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Assessment of Curlyleaf Pondweed Turion Distribution & Abundance in the Red Cedar Chain of Lakes

Red Cedar Lake – *Barron County, WI (#2109600)*
Hemlock Lake – *Barron County, WI (#2109800)*
Balsam Lake – *Washburn County, WI (#2112800)*

Surveyed October 25, 2021

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Prepared for the Red Cedar Lakes Association (Mikana, WI) – November 2021

Introduction

Curlyleaf Pondweed: An Unwanted Invader

Curlyleaf pondweed (*Potamogeton crispus*) is an invasive aquatic plant that typically forms dense surface growth (Figure 1) and displaces native aquatic plants (Madsen and Crowell 2002). Consequently, it has dramatically reduced the recreational and ecological quality of many lakes in the upper Midwest (Catling and Dobson 1985, Bolduan et al. 1994). Curlyleaf's ability to dominate the plant community in lakes is enhanced by its novel life-cycle (Figure 2, Tobiessen and Snow 1984). Although it is considered a perennial species, it behaves as a winter annual in northern lakes (Netherland et al. 2000, Madsen and Crowell 2002), sprouting from turions (reproductive buds) in the fall, persisting as small shoots under the ice during the winter, growing rapidly in the early spring (Kunii 1982, Tobiessen and Snow 1984), and forming dense surface growth and new turions in May and June (Wehrmeister and Stuckey 1992, Bolduan et al. 1994). Curlyleaf plants typically die off by mid-summer and deposit any newly-produced turions to the lake sediments. Although this means that the dense matted curlyleaf growth is generally short lived and disappears in the early summer, the turions that were deposited to the lake sediments lead to new curlyleaf growth in the subsequent years. Although curlyleaf also produces seeds, under most conditions its annual life-cycle is thought to be almost entirely dependent upon sprouting from turions in lake sediments (Rogers and Breen 1980, Sastroutomo 1981, Bolduan et al. 1994). Consequently, there has been great interest in adopting management strategies that can prevent turion production, deplete accumulated turions, and thus decrease nuisance growth.

Figure 1. Close-up showing wavy leaves typical of mature curlyleaf pondweed (left), and an image of dense, surface-matted curlyleaf growth in a heavily-infested lake (right).

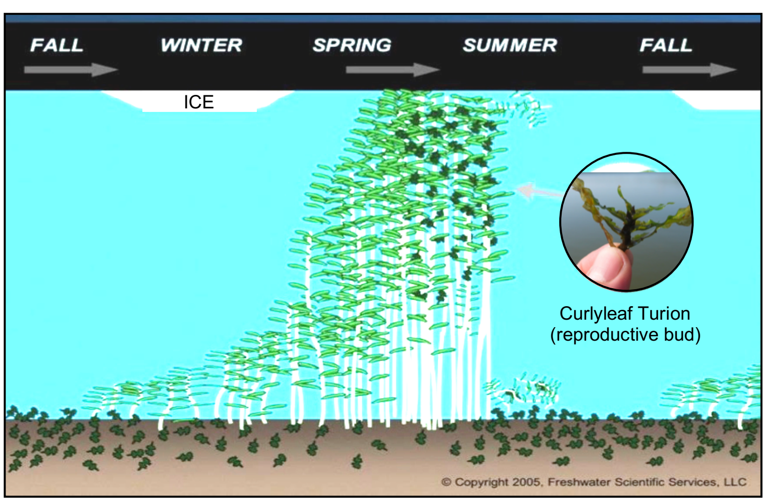


Figure 2. Diagram showing annual curlyleaf life-cycle in northern lakes.

Purpose of Turion Survey

This survey was designed to assess the abundance of curlyleaf pondweed turions in the sediments of the Red Cedar Lakes (Balsam, Hemlock, and Red Cedar Lake) after nearly ten years of management. The information gained from this assessment allows us to (1) evaluate whether past management has substantially reduced the abundance or distribution of curlyleaf turions in the lake, and (2) compare the current curlyleaf infestation to other infested lakes.

Objectives

1) Map turion abundance throughout the three lakes
2) Estimate the lake-wide mean turion abundance for each lake
3) Estimate mean turion abundance within previously delineated beds of curlyleaf
4) Evaluate changes in turion abundance relative to results from the 2012 survey
5) Evaluate the turion abundance in the Red Cedar Lakes relative to other infested lakes

Value of Monitoring Turions

Although curlyleaf can sprout from seeds and persistent roots or rhizomes under some conditions, previous studies suggest that turions are by far the most important source of new curlyleaf pondweed growth in northern lakes (Bolduan et al. 1994, Rogers and Breen 1980). Most evaluations of curlyleaf pondweed infestations in lakes focus on the distribution (% occurrence) and density (biomass or rake ratings) of curlyleaf plants in a lake. Although these metrics provide a very good assessment of nuisance level at the time of the survey, they can be affected greatly by annual differences in weather, in-lake conditions, and the timing of the survey, even if turion abundance and distribution remain relatively constant between years (Johnson 2012, Valley and Heiskary 2012, Tobiessen and Snow 1984). Consequently, these plant-growth assessment are likely more sensitive than turion assessments to both weather differences and the timing of surveys. Although turion sprouting may also be affected by weather to some degree (stronger sprouting cues in some years), fall turion abundance is a very good indicator of the overall potential for nuisance curlyleaf growth in the following year (Figures 9 and 10). For this reason, I believe that fall turion monitoring is a superior method for (1) evaluating a lake's overall degree of curlyleaf infestation relative to other lakes, (2) tracking natural changes in the severity of curlyleaf infestation over time (spreading or increasing in density), and (3) assessing whether control activities are reducing the potential for nuisance curlyleaf pondweed growth in infested lakes.

