AQUATIC VEGETATION OF BIG MUSKEGO LAKE: 1995 SURVEY

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Abstract

The aquatic vegetation of Big Muskego Lake, Waukesha County, Wisconsin was quantified during August of 1995 using biomass samples at 54 randomized locations, presence/absence observations at 214 point sample locations, and interpretation of aerial photographs taken during the same time period. In addition, water and sediment depths were measured at all sample sites. Eurasian watermilfoil (*Myriophyllum spicatum* L.), a nonnative invasive species, was by far the dominant submersed species, with 75.3 g DW m^{-2} biomass out of a total community biomass of 93.5 g DW m^{-2}, or 80% of total plant community biomass. Eurasian watermilfoil was found in almost 90% of the 214 points. No vegetation was observed in 6.6% of the locations, and only 4% of locations had vegetation without Eurasian watermilfoil. The total species list for the lake included 19 species, with 4 emergent species, 2 floating leaved species, and 13 submersed species. The total number of aquatic plant species was average for a temperate eutrophic lake, but diversity and distribution of these species within the lake was unusually low. The mean diversity at each sample location was low at 1.45 species; however, most of these were nonnative species. The average number of native species was 0.43 per location. Water depth averaged only 101 cm at the 214 sample locations. Maximum water depth was 170 cm. Most locations had in excess of 200 cm of flocculent organic sediment overlying parent material or original firm lake bottom.

Preface

This study was sponsored by the U.S. Army Corps of Engineers-Detroit District under a Section 22 agreement co-sponsored by the Wisconsin Department of Natural Resources. This study was one task under a larger project, "Effects of Lake Drawdown on Sediment Dynamics and Macrophyte Distribution in the Big Muskego Lake Complex, Wisconsin," for which Dr. John W. Barko and Mr. William F. James, U.S. Army Engineer Waterways Experiment Station (WES) Environmental Laboratory (EL) were Principal Investigators.

The work was performed and the report prepared by Dr. John D. Madsen, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), EL, WES. Technical assistance in the field was provided by Mr. R. Michael Stewart (EPEB), and in the laboratory by Ms. Chetta S. Owens, Ms. Dian Smith, and Ms. Melissa Smith of the Lewisville Aquatic Ecosystem Research Facility (LAERF), EPEB. The authors also thank Mr. Daniel Helsel of the Wisconsin Department of Natural Resources for assistance in the development and performance of this study. Reviews of this report were provided by Mr. William James and Mr. R. Michael Stewart, both of EPEB.

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Introduction

Many small, shallow lakes in agricultural or developing residential areas become filled with sediment over time. These lakes often fill with several feet of highly organic sediment that convert a healthy small lake into a very shallow water body dominated by littoral zone, rather than having a mixture of littoral and pelagic environments. These changes may be accompanied by changes in fish and aquatic plant communities.

In addition, shallow lakes are often susceptible to wind-driven currents and wave action that resuspend sediments, causing high turbidity levels (James and Barko 1994). High turbidity may result in the reduction in abundance of aquatic plants, or their complete elimination, which in turn results in increased resuspension of sediments (Barko et al. 1986). High organic content of sediments also reduce growth of rooted submersed and floating-leaved plants (Barko and Smart 1983), which may further promote resuspension and increased turbidity, creating a positive feedback that results in low plant distribution and abundance, high turbidity, and increased wave activity (James and Barko 1994).

The objectives of this study were to 1) characterize the distribution and abundance of aquatic plants in Big Muskego Lake, including species composition, 2) provide a baseline for pretreatment conditions before a drawdown of the lake in late 1995, 3) utilize aerial photography to evaluate gradients in the distribution of submersed, floating-leaf and emergent vegetation, and 4) identify environmental parameters limiting plant growth in the lake.

Study Site

Big Muskego Lake is located in eastern Wisconsin, in Waukesha County, township of Muskego (Figure 1). The shoreline of the lake is predominantly marshy and poorly defined due to fluctuating stands of cattail (*Typha latifolia* L.). In addition, cattail often forms floating mat islands that can change location or be blown against the shoreline. The primary use of the lake is for fishing and waterfowl hunting.

Materials and Methods

Species List

Throughout the survey effort, all species observed were recorded, and herbarium voucher specimens were collected. Specimens were shipped to WES' Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, TX, where they were pressed, mounted and archived as a permanent record. All taxonomically-difficult species were referred to experts for identification. Voucher specimens are currently maintained at the LAERF herbarium.

Biomass

Biomass samples were collected at 54 stratified-random locations in the lake, previously determined and utilized for sediment collections (Figure 2, James and Barko 1996). The sites were located using a Trimble (Santa Rosa, CA) GeoExplorer II Global Positioning System (GPS). At each location, a single biomass sample was collected using a 0.1 m^2 quadrat (Madsen 1993). Only shoot portions were collected. Samples were shipped to LAERF, where they were sorted to species and dried to constant weight at 55 C.

