A Comparison of Sampling Protocols to Estimate Species Composition, Percent Cover, and Biomass of Macrophytes in Chief Lake, Michigan

by
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Abstract.—Macrophytes are an important component of aquatic ecosystems and affect lake chemistry, water quality, and distributions and interactions of higher trophic levels. Three methods used for assessing macrophyte biomass or percent cover in Michigan lakes were compared in Chief Lake, Manistee County, Michigan. The first method assesses biomass from transects, the second method uses hydroacoustics to obtain results on percent cover, biomass, and plant height, and the third determines percent cover from visual estimations. The first two methods are used by the Michigan Department of Natural Resources (DNR) and the third is used by the Department of Environmental Quality (DEQ). Species abundances and the number of species each method found in total and at each sampling site were compared. Najas was the dominant species in the lake and represented 85.9% of the total plant biomass measured by the DNR and 53.7% of the plant cover estimated by the DEQ. The DNR Method found 28 species to the 20 species found by the DEQ Method. However, no significant difference was detected in the number of species found at each sampling site. Because the DNR Method measures biomass and the DEQ Method records percent cover, a correlation was sought between biomass and percent cover ranking. No significant correlation was found. A comparison of percent covers recorded for all three methods was made. This was possible due to an application of the DEQ visual estimation technique along DNR transects. The DEQ Method found 71.3% cover, the DNR Method found 74.0% cover, and the Hydroacoustic Method recorded 74.2% macrophyte cover in Chief Lake. The comparisons resulted in similar percent covers for all three methods, although a difference was found when comparing the percent cover from the Hydroacoustic Method in only the area covered by the DEQ to the DEQ results. Finally, the possibility of reducing sample sizes of each

method was considered. All methods could undergo substantial reductions in sample sizes and still obtain similar total percent cover or biomass results. While the data appears to show that the DEQ percent cover index can be applied to DNR transects and make the methods relatable in the future, other information suggests that these results are a fluke. Another method for surveying macrophytes, used by US Geological Survey's Long Term Monitoring Program is suggested.

Introduction

Aquatic macrophytes are important to lentic systems for multiple reasons. They have a large influence on the littoral zone of lakes since they are the primary producers. Macrophytes reduce shoreline erosion by dampening wave energy, trapping particles and associated nutrients, and providing habitat for invertebrates feeding on periphyton, detritus, and microorganisms. Macrophytes also provide a habitat for the feeding, breeding, and refuge of littoral fish. The decomposition of macrophytes has an important effect on the dissolved oxygen concentrations and the cycling of nutrients and contaminants as well (Wetzel 2001).

The concentration of macrophytes affects the production of consumers in a lake. Wiley et al. (1984) provided evidence that invertebrates and insectivorous fish production increase with macrophyte concentration, and that piscivorous *Micropterus salmoides* production has a unimodal relationship with macrophyte concentrations. The piscivorous fish probably have such a relationship because their relative foraging efficiency decreases with higher macrophyte concentrations, but their production increases to a point because there are more insectivorous fish for them to prey upon. This relationship suggests that there is an optimal macrophyte concentration for production of piscivores in a lake,

which the study found to be at 52 g/m^3 (dry weight). This is one reason that ecosystem managers would be interested in knowing the macrophyte concentration in a lake.

Species richness and abundance of fish may also be significantly lower in areas with sparse or absent macrophyte cover. In Lake Huron and Lake Ontario, Randall et al. (1995) found that the abundance of fish was 2.3 times higher at high macrophyte densities than at low densities. Species richness of fish was significantly lower in areas of sparse or absent macrophyte cover. However, fish size and mass were smaller at high macrophyte densities, a finding confirmed by Wiley et al. (1984). A fish production index based on fish biomass and size was also significantly higher in vegetated areas (Randall et al 1995).

Species richness of macrophytes also affects the distribution of fish species in a lake. Weaver et al. (1997) provided evidence that certain species of fish are affected by the richness of macrophyte species in patches. In their study, juvenile fishes including *Lepomis macrochirus*, *Pomoxis nigromaculatus*, and *Morone chrysops* were more often found in macrophyte patches with lower species richness. Many of these patches were dominated by Eurasian watermilfoil. (Common and scientific specific names of aquatic plants mentioned in this document are listed in Appendix A). However, older fish and other species like *Perca flavescens* dominated areas of dense and species-rich macrophyte patches. Species richness and composition as well as percent cover are therefore also important variables for a macrophyte sampling protocol to assess.

The occurrence of non-native species is another critical component to consider. Presence of non-native plant species can have a large influence on aquatic ecosystems, significantly altering lake productivity, species composition, and food web dynamics

(Kelly and Hawes 2005). Presence of threatened and endangered species are therefore of regulatory and conservation interest.

For these reasons it is important to determine appropriate sampling protocols for quantifying species composition, density, biomass, and percent cover of macrophytes. Personnel at the Institute for Fisheries Research and the Michigan Department of Natural Resources have asked for a clear protocol for macrophyte sampling (O'Neal et al. 2004, O'Neal and Soulliere 2006). Additionally, personnel at the DNR have asked for a comparison of its method to the method of the DEQ to determine how data can best be shared between the two departments. Also, both the DNR and DEQ protocols call for sampling of the entire lake, which may not be necessary. Smaller sample sizes might estimate just as well, which would reduce the time and effort put into sampling. The goals of this study are to address these issues of comparing and relating the two methods, optimizing sampling efficiency, and recommending improvements to the methods.

Study Site

Chief Lake in Manistee County, Michigan was chosen as the study site. The lake, on the northwest side of the Lower Peninsula, had no known presence of invasive species at the time of selection (R. Haas, personal communication). The lake has a surface area of approximately 51 hectares (126 hectares), an average depth of 1 meter, and a maximum depth of 10 meters. It is a seepage lake and a map from the Institute for Fisheries Research indicates a substrate consisting primarily of sandy or organic material (Appendix B). Much of the lakeshore is developed and the lake was treated with herbicide 5 years ago (R. Haas, personal communication). With these characteristics, Chief Lake is similar to many other lakes in Michigan.

Methods

The necessary data were collected using the standard methods of the Michigan Department of Environmental Quality and the Michigan Department of Natural Resources for assessing macrophytes, described below. DEQ and DNR personnel conducted their respective surveys themselves. In addition, a hydroacoustic survey of the lake was completed by the DNR.

DEQ Method.—To perform the DEQ's method, DEQ personnel Eric Bacon and Brett Wiseley came to Chief Lake on August 16, 2007. Prior to the visit, the lake was divided into different Aquatic Vegetation Assessment Sites (AVAS) corresponding to Hydroacoustic transect locations (Appendix C). Each AVAS was approximately 100 meters wide. The AVAS boundaries were loaded into a Garmin GPS unit for easy location on the survey date. The survey began at the public access site at the southwest end of the lake and then continued around the perimeter in a clockwise fashion.

Actual starting points for each AVAS were recorded in the GPS unit and later checked against the planned start points. One person steered the boat in a zigzag pattern, alternately driving as close to shore as possible and then as far from shore as plant cover was estimated to occur. Another person stood in the front of the boat, collecting samples of plants from the lake bottom by throwing and retrieving a modified thatching rake attached to a rope long enough not to limit toss distance. The rake thrower called out the names of the plants found while boating through the AVAS. At the end of each AVAS, an estimate of percent cover for each type of plant was recorded on a map of the lake, thus providing a record of macrophyte spatial distributions (Appendix D). The plant

percent cover estimates were recorded as "found," "sparse," "common," or "dense," using the following classifications and codes:

> **(a) = found**: one or two plants of a species found in an AVAS, equivalent to ***less than 2%*** of the total AVAS surface area.
> **(b) = sparse**: scattered distribution of a species in an AVAS, equivalent to ***between 2% and 20%*** of the total AVAS surface area.
> **(c) = common**: common distribution of a species where the species is easily found in an AVAS, equivalent to ***between 21% and 60%*** of the total AVAS surface area.
> **(d) = dense**: dense distribution of a species where the species is present in considerable quantities throughout an AVAS, equivalent to ***greater than 60%*** of the total AVAS surface area (MDEQ 2005).

After the survey, the data was entered into the DEQ's Standard Aquatic Vegetation Assessment Site Species Density Sheet and then into the Standard Aquatic Vegetation Summary Sheet (Appendix E). These worksheets are available on their website at http://www.michigan.gov/deq/0,1607,7-135-3313_3681_3710-81012--,00.html. These sheets compile all of the data from the AVAS's onto one Excel spreadsheet. In the Summary Sheet the total numbers of a's, b's, c's, and d's of a species are multiplied by different factors (1, 10, 40, and 80 respectively) and then divided by the number of AVAS's to obtain the average percent cover for that species in the lake. A different average percent cover is computed for each species; these are then added together to obtain a general average percent cover of each AVAS (DEQ Procedures). An estimate of percent cover for the whole lake was calculated by summing the individual percent covers of each species.

DNR Method.—To perform the DNR Method, DNR personnel Bob Haas and Ken Koster worked on Chief Lake August 22 and 23, 2007. For this method, transects were established 50 meters apart around the perimeter of the lake (Appendix F). Eighteen of seventy total transects were randomly selected for sampling. The first transect was

randomly selected and the rest were evenly distributed around the lake. Eighteen transects were sampled because that was the most that could be completed in two days' time, resulting in an average spacing of 200 m between transects. Usually DNR transects are established every 200 m around a lake basin, so this survey's methods were in accordance with past DNR surveys. Samples were taken along the transects at depths of 0.25 m, 0.5 m, 1 m, and each additional meter of depth into the lake until hook tosses no longer returned macrophytes or macroalgae. To take a sample, a grapple hook attached to a rope was tossed once to each side of the transect, parallel to shore. The hook was tossed underhand about 5 meters, allowed to sink to the bottom, and then dragged along the bottom and into the boat to retrieve the macrophytes. It is possible to standardize hook tosses by noting the distance of each toss, but this was not done in this study. At each depth, the resulting sample was weighed, divided by species, and then weighed by species. A note of whether the sample was light, medium, or heavy was also recorded.