Description of Lakes

The Red Cedar Lakes straddle the border between Barron and Washburn Counties in northwestern Wisconsin (Figures 3 and 4, Table 1). These lakes are highly valued in the region for fishing and boating.

Hemlock Lake is a fertile waterbody (eutrophic) that typically experiences low to moderate summer water clarity (average Secchi ~5 ft, Table 1). By contrast, Balsam and Red Cedar Lake are less fertile (mesotrophic) and typically experience greater summer water clarity (average Secchi ~8 to 11 ft, Table 1). Detailed overviews of the lakes' watershed characteristics, nutrient loading, and water quality are provided in a 2003 USGS report (Robertson et al. 2003).

All three of the surveyed lakes are known to be infested with curlyleaf pondweed (Johnson 2011). The Red Cedar Lakes Association (RCLA) has been actively managing curlyleaf in the lakes for the past 10 years to minimize the negative effects of the infestation on lake use and overall lake ecology.

Figure 3. Map of Balsam, Hemlock, and Red Cedar Lakes.

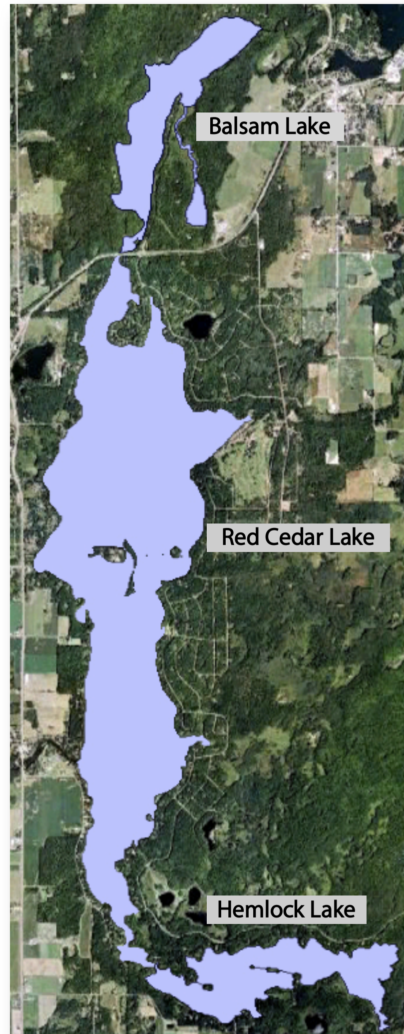


Figure 4. Location of the Red Cedar Lakes in Wisconsin

Table 1. Lake identifiers and characteristics (WDNR 2012). Lake areas and depths as reported on lake bathymetric maps.

	Balsam	**Hemlock**	**Red Cedar**
County	Washburn	Barron	Barron
ID# (WBIC)	21-128-00	21-098-00	21-096-00
Surface Area *(acres)*	295	360	1840
Maximum Depth *(ft)*	49	21	53
Mean Depth *(ft)*	25	8	27
Summer Water Clarity *(ft)*	11	5	8
Trophic State (fertility)	mesotrophic	eutrophic	mesotrophic

Curlyleaf Pondweed Bed Delineation in 2021

Freshwater Scientific Services conducted a lake-wide search for curlyleaf pondweed on June 3, 2021, with a focus on those areas that had supported curlyleaf growth in the past. During this survey, we navigated a winding search path over nearshore areas while using a combination of surface observations, rake tosses, and sonar readings to locate any areas of curlyleaf. For locations where we found curlyleaf, we recorded the GPS location, water depth, and curlyleaf growth density (0 to 3 scale based upon stem density). These recorded locations and site data were entered into desktop GIS software for detailed mapping of curlyleaf beds (Figure 5).