In addition, water depth at each point was measured using a Magna III Portable depth finder (Eagle Electronics, Tulsa, OK). Measurements were made and recorded in tenths of a foot, and later converted to meters. Dominant species at each site were also determined in the field and recorded, as a quality assurance measure for sample processing.

Species Distribution

Species distribution and diversity were evaluated and mapped for the entire lake using a 200 m x 200 m grided arrangement of sampling points throughout the lake. In essence, this resulted in parallel east-west transects spaced 200 m from each other (north-south distance), with sample points located every 200 m along each transect (e.g., Figure 14). A total of 214 points were sampled. At each point, all aquatic plant species located in a defined area using a rake were recorded.

In addition to plant species presence or absence, a 350 cm long rod calibrated in 10 cm intervals was used to determine water depth by direct measurement, with the sediment-water interface being defined as the first resistance to the measuring rod. The rod was then inserted as deep as possible with moderate force, to determine the depth of the organic muck overlying the original lake bottom of firm bottom of sand or cobble. The depth of both muck and water was recorded (as "total depth"), and the difference was recorded as an estimate of the flocculent organic sediment depth. In many instances, a firm bottom was not reached. Therefore, sediment depths of 200 cm or more are generally underestimates of the actual flocculent sediment depth.

Light Measurements

On 22 August 1995, three locations were measured for light profile and Secchi Disk depth. The light profile was measured using a Li-Cor (Lincoln, NB) LI-1000 meter with both a surface PAR probe (deck cell) and a submersible PAR probe. Light intensity, as quanta of photosynthetically-active radiation (PAR), was measured at just below the surface and at 0.5 m depth intervals below the surface with the submersed probe. A simultaneous reading to each of these water column readings was taken with the deck cell. From these readings, the percent light transmission can be calculated using the formula:

$$T_z = ((S_z/D_z)/(S_0/D_0) \; x \; 100 \qquad \textbf{(1)}$$

where T_z is percent light transmission at depth z (in meters), S_z is the submersed probe reading at depth z, D_z is the deck cell reading simultaneous to the submersed cell reading at depth z, and S_0 and D_0 are the submersed and deck cell readings, respectively. The light intensity with depth profile was also used to calculate light extinction coefficients, using the following formula:

$$K_d=(\ln(I_{z_1})-\ln(I_{z_2}))/(z_2-z_1) \quad \textbf{(2)}$$

where K_d is the light extinction coefficient, I_z is the light intensity at either depth z_1 or z_2.

Aerial Photography

Aerial photography was taken by fixed-wing aircraft using false-color infrared film in a 35mm format. Big Muskego Lake was photographed in both July and August of 1995, but no significant differences were noted between the two flights, so only the data from the August overflight were used. Photo interpretation was done manually, with a 1 cm by 1 cm scaled grid (approximately 200 m by 200 m ground scale), with each intersecting point on the grid being interpreted by the values presented in Table 1. This information was used to quantify percent frequency of different vegetation types in the lake. Digitized maps were also made from the aerial overflights.

Results and Discussion

Species List

A total of 19 aquatic plant species were found in Big Muskego Lake (Table 2). Of these species, 4 were emergent aquatic plants, 2 floating leaved species, and the remaining 13 were submersed species. Four nonindigenous plants were observed: *Lythrum salicaria* (purple loosestrife), *Myriophyllum spicatum* (Eurasian watermilfoil), *Potamogeton crispus* (curly-leaf pondweed), and *Najas marina* (spiny or marine naiad). The total number of aquatic species present in this lake is typical of many temperate, eutrophic lakes (Madsen et al. 1993).

Biomass

Biomass of submersed aquatic macrophytes was rather low for an eutrophic lake, with a total biomass (i.e., all species combined) of only 93.5 g m^{-2}, and a mean biomass of the dominant species (*M. spicatum*) of only 75.3 g m^{-2} (Figure 3A). Littoral zone macrophyte communities in mesotrophic and eutrophic lakes typically have average biomass ranging from 150 to 300 g m^{-2} (Wetzel 1982). The low range of biomass sampled at Big Muskego Lake may be due to both high turbidity (Vant et al. 1986, Barko et al. 1986) and high organic content of the sediment (Barko and Smart 1983, 1986). James and Barko (1996) report sediment perecnt organic matter content averaging 44.5 for Big Muskego Lake, substantially above levels reported to reduce macrophyte growth (Barko and Smart 1983, 1986). Additional discussion of low light affects on plant abundance is presented in the section on **Light Measurements**.

Biomass of the plant community was strongly dominated by *M. spicatum*, which composed 90.6% of the total plant community biomass (Figure 3B). *Potamogeton amplifolius* (5.1%), *P. richardsonii* (1.6%), and *M. sibiricum* (1.4%) followed in importance, with other species composing only trace amounts (i.e., less than 1%, of total community biomass). Since sampling occurred in August, it is probable that *P. crispus* was much more abundant earlier in the growing season since it typically senesces by mid-July, but other species should have been near their peak biomass levels in August. An additional aspect of plant community dominance is the spatial distribution of dominant plant species, as shown in Figure 4. *Myriophyllum spicatum* was dominant in 94% of the sites (n=51 of 54). *Myriophyllum sibiricum* was dominant at one site in the north central portion of the lake, and *P. amplifolius* was dominant at two contiguous sites near the east central shore of the lake.