An attempt was made to apply the DEQ's visual estimations of percent cover to the DNR biomass method in the event no correlation between DNR biomass and DEQ percent cover existed. If the method could be applied easily, DNR personnel could use it in the future to relate their data to DEQ data. At each depth a percent cover index from A to D (low to high) was assigned to each species found at that depth, much like the DEQ assigns a percent cover index to each species in an AVAS. This resulted in a percent cover estimation for each depth, which then could be combined to create percent cover estimate for each transect and for the whole lake.

Hydroacoustic Method.—In addition to the DNR and DEQ methods, a hydroacoustic unit from BioSonics was used by DNR personnel Bob Haas and Ken Koster on August

21, 2007 to assess macrophyte cover in the lake. The unit was set to 430 kHz and had a 6 degree beam angle. The unit used a GPS unit to mark its position while it sent pings to the bottom of the lake at a rate of approximately 10 pings per second. Information was recorded about the depth of the lake as well as the depth of plants, their height, and percent cover of the area traversed by the unit. The hydroacoustic unit was used across thirty-nine transects of varying length, recording 5,768 reports which summarized 11 pings for each report (R. Haas, personal communication). A map of the hydroacoustic reports can be found in Appendix G.

Statistics.—Analyses were made of several aspects of these methods. The first data compared was the relative abundance of species that each method found. Then the number of species found at each sample site was compared using a Mann-Whitney test because data was not normally distributed. Next a correlation was sought between the biomass results of the DNR Method and the percent cover index used in the DEQ Method. Total percent covers generated by the DEQ Method, by the application of the DEQ percent cover index to the DNR Method, and by the Hydroacoustic Method were compared using a Kruskall-Wallis test. Pair-wise comparisons were made using Mann-Whitney tests, because this data was also not normally distributed. The percent covers generated by the Hydroacoustic Method in just the areas sampled by the DNR or the DEQ were compared to the results of each method using Mann-Whitney tests to see how well each method assessed the area it surveyed. Finally, an analysis using methods outlined in Scheaffer et al. (1979) was made to determine the number of samples necessary to get a result within a certain percentage of the result of an entire survey. First, the lake was divided into two strata since it is composed of two distinct basins.

Chief Lake has one basin that is fairly homogenous in depth, at about 1 meter. The other lake basin varied much more, getting deeper toward the center of the lake with maximum depth of 10 meters (Appendix H). To correctly assess the lake and determine the optimum sample size, weighting factors must be calculated both to distribute the number of samples to each stratum and to give the variance of each strata appropriate weight in the formulas. Weights were calculated as follows:

$$\text{Shallow stratum weight} = w_1 = N_1\sigma_1 / \Sigma(N_i\,\sigma_i)$$

$$\text{Deep stratum weight} = w_2 = N_2\,\sigma_2 / \Sigma(N_i\,\sigma_i)$$

where N_i is the size of the i^{th} stratum and σ_i is the standard deviation of the i^{th} stratum. .

Then the number of samples, n, necessary to obtain results within a certain percent, B, of the full survey is calculated by

$$n = \frac{N_i^{\,2}\sigma_i^{\,2}/w_i}{(N^2B^2/4) + N_i^{\,2}\sigma_i^{\,2}}$$

where N is the size of the population (of all strata combined).

Graphs showing how variance decreased with increased sample size were generated. Variances (V) for each number of samples, n, was calculated by

$$V = \frac{1}{N^2} \cdot N_i^{\,2}\,\frac{N_i - n_i}{N_i}\,\frac{s^2}{n_i}$$

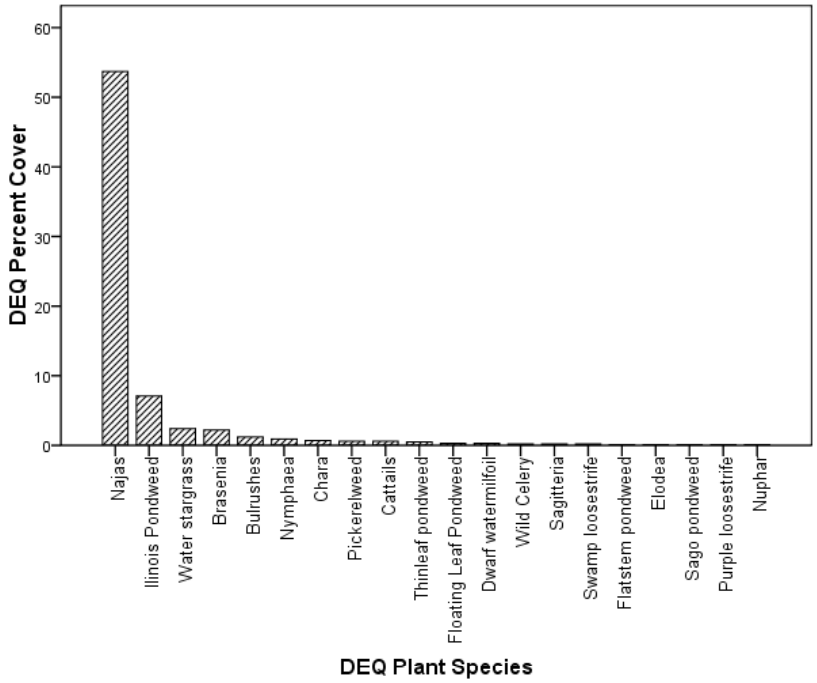
where s^2 is the sample variance.

Results

Species abundances.—The relative species abundances produced by each method were compared. The most abundant species for both methods was *Najas*. Beyond that, the two methods differed (Figure 1). There was also a difference in the number of species found for each method. The DNR Method found a total of 28 different species,

although two of them could not be identified precisely. The DEQ Method found 20 species in comparison. The hydroacoustic unit does not identify macrophytes by species.

The number of species found at each sampling site (transect or AVAS) for each method was compared as well. The two methods were not significantly different in the number of species that each one found at each sampling location (Mann-Whitney, P = 0.43). While the DNR Method found a higher number of macrophyte species overall, it did not find a higher number of species at each transect than the DEQ Method found at each AVAS.



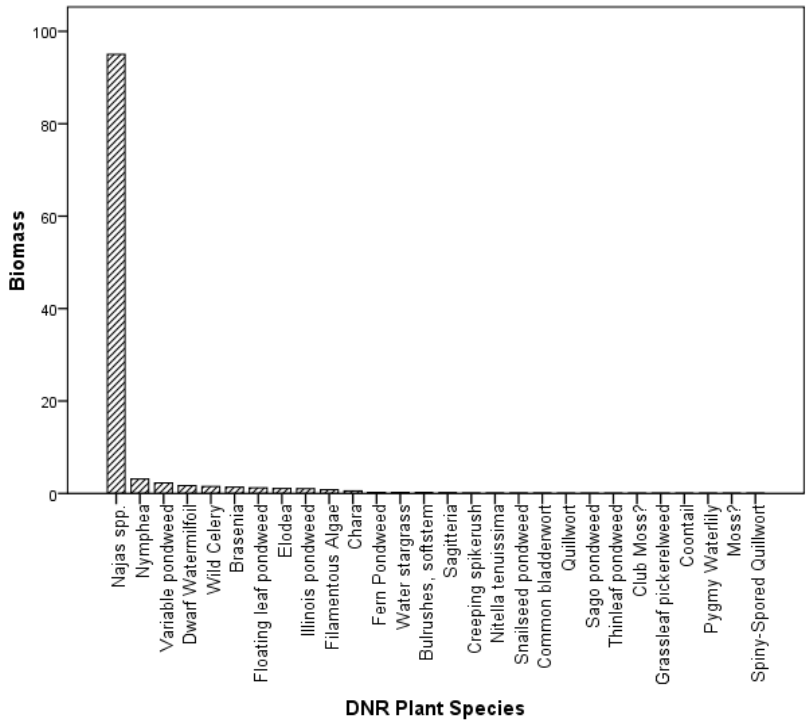


Figure 1. –Species abundances as found by the DEQ and DNR Methods. The DEQ Method ranks species by percent cover while the DNR Method ranks species by biomass (kg wet weight).

Correlations.—Comparisons of the DNR, DEQ, and Hydroacoustic methods were made in several ways. First, since these methods do not assess the same parameter (DNR surveys for biomass and DEQ records percent cover), a correlation was sought between the two methods. Using data from AVAS's containing a DNR transect, the percent cover index code assigned to a species by the DEQ was analyzed for correlation with the biomass recorded for that species by the DNR. Only the four most abundant species were analyzed because it quickly became clear that the results were not correlated. The correlations and their significances are summarized in Table 1. To get a visual perspective of this data, a boxplot was created to show how data was distributed for *Najas* (Figure 2). The boxes encompass similar areas and the means are comparable. Boxplots generated for the other three species produced similar results. This confirms

that different percent covers (A being 0-2% through D being >60), do not have different biomasses and are not correlated to the DNR biomasses.

