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Aquatic macrophyte community shifts in five shallow lakes in Sibley County, Minnesota

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ABSTRACT

The aquatic macrophyte community is one of the driving factors that affects the structure and function of freshwater systems. The shallow lakes of Sibley County, Minnesota, have been understudied and the purpose of this study was to describe aquatic macrophyte communities in these lakes and document seasonal changes in community structure in the presence of aquatic invasive plants. Entire lake surveys were conducted on all five lakes using the point-intercept method in both the early growing season and late growing season in 2019. The dominant native macrophyte in Sibley County lakes was sago pondweed [*Stuckenia pectinata* (L.) Böerner], with one lake (Schilling Lake) being dominated by curlyleaf pondweed (*Potamogeton crispus* L.), at least during the early season. Significant shifts in the macrophyte community were found in nearly every lake, and the shifts differed depending on the species composition and the presence or absence of aquatic invasive species. Schilling Lake had the greatest change in mean species richness from 0.69 in the early season to 1.11 in the late season. The presence of curlyleaf pondweed in Schilling Lake was a primary driver for the community shift from early to late season. In Schilling Lake, curlyleaf pondweed had a frequency of 44.4% in the early season, which decreased to 13.9% in the late season. Conversely, sago pondweed had a frequency of 6.3% in the early season, which increased to 63.9% in the late season. Overall, all lakes in this study were relatively species-poor compared to other large lakes in southern Minnesota.

Key words: life history, phenology, point intercept survey, *Potamogeton crispus*, submersed aquatic vegetation, *Stuckenia pectinate*.

INTRODUCTION

Aquatic macrophytes are one of the major factors that affect the structure and function of shallow lakes (Wetzel 2001, Scheffer 2004). Macrophytes increase biodiversity, contribute to primary productivity, mitigate flooding, improve water quality, and provide food and habitat for all other organisms (Ozimek et al. 1990; Madsen et al. 1996, 2008; Scheffer 2004; Wersal and Madsen 2012). In shallow, eutrophic systems, aquatic macrophytes are essential in moderating the intensity and frequency of algal blooms, a common disturbance in these systems (Takamura et al. 2003, Bakker et al. 2010). Aquatic macrophytes can reduce algal blooms by competing with algae for nutrients and light (Takamura et al. 2003, Bakker et al. 2010). Additionally, submersed aquatic vegetation can reduce the resuspension of lake sediment, which is a major source of autochthonous phosphorus that can promote algal blooms (Barko et al. 1991, Zhu et al. 2015).

In southern Minnesota, one of the most dominant native aquatic macrophytes is *Stuckenia pectinata* (L.) Böerner (sago pondweed), a cosmopolitan submersed species that is essential to the shallow lake ecosystem (Case and Madsen 2004, Madsen et al. 2006, Wersal et al. 2006). It is an herbaceous perennial that produces tubers from which new shoot growth will grow each season (Case and Madsen 2004, Wersal et al. 2006). Sago pondweed is important for nutrient cycling, it provides habitat for fish and aquatic invertebrates, and its fruits and tubers are an important food source for waterfowl (Kantrud 1990, Wersal et al. 2005). The growth of sago pondweed is initiated with tuber germination in the spring and it typically reaches maximum growth in mid to late summer and can form dense, monotypic canopies (Wersal et al. 2006). After sago pondweed reaches its growth maximum, it will flower and then fruit. The shoots can persist into autumn, at which point they will die back to its tubers and overwinter (Kantrud 1990, Case and Madsen 2004, Wersal et al. 2006). The phenology of sago pondweed is typical of submersed macrophytes in temperate North America.

