Factors affecting the abundance and control of curlyleaf pondweed in managed and unmanaged systems: analysis of results from 60 lakes

Final Report to the Minnesota Aquatic Invasive Species Research Center
ENRTF Phase I Project: Developing and evaluating new techniques to selectively control invasive plants: Activity I factors influencing selective herbicide control of curlyleaf pondweed

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Abstract:

Curlyleaf pondweed (*Potamogeton crispus*) is one of the most widespread and problematic invasive aquatic plants in Minnesota. It sprouts from turions (winter buds) in the fall and winter and grows rapidly to the surface in the spring before senescing in early summer. Selective control can be attained with early-season herbicide treatments.

To provide an analysis of factors affecting curlyleaf abundance in untreated and herbicide-treated lakes, we collated pre-existing data from a variety of agencies and researchers; we analyzed data on curlyleaf pondweed frequency of occurrence and relative density from 60 lakes across Minnesota. The lakes had surveys conducted in May (pretreatment timing) or June (peak curlyleaf coverage) between 2006-2015; several lakes had data for all ten years. Forty-nine lakes had data for years not treated with herbicide, with one to eight years of data from each (mean of three years). Twenty-two lakes had data associated with curlyleaf pondweed herbicide treatments (one to nine years of treatment; mean of 3.8 years).

For the untreated lakes, productivity (as indicated by prior summer Secchi depth) and over-winter conditions (snow cover or ice duration) were important predictors of curlyleaf with greater curlyleaf abundance in lakes with higher productivity and milder overwinter conditions (shorter duration of ice cover and lesser snow depth). For herbicide treated lakes, consecutive years of treatment was also important; early season abundance decreased with more years of prior treatment. There were diminishing returns from repeated treatment and curlyleaf abundance can rebound quickly once treatment stops. June density and frequency appeared less affected by overwinter conditions and more by spring growing conditions and the effect of treatment that year. Mild winters will likely result in more abundant populations that spring, and managers should plan for more extensive treatments following mild winters. Repeated treatments will decrease curlyleaf frequency and abundance, but must be sustained.

Background:

Curlyleaf pondweed (*Potamogeton crispus)* is a major nuisance in Minnesota and North America and has been widespread since the early 1900s (Bolduan et al. 1994, ISP 2013). It occurs in over 750 waterbodies in Minnesota (ISP 2013). Its life history makes the plant particularly problematic (Woolf 2009). In many lakes it sprouts from turions in late summer or fall, grows until temperatures decline below 5 ˚C, and overwinters under the ice (Bolduan et al.

1994). When water temperatures warm above 10 ˚C in the spring the plant starts growing rapidly and can outcompete native plants. Surface mats are often produced along with the vegetative turions at temperatures around 25 ˚C and the plant will then senesce and decay. Poor water clarity after senescence often further inhibits native plant communities. The dormant turions persist in the sediment through summer to sprout in the fall when temperatures decline and clarity improves (Bolduan et al. 1994). Curlyleaf pondweed can be controlled with physical and mechanical methods, but regrowth is an issue (McComas and Stuckert 2000, Woolf 2009) and no selective biological controls are available (Woolf 2009).

Methods to selectively control curlyleaf pondweed with low-dose, early-season, lake-wide treatments with endothall were developed by the Army Corps (Poovey et al. 2002, Skogerboe et al. 2008). These treatments are usually conducted in late May or early June prior to peak curlyleaf growth when water temperatures are between 10 and 15 ˚C to minimize effects on native plants. Recent assessments indicate that these treatments can reduce curlyleaf abundance and turion production in the year of treatment (Johnson et al. 2012) with relatively little harm to native plants (Jones et al. 2012). However, substantial stocks of viable turions remain even after three or more years of treatment and it is not clear how quickly curlyleaf will return to nuisance levels after treatment stops (Johnson et al. 2012). After 3 years of whole lake treatment (entire littoral) with endothall McCommas et al. (2015) were able to reduce effort to spot treatments (4 to 32% of littoral), but treatment was required each of the subsequent 4 years. There are both financial and environmental concerns if treatment must continue every year to maintain control.

