MEMORANDUM
Comfort Lake-Forest Lake Watershed District

To: Board of Managers **Date:** March 22, 2019

From: Mike Kinney

Subject: 2018 Comfort Lake Nitrogen Study Report Final Draft

Background/Discussion

Enclosed is the 2018 Comfort Lake Nitrogen-Eurasian Watermilfoil Study Report from Blue Water Science. The original draft report provided for the January 24, 2019 regular meeting was simply a compilation of data tables and did not include any explanation, recommendations and/or conclusions as it relates to nitrogen and its relationship to EWM plant growth in terms of being a limiting factor or not.

Recommended Action

Proposed Motion: Manager ___________ moves to accept the Nitrogen Study Report dated March 14, 2019. Seconded by Manager ___________.

Attached: Nitrogen Influence on Eurasian Watermilfoil Growth in Comfort Lake

Underwater View of Eurasian Watermilfoil in Comfort Lake in June 2018

Nitrogen Influence on Eurasian Watermilfoil Growth in Comfort Lake, Chisago County, 2018

Prepared for:
Comfort Lake/Forest Lake Watershed District
Forest Lake, Minnesota

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March 14, 2019

Nitrogen Influence on Eurasian Watermilfoil in Comfort Lake, Chisago County, 2018

Summary

We analyzed water chemistry, lake sediments, and Eurasian watermilfoil tissue to determine factors that could produce heavy Eurasian watermilfoil (EWM) growth in Comfort Lake.

Plant tissue to lake sediment nutrient ratios were also examined to evaluate plant nutrient use efficiency. The methods used in this approach are similar to agricultural methods used for evaluating crop yields. However, in this case predicting the yield of the EWM "crop" is the objective.

Results of selected water parameters (Table S1) and the ratio of plant tissue to lake sediment concentrations is shown in Table S2. Based on these results, high sediment nitrogen is correlated with heavy EWM growth. Also sediment Olsen phosphorus is better utilized than Bray phosphorus for heavy EWM growth indicating calcareous sediments are conducive for heavy EWM growth.

Conclusions on drivers for heavy growth of EWM are not definitive but the sediment nitrogen concentration appears to be a significant factor in influencing light or heavy EWM growth based on low or high sediment nitrogen concentrations.

Figure S1. EWM growth in Comfort Lake in June 2018.

Table S1. Water chemistry from Comfort Lake.

Water Sample Parameter	Comfort Inflow Sites		Comfort Lake Sites			NCHF Ecoregion Values for Streams
	1 - Inlet	2 - Inlet	3 - North	4 - Mid	5 - South	
Nitrate+Nitrite (ppm)	0.26	0.27	<0.05	<0.05	<0.05	0.04-0.26
Ammonia Nitrogen (ppm)	0.57	0.71	<0.16	0.28	0.28	--
Total Kjeldahl Nitrogen (ppm)	1.3	1.3	1.4	1.3	1.3	--
Total Phosphorus (ppb)	62	59	26	25	25	60-150
pH	7.9	8.0	8.0	8.3	8.3	7.9-8.3
Conductivity (µmhos)	513	496	435	410	402	--

Table S2. 2018 Plant tissue:sediment chemistry ratio for Comfort Lake.

Parameter (ppm)	2018 Plant Tissue: Sediment Chemistry Ratios		Comments
	Light	Heavy	
Boron	96	317	Tissue B was similar, but sediment-B was lower in light growth areas.
Calcium	43	47	
Copper	2.76	7.50	High ratio due to low copper in sediments. Does not impact EWM growth.
Iron	18	26	
Potassium	423	652	
Magnesium	24	36	
Manganese	97	59	
Phosphorus (Soil-Bray)	358	2,017	Bray-P is under estimated in calcareous sediments. Comfort sediments are calcareous.
Phosphorus (Soil-Olsen)	200	248	
Sulfur	680	841	Slightly high. Not sure role of sulfur in EWM growth.
Zinc	5.38	5.57	
Nitrogen	5,813	9,318	Higher ratio for heavy growth due to elevated tissue N.

Observations and Conclusions

- The incoming nitrogen loading from the major stream inflow is close to ecoregion stream values for the North Central Hardwood Forest Ecoregion (Table S1). Incoming nitrogen doesn't appear to be the factor producing abundant EWM growth, rather it, is likely sediment nitrogen.
- Tissue nutrient concentrations can change over the growing season and not enough is known about aquatic plant tissue concentrations. Lake sediment concentrations are more stable. Might be best to use sediment data as a guide to evaluate EWM growth potential.
- For Bray P soil testing, the acid extractent is neutralized by $CaCO_3$ and CaF_2 is formed. This produces false low values of available-P in calcareous sediments. Olsen-P is a better method for P determination in calcareous sediments.
- EWM and CLP are different plants. CLP has a C4 photosynthetic pathway. This pathway uses nitrogen efficiently and therefore CLP can thrive under low or high N conditions. EWM has a C3 photosynthetic pathway. This pathway has a low N use efficiency. Theoretically, it should take extra nitrogen to produce heavy EWM growth.

EWM was first observed in Comfort Lake in 2014 and is still relatively new in Comfort Lake. Although EWM has been assigned moderate to heavy growth around much of the shallow nearshore areas (Figure S2), sediment nitrogen concentrations indicate the long-term EWM growth potential is light to moderate. The EWM beds have been rated as heavy growth at many sites in Comfort Lake (Figure S3), the growth is a recreational concern and not an ecological problem. It is predicted EWM growth will be less dense in the future after the initial rapid expansion of EWM reverts to a long-term stable state based on low to moderate sediment nitrogen concentrations.