Potamogeton crispus L. (curlyleaf pondweed) is a widespread aquatic invasive macrophyte that is common in the upper Midwest (Woolf and Madsen 2003). Like other aquatic invasive macrophytes, curlyleaf pondweed is detrimental both economically and ecologically. Curlyleaf pondweed negatively affects systems by changing habitat structure, altering nutrient cycling, and inhibiting recreation and navigation (Rockwell 2003, Pimentel et al. 2005). Curlyleaf pondweed is a fast-growing perennial that can form thick, monospecific canopies that shade out native macrophytes, reduce biodiversity, and alter the structure and function of affected systems (Bolduan et al. 1994, Woolf and Madsen 2003, Turnage et al. 2018). Compared to most other submersed macrophytes in temperate North America, curlyleaf pondweed has an atypical seasonal life history. In the early spring, curlyleaf pondweed exhibits rapid shoot growth that forms dense canopies that can reach the surface in shallow lakes. Curlyleaf pondweed's maximum growth occurs in May and June, at which point it flowers and forms turions, a rigid asexual propagule formed at the axillary buds (Bolduan et al. 1994, Turnage et al. 2018). In late June

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Table 1. The physical and geographical properties of all five lakes in Sibley County, Minnesota, 2019. Average and maximum depths calculated from 2019 survey data.

	Latitude	Longitude	Total Area (ha)	Average Depth (m)	Maximum Depth (m)	Secchi Depth (cm)
High Island Lake	44°40′4″N	94°12′37″W	699	1.68	2.90	149
Titlow Lake	44°34′11″N	94°12′0″W	360	1.50	1.83	22
Schilling Lake	44°41′45″N	94°12′37″W	355	1.68	2.59	86
Silver Lake	44°37′7″N	93°58′16″W	292	1.65	2.38	10
Clear Lake	44°27′24″N	94°30′53″W	204	2.29	3.66	29

and into July, curlyleaf pondweed shoots senesce and the turions are deposited onto the sediment. The turions then start to sprout in autumn, and curlyleaf pondweed's growth will persist through the winter until spring where it initiates rapid growth (Woolf and Madsen 2003, Turnage et al. 2018). This unconventional "boom-and-bust" phenology can drastically alter the community structure of lakes where it becomes established.

Macrophyte communities change over time, and the seasonal phenology of plants is a driving factor for shifts in lake community structure (Wersal et al. 2006, Sayer et al. 2010). Since the macrophyte community is so influential on the system as a whole, describing the macrophyte community is very important for studying and managing lake systems. In Sibley County (Co.), Minnesota, to our knowledge, there have been no previous quantitative assessments of the aquatic macrophyte communities. However, Schilling Lake, in Sibley Co., has a well-established population of curlyleaf pondweed that dominates the lake in the spring (Schmid and Wersal 2020). The primary purpose of this study was to describe the macrophyte communities in five shallow lakes, as well as analyze the seasonal shifts in macrophyte communities if they occur. Since seasonal phenology is a primary driver of aquatic plant community structure, the Sibley Co. aquatic macrophyte community should exhibit significant seasonal shifts depending upon the plant species present. Additionally, the infestation of curlyleaf pondweed in Schilling Lake will should affect the macrophyte community dynamics over the growing season.

MATERIALS AND METHODS

Study site

The study took place in five natural, shallow lakes in Sibley Co., Minnesota. Sibley Co. is situated in the Prairie Pothole Region of the Midwestern United States. The dominant land use in Sibley Co. is cultivated land, which made up 79% of the county's total land in 2017 (Sibley County 2018). The five lakes studied were High Island Lake, Titlow Lake, Schilling Lake, Silver Lake, and Clear Lake (Table 1; Figure 1). These systems are eutrophic to hypereutrophic lakes that are warm, productive, and turbid throughout the growing season. These lakes are primarily used for recreation including boating, fishing, and duck hunting. The dominant aquatic macrophytes in these lakes are *Ceratophyllum demersum* L. (coontail), curlyleaf pondweed, sago pondweed, and *Typha* spp. (cattails) (Schmid and Wersal 2020).

