Orchard Lake Iron Treatment Site in 2006

Impact of Sediment Iron Treatment on Curlyleaf Pondweed in Orchard and Lee Lakes, Lakeville, Minnesota

Iron Treatment Dates: Orchard Lake: March 9, 2004
Lee Lake: March 10, 2004

Mechanical Harvesting: Orchard Lake: May - June 2004 through 2008

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Summary

Curlyleaf pondweed is an exotic plant that can grow to nuisance conditions in lakes. When curlyleaf dies back in early summer, phosphorus is released from the decaying plant matter and contributes to algae blooms.

Long term curlyleaf control methods are needed.

By evaluating the relationship between curlyleaf growth and lake sediment characteristics, it was found that lakes with naturally high sediment iron concentrations had low curlyleaf densities.

A test was conducted in Orchard Lake and Lee Lake to determine if adding iron filings to the lake sediments, which would mimic naturally occurring conditions in lakes with non-nuisance curlyleaf conditions, could control nuisance curlyleaf growth. Monitoring results in the fourth growing season after the iron addition found nuisance curlyleaf growth was controlled in the iron-treated plots.

Figure 1. Curlyleaf pondweed plant with two turions in Orchard Lake.

Iron filings were added to two one-acre plots in Orchard Lake and to two one-half acre plots in Lee Lake in March of 2004.

Applying iron filings to sediments appears to reduce the density of curlyleaf pondweed. In Orchard Lake, there was no obvious reduction in stem density or biomass in iron treatment sites in May of 2004 when compared to reference sites (Table 1). However, in the second growing season (May 2005), and continuing into the fifth growing season (2008), there has been a decrease in curlyleaf stem density and biomass in Orchard Lake.

In Lee Lake, monitoring in 2004 found that curlyleaf pondweed was scarce, not only in the treatment sites, but also in the reference sites (Table 1). This was due either to a lakewide curlyleaf decline attributed to the iron treatment which occurred in only a small area of the lake (one acre out of the 25 lake acres) or, more probably, the curlyelaf community died back earlier then usual. In 2005-2008, curlyleaf was once again present in Lee Lake. There was a reduction in stem densities and in biomass compared to pre-iron conditions, but not as dramatic as the reduction that has occurred in Orchard Lake.

Table 1. Summary of stem density and biomass results for 2004, 2005, 2006, 2007, and 2008. Iron filings were added to Orchard Lake on March 9, 2004 and to Lee Lake on March 10, 2004.

	Stem Density (#/m^2)		Biomass (g-dry wt/m^2)	
	Treatment	Reference	Treatment	Reference
ORCHARD				
Pre-Iron (June 7, 2003)	454 (n=15)	436 (n=10)	307 (n=5)	391 (n=5)
Post Iron - yr 1 (May 24, 2004)	425 (n=20)	403 (n=20)	190 (n=11)	158 (n=12)
Post Iron - yr 2 (May 23, 2005)	219 (n=20)	407 (n=20)	101 (n=12)	167 (n=12)
Post Iron - yr 3 (May 30, 2006)	89 (n=20)	341 (n=20)	27 (n=12)	177 (n=10)
Post Iron - yr 4 (May 22, 2007)	240 (n=20)	514 (n=20)	60 (n=10)	184 (n=10)
Post Iron - yr 5 (May 30, 2008)	78 (n=20)	360 (n=20)	28 (n=6)	96 (n=6)
LEE				
Pre-Iron (May 31, 2003)	272 (n=5)	--	83 (n=5)	--
Post Iron - yr 1 (June 12, 2004)	6 (n=20)	3 (n=20)	2 (n=20)	0.4 (n=20)
Post Iron - yr 2 (May 23, 2005)	211 (n=20)	320 (n=20)	76 (n=12)	99 (n=12)
Post Iron - yr 3 (May 30, 2006)	151 (n=20)	368 (n=20)	23 (n=10)	62 (n=10)
Post Iron - yr 4 (May 12, 2007)	77 (n=20)	237 (n=20)	43 (n=10)	114 (n=10)
Post Iron - yr 5 (May 30, 2008)	13 (n=20)	162 (n=20)	4 (n=20)	53 (n=7)

Lee Lake, Lakeville, Minnesota

Lee Lake is a 25-acre lake in Lakeville, Minnesota. Iron filings were added to two ½-acre plots on March 10, 2004. In the treated area, sites were monitored within known heavy curlyleaf growth areas based on sampling from 2002 and 2003. Two reference areas were also delineated in known heavy growth areas (Figure 2). Results are shown in Figure 3.

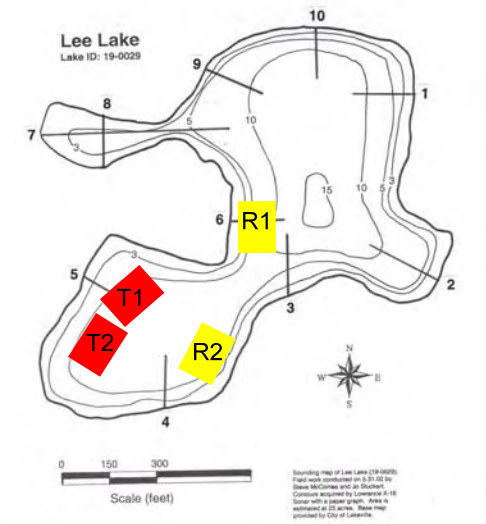


Figure 2. Locations of treatment (T1 and T2) and reference (R1 and R2) sites.

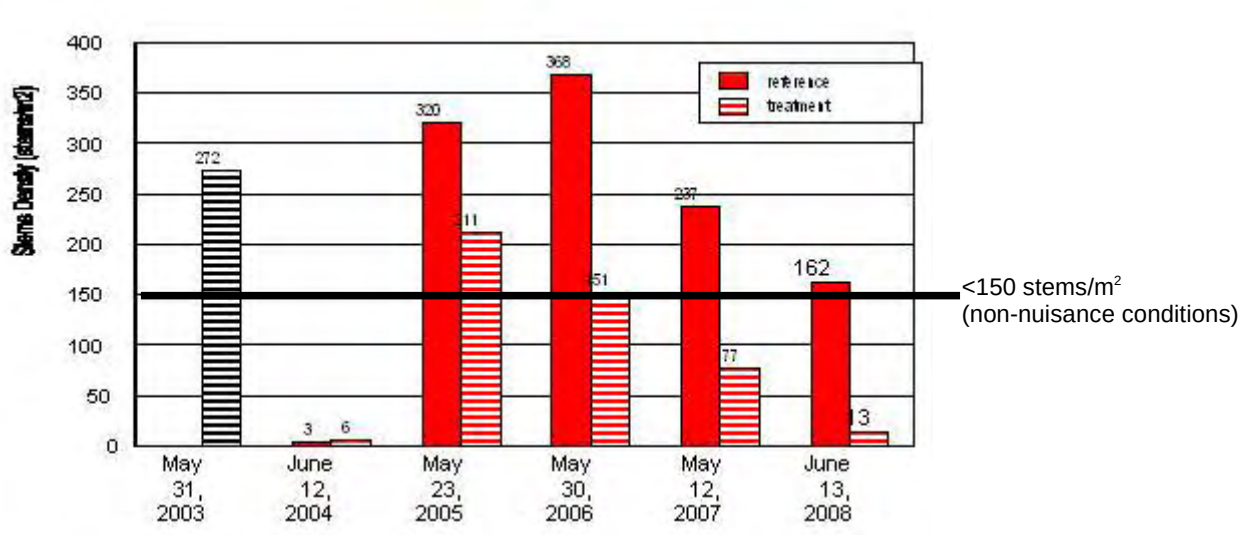


Figure 3. Average of Lee Lake curlyleaf pondweed stem densities for reference and treatment sites for pre-treatment conditions in 2003 (black bar) and for post treatment conditions (red bars).

Orchard Lake, Lakeville, Minnesota

Orchard Lake is a 234-acre lake in Lakeville, Minnesota. Iron filings were added to two 1-acre plots on March 9, 2004. One site in each of the two treated plots was monitored within known heavy curlyleaf growth areas based on sampling from 2002 and 2003. In addition, two reference areas, located in known heavy growth areas, were also monitored (Figure 4). Results are shown in Figure 5.

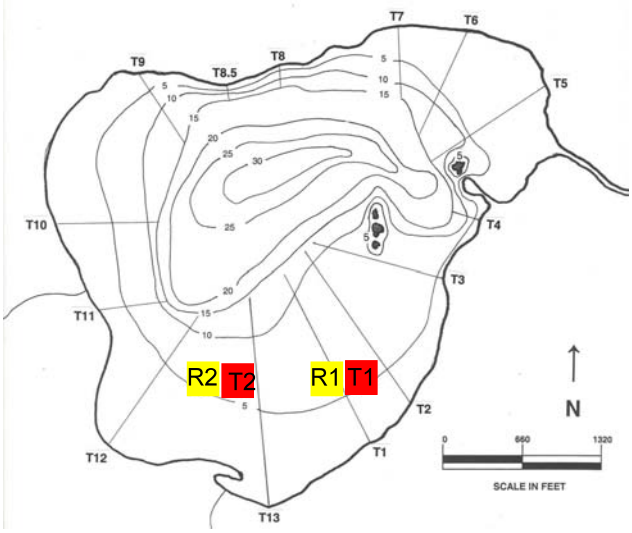


Figure 4. Locations of treatment (T1 and T2) and reference (R1 and R2) sites.

