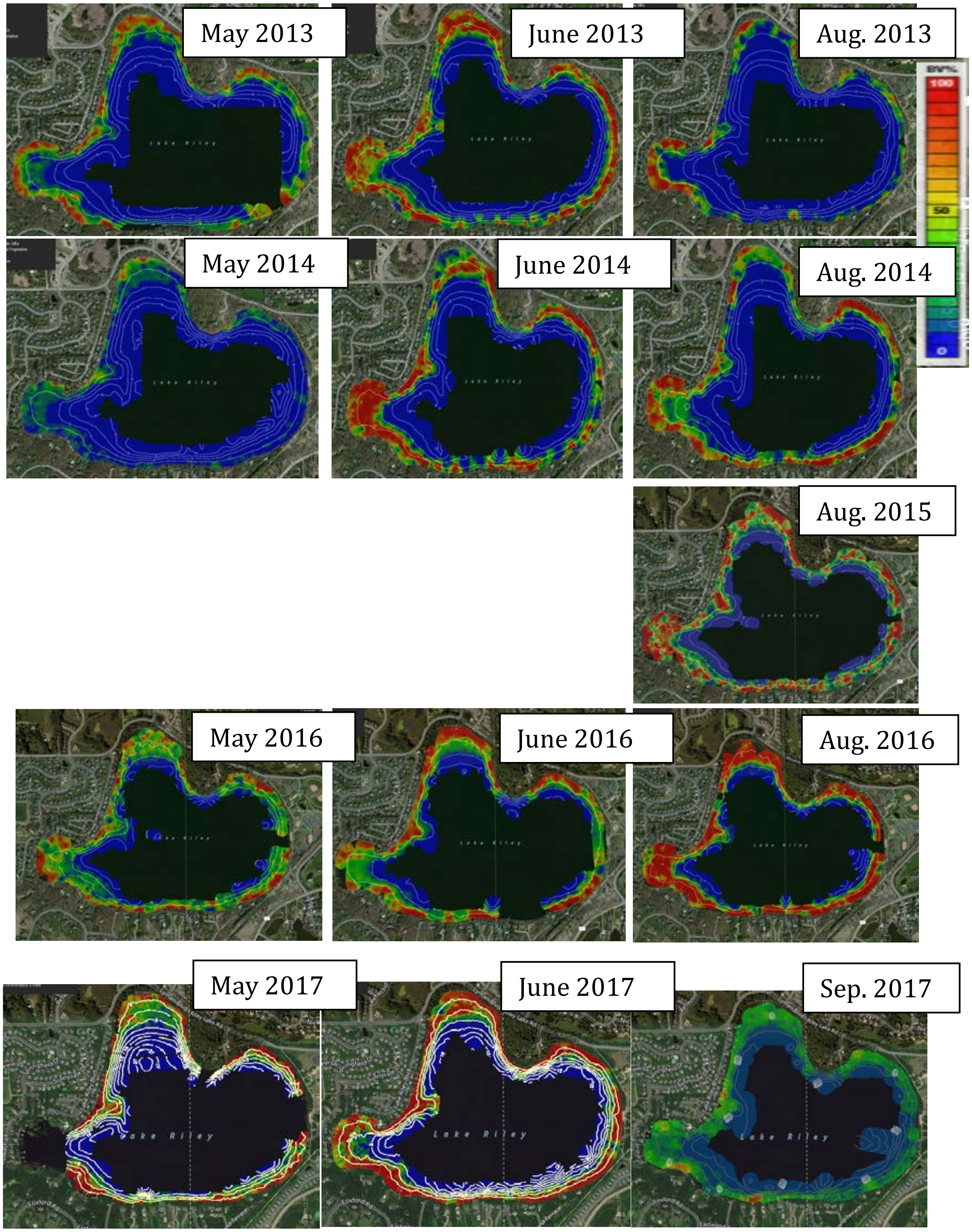


Figure 25. Aquatic bathymetry and vegetation maps of Lake Riley. Data collected during point intercept aquatic vegetation surveys on: 8 May 2013, 18 June 2013, 14 August 2013, 16 May 2014, 18 June 2014 and 12 August 2014, 13 August 2015, 4 May 2016, 9 June 2016, 5 August 2016, 10 May 2017, 5 June 2017, and 6 September 2017. Equipment failure corrupted data in May and June 2015. 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 12. Lake-wide percent area cover (PAC) and average biovolume (BV) for May, June and August 2013 and May, July and August 2014, August 2015 in Lake Riley, and May, June, and August 2016 and 2017. Values coincide with maps in Figure 25. 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	42.9%	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%	51.0%
June 2017	60.9%	62.8%
MidJune 2017	29.5%	42.2%
September 2017	46.6%	18.9%

The effects of the milfoil treatment in 2017 are clear in both the maps and the coverage and biovolume, estimates. Coverage declined to <50% in September 2017 and biovolume at 19% was the lowest since May 2014 (Table 12)

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. Significant increases in both frequency of occurrence and biomass of natives were observed in 2016. 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 greatly reduce Eurasian watermilfoil.

Eurasian watermilfoil had been present at nuisance levels and the 2015 and 2016 herbicide treatments to control it appeared to reduce the August occurrence and biomass. However, the milfoil biomass is generally reduced by August in most years and the reductions were not a large as expected so it is unknown the extent to which the population was controlled. The use of granular herbicides, with slightly higher doses in 2017 was aimed at getting better exposure to the herbicide. Unfortunatley, the herbicide residue samples were not properly preserved, so it is not certain what the actual exposures were but the almost lake-wide reduction in Eurasian watermilfoil suggests the treatments were quite effective. There were no obvious differences in effects due to either herbicide. Genetic testing of plants collected in September 2017 revealed no hybrid watermilfoil and indicated that all plants remaining after treatment were pure Eurasian watermilfoil. This indicates that selection for herbicide tolerant hybrids is not currently a concern in Lake Riley (Larue et al. 2013) and further testing (as part of LCCMR project to Newman and Thum) will determine the genotypes present.

It is not certain that the auxin mimic treatments had an effect on native plants but the reduction in cootail (particularly coontail biomass) and Canada waterweed is consistent with other studies (e.g.. Nault et al. 2012, 2014) as is the failure of bushy pondweed and wild celery to continue to increase. Given the very low density of Eurasian watermilfoil in late summer 2017 and the potential impacts on native plants it is recommended that no treatment be conducted in 2018 to see if the native plants can recover. If good water clarity is sustained the native plants should rebound to levels exceeding 2016. Further control of Eurasian watermilfoil can then be assessed at the end of 2018. Milfoil weevils were present in 2012-2015 might be worthy of consideration if native plants expand and sunfish densities are not too high.

Curlyleaf pondweed appears reduced from the four consecutive years of treatment based on frequency of occurrence, biomass, as well as turion densities. The 2016 increase in frequency of occurrence and biomass warranted continued treatment in 2017 and this treatment was very effective controlling curlyleaf and keeping turion densities very low, despite fewer acres having been treated. Curlyleaf should be assessed after iceout in 2018 and if growth apprears dense an early season endothall treatment should be planned. If growth is not dense then no treatment of curlyleaf would be warranted. The curlyleaf treatments appear to have less effect on natives than the later summer milfoil treatments and could promote natives if not the treatment is not aggressive.

If the invasives remain in check, and good clarity persists, the native plants should have more space and light, and less competition from the invasives and ideally be able to establish and expand in 2018 with the continued improved clarity from the alum treatment. If recovery of the native plant community does not progress in 2018, planting or transplanting should be considered to jump-start the recovery, but the presence of propagules in the seed bank suggests natural recruitment should be sufficient. It will be important to continue assessment of both frequency and biomass in June and August to compare to previous results. A survey in May would be useful but not as essential.

VIII. Staring Lake Results

Staring Lake is a eutrophic lake in the Purgatory Creek Watershed. The lake is about 66 hectares (164 acres), with a maximum depth of 4.9m (16ft) (MN DNR LakeFinder 2016). Until 2015, Staring Lake has had a high population of carp (Bajer and Sorensen personal communication, Newman et al. in prep) 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 (Newman et al. in prep.). Increases in native and exotic plant diversity, frequency of occurrence, and biomass occurred in the 2015 and 2016 surveys relative to previous years. Additonally, in 2015 the later summer water clarity improved somewhat relative to previous years (Figure 26). However, in 2016 and 2017 the summer Secchi depth did not further improve and may have constrained native plant expansion.