Macrophyte surveys

The entirety of all five lakes (with the exception of High Island Lake) was surveyed during the early season (May and June) and late season (August and September) of 2019. High Island Lake was dewatered between the early-season and late-season surveys in order to repair a dam on High Island Creek. This drawdown prevented the execution of a late season survey on High Island Lake during 2019. The macrophyte surveys were conducted using the point-intercept method similar to other studies in southern Minnesota lakes (Case and Madsen 2004, Madsen et al. 2006, Madsen and Wersal 2017, Wersal et al. 2006). Survey points were arranged in a predetermined 150-m grid for High Island Lake ($n = 318$), Titlow Lake ($n = 163$), Schilling Lake ($n = 160$), Silver Lake ($n = 129$), and Clear Lake ($n = 90$); the same points were surveyed during both surveys. A ruggedized tablet computer,[1] with a global positioning system accuracy of 1 to 2 m, was used to navigate to each point. At each point, a plant rake was deployed, and when it reached the benthos, it was retrieved, after which plant species presence or absence was recorded. Additionally, the depth at each point was measured using a sounding rod. Spatial data were recorded electronically using software[2] that also allowed for navigation to specific survey points as well as displaying and collecting geographic and attribute data while in the field, thus reducing data entry errors and post processing time. Collected data were recorded in database templates using specific pick lists constructed for this project (Wersal et al. 2010, Cox et al. 2014, Madsen et al. 2015). The survey grid was relatively large at 150 m and the nature of the point-intercept method infrequently places sample points at or near the shore, which can render it less sensitive than other sampling methods for sampling the emergent macrophyte community. To address this limitation, all observed species were qualitatively recorded (even if they were not present at a sample point) and combined with the sampled species to produce a complete species richness list. The species that were recorded qualitatively included both littoral and shoreline plants that were observed, but missed by the survey. During each survey, Secchi depth was recorded in the center of the lake around noon on a clear day.

Statistical analyses

Plant species presence was averaged over all points sampled and multiplied by 100 to report the percentage frequency for each species. The shifts in the frequency of individual species from early to late season were analyzed using a McNemar's test.[3] The McNemar's test assesses the

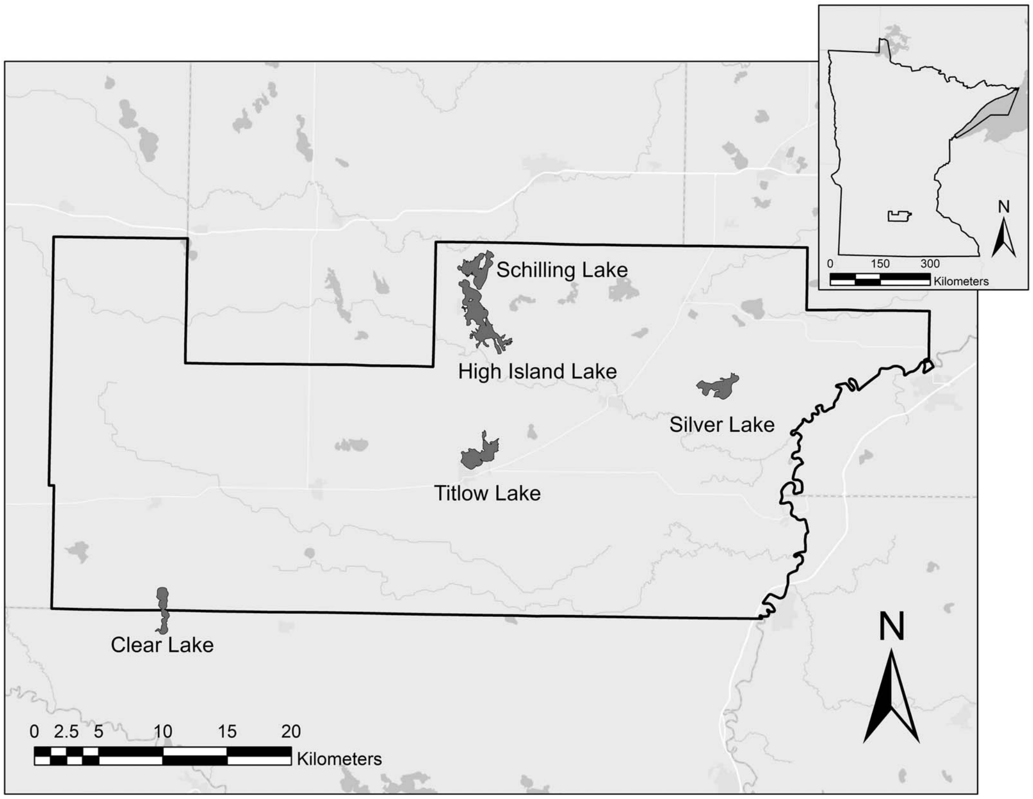

Figure 1. Five survey lakes in Sibley County, Minnesota. The black line indicates the extent of Sibley County. Surveys occurred during early and late portions of the 2019 growing season.