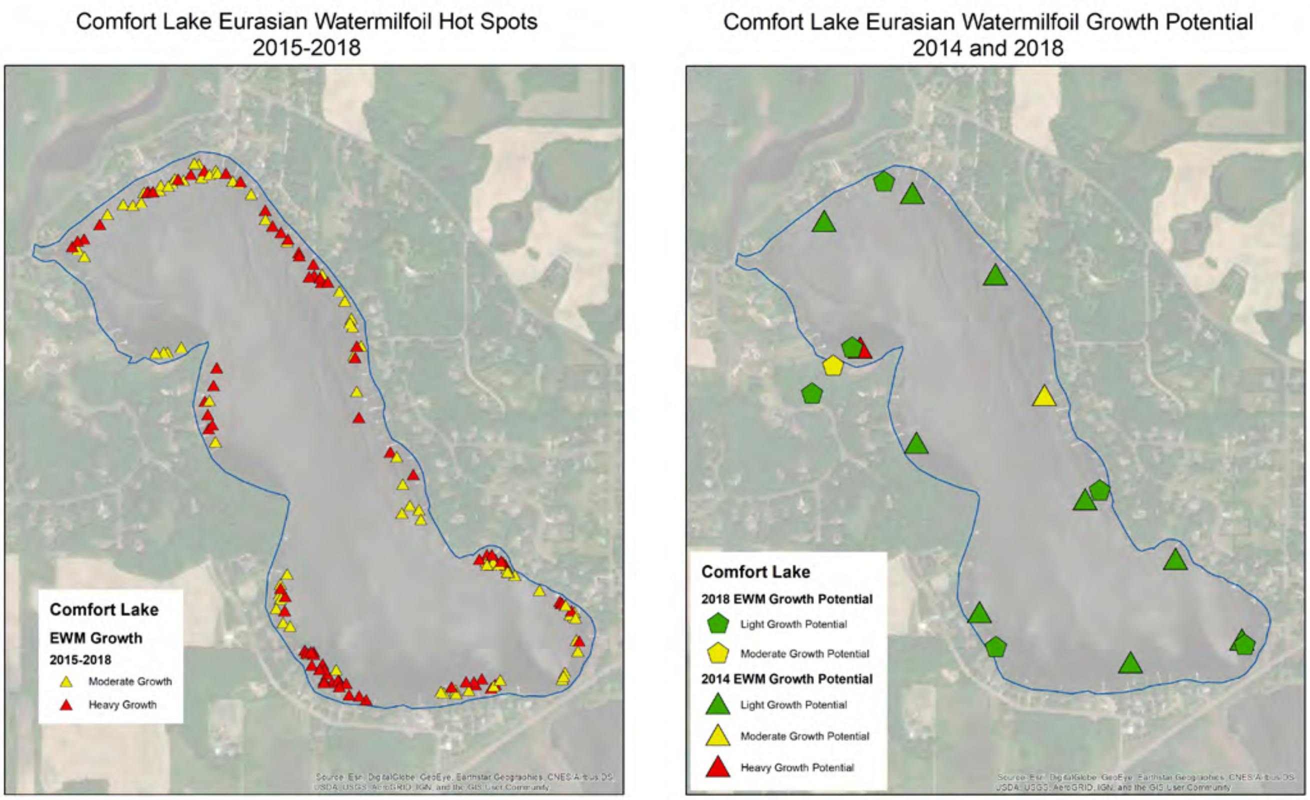


Figure S2. [left] EWM hot spot map for 2015-2018 growth.
[right] EWM growth potential in 2014 and 2018.

Figure S3. [left] An EWM bed found in Comfort Lake in 2018. Most beds are in 3 to 4 feet of water depth. [right] Underwater view of EWM in Comfort Lake in 2018. Typically, growth is mostly single stems with little branching near the surface.

Nitrogen Influence on Eurasian Watermilfoil in Comfort Lake, Chisago County, 2018

Introduction

Eurasian watermilfoil (EWM), *Myriophyllum spicatum*, is a non-native aquatic plant. Over the years, research has explored the ecology of EWM but there are still many questions regarding its essential nutrient requirements and conditions that produce heavy EWM growth.

Several lakes within the Comfort Lake/Forest Lake Watershed District (CLFLWD) support a wide distribution of EWM at mostly moderate densities. The aim of this study was to evaluate conditions that influence EWM growth in Comfort Lake with the potential to extrapolate predicting potential EWM growth in other CLFLWD lakes.

Figure 1. EWM growth in Comfort Lake in June 2018.

Methods

Water Chemistry: Water samples were collected from Comfort Lake on August 30, 2018. Water samples were analyzed at the Research Analytical Laboratory at the University of Minnesota using inductively coupled plasma emission spectrometry (ICP). A total of 26 elements were analyzed and are listed in Table 1.

Table 1. A total of 26 parameters were analyzed in lake water samples.

Al	Aluminum	Cr	Chromium	Mo	Molybdenum	Si	Silicon
B	Boron	Cu	Copper	Na	Sodium	Sr	Strontium
Ba	Barium	Fe	Iron	Ni	Nickel	Ti	Titanium
Be	Beryllium	K	Potassium	P	Phosphorus	V	Vanadium
Ca	Calcium	Li	Lithium	Pb	Lead	Zn	Zinc
Cd	Cadmium	Mg	Magnesium	Rb	Rubidum		
Co	Cobalt	Mn	Manganese	S	Sulfur		

Sediment Chemistry: In Comfort Lake a total of 7 samples were collected on August 30, 2018 from depths ranging from 2 to 4 feet. Location of sample sites is shown in Figure 4. Samples in shallow water were collected using a modified soil auger, 5.2 inches in diameter. Soils were sampled to a sediment depth of 6 inches. The lake soil from the sampler was transferred to 1-gallon zip-lock bags and sent to the University of Minnesota Soil Testing and Research Analytical Laboratory.

At the lab, sediment samples were air dried at room temperature, crushed and sieved through a 2 mm mesh sieve. Sediment samples were analyzed using standard agricultural soil testing methods. Fifteen parameters were tested for each soil sample. A summary of extractants and procedures is shown in Table 2. Routine soil test results are given on a weight per volume basis.

Table 2. Soil testing extractants used by University of Minnesota Soil Testing and Research Analytical Laboratory. These are standard extractants used for routine soil tests by most Midwestern soil testing laboratories (reference: Western States Laboratory Proficiency Testing Program: Soil and Plant Analytical Methods, 1996-Version 3).

Parameter	Extractant
P-Bray	0.025M HCL in 0.03M NH_4F
P-Olsen	0.5M $NaHCO_3$
NH_4-N	2N KCL
K, Ca, Mg	1N NH_4OA_c (ammonium acetate)
Fe, Mn, Zn, Cu	DTPA (diethylenetriamine pentaacetic acid)
B	Hot water
SO_4-S	$Ca(H_2PO_4)_2$
pH	water
Organic matter	Loss on ignition at 360°C

Figure 2. Soil auger used to collect lake sediments in water depths to 10 feet.

Figure 4. Sample locations of EWM plant samples, water samples, and sediment samples collected on August 30, 2018.

Table 4. Role of nutrients for the mineral nutrition in plants (based on references from Gardner, F.P., R.B. Pearce, and R.L. Mitchell. 1985. Physiology of Crop Plants; Foth, H.D. and B.G. Ellis. 1997. Soil Fertility 2nd Edition; and Kabata-Pendias, A. 2011. Trace elements in soils and plants, 4th Ed. CRC Press.)