Species	df	Correlation	*P*
Najas	16	0.09	0.72
Potamogeton illinoensis	16	0.37	0.13
Brasenia	16	0.40	0.10
Chara	16	-0.20	0.43

Table 1.—Results of correlations between DEQ percent cover index and DNR biomass estimate for four most abundance macrophyte species.

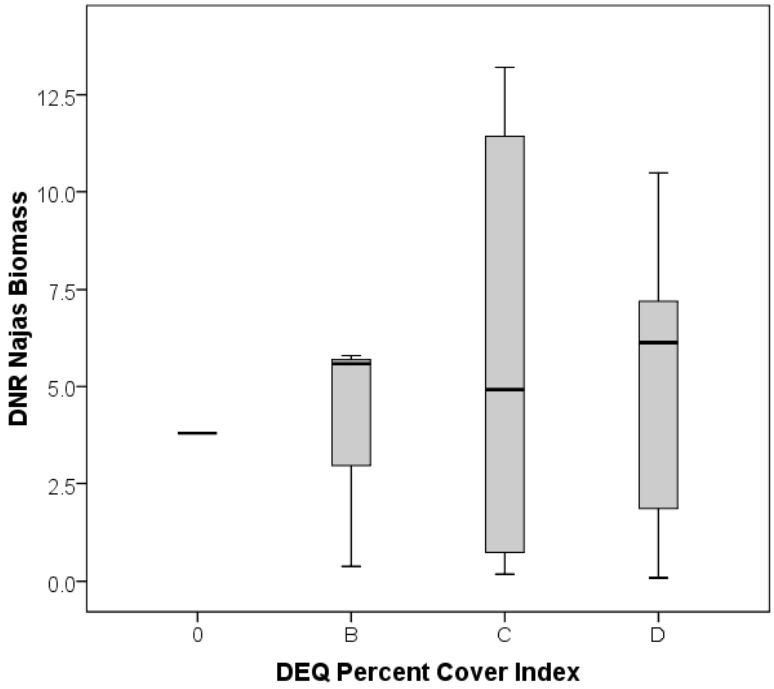


Figure 2.—Boxplot displaying range of DNR biomasses recorded for each DEQ percent cover index ranking for the macrophyte species *Najas*. The boxes span similar areas, indicating that there is no correlation between an increased biomass and a higher percent cover index ranking. A DEQ ranking of "0" indicates that the DEQ did not record that species in an AVAS where the DNR did find it in the corresponding transect.

Percent cover comparisons.—Percent covers generated by each method were compared. The DEQ Method found that Chief Lake had a macrophyte percent cover of

71.3%. The Hydroacoustic Method's average percent cover result was 74.2%. The application of the DEQ Method to the DNR transects resulted in an average percent cover of 17.6%. This estimate seemed extraordinarily low, compared to the amount of cover observed in the lake and in light of the results of the other methods. It was suggested that when one makes visual estimations of percent cover, one remembers the highest densities best. Therefore, perhaps the highest densities recorded at a transect should be used in the calculations instead of the average of densities recorded for each toss along the transect. This maximum DNR percent cover assessment resulted in an average percent cover of 74.0%, much closer to the DEQ and Hydroacoustic estimates. None of the four data distributions were normal. A non-parametric Kruskall-Wallis test, $P < 0.01$, showed that the four results were significantly different. After removing the obviously different DNR average percent cover of 17.6%, the Kruskall-Wallis test again showed that the three remaining methods had significantly different results ($P < 0.01$). A Mann-Whitney test was then used to make pair-wise comparisons, summarized in Table 2. All comparisons were significantly different except for the DNR Maximum and the DEQ Method. These results suggest that the DNR Maximum Method applied to transects would give results similar to the DEQ Method.

Methods Compared	df	*P*
DEQ, Hydroacoustic	1	< 0.01
DNR Avg, Hydroacoustic	1	< 0.01
DNR Max, Hydroacoustic	1	< 0.05
DNR Avg, DNR Max	1	< 0.01
DEQ, DNR Avg	1	< 0.01
DEQ, DNR Max	1	0.25

Table 2.—Results of pair-wise comparisons of percent covers produced by each method, made by a Mann-Whitney test. The DEQ Method and the DNR Maximum Method were the only methods with similar results. The Hydroacoustic Method results were probably significantly different due to a much larger sample size.

The Hydroacoustic Method results may have been significantly different from the DEQ and DNR Method results because the sample size was so much larger (5,782 instead of 35 and 18, respectively). Thirty sets of 200 randomly-selected reports were aggregated, each set producing an average percent cover for the 200 reports within it. This would summarize the same amount of information, but result in a smaller *N* when analyzing the data. Using this value as the Hydroacoustic Method result, the percent covers for each method were not significantly different (Kruskall-Wallis, $P = 0.09$). This suggests that sample size was causing a difference between the Hydroacoustic Method results and the DEQ and DNR Method results.

Each method sampled a different proportion of the lake surface area. The Hydroacoustic Method sampled nearly the entire lake except for very shallow areas and areas with very dense floating-leaf macrophytes. The DEQ Method generally sampled within 12 meters of shore, rarely getting near the center of the lake. The DNR Transect Method was intermediate; transects extended from near shore (0.25 meters depth) to the deepest location of plants in both basins. Percent cover results were compared of the DNR Maximum Method and the DEQ Method to the Hydroacoustic percent covers in only the common areas sampled by each method using Mann-Whitney tests. The results generated by the DNR Maximum Method were similar to those of the Hydroacoustic Method along those same transects to the extent which the DNR sampled ($P = 0.46$). However, the comparison of the DEQ percent cover results to the Hydroacoustic reports contained in DEQ AVAS's were significantly different ($P < 0.01$). From this information, it appears that the DEQ Method significantly underestimated the percent

cover in the area it sampled. The mean percent covers generated by each method in its sampling area and the results of the tests are summarized in Table 3.

Method	Mean	SD	df	*P*
DNR Maximum Method	73.6	39.2	—	—
Hydroacoustic of DNR Transects	84.3	18.6	1	0.48
DEQ Method	71.3	32.7	—	—
Hydroacoustic of DEQ AVAS	84.7	22.3		< 0.01

Table 3.—Percent covers generated by the DNR Maximum and DEQ Methods along with the average percent cover found by the Hydroacoustic Method in only the areas sampled by the DNR Maximum or DEQ Methods. A Mann-Whitney test was used to compare the Hydroacoustic result from the sampling area to its respective method. The DEQ Method differed significantly from the Hydroacoustic results in areas covered by AVAS's while the DNR Maximum Method was not significantly different from Hydroacoustic results along its transects.

Reducing sample sizes.—Each method was assessed to determine if the number of samples could be reduced, using statistical methods described above. For the DEQ Method, the number of AVAS's could be reduced from 35 to 19 and still get results within 10% of the full sample's percent cover. For the DNR biomass method, the variance among samples was so low that only 1 transect instead of 18 would be necessary to get biomass per toss results within 1% of the results of doing all 18 transects. The Hydroacoustic Method consisted of 5738 reports, each report being the average of 11 pings. In order to get results within 10% of the results of the full survey, only 61 reports are necessary. See Figure 3 for graphs of the decrease in variance associated with increased sample size for the DEQ and DNR Methods.

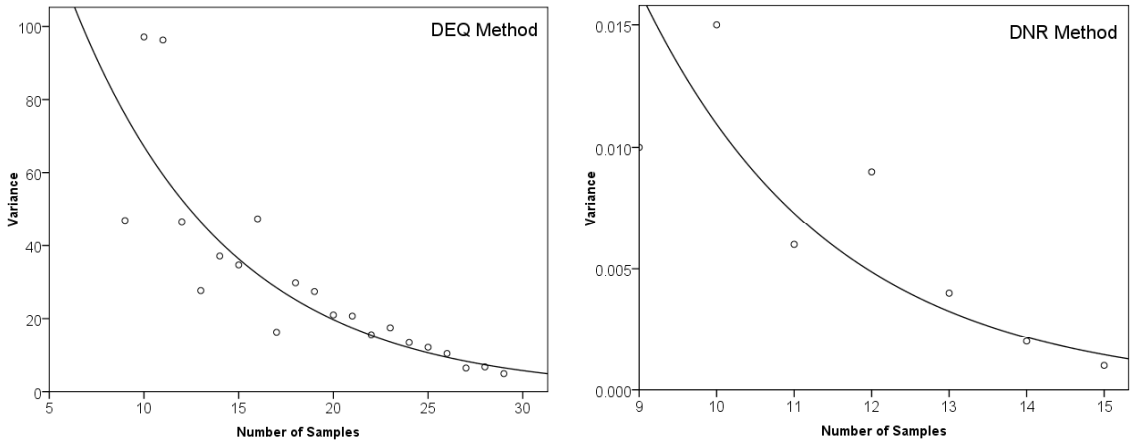


Figure 3.—Decrease in variance of results for each method. Variance decreases until it plateaus, indicating that an increase in samples will not benefit the results. Note the difference in scale between each graph. The DNR graph has a very small variance even with the smallest number of samples possible in stratified random sampling. Lines represent an exponential fit to the data points, shown as circles.

Discussion

The purpose of this study is to quantitatively compare the macrophyte sampling techniques, evaluate the information produced per unit effort, and make recommendations to improve the methods. Additional observations were made regarding the limits of the methods and any possible subjectivity that might interfere with results. Issues were found concerning the time required to do the survey, subjectivity, limits of the technique, equipment problems, the amount of lake sampled, and the quality of data.