data's difference in correlated proportions for dichotomous dependent variables that are not independent (Case and Madsen 2004, Madsen et al. 2006, Wersal et al. 2006, Madsen et al. 2015). In addition to percentage frequency, the mean species richness was calculated as the average number of species per point from a specific survey. At each lake (except High Island) the mean species richness values in the early season and late season were compared using a Wilcoxon Signed Rank test,[4] which compares the changes in ranks of data from paired independent variables (Zar 1999). Only macrophytes that were recorded from the sample points in the surveys were used in the McNemar's test and Wilcoxon Signed Rank test. All statistical analyses were conducted at an $\alpha \leq 0.05$ significance level.

RESULTS AND DISCUSSION

Macrophyte data from the early- and late-season surveys showed a significant shift in the macrophyte communities of Titlow Lake, Schilling Lake, and Clear Lake during the 2019 growing season (Table 2). During the early-season survey, sago pondweed was dominant in High Island Lake with a sample frequency of 49% (Table 2). Titlow Lake had a mean species richness of 0.16 in the early season and 0.28 in the late season ($P = 0.005$) (Table 2). Sago pondweed was the dominant macrophyte for the entire growing season with sample frequencies of 14.8% and 25.3% ($P = 0.013$) during the early-season and late-season surveys respectively. Schilling Lake had the greatest mean species richness that changed from 0.69 in the early season to 1.11 in the late season ($P < 0.001$) (Table 2). Curlyleaf pondweed was the dominant macrophyte in Schilling Lake during the early-season survey with a sample frequency of 44.4% (Table 2). However, the presence of curlyleaf pondweed declined to 13.9% from early to late season ($P < 0.001$) (Table 2). Sago pondweed was found in only 6.3% of samples in the early season, but it exhibited an increase in frequency to 63.9% during the late-season survey ($P < 0.001$) and became the dominant macrophyte in Schilling Lake (Table 2). High Island Lake had the second highest mean species richness (0.62) during the early season and had no data for a late-season survey due to the drawdown in midsummer 2019 (Table 2). These data also showed that all five of these lakes were relatively species-poor compared to other lakes in southern Minnesota (Madsen et al. 2006).

Titlow Lake exhibited shifts in the macrophyte population in 2019 ($P = 0.005$) (Table 2). Sago pondweed was the dominant macrophyte in Titlow Lake and increased in frequency from early season to late season ($P = 0.013$) (Table 2; Figure 3). This magnitude of increase (44% increase between early and late season) may be more typical of a shallow lake in this region that is not infested with curlyleaf pondweed. Conversely, in Schilling Lake, the increase in sago pondweed was 89% between the early-season and late-season surveys. The large increase corresponds with the senescence of curlyleaf pondweed that infests Schilling Lake.

Table 2. Sample frequency (%) values of individual macrophytes and mean species richness of sample points during the early- and late-season surveys. Sample frequency values were compared using a McNemar's test and mean species richness values were compared using the Wilcoxon Signed Rank test.

