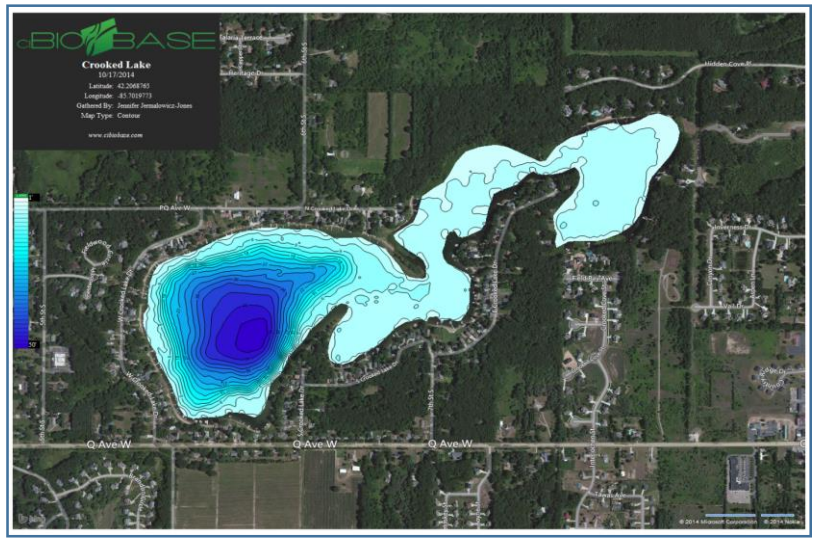
Crooked Lake LFA Evaluation Data, Results, and Recommendations

By: Restorative Lake Sciences

Jennifer L. Jermalowicz-Jones, PhD

May 25, 2017



Restorative Lake Sciences™

Original CLTA Objectives

- Reduce weeds (both native and invasive species)
- Reduce muck (both depth and extent)
- Maintain or improve water quality (clarity, transparency, etc.)

Benthic & Aquatic Vegetation Scanning

- Contour Innovations Technology (2013)
- Lowrance HDS echo-sounder; WAAS-corrected
- 15-20 data signals per second w/200 kHz transducer; 20° beam angle
- All data uploaded from HDS unit to BioBase cloud server
- Method supported by peer-reviewed research including: Valley et al., (2015); Valley (2016); Winfield et al., (2015) among others

Changes in Crooked Lake Water Quality (by parameter per Basin)

MDEQ WQ Sampling Requirements from LFA Permit (Issued by Larry Poynter)

- Sample each basin at mid or bottom depth ONCE prior to operation of LFA
- Sample each basin in May and July of each year at mid or bottom depth
- Laboratory QA/QC: Nelac-certified laboratory (TRACE Analytical, Inc.)


Crooked Lake
Kalamazoo County, MI
Legend
Water Quality Sample Site
N42.21°
W85.690
001
002
003
004
Crooked Lake
W-P-Q-Ave-N
Crooked-Lake-Dr
E-Crooked-Lake-Dr
S-Crooked-Lake-Dr
Crooked-Lake-Dr-W
Field-Bay
Canyon-Dr
Crooked-Cove-St
Drake-Ridge
S-7th-St
W-Q-Ave
Interlochen-St
Boyne-St
Tawas-Ave
S-6th-St
Brandon-St
1000 ft
N
Google earth
© 2014 Google

Statistical Analysis of Physical WQ Parameters (Pre-Aeration). Note: Pre-aeration was only a single data point due to MDEQ requirements. Otherwise, we could have run an Repeated Measures ANOVA.

BASIN	WEST	MIDDLE	NORTH	HIDDEN COVE
DO (mg/L)* bottom	2.0	7.9	7.6	7.5
pH (S.U.)	8.7	8.6	8.7	8.6
Conductivity ($\mu S\ cm^{-1}$)	265	264	268	293
Secchi (feet)	19.0	3.0+	2.0+	3.0+

Statistical Analysis of Physical WQ Parameters (Post-Aeration). Note: Pre-aeration was only a single data point due to MDEQ requirements. Otherwise, we could have run an Repeated Measures ANOVA. Here, the means and standard deviations are presented.

BASIN	DO (mg/L)	pH (S.U.)	Conductivity ($\mu s\ cm^{-1}$)	Secchi (feet)
WEST	7.4±0.7	8.5±0.3	275±24	16.0±6.4
MIDDLE	8.1±0.7	8.5±0.2	276±26	4.1±1.8
NORTH	8.1±0.7	8.5±0.1	280±30	3.8±1.3
HIDDEN COVE	8.3±0.7	8.4±0.3	278±50	4.2±1.8

Statistical Analysis of Chemical WQ Parameters (Pre-Aeration). Note: Pre-aeration was only a single data point due to MDEQ requirements. Otherwise, we could have run an Repeated Measures ANOVA.

BASIN	WEST	MIDDLE	NORTH	HIDDEN COVE
TP (µg/L)	<0.010	<0.010	<0.010	<0.010
Ortho-P (µg/L)	<0.010	<0.010	<0.010	<0.010
TSS (mg/L)	<10	<10	<10	<10
Chl-a (µg/L)	0.64	0.79	1.16	1.03

Statistical Analysis of Chemical WQ Parameters (Post-Aeration). Note: Pre-aeration was only a single data point due to MDEQ requirements. Otherwise, we could have run an Repeated Measures ANOVA. Here, the means and standard deviations are presented.

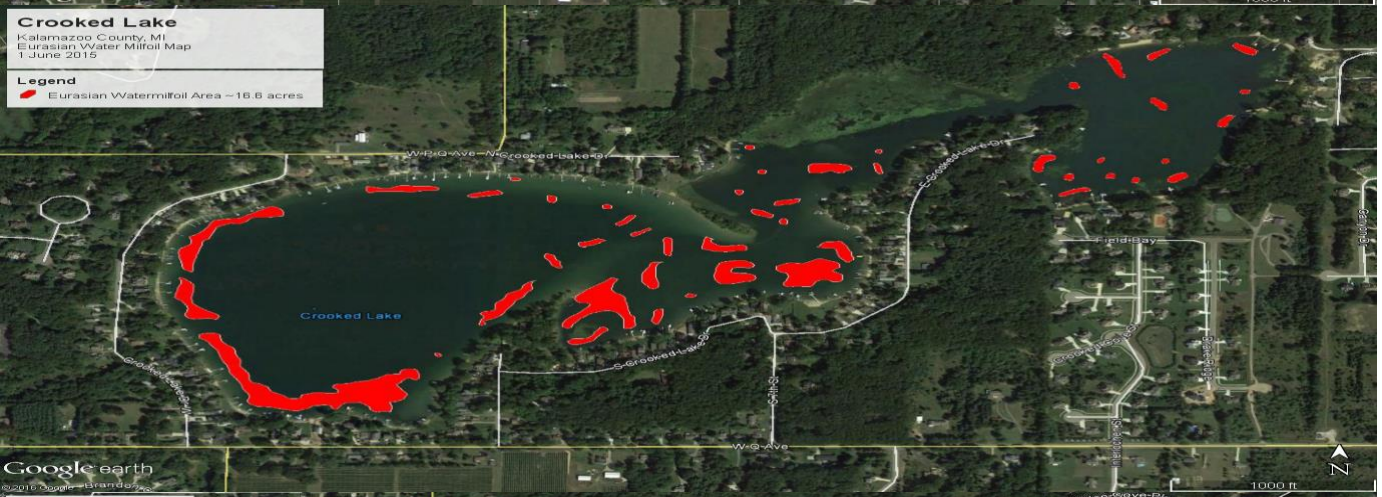
BASIN	TP (µg/L)	Ortho-P (µg/L)	TSS (mg/L)	Chl-a µg/L)
WEST	0.013±0.0	0.010±0.0	12±5.7	1.3±2.6
MIDDLE	0.012±0.0	0.010±0.0	13±8.3	0.2±0.4
NORTH	0.012±0.0	0.010±0.0	12±3.9	0.5±0.5
HIDDEN COVE	0.010±0.0	0.010±0.0	11±2.3	0.5±0.5

Conclusions on Chemical WQ Data

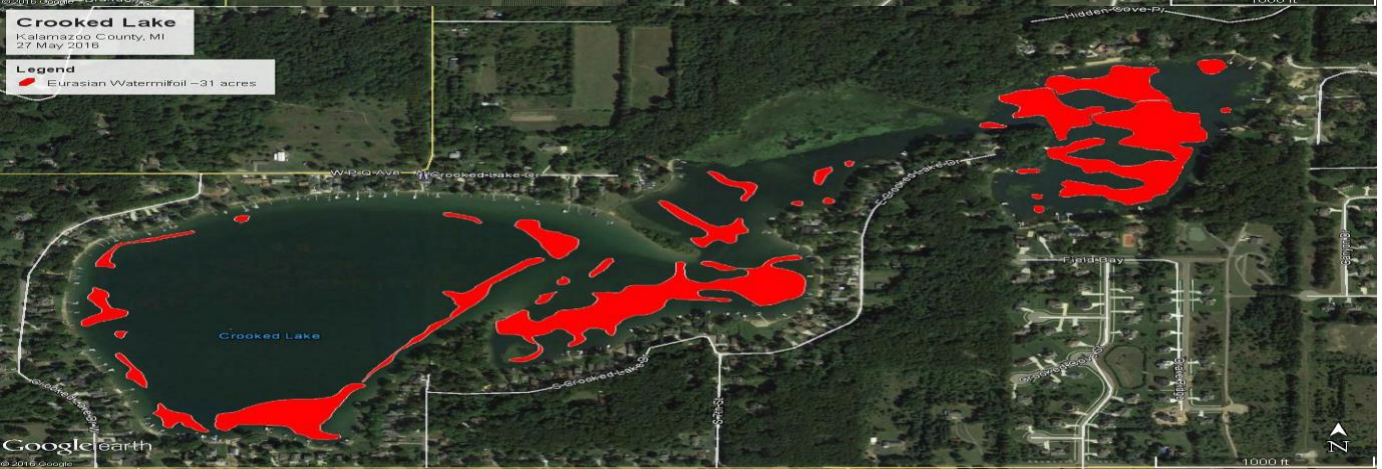
- Although a Repeated Measures ANOVA is preferred and could not be run, we found very little changes in TP, ortho-P, TSS, and Chl-a when compared to the baseline conditions (Due to the standard deviations being in the same range as the baseline data, this means that LFA is not having a significant impact on these variables

Changes in Crooked Lake EWM (by Basin in Acres)

2014 Pre-Aeration



2015 Post-Aeration



2016 Pre-Aeration

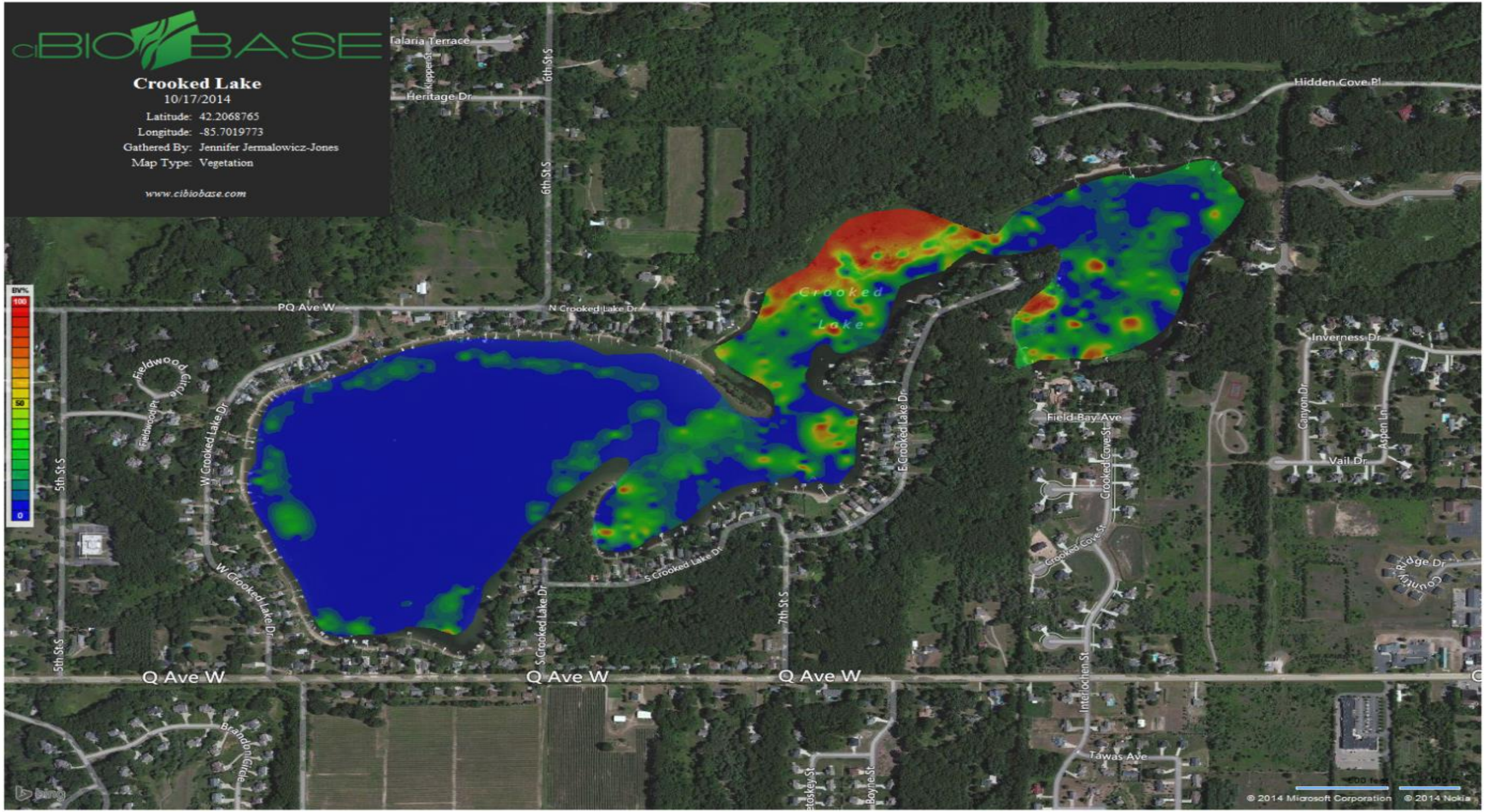
Change in EWM (acres with time)