Nitrogen (N)	Major nutrient. Nitrogen is a constituent in amino acids, amides, proteins, and nucleoprotein. It is essential to cell division, expansion, and growth.
Phosphorus (P)	Major nutrient. Phosphorus is essential as a component of the energy transfer compound - ATP, for genetic information system (DNR & RNA), for cell membranes and phosphoprotein.
Potassium (K)	Major nutrient. Potassium is essential to plants because it acts as enzyme activators for certain enzymes and aids in the maintenance of osmotic potential and water uptake. Most soils are buffered for potassium so yearly fluctuations are minor
Aluminum (Al)	Aluminum common in nearly every plant however the function of Al in plants is not well understood. Plants have differing tolerances to Al concentrations, it can potentially impair nutrient uptake and transport
Beryllium (Br)	Beryllium is absorbed similar to other cations like Mg2+ and Ca2+, however it does not have any known plant uses. It can sometimes be used as an indicator of potential industrial pollutants.
Boron (B)	Boron may influence cell development by controlling sugar transport and polysaccharide formation. Requirements for B and Ca often go hand in hand in hand; this has suggested that B may be needed for cell wall formation and for metabolism of pectic compounds.
Cadmium (Cd)	Cadmium is not used in biological processes of plants but can be absorbed and eventually accumulate in roots
Calcium (Ca)	Calcium is a component of the cell wall and is essential for cell division and elongation.
Chromium (Cr)	Chromium does not appear to be an essential micro-nutrient in plants and is only slightly mobile.
Cobalt (Co)	Cobalt is found in plants, it is needed for fixing N2 in cyanobacteria and some microorganisms. Low concentrations of Co can stimulate growth of algae and plants while higher concentrations are toxic.
Copper (Cu)	Copper is part of the chloroplast enzyme plastocyanin in the electron transport system between photosystmes I and II. It is present as an exchange ion on soil particles and minutely in the soil solution. Copper may become toxic in soils with use of copper sprays.
Iron (Fe)	Iron is a constituent of the electron transport enzymes. Although Fe is not a part of the chlorophyll molecule it affects chlorophyll levels because it must be present for chloroplast ultra structure formation. Iron deficiencies can reduce the number and size of chloroplast.
Lead (Pb)	Lead is not used in plant metabolism but is found naturally in plants. Pb can be a serious pollutant in the environment at higher concentrations.
Lithium (Li)	Lithium is not known to be an essential micro-nutrient but it can be readily taken up by plants.
Magnesium (Mg)	Magnesium is the center of the chlorophyll molecule. Magnesium also binds with ADP, ATP, and organic acids and therefore is essential for hundreds of enzymatic reactions. Magnesium is a cofactor for many enzymes. Nitrogen metabolism and protein synthesis are also dependent on the presence of Mg.
Manganese (Mn)	Manganese is an activator of several enzymes especially those involved in fatty acid and nucleotide synthesis and is essential in respiration and photosynthesis.
Molybdenum (Mo)	Molybdenum is an essential micro-nutrient for plant growth and helps form essential enzymes at low concentrations. At higher concentrations it can inhibit enzyme formation.
Nickel (Ni)	Nickel is not an essential in plant metabolism but is necessary for the nodulations in legumes. At higher concentration Ni is a pollutant.
Organic matter	Organic matter exerts a profound influence on almost every facet of the nature of soil. Most A horizons contain about 1 to 6 percent organic matter. A soil with greater than 20% organic matter is an organic soil and is classified as either peat or muck.
pH	pH has little or no direct effect on plant growth, however indirect effects are numerous and potent. An optimum pH is somewhere between 6.0 and 7.5. Low pH makes macro-nutrients less available whereas high pH makes micro-nutrients less available.
Rubidium (Rb)	Rubidium is a monovalent cation and may partly substitute for K but doesn't have a metabolic role. It can be toxic at high concentrations, but toxicity varies depending on the plant species
Silicon (Si)	Silicon is very common in soils and present in plants, however it is not deemed an essential plant mineral but has been shown to strengthen plants.
Sodium (Na)	Sodium is the most soluble of the salts. It may be a micro-nutrient, but generally is so abundant is rarely limiting. It is leachable and its concentration gradually decreases over time.
Strontium (Sr)	Strontium is not a plant micro-nutrient but it can be taken up by plants. Sr can accumulate in roots but is rarely translocated to other parts of the plant.
Sulfur (S)	Sulfur is a constituent of the amino acids homocysteine, cysteine, and methionine. It also activities certain proteolytic enzymes and is a constituent of coenzyme A glutathione and certain vitamins. Sulfur is primarily absorbed as the SO_4 ion.
Titanium (Ti)	Titanium is relatively unavailable for plants and does not appear to be mobile. Ti does not classify as an essential nutrient for plants but there are some indicators of growth enhancement of some crops.
Vanadium (Va)	Vanadium: has been found to be essential for some alga species as well as bacteria but not yet known to be essential for rooted plants.
Zinc (Zn)	Zinc is essential for the enzymes in the synthesis of tryptophan. Zinc levels are positively correlated with increasing organic matter and negatively correlated with increasing pH.

Results

Water Chemistry: Lake water samples were collected in Comfort Lake and in 3 other lakes that all have EWM and were analyzed using inductively coupled plasma emission spectroscopy (ICP). A total of 27 elements were analyzed that included micro and macro nutrients (Table 5). All 4 lakes have somewhat similar micro nutrient concentrations. Comfort Lake had slightly higher concentrations than the other lakes for calcium (Ca) and silicon (Si).

It appears that water chemistry in Comfort Lake does not have unique characteristics that would produce heavier EWM growth when compared to other lakes.

Table 5. Water chemistry using ICP analysis from Comfort Lake (collected on August 30, 2018) and 3 other lakes.

	2018 Water Chemistry Comfort Lake (Mid Lake)(ppm)		2018 Water Chemistry Lakes with EWM Light Growth (ppm)		
	Comfort	Comfort - Dup	Round (Light)	Staring (Light)	Lac Lavon (Light)
Al	<0.011	<0.011	<0.011	<0.011	<0.011
As	0.005	0.005	0.002	0.005	0.002
B	0.022	0.022	0.008	0.029	0.018
Ba	0.049	0.049	0.014	0.059	0.046
Be	<0.001	<0.001	<0.001	<0.001	<0.001
Ca	45.7	45.8	13.3	30.3	27.8
Cd	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.002	<0.002	<0.002	<0.002	<0.002
Cr	<0.001	<0.001	<0.001	<0.001	<0.001
Cu	0.002	0.001	0.002	<0.001	<0.001
Fe	0.005	0.005	0.004	0.035	0.001
K	3.02	3.05	2.15	3.74	3.23
Li	0.004	0.003	<0.002	0.007	0.003
Mg	16.3	16.4	3.8	23.0	19.1
Mn	<0.001	<0.001	<0.001	0.001	<0.001
Mo	<0.002	<0.002	<0.002	0.002	<0.002
Na	21.3	21.4	43.7	64.6	52.3
Ni	<0.003	<0.003	<0.003	<0.003	<0.003
P	<0.010	<0.010	0.03	0.05	<0.010
Pb	<0.012	<0.012	<0.012	<0.012	<0.012
Rb	<0.001	<0.001	<0.001	<0.001	<0.001
S	1.20	1.20	0.67	4.64	0.71
Si	5.94	5.96	0.26	1.92	2.59
Sr	0.100	0.099	0.029	0.12	0.066
Ti	0.003	0.003	0.002	0.002	0.002
V	0.001	<0.001	<0.001	0.002	0.001
Zn	<0.001	<0.001	<0.001	<0.001	<0.001