Time spent.—With regard to time spent, the DEQ Method required approximately 3 hours to assess the entire lake. The sampling went very smoothly and the completion of all 35 AVAS's required only part of one afternoon. Two DEQ personnel were necessary to complete the assessment; total effort on the water was about 6 person-hours. The DNR Method required much more time to perform. Due to the nature of the method (involving the collection of samples and the separation and weighing of species), the DNR Method was much slower. In two days of sampling (about 16 hours), 18 transects were

completed with 3-6 people working at a given time; total effort on the water was about 64 person-hours. The transects sampled were distributed all around the perimeter of the lake. The Hydroacoustic Method was completed in an afternoon (about 6 hours) and could be completed with two people, like the DEQ Method. Total effort on the water was about 12 person-hours. There was little work beyond initial set-up of equipment.

Because the DEQ Method is so quick, multiple lakes could be surveyed in one day, depending on size. The Hydroacoustic Method also could survey multiple lakes in a day, but it is somewhat slower as it required approximately 6 hours to survey Chief Lake. The DNR Method takes much more time than either two methods, so it is not recommended as a rapid macrophyte assessment technique. However, the extra time does allow for a more complete sampling at a range of depths.

Subjectivity.—One issue with each technique is that of subjectivity. The DEQ Method requires visual estimations of percent cover. Nothing is actually measured quantitatively using this method. Percent covers reported may vary among individuals, which results in potential subjectivity. DEQ personnel did say that they attempted to limit variance in estimates through cross-training of staff. This should reduce the amount of subjectivity involved.

However, DEQ personnel sometimes did not record data as listed in their procedures. During the survey the boat could not reach certain areas of the lake due to shallowness and dense plant cover. Personnel recorded information based on visual estimates of these areas, but they should also have indicated on the map the presence of plant densities so thick that the area could not be reached. This was not done, showing how data recorded can be influenced by the persons sampling.

The DNR Method is also subject to biases. Procedures may not always be followed as intended. During sampling, DNR personnel mentioned that the sample from each depth should be spun in a bucket with holes for water to escape through the bottom due to centrifugal force. Water was not removed from the samples before taking their initial weights in this survey, however. This resulted in the initial total weight being greater than the sum of the individual weights by species. Instead of taking an initial weight, individual species weights could be added together to achieve a total. Much of the water would come off by the time species are separated and not taking an initial weight could reduce time spent in the field.

Limitations.— Another problem in the DNR Method is the inability to sample and subsequently record difficult-to-drag samples. For example, transect 8 began in a stand of cattails and bulrushes. Standard procedure would dictate a toss to the right, into the bulrushes, and then a subsequent toss to the left into the cattails. However, DNR personnel decided that two tosses to the right should be made due to the impossibility of dragging the grapple hook through a stand of cattails. This resulted in no record of cattails at transect 8 or in Chief Lake itself. If the grapple hook cannot sufficiently sample well-rooted plants, then other methods should be sought to include these plants in the dataset. Field notes could be made that additional species were seen.

The DNR Method can be limited in other aspects as well. Objectivity through weighing samples and random sampling are beneficial to a point, but not when it results in underreporting or omission of species present in a lake. For example, sampling at transect 1 failed to record the presence of a dense population of *Nymphaea* in this part of the lake. The locations of the 0.25, 0.5, and 1 meter depths along this transect happened

to occur in the few areas with no *Nymphaea*, so there is no record of any white water lilies in an area inundated with them. This is a shortcoming of the DNR Method that could easily be corrected by taking field notes. The DEQ Method does not have this problem because the surveyor is able to record any plants seen within the AVAS, whether they are caught in the thatching rake or not. The hydroacoustic unit does not record data by species, one weakness of the method.

Another issue common among all three is that of boat access to near-shore areas or those dense in macrophytes. The DEQ Method has a lot of flexibility when it comes to recording data from shallow or densely-packed areas. If a boat cannot reach these areas, the thatching rake can be tossed in to get a sample or the surveyor can also make visual assessments from what he/she can see at a distance. There is always the possibility that the rake toss may not reach or that personnel cannot identify plants from that distance.

The DNR Method is more limited in this respect. There are not many problems with sampling shallow areas because sampling begins at 0.25 meters, so it is not necessary to go closer to shore than that. The boat can usually reach this depth or personnel can get out of the boat and wade in to that depth. Areas densely-packed with macrophytes can pose more of a problem. If the boat cannot reach the necessary depths and it is too deep for personnel to wade to them, sampling is limited to where one can reach. This situation would result in underreporting of biomass and possibly species richness. The Hydroacoustic Method is also limited by the ability of the boat to reach shallow or dense areas. Again, writing field notes could provide information on species and estimated densities in these areas.

Another potential issue with the DNR Method is the possibility of the sample falling from the hook. The grapple hook seemed to be good at dragging in large amounts of dense macrophytes. However, it appeared that it was fairly easy for very small samples to fall off of the hook before reaching the boat. One had to maintain a consistent drag speed in order to lose as little as possible. The thatching rake the DEQ uses may also lose plants if the lake surface is rough, if the rake is not retrieved with a steady pull, or if there are very few macrophytes in the area (E. Bacon, personal communication). The Hydroacoustic Method does not take any samples, so this is a non-issue.

Problems in methodology.—Another issue in the DNR Method is in the recording of small amounts of macrophytes. If a very small sample was taken, it was automatically recorded as 0.01 kg, equivalent to 10 grams, even if it was one stem of a plant not weighing nearly that much. This made it possible for the sum of the species weights to be larger than the initial total weight taken, which could result in over-reporting of low biomass species. This happened at transects where low amounts of macrophytes were retrieved. Overall this had a small effect on total biomass.

The DEQ Method also has its own problems. The nature of the method requires that the person throwing the rake and assigning the percent cover ratings to each species can see the bottom of the lake. If the person cannot see the bottom and the plants growing there, then they cannot truly assign a percent cover. Chief Lake had macrophyte cover present well below visible depths, but the DEQ Method did not extend its survey out into the lake to cover these areas. It missed quite a bit of plant cover, according to the Hydroacoustic data. The DNR Method surveyed to every meter of depth as long as plant cover was present, so much more of the lake was sampled (Appendix I). The

Hydroacoustic Method sampled straight across the lake at all of its transects, so it also did not miss deep cover.

In addition to the potential for missing species located farther from shore, personnel can underestimate or overestimate the percent cover. In Chief Lake, the percent cover result of the Hydroacoustic Method from the area sampled by the DEQ was significantly higher than that generated by the DEQ survey. A comparison of the Hydroacoustic results along sampled DNR transects had different results. The DNR Maximum Method accurately assessed percent cover in the area that it sampled and was also a good estimate for percent cover in the whole lake (if the Hydroacoustic results are used as the standard). The DNR transects went deeper into the lake and covered more lake area than the DEQ AVAS's. It appears that the extent of the area surveyed is a critical factor in accurately assessing percent cover. If a lake is not entirely composed of littoral zone, then the lack of plants in the benthic zone will lower the overall percent cover for the lake. This is a possible reason why the DEQ Method could have underestimated cover in its AVAS's but still achieved overall results similar to the full Hydroacoustic survey. Perhaps the DEQ Method would have more accurately assessed the littoral zone had sampling covered more of the littoral area in the lake. In any case, an inaccurate assessment in this instance casts a shadow on the certainty of DEQ Method results in other lakes, especially ones without a macrophyte-free benthic zone to lower the average percent cover. Further study should be done to compare DEQ results to Hydroacoustic surveys in other lakes.

An additional problem in the DEQ Method is that the percent cover index uses broad categories for cover. It potentially introduces substantial error into the calculations even

if the visual estimates are accurate. For example, any estimate between 21% and 60% is coded as a "c" and later assigned a value of 40% in the calculations.

Data.—Finally, one could consider the quality of the data from each method to be different. The DNR Method does provide information on something that has been measured, not estimated. The DEQ Method does not supply data of this nature. The Hydroacoustic Method also presents data that is measured and not based on estimations made by people. One more perk of the hydroacoustic unit is that it provides data that is ready to use in spreadsheets, saving the time of entering field data by hand.

Conclusions

Although this study sought a correlation between DEQ percent cover estimates and DNR biomass, no correlation could be found. Therefore there is no way to convert DEQ percent covers to DNR biomass or vice versa. However, if one records percent covers for rake samples along the DNR transects a comparable percent cover result is produced. At first glance it appears that the results of the two methods can be related by adding the DNR Maximum Method for percent cover in the future. However, this conclusion is flawed.

Although the Hydroacoustic Method initially reported an average percent cover that was significantly different from the results of the DEQ Method and the DNR Maximum percent cover, the results were similar when Hydroacoustic data were summarized to reduce sample size. It is interesting, and probably happenstance, that the DEQ and DNR Maximum methods recorded results so similar to the Hydroacoustic Method. Despite the similarities, the DEQ Method significantly underestimated cover in the area it sampled and casts doubt on its overall percent cover result. It appears that cover in the lake was

distributed in such a way that the DEQ Method came up with a similar result by chance. Results from the DEQ Method may therefore differ from those of the Hydroacoustic Method or the DNR Maximum Method in other lakes. The application of the DEQ percent cover index to the DNR Method is probably not worthwhile, but further comparisons of Hydroacoustic results to DEQ and any future DNR Maximum results should be made if the DEQ Method continues to be used.