Basin	2014	2015	2016	Net Change
Hidden Cove	**1.3**	**5.0**	**12.6**	**+11.3 acres**
Basin 2	**3.6**	**1.5**	**2.0**	**-1.6 acres**
Basin 3	**6.5**	**1.8**	**7.9**	**+1.4 acres**
Basin 4 (West Basin)	**12.0**	**8.5**	**8.4**	**-3.6 acres**

Other Invasives

- RLS created polygon maps for the primary invasive (EWM) and also for secondary and tertiary invasives-Curly-leaf Pondweed (CLP) and Starry Stonewort (SS)

Changes in Crooked Lake Aquatic Vegetation Biovolume (by Basin in % Cover)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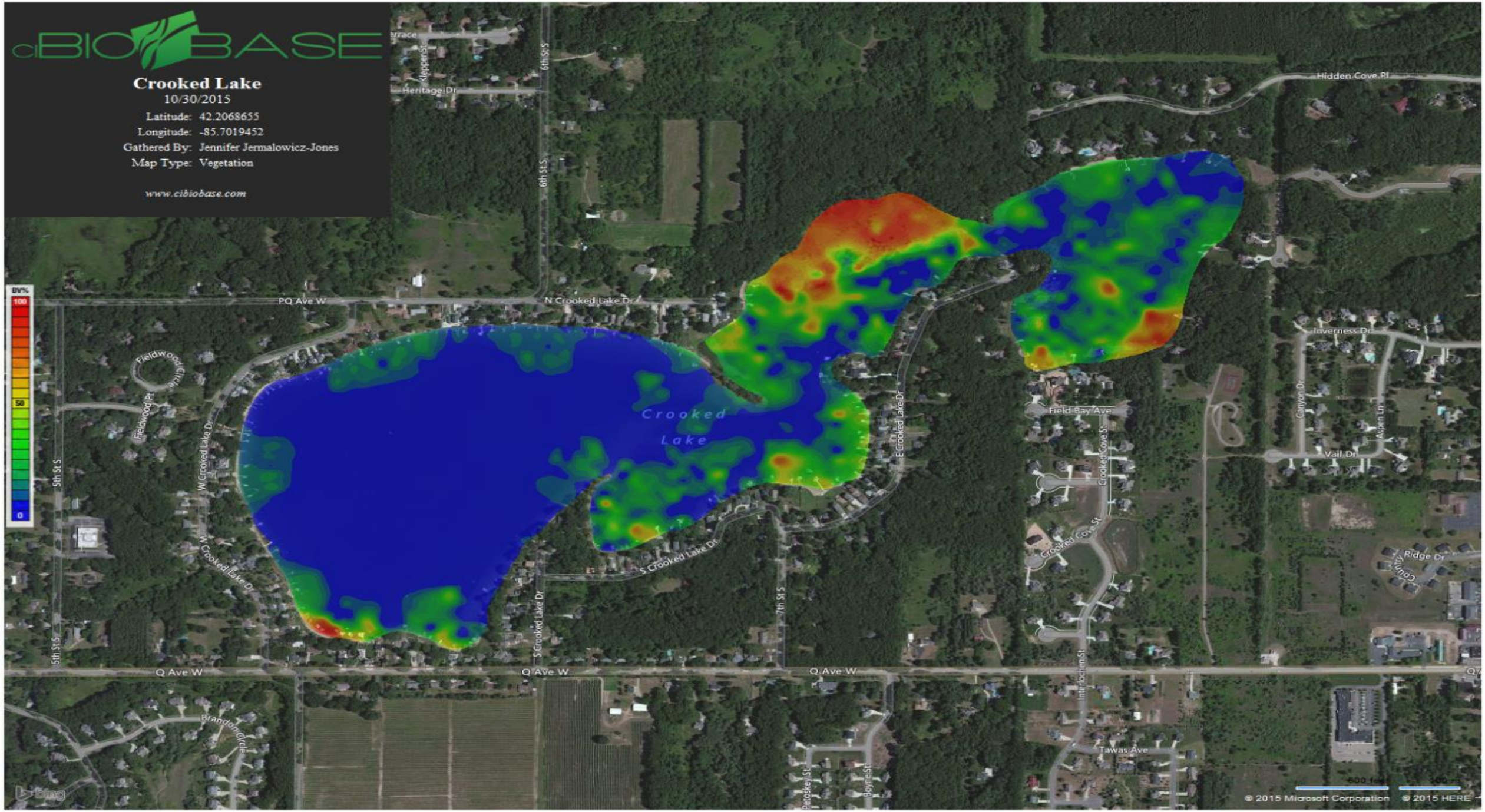
Crooked Lake
10/17/2014
Latitude: 42.2068765
Longitude: -85.7019773
Gathered By: Jennifer Jermalowicz-Jones
Map Type: Vegetation
www.cibiobase.com
BV%
100
50
0
Talaria Terrace
Klepper St
Heritage Dr
6th St S
Hidden Cove Pl
PQ Ave W
N Crooked Lake Dr
Crooked Lake
Inverness Dr
Canyon Dr
Aspen Ln
Vail Dr
Fieldwood Circle
Fieldwood Pl
W Crooked Lake Dr
5th St S
E Crooked Lake Dr
Field Bay Ave
Crooked Cove St
S Crooked Lake Dr
7th St S
Country Ridge Dr
Q Ave W
Q Ave W
Q Ave W
Interlochen St
Brandon Circle
Tawas Ave
Petoskey St
Boyne St
© 2014 Microsoft Corporation
© 2014 Nokia


cIBIOBASE
Crooked Lake
10/30/2015
Latitude: 42.2068655
Longitude: -85.7019452
Gathered By: Jennifer Jermalowicz-Jones
Map Type: Vegetation
www.cibiobase.com
BV%
100
50
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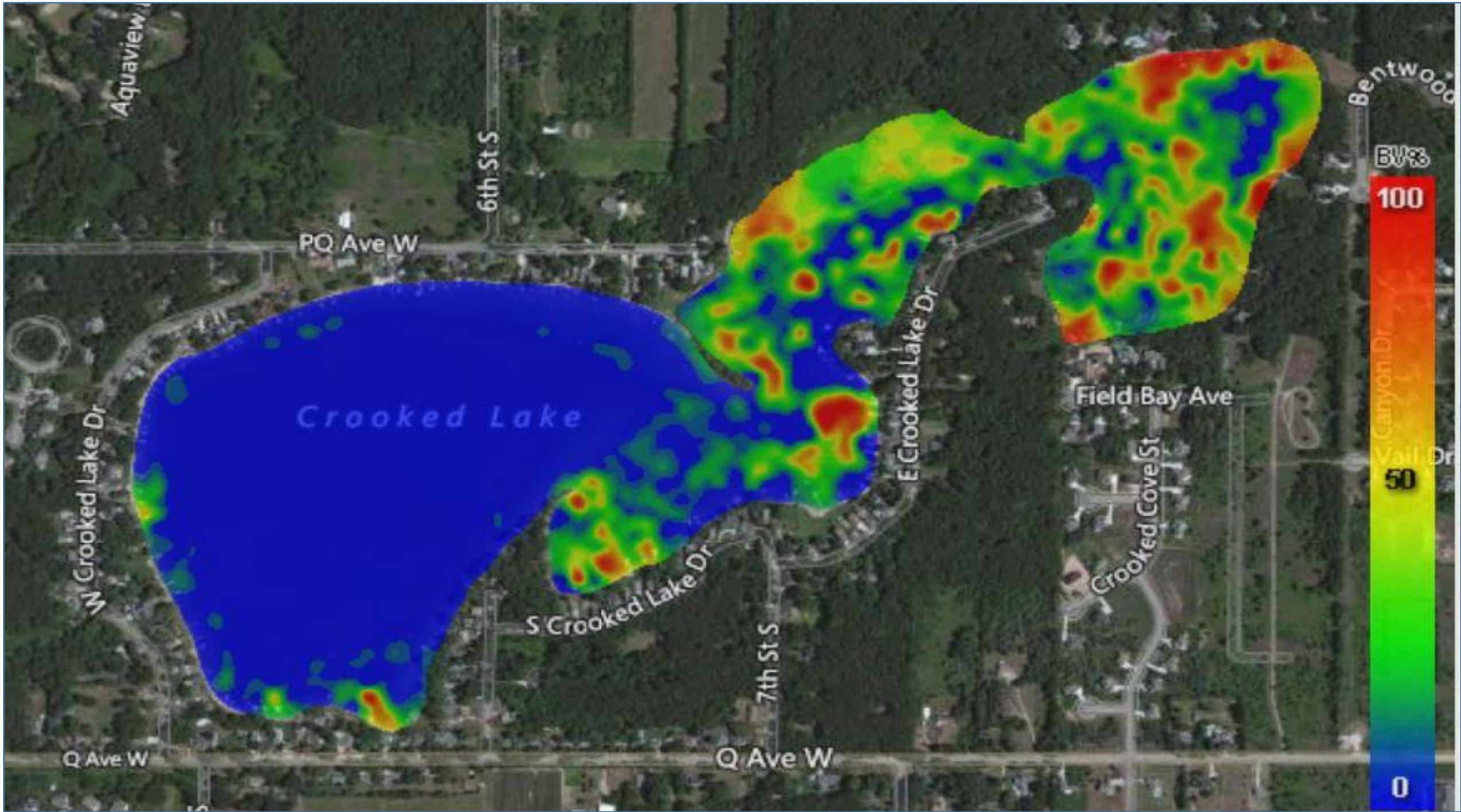
Crooked Lake
PQ Ave W
N Crooked Lake Dr
Q Ave W
S Crooked Lake Dr
E Crooked Lake Dr
W Crooked Lake Dr
5th St S
6th St S
7th St S
Heritage Dr
Hidden Cove Pl
Inverness Dr
Canyon Dr
Aspen Ln
Vail Dr
Field Bay Ave
Crooked Cove St
Ridge Dr
Fieldwood Circle
Fieldwood Pl
Brandon Circle
Tawas Ave
Interlochen St
Petoskey St
Boyne St
© 2015 Microsoft Corporation
© 2015 HERE