Plant biomass levels were spatially variable within the lake, as is typical of macrophyte biomass in littoral communities. However, some trends are notable. Total plant biomass was highest in the northeast corner of the lake, the eastern edge, and the southwestern end near the outlet (Figures 5, 6). Sediments in the northeastern and eastern shore areas were lower in organic content than average (James and Barko 1996), and these sites also had a shallower overlying layer of organic sediments (see **Sediment Depth** below). The southwestern end near the outlet had higher sediment nitrogen content than average (James and Barko 1996), which may explain higher biomass levels in this region. Sediment nitrogen is typically implicated as limiting submersed macrophyte growth in most inland lakes (Anderson and Kalff 1986).

The distribution of *M. spicatum* biomass was similar to that observed for total plant biomass, with two major exceptions (Figures 7,8). First, a notable zone of low plant biomass bisected the lake in the central region, from north to south. This area was the deepest portion of the lake (see **Water Depth** below). Second, the high total plant biomass region along the eastern shore was absent for *M. spicatum* biomass; this region was the only area within Big Muskego

Lake dominated by plant species other than *M. spicatum*, notably *P. amplifolius* and *P. richardsonii* (Figures 9, 10).

Species Distribution

Of the 214 sites examined by point sampling, 93.4% had aquatic vegetation present (Table 3). Of the 6.6% of sites without vegetation, most occurred in the deepest part of the lake (see **Water Depth** below). Of the 93.4% of sites with plants, only 3.3% did not have *M. spicatum* present. *Myriophyllum spicatum* was by far the most widespread and commonly-occurring plant, being present at 89.7% of sites. No other species occurred in more than 10% of the locations examined. The next most common species were *T. latifolia* (9.9%), *L. salicaria* (9.4%), *N. luteum* (6.1%), and *N. tuberosa*. These emergent and floating-leaved plants may have been most common after *M. spicatum* due to high turbidity. Following *M. spicatum*, the next most common submersed species included *C. demersum* (4.2%), *M. sibiricum* (5.6%), *P. amplifolius* (3.3%), *P. pectinatus* (2.4%), and *U. vulgaris* (2.9%).

Species diversity was extremely low in the lake, with an average diversity per sampled site of 1.45. With the exclusion of introduced species, the average number of native species per site was 0.43 (Table 4). The vast majority of sites (65.7%) had only one species present, and this was most frequently *M. spicatum* (Figure 11A). Native species diversity was also quite low. The vast majority (71.8%) of sites did not have a native species present, and of those with native species, most had only one (19.7%), and only 3% had two or more native plant species (Figure 11B).

Myriophyllum spicatum has been demonstrated to cause reductions in native plant community abundance and diversity (Madsen et al 1991b), possibly through intense shading from a dense surface canopy (Madsen et al. 1991a). The development of near-monospecific communities by the nonnative *M. spicatum* has been quantitatively documented in many other lake systems, both natural and manmade, including Kirk Pond, OR (Madsen et al. 1994), the Pend Oreille River, WA (Getsinger et al. 1996, 1997), Lake George, NY (Madsen et al. 1991b). If a diverse native plant submersed plant community had existed at some time in the past, increased turbidity in Big Muskego Lake may have been responsible for a possible decline of native plants, with *M. spicatum* spreading and surviving due to a growth form that is adaptive to the limitations of highly turbid conditions if water is sufficiently shallow for the canopy to be quickly formed (see **Water Depth** below).

Light Environment

The average Secchi disk depth for Big Muskego Lake was 0.53 m, with a range from 0.48 to 0.62 m (Table 5). Light profiles indicate a rapid extinction of light with depth, as expected from high turbidity and low Secchi disk readings (Figure 12). Average K_d for the three sites was 3.41 (Table 5). These parameters indicate a rapid attenuation of light through the water column, and shallow euphotic zone for macrophyte colonization. Since Big Muskego Lake is currently only 1.7 m deep, turbidity alone does not greatly limit plant distribution.

The depth to which 10% of surface light penetrates is one conservative indicator of potential maximum depth of colonization for macrophytes (z_c, Sheldon and Boylen 1977). An estimate of the 10% of surface light from these graphs would be from 0.6 to 0.8 m. More quantitative empirical relationships have also been developed to equate both Secchi disk depth and light extinction coefficient to z_c. For over 100 north temperate lakes, Canfield et al. (1985) developed the following expression:

$$\log(z_c)=0.61*\log z_{SD}+0.26 \quad \textbf{(3)}$$

in which z_c = maximum depth of macrophyte colonization (m), and z_{SD} = Secchi disk depth (m). For 90 lakes, Chambers and Kalff (1985) found the relationship:

$$z_c=(1.33*\log(z_{SD})+1.40)^2 \quad \textbf{(4)}$$

This relationship was found to be further moderated by other optical properties of lakes, such as color (Chambers and Prepas 1988). A third study relevant to this discussion is that by Vant et al. (1986), in which New Zealand lakes were studied. They found light attenuation strictly limited the maximum depth of macrophyte colonization, which they expressed using the attenuation coefficient, K_d :

$$z_c=4.34/K_d \quad \textbf{(5)}$$

All three equations have been used to calculated expected z_c for the three Big Muskego Lake stations at which light data were collected (Table 5). Estimates of z_c range from 0.98 to 1.47, with an average of 1.19. Observed z_c will be discussed in the next section (see **Water Depth** below).