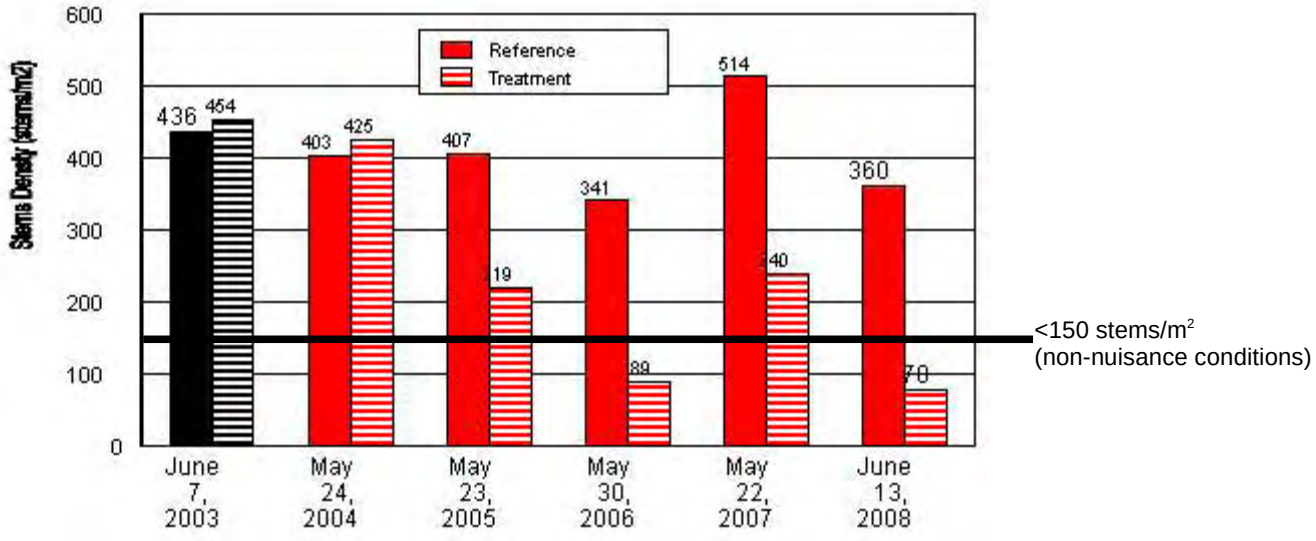


Figure 5. Average of Orchard Lake curlyleaf pondweed stem densities for reference and treatment sites for pre-treatment conditions in 2003 (black bars) and for post treatment conditions (red bars).

Conclusion and Recommendations: The iron treatment reduced stem densities in the iron treatment plots compared to reference plots in 2005, 2006, and 2007. In the treated plots, the stem densities were below the nuisance criteria of 150 stems/m^2 only in 2006. The curlyleaf pondweed has also declined in Lee Lake. Curlyleaf stem densities have been less in the treated plots compared to the reference plots from 2005 through 2008. Stem densities were below nuisance densities in 2006, 2007, and 2008.

Curlyleaf monitoring is recommended in 2009 to see if curlyleaf control is sustained in both Orchard Lake and Lee Lake.

Introduction

The City of Lakeville has been actively managing lakes located in the City of Lakeville for a number of years. A persistent problem on several lakes has been curlyleaf pondweed, a non-native aquatic plant, that can grow to nuisance conditions and produce adverse impacts on water quality.

Previous research has found that mechanical harvesting and herbicides can alleviate nuisance conditions for the season, but it takes an annual effort which also incurs an annual expense.

Recent work on lake sediments on Lakeville lakes with curlyleaf such as Marion, Orchard, and Lee indicated that curlyleaf growth seemed to be naturally controlled with high levels of naturally occurring sediment iron, especially when the pH was less than 7.7 and sediment bulk density was greater than 0.51 g-dry/cm^3.

The objective of this study was to determine if adding iron to lake sediments, which would mimic conditions found in lakes with non-nuisance curlyleaf growth, could reduce the excessive growth of curlyleaf pondweed found in some areas of Orchard and Lee Lakes.

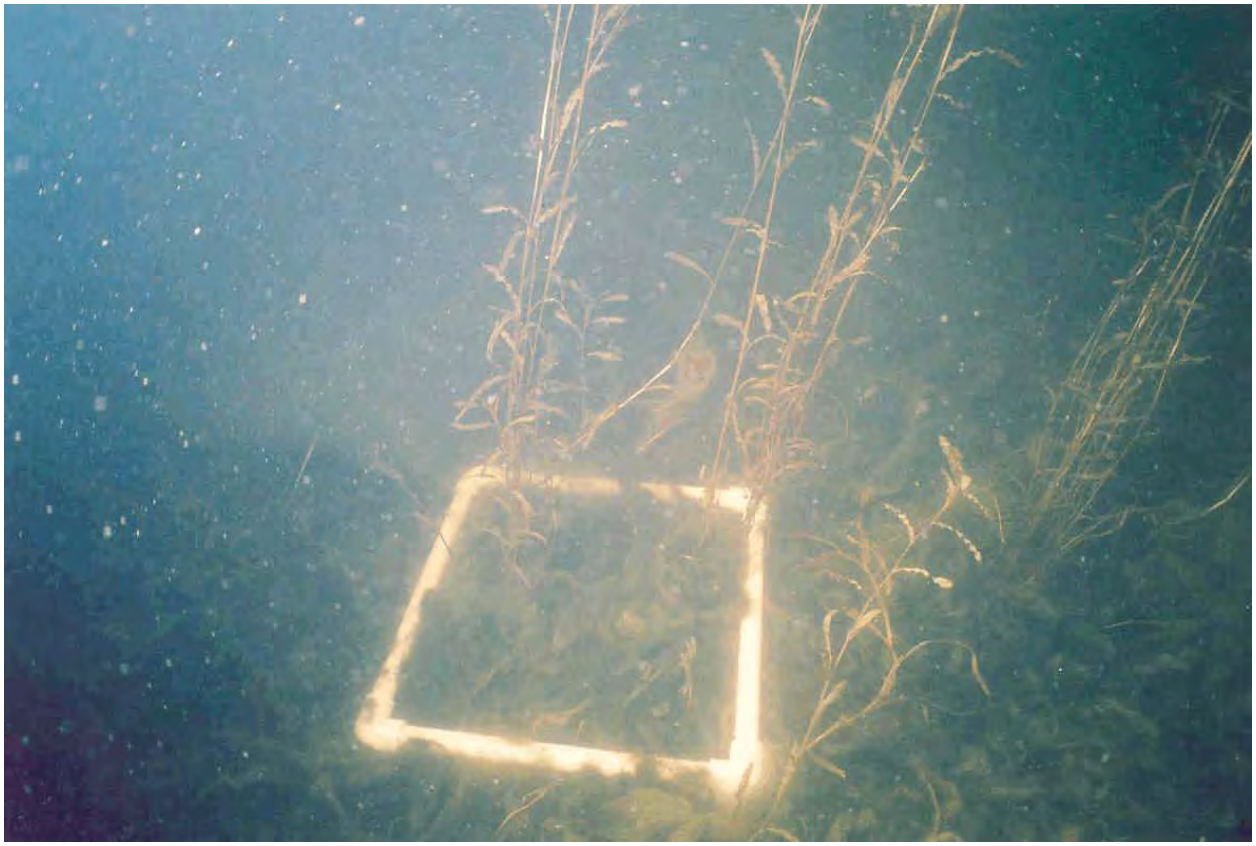


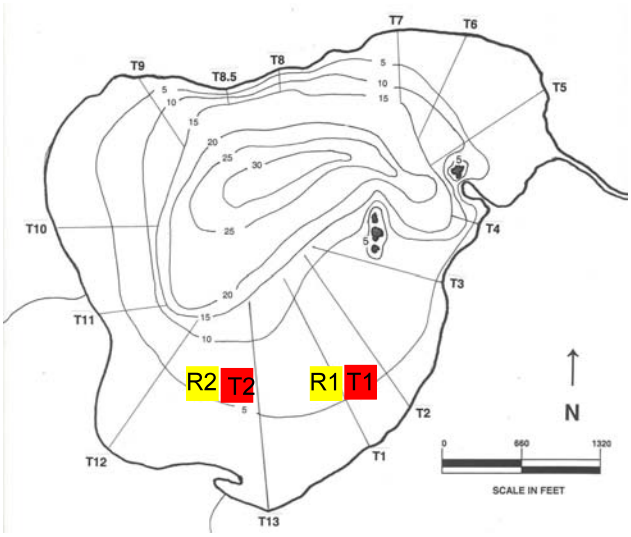
Figure 1. Non-nuisance curlyleaf pondweed growing in Treated Area 1 in Orchard Lake in May 2007.

Methods

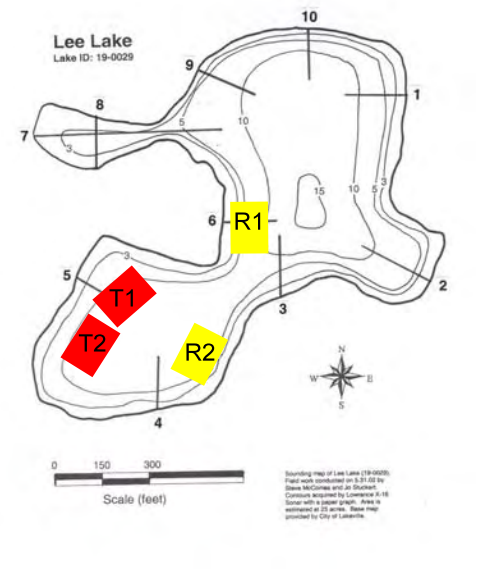
Study Areas: Two Lakeville lakes had delineated areas treated with iron filings to determine if iron could control nuisance growth of curlyleaf pondweed.

In Orchard Lake, two 1-acre plots were delineated within known nuisance curlyleaf growth areas based on monitoring from 2002 and 2003. In addition, two reference areas, located in known nuisance areas, were also delineated (Figure 2).

In Lee Lake, two ½-acre plots were delineated within known nuisance curlyleaf growth areas based on monitoring from 2002 and 2003. Two reference areas were also delineated in known nuisance growth areas (Figure 2).



Orchard Lake (234 acres): Treatment and Reference sites.



Lee Lake (25 acres): Treatment and Reference sites.

Figure 2. Locations of treatment and reference sites.

Methods - continued

Iron Application: For both Orchard and Lee Lakes, 4-inch diameter holes were drilled through the ice, thirty feet apart. Approximately 60 pounds of iron filings were poured into each hole (Figure 3). The final sediment iron dose was equivalent to about 30 grams of elemental iron per square foot of lake bottom.

Iron filings were added to Orchard Lake on March 9, 2004 and to Lee Lake on March 10, 2004.

Figure 3. [top] Iron addition into Orchard Lake on March 9, 2004.
[bottom] Pattern of holes drilled in the ice through which iron filings were added.

Methods - continued

Stem Density and Biomass Determination: Curlyleaf pondweed stem densities were quantified using a 0.1 m^2 quadrat (a square frame, with sides about 1-foot long). Curlyleaf stem counts were made with Scuba diving efforts. Locations for stem counts were randomly selected within treatment and reference areas by swimming on a line for 5 strokes and then placing the quadrat on the lake bottom.

For biomass determinations, all curlyleaf stems within the quadrat were collected and dried at 60ºC for 24 hours and weighed.