Aquaview
6th St S
PQ Ave W
Crooked Lake
W Crooked Lake Dr
E Crooked Lake Dr
S Crooked Lake Dr
7th St S
Field Bay Ave
Crooked Cove St
Canyon Dr
Vail Dr
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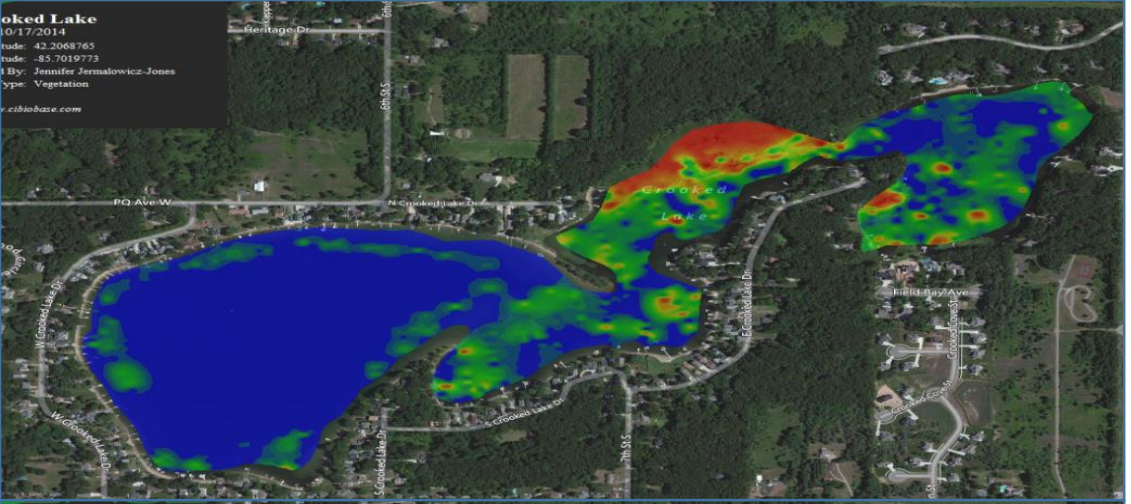
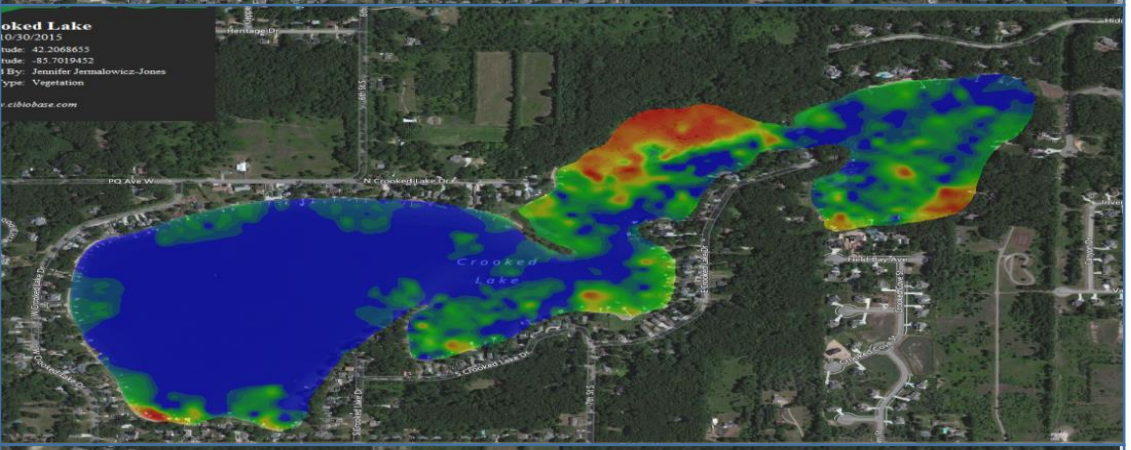
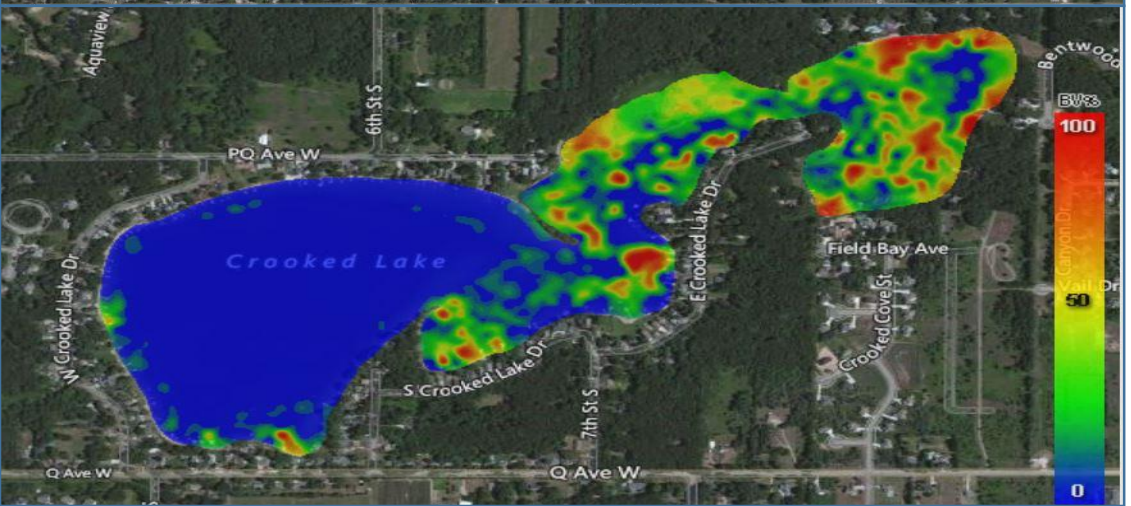


2014 (Pre-Aeration)



2015 (1 Year Post-Aeration)

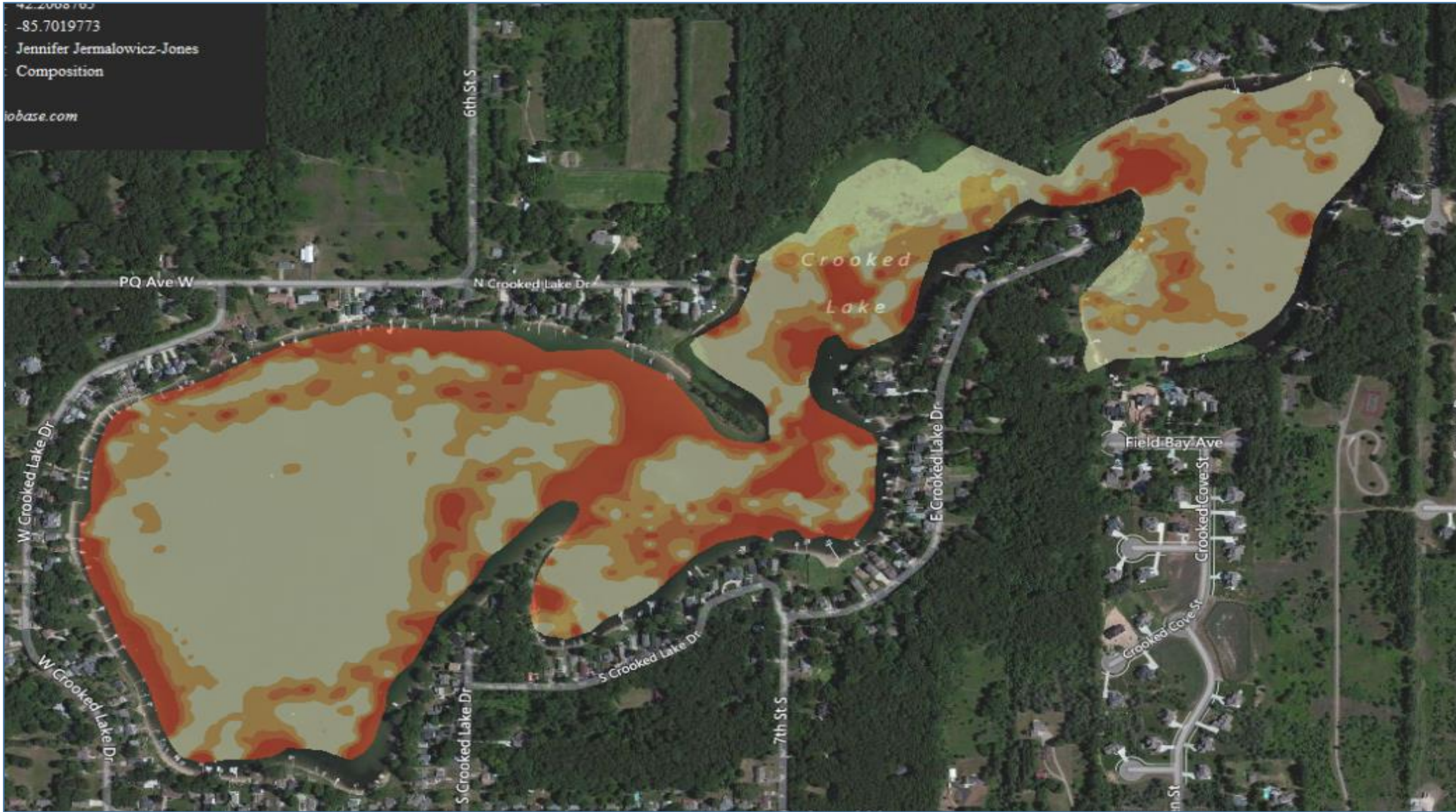


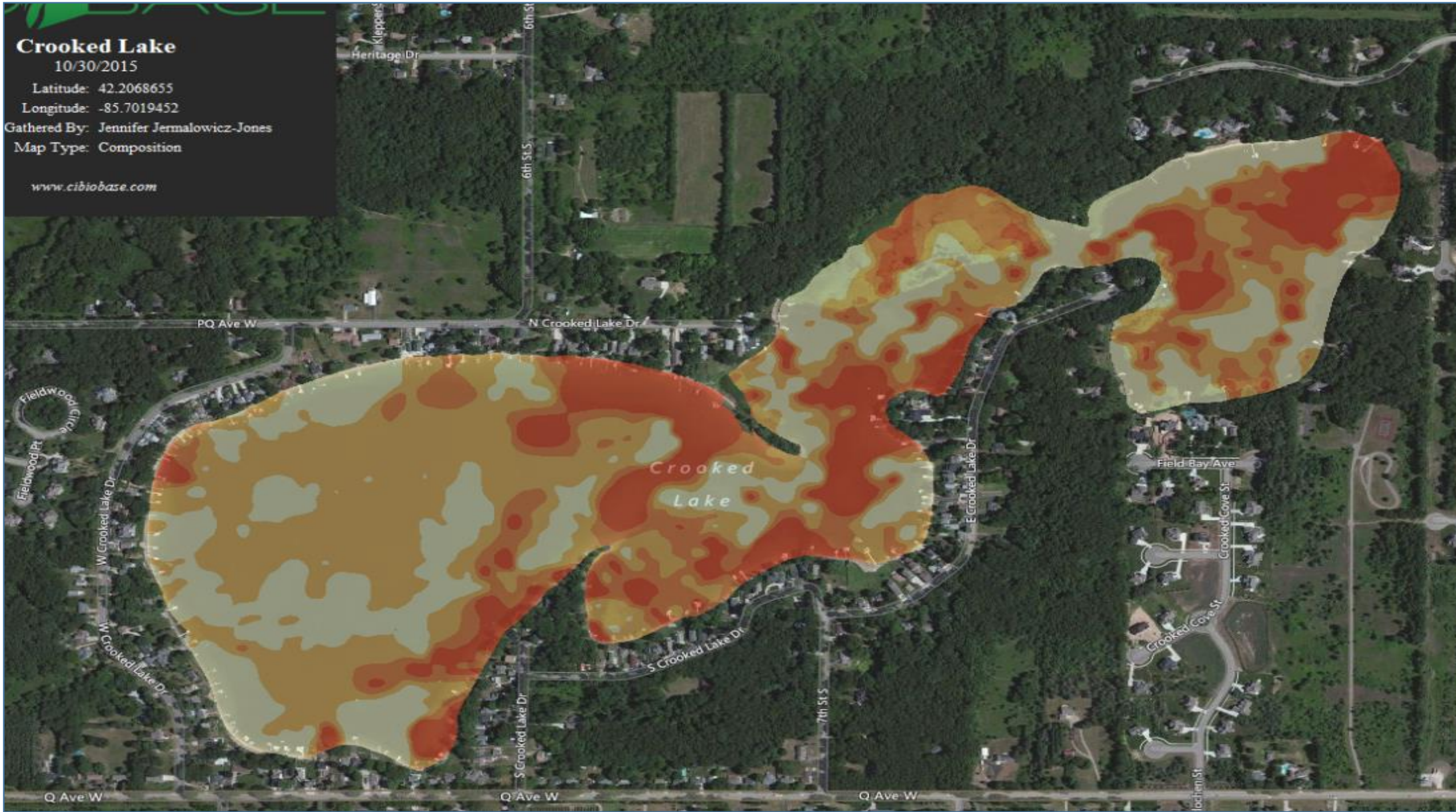
2016 (2 Year Post-Aeration)