In addition to assessing the effects of herbicidal treatments on curlyleaf, a better understanding of the factors that affect curly occurrence and abundance in lakes would be useful to further guide management. Valley and Heiskary (2012; see also Heiskary and Valley 2012) presented evidence that winter conditions (cumulative snow depth) could affect curlyleaf frequency of occurrence with reduced frequency following winters with heavy snow cover. Winter conditions could therefore influence the need for or extent of management in the following spring.

These previous studies focused on a limited set of lakes and the aim of this project was to obtain results from a broader set of lakes across Minnesota to see if the results hold over a broader range of locations and longer time period and to determine if there are other factors that affect curlyleaf abundance or effectiveness of control. An analysis of existing data collected by the DNR, watershed and park districts and consultants may be able to address these issues in lieu of a complete new multi-year study. Plant surveys from these lakes, which are distributed across the state and express a range of water quality, will also be useful to help factor out climatic and annual variability in plant abundance.

Methods:

We contacted over 15 consultants, agency personnel and researchers identified by us and the DNR who were known to have conducted plant surveys that would include curlyleaf pondweed. We requested data sets that included point-intercept survey data with at least one survey in spring or early summer to capture peak curlyleaf growth. We combined these surveys with data we obtained on a previously published project (11 lakes, Johnson et al. 2012, Jones et al. 2012), ongoing data from 5 lakes in the Purgatory Bluff Creek Watershed District and 13 lakes from the Minnesota DNR Sentinel Lakes program (D.L. Dustin). In total, we obtained data for 67 lakes; data from 60 of these lakes (Fig. 1) were suitable for our analysis with point intercept surveys conducted in May (pretreatment timing) or June (peak curlyleaf coverage). These sixty lakes cover the period of 2006-2015; several lakes had data for all ten years. Data for years not treated were available from forty-nine lakes with one to eight years of data for each (mean of three years). Twenty-two lakes had data associated with curlyleaf pondweed herbicide treatments (one to nine years of treatment; mean of 3.8 years).

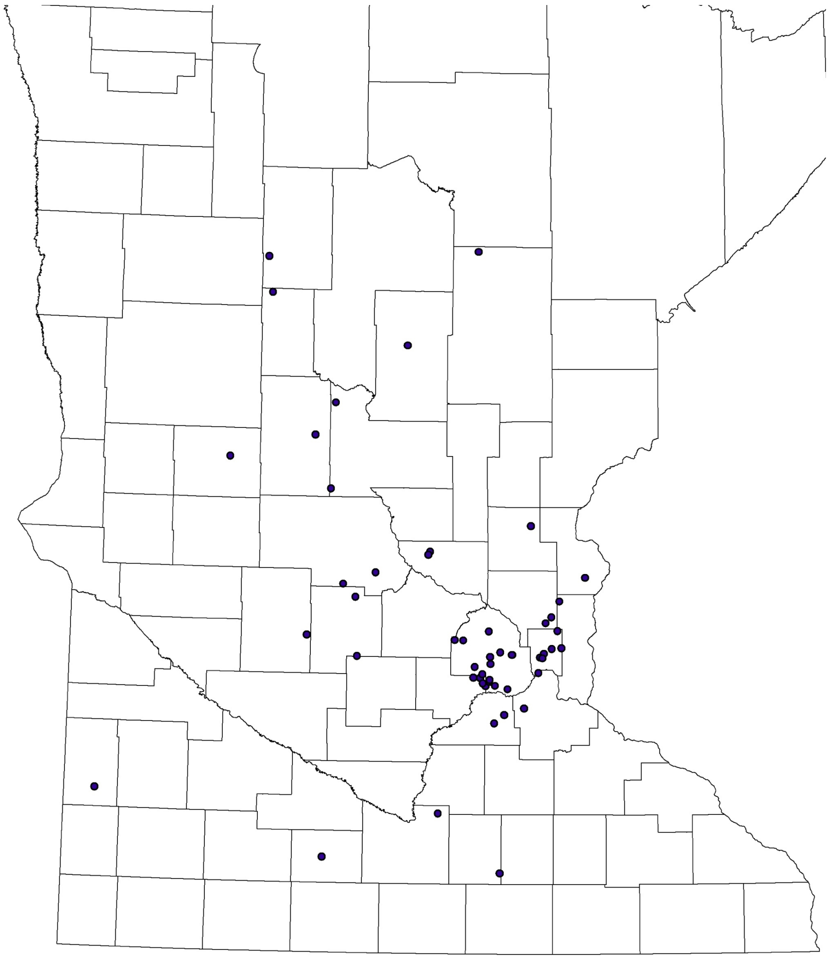

Fig. 1. Distribution of curlyleaf pondweed lakes used in the analysis.