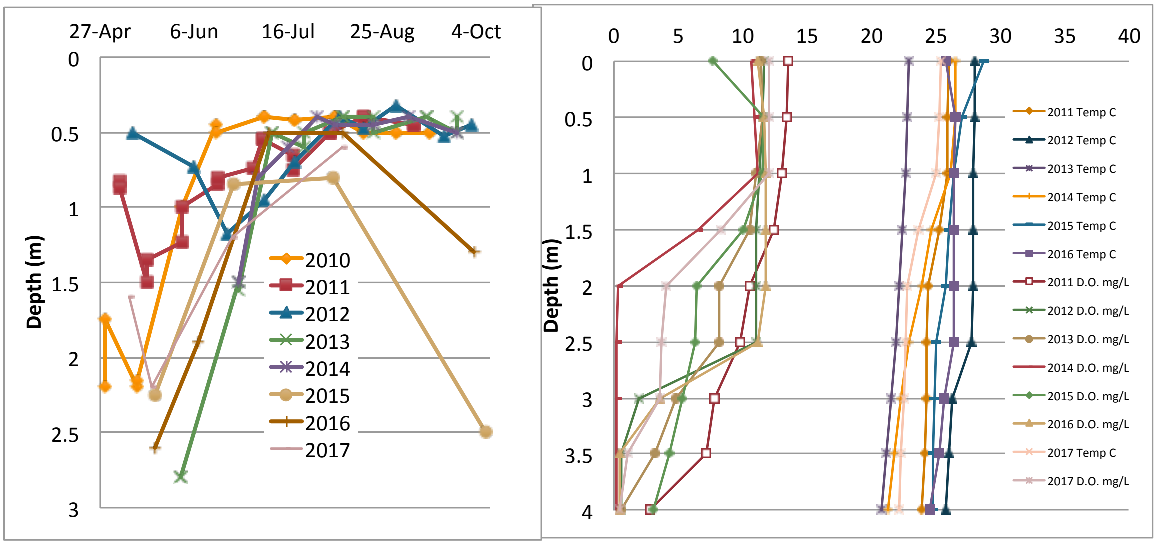


Figure 26. Secchi depths for Staring Lake 2010 through 2017 (Bajer and Sorensen unpublished data, and our data) and dissolved oxygen (mg/L) and temperature (°C) profiles taken in August 2011 through August 2017.

Water quality:

The summer Secchi depths increased after carp removal in 2015. There was a slight decrease in late summer Secchi depth in 2016 relative to 2015 with a July Secchi depth of 0.7m and August Secchi of 0.5m. However, the 2016 fall Secchi depth improved to 1.4 meters in the beginning of October, higher than pre-carp removal levels but still a meter less than the 2015 observation (Figure 26). Clarity in June 2017 was lower, but August slightly better than 2016. Water clarity appears to still be limiting the plant community. Dissolved oxygen profiles show that an anoxic hypolimnion may exist from below 2m to 4m during the summer depending on the year (Figure 26). Three of the six years show some dissolved oxygen throughout the entire water column, likely due to lack of stratification.

Aquatic Vegetation Survey:

Point intercept surveys were conducted in Staring Lake in June and August 2011, 2012, 2013 and 2014. In 2015 surveys were conducted in May, June, August, and October. In 2016 and 2017, surveys occurred in May, June, and August (Table 13). Plants increased throughout Staring after carp removal, from < 15% in 2011-2013 to >40% in 2015 and > 50% in 2016-2017 (Figure 27). Furthermore, plant coverage persisted > 50% into August. Submersed plant species increased from 4 in 2011 to 11 in 2016. No additional species were observed in 2016 or 2017 and the species diversity includes 19 observed species (Table 14). 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.

Curlyleaf pondweed was generally the most frequently occurring species in June each year (Figure 28). In 2016, curlyleaf frequency increased to over 65%, almost doubling in occurrence within one year (Figure 28). This led to an herbicide treatment in 2017. White and yellow water lilies were previously two of the most commonly occurring native species in Staring, 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 28). With poorer water clarity in 2017, Canada waterweed and chara declined but coontail continued to increase.

In 2016, chara and Canada waterweed had greater biomass than curlyleaf despite curlyleaf having a higher frequency of occurrence. Curlyleaf had the third greatest biomass in June 2016 (Figures 29). In August, Canada waterweed, coontail, and chara had the greatest biomass. The 2016 increases in biomass were significant for several species (Figure 29). Overall, native species biomass significantly increased in 2016 (Figure 31). However, the increase can be attributed primarily to one species: Canada waterweed. The increase did not persist and biomass in 2017 was lower even than 2015 (Figures 29 and 31). Thus, although plants persisted throughout the lake and coontail even expanded its occurrence, the abundance of plants was reduced.

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 - 2017 (Table 14).

Curlyleaf Pondweed Turion Surveys:

We conducted fall sediment turion surveys in October of 2011 through 2017. Until 2015, no turions were found in the sediments of Staring Lake in fall despite production of some turions in the spring. 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 95% viable. After herbicide treatment in 2017 the density droped to 1.1 ± 2 /m^2.

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) 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 30). Futhrmore, most of the plants found in June were dead or dying and sparse; most occurrences were of single or few plants (all 1s and 2s on 5 pt scale). Biomass was 0.1 ± 0.06 g/m^2 in 2017 compared to 60 g/m^2 in June 2016. Turion production was almost eliminated and fall turion density dropped to 1 ± 1/m^2 in October 2017.

Table 13. Summary of point intercept surveys in Staring Lake from 2011 through 2017. 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 Submersed 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

Table 14. Aquatic plants found in surveys conducted in Staring Lake 2011 through 2017.

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
Narrow leaf 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 classified as *Zosterella dubia*.

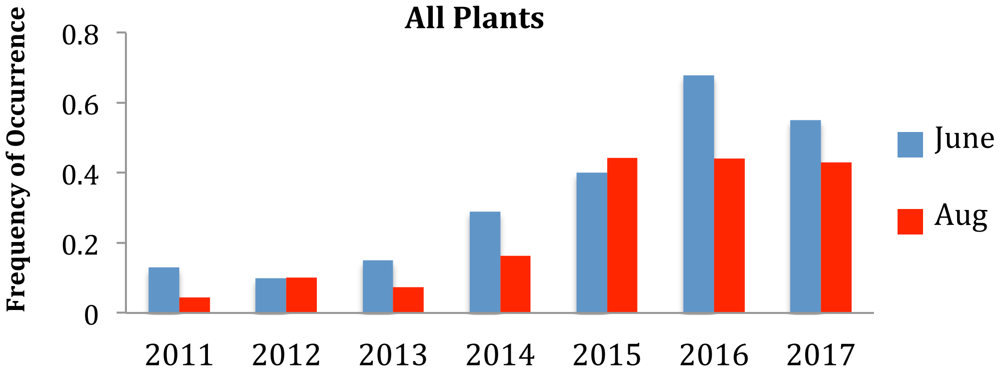


Figure 27. The frequency of occurrence of aquatic plants in Staring Lake, June and August 2011-2017.

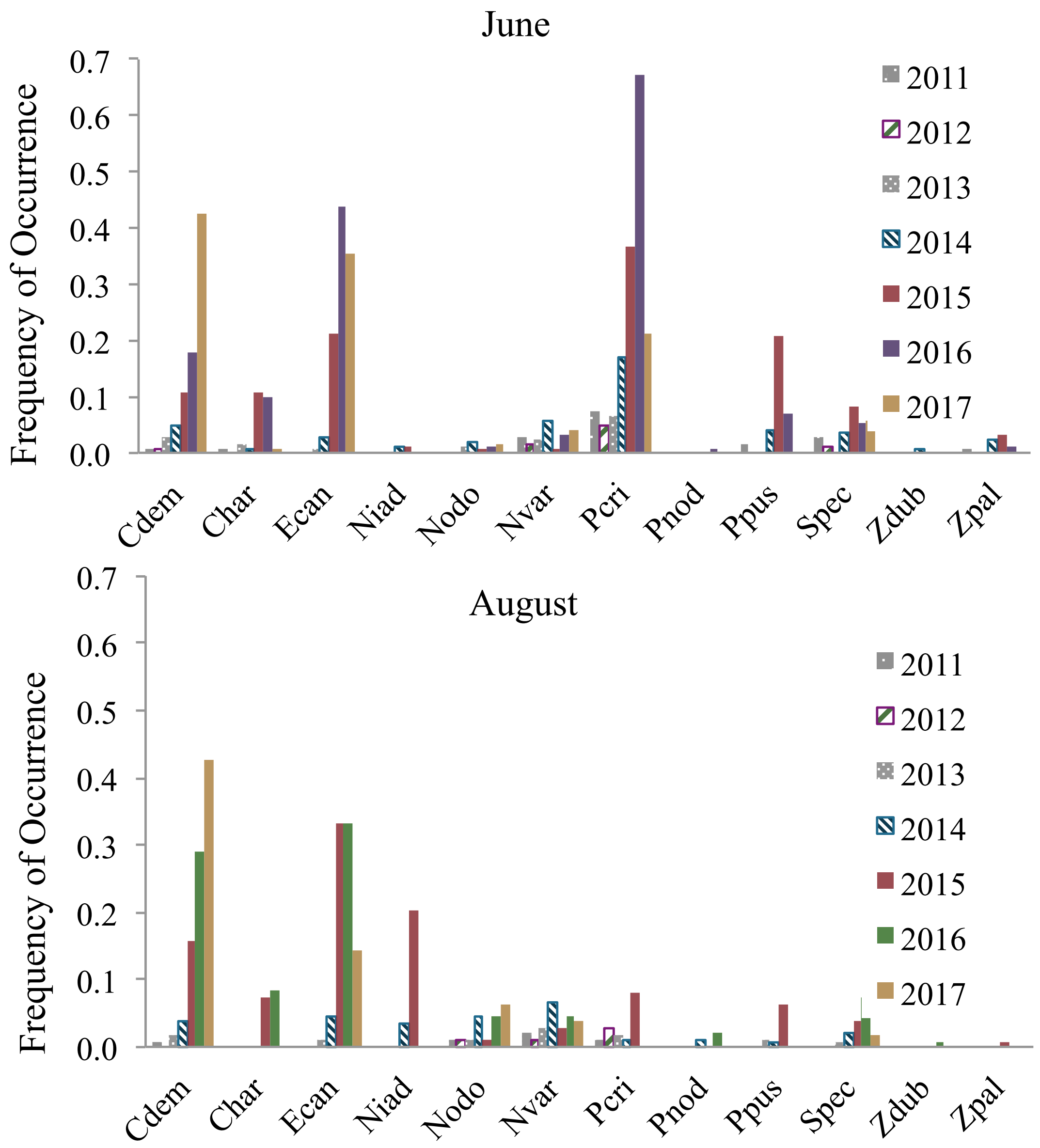


Figure 28. Frequency of occurrence of the most commonly occurring species in Staring Lake surveys in June and August 2011 through 2017. See Table 14 for abbreviations.