Nitrogen, Phosphorus, pH, and Conductivity: Nitrogen has been shown by other researchers to produce heavy EWM growth. The major inlet to Comfort Lake was sampled and 3 lake sites were sampled as well on August 30, 2018. The nitrogen concentration with stream flow coming into Comfort Lake is typical for streams in the ecoregion. The incoming nitrogen loading does not appear to be excessive. These loadings would not appear to produce heavy EWM growth. Lake nitrogen concentrations are also moderate (Table 6). EWM in Comfort Lake most likely gets it nitrogen from lake sediments.

Table 6. Inflow and lake water samples collected on August 30, 2018.

Water Sample Parameter	Comfort Inflow Sites		Comfort Lake Sites			NCHF Ecoregion Values for Streams
	1 - Inlet	2 - Inlet (50 m from 1)	3 - North	4 - Mid	5 - South	
Nitrate+Nitrite (ppm)	0.26	0.27	<0.05	<0.05	<0.05	0.04-0.26
Ammonia Nitrogen (ppm)	0.57	0.71	<0.16	0.28	0.28	--
Total Kjeldahl Nitrogen (ppm)	1.3	1.3	1.4	1.3	1.3	--
Total Phosphorus (ppb)	62	59	26	25	25	60-150
pH	7.9	8.0	8.0	8.3	8.3	7.9-8.3
Conductivity (µmhos)	513	496	435	410	402	--

Lake Sediment Chemistry: Theoretically, lake sediments act as soils and are a rooting medium for plants much lake agricultural soils. Lake sediments will have a significant influence on aquatic plant growth although a number of other variables such as light and slope impact growth as well. The Comfort Lake sediment chemistry from 6 lake sites and one inlet site are listed in Table 7.

A working theory is that sediment nitrogen is correlated with EWM growth. However, nitrogen in the site without EWM (Site 7) was not different compared to sites with EWM (Table 7). In 2018, there may have been other nutrients that limited EWM growth at Site 7 (possible limiting nutrients are shown with green shading in Table 7).

Table 7. Lake sediment chemistry for Comfort Lake. Sediments were collected on August 30, 2018.

Parameter	Inlet Comfort 1	No EWM Comfort 7	Sparse Comfort 5	Light Comfort 2	Light Comfort 3	Light Comfort 4	Heavy Comfort 6
Bulk Density (wt/8.51)	1.35	0.74	0.72	1.01	1.21	1.43	0.84
Bray P (ppm)	23	1	1	9	12	1	1
Bray P (ppm) adjusted	26.3	0.6	0.6	7.7	12.4	1.2	0.7
Olsen P (ppm)	12	5	14	19	14	6	8
Olsen P (ppm)adjusted	13.7	3.1	8.5	16.3	14.4	7.3	5.7
K (ppm)	22	12	26	28	23	22	23
K (ppm) adjusted	25.2	7.5	15.9	24.1	23.7	26.7	16.4
Organic matter (%)	1.5	4.9	4.5	6.1	2.8	0.6	4.1
Water pH	7.4	7.8	7.6	7	7.3	7.5	7.7
Boron (ppm)	0.263	0.259	0.334	0.676	0.346	0.261	0.184
Boron (ppm) adjusted	0.3	0.2	0.2	0.6	0.4	0.3	0.1
Fe (ppm)	153	150	87.9	260	137	36.0	90.4
Fe (ppm) adjusted	175	93.9	53.6	223	142	43.6	64.6
Mn (ppm)	15.6	47.0	80.9	34.9	21.2	13.0	37.8
Mn (ppm) adjusted	17.8	29.5	49.4	30	21.9	15.8	27
Zn (ppm)	2.47	0.311	0.540	4.20	2.90	0.654	2.25
Zn (ppm) adjusted	2.8	0.2	0.3	3.6	3.0	0.8	1.6
Cu (ppm)	1.17	0.448	0.626	2.01	1.20	0.498	0.569
Cu (ppm) adjusted	1.3	0.3	0.4	1.7	1.2	0.6	0.4
Ca (ppm)	1028	3285	2880	2159	1830	1960	3172
Ca (ppm) adjusted	1177	2061	1759	1857	1885	2377	2267
Mg (ppm)	165	156	162	243	148	92.8	140
Mg (ppm) adjusted	189	98.1	98.7	209	152	113	100.3
SO_4-S (ppm)	39	24	41	115	117	147	51
SO_4-S (ppm) adjusted	44.6	14.7	25	98.9	121	178	36.4
NH4-N (ppm)	1.85	4.23	3.83	5.6	3	2.45	3.02
NH4-N (ppm) adjusted	2.1	2.7	2.3	4.8	3.1	3	2.2
10 gm Scoop Wt	11.5	6.32	6.1	8.69	10.4	12.2	7.21
10 gm Scoop Wt	11.3	6.25	6.04	8.41	10.4	12.1	7.07
10 gm Scoop Wt	11.6	6.25	6.18	8.71	10.1	12.1	7.16
Average Scoop	11.5	6.27	6.11	8.6	10.3	12.1	7.15
Correction factor	1.14	0.63	0.61	0.86	1.03	1.21	0.71
Fe/Mn	9.8	3.2	1.1	7.5	6.5	2.8	2.4

Aquatic Plant Tissue: In Comfort Lake concentrations of several elements were lower in the EWM plant tissue at lake sites with heavy growth compared to the lake Site 5 with sparse EWM growth. Arsenic, boron, cadmium, and iron were higher in EWM plant tissue with sparse growth compared to heavy growth (Table 8).

Nitrogen content in EWM tissue was similar for sparse, light, and heavy growth in Comfort Lake.

Table 8. Plant tissue analysis from lakes with EWM. Results are in ppm.