The DEQ might consider another method to assess macrophytes. A method developed to assess the relative abundance and distribution of submersed plants (Jessen and Lound, 1962; Deppe and Lathrop, 1992) was adopted by the U.S. Geological Survey's Long Term Monitoring Program (Yin et al. 2000) and subsequently studied for its effectiveness in predicting total vegetation biomass (Kenow et al. 2007). The method, described in detail by Yin et al. (2000), involves anchoring a boat and taking rake samples at 6 locations around the boat. The area sampled is standardized by the length and width of the rake. Plant density is quantified by assigning different density ratings based on the percentage of rake teeth filled with plants. These ranges could introduce some error into the results. However, Kenow et al. (2007) compared the results of this method to the results of collecting submerged plants by hand from quadrats. They concluded that the rake method could accurately and precisely predict total submersed macrophyte biomass as well as the biomass of certain species. They also found that this method required an average of 10 minutes per site to collect the data.

This USGS Method seems to be a quick and effective way to get data that the DEQ should consider using. Also, the accuracy of biomass results of the DNR was not assessed in this study, but the DNR may want to consider using the USGS Method as

well. It seems as though the method could save the DNR some time. Finally, if all three agencies use this method, data would automatically be comparable and shareable among them.

Analyses made in this study have also indicated that all methods could stand a reduction in sample sizes. At least on Chief Lake, it was not necessary for the DEQ to sample the entire perimeter. An estimate of percent cover could have been made within 10% of the total assessment had only half of the AVAS's been sampled. The sample time could have been reduced accordingly. The DNR Method sample size could have been greatly reduced, only needing one sample to be within 1% of the results of the full survey! Considering how long 18 transects took (64 person-hours), any reduction would be an improvement. Finally, the Hydroacoustic Method could reduce its sample size by 94% in order to be within 10% of the full survey results for percent cover. However, these reduced sample sizes do not take into account differences one would find with number of species found, differences in percent cover or biomass by species, or the maps that can be produced showing spatial locations of macrophytes. These analyses focused solely on the overall percent cover or biomass estimates. In actuality, completing only one transect would not be recommended for the DNR Method.

Finally, consideration for time and effort should be made when choosing a sampling protocol. The DEQ Method was fast, and personnel said that non-DEQ staff could perform the method after a training session. It is an easy and quick way to get an idea of the percent cover in a lake, where certain plants are located, and the main species represented in a lake. However, if one is looking for an estimate of biomass, the DNR Method would be better. Also, more time is spent looking closely at macrophytes using

this method and it did find more species overall (28 versus 20). Nevertheless, no difference was found between the DNR and DEQ Methods in how many species were found at each sample site. More comparisons should be made of the number of species each method finds at other lakes to be able to compare the total number of species found.

Still, it appears that either method will give a good indication of the species found in a lake. The DNR Method did find a higher number of species and a threatened macrophyte species in Chief Lake, *Potamogeton bicupulatus*, while the DEQ Method did not. From this limited information it seems that the DNR Method might be preferred if searching for every species present or for endangered species. However, Wandell (2001, 2004) found that the DEQ Method identified a similar number of species to a transect method developed by Michigan State University limnology staff for citizen monitors. The Citizen Monitoring Method is similar to the DNR Method in that samples are taken along a transect at different depths, but four samples are taken at each depth instead of two. In the first of these studies, the DEQ Method found 20 species while the Citizen Survey Method found 23. In the second study, the DEQ Method found 20 species to the 19 found by the Citizen Survey Method. Therefore it is plausible that the DEQ and DNR Methods will find a similar number of species if their results from other lakes are compared.

In choosing any method it is necessary to remember the time each method requires to find a variety of species. Again, 18 transects could be surveyed with about 64 person-hours of work for the DNR Method, while the DEQ Method needed 6 person-hours for 35 AVAS's. The speed of the DEQ Method is a strength, but it also resulted in 8 of 28 species being missed. While the DNR Method uses more time on in-depth examination

of samples, the data is limited to what is caught in the grapple hook tosses. Therefore several species may be missed using this method. An effort should be made by the DNR to keep a record of species seen during the survey in addition to those captured during tosses. This would provide more information without adding much effort.

The Hydroacoustic Method would be competitive with the DEQ Method for a quick way of assessing percent cover if future comparisons show that their results remain similar. The human subjectivity factor in the Hydroacoustic Method is greatly reduced because percent cover is measured through averaging a set of 11 pings that report presence or absence of cover. No human estimation is involved. Additionally, the surveyor can work with the data to create a detailed map of the bottom of the lake and the location of macrophytes. The identification and locations of macrophyte species is not performed, however, so the Hydroacoustic Method should only be used to find a general percent cover or to map general information. This method could be improved by taking samples as the hydroacoustic unit records data. Species could be assigned codes and quickly recorded on a map, like in the DEQ Method. Then data would be available on the major macrophyte species in the lake, their locations, and their total percent cover. The DNR Method is an in-depth survey technique, and its DNR Maximum percent cover results may or may not be similar to Hydroacoustic Method results in the future. Further comparisons should be made of this method as well.

After completing the surveys, Chief Lake may not have been the best location. The macrophytes in the lake were extremely dominated by one species, *Najas*. Because of this dominance, a lake with a more diverse macrophyte community may have found greater disparities between methods with regard to the number of species found.

Additionally, the DEQ Method was not applied to the DNR Method by trained DEQ personnel, although the density estimates were recorded by H. Ziegenmeyer who had seen the DEQ Method performed. Results might vary for this application if someone else performs the survey in the future. Another issue is that Hydroacoustic biomass results were not compared to DNR Method biomass results because calculating biomass from Hydroacoustic data is difficult and time consuming. Therefore, no information regarding the efficacy of the DNR Method for sampling biomass was obtained. Finally, since only one lake was studied, results for percent cover and biomass would differ in other lakes and so more comparisons should be made to support or oppose the results of this study.

All of the methods assessed in this study have their pros and cons and one should chose the method that best corresponds to the variable one wants to measure. The DNR and DEQ should consider adopting the method used by the USGS Long Term Resource Monitoring Program. One or both departments may want to consider a change in survey technique. In any case, subjectivity should be reduced as much as possible and an effort should be made to improve the methods and reduce errors during sampling.

Acknowledgements

I would like to thank Dr. Jim Breck and Dr. Ed Rutherford (University of Michigan), Bob Haas (DNR) for their immense contributions to this project. Ken Koster (DNR), and Eric Bacon and Brett Wiseley (DEQ) were also instrumental in this study. Additional support was provided by Karen and Karl Ziegenmeyer, Jim and Sue Ozinga, and Jose Dagoberto Vanegas. This research was partially funded by the University of Michigan Honors Program.

