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Muskegon Lake Sediment Classification and Habitat Mapping

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Abstract

There were three lines of evidence that Muskegon Lake could be successfully classified into distinct ecological habitats from acoustic signals. These include acoustic classification, physical characteristics of the sediments, and visual observations. Sediments from each acoustic class (48 total sites) were used to characterize the physical conditions of the class. The 95% of the sites were correctly classified. Video stills at each site were used to verify that physical measurements and visual sediment conditions were similar. The sediments maps will be useful for future benthic work at Muskegon Lake. The methods can be used to characterize benthic locations in the Great Lakes where environmental conditions are not known. (Biological results to follow by close December 31, 2012 or later).

Background Introduction

Benthic habitat maps are useful for providing fresh water assessments for resource managers and ecological analysis. In an effort to develop benthic habitat maps in support of the restoration of Muskegon Lake, sediment classification will be performed along with benthic surveys conducted between 2009 and 2011. Over the three years, 387 *in-situ* samples were collected for biological and physical characterization of Muskegon Lake. For the research on sediment classification, an additional 72 physical and 155 biological samples were collected in June and September 2012. The mapping of benthic habitats is achieved from the combination of direct biological or geological observations with data from remote-sensing acoustic systems. Recent advances in acoustic technologies are offering new insights and opportunities to explore and map lakebed habitats. Benthic studies have traditionally used grabs and/or dredges to quantify the invertebrate fauna of the lake floor. The data generated from such techniques provides single, geographically separated points of data across the area of lakebed under investigation. In order to produce biotope maps (physical habitats and their associated biological assemblages) from such sources of data it is necessary to interpolate between these data points. However, interpolation has the potential to overlook discrete lakebed features and/or biological assemblages, which may lie between sample stations. For this reason the use of acoustic techniques to assist in mapping the geographical distribution of biotopes can be seen to have many potential advantages, including the prospect of 100% coverage of the lakebed as resources allow or priorities dictate.

The production of high-resolution biotope maps of the lakebed will assist in future site-specific environmental assessments of potential degraded areas, and would be of value during any subsequent environmental monitoring activities. The main objectives of this study were to assess the utility of lakebed mapping techniques for surveying habitats, and to investigate the factors controlling the distribution, type and diversity of their associated biological communities. Muskegon Lake was intensively surveyed using a single beam sonar system. The lake was then divided into acoustically distinct regions which, following ground-truthing using underwater video and grab samples, were found to relate to discrete habitat types. Each region was sampled using a suite of physical sampling and visual techniques. The main sampling tools were a 0.02 m^2 petite PONAR grab sampler and a camera/video platform (two video cameras, SRF digital camera and light). These instruments were used to characterize the benthic communities and sediment characteristics within each region. Relationships between acoustic regions, physical habitat characteristics, and assemblages were then investigated using a range of univariate and multivariate techniques. Results from these analyses were used to identify discrete biotopes (physical habitats and associated communities) at each site, and to establish which factors were responsible for the distribution, type and diversity of communities within each region.

Theory

Lakebed classification is the organization of lakebeds into discrete units based on characteristics of acoustic backscatter generated by a sounder as energy reflects off of the sediments to the echo sounder transducer. The signal shape is influenced by lakebed characteristics – physical properties of the surface material or immediate lakebed subsurface (Figure 1). The acoustic response represents an average volume of material, the size of which is a function of the transducer beam width and the frequency of the transducer.

Environmental variables that are ecologically relevant and easily measured over large areas are useful for modeling species distributions and habitats. The degree to which a particular habitat is utilized is considered to be indicative of habitat quality (Freitas et al 2003). Species habitat requirements may then be represented as simple ranges in common environmental variables (water depth, grain size, TOC and sediment type) that are known to support a population. Ultimately, more informative quantitative models are needed to address benthic habitats that are considered degraded such as in AOC when a Beneficial Use Impairment (BUI) includes Degradation of Benthos. The overall value of an environmental variable in habitat distribution models will be related to its ability to explain variance in benthic macroinvertebrate abundance or predict distributions. Temperature and depth are perhaps the most commonly used aquatic habitat variables and these data are readily available or easily obtained. Surficial sediments are also known to affect the distribution and abundance of benthic macroinvertebrates, but direct sampling with grabs and cores is too inefficient for larger areas (Ellingsen 2002). Acoustic returns from the lakefloor, on the other hand, include considerable information about physical properties of the lakefloor, can be continuously collected over extensive areas, and could thus potentially substitute for sediment data in benthic macroinvertebrate habitat models.

The main objective of the study was to determine the consistency of the classification and comparison against sediment characteristics, habitats and benthic macroinvertebrate communities. Therefore combining lakebed classes with environmental variables that are ecologically relevant and easily measured over large areas are useful for modeling macrobenthic communities and unique benthic habitats. In this study, we will use a systematic survey data to identify suitable habitats for the community of benthic invertebrates, with the assumption that macroinvertebrate density data reflect habitat utilization.

Acoustic Data Acquisition

Distinct acoustic classes will be identified through an unsupervised classification system using principle component analysis, discriminate analyses, analysis of variance, and univariate descriptive statistics. Grab samples for characterizing the geology and biology of the Muskegon Lake benthic community were collected one year after the lakebed classification survey. Photography and video were used to associate acoustic classes with biological and geological measurements. The hypothesis is that distinct benthic habitats will be associated with different acoustic bottom types. The data collected in Muskegon Lake is ideal for developing and testing this concept.

Survey

Acoustic data was collected in August 9-12, 2011 and November 7-8, 2011 in Muskegon Lake to a maximum depth of 26 m. The planned survey lines were created in HYPACK. Total survey coverage of the survey was the length and breath of the lake, i.e. approximately 2 km by 7 km, and over 200 km of track-lines were covered during six days of surveying (Figure 2). The distance between survey lines was approximately 60 meters and the survey plan covered the entire lake. A Furuno Echo echosounder and transducer with a sampling frequency of 200 kHz (transducer beam width 9°) were connected to the QTC VIEW 5.5 system. The positioning equipment was a Gramin Global Positioning System and position was logged continuously along with acoustic data and depth. The electronic data was processed with QTC IMPACT™ and QTC CLAMS™ software (Figure 2.).

The survey was done in two steps. For deeper water, a 44' vessel was outfitted with a Furuno FCV-295 Echo Sounder, a hull-mounted AIRMAR 600 watt dual beam transducer, and Garmin Marine GPS receiver. For the shallow water portion of the survey, a 24' vessel was used in November 2011. The same Furuno FVC-295 Echo Sounder and Garmin Marine GPS receiver were transferred from the larger vessel and were used on the second portion of the survey. An identical AIRMAR transducer was mounted on an over-the-side strut for this portion of the survey. The GPS unit was mounted directly over the transducer. The lake was calm during the acoustic survey but the use of a strut restricted the survey speed to about 4–5 knots. The survey tracks were intersected to ensure there were adequate crossing lines for repeatability checks in the acoustic classification.

The size of the lakebed acoustic footprint is a function of the beam width and the water depth (Galloway and Collins, 1998). An average water depth during the survey of 10 m and a 9° beam width gave an average seabed footprint of 2.5 m (diameter). The along-track coverage is a function of the ping rate and the vessel speed (Collins *et al.*, 1996). An averaged echo from an ensemble of five consecutive echo returns is automatically computed and a single output record is generated to reduce the processing load and stabilize the signals (Lurton and Pouliquen, 1992; Prager *et al.*, 1995).