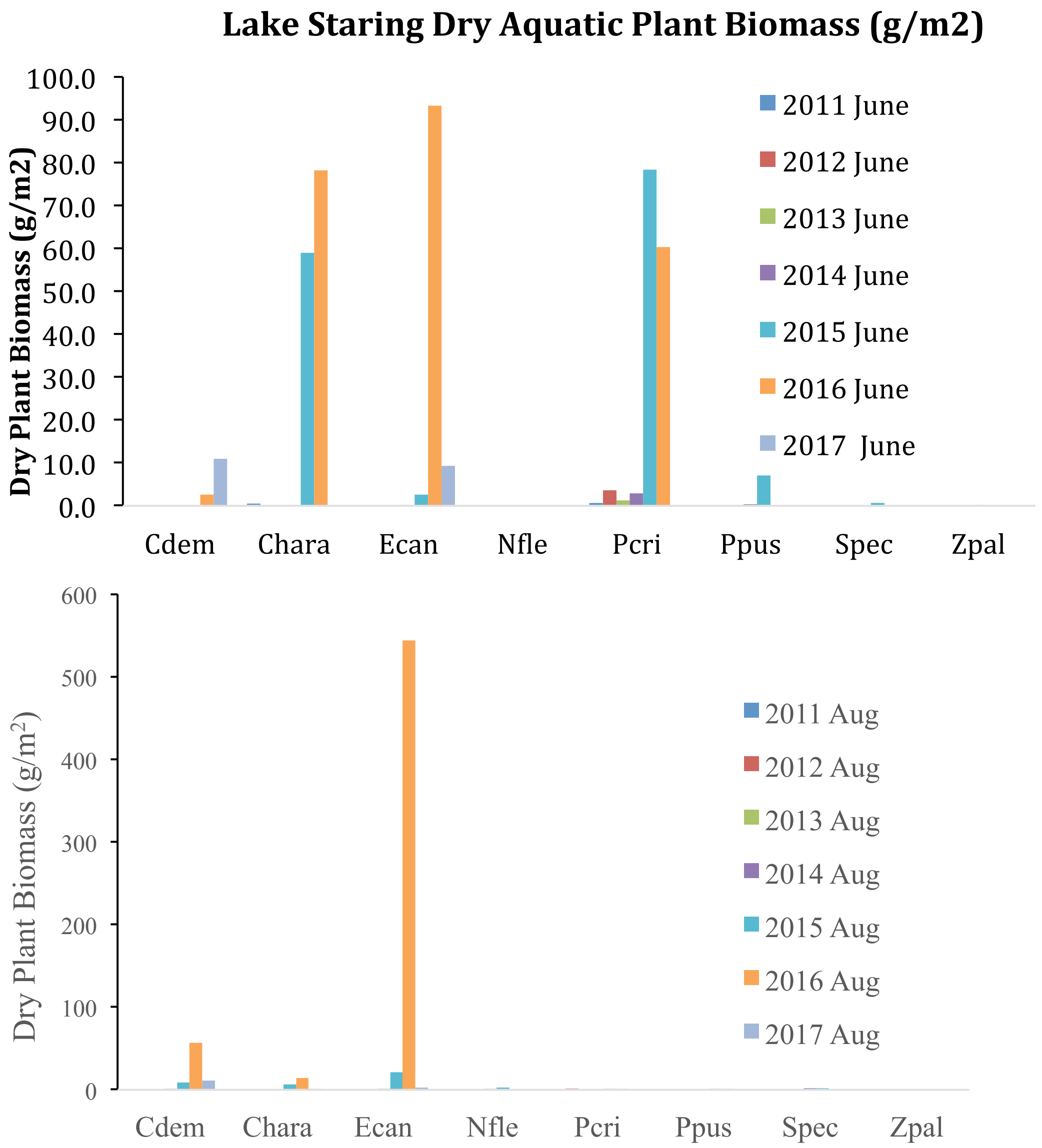
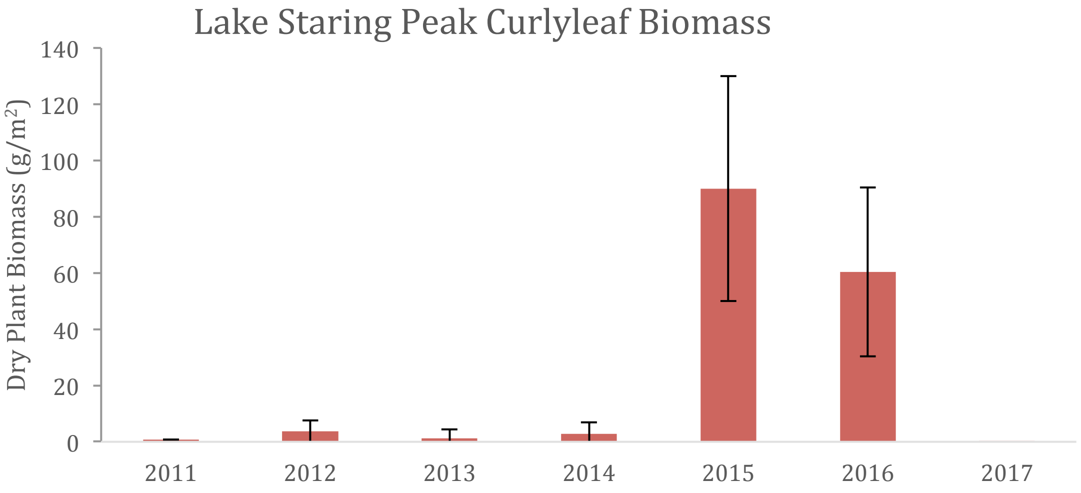


Figure 29. Dry aquatic plant biomass (g dry/m^2) for the most commonly occurring species in Staring Lake surveys June and August 2011 through 2017. See Table 14 for abbreviations. We attempted to collect biomass in August 2011 and August 2013 and found no plants at any biomass sampling sites.



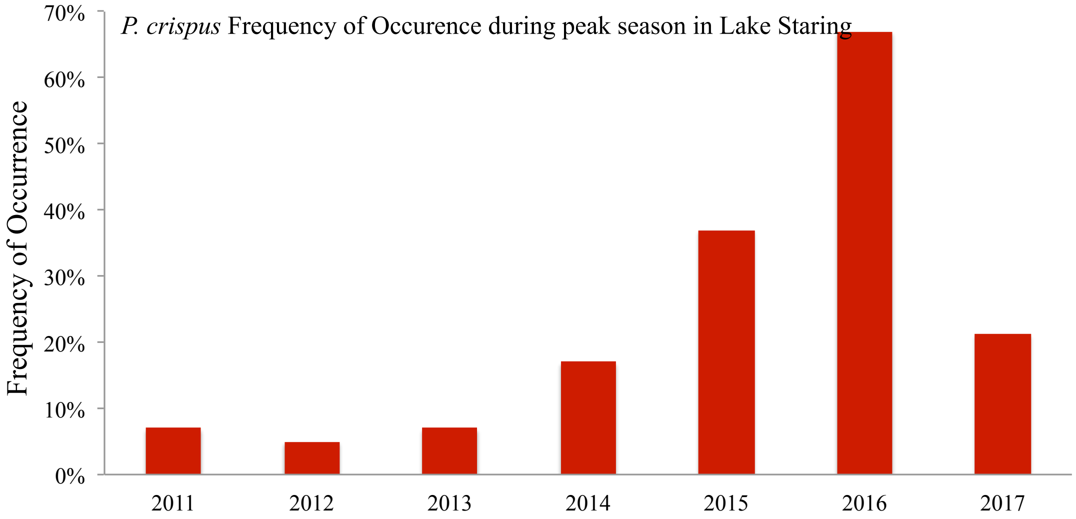


Figure 30. Frequency of occurrence and mean dry biomass of curlyleaf pondweed in Lake Staring from 2011 through 2017 at June peak season growth. Curlyleaf was treated with endothall before the peak in 2017.