Water Depth

The mean water depth of Big Muskego Lake was 1.01 m, with a maximum depth of 1.70 m (Table 4). Approximately 78% of the lake was between 0.8 to 1.2 m of depth (Figure 13A). Only 2% of the lake was deeper than 1.2 m (Figure 13B). The actual depth soundings in the lake are shown in Figure 14, with a contour plot shown in Figure 15. Three deeper basins (in a relative sense) were observed in the northeast, east, and southwest portions of the lake, where depths exceed 120 cm (1.2 m).

Plant distribution was limited by depth, as shown by relationships of both biomass (Figure 16) and species distribution and diversity (Figure 17) with depth. *Myriophyllum spicatum* biomass was restricted to areas less than 1.2 m deep (Figure 16B), which is approximately the maximum depth of colonization predicted by the empirical models (Table 5). Native plants were restricted to depths less than 0.9 m, with the peak in biomass occurring at 0.7 m depth (Figure 16C).

The occurrence of *M. spicatum*, as seen in plant distribution data, was uniform from 0.2 to 1.0 m, with no *M. spicatum* found in the 0-0.2 m depth range, and decreasing in distribution above 1.2 m (Figure 17A). Although 50% of the sites in the 1.4 m depth class had some *M. spicatum* present, but no occurrence of this species was found beyond 1.6 m. Therefore, the true maximum depth of *M. spicatum* colonization observed for the lake is between 1.4 and 1.6 m. The number of species per site peaked in the 0.2 m depth range, and was less than one per location beyond 1 m depth (Figure 17B). Native plant diversity was highest in the 0.2 m depth class, remains above 4 at the 0.4 m depth class, and was below 1 species per site between 0.8 m and 1.2 m (Figure 17C). No native plants were observed at depths deeper than 1.4 m, so the maximum depth of colonization for native species was between 1.2 and 1.4 m. These observation are consistent with expected distributions calculated from empirical models of maximum colonization depths for submersed aquatic macrophytes in Big Muskego Lake (Table 5).

Sediment Depth

The depth of flocculent sediment was estimated to compare pre-drawdown sediment accumulations to post-drawdown sediment consolidation. We also chose this simple method to develop a spatial image of sediment accumulation. The average depth of sediment was 200 cm (Table 4). However, the results need further interpretation. If the raw calculations for sediment depth are considered, the median depth was 2.4 m (Figure 18A). In 75% of the locations surveyed, the rod could be inserted up to 3 m in total (water and sediment) depth, without touching firm bottom (Figure 18B). Therefore, the actual depth of the soft, flocculent organic sediment could be substantially more than 2 m deep. If sites of more than 2 m sediment depth are excluded, the distributions of sediment depths at the remaining sites is more evenly distributed (Figure 18C). The best estimate should be that the majority (70%) of sites have sediment depths in excess of 2 m (Figure 18D). Since early records indicate that Big Muskego Lake once had a maximum depth of 50 feet, sediment accumulations may be substantially more than 2 m.

The calculated sediment depths (in cm) are shown in Figure 19. An isopleth map of sediment depths shows that the remaining natural shoreline just underlies the deposition of organic sediments along the eastern and southern shore of the lake (Figure 20). In addition, two shallow island-like areas have a detectable firm substrate near the center of the lake. The former western and northern shoreline were not detectable by the sediment probe and may lie at some distance from the present western and northern shorelines. At present, the previous shoreline is overgrown with a floating mat of cattail-dominated wetland vegetation.

Aerial Photography

A hand-digitized interpretation of the aerial photography is shown in Figure 21. The open water category includes submersed vegetation, because it was too difficult to delineate individual beds from open water areas for this map. However, submersed plant areas were identified from point samples during manual interpretation of the maps using the grid system. From aerial photographs, the area of open water is estimated to be 29.2%, submersed beds cover 26.9%, floating plants cover 10.7% and wetlands or emergent plants cover 33.2% (Table 6). Rough estimates of areal coverages are also given. If these are compared to similar cover classes from the boat survey, some differences are noted (Table 7). Most importantly, the estimated proportions of open water (6.5% boat versus 29.2% aerial) and submersed plants (73.7% boat versus 26.9% aerial) are dramatically different. The boat surveys detected plants growing low in the water column, whereas the high turbidity of Big Muskego lake prevented detection of submersed plants in the photographs, except those growing within the upper few centimeters of the water column. Floating-leaved plants had similar occurrences in both surveys (9.9% boat versus 10.7% aerial). Wetland plants covered a significantly larger area in the aerial survey (33.2%) than in the boat survey (9.9%) because the boat survey underestimates the size of the lake due to the impenetrable edge of cattails, and the aerial survey may actually overestimate the size of the lake because the wetland may extend beyond the boundaries of the lake bed. However, the aerial survey gives a more accurate view of the geographic extent of emergent and wetland vegetation in and around Big Muskego Lake.