Echo Data Analysis

Each echo ensemble was digitized by QTC VIEW 5.5 and stored on a PC. The averaged echo trace is automatically processed by a series of algorithms sensitive to different components of the echo shape as well as the spectral content of the echoes and 166 features. Although their physical or mathematical meaning unknown, the features have been shown to be very descriptive of different sediment types (Collins *et al.*, 1996). Post-processing analysis of the acoustic data was carried out using the software packages CAPS and QTC IMPACT, described in Quester Tangent Corporation (1999).

Most of the 166 parameters carry limited information (the variance of any individual parameter is small) or redundant information (the covariance of any individual parameter with the other parameters is small, see Prager et al., 1995). Principal component analysis (PCA) was used to determine the best combination of the 166 features for the discrimination of the echoes. According to Prager et al. (1995) the first three principal components generally account for more than 95% of the covariance produced from several thousand pings spanning a wide variety of seabed types. The 166 feature combinations are therefore automatically reduced to these three composite values, labeled Q1, Q2, and Q3 (Collins and Lacroix, 1997), and the remainder of the information is not used to obtain the classification. The QTC software allows users to plot the Q-values in a three-dimensional graph (Q-space) along the three principal components.

Before conducting the classification of lakebeds through PCA, poor quality records within an FFV matrix needs to be rejected. The Waveform Editor in QTC IMPACT is a tool that enables the user to assess the quality of raw echo waveforms. Quality Assurance is the role of the Waveform Editor. Common flaws include low signal-to-noise ratio, clipping (electronic problem), acoustic interference, electrical interference, and incorrect triggering. Subsequent to examining the echo waveforms, a bottom pick is chosen. This identifies the data window surrounding the lakebed. Accurate bottom picks (lake bottom location) are critical for successful bottom classification.

Finally, a software package (QTC IMPACT) was used to create a catalogue of information for echo classification. Principle component analysis is used to determine those echos that are most similar and cluster within the first three PCA axes. The process is to reduce the data matrix into component scores and loadings. Next, QTC IMPACT uses an auto clustering technique to slit the data into logical acoustic regimes. The cataloguing process is used in generating a final catalogue of the survey lines.

Sediment Classification Validation and Habitat Mapping

For validation of the three major acoustic classes, two data set were collected in June and September 2012. Between June 3-June 212, 2012, 72locations were visited to collect sediment grab samples, video, and photographs. These data were used to determine geological sediment characteristics (Figure 3). The top 3 cm of each grab sample was analyzed for grain-size, percent dry weight, and total organic carbon. The silt-clay fraction (<0.063 mm) was separated from the sand-gravel fraction (>0.063 mm) of the samples. The sand-gravel fraction of samples was divided into six fractions using six sieves (>0.063, >0.125, >0.250, >0.500, >1.000, and >2.000 mm). Sixty-three biological samples were collected in June 2012 and additional 66 samples were collected in September 2012.

At each station, benthic macroinvertebrates were collected following the methods of Nalepa (1987). Sediment was collected using a Petite PONAR with a sampling area of 0.00 m2 (15.24cm x 15.24cm). Each sample consisted of three replicate samples. The contents of each PONAR sample was washed into a large tub and then washed in an elutriation devise with 0.5 mm Nitex mesh sleeve. Material and organisms retained were preserved in 10% buffered formalin, containing Rose Bengal stain. In the laboratory, all preserved organisms were picked, identified to major taxonomic groupings, and counted. Specimens of Oligochaeta and Chironomidae were mounted on glass slides with CMC9, a semi-permanent mounting medium and identified to lowest feasible taxa by a contractor (EcoAnalyst, Inc). The abundance for each sample was obtained by averaging the three replicate counts. Mysids, nematodes, and ostracods were not included in analyses. The sampling sites were categorized into three acoustic groups and one nearshore group.

The station location for all of the biological and physical information was sited in the middle of each acoustic class. Discriminate analysis was used to classify the three habitat types in Muskegon Lake for the physical data. Discriminate analysis is related to both multivariate analysis of variance and multiple regression. The cases are grouped in cells like a one-way multivariate analysis of variance and the predictor variables form an equation like that for multiple regression. In discriminate analysis, Wilk's lambda, the same test used in multivariate ANOVA, is used to test multivariate differences among groups. Another discriminate analysis was used to classify four habitat types in Muskegon Lake. Three of the habitat types were identified by acoustic and the fourth by depth (average depth was 2 m) and location (within 50 m of the shoreline).

Results

Bathymetry and Acoustic Classification

The acoustic data was collected along a 200 km track in Muskegon Lake as points along the vessel track (Figure 2 and Table 1). Echo returns from the survey were used to create a detailed bathymetry map of Muskegon Lake. Lake depth was corrected for transducer location. Average depth was 10.3 m and 78% of the survey was conducted in waters less than 15 m deep (Figure 3, Table 1).

Eight distinct acoustic classes were identified through the unsupervised classification survey (Figure 4 and Table 2). The distinct acoustic classes were overlaid on Muskegon Lake. Shallow areas that were not surveyed are masked. Acoustic class yellow-5 is the most common type and appears to be associated with the drowned river channels. The next most common sediment class is class green-2 found most often in offshore waters at shallower depths. The next most common acoustic class is class orange-6. This acoustic class was found in similar locations to class green-2. These three acoustic classes made up 89% of the total number of echoes and they were used for the validation portion of the study. The next most abundant acoustic class (light green-4) was a transitional acoustic class that was found in areas between the three largest acoustic classes.

Discriminate analysis was used to characterize the three most common acoustic classes and to assess the goodness of fit of the sites that were sampled within the boundaries of each acoustic class (figure 5). Results from the discriminate analyses of physical character measurements in 2012 for the three acoustic classes are shown in Table 3. The most abundant acoustic class (yellow-5) has the largest average values for silt (92%), TOC (10%), and depth (14 m). The next most abundant acoustic class (green-2) has the largest average values of sand (82%), dry weight (55%) and lowest average value for TOC (3%). The third most abundant acoustic class (orange-6) has intermediate average values for silt, sand, and TOC. The classification tables reveal that only one case was misclassified with an overall classification rate of 98%. The jackknifed classification is used to remedy the problem of using the same cases to create the functions. The cross validation using jackknifed classification reveal that 90% of the cases are correctly classified. The green acoustic class was most often misclassified. The green acoustic class was most often misclassified. The discriminate analysis was statistically significant ($p< 0.000$) and the first discriminate factor accounted for 98% of the total dispersion.

Results from the discriminate analyses for the four classes are shown in Table 4. As mentioned before, the most abundant acoustic class (yellow-5) has the largest average values for silt (92%), TOC (10%), and depth (14 m). The next most abundant acoustic class (green-2) has the largest average values of sand (82%), dry weight (55%) and lowest average value for TOC (3%). The fourth sediment type was found in shallow areas of Muskegon. The physical characteristics of the sediments in the shallow zone are shallow depth (2 m), low TOC (2 %), high dry weight (69%), and sand-silt mixture (76% & 24% respectively. The classification tables reveal that only four cases were misclassified with an overall classification rate of 97%. The cross validation using jackknifed classification reveal that 92% of the cases are correctly classified.

Additional evidence of four distinct sediment types was obtained from video stills and camera photos. The yellow-5 acoustic class is soft and silty (Figure 5), the green acoustic class is sandy and hard (Figure 6), the physical characteristics of the orange-6 sediment class are intermediate between the yellow and green classes (Figure 7), and the shallow-class is nearshore, in shallow water, and supports large beds of macrophytes (Figure 8). Druses of dreissenid mussels were found in the orange sediment class. In the green sediment class, there were three distinct regions in the western end of Muskegon Lake (Figure 9), that is a north-west region (N-W), a westerly (W) region, and an easterly region (E). In the N-W portion of the sandy sediments, mussels form a dense bed. In the W portion of the sandy sediments, mussels are found in druses with the sediments being relatively bare. In the E portion of the sandy sediments, mussel shells cover the sediments (Figure 9).