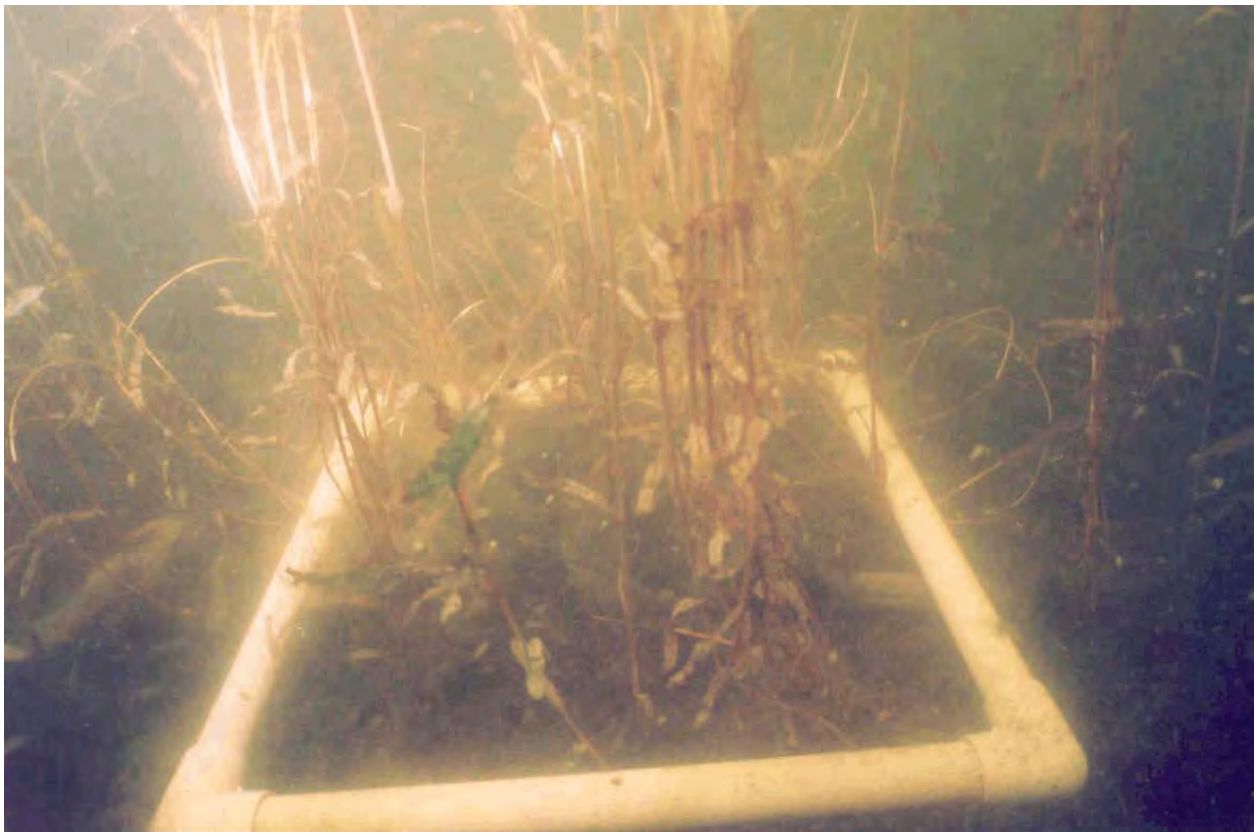


Figure 4. The 0.1 meter^2 quadrat is in position on the lake bottom in Orchard Lake in May, 2006. All curlyleaf plants found within the square frame were counted.

Results for Orchard Lake

Monitoring results for stem densities (stems/m^2), curlyleaf biomass (g-dry weight/m^2) and stem weights (grams/stem) are shown in Tables 1, 2, and 3. Iron filings were introduced on March 9, 2004 and post iron monitoring for curlyleaf took place on May 24, 2004, about 75 days after the iron dose. From 2005 through 2008 curlyleaf densities have continued to be monitored. Results indicate that the iron addition did not significantly reduce curlyleaf pondweed stem densities in the first growing season after the iron addition. However, results from the second through the fifth year found stem densities and biomass were less in the iron treated areas compared to pre-treatment levels as well as compared to the untreated reference sites. All sites were in 5.5 to 6.0 feet of water.

Figure 5. [top] Orchard Lake curlyleaf and filamentous algae conditions in May of 2003, prior to the iron treatment.
[bottom] Orchard Lake in June 2005. Mechanical harvesting has occurred on approximately 70 acres of Orchard Lake from 2004 through 2008.

Orchard Lake Stem Densities

Stem densities collected on June 7, 2003 prior to the iron treatment were high in both the treatment area and the reference area (Table 1). Curlyleaf results in 2004, after the iron treatment, found stem densities in the treatment area were slightly less compared to the pre-treatment densities collected in the treatment area. However, stem densities in the treatment area were similar to the stem densities in the reference area (Table 1). Results in from 2005 through 2008 found lower densities of curlyleaf in the iron treated area (Table 1).

Orchard Lake Biomass

Curlyleaf biomass was collected from within the quadrats when stem density counts were taken. Biomass measurements taken in the treatment and reference area in 2003, prior to the iron treatment, were high although the average biomass was slightly lower in the treatment site T2 then the reference site R1 (Table 2).

After the iron treatment on March 9, 2004, sampling results on May 24, 2004, the first growing season after treatment, found only the T2 site still had a high curlyleaf biomass. T1, R1, and R2 had lower curlyleaf biomass compared to pre-treatment biomass measurements. It is not clear why biomass would be reduced in 3 out of the 4 sample sites. However because the reference areas are close to the treatment areas, there could possibly be some iron treatment effects in the reference areas. Sampling results in 2005, 2006, 2007, and 2008, found biomass to be less in the treated sites compared to the reference sites. The biomass at both the treated and reference sites was less compared to pretreatment conditions.

Orchard Lake Stem Weights

Individual stem weights (g/stem) were less in two out of four sample sites for the curlyleaf collected on May 24, 2004, about 75 days after the iron treatment (Table 3). It is possible iron effects may inhibit the weight of curlyleaf plants by inhibiting maximum growth, which would affect individual plant weights.

Sampling in 2005, 2006, 2007, and 2008 found individual stem weights to be less compared to pretreatment as well as 2004 values.

Table 1. Orchard Lake stem densities (stems/m^2).

June 7, 2003 - Pre Iron (iron added March 9, 2004).

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	520	380	480	present,
2	550	650	490	not counted
3	220	610	350	
4	440	440	440	
5	470	350	510	
6	490		440	
7	340		350	
8	420		510	
9	370		440	
10	390		350	
Average	421	486	436	

May 24, 2004 - Post Iron - 1st growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	610	570	280	150
2	250	580	250	110
3	520	340	430	360
4	510	810	450	490
5	480	410	690	370
6	370	200	500	560
7	300	610	550	500
8	350	620	540	270
9	200	180	420	720
10	290	300	250	170
Average	388	462	436	370

May 23, 2005 - Post Iron - 2nd growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	290	170	320	490
2	150	140	400	770
3	210	200	190	370
4	140	190	230	640
5	230	430	270	400
6	130	280	450	370
7	220	360	120	420
8	190	180	270	650
9	150	90	190	750
10	330	300	300	530
Average	204	234	274	539

May 30, 2006 - Post Iron - 3rd growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	0	60	130	560
2	0	60	300	330
3	20	100	330	360
4	40	90	210	420
5	20	140	370	540
6	60	60	170	190
7	90	220	460	510
8	110	70	240	350
9	60	42	220	580
10	50	110	280	260
Average	45	133	271	410

May 22, 2007 - Post Iron - 4th growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	300	1,050	530	1,090
2	350	270	250	800
3	30	280	400	680
4	140	200	270	510
5	100	240	220	1,080
6	140	100	610	770
7	160	250	250	580
8	30	300	400	620
9	80	380	150	470
10	120	280	200	400
Average	***145***	***335***	***328***	***700***

May 30, 2008 - Post Iron - 5th growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	180	70	200	580
2	30	40	300	430
3	140	50	390	170
4	40	230	230	360
5	60	90	380	330
6	0	20	430	350
7	0	140	470	600
8	0	120	240	270
9	0	180	160	320
10	0	160	440	550
Average	45	110	324	396

Table 2. Orchard Lake curlyleaf biomass.

June 7, 2003 - Pre Iron (iron added March 9, 2004)

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (untreated) (g-dry weight/m^2)	
	T1	T2	R1	R2
1	353.6 est	237.1	530.8	ND
2	374.0 est	557.3	275.8	
3	149.6 est	501.2	366.2	
4	299.2 est	235.3	515.3	
5	319.6 est	204.0	404.1	
6	333.2 est		382.8 est	
7	231.2 est		304.5 est	
8	285.6 est		443.7 est	
9	251.6 est		382.8 est	
10	265.2 est		304.5 est	
Average	286.3	***347.0***	***418.4***	

May 24, 2004 - Post Iron - 1st growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (untreated) (g-dry weight/m^2)	
	T1	T2	R1	R2
1	92.0	454.9	77.0	144.7
2	40.2	377.5	30.9	31.9
3	106.1	190.5	148.5	240.6
4	167.3	463.1	140.2	137.2
5	99.9	284.1	248.6	349.0
6	53.8	130.9 est	87.0	120.0
7	60.0 est	396.5 est	148.5 est	280.0 est
8	70.0 est	403.0 est	145.8 est	151.2 est
9	40.0 est	117.0 est	113.4 est	403.2 est
10	58.0 est	195.0 est	67.5 est	95.2 est
Average	***78.7***	***301.2***	***120.7***	***195.3***

May 23, 2005 - Post Iron - 2nd growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (untreated) (g-dry weight/m^2)	
	T1	T2	R1	R2
1	179.5	59.1	114.4	132.8
2	42.4	111.2	145.2	245.2
3	78.8	49.2	67.4	189.6
4	56.8	83.8	131.4	257.4
5	80.5	279.3	201.5	201.3
6	78.0	94.9	139.9	157.9
7	96.8 est	169.2 est	54.0 est	172.2 est
8	83.8 est	84.6 est	121.5 est	266.5 est
9	66.0 est	42.3 est	85.5 est	307.5 est
10	145.2 est	141.0 est	135.0 est	217.3 est
Average	***90.8***	***111.5***	***119.6***	***214.8***