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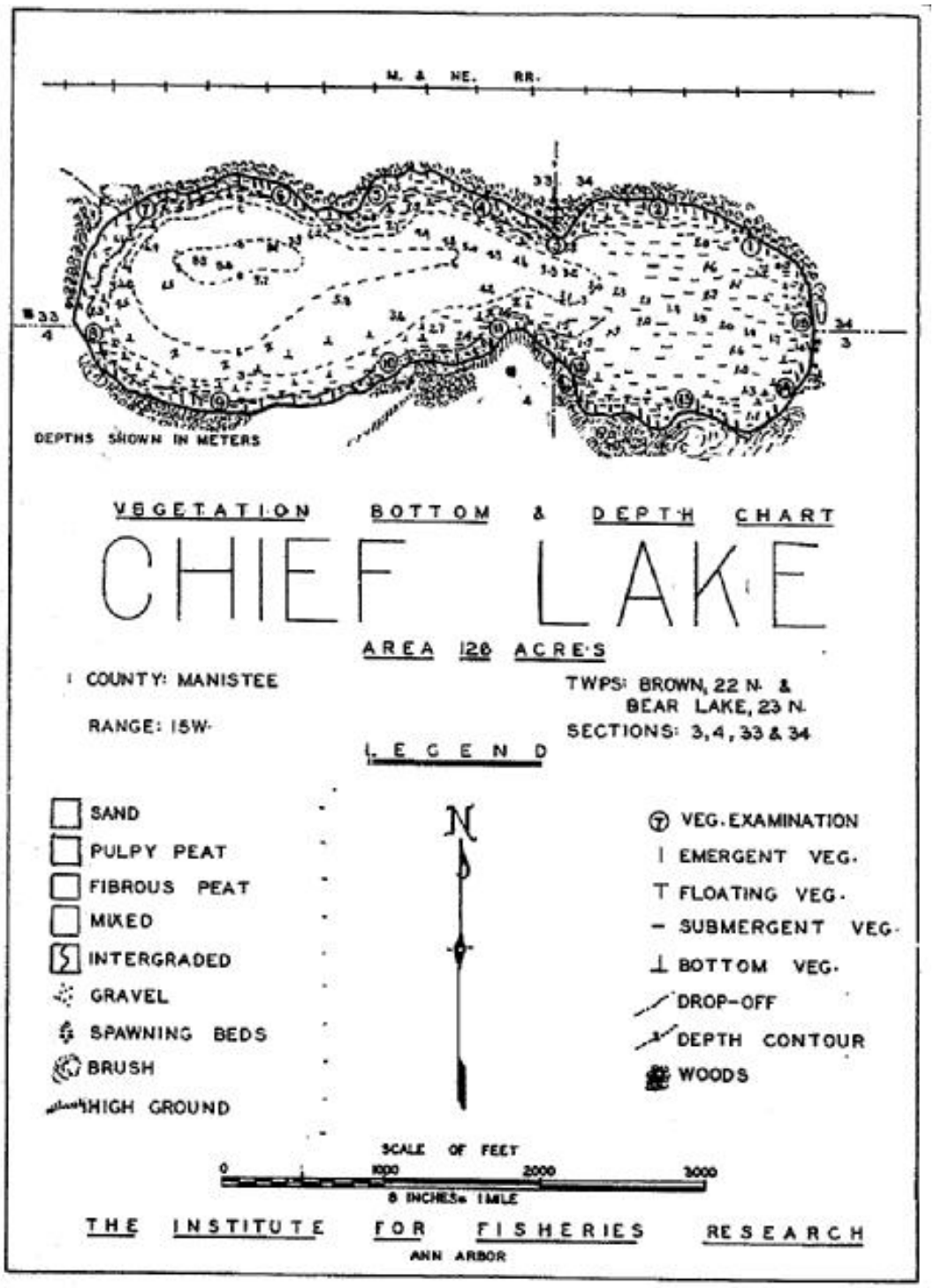
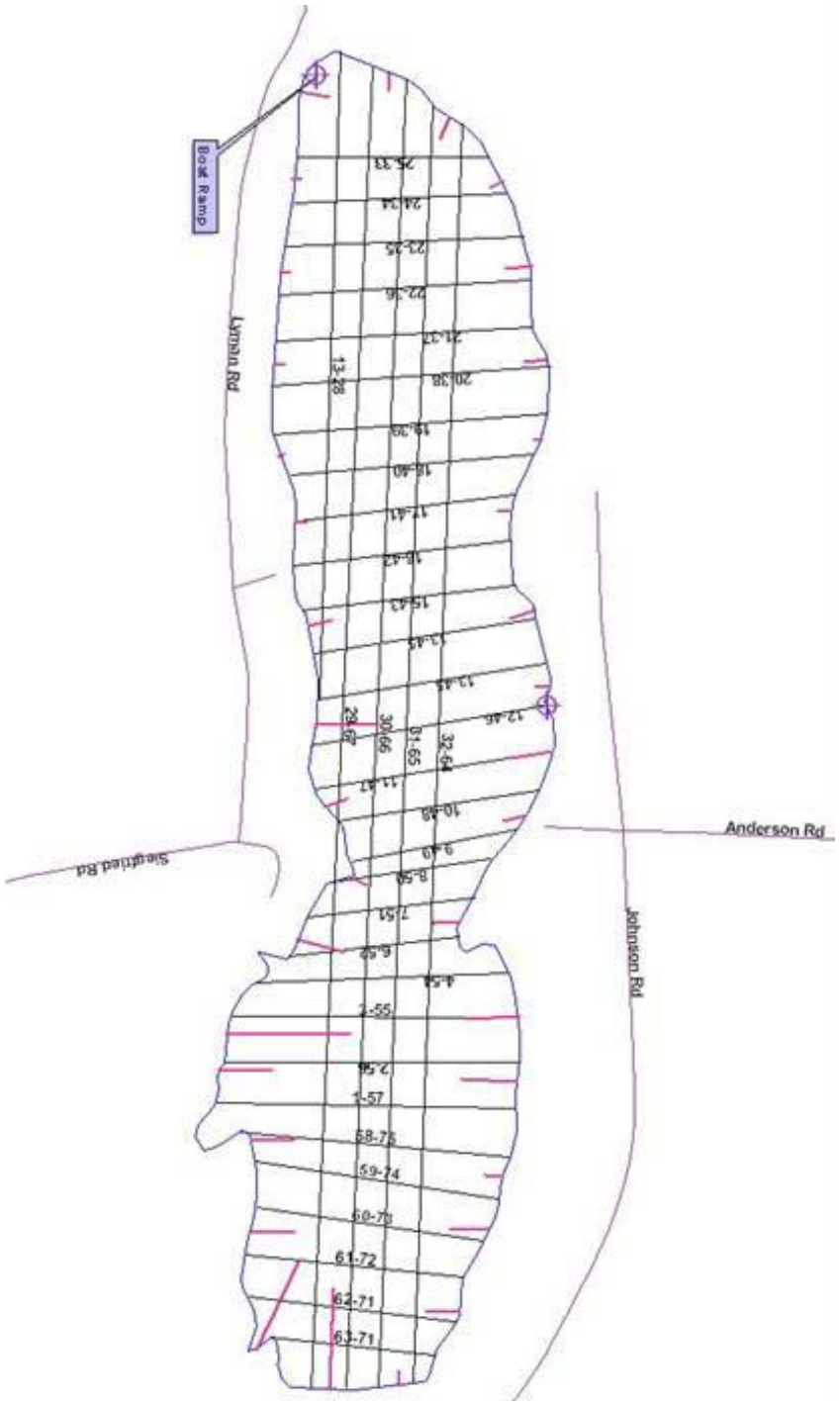
Appendix A: Common and scientific names of macrophytes mentioned in this document.

Common Name	Scientific Name
Arrowhead (submergent)	*Sagittaria*
Bulrushes	*Scirpus spp.*
Cattails	*Typha spp.*
Club moss?	*Lycopsid spp.*
Common bladderwort	*Utricularia spp.*
Common elodea	*Elodea*
Coontail	*Ceratophyllum demersum*
Creeping spikerush	*Eleocharis palustris*
Dwarf stonewort	*Nitella tenuissima*
Dwarf watermilfoil	*Myriophyllum tenellum*
Eurasian watermilfoil	*Myriophyllum spicatum*
Fern pondweed	*Potamogeton robbinsii*
Filamentous algae	*Cyanophyta spp.*
Flatstem pondweed	*Potamogeton zosteriformis*
Floating leaf pondweed	*Potamogeton natans*
Grassleaf pickerelweed	*Pontederia spp.*
Illinois pondweed	*Potamogeton illinoensis*
Moss?	*Bryophyta spp.*
Naiad spp.	*Najas spp.*
Pickerelweed	*Pontederia cordata*
Purple loosestrife	*Lythrum salicaria*
Pygmy water lily	*Nymphaea tetragona*
Quillwort	*Isoetes spp.*
Sago pondweed	*Potamogeton pectinatus*
Snailseed pondweed	*Potamogeton bicupulatus*
Spiny-spored quillwort	*Isoetes echinospora*
Stonewort	*Chara spp.*
Swamp loosestrife	*Decodon verticillatus*
Thinleaf pondweed	*Potamogeton pusillus*
Variable pondweed	*Potamogeton gramineus*
Water stargrass	*Heteranthera dubia*
Watershield	*Brasenia*
White water lily	*Nymphaea odorata*
Wild celery	*Vallisneria americana*
Yellow water lily	*Nuphar*

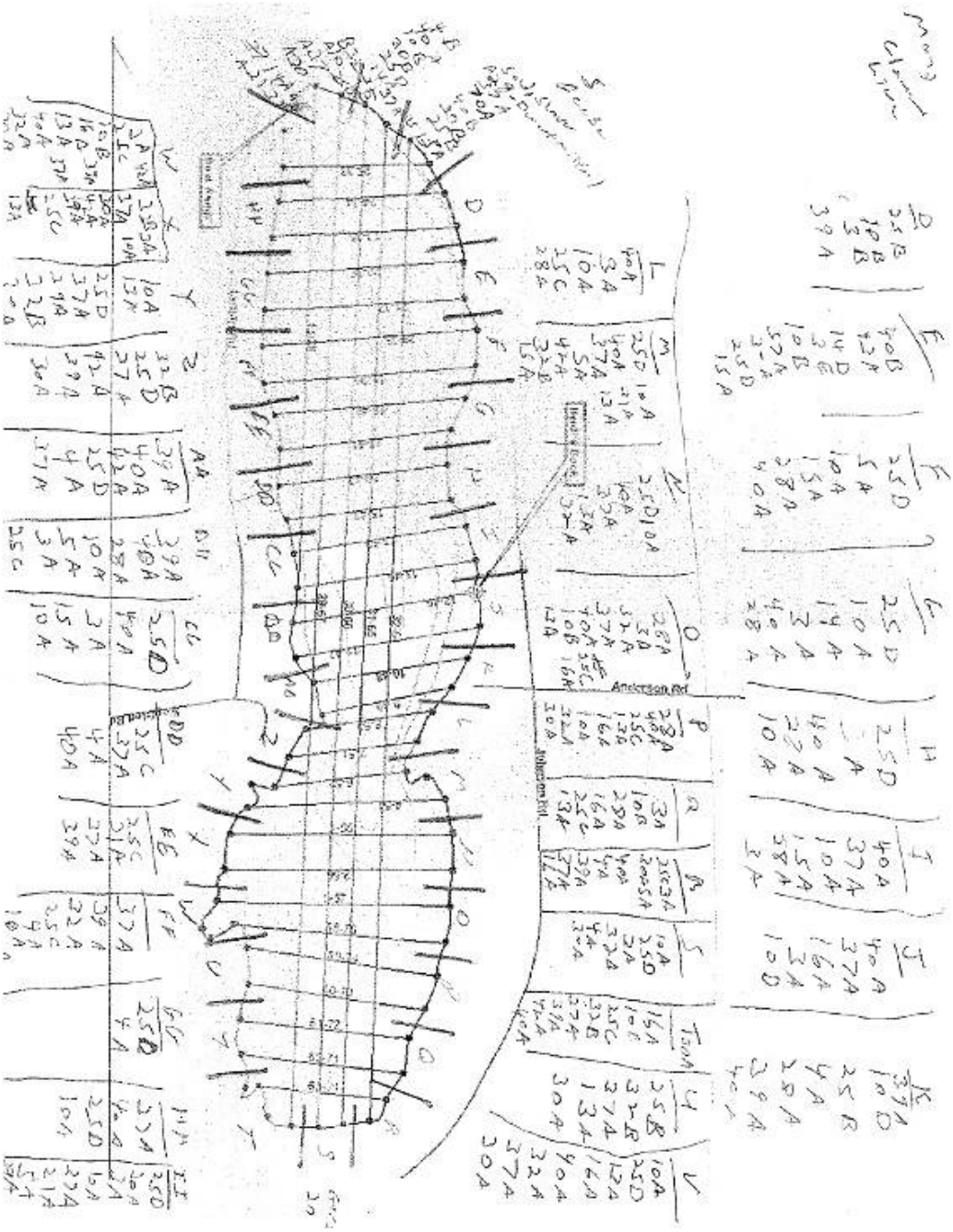
Appendix B: Map of Chief Lake, Manistee County, Michigan, prepared by the Institute for Fisheries Research, Ann Arbor. Surface area is 51 hectares (126 acres), with a maximum depth of 10 meters.