Summary

The aquatic vegetation of Big Muskego Lake, Waukesha County, Wisconsin was quantified during August of 1995 using biomass samples at 54 randomized locations, presence/absence observations at 214 point sample locations, and interpretation of aerial photographs taken during the same time period. In addition, water and sediment depths were measured at all 214 point sample sites, as well as water depth at the 54 biomass sampling locations.

The findings were as follows:

1. Eurasian watermilfoil (*Myriophyllum spicatum* L.), a nonnative invasive species, was by far the dominant submersed species, with 75.3 g DW m^{-2} biomass out of a total community biomass of 93.5 g DW m^{-2}, or 80% of the biomass. Eurasian watermilfoil biomass was

still relatively low, compared to many lakes, possibly due to very low transparency and a poor, flocculent sediment high in particulate organic matter.

2. From a sampling of over 214 points in Big Muskego Lake, Eurasian watermilfoil was found in almost 90% of these points. No vegetation was observed in 6.6% of the locations, and only 4% of locations had vegetation without Eurasian watermilfoil. Eurasian watermilfoil was the only species found at 64% of the sites.

3. The total species list for the lake included 19 species, with 4 emergent species, 2 floating leaved species, and 13 submersed species. The total number of aquatic plant species was average for a temperate eutrophic lake, but diversity and distribution of these species within the lake was unusually low.

4. The mean diversity at each sample location was low at 1.45 species; however, most of these were nonnative species. The average number of native species was very low at 0.43 per location.

5. Water depth averaged only 101 cm at the 214 sample locations. Maximum water depth was 170 cm. Due to the sampling technique employed, we could not measure combined water and sediment depths of more than 350 cm. Most locations had in excess of 250 cm of flocculent sediment.

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Tables

Table 1. Cover classes used in the interpretation of aerial photographs.

Code	Description
f	Agricultural Field
fl	Floating Plant
h	Highway
o	Open Water
s	Submersed Plant
t	Trees, wood lot
w	Wetland, emergent plants
b	Building

Table 2. Species observed in Big Muskego Lake by scientific name, common name, and growth form, with nonnative species noted.

Scientific Name and Authority	Common Name	Growth Form	Non-indigenous
Carex sp.	Rush	Emergent	
Ceratophyllum demersum L.	Coontail	Submersed	
Heteranthera dubia (Jacq.) MacM.	Water stargrass	Submersed	
Lythrum salicaria L.	Purple loosestrife	Emergent	Y
Myriophyllum sibiricum Komarov	Northern watermilfoil	Submersed	
Myriophyllum spicatum L.	Eurasian watermilfoil	Submersed	Y
Najas flexilis (Willd.) Rostk. & Schmidt	Northern naiad	Submersed	
Najas marina L.	Marine naiad	Submersed	Y
Nuphar luteum L.	Yellow pondlily	Floating	
Nymphaea tuberosa Paine	White waterlily	Floating	
Potamogeton amplifolius Tuckerm.	Wideleaf pondweed	Submersed	
Potamogeton crispus L.	Curlyleaf pondweed	Submersed	Y
Potamogeton pectinatus L.	Sago pondweed	Submersed	
Potamogeton pusillus L.	Narrowleaf pondweed	Submersed	
Potamogeton richardsonii (Benn.) Rydb.	Whitestem Pondweed	Submersed	
Ranunculus longirostris Godron.	Water crowfoot	Submersed	
Scirpus spp.	Bulrush	Emergent	
Typha latifolia L.	Cattail	Emergent	
Utricularia vulgaris L.	Common bladderwort	Submersed	

Table 3. Aquatic plant percent frequency of occurrence at 214 sample point locations at Big Muskego Lake in August 1995.

Scientific Name	Percent Occurrence
No Plants Present	6.6
Carex sp.	0.9
Ceratophyllum demersum	4.2
Heteranthera dubia	0.9
Lythrum salicaria	9.4
Myriophyllum sibiricum	5.6
Myriophyllum spicatum	89.7
Najas flexilis	0.5
Najas marina	1.9
Nuphar luteum	6.1
Nymphaea tuberosa	5.2
Potamogeton amplifolius	3.3
Potamogeton crispus	0.9
Potamogeton pectinatus	2.4
Potamogeton pusillus	0.5
Potamogeton richardsonii	0.0
Ranunculus longirostris	0.9
Scirpus spp.	0.5
Typha latifolia	9.9
Utricularia vulgaris	2.9

Table 4. Mean and standard error of the mean for: number of species, number of native species, water depth (cm) and sediment depth (cm) at 214 sample point locations in Big Muskego Lake during August 1995.