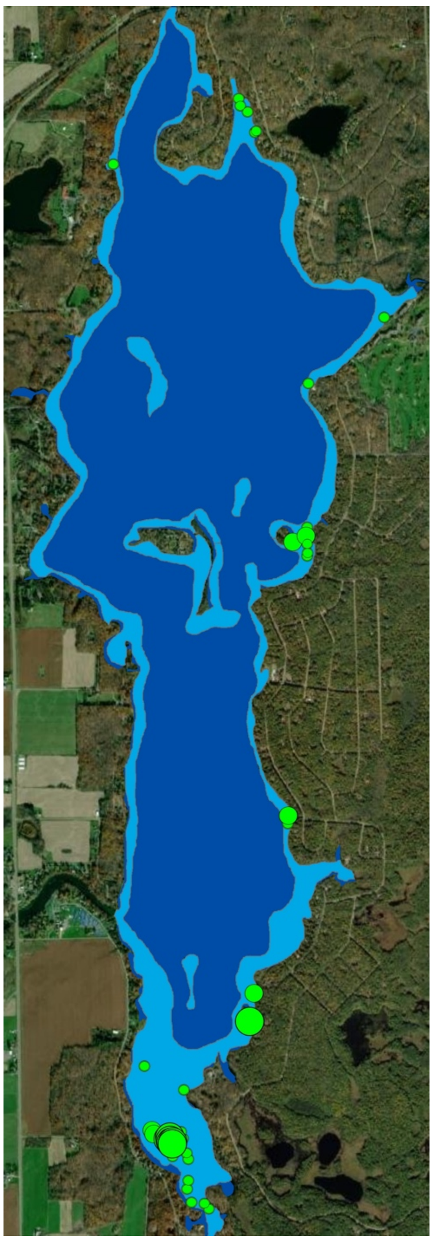
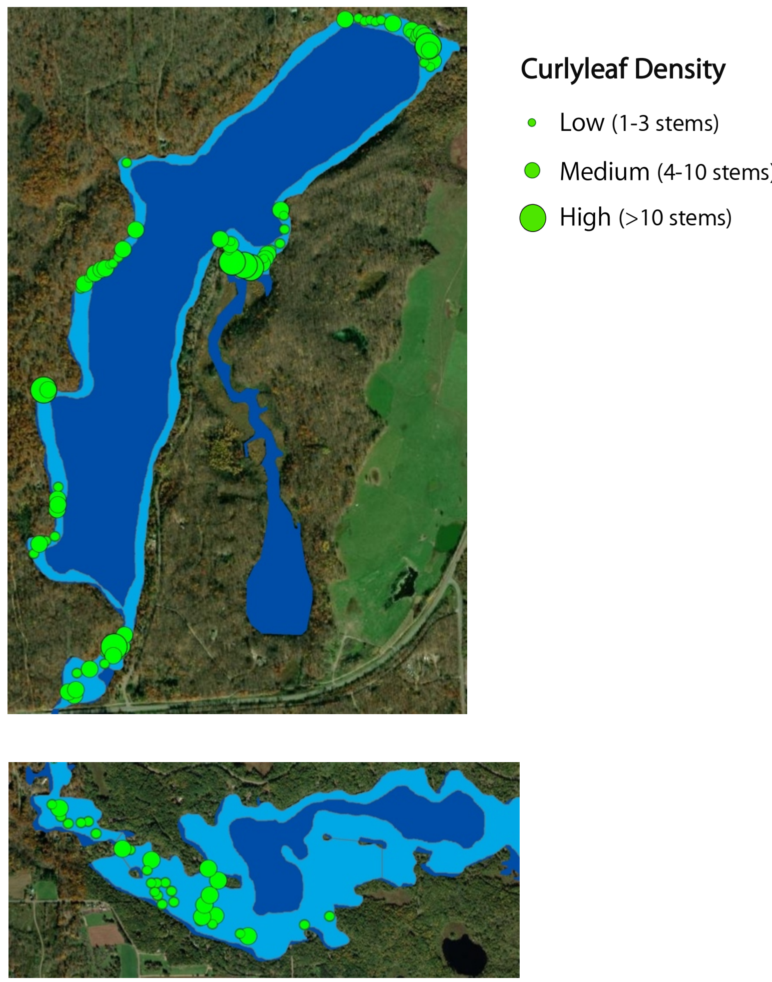


Figure 5. Maps showing the littoral area of each lake (light blue; ≤15 ft), and the locations where we found curlyleaf pondweed during the June 2021 surveys of Balsam, Hemlock, and Red Cedar Lakes. Density based upon number of stems retrieved on rake.