For this analysis we focused on curlyleaf pondweed response and thus on the early season May and June curlyleaf data. We collated and organized the native plant data from mid-summer surveys for future analysis but did not analyze those results, which will require more sophisticated analyses. For the curlyleaf data sets, we used frequency of occurrence and relative density (relative rake rating) as the response. All data sets had frequency of occurrence responses and to standardize the maximum depth considered, we restricted the analysis to depths ≤ 3.7m (i.e. frequency of occurrence in depths ≤ 3.7m). We also computed and analyzed for mean relative rake density for the 30 lakes that had relative density ratings (1 to 4, with 1 being low density – one or few stems and 4 being high density, filling the rake). We computed the mean rating for only sites with curlyleaf (e.g., no ratings of zero). This provides an estimate of relative abundance or density when the plant is present. Each lake was classified each year as treated (permitted and generally delineated) or not treated (may include local homeowner shoreline treatments, but not large scale or offshore treatments) and contiguous years of treatment was used as an indication of duration of treatment.

We obtained water quality data from the Minnesota Pollution Control Agency (https://cf.pca.state.mn.us//water/watershedweb/wdip/) and snow depth and duration of ice cover data from the Minnesota DNR and State Climatology Office (http://www.dnr.state.mn.us/climate/historical/index.html). We used the previous year August Secchi depth as an index of lake productivity (data for TSI and P concentration were sparser) and decimal latitude as an index of growing conditions. We then used mixed effects linear models (e.g. Valley and Heiskary 2012) with lakes as random effects, and treatment, year, years of treatment and other climatic and environmental factors as fixed effects to assess factors that affect curlyleaf frequency of occurrence or relative density separately in treated and untreated lakes and separately for pretreatment surveys (May) and June (post treatment or time of peak curlyleaf in untreated lakes) surveys. Models were selected based on the lowest AIC and also significance of variables within the model.

Results and discussion:

Treated lakes had lower frequencies of occurrence and relative density than untreated lakes in both May and June (Fig. 2, Table 1). Although May frequency was not significantly lower in treated lakes, relative density was, suggesting that the prior years of treatment reduced density in the following May. As expected, June frequency was significantly reduced by treatment and there was not a significant change in frequency in untreated lakes. Relative density in treated lakes was significantly lower than untreated lakes in both May and June (Table 1).

Table 1. Mean (and 2 SE) early season (May; pretreatment) and June frequency of occurrence (Freq) and relative density (Rel Dens; 1-4) at sites where plants were found.

Lake	May Freq	Jun Freq	May Rel Dens	Jun Rel Dens
Treated	0.37	0.13	1.31	1.20
2 SE	0.05	0.03	0.10	0.14
Untreated	0.41	0.36	1.96	2.07
2 SE	0.08	0.05	0.32	0.18