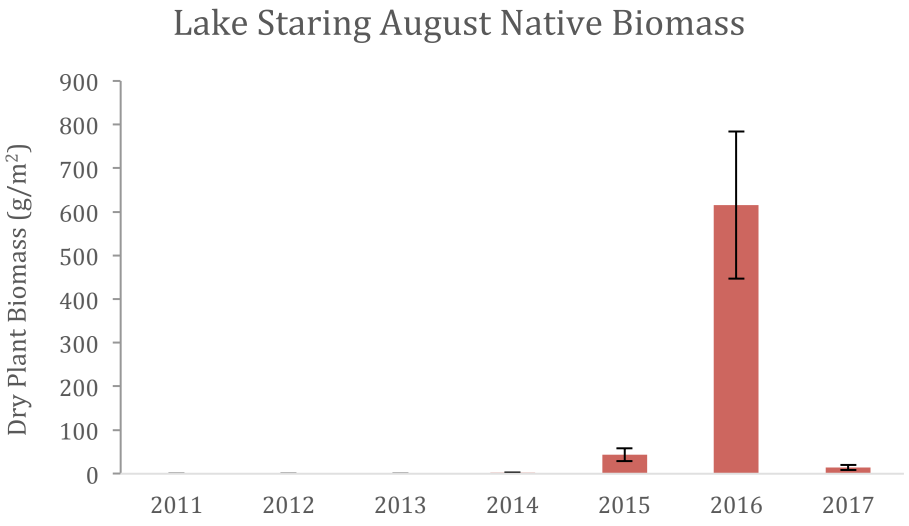


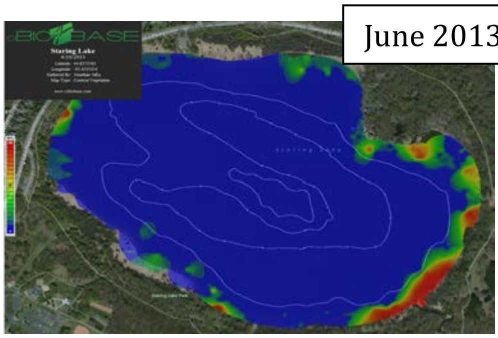
Figure 31. Mean dry biomass of native plants in Lake Staring from 2011 through 2017 at August peak season growth.

Eurasian Watermilfoil Herbicide Treatment

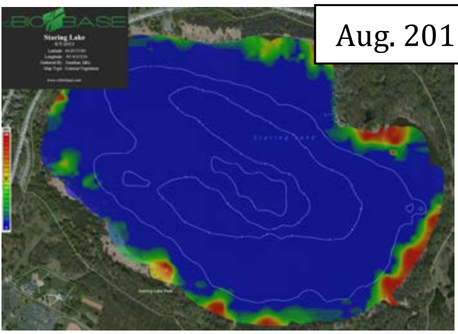
In September of 2015 and August of 2016, Eurasian watermilfoil was observed in small patches in Lake Staring. In October of 2015 and September of 2016, efforts by the watershed district with assistance from James Johnson of Freshwater Services, LLC, occurred to manually pull milfoil. Following these treatments an herbicide application consisting of granular Triclopyr (known as Renovate3®) took place to control the remaining plants. The mechanism causing the appearance of Eurasian watermilfoil remains unknown. Monitoring for the species has continued and milfoil has not expanded enough to be detected in our point intercept surveys but has been found during searches for its presence by district personnel.

Aquatic Bathymetry and Vegetation Mapping

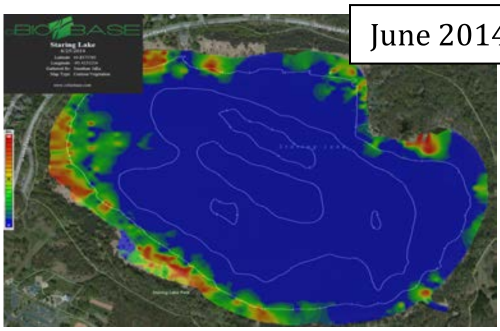
Prior to 2015, plants were generally restricted to depths shallower than 2m (Figure 32), percent area covered was usually <20%, and mean biovolume 35% or less (Table 15). In 2015, plants started to colonize in water deeper than 2.0m, the percent area covered increased in August and October to just under 50% and the mean biovolume was approximately 65% (Table 15). 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 (Tables 13 and 15, Figure 32). 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 15).



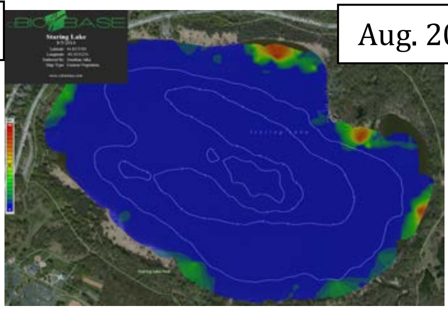
June 2013



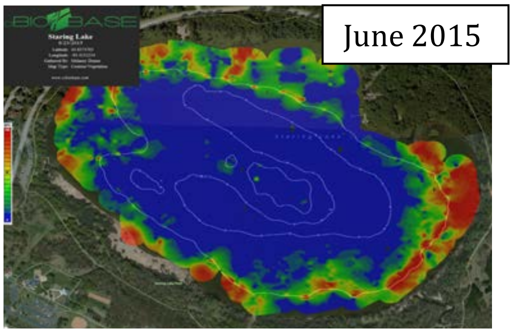
Aug. 2013



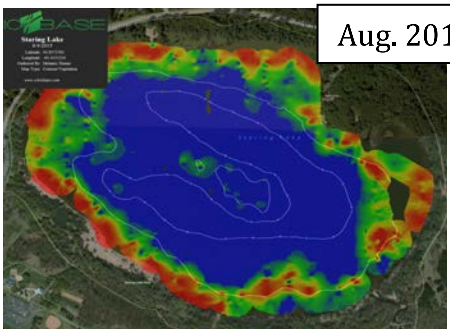
June 2014



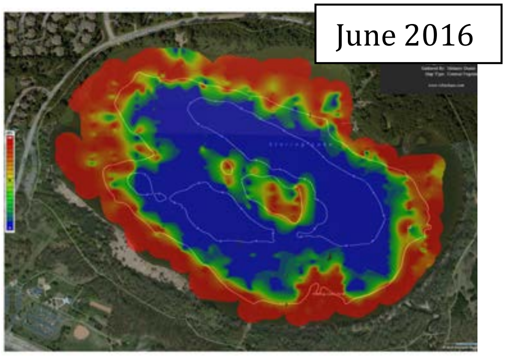
Aug. 2014



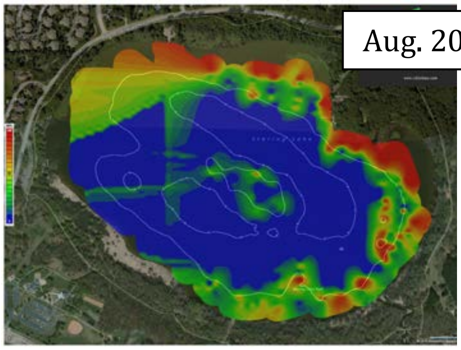
June 2015



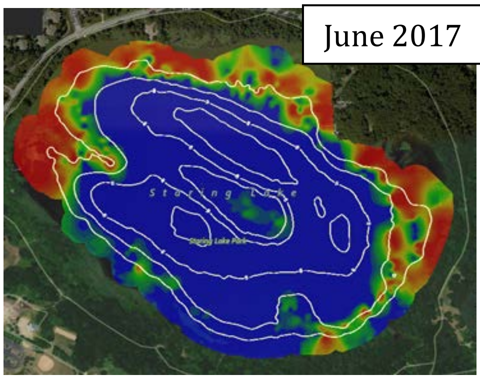
Aug. 2015



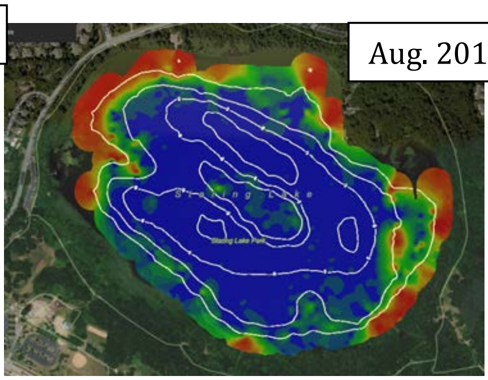
June 2016



Aug. 2016



June 2017



Aug. 2017

Figure 32. Aquatic bathymetry and vegetation maps of Staring Lake. Sonar data collected during point intercept aquatic vegetation surveys 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 and 8 August 2017. 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 15. Lake-wide percent area cover (PAC) and average biovolume (BV) for data collected in June and August 2013, July and August 2014, May, June, August, and October of 2015, and May, June and August 2016 in Staring Lake. Values coincide with maps in Figure 32. 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%

Recommendations for Staring Lake:

By 2015 carp were lowered 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 has recurred in 2016 after a 2015 rapid response to control it. However, brittle naiad (*Najas minor*) was not observed in 2016 despite occurring at several points in 2015. 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 and depending on results of delineation another treatment in this block is recommended for 2018. If there is little curlyleaf found there in May and abundance is higher in the southeast, treatment of the southeast 1/3 would be warranted.

Spot treatment or focused pulling of Eurasian watermilfoil should be considered again for 2017. Continued surveys will allow for consistent monitoring of the plant community and to track exotic species expansion. Lastly, continued control of the carp population is necessary to maintain the clear water state. The 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 the turbid, low macrophyte abundance state.

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 tansplanting is considered. It will be essential to monitor and control carp in Staring as further increases in carp abundance would likely revert the lake to pre-2015 conditions.

IX. Lake Susan Results

Lake Susan (DOW ID 10-001300) is a small kettle lake, downstream about two kilometers southeast of Lake Ann, within Chanhassen city limits and upstream from Rice Marsh Lake and Lake Riley. Lake Susan covers about 38 hectares (93 acres), with approximately 30 hectares (75 acres) littoral and a maximum depth of about 5.2m (17ft)(MN DNR LakeFinder 2016). Carp removal occurred in the winter of 2009. Following successful carp removal, aquatic plant transplanting experiments began in the summer of 2009 and ended in the summer of 2011. 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 whole-lake 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.

Water Quality:

Water clarity has improved in the spring in Lake Susan since carp removal, but usually declined to 1m or less by early summer (Figure 33). Water clarity was typically very low during much of the native aquatic plant growing season. The dissolved oxygen profiles show that by July there was often an anoxic hypolimnion beginning at 3.5m and deeper (Figure 33).