Parameter (ppm)	2018 EWM Tissue Analysis							
	Sparse Comfort 5	Light Comfort 2	Light Comfort 2 - Lab Dup	Light Comfort 2 Average (n=2)	Light Comfort 3	Light Comfort 4	Light Growth Average (n=3)	Heavy Comfort 6
Al	254	655	743	699	484	340	508	360
As	12.85	2.33	2.54	2.43	2.69	2.15	2.42	2.11
B	74.1	31.2	32.6	31.9	38.2	44.4	38.2	31.7
Ba	119	85.7	88.6	87	108	150	115	139
Be	0.030	0.038	0.042	0.040	0.036	0.035	0.037	0.032
Ca	86481	36217	37602	36909	74296	149357	86854	105908
Cd	0.076	0.042	0.034	0.04	0.003	<0.001	0.01	<0.001
Co	0.302	0.985	1.078	1.03	0.722	0.328	0.69	0.34
Cr	1.009	1.236	1.230	1.23	0.623	0.846	0.90	0.57
Cu	3.781	3.804	4.109	3.96	2.640	3.085	3.23	3.00
Fe	4387	2760	2935	2848	2122	2162	2377	1674
K	13254	12518	12734	12626	9460	9413	10499	10692
Li	0.902	0.757	0.873	0.82	0.951	1.319	1.03	1.06
Mg	3949	3363	3407	3385	3595	4388	3789	3577
Mn	2249	2797	3003	2900	2239	1450	2196	1581
Mo	1.275	0.777	0.736	0.76	0.859	0.443	0.69	0.95
Na	10070	8528	8669	8598	7639	7242	7826	7592
Ni	0.939	1.65	1.73	1.69	1.06	0.931	1.23	0.84
P	1938	3759	3850	3805	2185	1646	2545	1412
Pb	1.12	1.17	1.25	1.21	0.940	0.963	1.04	0.97
Rb	<0.111	<0.111	2.011	1.06	<0.111	<0.111	0.43	<0.111
S	2475	2069	2047	2058	2349	3096	2501	2540
Si	577	625	669	647	638	584	623	615
Sr	78.8	44.3	45.4	44.8	67.7	110	74.2	87.6
Ti	5.20	7.91	8.95	8.43	6.23	6.37	7.01	5.57
V	2.23	3.27	3.65	3.46	2.50	1.93	2.63	1.68
Zn	16.4	21.1	21.6	21.4	9.88	8.70	13.3	8.91
Total N %	2.38	2.66	2.69	2.67	2.03	1.63	2.11	2.05
Total C %	35.84	36.8	36.58	36.7	34.70	29.11	33.5	34.53
N:P	12.30	7.1	7.0	7.0	9.3	9.9	8.3	14.50

Summary of Water Chemistry, Sediment Chemistry, and EWM Tissue Concentrations: Results from water, lake sediment, and EWM tissue concentrations are summarized in Table 9 Sediment chemistry was slightly different comparing light growth to heavy growth. Sediment phosphorus, iron, and sulfur were higher in EWM patches of light growth compared to heavy growth. In the EWM tissue, phosphorus and iron were higher in light growth compared to heavy growth whereas sulfur was about the same. Sediment sulfur does not likely influence EWM growth at these sediment concentrations.

Table 9. Summary of Comfort Lake water, sediment chemistry, and plant tissue (collected August 30, 2018).

Parameter (ppm)	2018 Water Chemistry from Mid Lake (ICP analyses)(ppm)	
	Comfort	Comfort - Dup
Al	<0.011	<0.011
As	0.005	0.005
B	0.022	0.022
Ba	0.049	0.049
Be	<0.001	<0.001
Ca	45.7	45.8
Cd	<0.001	<0.001
Co	<0.002	<0.002
Cr	<0.001	<0.001
Cu	0.002	0.001
Fe	0.005	0.005
K	3.02	3.05
Li	0.004	0.003
Mg	16.3	16.4
Mn	<0.001	<0.001
Mo	<0.002	<0.002
Na	21.3	21.4
Ni	<0.003	<0.003
P	<0.010	<0.010
Pb	<0.012	<0.012
Rb	<0.001	<0.001
S	1.20	1.20
Si	5.94	5.96
Sr	0.100	0.099
Ti	0.003	0.003
V	0.001	<0.001
Zn	<0.001	<0.001

Parameter	2018 Sediment Chemistry	
	Light Growth Average (n=3)	Heavy Growth Average (n=1)
Bulk Density (wt/8.51)	1.25	0.84
Boron (ppm) adjusted	0.4	0.1
Ca (ppm) adjusted	1824	2267
Cu (ppm) adjusted	1.2	0.4
Fe (ppm) adjusted	146.0	64.6
K (ppm) adjusted	24.9	16.4
Mg (ppm) adjusted	166	100.3
Mn (ppm) adjusted	21.4	27
NH4-N (ppm) adjusted	3.25	2.2
Organic matter (%)	2.75	4.1
P-Bray (ppm) adjusted	11.9	0.7
P-Olsen (ppm) adjusted	12.9	5.7
pH	7.3	7.7
S (ppm) adjusted	111	36.4
Zn (ppm) adjusted	2.55	1.6
Average Scoop	10.6	7.15
Correction factor	1.06	0.71
Fe/Mn	6.65	2.4

Parameter (ppm)	2018 EWM Tissue (ppm)	
	Light Growth Average (n= 4)	Heavy Growth Average (n=1)
Al	508	360
As	2.42	2.11
B	38.2	31.7
Ba	115	139
Be	0.037	0.032
Ca	86854	105908
Cd	0.01	<0.001
Co	0.69	0.34
Cr	0.90	0.57
Cu	3.23	3.00
Fe	2377	1674
K	10499	10692
Li	1.03	1.06
Mg	3789	3577
Mn	2196	1581
Mo	0.69	0.95
Na	7826	7592
Ni	1.23	0.84
P	2545	1412
Pb	1.04	0.97
Rb	0.43	<0.111
S	2501	2540
Si	623	615
Sr	74.2	87.6
Ti	7.01	5.57
V	2.63	1.68
Zn	13.3	8.91
Total N %	2.11	2.05
Total C %	33.5	34.53

Ratio of Plant tissue to Water Chemistry: EWM may receive some nutrient requirements from the water column but the extremely high ratios of plant tissue to water chemistry indicates those elements are likely derived from the sediments rather than uptake from the open water. Aluminum, iron, manganese, nitrogen, and phosphorus are likely sediment sources to EWM tissue along with a host of other elements.

Table 10. Water chemistry and plant tissue analysis for EWM.