The original design was to explore the eastern end of Muskegon Lake. The acoustic signature in this area (Figure 4) was a mixture of all three important classes. Results from the discriminate analyses for five "acoustic" classes are shown in Table 5. The physical characteristics of the sediments in the mixed zone are not very distinct from the other acoustic classes and the sand-silt mixture is 29% & 71% respectively. The classification tables reveal that four were misclassified with an overall classification rate of 95%. The cross validation using the jackknifed classification reveal that 86% of the cases are correctly classified with eight cases misclassified. The mixed class was most often misclassified. Due to windy conditions, no video or camera results are available.

Conclusions

The benthic maps covering Muskegon Lake were created by a combination of acoustics in the deeper portion of the lake and grab sampling within the shallow portion of the lake. The photographic surveys validated that there were at least four distinct classes of sediments, i.e. a silty-deep habitat, a shallower sandy habitat, a shallower silty-sandy habitat, and a vegetative shallow habitat. The approach allowed for a habitat/depth map of Muskegon Lake to be created that will be used for future sampling. The technique is transferable to other Great Lakes drowned river mouths. To use the existing catalogue of sediment classes, the echo sounder and transducer would need to be identical to the equipment used in our study.

It should also be noted that this study was limited to a specific quasi-homogeneous soft-sediment lake environment. To improve portability, additional sediment types (cobble, rock) could be surveyed and combined with the existing acoustic dataset. As mentioned above, it is imperative that the identical equipment be used in future surveys. This research could be used to develop rapid assessment techniques of aquatic sites with the expanded acoustic/sediment catalogue.

A final improvement to establishing different habitats for Muskegon Lake and other drowned river mouth lakes is to explore the association of benthic macroinvertebrate community to each sediment type. As mentioned, biological samples were collected in June and September 2012 to establish this relationship.

Future work

- Compete analysis of data collected in 2012 including biological samples collected in 2012.
- Developing an expanded sediment catalogue by sampling in Lake Michigan with the identical sonar equipment
- Testing the method on another drowned river mouth
- Complete analysis of video and photographs including the area a the western end of Muskegon Lake

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Quester Tangent Corporation 1989, Quester Tangent Corporation, 6582 Bryn Road, Saanichton, British Columbia V8M 1X6 Canada

Table 1. Echo count and percent of the total are shown for each depth interval in Muskegon Lake in 2011.

Depth (m)	Count	Percent
-2	740	0.9%
-3	4560	5.3%
-4	4880	5.7%
-5	4420	5.1%
-6	3630	4.2%
-7	3550	4.1%
-8	5510	6.4%
-9	5580	6.5%
-10	6340	7.3%
-11	7130	8.3%
-12	7560	8.8%
-13	8290	9.6%
-14	5580	6.5%
-15	4220	4.9%
-16	5910	6.8%
-17	2410	2.8%
-18	1780	2.1%
-19	1570	1.8%
-20	910	1.1%
-21	830	1.0%
-22	410	0.5%
-23	210	0.2%
-24	170	0.2%
-25	70	0.1%
-26	50	0.1%

Table 2. Echo count and percent of the total are shown for each acoustic class in Muskegon Lake in 2011.

Acoustic Class	Count	Percent
Blue - 1	1,300	1.5%
Green - 2	18,600	21.5%
Light Green - 3	600	0.7%
Green/Yellow - 4	5,300	6.1%
Yellow - 5	42,000	48.7%
Yellow/Orange – 6	15,500	18.0%
Orange - 7	800	0.9%
Dark Orange - 8	2,200	2.5%

Table 3. Results from a discriminate analysis on three acoustic classes, Green (2), Yellow (5), and Yellow/Orange (6). The locations of each acoustic class is found on Figure 5.

2012	**Grain Size**		
N	20	22	6
Acoustic Class	**Green -2**	**Yellow-5**	**Orange-6**
Depth (m)	7	14	7
% TOC	3	10	7
% Dry Weight	55	13	18
> 2000 um	15	1	11
1000-2000 um	4	0	2
500-1000 um	5	0	1
250-500 um	35	1	12
125-250 um	22	2	15
63-125 um	2	4	5
< 63 um	18	92	54

Classification Matrix (cases in row categories classified into columns)

	Green -2	**Yellow-5**	**Orange-6**	% Correct
Green -2	19	0	1	95
Yellow-5	0	22	0	100
Orange-6	0	0	6	100
Total	19	22	7	98

Jackknifed classification matrix

	Green -2	**Yellow-5**	**Orange-6**	% Correct
Green -2	17	1	2	85
Yellow-5	0	21	1	95
Orange-6	1	0	5	83
Total	18	22	8	90

Wilks' lamda	lambda	
Lambda = 0.0341	df = 9, 2, 45	
Approx. F = 18.164	df = 18, 74	prob = 0.0000

Eignevalues

18.98	0.47

Cummulative proportion of total dispersion

0.98	1.00

Table 4. Results from a discriminate analysis on five classes, Green (2), Yellow (5), and Yellow/Orange (6), Shallow (S). The locations of each cluster are found on Figure 5.

2012	Grain Size			
N	20	6	13	22
Acoustic Class	**Green-2**	**Orange-6**	**Shallow-S**	**Yellow-5**
Depth (m)	7	7	2	14
% TOC	3	7	2	10
% Dry Weight	55	18	69	13
> 2000 um	15	11	4	1
1000-2000 um	4	2	2	0
500-1000 um	5	1	3	0
250-500 um	35	12	33	1
125-250 um	22	15	27	2
63-125 um	2	5	7	4
< 63 um	18	54	24	92

Classification Matrix (cases in row categories classified into columns)

	Green-2	**Orange-6**	**Shallow-S**	**Yellow-5**	**% Correct**
Green-2	19	1	0	0	95
Orange-6	0	6	0	0	100
Shallow-S	0	0	13	0	100
Yellow-5	0	1	0	21	95
Total	19	8	13	21	97

Jackknifed classification matrix

	Green-2	**Orange-6**	**Shallow-S**	**Yellow-5**	**% Correct**
Green-2	18	2	0	0	90
Orange-6	1	5	0	0	83
Shallow-S	0	1	12	0	92
Yellow-5	0	1	0	21	95
Total	19	9	12	21	92

Wilks' lamda	lambda	
Lambda = 0.0099	df = 9, 3, 57	
Approx. F = 20.45	df = 24, 143	prob = 0.0000

Table 4. Results from a discriminate analysis on five classes, Green (2), Yellow (5), and Yellow/Orange (6), Shallow (S). The locations of each cluster are found on Figure 5.