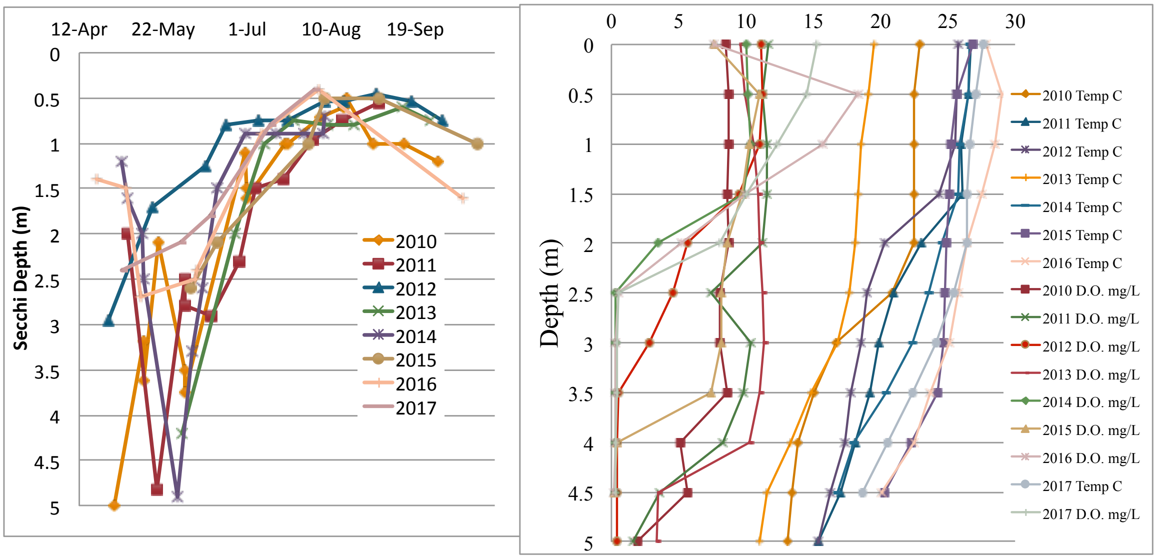


Figure 33. Secchi depths for Lake Susan 2010 through 2017 (Bajer and Sorensen unpublished data, personal communication) and dissolved oxygen (mg/L) and temperature (°C) profiles taken in August 2011 through August 2017.

Aquatic Vegetation Survey:

Plants have been sampled in Lake Susan since 2009. We have observed 23 different species (including transplanted species) in Lake Susan from 2009 to 2017 (Table 16). Lake Susan had relatively low to moderate plant diversity, but increased from 9 native taxa in 2009 (Newman 2009) to 15 native taxa found in 2014. 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. Overall, the maximum depth of growth of observed has been variable but in 2015 and 2016 the depths decreased to shallower than 3m, but expanded to > 3m in 2017 (Table 17).

Typically coontail and curlyleaf pondweed were the most frequently occurring species in May (Figure 34). Coontail, curlyleaf pondweed, Canada waterweed, sago pondweed and narrow leaf pondweed were the most frequently occurring species in June (Figure 34). Coontail, Canada waterweed, naiad, white water lily, and yellow water lily were the most frequently occurring species in August (Figure 34). In 2016 and 2017, Canada waterweed and narrowleaf and sago pondweeds became less frequent and cootail and water lilies expanded. Transplanted species 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. The invasive Eurasian watermilfoil has continued to decline in frequency since 2011.

Total native plant biomass in August has been variable as biomass increased after carp removal from 2009-2011, but then declined in 2012 (Table 18, Figure 35) when curlyleaf pondweed peaked (Figure 36). This, along with an increasing density of turions in the sediment (Table 19), led to the decision to control the curlyleaf with early season endothall treatments in spring 2013. Native plant biomass in August increased after herbicide treatments in 2013 and 2014 (Table 18). In 2015, although herbicide treatment did not occur, native plant biomass remained similar to previous levels (Figure 35). In 2016, curlyleaf was treated again but the native plant biomass declined relative to 2015, however the decline was not significant. Native biomass in 2017 was similar to 2016. Coontail typically had the highest biomass in all months in Lake Susan (Figure 37) and increased its dominance in 2016 and 2017. Curlyleaf pondweed, Canada waterweed, narrow leaf pondweed and American lotus are some of the other higher biomass producing plants in Lake Susan. Bushy pondweed (22g/m^2) and waterstargrass were abundant enough in 2017 to show up in biomass samples, although their lakewide biomass was low.

Eurasian watermilfoil biomass remained at less than 3g dry/m^2 since 2011, with the exception of June 2017 (29 g dry/m^2); it was not found in August of 2017. Curlyleaf biomass peaked in 2012, but then was low during the treatment years of 2013 and 2014. However, curlyleaf biomass increased in 2015 to 30 g dry/m^2 but decreased again in 2016 to under 20 g dry/m^2. This is lower than native plant biomass (78 g/m^2), much lower than lakes with dense curlyleaf (>300 g/m^2), and below the peak of 50 g/m^2 in 2012. The treatment in 2017 was even more effective and curlyleaf biomass was < 1g/m^2.

Milfoil Herbivore Population:

Eurasian watermilfoil has declined in both frequency of occurrence (Figure 34) and biomass (Figure 37) since we began surveying in Lake Susan. The declines may be partially attributed to relatively high densities of milfoil weevils when milfoil was present in the lake. We began monitoring the milfoil herbivore population in 2010 and the weevil densities were variable but persistent throughout observation years. Weevil populations were lower in 2013 through 2016 and no weevils were found in 2017 (Table 20), but Eurasian watermilfoil was also at very low densities and difficult to find. It is likely the milfoil weevil aided in the control of Eurasian watermilfoil and is perhaps suppressing any resurgence.

2013 and 2014 Whole Lake 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 39), biomass (Figure 40) and turion density in the sediments (Table 19). Curlyleaf pondweed was observed in over 40% of sites sampled in the littoral zone in 2012 and declined to less than 10% of sites sampled in the littoral zone in 2013 and 2014 post-treatment (June). The low frequency and biomass, along with low turion density in fall of 2014, led to the decision to not treat in 2015. In 2015, without treatment, the peak season frequency of occurrence increased to 25% of sampled littoral points. At its peak in 2012, we observed a littoral-wide average curlyleaf biomass of about 50 g dry/m^2. Curlyleaf biomass values declined to under 5 g dry/m^2 in 2013 and 2014, which was also significant ($p \leq 0.05$). Biomass in 2015 significantly increased to about 30 g dry/m^2, however this is still lower than the peak in 2012 and much less than current native plant biomass and nuisance levels in other lakes. Turion densities in the sediments declined from a peak of 87 turions/m^2 in 2012 to about 8 turions/m^2 in 2014 (Table 19). In 2015, the turion density remained low at 11 turions/m^2. Turion viability increased from 67% in 2014 to 99% in 2015. Mean total native plant biomass increased in 2013 and 2014 compared to previous years, although the increases were not significant (Figure 35). Although curlyleaf frequency increased in 2015 the native plant biomass and frequency remained similar to 2014 observations.

2016-2017 Curlyleaf Pondweed Half-Lake Herbicide Treatments:

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 (Figure 39). This was done to evaluate the effect of the herbicide application on the native plant community. The plant community of the western, untreated side of Lake Susan was compared to plant community in the eastern, treated side of the lake. Extra point intercept survey sites were created and sampled on the western third of the lake and the eastern third of the lake. Biomass samples were also collected at each of the extra sampling points. Points were included if they were at a depth of 3.0m or less due to the limited plant growth deeper than 3.0m. The results of the extra surveying indicated that there was no distinct pattern in the native plant community response to the herbicide treatment between the untreated and treated sides of Lake Susan. The curlyleaf frequency of occurrence and relative abundance decreased in the treatment area in June relative to May 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.

Additionally, the results of the herbicide residual analysis indicated that the herbicide was retained in low concentrations throughout the first day but then dissipated to detection limits by the fourth day. By 4 h after application, the average concentration in the treatment plots was 0.1mg/L, below the target concentration of 1 mg/L.

The split treatment in 2017 was much more effective at controlling curlyleaf; curlyleaf biomass (Figure 36) and frequency (Figure 39) were both reduced compared to 2015 and 2016 and were comparable to 2013 and 2014. Unfortunately the residue samples were not properly preserved but control was lake wide. Although some curlyeaf plants remained on the untreated western side, abundance there was very low. Native plants did not appear affected and increased in frequency (Figure 40) but not biomass (Figure 35)

Table 16. Aquatic plants found in surveys conducted in Lake Susan 2009 through 2015.
*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
*Water stargrass	*Zosterella dubia*[1]	Zdub	2011
**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
Narrow leaf 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 wild celery	*Vallisneria americana*	Vame	2011
Horned pondweed	*Zannichellia palustris*	Zpal	2013
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] now called *Heteranthera dubia*.