Parameter	Mean	Standard Error of the Mean
Number of species observed (Species richness or diversity)	1.45	0.08
Number of native species observed (Species richness or diversity)	0.43	0.06
Water depth (cm)	101	1.3
Sediment depth (cm)	198+	5.4

Table 5. Station number, UTM coordinates, Secchi disk depth, and light extinction coefficient (K_d), and calculated maximum depth of aquatic plants (z_c) for three sites in Big Muskego Lake, and their average value.

Parameter	Site 1	Site 2	Site 3	Average
Station Number	40	73	84	--
UTM North	4746400	4746800	4748000	--
UTM East	408200	408800	409000	--
Secchi Disk Depth (m)	0.50	0.48	0.62	0.53
K_d, eq. 2	4.14	3.12	2.96	3.41
z_c based on Secchi Disk Depth, eq. 3 (Canfield et al. 1985)	1.19	1.16	1.36	1.24
z_c based on Secchi Disk Depth, eq. 4 (Chambers and Kalff 1985)	1.00	0.98	1.12	1.03
z_c based on K_d, eq. 5 (Vant et al. 1986)	1.05	1.39	1.47	1.30
z_c Average from above three calculations	1.08	1.18	1.32	1.19

Table 6. Aerial photography photointerpretation from grid analysis of Big Muskego Lake.

Category	Frequency of Occurrence	% Cover	Estimated Area (hectares)
Open Water	79	29.2	316
Submersed Plants	73	26.9	292
Floating Plants	29	10.7	116
Wetlands / Emergent Plants	90	33.2	360
Total	271	100	1,084

Table 7. Vegetation class identification for 214 sites surveyed by boat in Big Muskego Lake.

Vegetation Class	Frequency of Occurrence	Percent	Estimated Area (hectares)
Open water (No plants)	14	6.5	56
Submersed Plants	157	73.7	628
Floating-leaf Plants	21	9.9	84
Wetland / Emergent Plants	21	9.9	84
Total	213	100	852

Figures

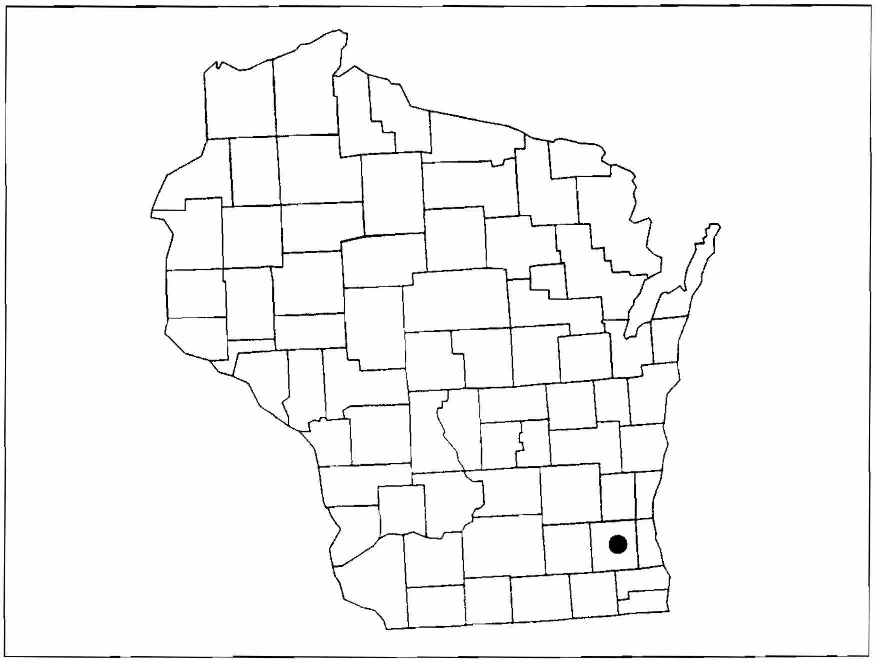


Figure 1. Location of Big Muskego Lake, Waukesha County, in the State of Wisconsin.