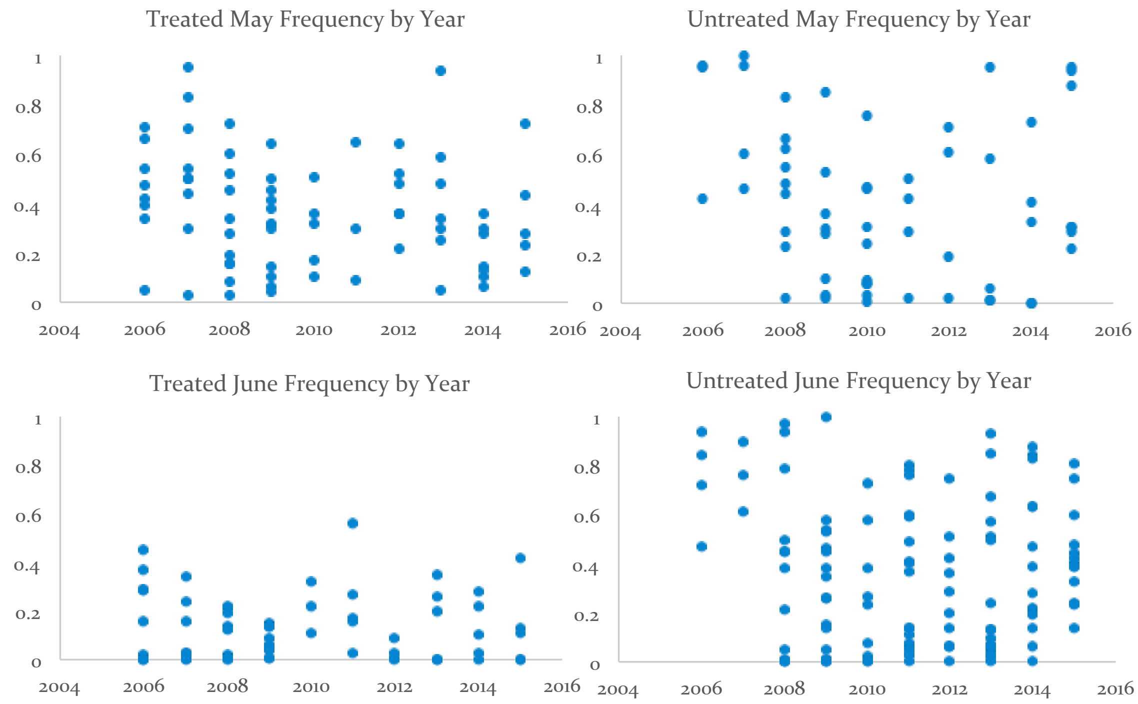

Fig. 2. May and June curlyleaf frequency of occurrence by year in treated and untreated lakes.

The mixed effects models revealed that for lakes treated with herbicides to control curlyleaf, the number of years treated was a significant predictor of early-season, pre-treatment curlyleaf frequency and relative density (Table 2), suggesting that repeated treatment with herbicides restricts curlyleaf distribution and abundance in the spring. Early season frequency in treated lakes was also influenced by the previous summer August Secchi depth (an overall indication of clarity and productivity) and winter conditions (ice duration or snow depth), but relative density (where plants occurred) appeared less affected by winter conditions. In untreated lakes, spring early season curlyleaf frequency and relative density were best predicted by a combination of environmental factors including mean snow depth, duration of ice cover, and previous summer Secchi depth (Table 2). The negative relationships with Secchi indicate curlyleaf is more frequent and dense in more eutrophic lakes, and negative relationships with snow and ice cover indicate the overwinter effects of reduced light on curlyleaf frequency and relative abundance.

These results suggest that more severe winter conditions and repeated herbicide treatment create conditions less favorable for curlyleaf pondweed distribution and growth the following spring. For June peak curlyleaf relative density, years treated was less important (only the current year of treatment has an effect) and although winter environmental conditions appeared in some models they were generally not significant and not always negative. This suggests that aside from the immediate treatment effects, peak curlyleaf density is more influenced by spring growing conditions than prior year management or winter conditions.

Table 2. Results of best fit mixed effects models (lowest AIC with significant effects) for Early Season (May or April) curlyleaf frequency of occurrence (depth ≤3.7m) and relative density (1-4 for sites with plants) and June relative density.

Early Season Frequency best models

Treated lakes

Fixed effects	Estimate	SE	z	*p*
Intercept	6.703	2.998	2.236	0.025*
No. years treated	-0.546	0.239	-2.284	0.022*
Days ice cover	-0.042	0.021	-2.026	0.043*
Previous year Aug. Secchi	-1.019	0.610	-1.670	0.095

Untreated lakes

Fixed effects	Estimate	SE	z	*p*
Intercept	2.234	1.132	1.974	0.048*
Mean depth snow	-0.110	0.055	-2.004	0.045*
Previous year Aug. Secchi	-1.718	0.843	-2.309	0.042*