Table 17. Summary of point intercept surveys in Lake Susan from 2011 through 2016. 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 Submersed 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

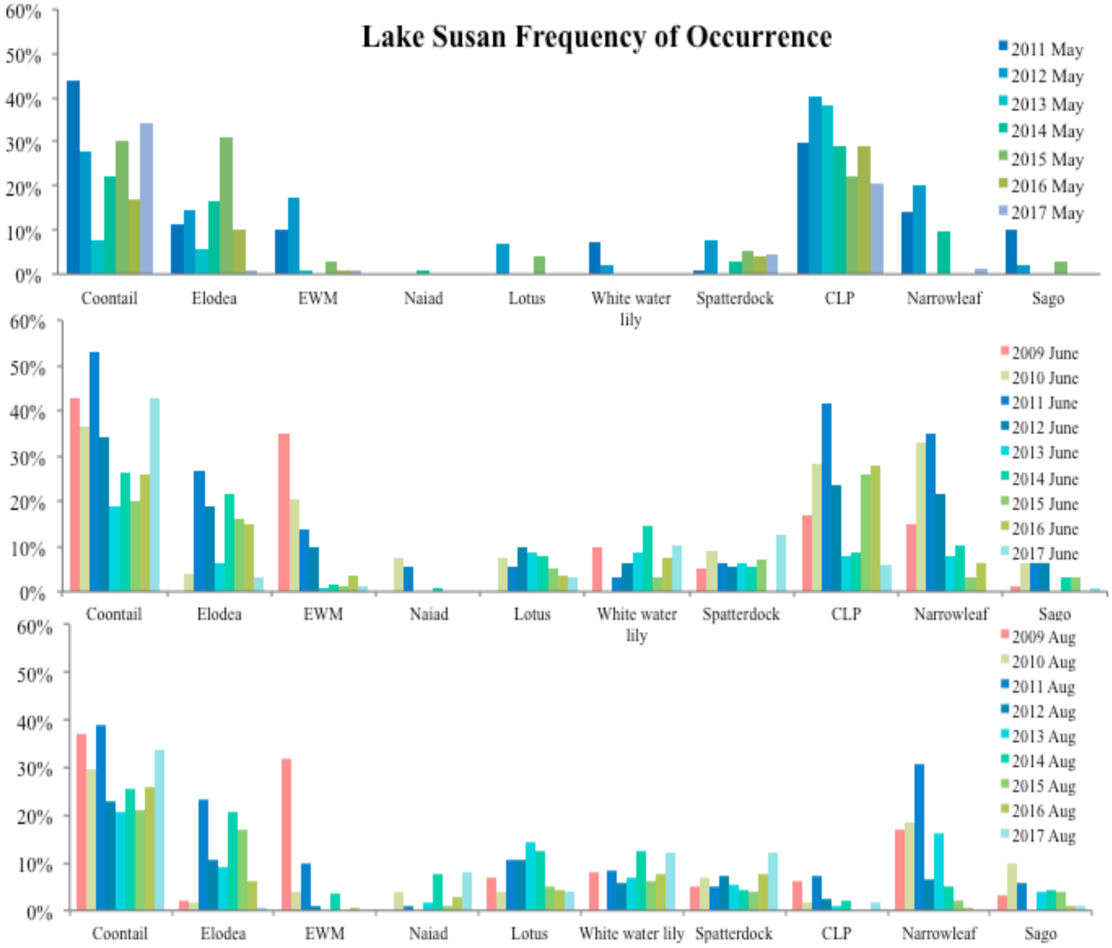


Figure 34. Frequency of occurrence for the most commonly occurring species in Lake Susan surveys May 2011 through 2016 and June and August 2009 through 2017.

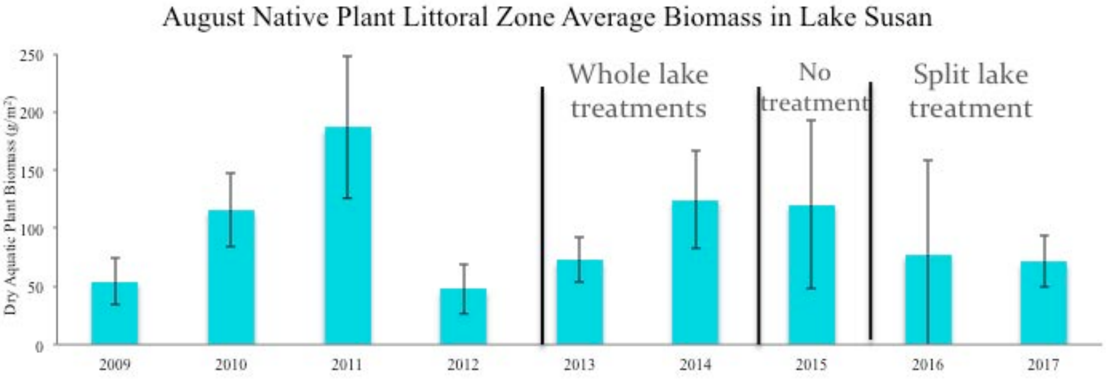


Figure 35. Mean total native plant biomass (g dry /m^2) in the littoral zone (August Surveys) in Lake Susan 2009 through 2017. The vertical lines represent the treatments for 2013 - 2017.

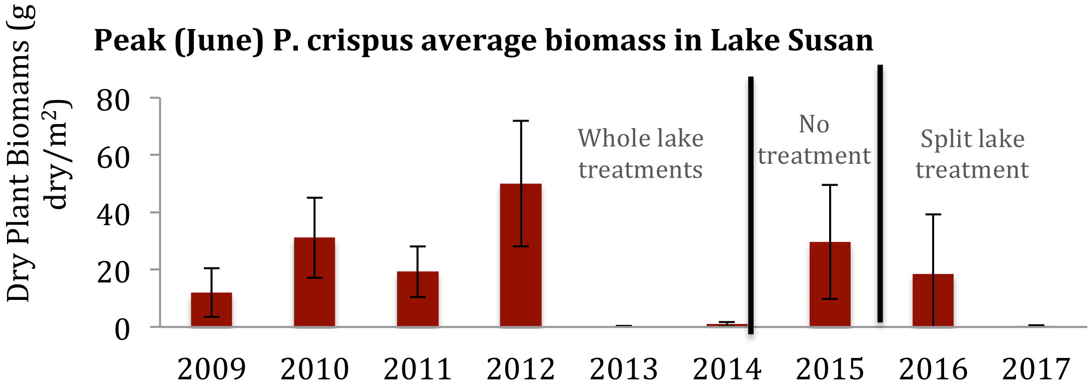


Figure 36. Peak biomass (g dry/m^2) of curlyleaf pondweed in Lake Susan 2009 through 2017. The vertical lines represent the treatments and treatment years. Note: Treatment year declines in 2013-2014 are significant ($p \leq 0.05$).

Table 18. Mean dry plant biomass (g dry/m^2) of total native species and total exotic species (curlyleaf pondweed and Eurasian watermilfoil) in Lake Susan.

Date	Native (g dry/m^2)	Exotics (g dry/m^2)
June 2009	6.8	7.4
August 2009	54.3	7.6
June 2010	145.1	36.5
August 2010	115.8	0.7
September 2010	111.4	4.7
May 2011	36.0	5.3
June 2011	85.8	20.3
August 2011	186.9	2.4
May 2012	84.7	51.1
June 2012	73.5	6.9
August 2012	47.9	0.5
May 2013	1.3	6.5
June 2013	3.8	0.2
August 2013	73.0	0.2
May 2014	24.7	1.3
June 2014	47.1	1.0
August 2014	124.8	0.0
May 2015	12.3	1.0
June 2015	30.5	29.7
August 2015	120.3	0.6
May 2016	24.3	1.9
June 2016	91.5	21.7
August 2016	77.2	0.01