Species	Common Name	High Island Lake Early Season	Titlow Lake Early Season	Titlow Lake Late Season	Schilling Lake Early Season	Schilling Lake Late Season	Silver Lake Early Season	Silver Lake Late Season	Clear Lake Early Season	Clear Lake Late Season
Carex spp. L.	True sedge				2.78	2.78	1.68			
Ceratophyllum demersum L.	Coontail	2.00				0.04				
Chara spp. L.	Muskgrass					0.69				
Lemna minor L.	Lesser duckweed	2.80	0.62	3.09	2.08	9.72*	2.52	5.04		1.11
Lemna trisulca L.	Star duckweed	0.80				0.69				
Najas flexilis (Willd.) Rosk. & Schmidt	Slender naiad					3.47				
Nympheae odorata Ait.	White waterlily						10.08	9.24		
Phragmites australis (Cav.) Trin. ex Steud.	Common reed		0.60		0.69			0.84		
Potamogeton crispus L.	Curly pondweed				44.44	13.89*				
Sagittaria latifolia Willd.	Broadleaf arrowhead						0.84	0.84		
Schoenoplectus tabernaemontani (C.C.Gmel.) Palla	Softstem bulrush	0.40								
Spirodela polyrhiza (L.) Schleid	Greater duckweed					2.78				
Stuckenia pectinata (L.) Böerner	Sago pondweed	49.00	14.81	25.31*	6.25	63.89*	8.40		7.78	
Typha spp. L.	Cattail	4.80	0.62	1.23	15.28	5.56*	6.72	4.20		
Wolffia columbiana H. Karst	Columbian watermeal	0.80				1.39				
Mean species richness		0.62	0.16	0.28*	0.69	1.11*	0.30	0.20	0.08	0.01*

*Late-season values were significantly different ($P < 0.05$) from early-season values.

Schilling Lake exhibited the greatest shift in the macrophyte community from early to late season (Table 2). This shift was primarily driven by the infestation of curlyleaf pondweed in Schilling Lake. Curlyleaf pondweed is a canopy-forming invasive macrophyte with an atypical seasonal life history. The abundant growth exhibited by curlyleaf pondweed in Schilling Lake during spring greatly outcompeted the native macrophytes for light, thereby