Parameter (ppm)	2018 Water Chemistry (ppm)			2018 Plant Tissue (ppm)						Light Growth Ratio of Plant Tissue: Water Chemistry Average (n=6)	Heavy Growth Ratio of Plant Tissue: Water Chemistry Average (n=1)
	Comfort	Comfort - Dup	Average	Sparse Comfort 5	Light Comfort 2	Light Comfort 2 Dup	Light Comfort 3	Light Comfort 4	Heavy Comfort 6		
Al	<0.011	<0.011	0.011	254	655	743	484	340	360	50,503	32,768
As	0.005	0.005	0.005	12.85	2.328	2.541	2.687	2.148	2.11	485	422
B	0.022	0.022	0.022	74.1	31.2	32.6	38.2	44.4	31.7	1,663	1,439
Ba	0.049	0.049	0.049	119	85.7	88.6	108	150	139	2,204	2,845
Be	<0.001	<0.001	0.001	0.030	0.038	0.042	0.036	0.035	0.032	38	32
Ca	45.7	45.8	45.7	86,481	36,217	37,602	74,296	149,357	105,908	1,626	2,315
Cd	<0.001	<0.001	0.001	0.076	0.042	0.034	0.003	<0.001	<0.001	20	1
Co	<0.002	<0.002	0.002	0.302	0.985	1.078	0.722	0.328	0.343	389	172
Cr	<0.001	<0.001	0.001	1.01	1.24	1.23	0.623	0.846	0.569	984	569
Cu	0.002	0.001	0.002	3.78	3.80	4.11	2.64	3.09	3.00	2,273	2,003
Fe	0.005	0.005	0.005	4,387	2,760	2,935	2,122	2,162	1,674	498,988	334,762
K	3.02	3.05	3.03	13,254	12,518	12,734	9,460	9,413	10,692	3,636	3,524
Li	0.004	0.003	0.004	0.902	0.757	0.873	0.951	1.32	1.06	279	302
Mg	16.343	16.404	16.374	3949	3363	3407	3595	4388	3577	225	218
Mn	<0.001	<0.001	0.001	2249	2797	3003	2239	1450	1581	2,372,301	1,581,095
Mo	<0.002	<0.002	0.002	1.28	0.777	0.736	0.859	0.443	0.945	352	472
N			1.3	23,800	26,600	26,900	20,300	16,300	20,500	17,327	15,769
Na	21.3	21.4	21.4	10,070	8,528	8,669	7,639	7,242	7,592	375	355
Ni	<0.003	<0.003	0.003	0.939	1.65	1.73	1.06	0.931	0.837	447	279
P	<0.010	<0.010	0.010	1,938	3,759	3,850	2,185	1,646	1,412	286,004	141,180
Pb	<0.012	<0.012	0.012	1.12	1.17	1.25	0.940	0.963	0.974	90	81
Rb	<0.001	<0.001	0.001	<0.111	<0.111	2.011	<0.111	<0.111	<0.111	586	111
S	1.20	1.20	1.20	2,475	2,069	2,047	2,349	3,096	2,540	1,997	2,122
Si	5.94	5.96	5.95	577	625	669	638	584	615	106	103
Sr	0.1	0.099	0.100	78.8	44.3	45.4	67.7	110	87.6	672	880
Ti	0.003	0.003	0.003	5.20	7.91	8.95	6.23	6.37	5.57	2,455	1,858
V	0.001	<0.001	0.001	2.23	3.27	3.65	2.50	1.93	1.68	2,834	1,675
Zn	<0.001	<0.001	0.001	16.4	21.1	21.6	9.88	8.70	8.91	15,343	8,909

Ratio of Plant Tissue to Sediment Chemistry: Ratios of plant tissue to sediment concentrations for light and heavy EWM growth are shown in Table 11. Boron and Bray-phosphorus have higher ratios in heavy EWM growth compared to light EWM growth. Boron does not likely influence EWM growth since tissue concentrations were similar. The high ratio of Brays-phosphorus in heavy growth may indicate that sediment Bray-phosphorus is not very available, but Olsen-phosphorus is.

It appears the differences in chemistry between light growth and heavy growth in Comfort Lake were minor. One interpretation would be that although EWM growth was classified as light vs heavy, the heavy growth may have been a short term growth characteristic. Results from hundreds of other samples indicate heavy EWM growth occurs when sediment nitrogen is greater than 10 ppm (McComas unpublished). Based on these data from other lakes, EWM growth in Comfort Lake is predicted to be light to moderate in the future.

Table 11. Comparing average of light to heavy growth of EWM plant tissue to sediment chemistry ratios.

Parameter (ppm)	2018 Plant Tissue: Sediment Chemistry Ratios	
	Light	Heavy
B	96	317
Ca	43	47
Cu	2.76	7.50
Fe	18	26
K	423	652
Mg	24	36
Mn	97	59
P (Soil-Bray)	358	2017
P (Soil-Olsen)	200	248
S	680	841
Zn	5.38	5.57
N	5813	9318

EWM Growth Potential Based on Lake Sediment Chemistry: Based on previous sediment surveys (McComas unpublished) nutrient thresholds for types of EWM growth have been determined. For Comfort Lake it is predicted that EWM growth should be light to moderate on a long-term basis (Tables 12 and 13) because most of the lake sediment nitrogen concentrations are less than 5 ppm. EWM growth categories are defined in Figure 6.

Table 12. 2018: Comfort Lake sediment data and ratings for potential growth of Eurasian watermilfoil.

Site	Depth (ft)	NH_4 Conc (ppm)	Organic Matter (%)	Potential for EWM Growth
		<4	<0.5 and >20	Light (green)
		4 - 10	0.6 - 2 and 18 - 20	Moderate (yellow)
		>10	3 - 17	Heavy (red)
1	2	2.1	1.5	Light
2	3	4.8	6.1	Moderate
3	3	3.1	2.8	Light
4	4	3.0	0.6	Light
5	4	2.3	4.5	Light
6	3.6	2.2	4.1	Light
7	4	2.7	4.9	Light

Table 13. 2014: Comfort Lake sediment data and ratings for potential growth of Eurasian watermilfoil.