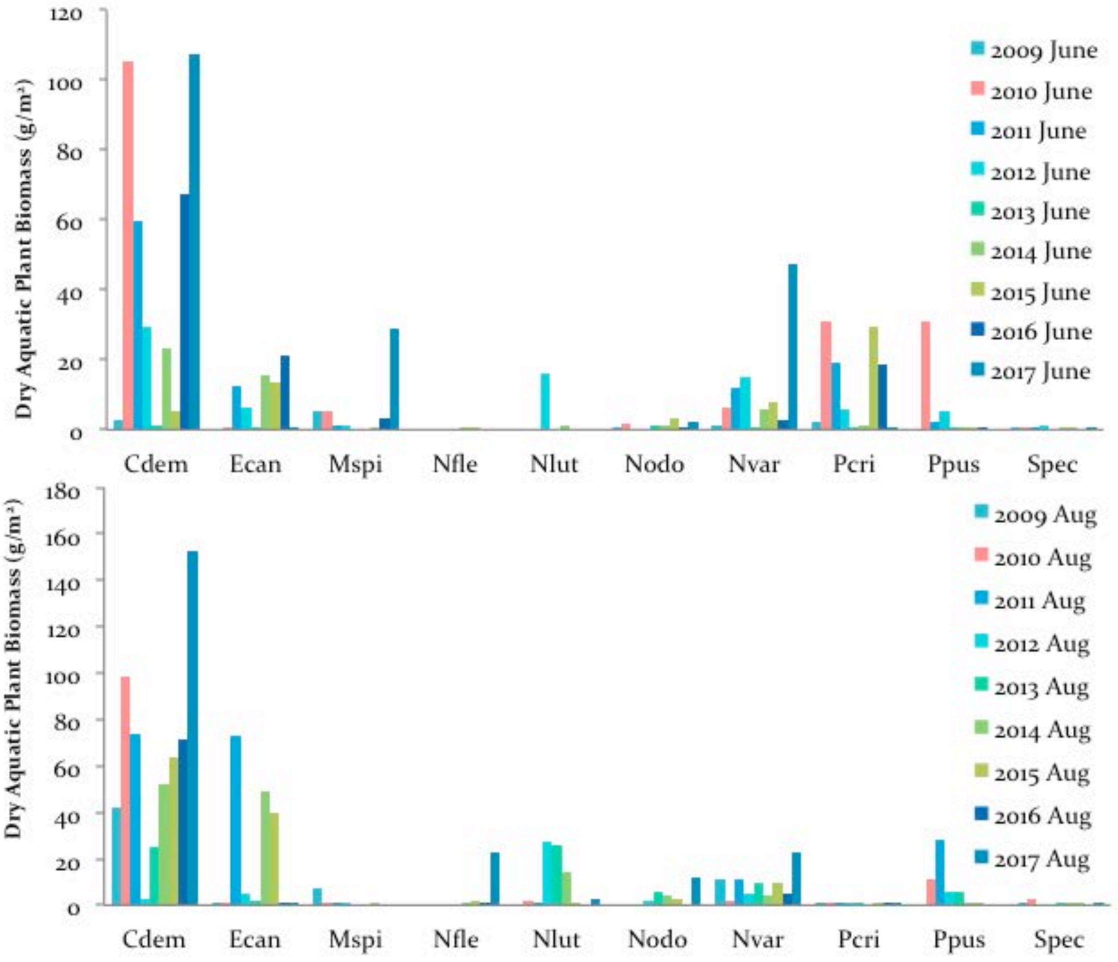


Figure 37. Dry Aquatic Plant Biomass (g dry/m^2) for the most commonly occurring species in Lake Susan surveys June and August 2009 through 2017. See Table 16 for abbreviations.

Table 19. Results from turion surveys conducted October 2011 through October 2017 in Lake Susan. Note: Decline from 2012 to 2014 is significant ($p \leq 0.05$).

Pcri	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

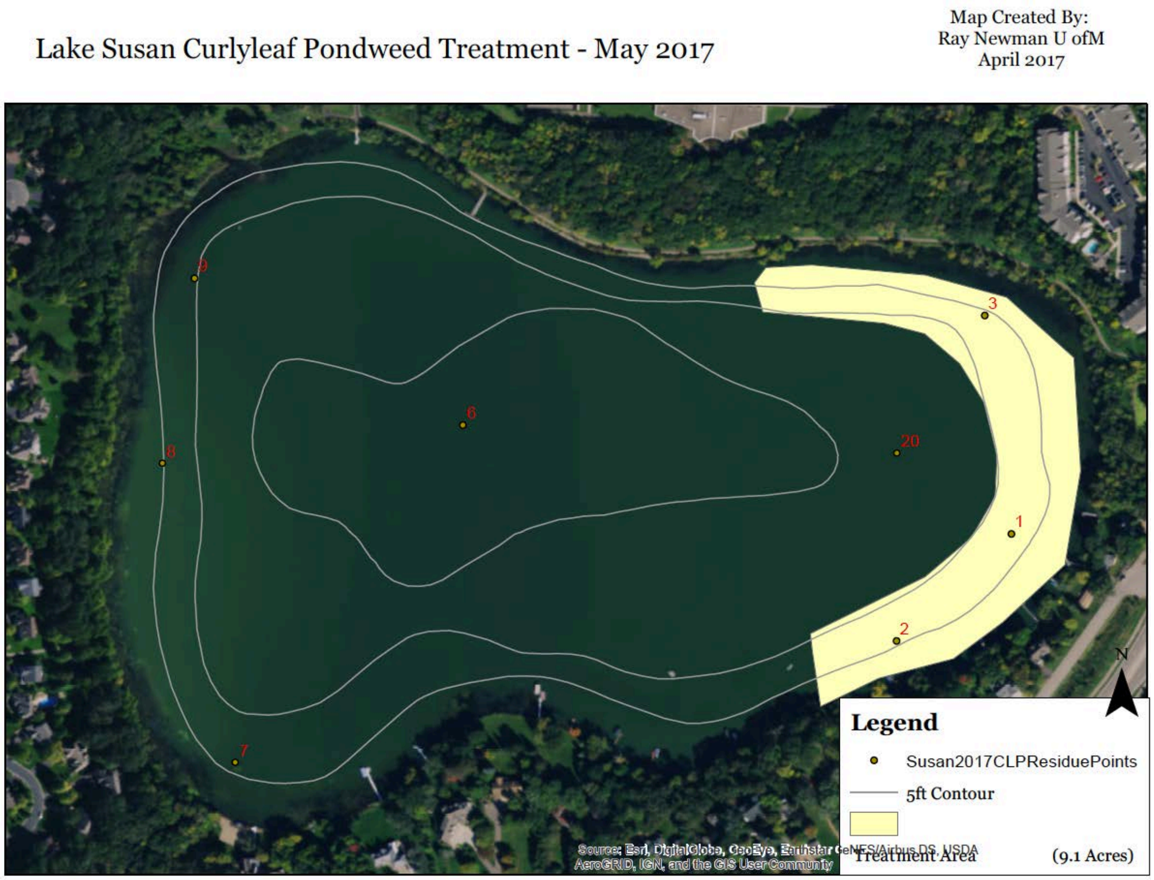


Figure 38. Area of of curlyleaf pondweed May 2017 half-lake endothall treatment. A similar but slight smaller area was treated in 2016.

Table 20. Results of Eurasian watermilfoil herbivore population surveys in Lake Susan 2010 through 2016. No milfoil or weevils were found in 2017 surveys. Values are lake-wide means for weevil populations expressed as total weevils in all life stages per stem.

Mspi	Weevils/Stem
2010	
4 June	0.82
17 June	0.87
6 July	0.27
27 July	0.19
17 August	0.04
4 September	0.04
2011	
7 June	0.21
7 July	0.17
3 August	0.15
1 September	0.13
2012	
1 June	0.48
28 June	0.12
8 August	0.09
2013	
3 June	0.13
26 June	0
29 July	0.08
27 August	0
2014	
5 June	0
30 June	0.06
28 July	0.11
26 August	0.04
2015	
1 June	0.01
30 July	0.11
2 September	0.01
2016	
June	0.01
July	0
August	0

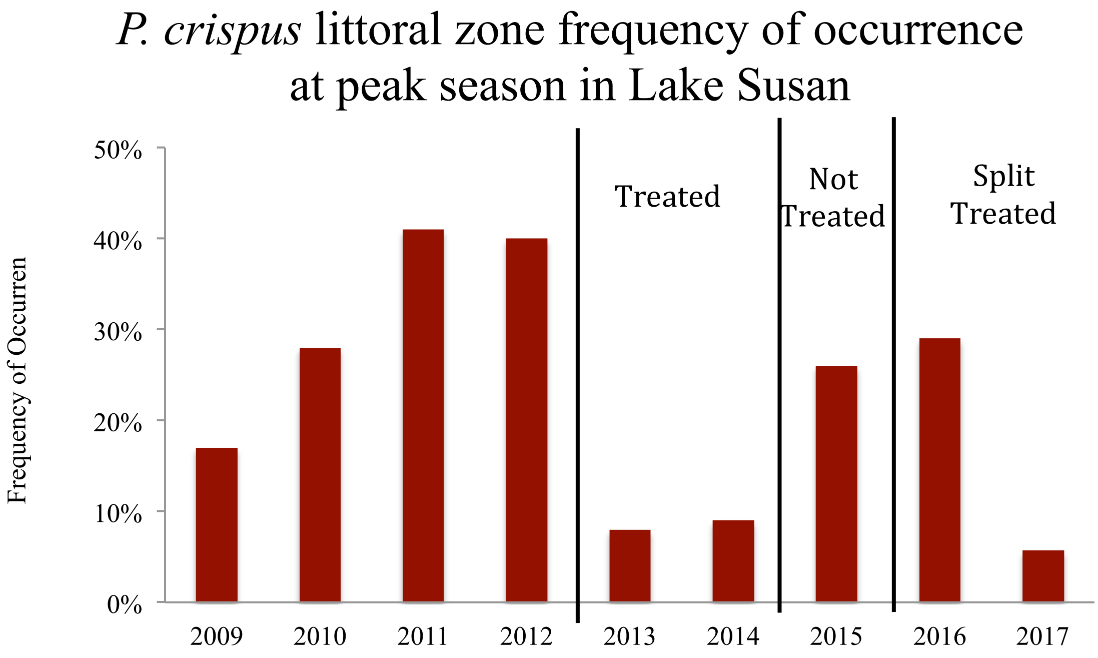


Figure 39. Peak frequency of occurrence for curlyleaf pondweed in Lake Susan 2009 through 2017. The vertical lines represent the treatment years of 2013 and 2014 and split treatments in 2016-2017. Note: Post-treatment declines are significant ($p \leq 0.05$) in 2013-2014.