Sampling & Analysis Methods

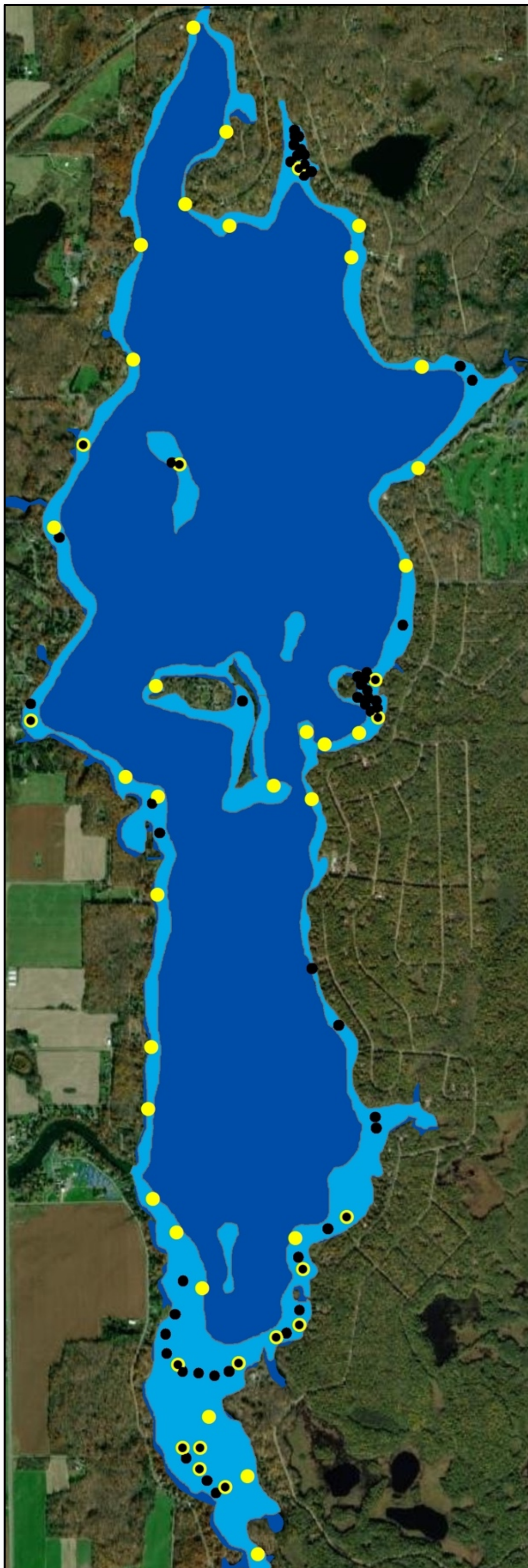
Turion Sample Collection & Processing

Freshwater Scientific Services used GIS software to generated 170 sampling points for the 2021 Red Cedar Lakes turion survey. Within this set, 119 points were purposely placed within the boundaries of previously identified curlyleaf beds, and 85 points were randomly placed throughout the near-shore (littoral) area of the three lakes (≤15 ft deep); 34 of the random littoral points also fell within curlyleaf plots. The set of random points were generated to provide a statistical estimate of the lake-wide mean turion abundance in the lakes, whereas the manually placed (non-random) points were added to provide additional detail within curlyleaf beds. Sample locations were loaded onto a handheld GPS unit (Garmin GPSMAP-78) to enable navigation to each point while in the field.

Staff from Freshwater Scientific Services collected sediment samples at all 170 sample locations (Figure 7) on October 25, 2021. At each location, we collected one sediment sample using a petite Ponar dredge (225 cm^2 basal area). Upon retrieving each sediment sample, we removed any material from the outside of the closed dredge, emptied the sampler contents into a sifting bucket (1-mm screen), and gently sifted the sample to remove fine sediment (Figure 6). The contents remaining in the bucket after sifting were placed into a labeled plastic bag and stored in a cooler while in the field. In the lab, we manually sorted turions from other debris and recorded total turion counts for each sample. Small turion fragments (those that did not included a portion of a central turion stem) and severely decayed turions (those that did not retain their shape when lightly squeezed) were discarded and were not included in the final turion counts.

We calculated turion abundance (turions/m^2) for each sampled location (number of turions ÷ 0.0225 m^2). We then calculated lake-wide turion abundance statistics using results from the random sample points, and within-bed statistics using results from samples collected within the delineated curlyleaf bed boundaries (all bed points + some random points). We then used GIS software to map turion abundance in the lakes (Figures 8 and 9).

Figure 6. Ponar sediment sampler (Wildlife Supply Company; Yulee, FL), sifting bucket, and a collected sediment sample for turion assessment (left); close-up of sprouting turions collected from lake sediments (below).



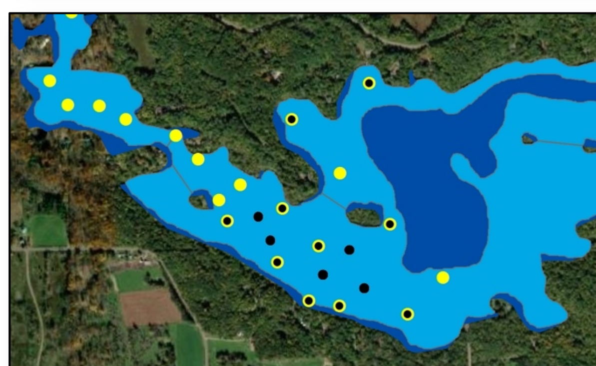


Figure 7. Maps showing the littoral area of each lake (light blue; ≤15 ft), and the locations of the 85 random littoral sample points (○) and 119 non-random sample points in curlyleaf beds (•) used for the 2021 turion surveys of Balsam, Hemlock, and Red Cedar Lakes. Note that some of the random points were also withing bed boundaries.

Results & Discussion

2021 Turion Distribution & Abundance

Lake-Wide (random littoral sites)

In 2021, we found that the percentage of sampled sites that had turions (% occurrence) was low in all three lakes; Balsam 11%; Red Cedar 4%; and Hemlock Lake 11%. Similarly, the mean turion abundance (turions/m^2) was also low in Balsam (26±21, mean±SE), Red Cedar (5±3), and Hemlock Lake (20±14); (see pages 9-11). These % occurrence and turion abundance values are much lower than typically seen in heavily infested lakes where it is common to find turions at >30% of sampled sites with mean turion abundance >500 turions/m^2; Johnson 2012). Based upon our sediment samples, much of the nearshore areas in the Red Cedar Chain have sandy and rocky sediments. This type of sediment does not generally support dense curlyleaf growth. Furthermore, most of the curlyleaf beds that we found in 2021 were in isolated bays with softer sediments, and consisted of scattered small patches or very narrow bands that hugged the shoreline. Although there were a few small areas where curlyleaf may reach nuisance density, overall, the curlyleaf infestation in the Red Cedar Chain is substantially lighter than typically seen in other infested lakes (Figs 9-10).

Within Curlyleaf Beds

The mean turion abundance in previously identified curlyleaf beds (12±7 to 57±25 turions/m^2) was roughly 2 times greater than the lake-wide means (Tables 2 and 3). A few isolated locations in each lake had moderate to high turion abundance (generally small bays with soft sediments, Figures 9 and 10) indicating that these locations had a greater potential to support dense curlyleaf growth that could impair local navigation and recreation. However, outside of these isolated areas, turion abundance was very low when compared to other infested lakes.