2012 Grain Size

Acoustic Class	**Green - 2**	**Yellow- 5**	**Y/O- 6**	**Shallow**	**Mixed (2&6)**
	20	22	6	13	20
Depth (m)	6.91	13.85	6.92	2.39	7.32
% TOC	3.18	10.35	7.30	2.27	7.38
% Dry Weight	0.55	0.13	0.18	0.69	0.29
> 2000 um	14.73	0.60	10.61	3.86	0.73
1000-2000 um	3.98	0.24	2.15	1.73	0.26
500-1000 um	4.86	0.22	1.16	3.13	0.85
250-500 um	35.06	0.81	12.03	33.41	7.29
125-250 um	21.82	1.99	14.94	27.24	7.03
63-125 um	1.87	4.30	4.66	6.71	13.06
< 63 um	17.68	91.84	54.46	23.93	70.78

Classification Matrix (cases in row categories classified into columns)

	Green - 2	**Yellow- 5**	**Y/O- 6**	**Shallow**	**Mixed (2&6)**	**% Correct**
Green -2	19	0	1	0	0	95
Yellow-5	0	21	0	0	1	95
Y/O- 6	0	0	6	0	0	100
Shallow	0	0	0	13	0	100
Mixed (2&6)	0	0	1	1	18	90
Total	19	21	8	14	19	95

Jackknifed classification matrix

	Green - 2	**Yellow- 5**	**Y/O- 6**	**Shallow**	**Mixed (2&6)**	**% Correct**
Green -2	16	0	2	1	1	80
Yellow-5	0	21	0	0	1	95
Y/O- 6	1	0	5	0	0	83
Shallow	0	0	0	11	2	85
Mixed (2&6)	0	0	2	1	17	85
Total	17	21	9	13	21	86

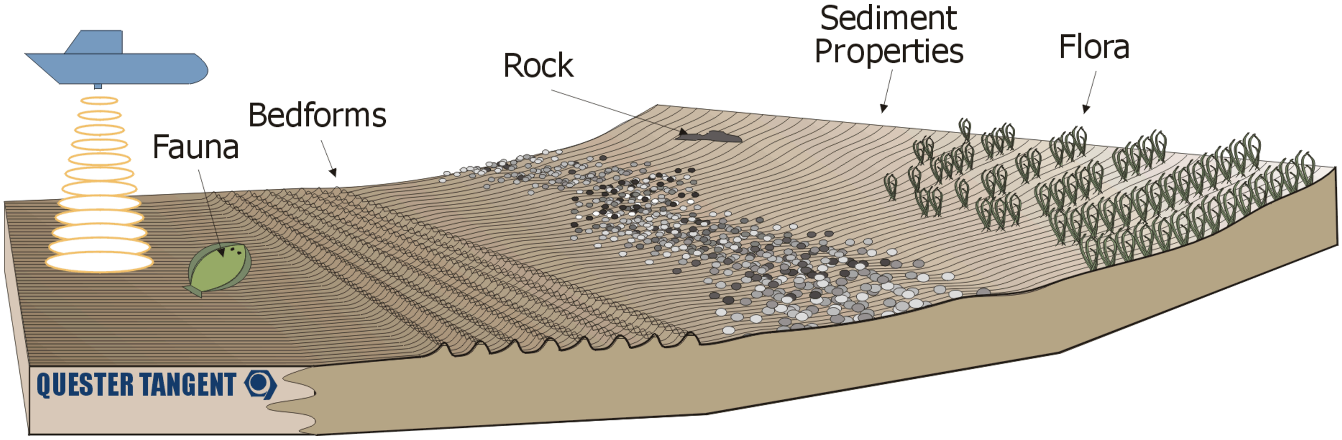


Figure 1. Cartoon of how QTC is used to classify sediments.

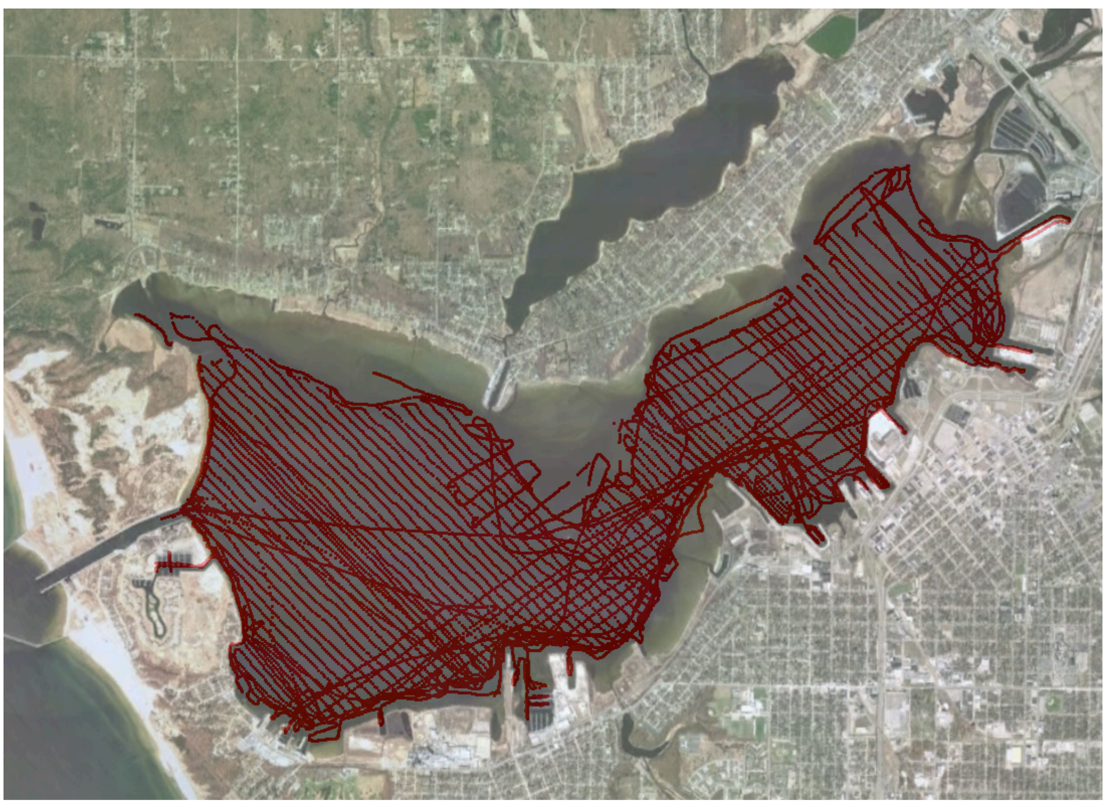


Figure 2. Survey lines are shown for the August and November 2012 acoustic survey of Muskegon Lake.

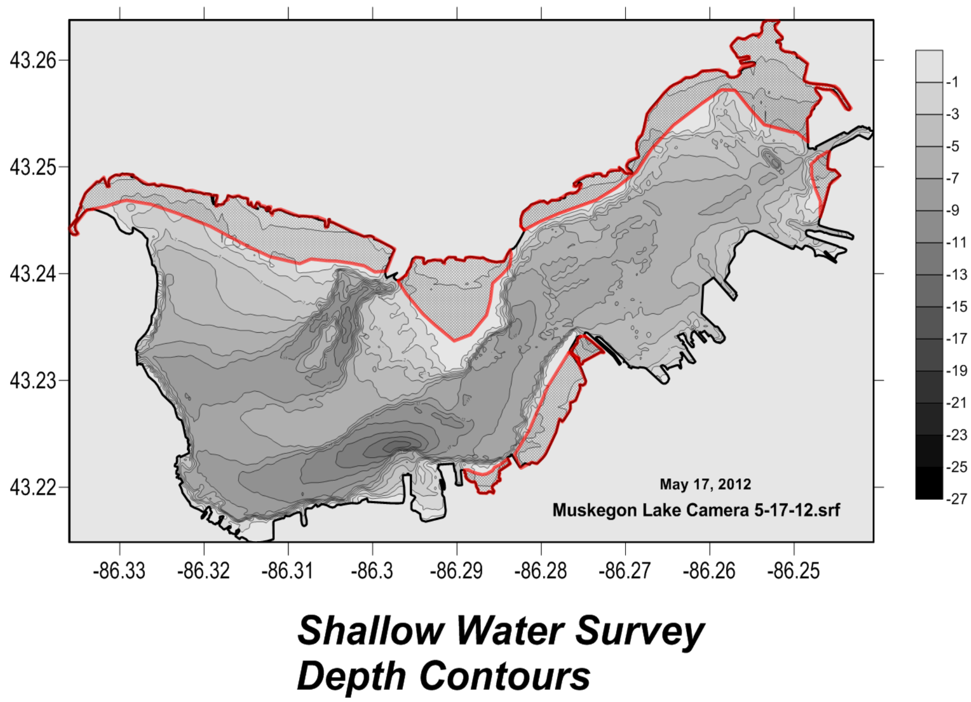


Figure 3. Bathymetry of Muskegon Lake estimated from lakebed backscatter that was generated from a Furno Echosounder.