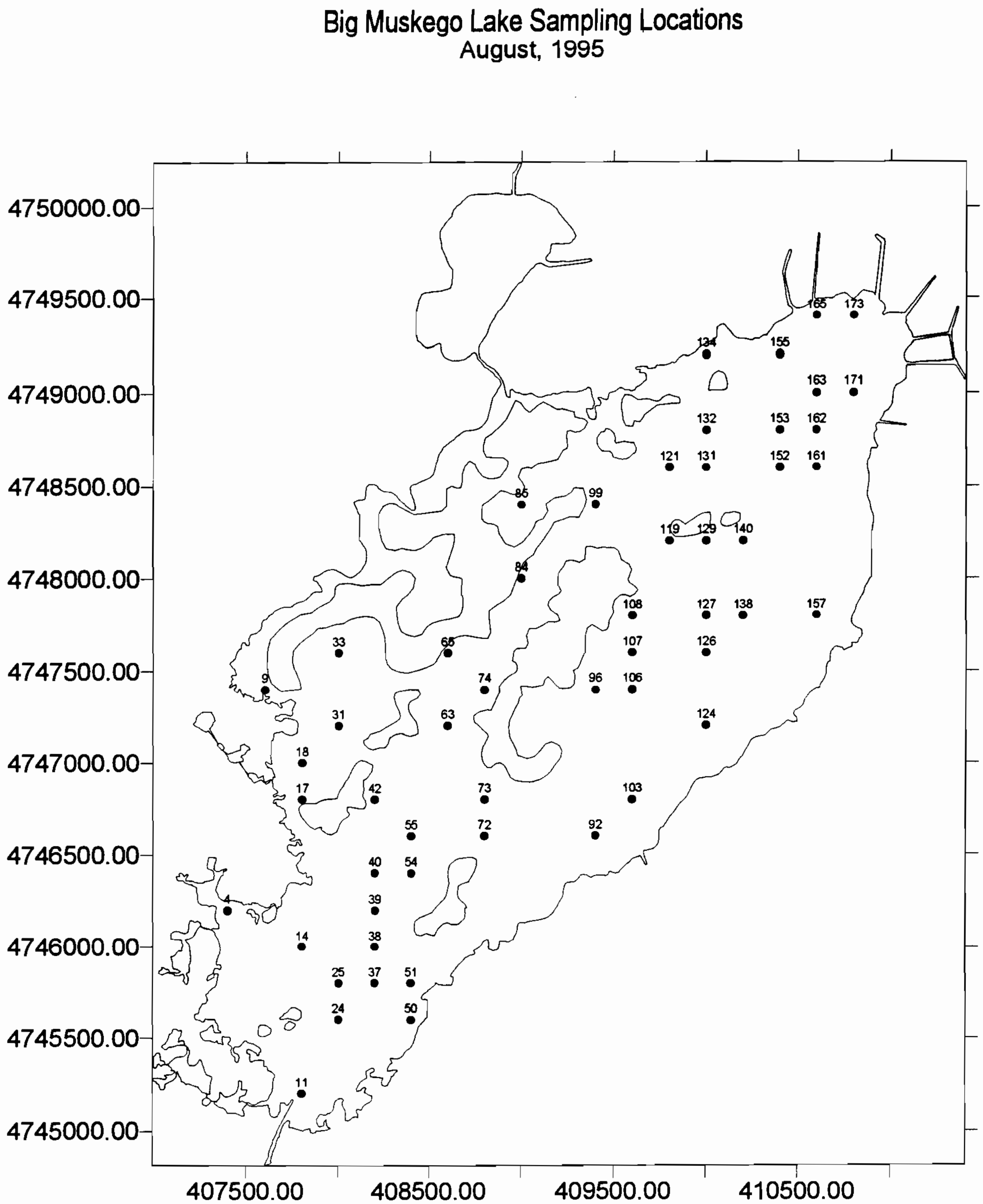


Figure 2. Biomass sample locations (n=54) in Big Muskego Lake.