Changes in Turion Distribution & Abundance: 2012–2021

Presence/Absence of Turions (% Occurrence)

Overall, we found that the lake-wide % occurrence of turions did not change significantly in any of the three lakes between 2012 and 2021 (chi-square test; all p-values >0.22). Although the past management actions did not get rid of curlyleaf, there were no indications that the curlyleaf infestation had expanded substantially within the lakes over the past decade.

Looking only at the points that were within previously identified curlyleaf beds, we did not find significant changes in the % occurrence of turions in Balsam Lake (35% to 29%, p=0.63) or Hemlock Lake (30% to 13%, p=0.23), but did find a significant reduction in Red Cedar Lake (46% to 15%, p<0.001). These findings suggest that the treatments between 2012 and 2021 reduced the occurrence of turions in some locations, but some turions remained in most of the areas that supported curlyleaf in the past. It is important to note that % occurrence is not a very sensitive indicator of change, as even a single remaining turion would equate to presence at a given site.

Turion Abundance (Turions/m^2)

Overall, we found that the lake-wide mean turion abundance did not change significantly in any of the three lakes between 2012 and 2021 (student's t-test; all $p \geq 0.08$). When we focused only on those points that were within identified curlyleaf beds, we found that mean turion abundance decreased significantly in Red Cedar Lake beds (58 to 13 turions/m^2, p<0.001), but did not change significantly in Balsam Lake (92 to 57, p=0.20) or Hemlock Lake (33 to 12, p=0.11). These findings suggest that the treatments between 2012 and 2021 reduced the abundance of turions in some locations, with greater reductions in Red Cedar Lake. However, a few areas still harbored high turion abundance. In particular, the northern end of Balsam Lake and the channel between Balsam and Red Cedar Lake. These areas have been difficult to treat effectively due to flowing water.

Table 2. 2012 statistics for curlyleaf pondweed turion frequency (% occurrence) and abundance (turions/m²) in Balsam, Hemlock, and Red Cedar Lakes (lake-wide and within-bed)

2012 Turion Statistics

	Balsam	Hemlock	Red Cedar	ALL
Total Sites Sampled	**37**	**39**	**78**	**154**
Random Points	19	26	46	91
CLP Bed Points	26	27	48	101

Lake-Wide Statistics *(random littoral points)*

	Balsam	Hemlock	Red Cedar	ALL
Samples (N)	19	26	46	91
% Samples with turions	11%	19%	11%	13%
Mean (turions/m²)	33	17	16	20
Std Error	±26	±8	±8	±7
Max (turions/m²)	489	178	222	489

CLP Bed Statistics *(only points in delineated CLP beds)*

	Balsam	Hemlock	Red Cedar	ALL
Samples (N)	26	27	48	101
% Samples with turions	35%	30%	46%	39%
Mean (turions/m²)	92	33	58	60
Std Error	±41	±12	±11	±12
Max (turions/m²)	933	222	311	933

Table 3. 2021 statistics for curlyleaf pondweed turion frequency (% occurrence) and abundance (turions/m²) in Balsam, Hemlock, and Red Cedar Lakes (lake-wide and within-bed)

2021 Turion Statistics

	Balsam	Hemlock	Red Cedar	ALL
Total Sites Sampled	**49**	**23**	**98**	**170**
Random Points	19	18	48	85
CLP Bed Points*	38	15	66	119