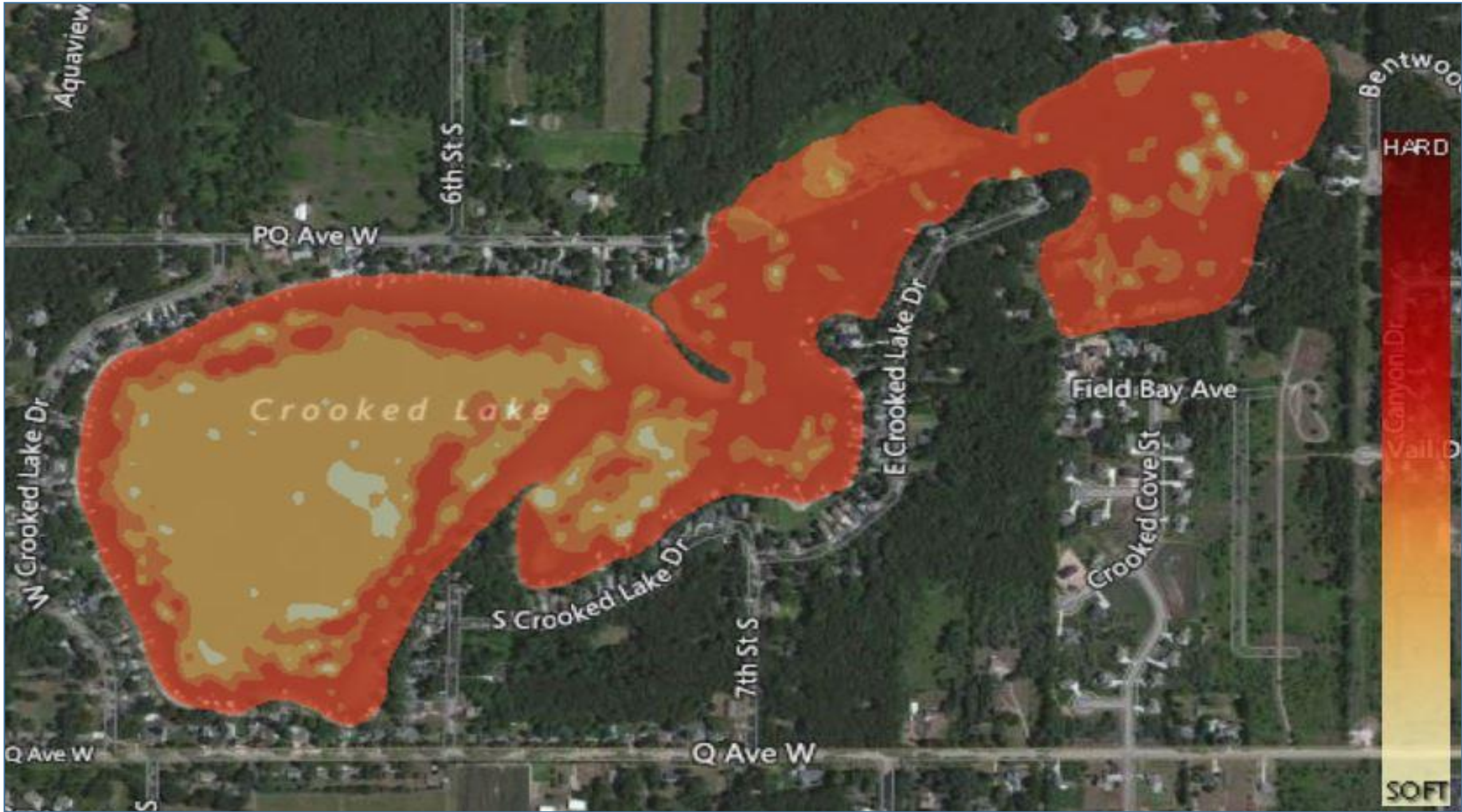
Change in Aquatic Vegetation Biovolume for Crooked Lake

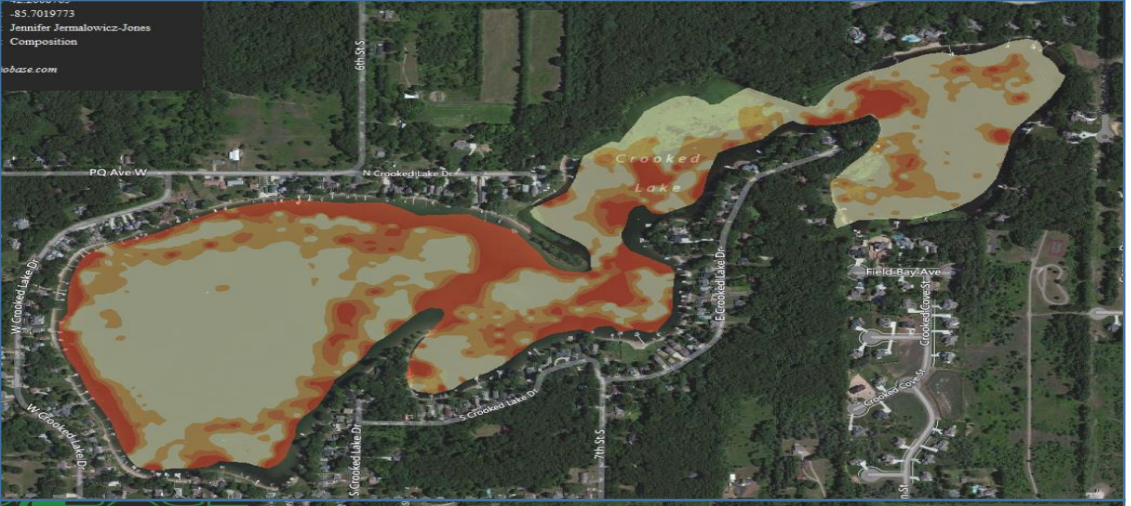
% Biovolume		2014	2015	2016
0-5%	SPARSE	57.5	39.8	41.5
5-20%		22.4	30.3	32.6
20-40%	COMMON	8.5	11.2	8.6
40-60%		3.8	3.8	5.6
60-80%		3.2	3.5	4.1
80-100%	DENSE	4.7	11.4	7.6

Changes in Crooked Lake Sediment Bottom Hardness (by Basin in % cover)

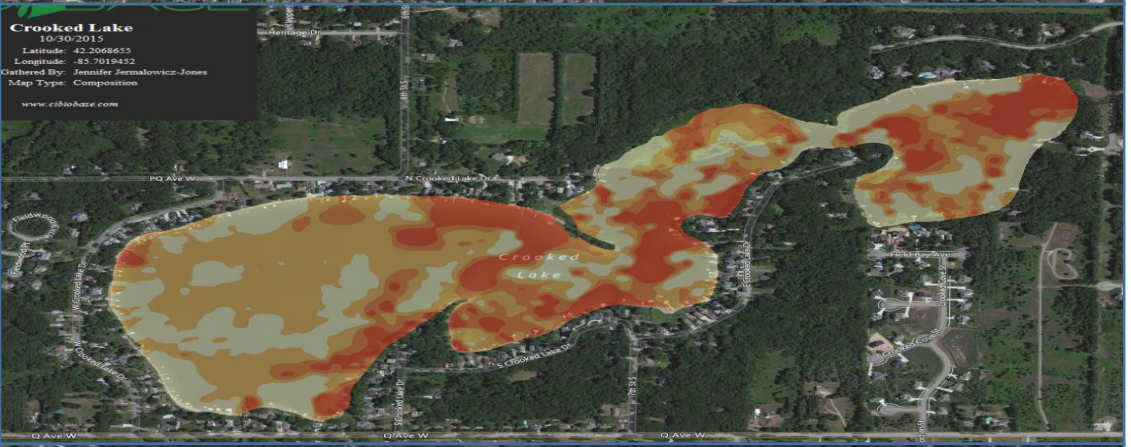

-85.7019773
Jennifer Jermalowicz-Jones
Composition
6th St S
PQ Ave W
N Crooked Lake Dr
Crooked Lake
W Crooked Lake Dr
E Crooked Lake Dr
Field Bay Ave
Crooked Cove St
S Crooked Lake Dr
7th St S


Crooked Lake
10/30/2015
Latitude: 42.2068655
Longitude: -85.7019452
Gathered By: Jennifer Jernalowicz-Jones
Map Type: Composition
www.cibiobase.com
Heritage Dr
6th St S
PQ Ave W
N Crooked Lake Dr
Fieldwood Circle
Fieldwood Pt
W Crooked Lake Dr
E Crooked Lake Dr
Crooked Lake
Field Bay Ave
Crooked Cove St
S Crooked Lake Dr
7th St S
Q Ave W
Q Ave W
Q Ave W


Aquaview
6th St S
PQ Ave W
Crooked Lake
W Crooked Lake Dr
E Crooked Lake Dr
S Crooked Lake Dr
7th St S
Field Bay Ave
Crooked Cove St
Q Ave W
Q Ave W
HARD
SOFT



2014 (Pre-Aeration)



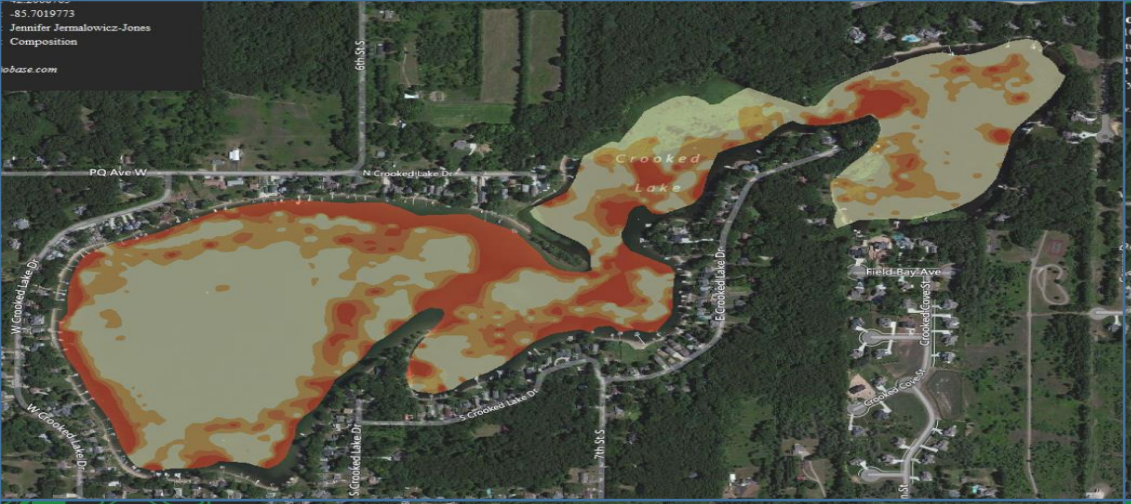
2015 (1 Year Post-Aeration)

2016 (2 Year Post-Aeration)

Changes in Bottom Sediment Hardness in Crooked Lake

	Pre-Aeration		Post-Aeration
Hardness	**2014**	**2015**	**2016**
Very Soft (<0.1 hardness); flocculent or semi-fluid	0.76%	0.34%	0.08%
Med Soft (0.1 to 0.2 hardness); gel-like	5.91%	2.70%	0.63%
Medium (0.2 to 0.3 hardness); consolidated granules	52.47%	44.00%	34.76%
Med Hard (0.3 to 0.4 hardness); sand	25.3%	37.54%	31.64%
Very Hard (>0.4 hardness); sand, gravel, rock	15.6%	15.42%	32.90%

Per Ray Valley: biovolume > 60% may also read as soft bottom; however, in reviewing the biovolume and sediment hardness maps, most areas with marked sediment hardness increase did not have >60% biovolume.