May 30, 2006 - Post Iron - 3rd growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (untreated) (g-dry weight/m^2)	
	T1	T2	R1	R2
1	5.6	15.6	72.9	94.4
2	16.3	34.0	98.7	171.0
3	37.3	34.5	58.3	170.0
4	39.0	39.6	71.0	411.1
5	21.0	68.5	169.8	375.0
6	6.0 est	25.2 est	45.5 est	347.2 est
7	12.0 est	92.4 est	105.0 est	204.6 est
8	6.0 est	29.4 est	115.5 est	223.2 est
9	0	17.6 est	73.5 est	260.4 est
10	0	46.2 est	129.5 est	334.8 est
Average	***14.3***	***40.3***	***94.0***	***259.2***

May 22, 2007 - Post Iron - 4th growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (untreated) (g-dry weight/m^2)	
	T1	T2	R1	R2
1	27.5	391.6	419.2	124.2
1	94.7	40.5	369.7	132.5
3	3	43.3	239.3	146.5
4	50.7	40.9	295.6	79.2
5	7.7	61.8	211.6	38.3
6	25.2 est	23.0 est	195.2 est	300.3 est
7	28.8 est	57.5 est	80.0 est	226.2 est
8	5.4 est	69.0 est	128.0 est	241.8 est
9	14.4 est	87.4 est	48.0 est	183.3 est
10	21.6 est	64.4 est	64.0 est	156.0 est
Average	***27.9***	***87.9***	***103.6***	***264.3***

May 30, 2008 - Post Iron - 5th growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (untreated) (g-dry weight/m^2)	
	T1	T2	R1	R2
1	63.5	27.0	30.6	107.8
1	14.0	23.0	72.2	98.1
3	64.8	8.2	70.2	228.9
4	14.4	80.5	41.4	191.4
5	21.6	31.5	68.4	141.9
6	0	7.0	77.4	56.1
7	0	49.0	84.6	115.5
8	0	42.0	43.2	89.1
9	0	63.0	28.8	105.6
10	0	56.0	79.2	181.5
Average	***17.8***	***38.7***	***59.6***	***131.6***

Table 3. Orchard Lake curlyleaf stem weights.

June 7, 2003

Sample	Iron Treatment Area			Sample	Reference Area		
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem		Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T2 - 1	38	23.71	0.62	R1 - 1	48	53.08	1.11
T2 - 2	65	55.73	0.86	R1 - 2	49	27.58	0.56
T2 - 3	61	50.12	0.82	R1 - 3	35	36.62	1.05
T2 - 4	44	23.53	0.54	R1 - 4	62	51.53	0.83
T2 - 5	35	20.40	0.58	R1 - 5	51	40.41	0.79
Average			***0.68***	***Average***			***0.87***

May 24, 2004

Sample	Iron Treatment Area			Sample	Reference Area		
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem		Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T1 - 1	61	9.2	0.15	R1 - 1	28	7.7	0.28
T1 - 2	25	4.02	0.16	R1 - 2	25	3.09	0.12
T1 - 3	52	10.61	0.20	R1 - 3	43	14.85	0.35
T1 - 4	51	16.73	0.33	R1 - 4	45	14.02	0.31
T1 - 5	48	9.99	0.21	R1 - 5	69	24.86	0.36
T1 - 6	37	5.38	0.15	R1 - 6	50	8.7	0.17
Average			***0.20***	***Average***			***0.27***
T2 - 1	57	45.49	0.80	R2 - 1	15	14.47	0.96
T2 - 2	58	37.75	0.65	R2 - 2	11	3.19	0.29
T2 - 3	34	19.05	0.56	R2 - 3	36	24.06	0.67
T2 - 4	81	46.31	0.57	R2 - 4	49	13.72	0.28
T2 - 5	41	28.41	0.69	R2 - 5	37	34.9	0.94
--	--	--	--	R2 - 6	56	12.0	0.21
Average			***0.65***	***Average***			***0.56***

May 23, 2005

Sample	Iron Treatment Area			Sample	Reference Area		
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem		Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T1 - 1	29	17.95	0.62	R1 - 1	32	11.44	0.36
T1 - 2	15	4.24	0.28	R1 - 2	40	14.52	0.36
T1 - 3	21	7.88	0.38	R1 - 3	19	6.74	0.36
T1 - 4	14	5.68	0.41	R1 - 4	23	13.14	0.57
T1 - 5	23	8.05	0.36	R1 - 5	27	20.15	0.75
T1 - 6	13	7.80	0.6	R1 - 6	45	13.99	0.31
Average			***0.44***	***Average***			***0.45***
T2 - 1	17	5.91	0.35	R2 - 1	49	13.28	0.27
T2 - 2	14	11.12	0.79	R2 - 2	77	24.52	0.32
T2 - 3	20	4.92	0.25	R2 - 3	37	18.96	0.51
T2 - 4	19	8.38	0.44	R2 - 4	64	25.74	0.40
T2 - 5	43	27.93	0.65	R2 - 5	40	20.13	0.50
T2 - 5	28	9.49	0.34	R2 - 6	37	15.79	0.43
Average			***0.47***	***Average***			***0.41***

May 30, 2006

Sample	Iron Treatment Area			Sample	Reference Area		
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem		Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T1 - 1	5	0.56	0.11	R1 - 1	17	7.29	0.43
T1 - 2	6	1.63	0.27	R1 - 2	22	9.87	0.45
T1 - 3	11	3.73	0.34	R1 - 3	24	5.83	0.24
T1 - 4	9	3.90	0.43	R1 - 4	28	7.10	0.25
T1 - 5	6	2.10	0.35	R1 - 5	46	16.98	0.37
Average			***0.3***	***Average***			***0.35***
T2 - 1	6	1.56	0.26	R2 - 1	19	9.44	0.50
T2 - 2	6	3.40	0.57	R2 - 2	26	17.10	0.66
T2 - 3	10	3.45	0.35	R2 - 3	35	17.00	0.49
T2 - 4	9	3.96	0.44	R2 - 4	51	41.11	0.81
T2 - 5	14	6.85	0.49	R2 - 5	58	37.50	0.65
Average			***0.42***	***Average***			***0.62***

Table 3. Orchard Lake curlyleaf stem weights.

May 22, 2007

Sample	Iron Treatment Area			Reference Area			
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem	Sample	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T1 - 1	30	2.75	0.09	R1 - 1	53	12.42	0.23
T1 - 2	35	9.47	0.27	R1 - 2	25	13.25	0.53
T1 - 3	3	0.3	0.1	R1 - 3	40	14.65	0.37
T1 - 4	14	5.07	0.36	R1 - 4	27	7.92	0.29
T1 - 5	10	0.77	0.08	R1 - 5	22	3.83	0.17
Average			***0.18***	***Average***			***0.32***
T2 - 1	105	39.16	0.37	R2 - 1	109	41.92	0.38
T2 - 2	27	4.05	0.15	R2 - 2	80	36.97	0.46
T2 - 3	28	4.33	0.15	R2 - 3	68	23.93	0.35
T2 - 4	20	4.09	0.20	R2 - 4	51	29.56	0.58
T2 - 5	24	6.18	0.26	R2 - 5	108	21.16	0.20
Average			***0.23***	***Average***			***0.39***

May 30, 2008

Sample	Iron Treatment Area			Reference Area			
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem	Sample	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T1 - 1	14	5.85	0.42	R1 - 1	34	3.06	0.09
T1 - 2	3	0.90	0.30	R1 - 2	20	4.03	0.20
T1 - 3				R1 - 3	30	7.22	0.24
Average			***0.36***	***Average***			***0.18***
T2 - 1	7	2.70	0.39	R2 - 1	33	10.78	0.33
T2 - 2	5	2.30	0.46	R2 - 2	36	9.81	0.27
T2 - 3	4	0.85	0.21	R2 - 3	60	22.89	0.38
Average			***0.35***	***Average***			***0.33***

Orchard Lake - 2004

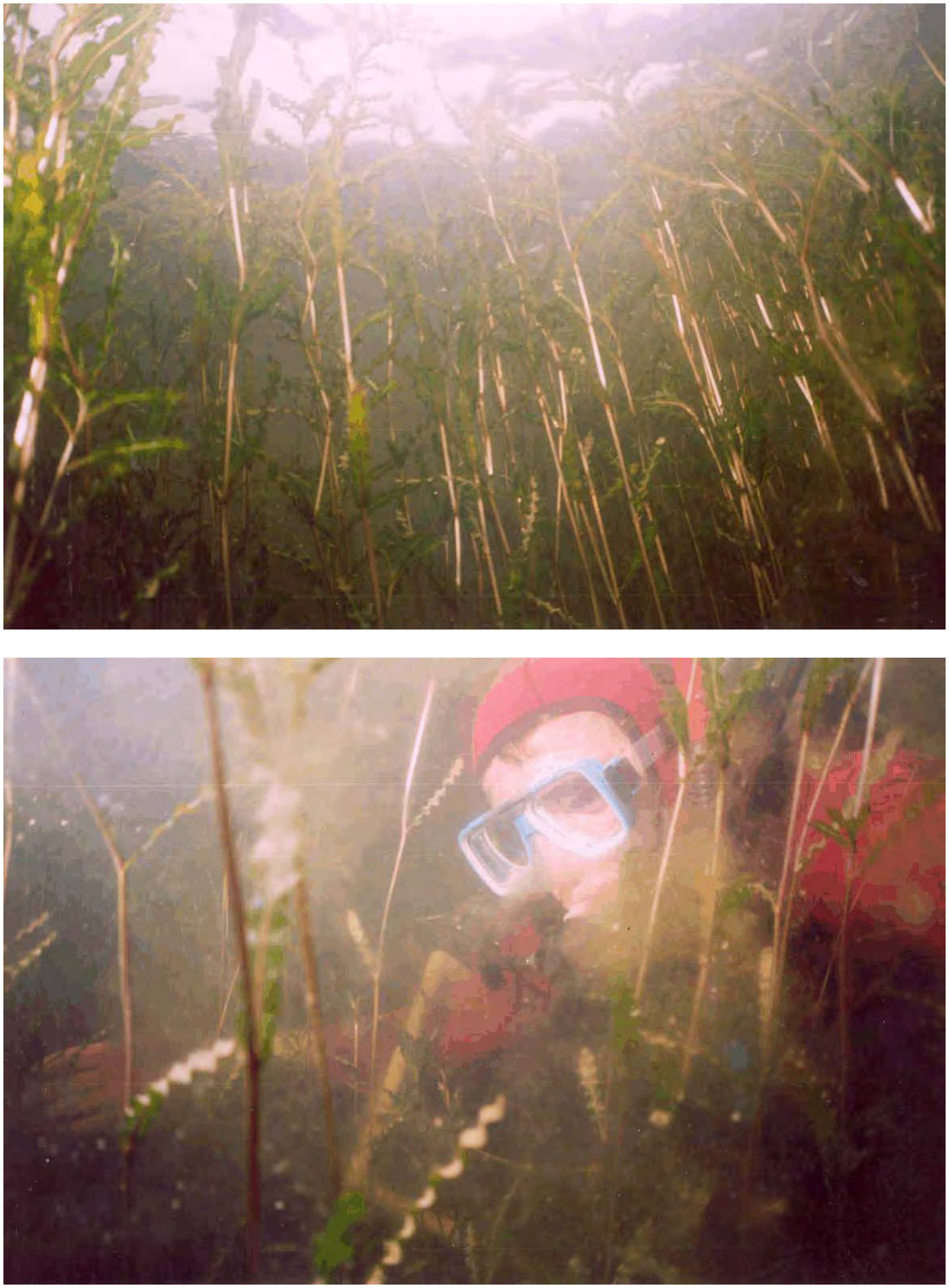


Figure 6. [top and bottom] Orchard Lake May 24, 2004, in area that was treated with iron filings on March 9, 2004. Stem densities were still high, but appeared to be slightly reduced compared to reference sites.