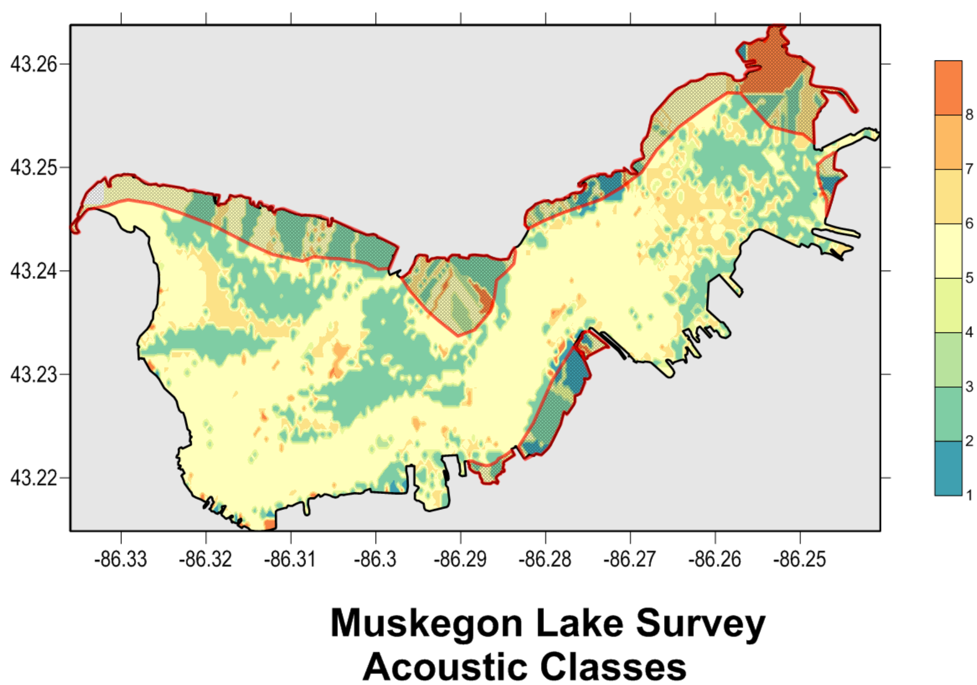


Figure 4. Eight acoustic classes were identified using QTC IMPACT that was generated from a Furno Echosounder.

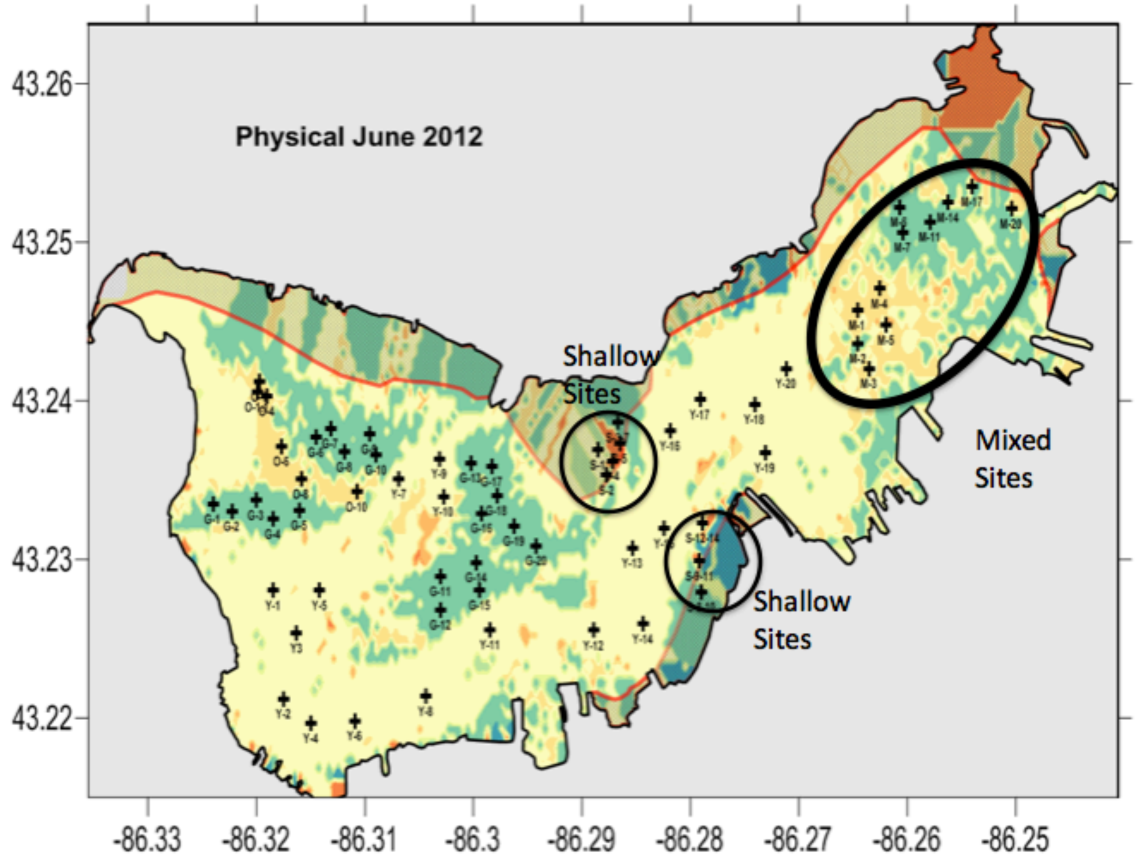


Figure 5. Sixty-five sites used for physical characteristics are show in Muskegon Lake. Samples were collected in June 2012.

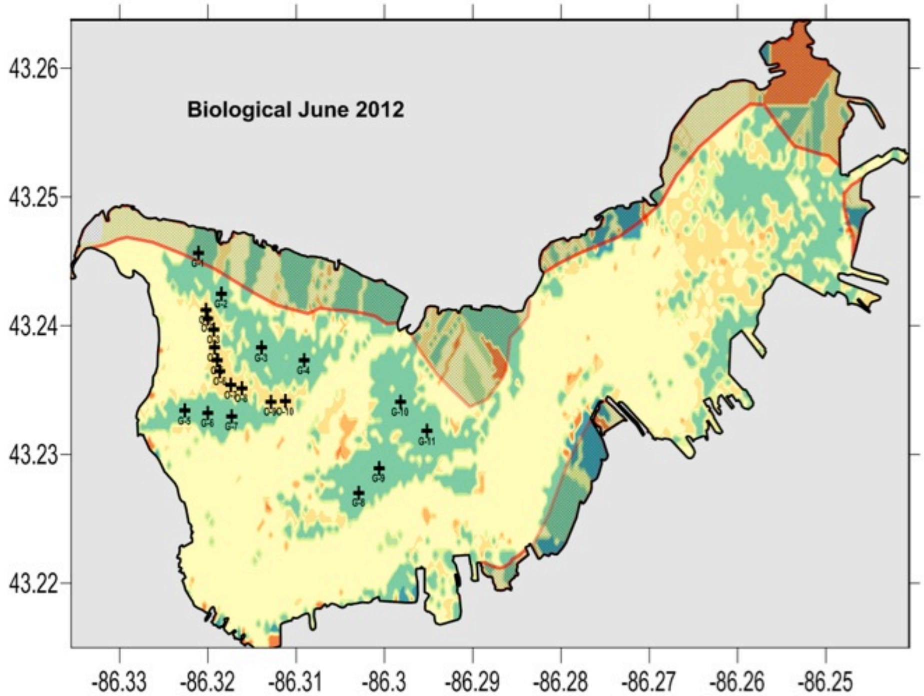


Figure 6. Nineteen sites used for benthos are show in Muskegon Lake. Samples were collected in June 2012