-85.7019773
Jennifer Jermalowicz-Jones
Composition
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Field Bay Ave
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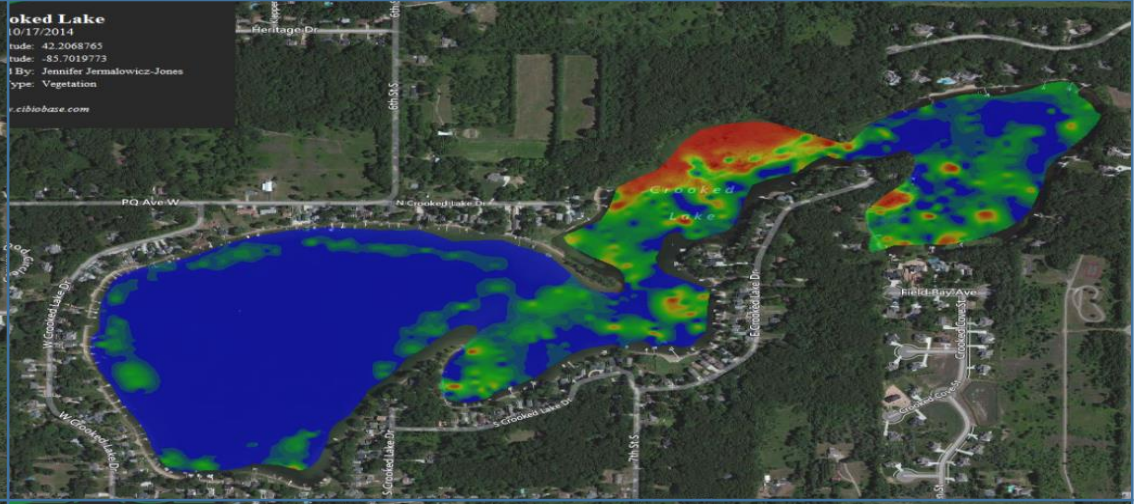
S Crooked Lake Dr
6th St S
7th St S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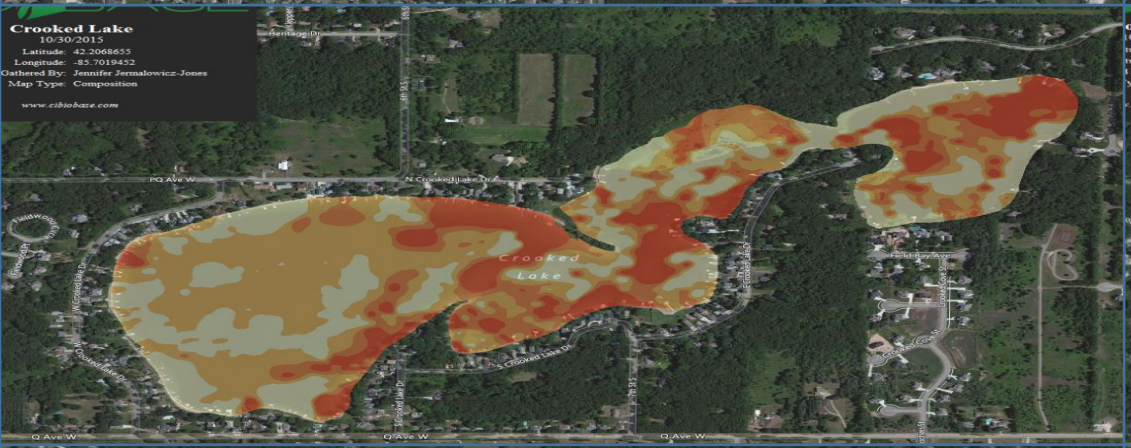
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Field Bay Ave
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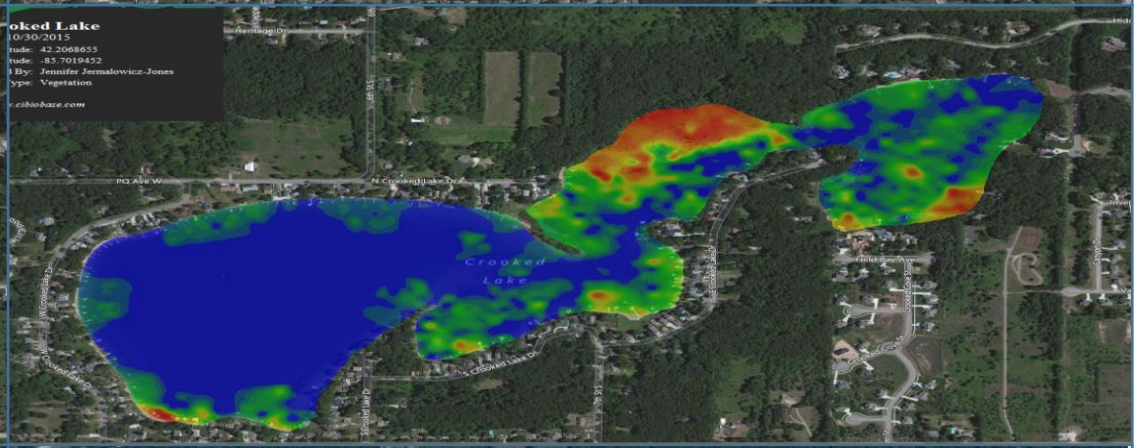
E Crooked Lake Dr
S Crooked Lake Dr
6th St S
7th St S
Q Ave W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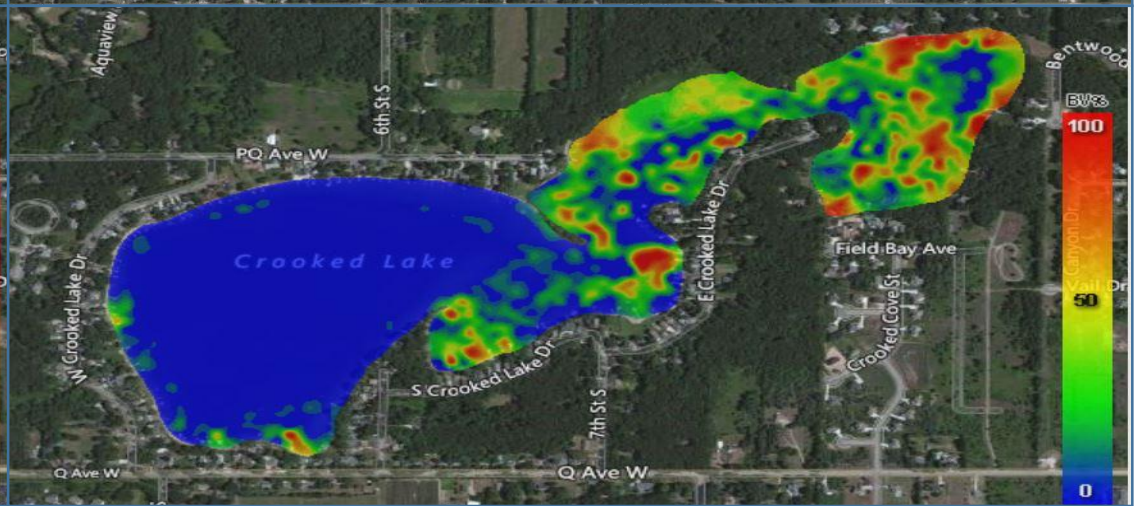
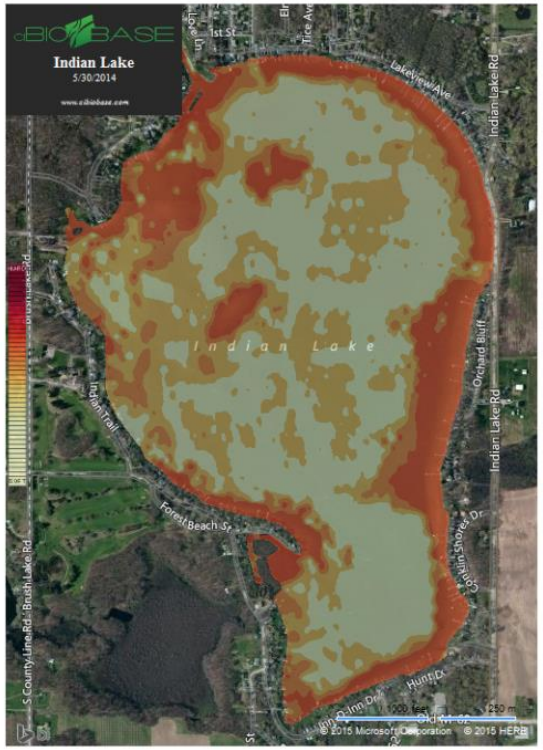
Aquaview
6th St S
PQ Ave W
Crooked Lake
Field Bay Ave
W Crooked Lake Dr
E Crooked Lake Dr
S Crooked Lake Dr
Crooked Cove St
7th St S
Q Ave W
HARD
SOFT


Aquaview
6th St S
PQ Ave W
Crooked Lake
Field Bay Ave
W Crooked Lake Dr
E Crooked Lake Dr
S Crooked Lake Dr
Crooked Cove St
7th St S
Q Ave W
BV%
100
50
0

Other Case Studies of LFA and Muck/Biovolume Reduction

Indian Lake, Cass County, MI

2014 (Pre-Aeration)



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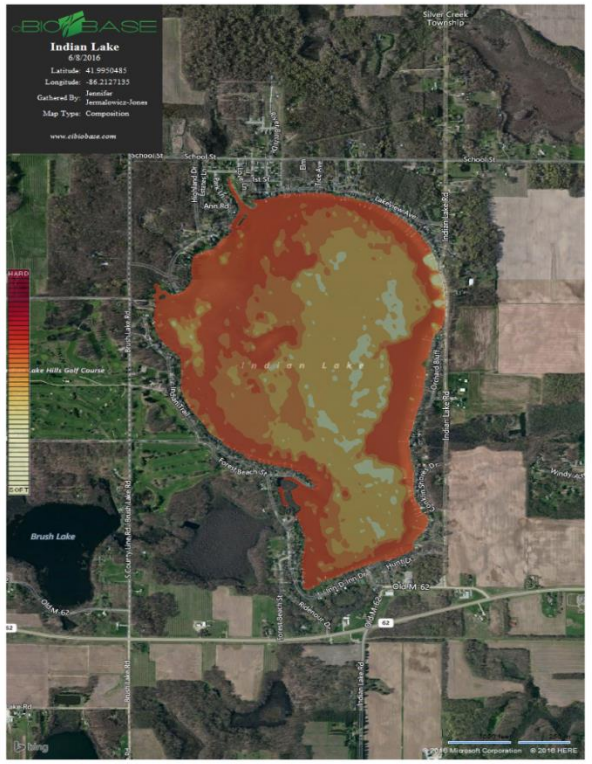
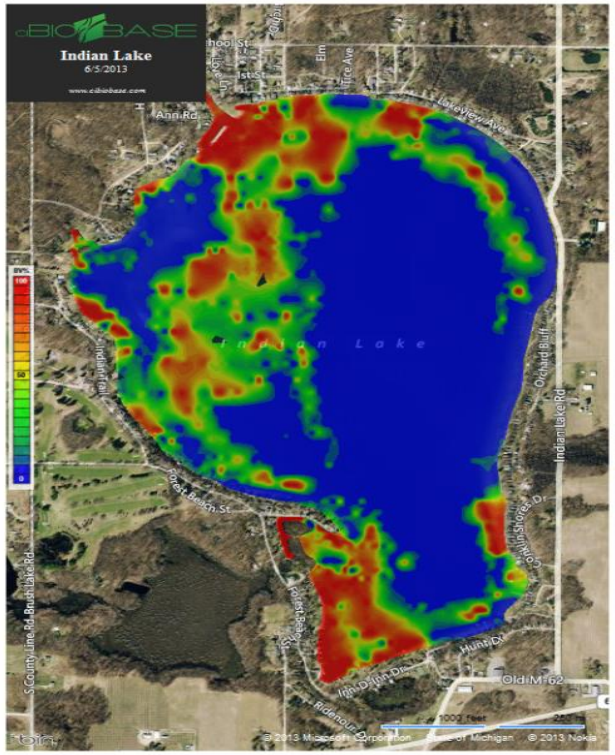
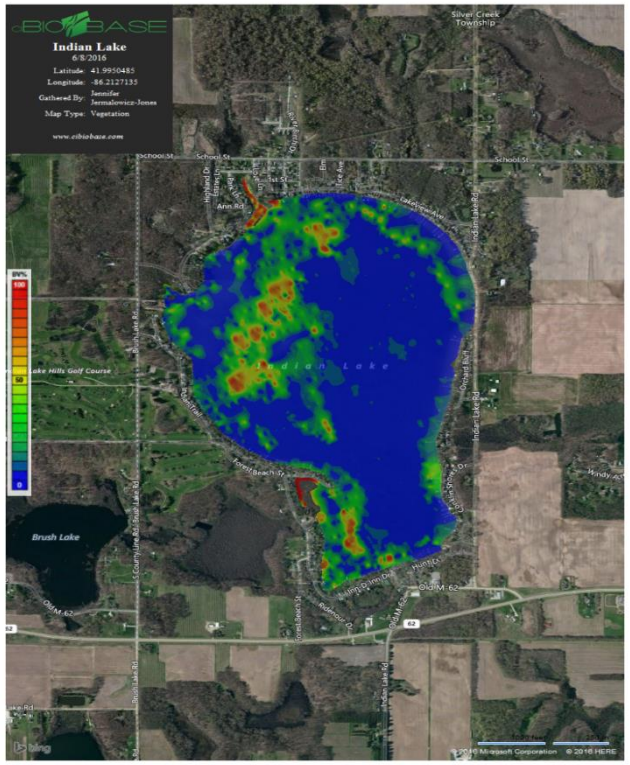


Indian Lake, Cass County, MI

2014 (Pre-Aeration)

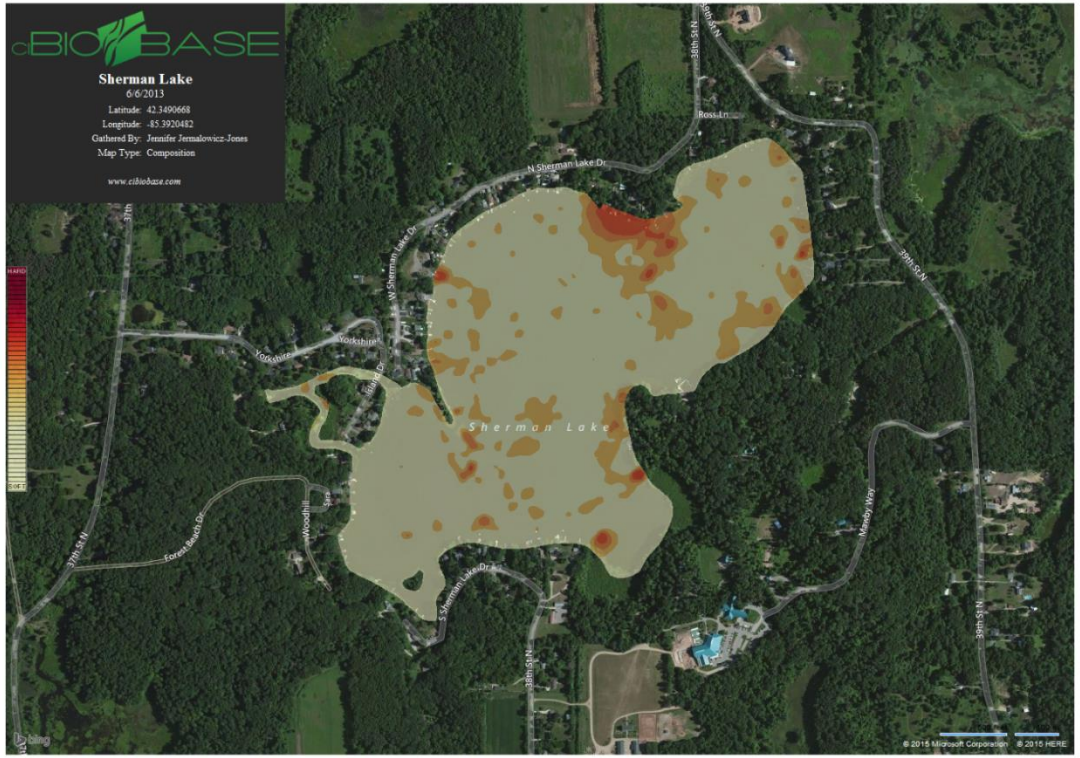


2016 (Post-Aeration)