Appendix C: Map of Chief Lake, Manistee County, Michigan created from contributions by Bob Haas (DNR) and Heidi Ziegenmeyer. Black, numbered lines indicate planned Hydroacoustic transect locations. Pink lines indicate AVAS edges and the extent to which the AVAS's went into the lake.



Appendix D: Map of Chief Lake, Manistee County, Michigan created by Bob Haas (DNR) and used by DEQ personnel Eric Bacon and Brett Wiseley to delineate AVAS's and record survey data on August 16, 2007.



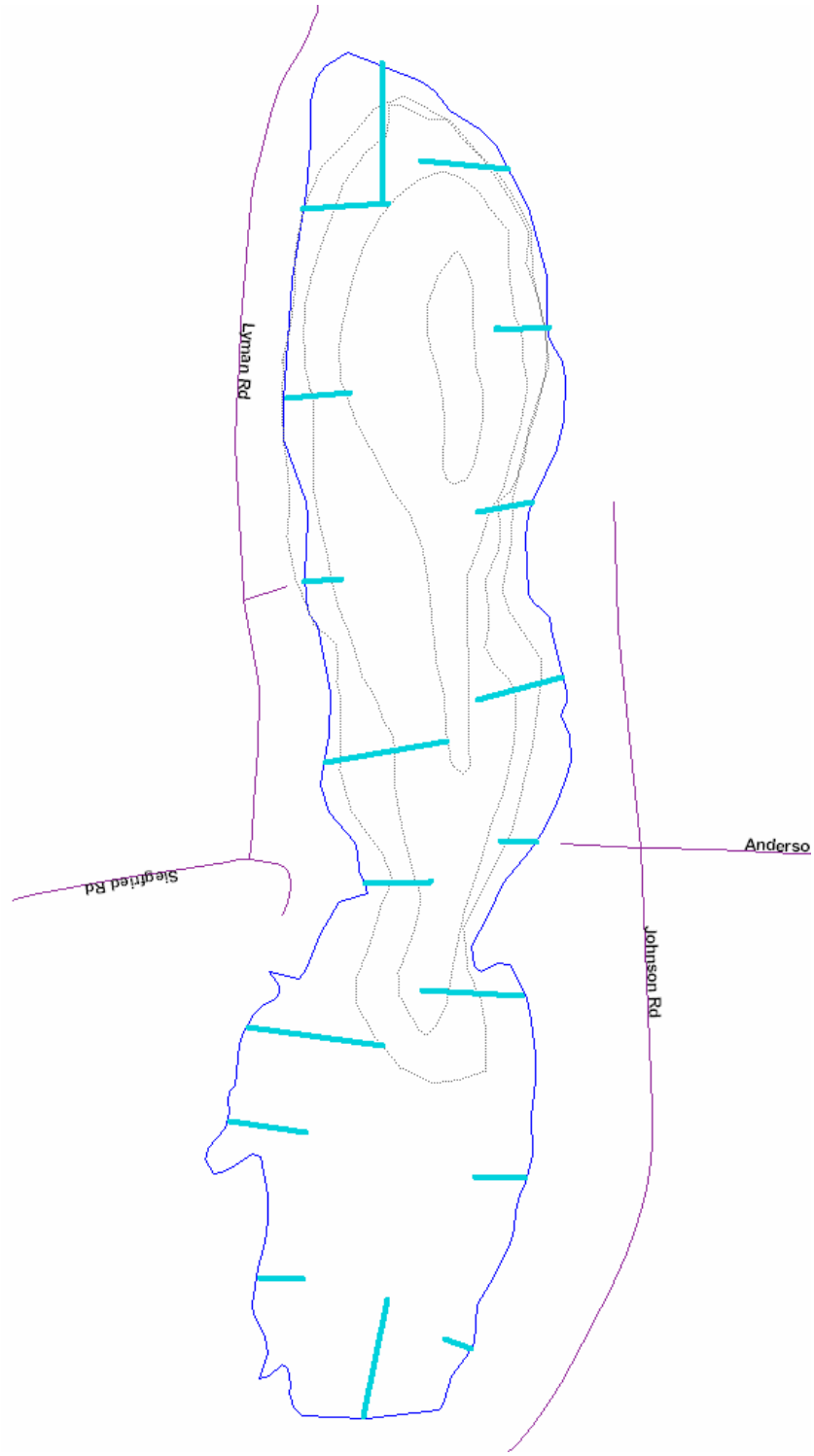
Appendix E: Excel spreadsheet used by DEQ personnel to compile survey data of Chief Lake, Manistee County, Michigan from August 16, 2007.

LAKE NAME- CHIEF LAKE COUNTY- MANISTEE SURVEY DATE: 8/16/2007

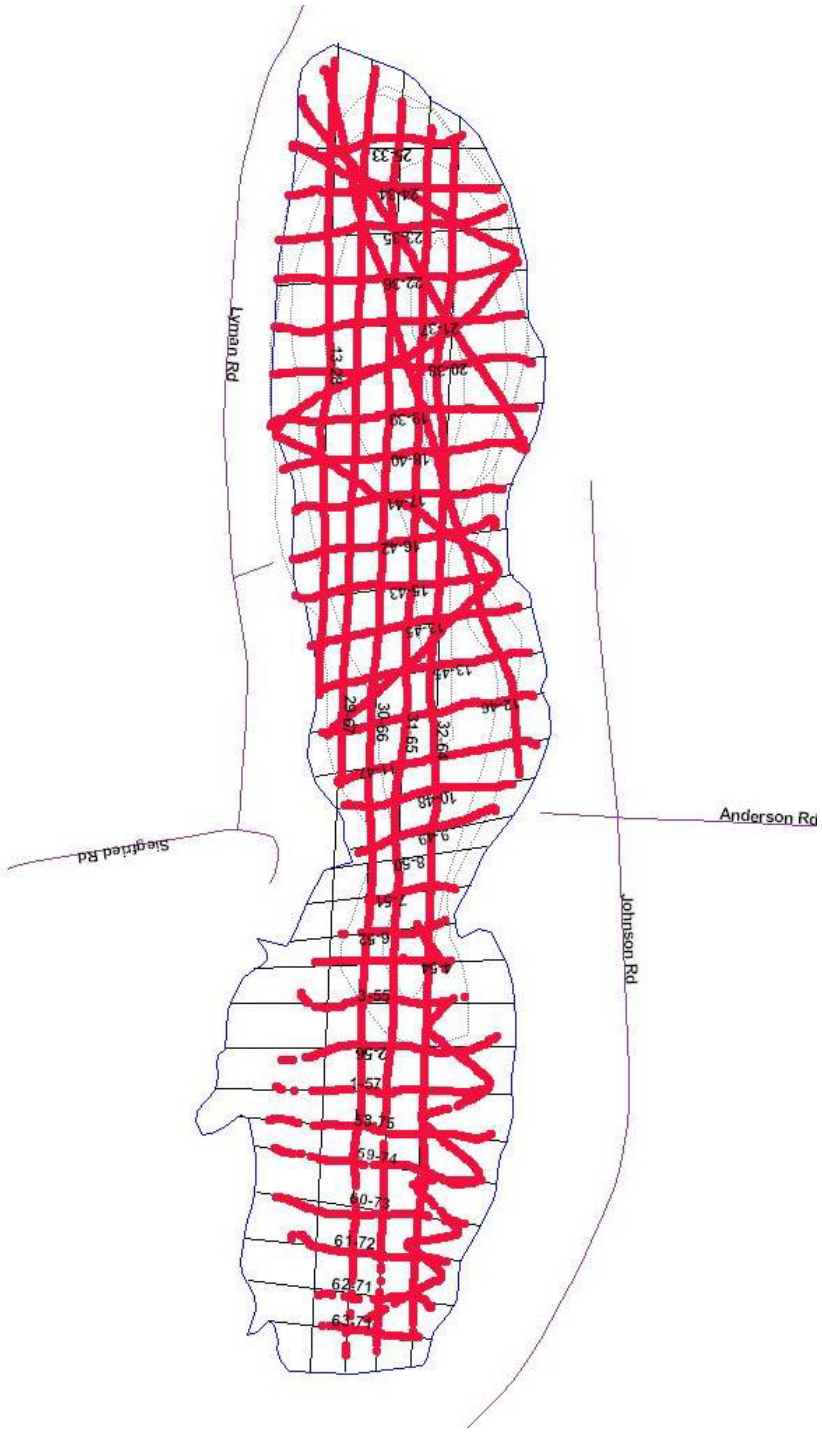
Standard Aquatic Vegetation Summary Sheet SURVEY BY: BACON, WISELEY, ZIEGENMEYER