Orchard Lake - 2005

Figure 7. [top] Orchard Lake untreated reference site on May 23, 2005. Stem densities averaged 407 stems/m^2.
[bottom] Orchard Lake iron treatment site on May 23, 2005. Stem densities averaged 219 stems/m^2.

Orchard Lake - 2006

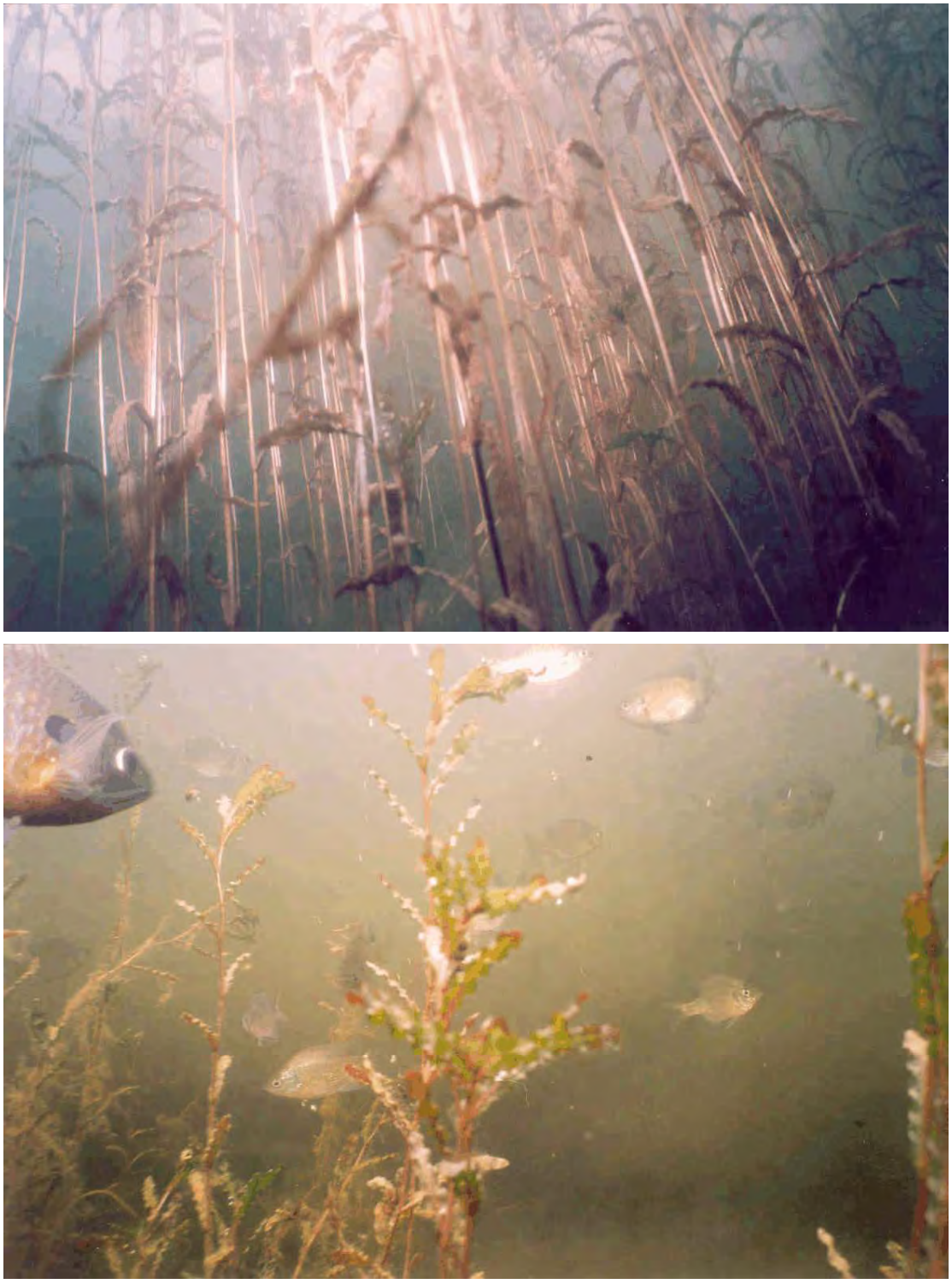


Figure 8. [top] Orchard Lake untreated reference site on May 30, 2006. Stem densities averaged 341 stems/m^2.
[bottom] Orchard Lake iron treatment site on May 30, 2006. Stem densities averaged 89 stems/m^2.

Orchard Lake - 2007

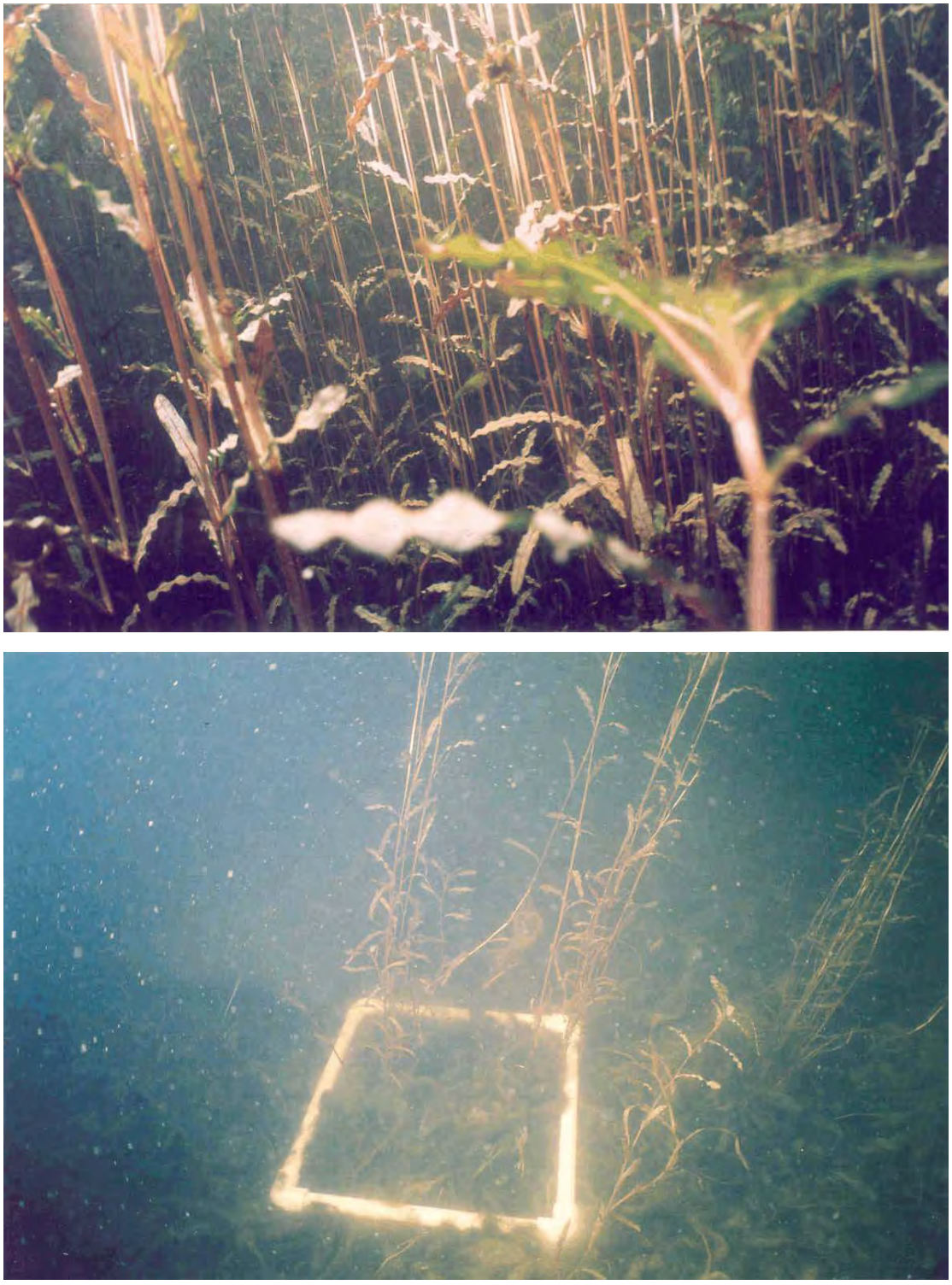


Figure 9. [top] Orchard Lake untreated reference site on May 22, 2007. Stems averaged 514 stems/m^2. [bottom] Orchard Lake iron treatment site on May 22, 2007. Stem densities averaged 240 stems/m^2.