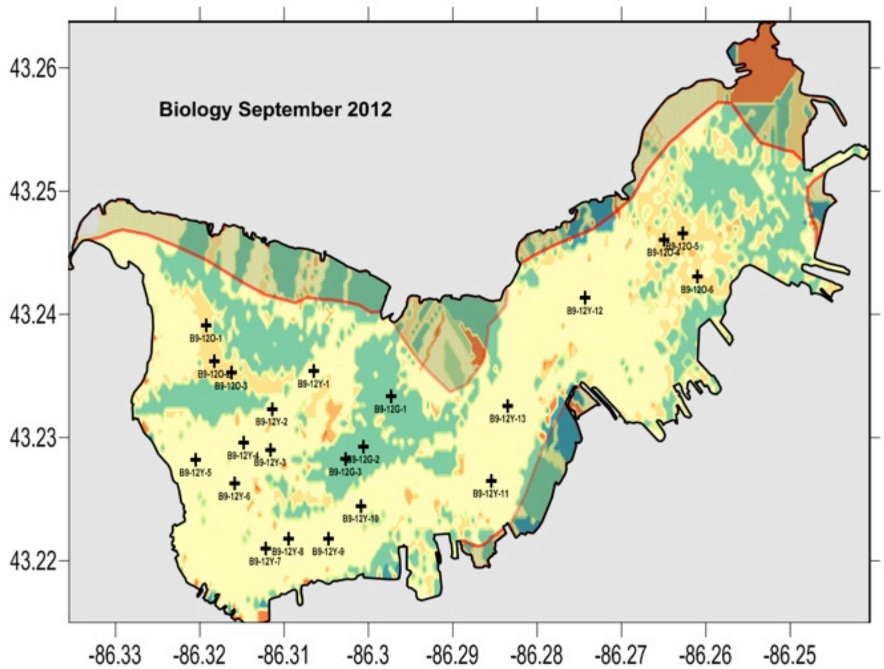
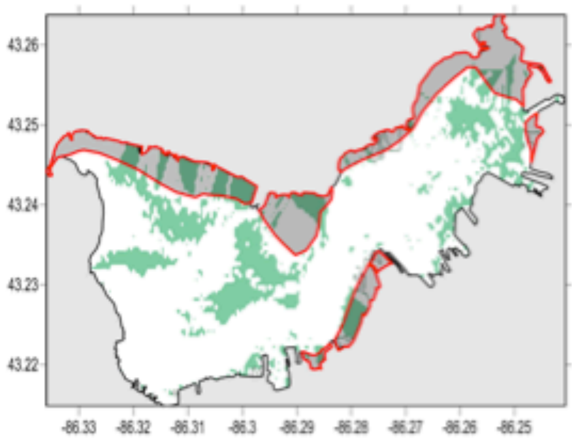


Figure 7. Location of Muskegon Lake sites for the additional twenty-two biological samples collected in September 2012.

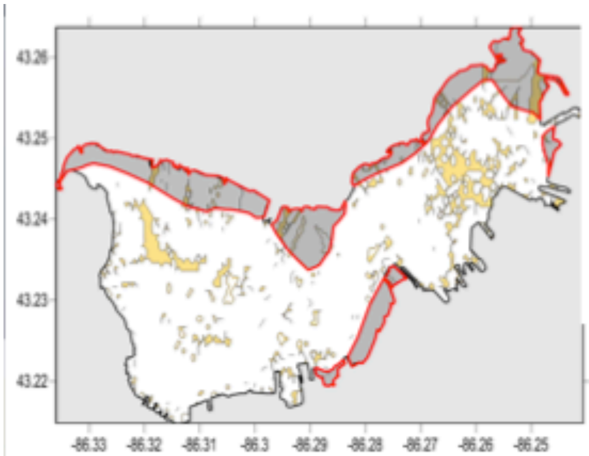
Acoustic Class	Yellow-5
% Area	49%
Depth (m)	13.85
% TOC	10.35
% Dry Weight	0.13
> 2000 um	0.6
1000-2000 um	0.24
500-1000 um	0.22
250-500 um	0.81
125-250 um	1.99
63-125 um	4.3
< 63 um	91.85

Figure 8. The physical characteristics and distribution of acoustic class 5 (Yellow) is show with a photograph. The sediments are a very silty and soft.



Acoustic Class	Green -2
% Area	22%
Depth (m)	6.91
% TOC	3.18
% Dry Weight	0.55
> 2000 um	14.73
1000-2000 um	3.98
500-1000 um	4.86
250-500 um	35.06
125-250 um	21.82
63-125 um	1.87
< 63 um	17.68

Figure 9. The physical characteristics and distribution of acoustic class 2 (Green) is show with a photograph. The sediments are a sandy substrate with little silt.



Acoustic Class	Orange-6
% Area	18%
Depth (m)	6.92
% TOC	7.3
% Dry Weight	0.18
> 2000 um	10.61
1000-2000 um	2.15
500-1000 um	1.16
250-500 um	12.03
125-250 um	14.94
63-125 um	4.66
< 63 um	54.46

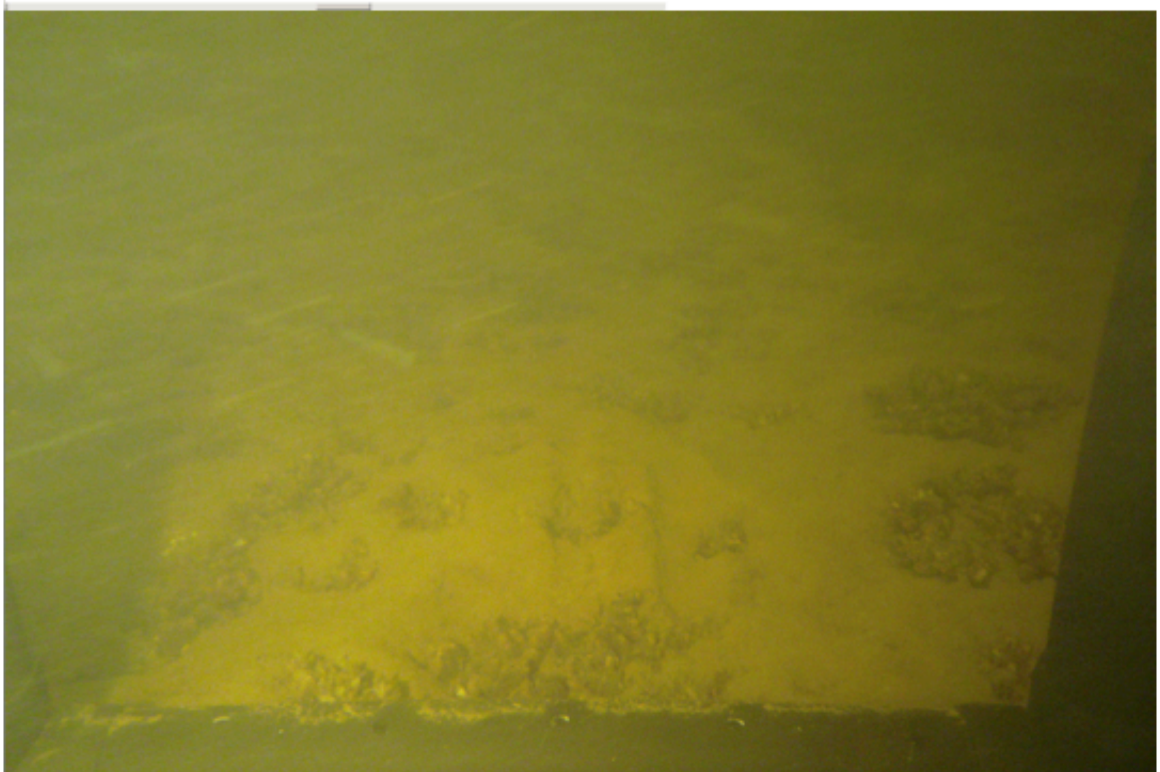


Figure 10. The physical characteristics and distribution of acoustic class 6 (Orange) is show with a photograph. The sediments are a silty substrate with moderate amounts of sand.