		Total number of AVAS's for each Density Catagory				Calculations				Sum of Previous Four Columns	Total Number of AVAS's	Quotient of Column 9 divided by Column 10		
		A	B	C	D	Catagory A x 1	Catagory B x10	Catagory C x 40	Catagory D x 80					
Code No	Plant Name	1	2	3	4	5	6	7	8	9	10	11	Code No	Plant Name
1	Eurasian milfoil	0	0	0	0	0	0	0	0	0	35	0.0	1	Eurasian milfoil
2	Curly leaf pondweed	0	0	0	0	0	0	0	0	0	35	0.0	2	Curly leaf pondweed
3	Chara	15	1	0	0	15	10	0	0	25	35	0.7	3	Chara
4	Thinleaf pondweed	7	1	0	0	7	10	0	0	17	35	0.5	4	Thinleaf pondweed
5	Flatstem pondweed	5	0	0	0	5	0	0	0	5	35	0.1	5	Flatstem pondweed
6	Robbins pondweed	0	0	0	0	0	0	0	0	0	35	0.0	6	Robbins pondweed
7	Variable pondweed	0	0	0	0	0	0	0	0	0	35	0.0	7	Variable pondweed
8	Whitestem pondweed	0	0	0	0	0	0	0	0	0	35	0.0	8	Whitestem pondweed
9	Richardsons pondweed	0	0	0	0	0	0	0	0	0	35	0.0	9	Richardsons pondweed
10	Illinois pondweed	18	7	0	2	18	70	0	160	248	35	7.1	10	Illinois pondweed
11	Large leaf pondweed	0	0	0	0	0	0	0	0	0	35	0.0	11	Large leaf pondweed
12	American pondweed	0	0	0	0	0	0	0	0	0	35	0.0	12	American pondweed
13	Floating leaf pondweed	9	0	0	0	9	0	0	0	9	35	0.3	13	Floating leaf pondweed
14	Water stargrass	4	0	0	1	4	0	0	80	84	35	2.4	14	Water stargrass
15	Wild Celery	6	0	0	0	6	0	0	0	6	35	0.2	15	Wild Celery
16	Sagitteria	8	0	0	0	8	0	0	0	8	35	0.2	16	Sagitteria
17	Northern milfoil	0	0	0	0	0	0	0	0	0	35	0.0	17	Northern milfoil
18	M. verticillatum	0	0	0	0	0	0	0	0	0	35	0.0	18	M. verticillatum
19	M. herterophyllum	0	0	0	0	0	0	0	0	0	35	0.0	19	M. herterophyllum
20	Coontail	0	0	0	0	0	0	0	0	0	35	0.0	20	Coontail
21	Elodea	2	0	0	0	2	0	0	0	2	35	0.1	21	Elodea
22	Utricularia spp.	0	0	0	0	0	0	0	0	0	35	0.0	22	Utricularia spp.
23	Bladderwort-mini	0	0	0	0	0	0	0	0	0	35	0.0	23	Bladderwort-mini
24	Buttercup	0	0	0	0	0	0	0	0	0	35	0.0	24	Buttercup
25	Najas spp.	0	4	12	17	0	40	480	1360	1880	35	53.7	25	Najas spp.
26	Brittle naiad	0	0	0	0	0	0	0	0	0	35	0.0	26	Brittle naiad
27	Sago pondweed	1	0	0	0	1	0	0	0	1	35	0.0	27	Sago pondweed
28	Dwarf watermilfoil	11	0	0	0	11	0	0	0	11	35	0.3	28	Dwarf watermilfoil
29						0	0	0	0	0	35	0.0	29	
30	Nymphaea	12	2	0	0	12	20	0	0	32	35	0.9	30	Nymphea
31	Nuphar	1	0	0	0	1	0	0	0	1	35	0.0	31	Nuphar
32	Brasenia	8	7	0	0	8	70	0	0	78	35	2.2	32	Brasenia
33	Lemna minor	0	0	0	0	0	0	0	0	0	35	0.0	33	Lemna minor
34	Spirodella	0	0	0	0	0	0	0	0	0	35	0.0	34	Spirodella
35	Watermeal	0	0	0	0	0	0	0	0	0	35	0.0	35	Watermeal
36	Arrowhead		0	0	0	0	0	0	0	0	35	0.0	36	Arrowhead
37	Pickerelweed	21	0	0	0	21	0	0	0	21	35	0.6	37	Pickerelweed
38	Arrow Arum	0	0	0	0	0	0	0	0	0	35	0.0	38	Arrow Arum
39	Cattails	12	1	0	0	12	10	0	0	22	35	0.6	39	Cattails
40	Bulrushes	21	2	0	0	21	20	0	0	41	35	1.2	40	Bulrushes
41	Iris	0	0	0	0	0	0	0	0	0	35	0.0	41	Iris
42	Swamp Loosestrife	6	0	0	0	6	0	0	0	6	35	0.2	42	Swamp Loosestrife
43	Purple Loosestrife	1	0	0	0	1	0	0	0	1	35	0.0	43	Purple Loosestrife
	TOTAL											71.3		

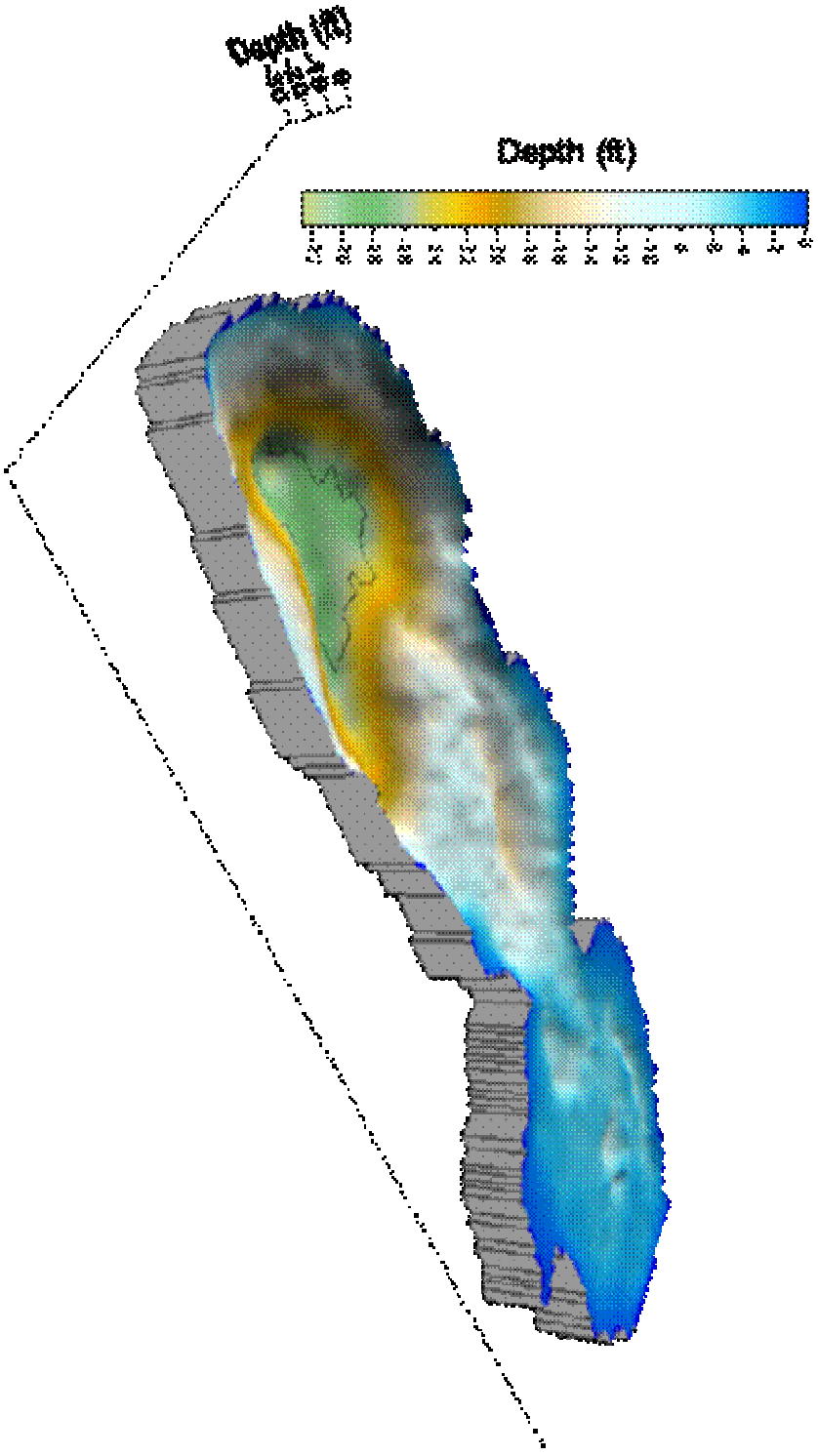
Appendix F: Map of Chief Lake, Manistee County, Michigan created from contributions by Bob Haas (DNR) and Heidi Ziegenmeyer. Blue lines indicate transects sampled by the DNR.



Appendix G: Map of Chief Lake, Manistee County, Michigan created from contributions by Bob Haas (DNR) and Heidi Ziegenmeyer, showing planning transects established by Bob Haas (DNR) at 50-m intervals. Red dots indicate locations of Hydroacoustic Method reports.



Appendix H: A map of Chief Lake, Manistee County, Michigan created by Bob Haas. The map indicates lake bathymetry.



Appendix I: Map of Chief Lake, Manistee County, Michigan created by Bob Haas (DNR). Shaded areas depict percent cover found by the Hydroacoustic Method. The zigzag line indicates the path taken by the DEQ. The line out to the center is where DEQ Secchi depth was taken. The black dots show the sampling sites of the DNR.