Orchard Lake - 2008

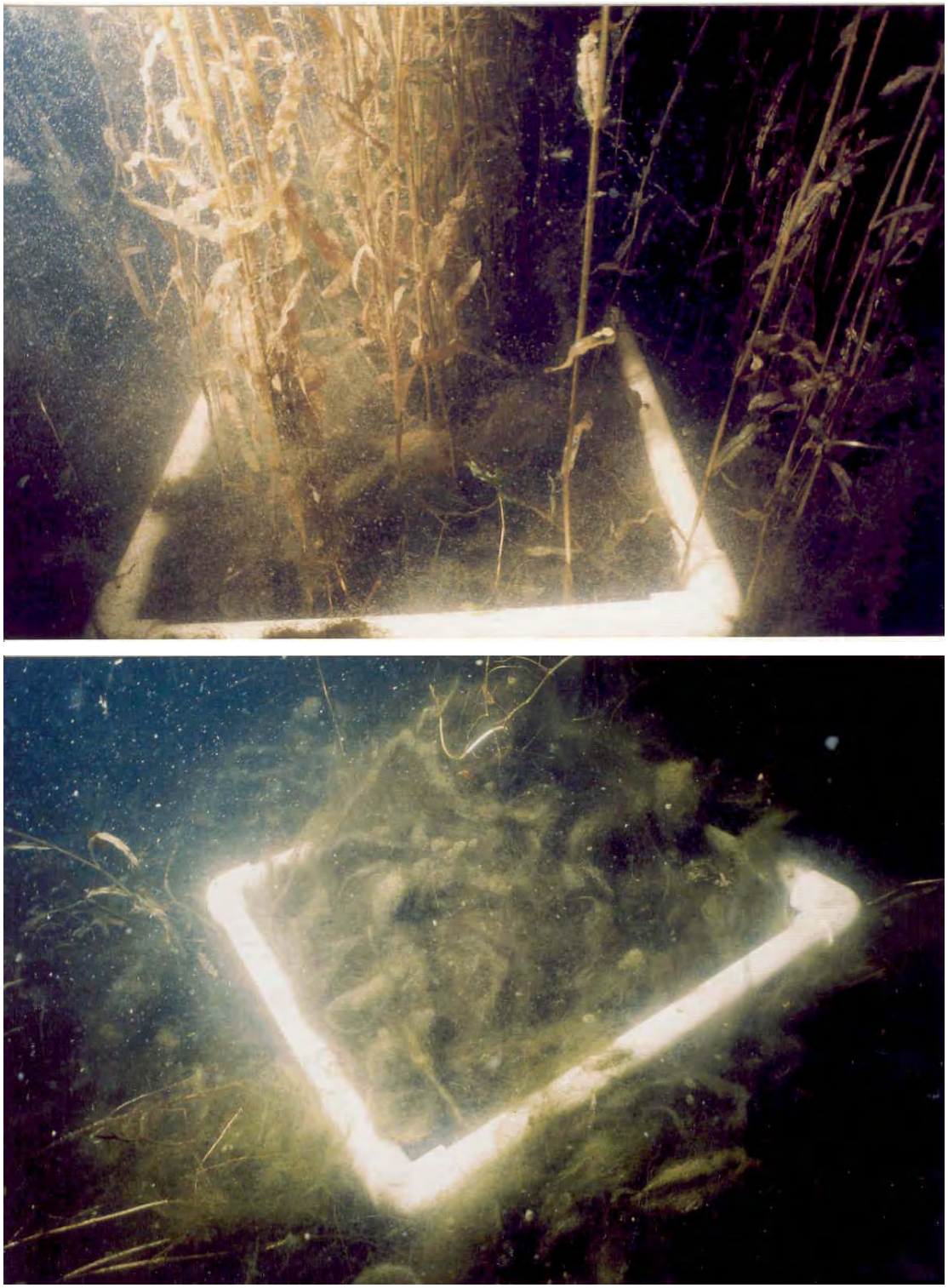


Figure 10. [top] Orchard Lake untreated reference site on May 30, 2008. Stems averaged 360 stems/m^2. [bottom] Orchard Lake iron treatment site on May 30, 2008. Stem densities averaged 78 stems/m^2.

Results for Lee Lake

Monitoring results for stem densities (stems/m^2) curlyleaf biomass (g-dry weight/m^2) and stem weights (grams/stem) are shown in Tables 4, 5, and 6. Iron filings were introduced on March 10, 2004 and post iron monitoring for curlyleaf took place on June 12, 2004, about 95 days after the iron dose and from 2005 through 2008.

In Lee Lake, monitoring results in 2004 found that curlyleaf pondweed was rare, not only in the treatment sites, but also in the reference sites (Table 1). In fact, curlyleaf was scarce throughout the whole lake. Curlyleaf was abundant in 2002 and 2003 and we are not sure why curlyleaf collapsed on a lakewide basis in 2004. However, curlyleaf reappeared in 2005. Findings in 2005 found there was only a slight reduction in stem densities and biomass compared to pre-iron conditions.

Figure 11. [top] Curlyleaf matting on the surface on Lee Lake in an untreated area on May 12, 2007. [bottom] Curlyleaf was less dense in the iron treatment areas on May 12, 2007.

Lee Lake Stem Densities

In 2003, prior to the iron treatment, curlyleaf was known to be widespread in Lee Lake, based on visual observations. However, only five stem density samples were collected in 2003 to quantify the density. Stem densities were high (Table 4) but not as high as they were in Orchard Lake. After the iron treatment of March 10, 2004, curlyleaf monitoring in Lee Lake on June 12, 2004 found curlyleaf pondweed stem densities had declined lakewide. Results of stem counts in both the T-sites and R-sites were low (Table 4). The whole lake curlyleaf decline was unexpected. However, it is probable that the annual summer curlyleaf die-off had occurred.

Curlyleaf reappeared in 2005 and in 2006 and 2007, at slightly lower densities compared to the pretreatment condition. Curlyleaf also had a slightly lower density in the treatment sites compared to the reference sites.

Lee Lake Biomass

Biomass measurements taken on May 31, 2003 at the T2 iron treatment site, prior to the iron addition, ranged from 42.7 to 124.3 g-dry wt/m^2 (Table 5). This is enough curlyleaf to produce light nuisance conditions.

In 2004, the first growing season after the iron treatment, curlyleaf biomass was very low in both the treatment sites (T1 and T21) and the reference sites (R1 and R2). In 2005, the second growing season after the iron treatment, curlyleaf was back but only slightly reduced in biomass compared to pre-treatment conditions. From 2005 through 2008, the treated area biomass was slightly less than the reference site.

Lee Lake Stem Weights

The individual stem weights (g/stem) in Lee Lake were low in 2003, prior to the iron treatment. They were also low in 2004 with the average stem weight being less than 0.5 g-dry wt/stem, except for one sample of 0.78 g-dry wt/stem (Table 6). The low stem weights are typical for curlyleaf found in light nuisance conditions (McComas unpublished).

Monitoring in 2005, 2006, 2007, and 2008 indicated stem weights were similar to stem weights found in pre-treatment conditions in 2003.

Table 4. Lee Lake stem densities.

May 31, 2003 - Pre Iron (iron added March 10, 2004).

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	present but	240	present but	present but
2	not counted	340	not counted	not counted
3		460		
4		220		
5		100		
average		272		

June 12, 2004 - Post Iron - 1st growing season

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	30	0	10	0
2	60	0	0	0
3	0	0	0	0
4	0	0	10	0
5	20	0	10	0
6	0	0	10	0
7	0	10	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	10	0
average	11	1	5	0

May 23, 2005 - Post Iron - 2nd growing season

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	220	130	570	390
2	290	290	360	190
3	230	190	220	190
4	280	90	320	270
5	420	90	250	140
6	210	210	470	410
7	180	140	510	320
8	240	210	220	310
9	180	290	300	360
10	190	210	290	310
average	244	177	351	289

May 29, 2006 - Post Iron - 3rd growing season

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	180	260	260	390
2	190	210	330	390
3	140	180	240	410
4	120	140	180	310
5	90	150	330	320
6	420	180	280	400
7	130	100	450	310
8	110	60	510	300
9	70	130	260	340
10	230	110	500	840
average	168	133	334	401

May 12, 2007 - Post Iron - 4th growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	50	50	370	170
2	30	100	430	410
3	90	100	180	310
4	60	170	430	160
5	90	70	210	160
6	40	100	180	120
7	150	110	260	280
8	100	40	260	200
9	50	30	190	160
10	30	70	240	290
Average	69	84	275	199

May 30, 2008 - Post Iron - 5th growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	30	10	130	160
2	100	20	180	140
3	60	40	180	180
4	0	0	280	230
5	0	0	200	90
6	0	0	230	100
7	0	0	90	120
8	0	0	140	120
9	0	0	120	210
10	0	0	180	160
Average	19	7	173	151

Table 5 . Lee Lake curlyleaf biomass.

May 31, 2003 - Pre Iron (iron added March 10, 2004)

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (g-dry weight/m^2)	
	T1	T2	R1	R2
1	not determined (ND)	90.8	ND	ND
2		91.3		
3		124.3		
4		67.4		
5		42.7		
Average		***83.3***		

June 12, 2004 - Post Iron - 1st growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (g-dry weight/m^2)	
	T1	T2	R1	R2
1	4.1	7.8	1.3	0
2	23.5	0	0.4	0
3	1.7	0	0.1	0
4	0	0	2.3	0
5	0	0	2.6	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
Average	***2.9***	***0.8***	***0.7***	***0***

May 23, 2005 - Post Iron - 2nd growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (g-dry weight/m^2)	
	T1	T2	R1	R2
1	77.9	29.7	131.8	127.1
2	74.0	121.0	112.4	67.3
3	74.2	47.9	70.6	54.4
4	131.6	34.8	111.5	97.5
5	156.4	49.2	102.8	60.2
6	80.3	56.9	116.5	94.0
7	64.8 est	49.0 est	158.1 est	108.9 est
8	86.4 est	73.5 est	68.2 est	102.3 est
9	64.8 est	101.5 est	93.0 est	118.8 est
10	68.4 est	73.5 est	89.9 est	102.3 est
Average	***87.9***	***63.7***	***105.5***	***93.3***

May 29, 2006 - Post Iron - 3rd growing season

Quadrat	Iron Treatment Site (g-dry weight/m^2)		Reference Site (g-dry weight/m^2)	
	T1	T2	R1	R2
1	10.4	11.0	45.5	73.2
2	3.1	14.3	54.7	93.3
3	12.1	25.4	56.1	70.4
4	30.1	14.4	113.1	28.0
5	72.7	25.3	42.4	96.6
6	19.8 est	41.6 est	41.6 est	74.1 est
7	20.9 est	33.6 est	52.8 est	74.1 est
8	15.4 est	28.8 est	38.4 est	77.9 est
9	13.2 est	22.4 est	28.8 est	58.9 est
10	9.9 est	24.0 est	52.8 est	60.8 est
Average	***20.8***	***24.1***	***52.6***	***70.7***

May 12, 2007 - Post Iron - 4th growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	41.4	31.3	173.0	82.5
2	6.9	58.9	171.5	226.3
3	34.0	70.5	87.0	171.5
4	18.5	135.6	137.0	99.5
5	34.9	34.3	75.4	55.7
6	17.2 est	64.0 est	73.8 est	61.2 est
7	64.5 est	70.4 est	106.6 est	142.8 est
8	43.0 est	25.6 est	106.6 est	102.0 est
9	21.5 est	19.4 est	77.9 est	81.6 est
10	12.9 est	44.8 est	98.4 est	142.9 est
Average	***29.5***	***55.5***	***110.7***	***117.1***

May 30, 2008 - Post Iron -5th growing season.