Early Season Relative Density best models

Treated lakes

Fixed effects	Estimate	SE	z	*p*
Intercept	0.432	0.131	3.303	0.001*
No. years treated	-0.060	0.018	-3.367	0.001*
Previous year Aug. Secchi	-0.012	0.072	-0.164	0.870

Untreated lakes

Fixed effects	Estimate	SE	z	*p*
Intercept	2.076	0.708	2.931	0.003*
Days ice cover	-0.011	0.005	-2.124	0.034*
Previous year Aug. Secchi	-0.044	0.139	-0.315	0.753

June Peak Relative Density best models

Treated lakes

Fixed effects	Estimate	SE	z	*p*
Intercept	0.225	0.181	1.248	0.212
Previous year Aug. Secchi	-0.087	0.149	-0.587	0.557

Untreated lakes

Fixed effects	Estimate	SE	z	*p*
Intercept	0.764	0.103	7.401	<0.001*
Previous year Aug. Secchi	-0.063	0.057	-1.092	0.275

Previous work (Johnson et al. 2012) had also suggested that repeated treatments could decrease curlyleaf frequency and biomass the following spring, and this larger data set suggests the reductions are consistent but not large (Table 3), with frequency declining from 48% occurrence to 35% after three years and 31% after 5 years of treatment. The post treatment reduction (from May to June) was much larger and after two or more years of treatment June frequency was around 10%. Thus repeating treatment may result in somewhat better control and lower post treatment occurrence, but effects on frequency in the following spring diminish.

Table 3. Curlyleaf pondweed frequency of occurrence in May (before treatment) and June (after treatment) in treated lake by years of consecutive treatment (±2SE).

YrsTrt	May	June
1	0.48 ±0.10	0.21 ±0.07
2	0.42 ±0.11	0.12 ±0.07
3	0.35 ±0.13	0.10 ±0.05
4	0.32 ±0.13	0.05 ±0.04
5	0.31 ±0.13	0.14 ±0.08

An unresolved question is how rapidly curlyleaf will return if treatments are stopped. Unfortunately, monitoring is often stopped when treatments are stopped. In the present data set there are 7 instances from 6 lakes where treatment was stopped and frequency was monitored in the untreated year. It does not appear that there is any noticeable effect on May frequency. However, there was always an increase June in the untreated years compared to treated years (mean of 0.23) and in several lakes the increase was substantial (from 0.09 to 0.73 and 0.22 to 0.56). Thus even stopping treatment for 1 year can result in substantial rebounds that would call for treatment again in the following year.

Our results provide additional support for Valley and Heiskary's (2012) finding that winter conditions, particularly winter snow depth, can affect curlyleaf, with decreasing curlyleaf frequency in years with deeper snow cover. Our results indicated that both snow cover and ice duration are associated with decreases in curlyleaf frequency and abundance in May. Managers can thus expect the need for more treatment over larger areas following shorter or milder winters with less snow cover. Our results also show that May pretreatment curlyleaf frequency and relative density decrease with repeated years of treatment, but the decreases are not large and substantial populations remain even after 5 years of treatment. In many instances the curlyleaf will quickly rebound if treatments cease.

Acknowledgements:

We thank Chip Welling of the Minnesota DNR who suggested this project and provided significant input and assistance with obtaining data sets. Data for 12 lakes were collected by graduate students James Johnson and Ajay Jones as part of a curlyleaf whole lake treatment study funded by the Minnesota DNR (Wendy Crowell was key to that project). Data for 5 lakes was collected by graduate students Josh Knopik, John JaKa and Melaney Dunne with funding from the Riley Purgatory Bluff Creek Watershed District. Additional data sets were provided by the Minnesota DNR SLICE program (Donna Dustin), Minnesota DNR Invasive Species Program (Allison Gamble and Keegan Lund), Capitol Region Watershed District (Britta Suppes), Ramsey Washington Watershed District (Simba Blood), Three Rivers Park District (Rich Brasch), Minnehaha Creek Watershed District (Eric Fieldseth), Rice Creek Watershed District (Matt Kocian), and consulting firms Barr Engineering (Meg Rattei), Bluewater Science (Steve McComas) and Freshwater Scientific Services (James Johnson). Their cooperation was key to this project and greatly appreciated. Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

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