Site	Depth (ft)	NH_4 Conc (ppm)	Organic Matter (%)	Potential for EWM Growth
		<4	<0.5 and >20	Light (green)
		4 - 10	0.6 - 2 and 18 - 20	Moderate (yellow)
		>10	3 - 17	Heavy (red)
C1	6	1.7	5.4	Light
C2	6	3.6	5.5	Light
C3	5	1.3	4.5	Light
C4	6	5.0	2.1	Moderate
C5	5	1.6	4.6	Light
C6	5	1.2	5.7	Light
C7	7	3.2	8.5	Light
C8	6	3.6	6.5	Light
C9	7	1.2	8.2	Light
C10	6	2.0	13.3	Light
C11	7	21.8	15.4	Heavy
C12	40	32.4	16.4	
C13	36	11.0	16.0	
C14	29	11.6	16.6	

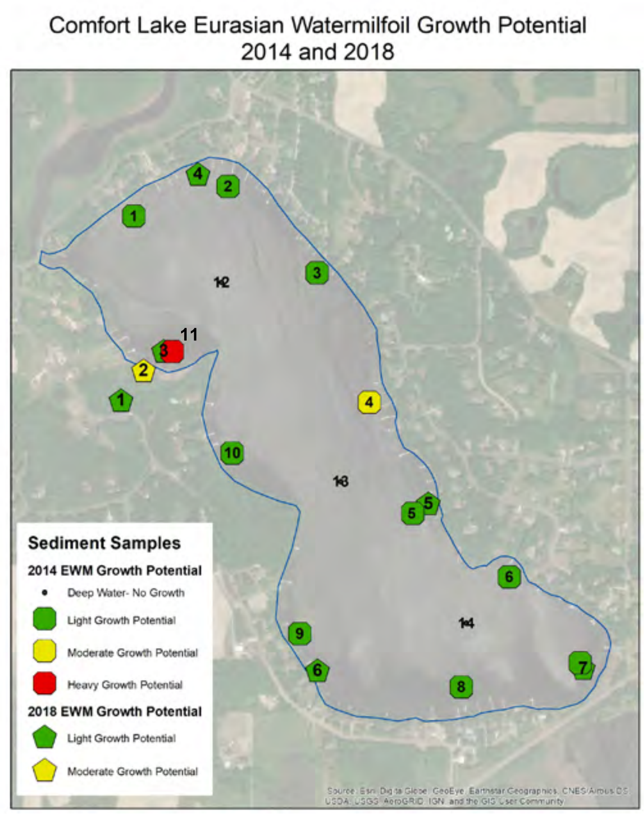


Figure 5. The color indicates the potential growth of Eurasian watermilfoil. Key: green = light growth, yellow = moderate growth, and red = heavy growth.

Eurasian Watermilfoil Growth Characteristics

(source: Steve McComas, Blue Water Science)

Light Growth Conditions

Plants rarely reach the surface.

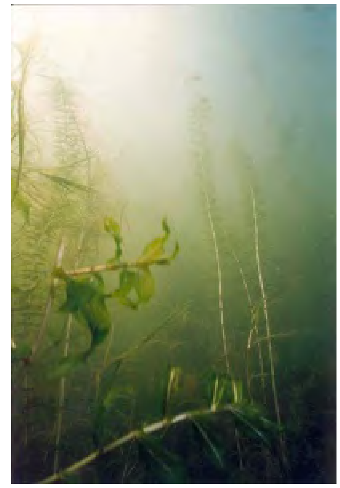
Plants are in scattered patches*.

Navigation and recreational activities generally are not hindered.

Stem density: 1 - 90 stems/m^2
Biomass: 0 - 70 g-dry wt/m^2

MnDNR rake sample density equivalent for light growth conditions: 1.

**patch = EWM stems arising from a single root crown. Generally 5 to 10+ stems sprout from a root crown.*



Moderate Growth Conditions

Broken surface canopy conditions. However, stems are usually unbranched.

Plants are in beds* with some patches.

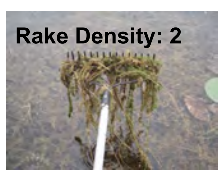
Navigation and recreational activities may be hindered.

Lake users may opt for control.

Stem density: 90 - 180 stems/m^2
Biomass: 70 - 200 g-dry wt/m^2

MnDNR rake sample density equivalent for moderate growth conditions: 2.

**beds = EWM patches close together forming an area of dominant EWM growth.*



Heavy Growth Conditions

Solid or near solid surface canopy conditions. Stems typically are branched near the surface.

Plants grow in continuous beds.

Navigation and recreational activities are limited.

Control is necessary for navigation and/or recreation.

Stem density: 180+ stems/m^2
Biomass: >200 g-dry wt/m^2

MnDNR rake sample density equivalent for heavy growth conditions: 3.

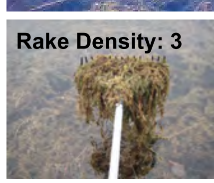


Figure 6. EWM growth category chart.

Discussion

In this project, several parameters appear to be correlated with light growth or with heavy EWM growth. Still, what is not known is if the nutrient concentration of the EWM tissue parameters are an artifact of sampling where nutrient concentrations could be diluted by heavy growth or if the nutrients are essential for metabolism.

It may be that EWM in Comfort Lake is still in an expansion and heavy growth phase often associated with new non-native plant introductions. EWM was first observed in Comfort Lake in 2014. From 2015 through 2018 EWM has expanded around Comfort Lake producing moderate to heavy growth in many nearshore locations (Figure 7). However, based on sediment conditions (Figure 7), it is predicted that EWM will exhibit mostly light growth on a long-term basis.

More information on tissue nutrient concentration over the growing season and sampling more lakes to determine nutrient concentration variability would be helpful.