Quadrat	Iron Treatment Site (stems/m^2)		Reference Site (untreated) (stems/m^2)	
	T1	T2	R1	R2
1	3.8	10.0	22.2	58.8
2	7.8	20.0	58.2	62.2
3	5.9	40.0	53.5	83.2
4	0	0	70.0	92.0
5	0	0	50.0	36.0
6	0	0	57.5	40.0
7	0	0	22.5	48.0
8	0	0	35.0	48.0
9	0	0	30.0	84.0
10	0	0	45.0	59.3
Average	***1.8***	***7.0***	***44.4***	***61.2***

Table 6. Lee Lake curlyleaf stem weights.

May 31, 2003

Sample	Iron Treatment Area			Reference Area			
	Stems (stems/ 0.1 m^2)	Dry Weight (grams)	g/stem	Sample	Stems (stems/ 0.1m^2)	Dry Weight (grams)	g/stem
T2 - 1	24	9.08	0.38	R1 - 1	ND	ND	ND
T2 - 2	34	9.13	0.27	R2 - 1	ND	ND	ND
T2 - 3	46	12.43	0.27				
T2 - 4	22	6.74	0.31				
T2 - 5	10	4.27	0.43				
Average	***27.2***	***8.33***	***0.33***				

June 12, 2004

Sample	Iron Treatment Area			Reference Area			
	Stems (stems/ 0.1m^2)	Dry Weight (grams)	g/stem	Sample	Stems (stems/ 0.1m^2)	Dry Weight (grams)	g/stem
T1- 1	3	0.41	0.14	R1 - 1	1	0.13	0.13
T1 - 2	6	2.35	0.39	R1 - 2	1	0.04	0.04
T1 - 3	2	0.17	0.09	R1 - 3	1	0.10	0.10
				R1 - 4	1	0.23	0.23
				R1 - 5	1	0.26	0.26
Average			***0.21***	***Average***			***0.15***
T2- 1	1	0.78	0.78	R2 - 1	no curlyleaf present		

May 23, 2005

Sample	Iron Treatment Area			Reference Area			
	Stems (stems/ 0.1m^2)	Dry Weight (grams)	g/stem	Sample	Stems (stems/ 0.1m^2)	Dry Weight (grams)	g/stem
T1-1	22	7.79	0.35	T1-1	57	13.18	0.23
T1-2	29	7.40	0.26	T1-2	36	11.24	0.31
T1-3	23	7.42	0.32	T1-3	22	7.06	0.32
T1-4	28	13.16	0.47	T1-4	32	11.15	0.35
T1-5	42	15.64	0.37	T1-5	25	10.28	0.41
T1-6	21	8.03	0.38	T1-6	47	11.65	0.25
Average			***0.36***	***Average***			***0.31***
T2-1	13	2.97	0.23	T2-1	39	12.71	0.33
T2-2	29	12.10	0.42	T2-2	19	6.73	0.35
T2-3	19	4.77	0.25	T2-3	19	5.44	0.28
T2-4	9	3.48	0.39	T2-4	27	9.75	0.36
T2-5	9	4.92	0.55	T2-5	14	6.02	0.43
T2-6	21	5.69	0.27	T2-6	41	9.40	0.23
Average			***0.35***	***Average***			***0.33***

May 29, 2006

Sample	Iron Treatment Area			Reference Area			
	Stems (stems/ 0.1m^2)	Dry Weight (grams)	g/stem	Sample	Stems (stems/ 0.1m^2)	Dry Weight (grams)	g/stem
T1 - 1	7	1.04	0.15	R1 - 1	26	4.55	0.18
T1 - 2	11	0.31	0.03	R1 - 2	28	5.47	0.20
T1 - 3	13	1.21	0.09	R1 - 3	45	5.61	0.12
T1 - 4	23	3.01	0.13	R1 - 4	50	11.31	0.23
T1 - 5	42	7.27	0.17	R1 - 5	51	4.24	0.08
Average			***0.11***	***Average***			***0.16***
T2 - 1	6	1.10	0.18	R2 - 1	30	7.32	0.24
T2 - 2	10	1.43	0.14	R2 - 2	31	9.33	0.30
T2 - 3	11	2.54	0.23	R2 - 3	34	7.04	0.21
T2 - 4	13	1.44	0.11	R2 - 4	40	2.80	0.07
T2 - 5	18	2.53	0.14	R2 - 5	84	9.66	0.12
Average			***0.16***	***Average***			***0.19***

Table 6. Lee Lake curlyleaf stem weights.

May 12, 2007

Sample	Iron Treatment Area			Sample	Reference Area		
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem		Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T1 - 1	5	4.14	0.83	R1 - 1	37	17.30	0.47
T1 - 2	3	0.69	0.23	R1 - 2	43	17.15	0.40
T1 - 3	9	3.40	0.38	R1 - 3	18	8.70	0.48
T1 - 4	6	1.85	0.31	R1 - 4	43	13.70	0.32
T1 - 5	9	3.49	0.39	R1 - 5	21	7.54	0.36
Average			***0.43***	***Average***			***0.41***
T2 - 1	5	3.13	0.63	R2 - 1	17	8.25	0.48
T2 - 2	10	5.89	0.59	R2 - 2	41	22.63	0.55
T2 - 3	10	7.05	0.71	R2 - 3	31	17.15	0.55
T2 - 4	17	13.56	0.80	R2 - 4	16	9.95	0.62
T2 - 5	7	3.43	0.49	R2 - 5	16	5.57	0.35
Average			***0.64***	***Average***			***0.51***

May 30, 2008

Sample	Iron Treatment Area			Sample	Reference Area		
	Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem		Stems (stems/ $0.1m^2$)	Dry Weight (grams)	g/stem
T1 - 1	6	0.59	0.10	R1 - 1	18	5.82	0.32
T1 - 2	3	0.38	0.13	R1 - 2	13	2.22	0.17
T1 - 3	10	0.78	0.08	R1 - 3	18	5.35	0.30
Average			***0.10***	***Average***			***0.25***
T2 - 1				R2 - 1	14	6.22	0.44
T2 - 2				R2 - 2	16	5.88	0.37
T2 - 3				R2 - 3	18	5.93	0.33
T2 - 4				R2 - 4	18	8.32	0.46
Average			***ND***	***Average***			***0.40***

Lee Lake - 2004

Figure 12. [top and bottom] Lee Lake, June 12, 2004 in areas treated with iron filings on March 10, 2004. Stem densities were low in the treated area, but they were also low in the reference area.

Lee Lake - 2005

Figure 13. [top] Lee Lake untreated reference site on May 23, 2005. Stem densities averaged 320 stems/m^2. [bottom] Lee Lake iron treatment site on May 23, 2005. Stem densities averaged 211 stems/m^2.

Lee Lake - 2006

Figure 14. [top] Lee Lake untreated reference site on May 30, 2006. Stem densities averaged 368 stems/m^2. [bottom] Lee Lake iron treatment site on May 30, 2006. Stem densities averaged 151 stems/m^2.

Lee Lake - 2007

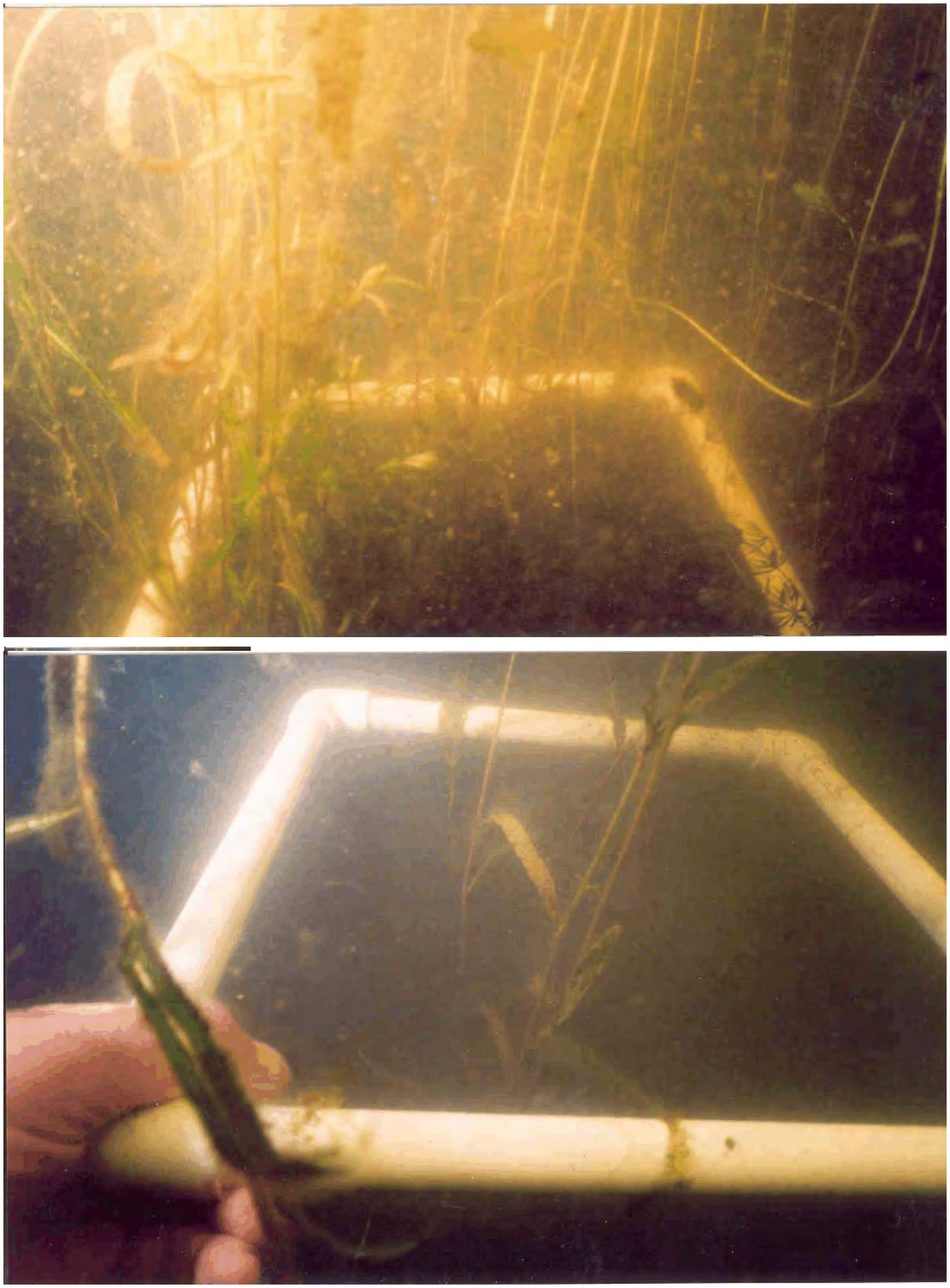


Figure 15. [top] Lee Lake untreated reference site on May 12, 2007. Stem densities averaged 237 stems/m^2. [bottom] Lee Lake iron treatment site on May 12, 2007. Stem densities averaged 77 stems/m^2.