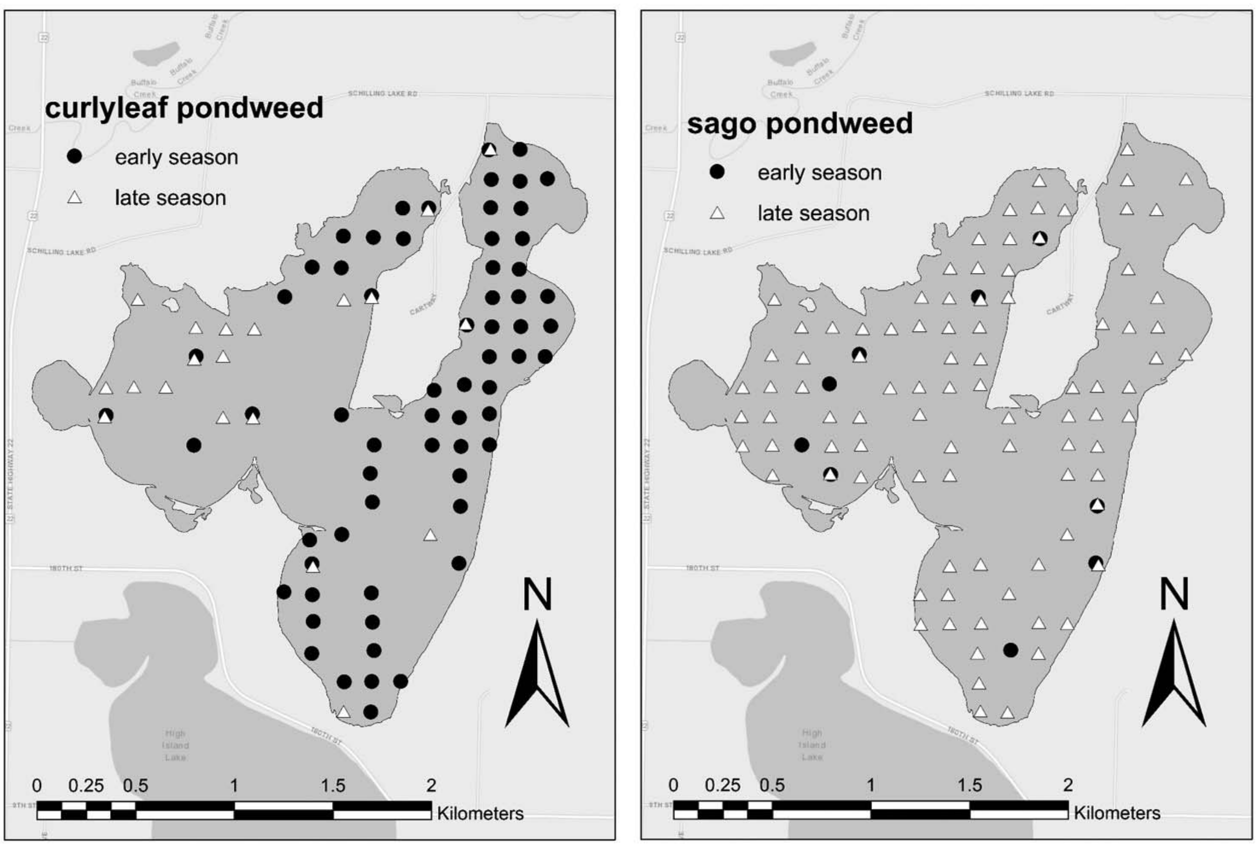

Figure 2. Distribution of curlyleaf pondweed (left) and sago pondweed (right) sampled in early- and late-season surveys in Schilling Lake, Sibley County, Minnesota, 2019.

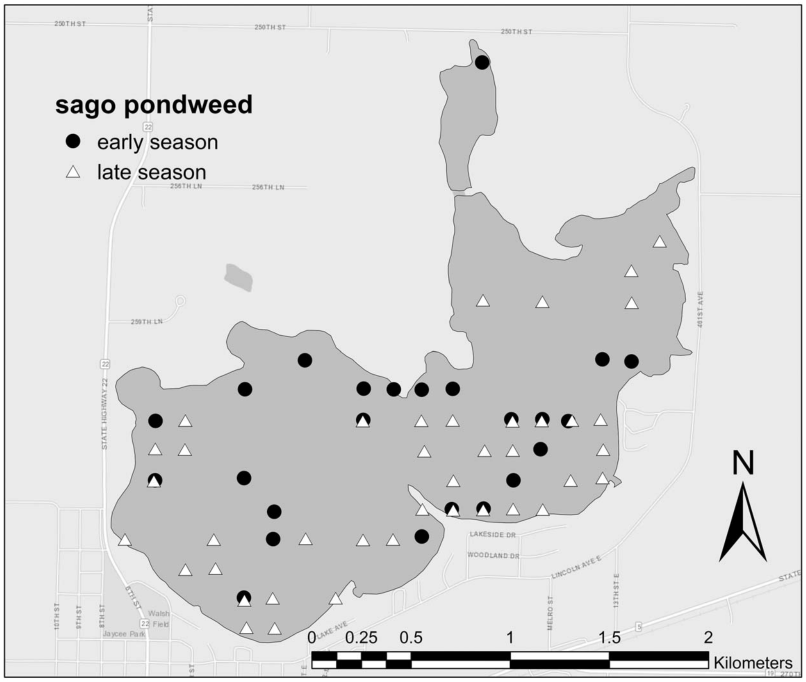

Figure 3. Distribution of sago pondweed sampled in early- and late-season surveys in Titlow Lake, Sibley County, Minnesota, 2019.

suppressing their growth, and displacing them for much of the early season (Madsen et al. 1991, Bolduan et al. 1994, Fleming and Dibble 2015) (Figure 2). The two species rarely coexisted at sample points surveyed (Figure 2). In the late season, after curlyleaf pondweed had senesced, the range of sago pondweed expanded ($P < 0.001$) (Table 2; Figure 2). The seasonal senescence of curlyleaf pondweed in the early summer likely resulted in a competitive release on the sago pondweed population that was then exploited by sago pondweed to become the dominant species in the lake. The mean species richness increased in the sample points largely due to increasing prevalence of sago pondweed, and coontail during the late-season survey (Table 2). Additionally, Schilling Lake also exhibited an increase in mean species richness as rare species that were not found during early season were sampled in the late season (e.g., slender naiad [*Najas flexilis* (Willd.) Rosk. & Schmidt] and muskgrass [*Chara* spp. L.]).