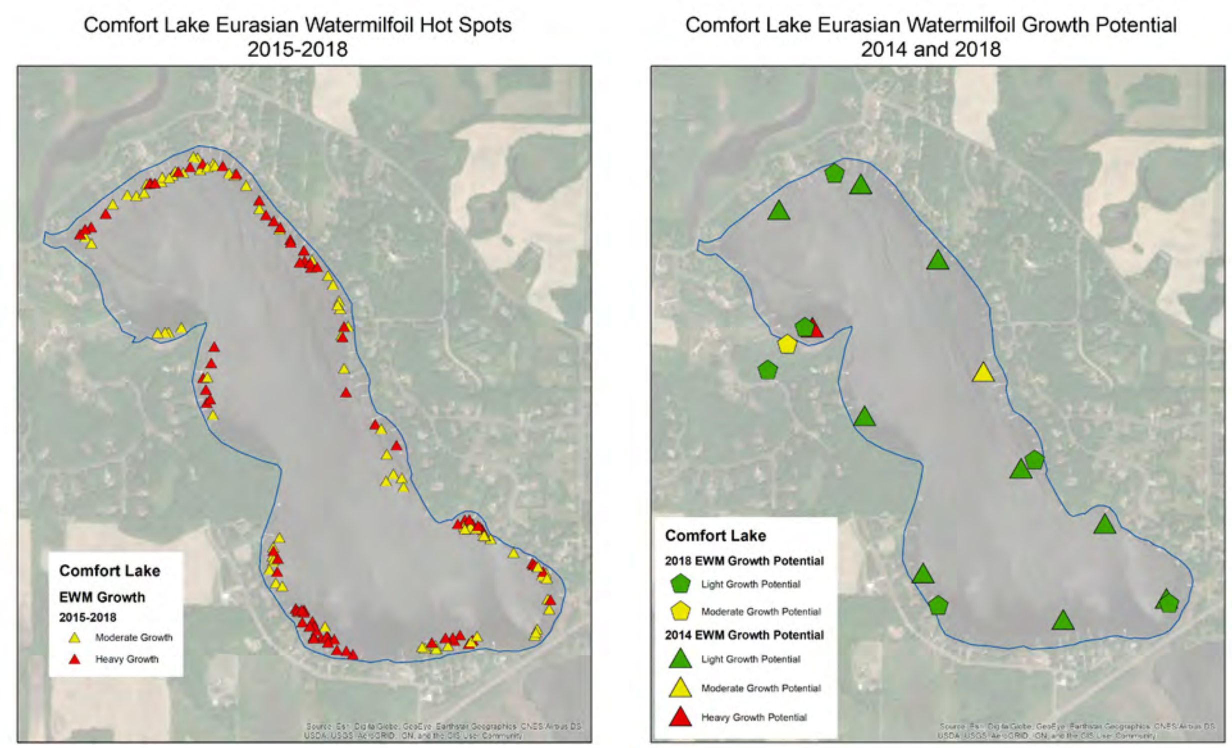


Figure 7. [left] EWM hot spot map for 2015-2018 growth. [right] EWM growth potential in 2014 and 2018.

APPENDIX

Other Applications of Lake Sediment Data: Predicting Curlyleaf Pondweed Growth Based on Sediment Data

Table 14. 2018 Comfort Lake sediment data and ratings for potential growth of curlyleaf pondweed growth.

Site	Depth (ft)	pH (su)	Bulk Density (g/cm3 dry)	Organic Matter (%)	Fe:Mn Ratio	Potential for Curlyleaf Pondweed Growth
		<7.4	>1.04	0.1-5	>4.5	Light (green)
		7.4 - 7.7	0.52 - 1.03	6-20	1.6 - 4.5	Moderate (yellow)
		>7.7	<0.51	>20	<1.6	Heavy (red)
1	2	7.4	1.35	1.5	9.8	Light
2	3	7.0	1.01	6.1	7.5	Moderate
3	3	7.3	1.21	2.8	6.5	Light
4	4	7.5	1.43	0.6	2.8	Moderate
5	4	7.6	0.72	4.5	1.1	Moderate
6	3.6	7.7	0.84	4.1	2.4	Moderate
7	4	7.8	0.74	4.9	3.2	Moderate

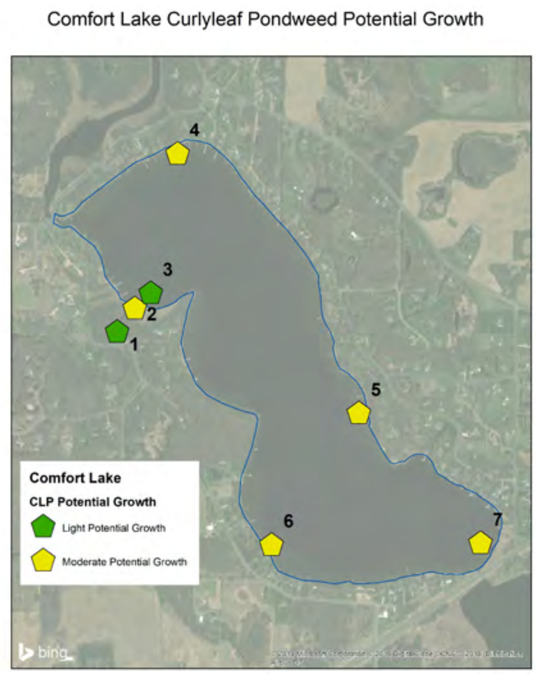


Figure 8. The color indicates the potential growth of curlyleaf pondweed. Key: green = light growth and yellow = moderate growth.

Table 15. 2014 Comfort Lake sediment data and ratings for potential growth of curlyleaf pondweed growth.

Site	Depth (ft)	pH (su)	Bulk Density (g/cm3 dry)	Organic Matter (%)	Fe:Mn Ratio	Potential for CLP Growth
		<7.4	>1.04	0.1-5	>4.5	Light (green)
		7.4 - 7.7	0.52 - 1.03	6-20	1.6 - 4.5	Moderate (yellow)
		>7.7	<0.51	>20	<1.6	Heavy (red)
C1	6	8.0	0.50	5.4	1.2	Heavy
C2	6	8.0	0.55	5.5	1.6	Moderate
C3	5	8.2	0.55	4.5	0.8	Moderate
C4	6	8.0	0.98	2.1	1.5	Moderate
C5	5	8.3	0.51	4.6	0.5	Heavy
C6	5	7.9	0.52	5.7	1.5	Moderate
C7	7	7.8	0.53	8.5	3.9	Moderate
C8	6	7.9	0.55	6.5	1.1	Heavy
C9	7	7.8	0.51	8.2	1.9	Moderate
C10	6	7.8	0.44	13.3	2.8	Moderate
C11	7	7.5	0.60	15.4	12.2	Moderate
C12	40	7.4	0.39	16.4	7.3	
C13	36	7.4	0.42	16.0	4.4	
C14	29	7.2	0.43	16.6	5.1	

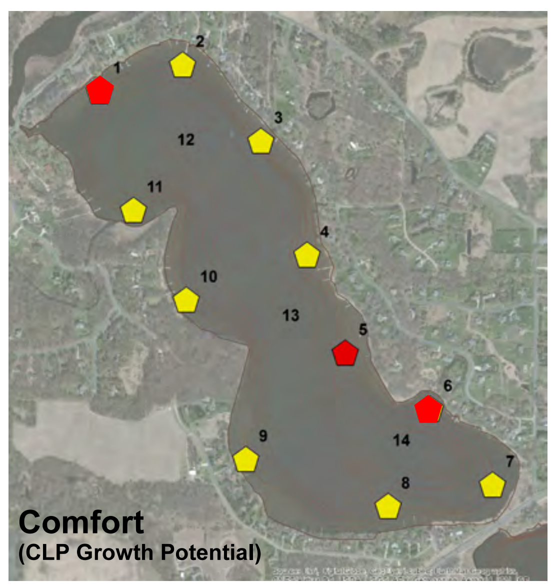


Figure 9. The color indicates the potential growth of curlyleaf pondweed.
Key: green = light growth, yellow = moderate growth, and red = heavy growth.