* Some random points were within CLP beds

Lake-Wide Statistics *(random littoral points)*

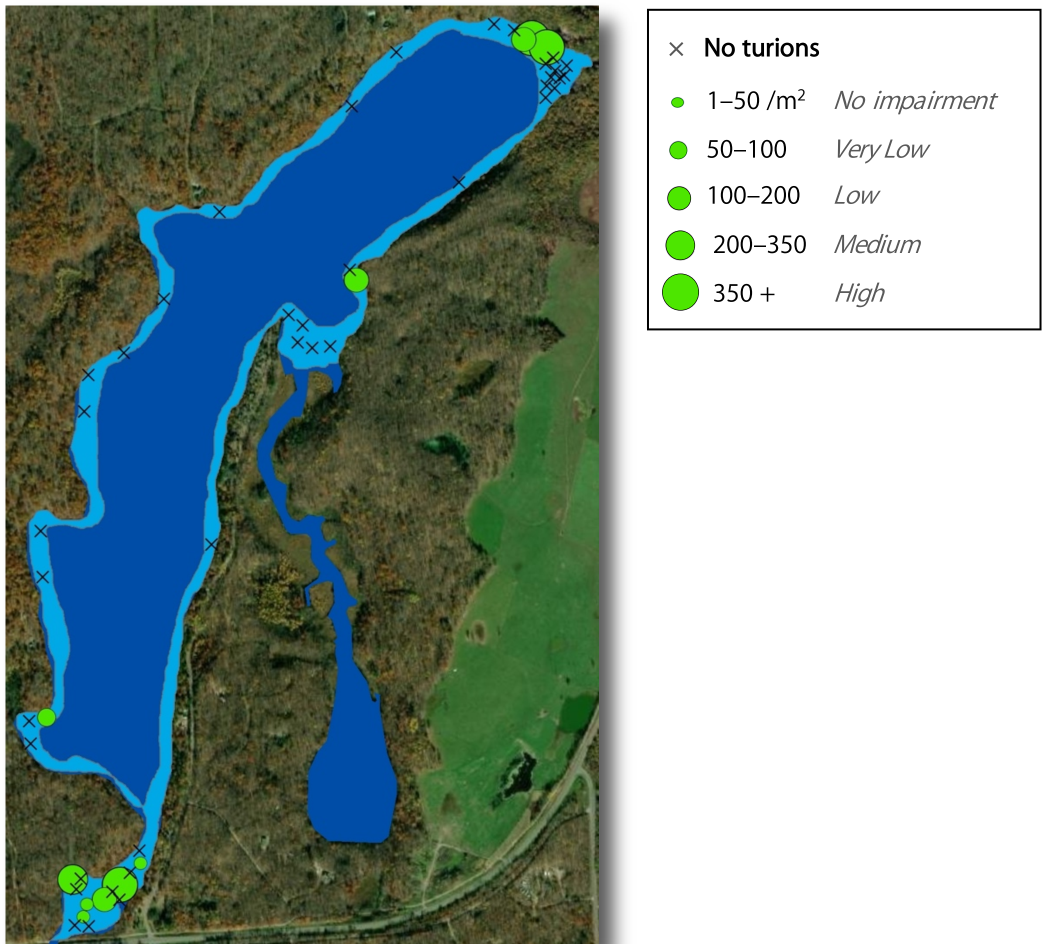
	Balsam	Hemlock	Red Cedar	ALL
Samples (N)	19	18	48	85
% Samples with turions	11%	11%	4%	7%
Mean (turions/m²)	26	20	5	13
Std Error	±21	±14	±3	±6
Max (turions/m²)	400	222	133	400

CLP Bed Statistics *(only points in delineated CLP beds)*

	Balsam	Hemlock	Red Cedar	ALL
Samples (N)	38	15	66	119
% Samples with turions	29%	13%	15%	19%
Mean (turions/m²)	57	12	13	27
Std Error	±25	±7	±5	±8
Max (turions/m²)	489	133	133	489

Figure 8. Map of curlyleaf pondweed turion abundance in Balsam and Hemlock Lakes (2021). Estimates of potential for impairment are based upon observed turion abundance and subjective impairment ratings from a previous study (Johnson et al. 2012; see Figures 10 and 11). Note that areas with greater turion abundance are generally the same areas that had higher curlyleaf pondweed density during the June 2021 delineation survey (Figure 5).

Balsam Lake



Hemlock Lake

Red Cedar Lake

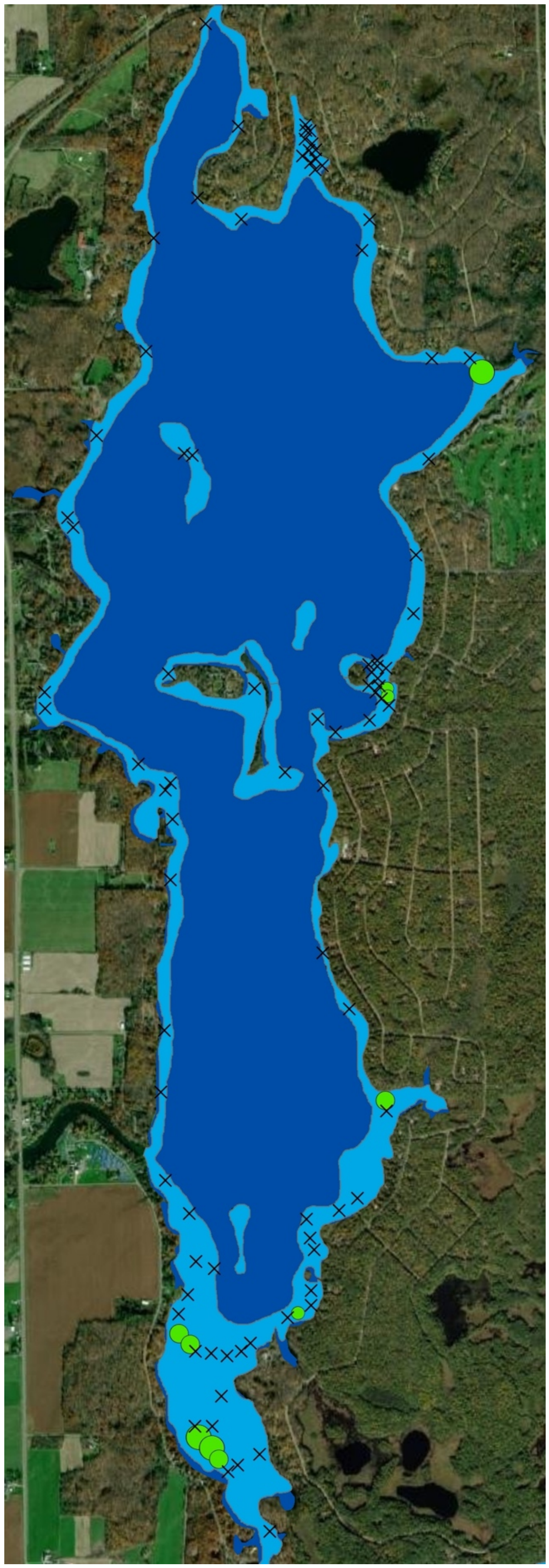


Figure 9. Map of curlyleaf pondweed turion abundance in Red Cedar Lake (2021). Estimates of the potential for impairment are based upon observed relationship between turion abundance and subjective impairment ratings from a previous study (Johnson et al. 2012; see Figures 10 and 11).