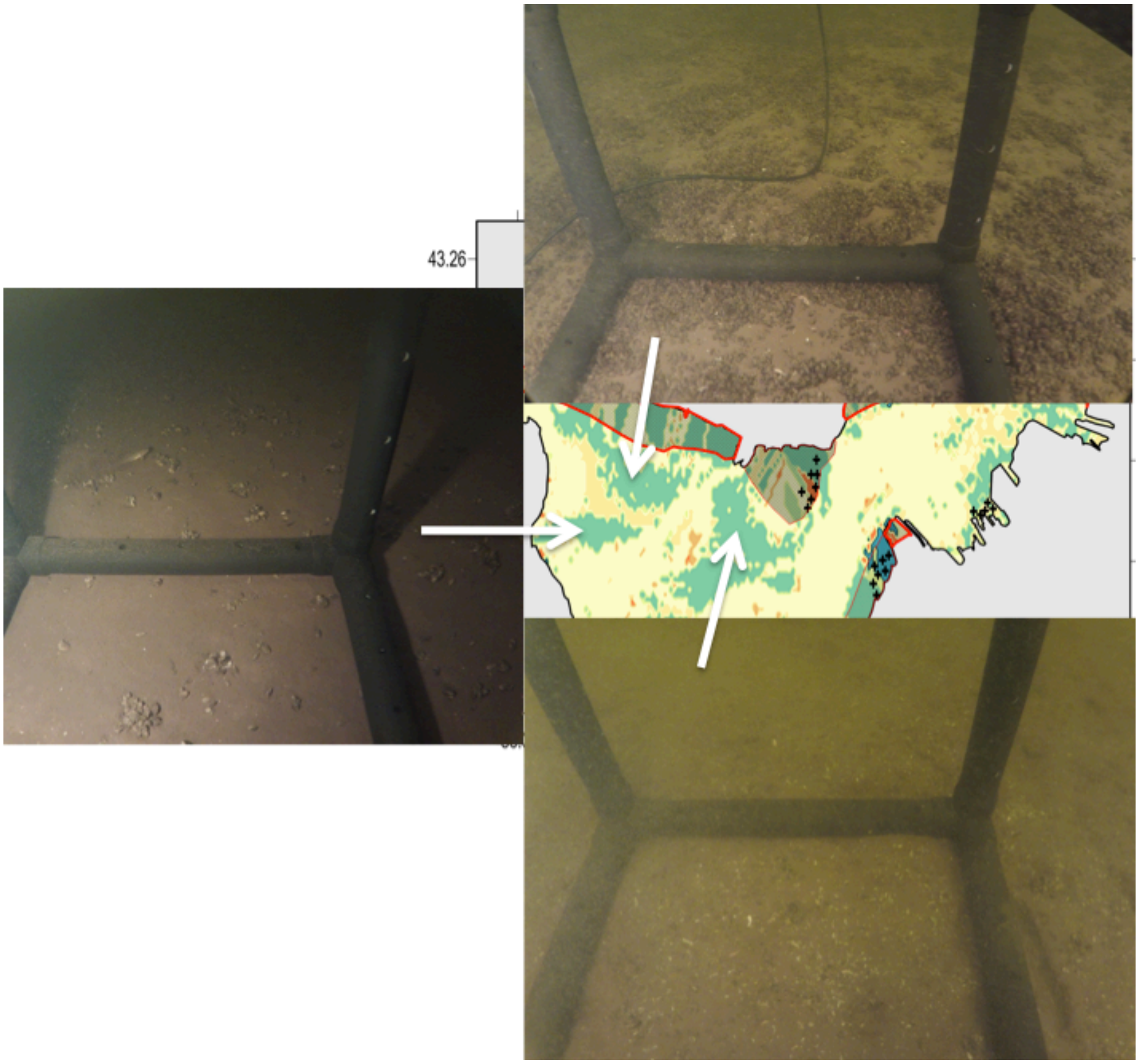
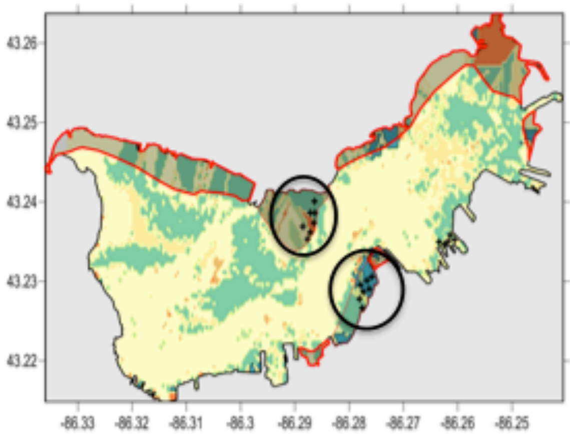


Figure 11. Dreissenid mussels are displayed for three areas of acoustic class 2 (Green) in Muskegon Lake. The sediments are a sandy substrate with little silt.



Acoustic Class	Shallow
% Area	NA
Depth (m)	2.39
% TOC	2.27
% Dry Weight	0.69
> 2000 um	3.86
1000-2000 um	1.73
500-1000 um	3.13
250-500 um	33.41
125-250 um	27.24
63-125 um	6.71
< 63 um	23.93