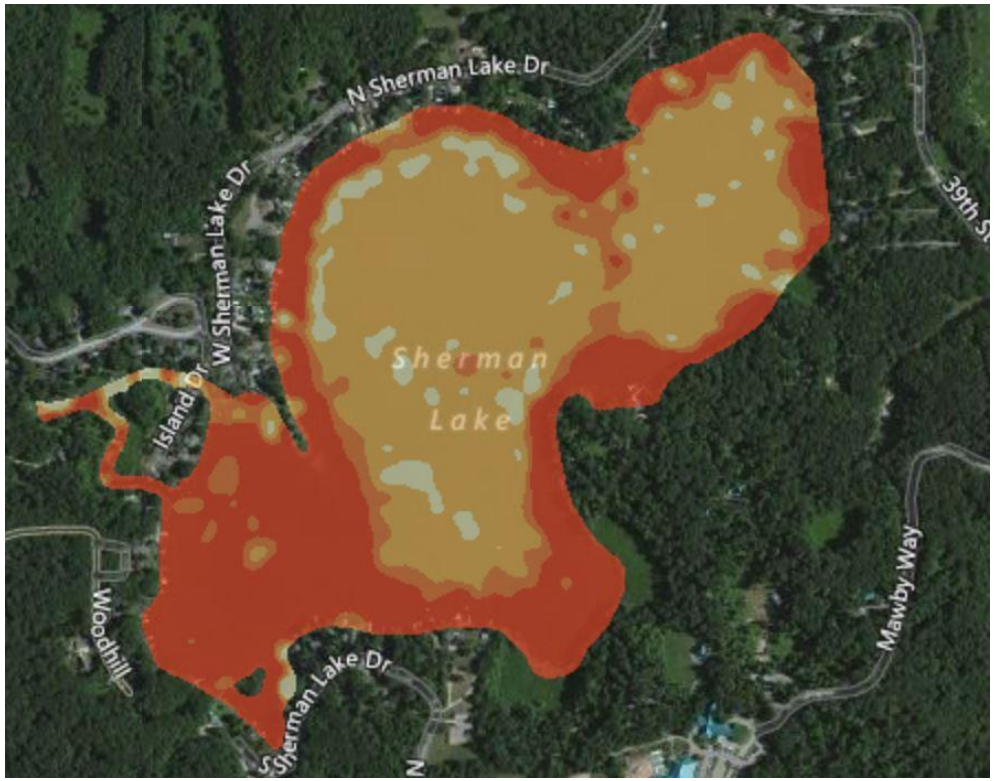


Sherman Lake, Kalamazoo County, MI

2013 (Pre-Aeration)

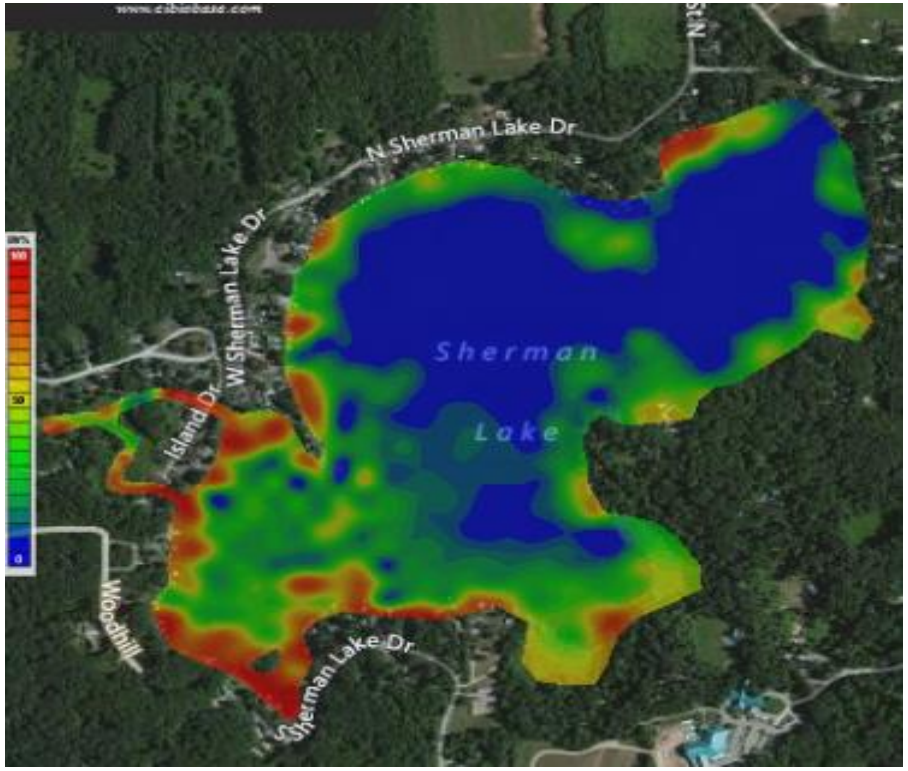


2016 (Post-Aeration)

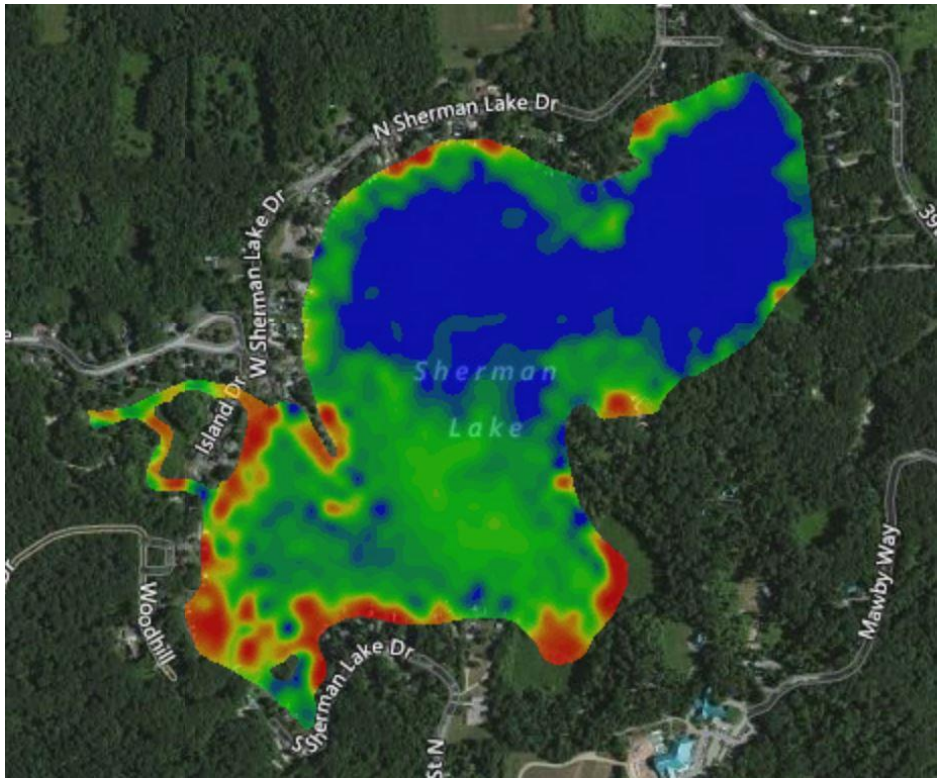


Sherman Lake, Kalamazoo County, MI

2013 (Pre-Aeration)



2016 (Post-Aeration)



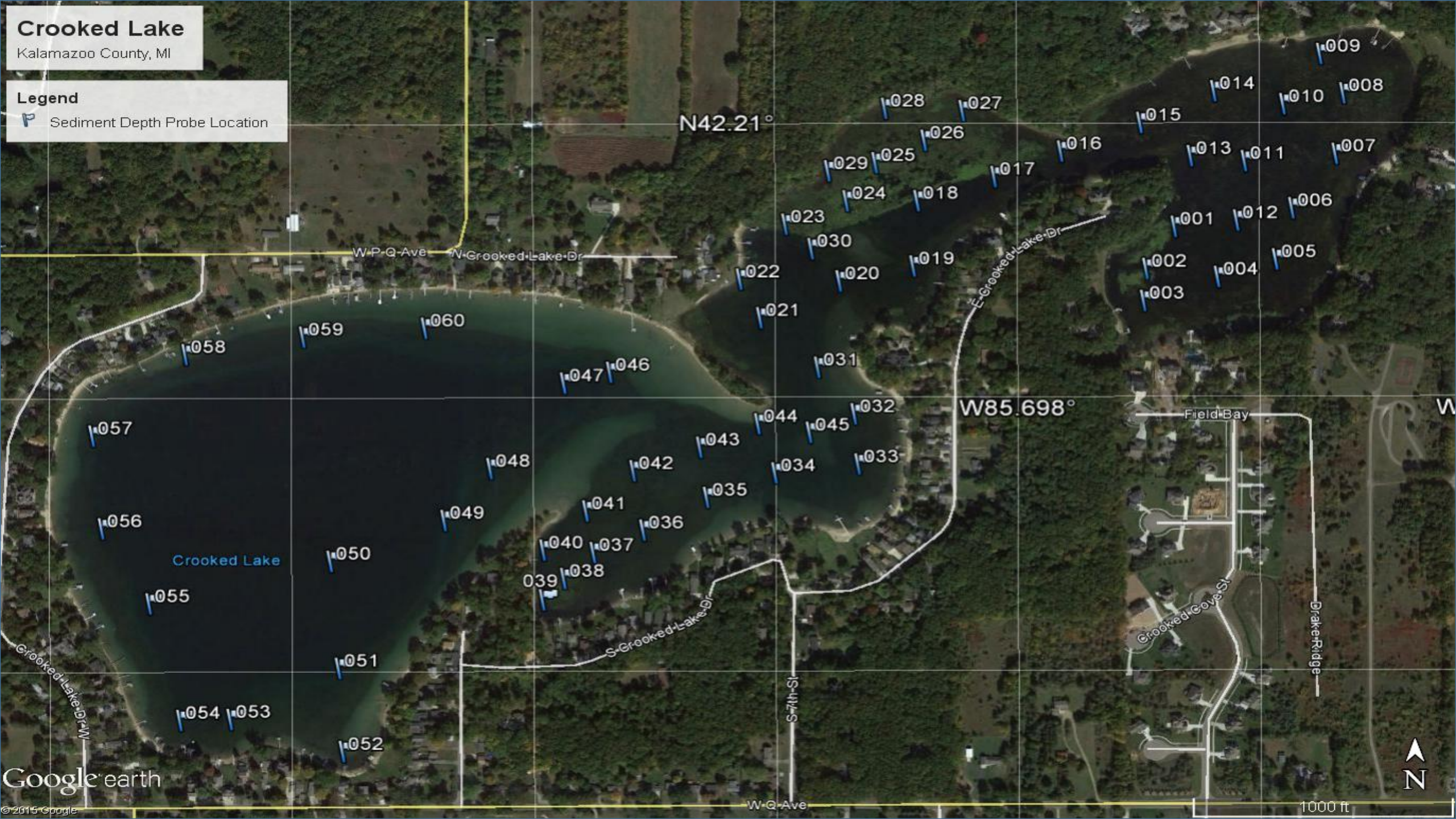
Changes in Crooked Lake Sediment % Organic Matter (by Basin)


Crooked Lake
Sediment Sampling Map
Kalamazoo County, MI
Legend
Sediment Sampling Location
N42.21°
028
010
025
016
013
007
001
019
004
022
046
032
043
034
056
049
040
037
050
052
W P Q Ave
N Crooked Lake Dr
E Crooked Lake Dr
S Crooked Lake Dr
Field Bay
Crooked Cove St
Drake Ridge
Crooked Lake
Google earth
© 2014 Google
1000 ft
N

Statistical Analysis of Sediment % Organic (Pre and Post-Aeration).