× No turions	
1–50 /m^2	*No Impairment*
50–100	*Very Low*
100–200	*Low*
200–350	*Medium*
350 +	*High*

Figure 10. 2021 lake-wide mean turion abundance for each of the Red Cedar Chain lakes and the potential for recreational impairment. Ranges for impairment potential were estimated from subjective assessments of nuisance level (Low, Med, High) and turion abundance data from Johnson et al. 2012 (Figure 11).

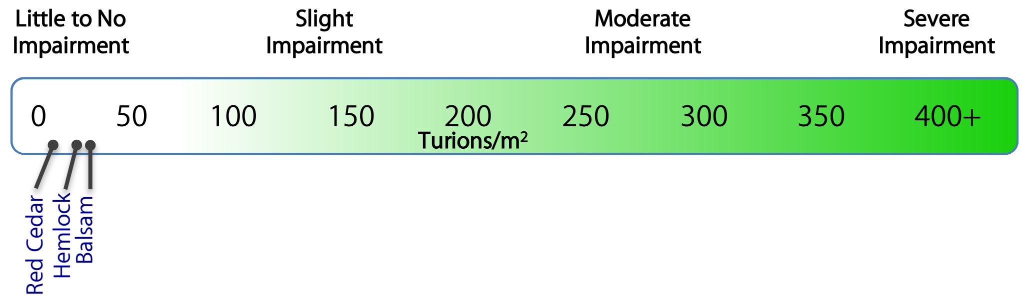
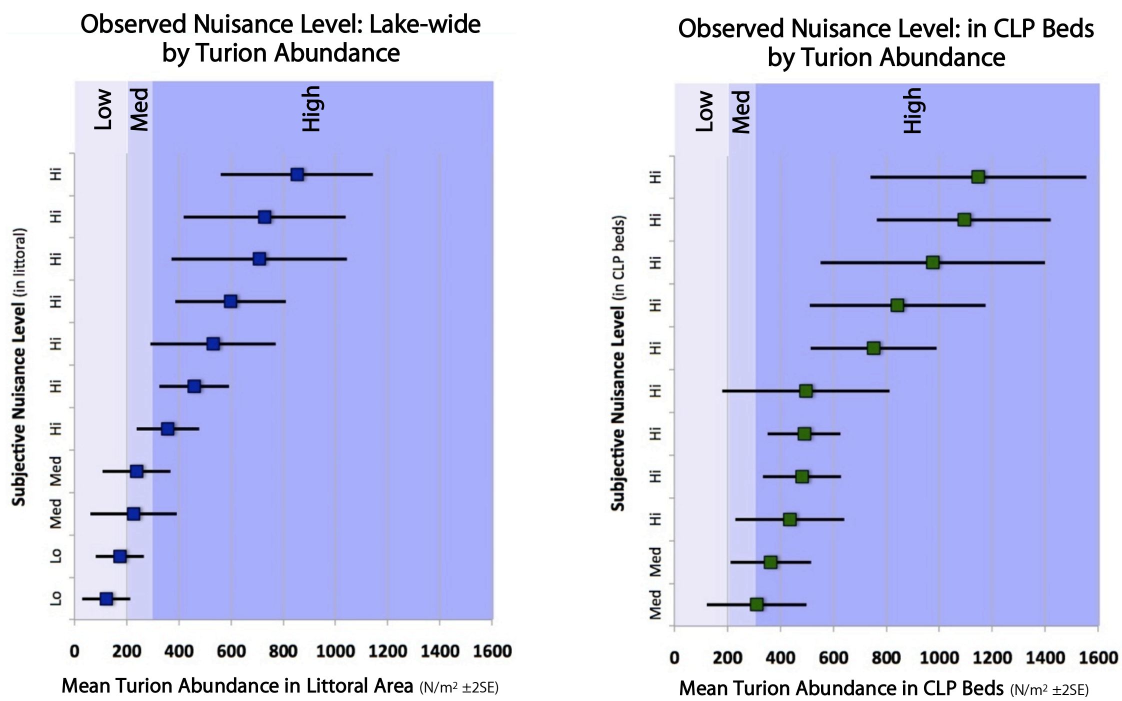


Figure 11. Relationship between turion abundance and curlyleaf pondweed nuisance level (subjectively rated). Nuisance level ratings are based upon the degree to which curlyleaf growth would be expected to impair boating in the area indicated (littoral area or in curlyleaf beds). Means and standard errors (SE) of turion abundance were calculated using data collected in previous studies (Johnson et al. 2012; N~40 in each lake). Error bars represent ±2SE. These plots are provided to allow comparison of the turion abundance in the Red Cedar Chain to values seen in other infested lakes.



Management Context

Since the initial turion survey in 2012, there have been substantial efforts to manage curlyleaf pondweed in the Red Cedar Chain. These efforts have included a combination of hand pulling and targeted herbicide treatments, guided by frequent surveys to map curlyleaf and assess the effects of management on curlyleaf and native aquatic plants. After a decade of effort, there are some clear patterns:

(1) Herbicide treatment successfully reduced the curlyleaf density and turion abundance in some areas; most notably in the larger plots in the far southern and northern portions of Red Cedar Lake and in the western portion of Hemlock Lake. Larger plots, such as these, are easier to treat effectively, as there is less rapid dispersion of the applied herbicide.