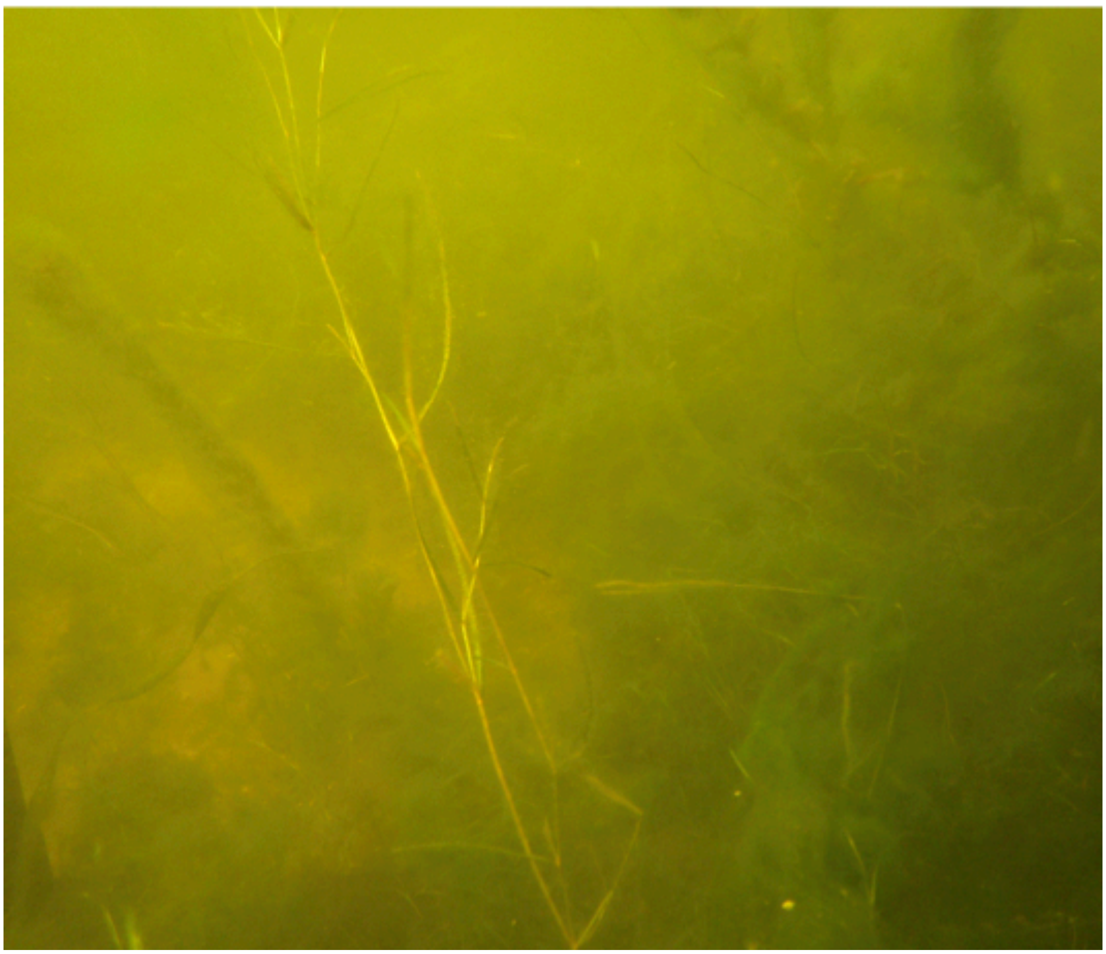


Figure 11. The physical characteristics and distribution of shallow sites (Black Dots) is show with a photograph. The sediments are a sandy/silty with lots of vegetation.

Appendix A. Physical characteristics of Muskegon Lake in 2012

Station	Depth	% Dry Weight	%TOC	>2000 µm	1000-2000 µm	500-1000 µm	250-500 µm	125-250 µm	63-125 µm	<63 µm
G-10	5.4	34%	4%	37%	4%	4%	31%	23%	2%	1%
G-11	8.7	72%	6%	23%	1%	2%	5%	4%	1%	63%
G-12	13.3	71%	2%	4%	10%	12%	40%	16%	0%	18%
G-13	4.6	54%	6%	29%	5%	3%	32%	22%	2%	7%
G-14	8.2	67%	1%	3%	4%	8%	34%	32%	2%	17%
G-15	8.4	68%	1%	3%	9%	12%	49%	24%	0%	3%
G-16	5.3	24%	6%	19%	7%	3%	19%	14%	6%	33%
G-17	3.6	63%	2%	28%	4%	4%	34%	24%	2%	5%
G-18	3.8	59%	5%	28%	8%	4%	26%	20%	2%	13%
G-19	3.5	72%	2%	18%	8%	7%	32%	30%	3%	3%
G-20	5.3	62%	2%	20%	4%	3%	25%	23%	3%	22%
G-5	9.7	42%	2%	2%	2%	4%	35%	24%	1%	32%
G-6	5.0	26%	4%	5%	2%	2%	29%	21%	3%	36%
G-7	4.9	38%	4%	14%	2%	2%	34%	24%	2%	22%
G-8	5.2	34%	6%	33%	3%	2%	21%	11%	2%	27%
G-9	3.8	40%	4%	19%	4%	2%	23%	27%	2%	23%
G1	10.0	73%	1%	0%	0%	3%	56%	30%	1%	10%
G2	10.0	73%	2%	2%	2%	14%	69%	12%	0%	1%
G3	9.6	68%	1%	2%	0%	3%	53%	30%	0%	11%
G4	9.9	65%	2%	6%	2%	4%	55%	26%	0%	6%
O-1	6.1	18%	6%	10%	8%	1%	24%	18%	3%	36%
O-10	8.7	16%	7%	5%	0%	1%	12%	12%	5%	65%
O-2	6.5	21%	8%	11%	1%	1%	11%	20%	4%	51%
O-4	6.3	16%	8%	7%	1%	1%	9%	16%	9%	58%
O-6	6.3	22%	7%	18%	1%	1%	11%	16%	4%	48%
O-8	7.6	16%	9%	13%	1%	1%	5%	8%	3%	69%
S-1	1.1	49%	9%	16%	9%	6%	50%	17%	2%	0%
S-12-14	0.6	76%	2%	0%	0%	2%	4%	4%	0%	90%
S-15	4.8	55%	3%	1%	1%	1%	33%	33%	31%	0%
S-16	3.0	78%	1%	0%	0%	2%	39%	41%	9%	8%
S-17	4.0	78%	1%	1%	1%	6%	27%	27%	2%	37%
S-18	5.2	65%	2%	1%	1%	2%	35%	45%	11%	6%
S-19	6.0	50%	3%	1%	0%	1%	16%	38%	26%	18%
S-2	1.2	75%	1%	3%	1%	3%	46%	34%	2%	11%
S-3-7	0.9	77%	1%	1%	1%	4%	54%	37%	0%	3%
S-4	1.1	64%	3%	10%	2%	4%	49%	29%	2%	4%
S-5	1.2	76%	1%	3%	2%	6%	53%	21%	0%	15%
S-8-10	1.2	77%	1%	13%	4%	3%	22%	22%	2%	34%
S-9-11	0.9	76%	2%	0%	0%	1%	6%	6%	0%	86%

Appendix A. Physical characteristics of Muskegon Lake in 2012 (Continued).

Station	Depth	% Dry Weight	%TOC	>2000 µm	1000-2000 µm	500-1000 µm	250-500 µm	125-250 µm	63-125 µm	<63 µm
Y-1	12.5	10%	10%	0%	0%	1%	2%	3%	3%	91%
Y-10	18.4	11%	11%	1%	1%	1%	1%	2%	4%	89%
Y-11	16.8	12%	10%	0%	0%	0%	1%	2%	3%	93%
Y-12	16.0	12%	10%	0%	0%	0%	1%	5%	4%	90%
Y-13	13.5	15%	10%	3%	1%	1%	2%	3%	3%	88%
Y-14	11.8	13%	11%	1%	0%	0%	1%	2%	4%	93%
Y-15	12.1	13%	10%	2%	0%	0%	1%	3%	7%	87%
Y-16	11.5	14%	11%	0%	0%	0%	1%	1%	3%	95%
Y-17	10.7	15%	10%	2%	0%	0%	1%	0%	2%	94%
Y-18	11.3	16%	10%	0%	0%	0%	0%	1%	2%	96%
Y-19	9.5	20%	8%	0%	0%	0%	0%	3%	13%	82%
Y-2	13.6	11%	10%	1%	0%	0%	1%	2%	7%	88%
Y-20	11.4	17%	10%	0%	0%	0%	0%	1%	3%	95%
Y-3	10.9	11%	10%	0%	0%	0%	1%	2%	2%	95%
Y-4A	14.3	11%	11%	0%	0%	0%	1%	1%	4%	94%
Y-4B	14.3	12%	11%	0%	0%	0%	1%	2%	4%	94%
Y-5	13.3	11%	10%	0%	0%	0%	1%	2%	2%	95%
Y-6	15.4	11%	11%	0%	0%	0%	1%	2%	4%	93%
Y-7A	15.9	12%	10%	0%	0%	0%	1%	2%	4%	93%
Y-7B	15.9	15%	11%	0%	0%	0%	0%	1%	3%	96%
Y-8	17.3	13%	11%	1%	0%	0%	1%	2%	4%	91%
Y-9	18.2	12%	12%	1%	1%	1%	1%	2%	8%	87%