The increase in species richness in Schilling Lake over the growing season suggests that the dominance of invasive macrophytes can displace native species and decrease species richness (Boylen et al. 1999, Houlahan and Findlay 2004, Fleming and Dibble 2015). However, when the competitive pressure is released, native species are able to fill that niche, and species richness can increase. This is evident by the increase in sago pondweed frequency as well as the appearance of rare species in Schilling Lake. Invasive, canopy-forming plants are known to reduce the density and abundance of native macrophytes (Madsen et al. 1991, Boylen et al. 1999, Santos et al. 2011). The life history of curlyleaf pondweed in northern North America is characterized by rapid, dense shoot growth that is high in intensity, but relatively short in duration (Woolf and Madsen 2003, Turnage et al. 2018). The decline of curlyleaf pondweed in the mid to late summer in tandem with the appearance of rare macrophytes in Schilling Lake during the late season suggests that curlyleaf pondweed infestation alone may not be enough to locally extirpate certain submersed macrophytes.

Since shallow, eutrophic lakes are characterized by high productivity, they often experience intense algal blooms that outcompete submersed aquatic vegetation for light and reduce habitat complexity (Phillips et al. 1978, Bakker et al. 2010). However, increases in the density and abundance of macrophytes may compete with algae in shallow lakes that reduce light availability (Takamura et al. 2003, Bakker et al. 2010). This suggests that a population of curlyleaf pondweed in a shallow, warm, species-poor, hypereutrophic lake in the Midwest may be more beneficial than the alternative of a lake with prominent algal blooms, high turbidity, and a lack of submersed macrophytes. Further evidence is required to support these claims and future studies should involve long-term assessments of the effects of curlyleaf pondweed on native plant community structure in combination with environmental monitoring.

The poor species richness in Silver Lake and Clear Lake is likely the result high turbidity caused by a combination of suspended sediment and phytoplankton (Table 1). Algal blooms are a primary driver in macrophyte decline in eutrophic and hypereutrophic lakes, and the occurrences of algal blooms can be reduced in waterbodies with higher macrophyte biomass (Phillips et al. 1978, Bakker et al. 2010). This would also be consistent with the long-term model that suggests that the duration of plant dominance is reduced by the prevalence of algal blooms in the mid to late summer (Sayer et al. 2010). Additionally, suspended fine sediments are a substantial contributor to turbidity in many systems (James et al. 2004). Submersed aquatic vegetation can reduce the wave action that resuspends sediment; however, there was little submersed vegetation in Silver and Clear lakes (Madsen et al. 2001, James et al. 2004). The algal bloom likely also explains why sago pondweed was found during the early-season survey but was absent in the late season (Table 2). In Clear Lake, the species richness was so poor that in both the early and late season, species were found in fewer than 10% of sample points (Table 2). Clear Lake was the deepest lake surveyed and had poor water clarity. These factors combined to result in a very species-poor plant community. Clear Lake is the most extreme example of the Sibley Co. lakes: that of a shallow, turbid lake that is nearly devoid of submersed aquatic vegetation.

In 2019, Sibley Co. lakes with relatively high species richness did experience shifts in the aquatic macrophyte community. Schilling Lake experienced the greatest shifts facilitated by the infestation of curlyleaf pondweed. Surveys of these lakes should be conducted annually to monitor the macrophyte communities and detect any new infestations of curlyleaf pondweed or other nonnative aquatic plant. The methodology should also be adopted and utilized in nearby counties to document macrophyte communities and the spread of aquatic invasive species in general.

SOURCES OF MATERIALS

[1]Yuma 2, Trimble Navigation Limited, 935 Stewart Drive, Sunnyvale, CA 94085.

[2]Site Mate, Farm Works Information Management, P.O. Box 250, Hamilton, IN 46742.

[3]SAS software, SAS Institute, 100 SAS Campus Drive, Cary, NC 27513.

[4]SPSS Statistics, IBM Co., 1 New Orchard Road, Armonk, NY 10504.

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