(2) Curlyleaf in the lakes did not expand or increase in density between 2012 and 2021. Although past management likely helped to keep curlyleaf from expanding in some areas, we believe that the sandy and rocky sediments found throughout most of Balsam and Red Cedar would not be able to support dense curlyleaf. These areas of unsuitable sediment have likely acted as a firewall that limited the expansion of curlyleaf to only those areas with softer sediment (bays and channels).

(3) Many of the managed areas did not show substantial reductions in curlyleaf density or turion abundance. In particular, the far northern portion of Balsam Lake and the channel between Balsam and Red Cedar still supported areas of denser curlyleaf in 2021. These areas experienced a high amount of flow, making it difficult to maintain the target herbicide concentration for long enough to provide control. Furthermore, many of the treated plots throughout the chain were very small (<1 acre). Such small plots next to large areas of open water can be very difficult to treat effectively due to rapid dispersion of applied herbicides.

The extent of curlyleaf growth found in early surveys (2011-2012), suggests that sporadic patches of curlyleaf had already established throughout the three lakes by 2012, with a few larger dense patches in areas with soft sediments. Such widespread curlyleaf suggests that this was not a new infestation and that it was well established in the lakes by 2012.

Based upon the above patterns and observations, we recommend that rather than trying to manage every small patch of curlyleaf on a lake-wide scale, future management of curlyleaf in the Red Cedar Chain should limit herbicide treatments to dense areas of curlyleaf greater than 2 acres in size (preferably larger). If desired, hand pulling, cutting, or harvesting could also be incorporated on a limited scale to manage small patches that reach nuisance density near homes or in navigation areas. This approach would help to ensure that money was not being wasted on ineffective herbicide treatment of small plots or on areas where sediments are not amenable to dense curlyleaf growth.

The areas with the greatest potential to form large areas of nuisance curlyleaf growth are:

(1) western Hemlock
(2) southern portions of Red Cedar and portions of channel to Hemlock
(3) eastern Red Cedar near the mouth of Pigeon Creek
(4) two northeastern bays of Red Cedar
(5) channel between Balsam and Red Cedar
(6) northern portion of Balsam at the mouth of the incoming river (other areas of denser curlyleaf in Balsam lake are either very narrow and near shore or intermixed with wild rice)

These areas should be the primary focus of future monitoring and management.

References & Additional Information

Bolduan BR, Van Eeckhout GC, Quade HW, Gannon JE. 1994. *Potamogeton crispus* - the other invader. Lake Reserv Manage. 10:113-125.

Catling PM, Dobson I. 1985. The biology of Canadian weeds. 69. *Potamogeton crispus* L. Can J Plant Sci. 65:655-668.

Johnson JA. 2011. Aquatic plant community of the Red Cedar Lakes: July/August 2011. *Report to* Short Elliott Hendrickson Inc. (Spooner, WI) and the Red Cedar Lakes Association (Mikana, WI). Freshwater Scientific Services, LLC. Maple Grove, MN. 67 pp.

Johnson JA, Jones AR, Newman RM. 2012. Evaluation of lake-wide, early-season herbicide treatments for controlling invasive curlyleaf pondweed (*Potamogeton crispus*) in Minnesota lakes. Lake Reserv Manage. 28:4

Kunii H. 1982. Life cycle and growth of *Potamogeton crispus* L. in a shallow pond, Ojaga-ika. Bot Mag Tokyo. 95:109-124.

Madsen JD, and Crowell W. 2002. Curlyleaf pondweed (*Potamogeton crispus* L.). LakeLine Magazine 22(1): 31-32.

Netherland MD, Skogerboe JD, Owens CS, Madsen JD. 2000. Influence of water temperature on the efficacy of diquat and endothall versus curlyleaf pondweed. J Aquat Plant Manage. 38:25-32.

Robertson DM, Rose WJ, Garn HS. 2003. Water quality and the effects of changes in phosphorus loading, Red Cedar Lakes, Barron and Washington Counties, Wisconsin. United States Department of the Interior and United States Geological Survey. Water-Resources Investigations Report 03–4238. Reston, VA. 42 pp.

Rogers KH, Breen CM. 1980. Growth and reproduction of *Potamogeton crispus* in a South African lake. J Ecol. 68:561-571.

Sastroutomo SS. 1981. Turion formation, dormancy and germination of curly pondweed, *Potamogeton crispus* L. Aquat Bot. 10:161-173.

Tobiessen P, Snow PD. 1984. Temperature and light effects on the growth of *Potamogeton crispus* in Collins Lake, New York State. Can J Bot. 62:2822-2826.

Valley R, Heiskary S. 2012. Short-term declines in curly-leaf pondweed in Minnesota: potential influences of snowfall. Lake Reserv Manage. 28:4 (*in press*)

Wehrmeister JR, Stuckey RL. 1992. The life history of *Potamogeton crispus*. Mich Bot. 31:3-16.

WDNR 2012. Wisconsin Department of Natural Resources. Madison, WI. Wisconsin Lakes website: http://dnr.wi.gov/lakes (accessed Nov 2012).