BASIN	2014	2015	2016	Significant? (p<.05)*
WEST	22±9	20.4±13	28.4±32	No
MIDDLE	31±5	29.8±6	21.4±15	No
NORTH	52±24	46±31	56±31	No
HIDDEN COVE	61±16	60±10	57.6±24	No

Changes in Crooked Lake Sediment Thickness (by Basin in)


Crooked Lake
Kalamazoo County, MI
Legend
Sediment Depth Probe Location
N42.21°
W85.698°
W-P-Q-Ave
N-Crooked-Lake-Dr
E-Crooked-Lake-Dr
S-Crooked-Lake-Dr
Crooked-Lake-Dr-W
S-7th-St
W-Q-Ave
Field-Bay
Crooked-Cove-St
Drake-Ridge
Crooked Lake
001
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056
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058
059
060
Google earth
© 2015 Google
1000 ft
N

Hidden Cove Statistical Analysis of Sediment Muck Thickness

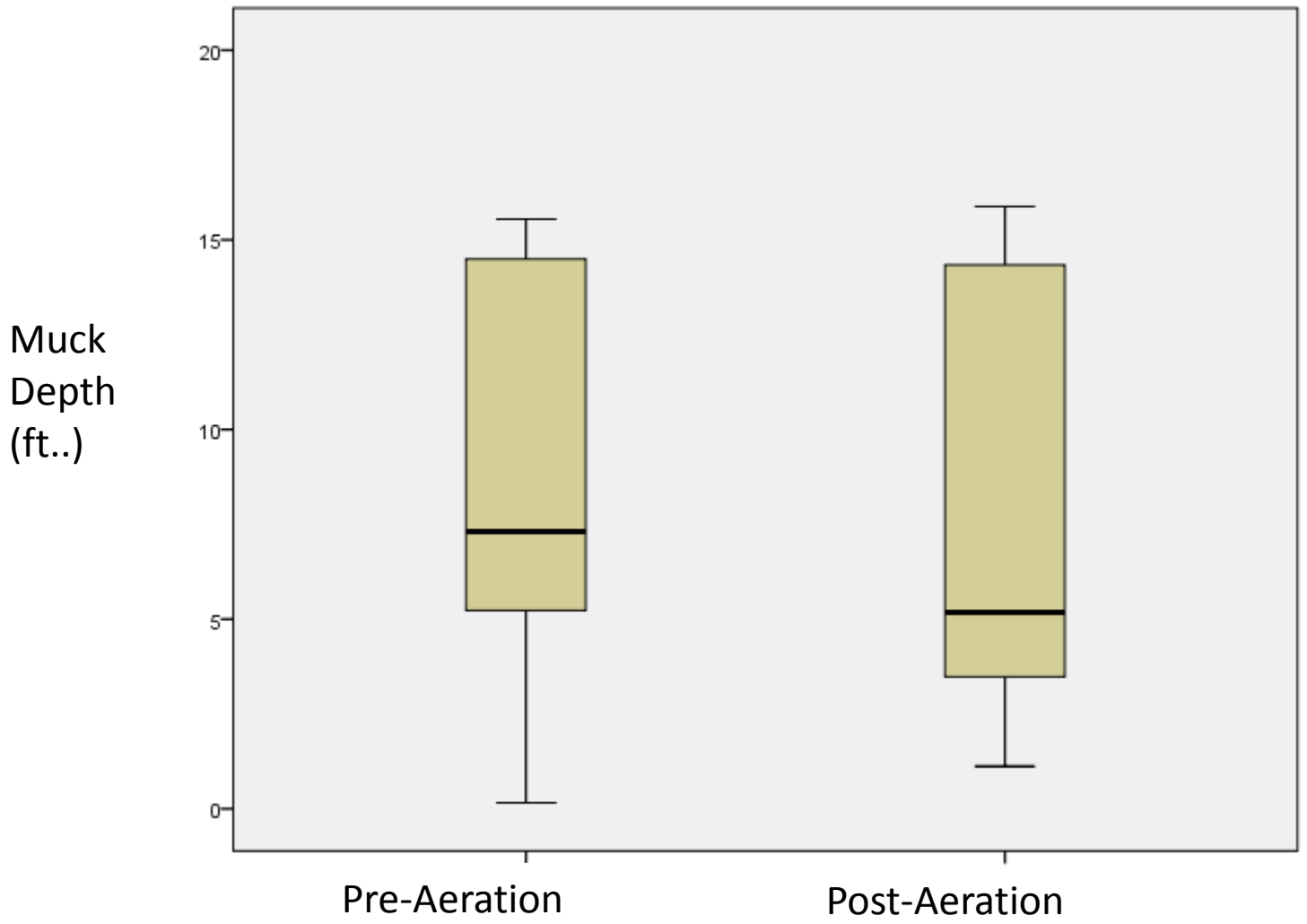
Group Statistics

	VAR00002	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	1.00	15	8.5693	5.02685	1.29793
	2.00	30	6.9677	4.21471	.76950

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00001	Equal variances assumed	1.332	.255	1.127	43	.266	1.60167	1.42153	-1.26512	4.46845
	Equal variances not assumed			1.061	24.132	.299	1.60167	1.50889	-1.51162	4.71496

Hidden Cove Pre-Aeration and Post-Aeration Sediment Thickness Data



North Basin Statistical Analysis of Sediment Muck Thickness

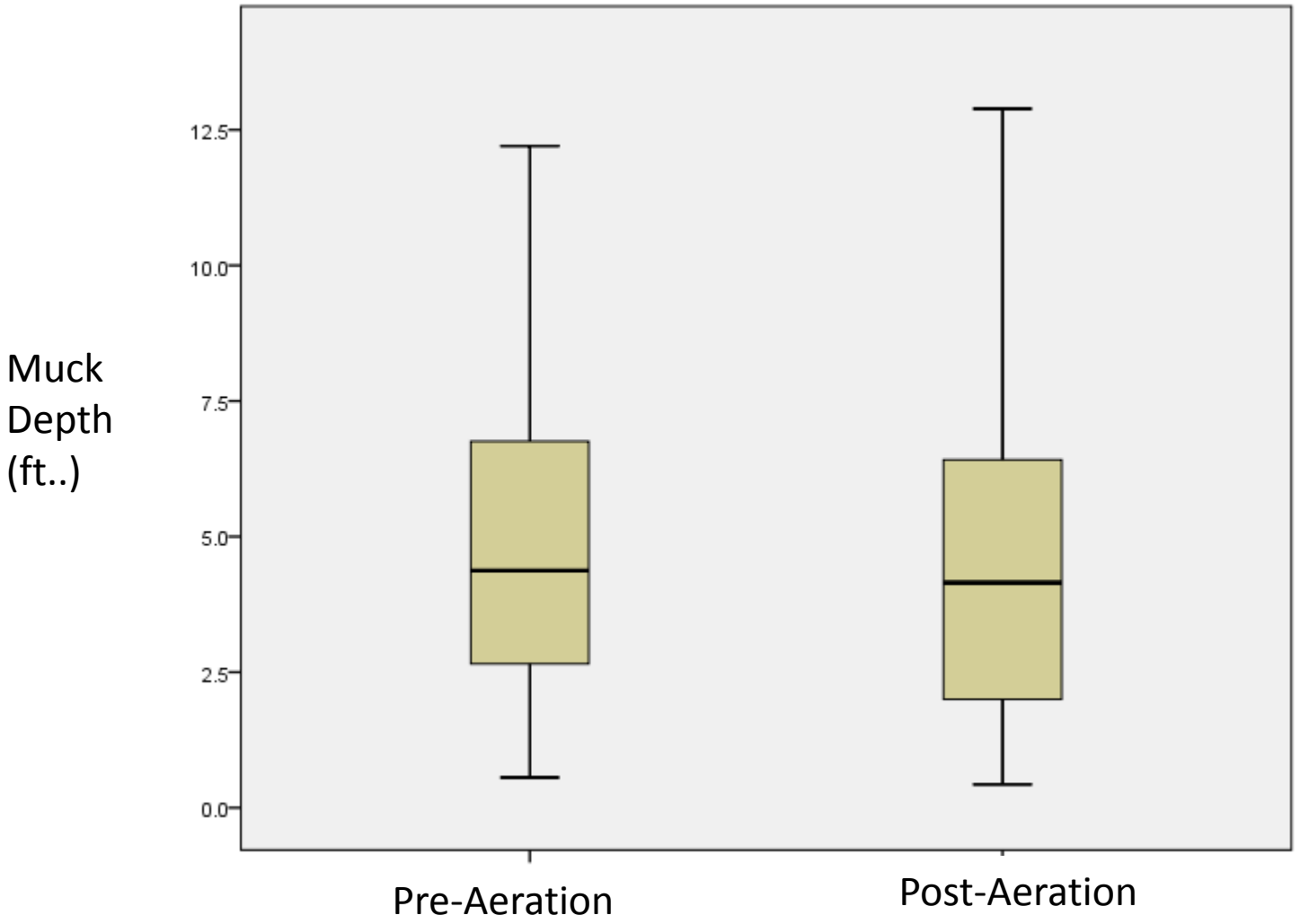
Group Statistics

	VAR00002	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	1.00	16	5.0706	3.30923	.82731
	2.00	32	4.6044	2.80912	.49659

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00001	Equal variances assumed	.636	.429	.511	46	.612	.46625	.91287	-1.37127	2.30377
	Equal variances not assumed			.483	26.116	.633	.46625	.96490	-1.51671	2.44921

North Basin Pre-Aeration and Post-Aeration Sediment Thickness Data



Middle Basin Statistical Analysis of Sediment Muck Thickness

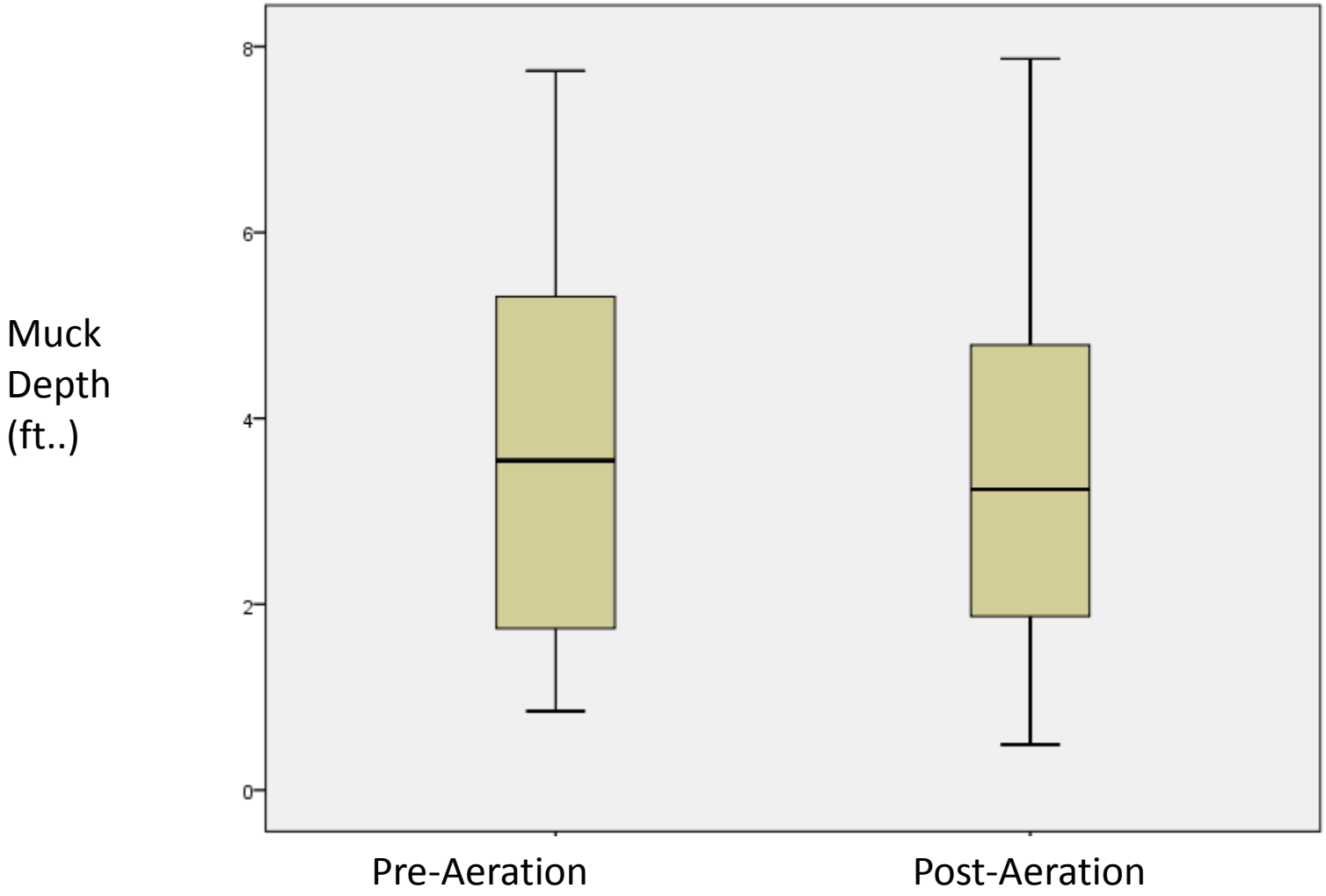
Group Statistics

	VAR00002	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	1.00	14	3.7107	2.04656	.54697
	2.00	28	3.4811	1.92899	.36455