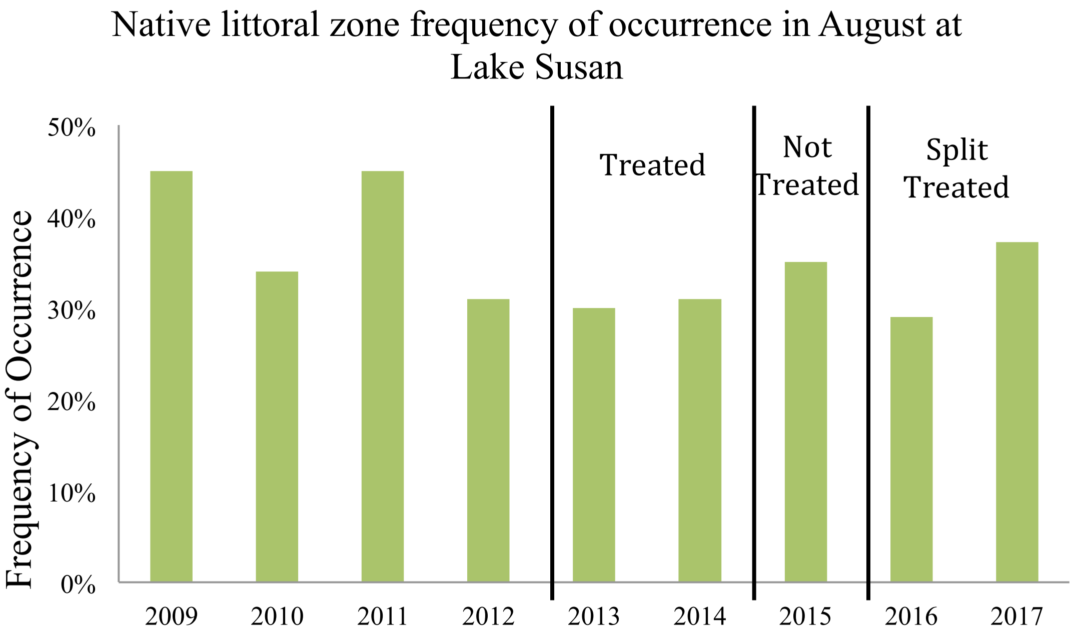


Figure 40. The frequency of occurrence of native aquatic plant species in Lake Susan, August 2009- 2017.

Aquatic Bathymetry and Vegetation Mapping

Plant coverage ranged from 18% to 40% and biovolume since 2015 from 40 to 60% (Table 21) but the highest biovolume was generally in water < 2m deep (Figure 41). 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 21). Coverage and biovolume in 2017 was similar to previous good years and improvements in water clarity will be needed to further expand plant coverage beyond 1 or 2m.

Table 21. Lake-wide percent area cover (PAC) and average biovolume (BV) for data collected in 2013 through 2017 in Lake Susan. Values coincide with maps in Figure 41. 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%

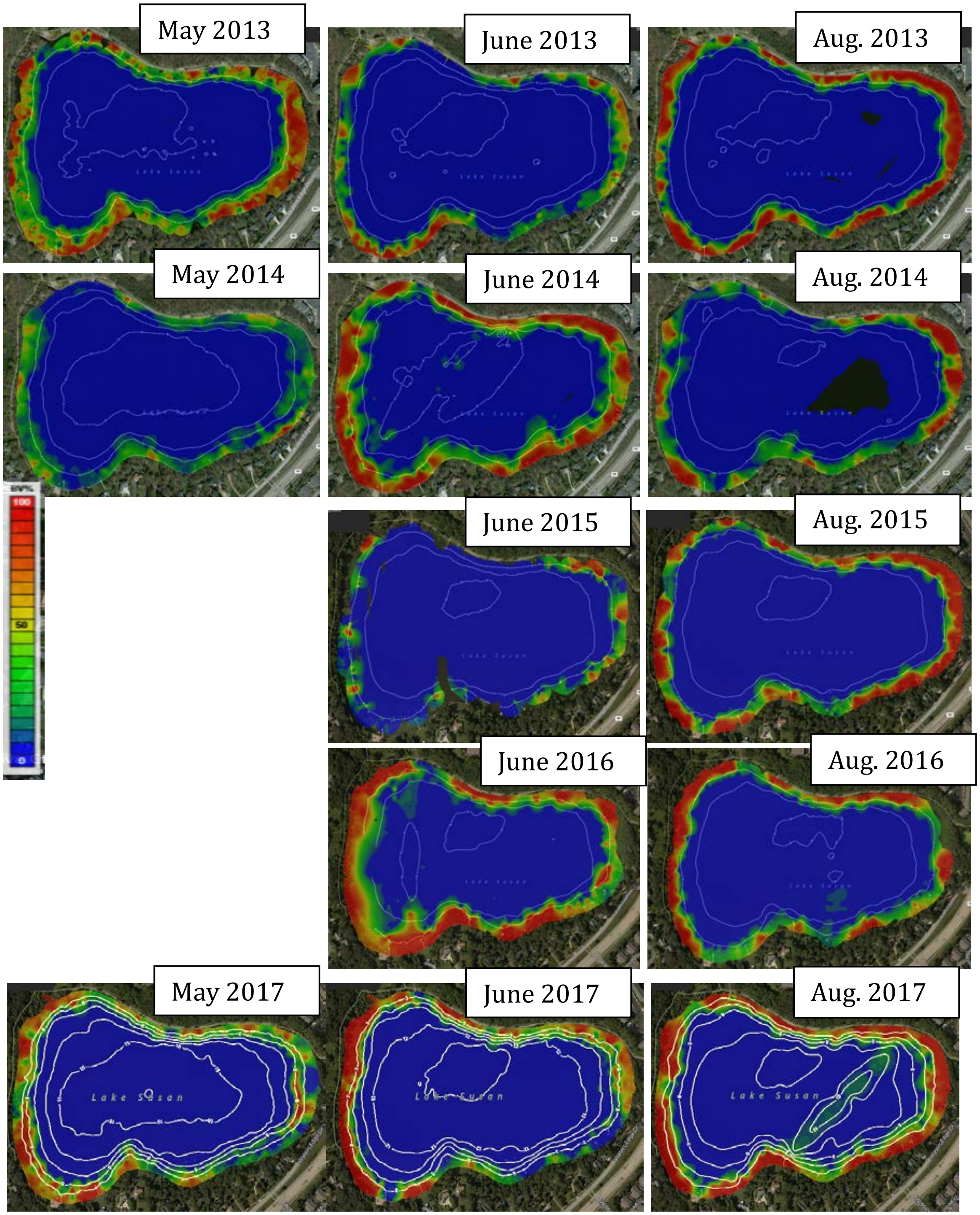


Figure 41. Aquatic bathymetry and vegetation maps of Lake Susan. Data collected during point intercept aquatic vegetation surveys on: 6 May 2013, 7 June 2013, 12 August 2013, 13 May 2014, 17 June 2014, 6 August 2014, June 26 2015, August 7 2015, June 6 2016, August 3 2016, 4 May 2017, 12 June 2017 and 1 August 2017. 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.

Lake Susan Recommendations

The split treatment approach appears to be effective, espescially with the slightly expanded treatment area and higher concentration in 2017. If curlyleaf is abundant in spring 2018 another split treatment will be beneficial contain the plant and to further our understanding of how the treatments effect native plant communities. Given the rapid rebound of curlyleaf without treatment in 2015, with lower turion densities than found in 2017, it would be wise to plan for a treatment in 2018, unless delineation surveys show a limited distribution with few plants.

The expansion of native plants in Lake Susan is limited by water clarity. Although some transplants established only bushy pondweed and water stargrass have expanded enough to remain in lake wide surveys and at very low density and biomass. Wild celery may persist but has not expanded and the decrease in Canada waterweed with an increase in coontail is concerning. A coontail, curlyleaf, Eurasian watermilfoil state should be avoided. With the limited water clarity Lake Susan will benefit from an alum treatment to bolster clarity and reduce internal nutrient loading; the plan for treatment in 2020 should be continued and accelerated to 2019 if possible. If alum treatments occur in the future, herbicide applications will likely be needed to control the spread and expansion of exotic species, certainly curlyleaf, and an LVMP should be developed along with the alum treatment if not before. If the transplanted taxa remain in the lake then they would be expected to respond to improved clarity. If they are not found in future surveys or within a year of improved water clarity, additional transplanting into deeper water could 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 all three lakes that were assessed (Riley, Staring and Susan). However, management of invasive curlyleaf pondweed and Eurasian watermilfoil is often needed and one or both increased to levels requiring mangment 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. Properly dosed herbicide treatments are effective at controlling the invasives and should continue on an as needed basis. Ideally, the invasive populations will become reduced to the extent that treatment will not need to occur each year, but this will not likely happen until native plants are able to expand.

Although direct disruption by carp was eliminated and water clarity generally improved in May and early June, poor water clarity throughout the summer has limited the expansion of native plants. Thus although transplants were success in Lake Susan they have not expanded their distribution or been able to compete with curlyleaf pondweed. The alum treatment in Lake Riley allowed the native plants to expand but aggressive invasive control in 2017 set back the recovery of the native plant community. If good water clarity persists in Lake Riley in 2018 and herbicide treatments avoided, the native plants should be able to respond and return to 2016 distribution and biomass or perhaps expand further. It is hypothesized that if rooted native plants can expand into much of the littoral that curlyleaf and Eurasian watermilfoil will be less problematic and easier to control. However, good water clarity ≥ 2.5 m will need to persist through the summer. Seed bank assessment and prior surveys suggest that 12 to 15 submersed native taxa should be present through the summer. Further control of invasives may be needed but care should be taken to sustain the native plants.

On Lake Staring and Lake Susan actions to further enhance summer water clarity are needed to develop healthy native plant communities which will be more resilient to exotic macrophyte profileration and will provide habitat for aquatic life. An alum treatment in Lake Susan will be particularly helpful. Containing carp populations in all three systems will be important. Carp do not appear to be an issue in Lakes Riley and Susan but vigilance in Staring is needed. Transplanting should only be considered once water clarity is ensured and a seedbank assessment is conducted. Based on past surveys Susan should be able to support 10 to 12 native plants; the potential in Lake Staring is less clear and a seedbank assessment would be useful.

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