Lee Lake - 2008

Figure 16. [top] Lee Lake untreated reference site on May 30, 2008. Stem densities averaged 162 stems/m^2. [bottom] Lee Lake iron treatment site on May 30, 2008. Stem densities averaged 11 stems/m^2.

Conclusion and Recommendations

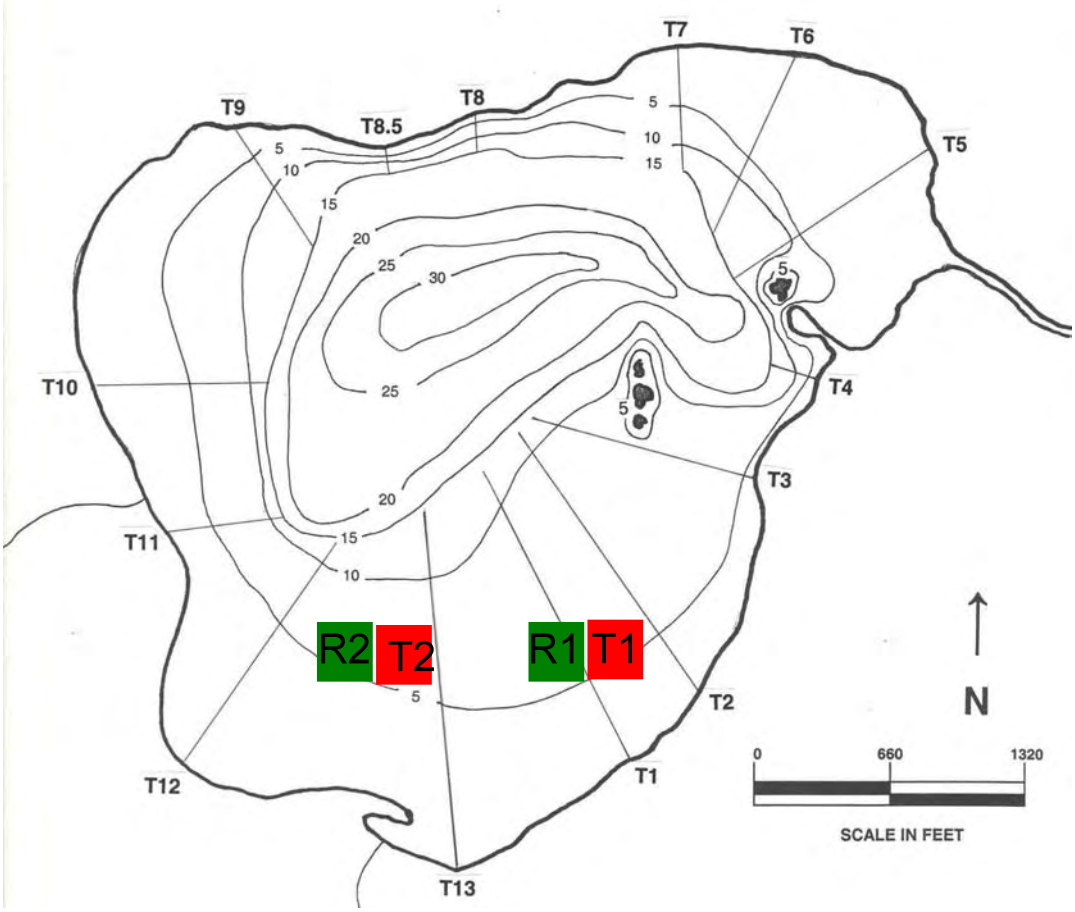
The iron treatment has reduced curlyleaf growth in Orchard Lake in treated areas compared to untreated areas. The curlyleaf pondweed has also declined in Lee Lake in treated areas compared to untreated areas (Table 7). Curlyleaf monitoring is recommended in 2009 to see if curlyleaf control is sustained in both Orchard Lake and Lee Lake.

Table 7. Summary of stem density and biomass results for 2004, 2005, 2006, 2007, and 2008. Iron filings were added to Orchard Lake on March 9, 2004 and to Lee Lake on March 10, 2004.

	Stem Density (#/m^2)		Biomass (g-dry wt/m^2)	
	Treatment	Reference	Treatment	Reference
ORCHARD				
Pre-Iron (June 7, 2003)	454 (n=15)	436 (n=10)	307 (n=5)	391 (n=5)
Post Iron - yr 1 (May 24, 2004)	425 (n=20)	403 (n=20)	190 (n=11)	158 (n=12)
Post Iron - yr 2 (May 23, 2005)	219 (n=20)	407 (n=20)	101 (n=12)	167 (n=12)
Post Iron - yr 3 (May 30, 2006)	89 (n=20)	341 (n=20)	27 (n=12)	177 (n=10)
Post Iron - yr 4 (May 22, 2007)	240 (n=20)	514 (n=20)	60 (n=10)	184 (n=10)
Post Iron - yr 5 (May 30, 2008)	78 (n=20)	360 (n=20)	28 (n=6)	96 (n=6)
LEE				
Pre-Iron (May 31, 2003)	272 (n=5)	--	83 (n=5)	--
Post Iron - yr 1 (June 12, 2004)	6 (n=20)	3 (n=20)	2 (n=20)	0.4 (n=20)
Post Iron - yr 2 (May 23, 2005)	211 (n=20)	320 (n=20)	76 (n=12)	99 (n=12)
Post Iron - yr 3 (May 30, 2006)	151 (n=20)	368 (n=20)	23 (n=10)	62 (n=10)
Post Iron - yr 4 (May 12, 2007)	77 (n=20)	237 (n=20)	43 (n=10)	114 (n=10)
Post Iron - yr 5 (May 30, 2008)	13 (n=20)	162 (n=20)	4 (n=20)	53 (n=7)

Appendix

Curlyleaf turion on a curlyleaf stem in Orchard Lake.



Orchard Lake: Treatment and Reference Sites

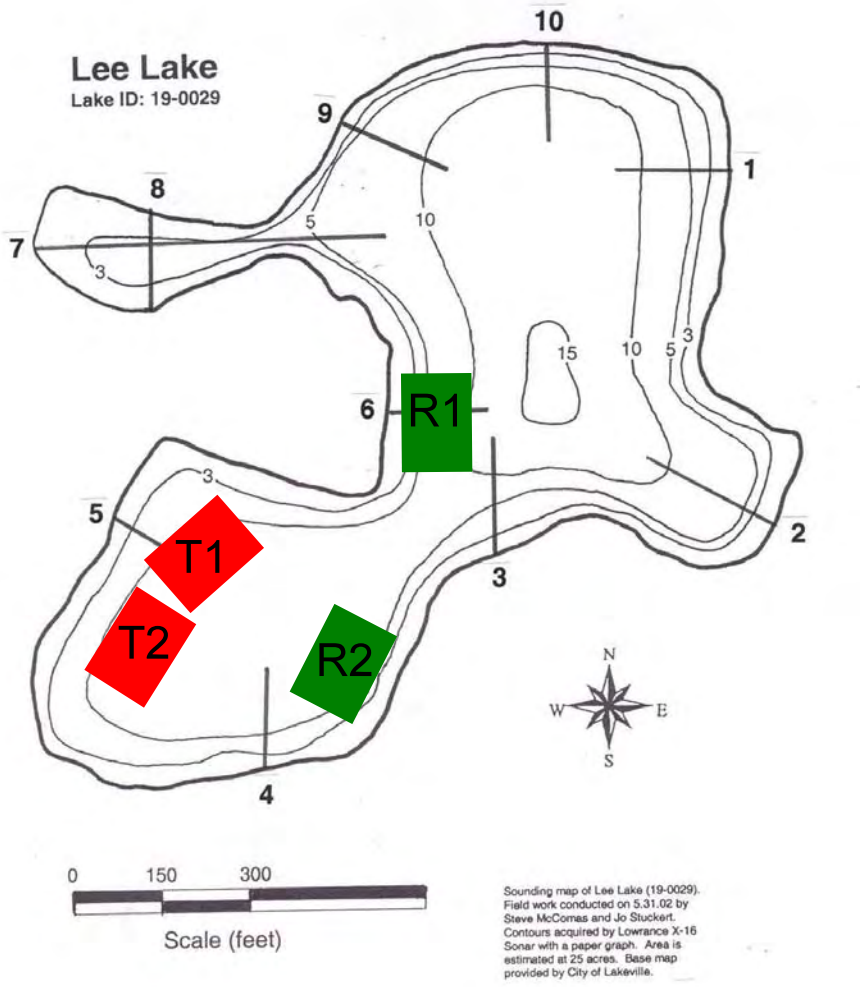
GPS coordinates for the center of each site (NAD 27 coord)

Site 1: 04 75 580 E
49 49 170 N
Site markers:
100 yards from wall
right of landing
5.5 - 6.5 feet of water depth

Site 2: 04 75 370 E
49 49 199 N
Site makers:
140 yards from shore
left of transect 13 on shore house (from left to right) big tan house, blue house, brown house
5.5 - 6.5 feet of water depth

Reference 1: 04 75 643 E
49 49 213 N
Site markers:
149 yards from shore
5-6 feet of water depth

Reference 2: 04 75 229 E
49 49 183 N
Site markers:
134 yards from shore
5-6 feet of water depth



Lee Lake: Treatment and Reference Sites

GPS coordinates for the center of each site

Site 1:
Site markers:
150 feet long by 120 feet deep
5.0 - 6.5 feet of water depth

Site 2:
Site makers:
150 feet long by 120 feet deep
5.0 - 6.5 feet of water depth

Reference 1:
Site markers:
on Transect 6 (used for plant survey)

Reference 2:
Site markers:
opposite side of bay from T1 and T2