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00001	Equal variances assumed	.002	.962	.356	40	.723	.22964	.64417	-1.07227	1.53156
	Equal variances not assumed			.349	24.762	.730	.22964	.65732	-1.12478	1.58407

Middle Basin Pre-Aeration and Post-Aeration Sediment Thickness Data



West Basin Statistical Analysis of Sediment Muck Thickness

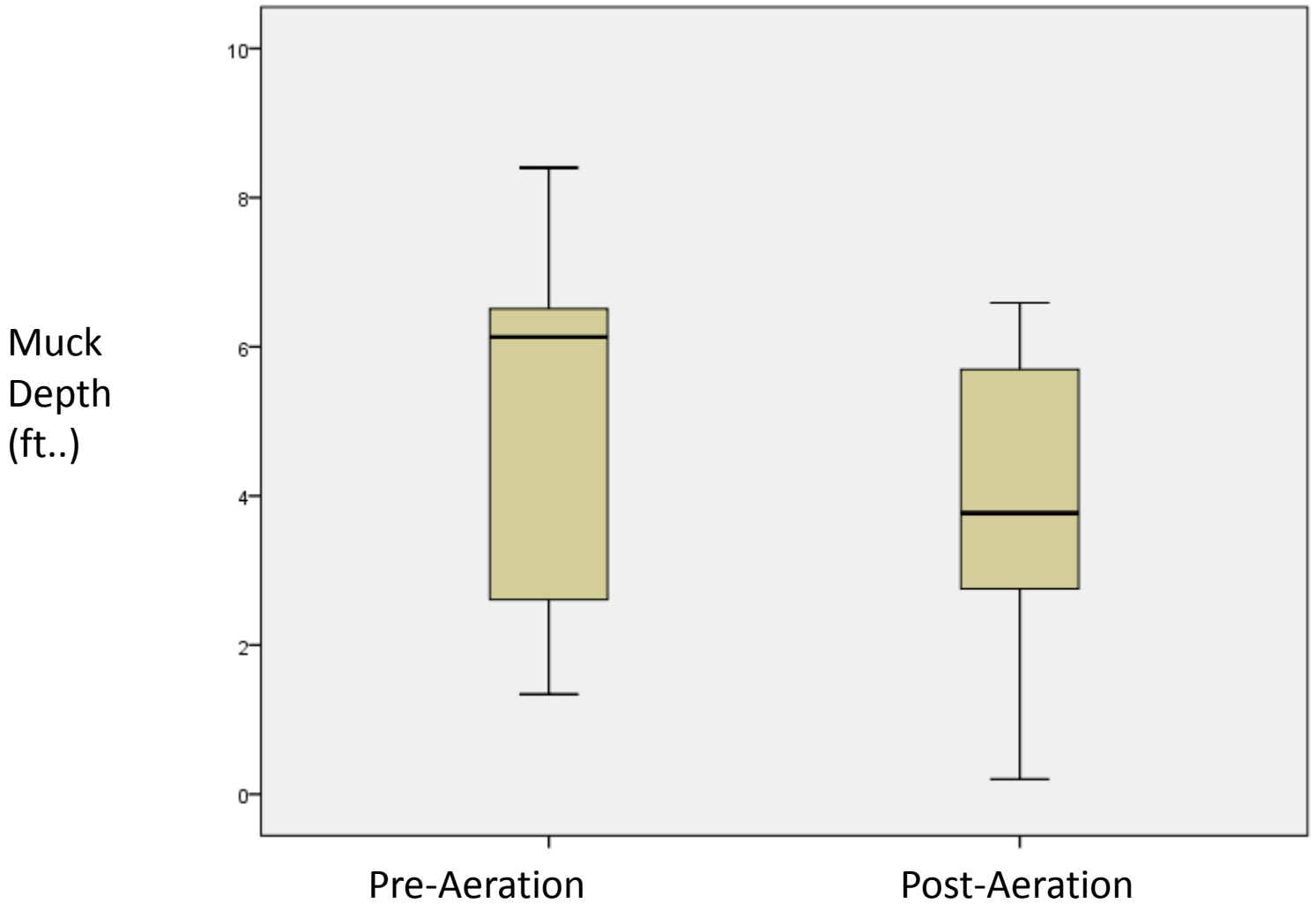
Group Statistics

	VAR00002	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	1.00	15	4.9133	2.43158	.62783
	2.00	30	4.2290	2.23251	.40760

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00001	Equal variances assumed	.770	.385	.941	43	.352	.68433	.72708	-.78196	2.15062
	Equal variances not assumed			.914	26.054	.369	.68433	.74854	-.85415	2.22282

West Basin Pre-Aeration and Post-Aeration Sediment Thickness Data



Muck Loss (by Basin)

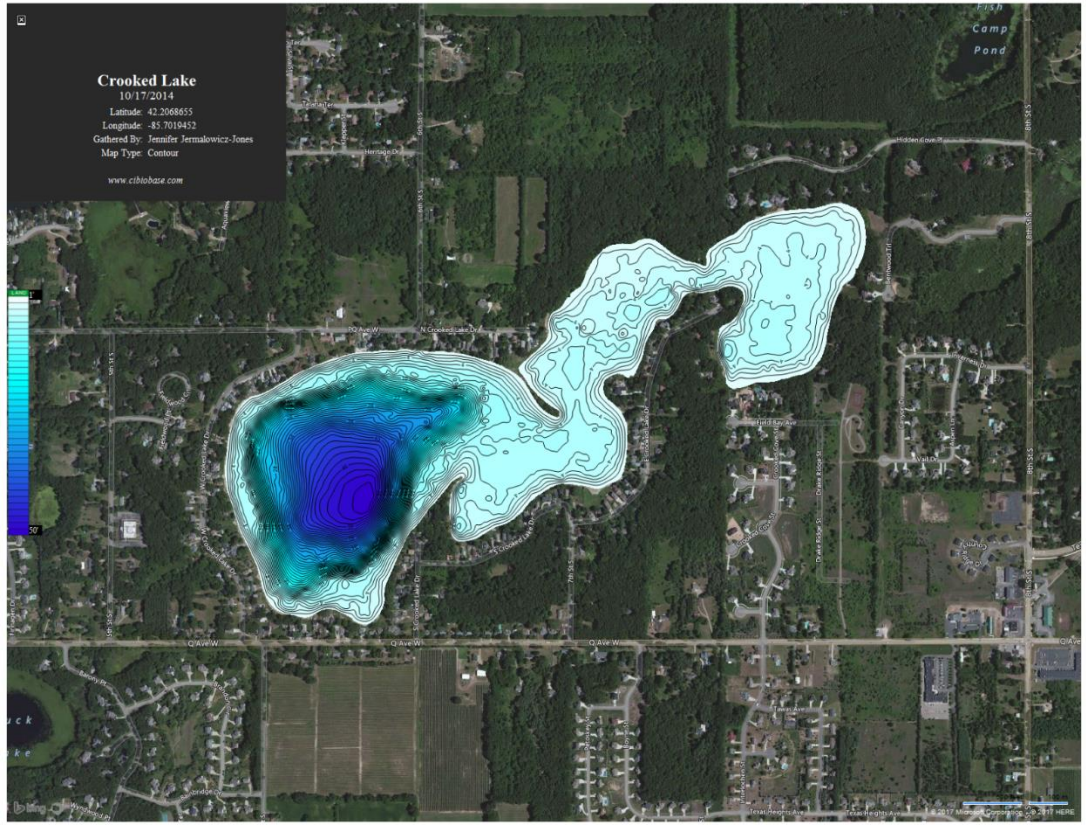
- Data consisted of 2014 (baseline) and 2015-2016 post-aeration
- Hidden Cove: 81% of n=16 sampling points had muck loss
- West Basin: 75% had muck loss
- North Basin: 56% had muck loss
- Middle Basin: 50% had muck loss

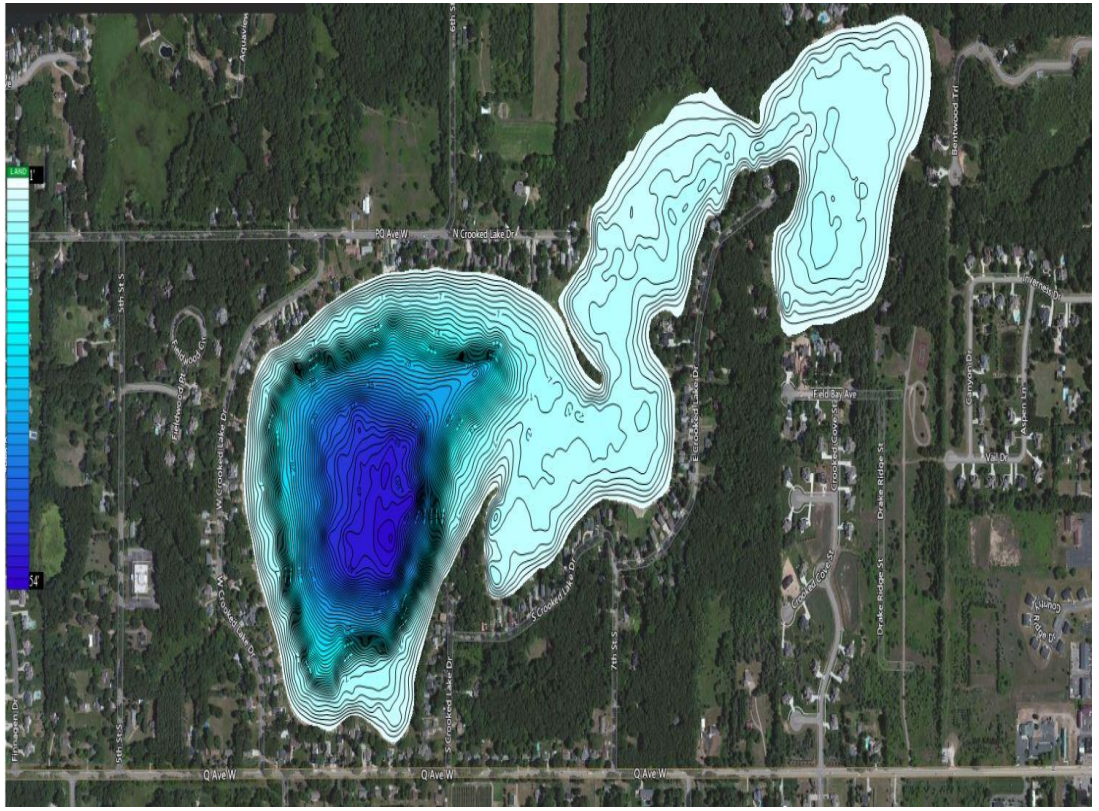
If LFA was not present, all four basins would have likely experienced muck gains

New Muck Loss Evaluation Method

- Uses bathymetry data analysis to compare baseline (2014) to post-aeration (2015-2016) changes in lake depth, volume.
- Areas between contour lines are carefully calculated and changes are then calculated
- Approximately 8,700 sampling data points factored into the analysis

2014 vs. 2016 Depth Contour Changes





Hidden Cove Muck Loss/Depth Gain

Year	Volume (acre-feet)	Max Depth (ft.)
2014	118.42	6.72
2015	115.40	5.91
2016	126.25	6.84

North Basin Muck Loss/Depth Gain

Year	Volume (acre-feet)	Max Depth (ft.)
2014	88.26	5.66
2015	85.72	5.94
2016	98.78	6.05

Middle Basin Muck Loss/Depth Gain

Year	Volume (acre-feet)	Max Depth (ft.)
2014	94.13	6.57
2015	91.43	6.85
2016	99.30	7.20

West Basin Muck Loss/Depth Gain

Year	Volume (acre-feet)	Max Depth (ft.)
2014	1,834.32	49.61
2015	1,893.78	51.36
2016	1,928.01	53.04

Conclusions

- There were no statistically significant changes in physical, chemical, sediment OM parameters before and after aeration.
- There were no statistically significant changes in sediment muck depth BUT the data shows more loss than gains
- There were significant changes in bottom with increased firmer bottom and decreased softer bottom

Original CLTA Objectives Met?

- Reduce weeds (both native and invasive species): NO
- Reduce muck (both depth and extent): YES*
- Maintain or improve water quality (clarity, transparency, etc.): YES

Recommendations

- GPS Point-Intercept survey with 50 points per basin for aquatic vegetation data collection
- Depth contour mapping/analysis to determine depth/volume changes
- Continue with BioBase and calculate changes in sediment hardness and also acres within depth contours; Remove sediment OM test and muck depth test
- Remove the MDEQ required tests and sediment %OM for 2017 and 2018. Instead, monitor top, middle, bottom TP, Ortho-P, DO, pH, Temp, Conductivity for each basin 3 times per season. Also collect composite chlorophyll-a and Secchi transparency.
- Continue to evaluate all statistically analyzed data into annual progress report
- Cannot have “control” sites since whole-lake is aerated
- Two years was not long enough to determine true efficacy given high variability found in nature
- Spot treatment with invasive species
- Testing augmentation well water (may be high in nutrients, solids, etc.)

Well Water a Problem for Weeds/Algae?