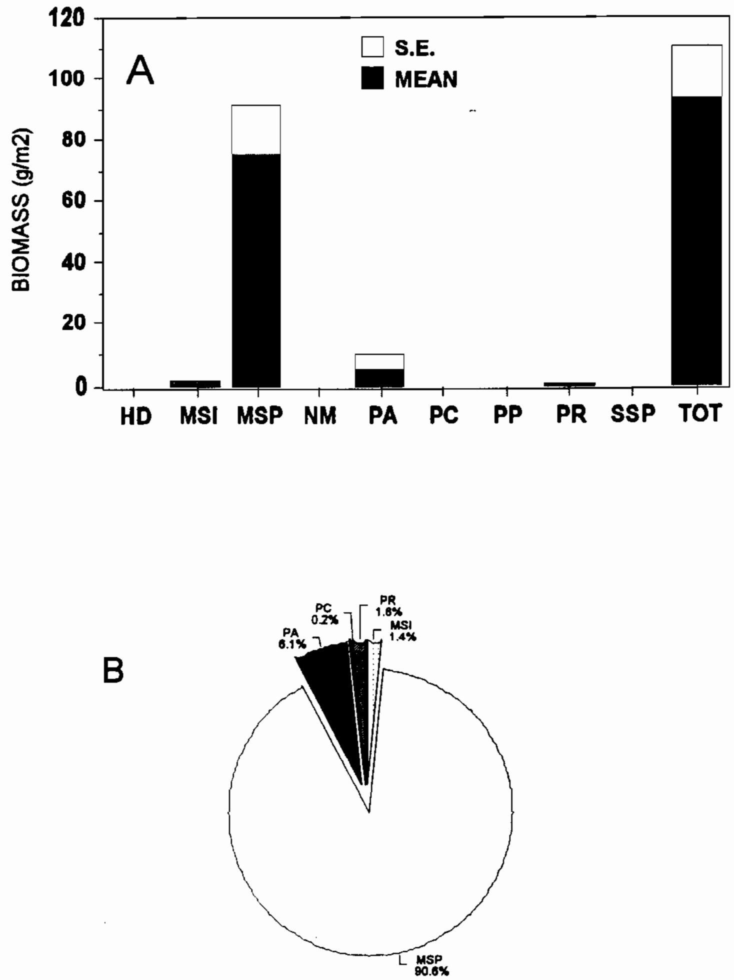


Figure 3. Biomass of aquatic macrophytes in Big Muskego Lake in 1995. A. Mean and standard error of eight species, and total biomass of all species per sample. B. Percent composition of total biomass. Legend: HD, *H. dubia*; MSI, *M. sibiricum*; MSP, *M. spicatum*, NM, *N. marina*, PA, *P. amplifolius*; PC, *P. crispus*; PP, *P. pusillus*; PR, *P. richardsonii*; SPP, *Scirpus* sp.; TOT, total biomass.

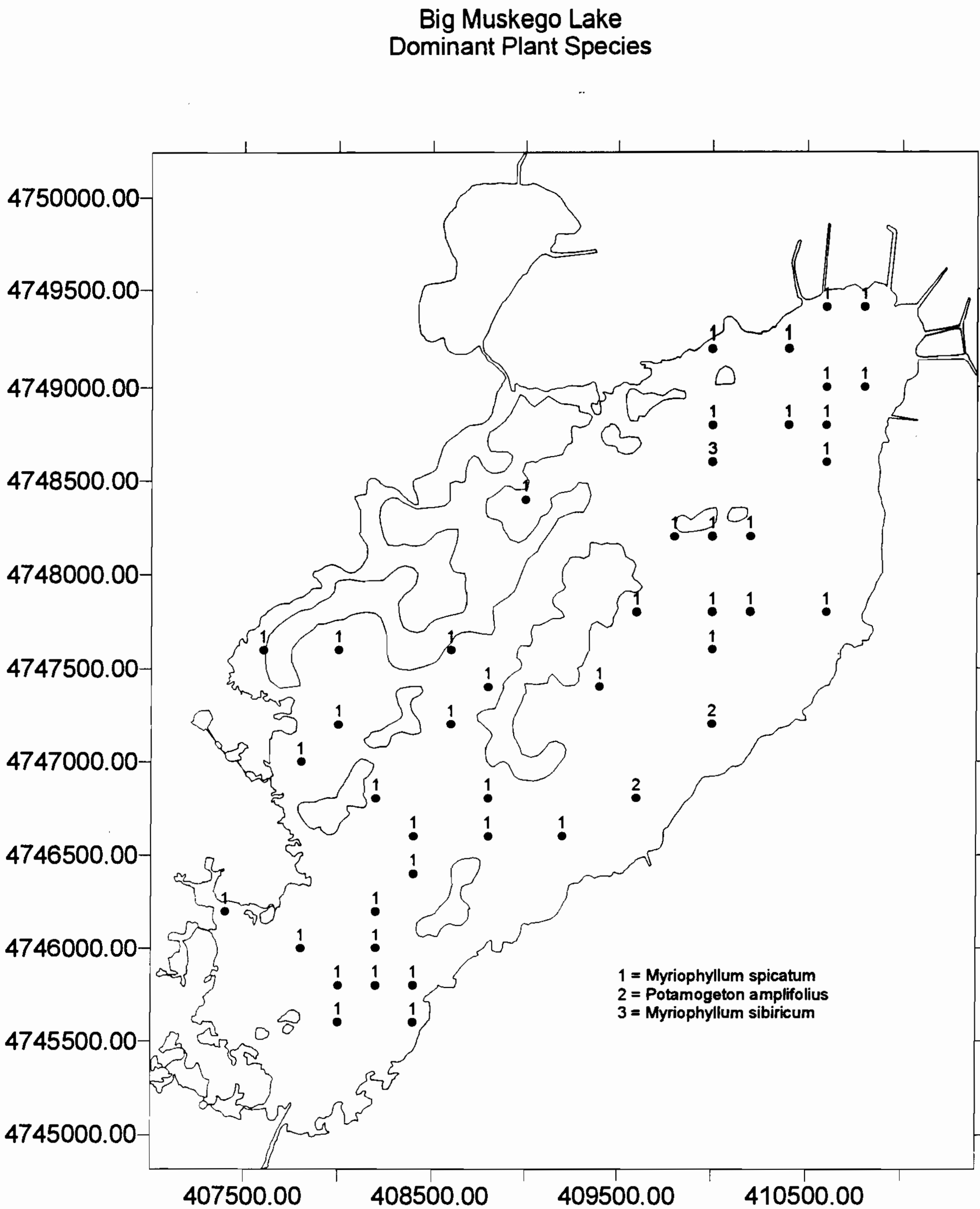


Figure 4. Dominant plant species at each of the 54 biomass sampling locations in Big Muskego Lake.

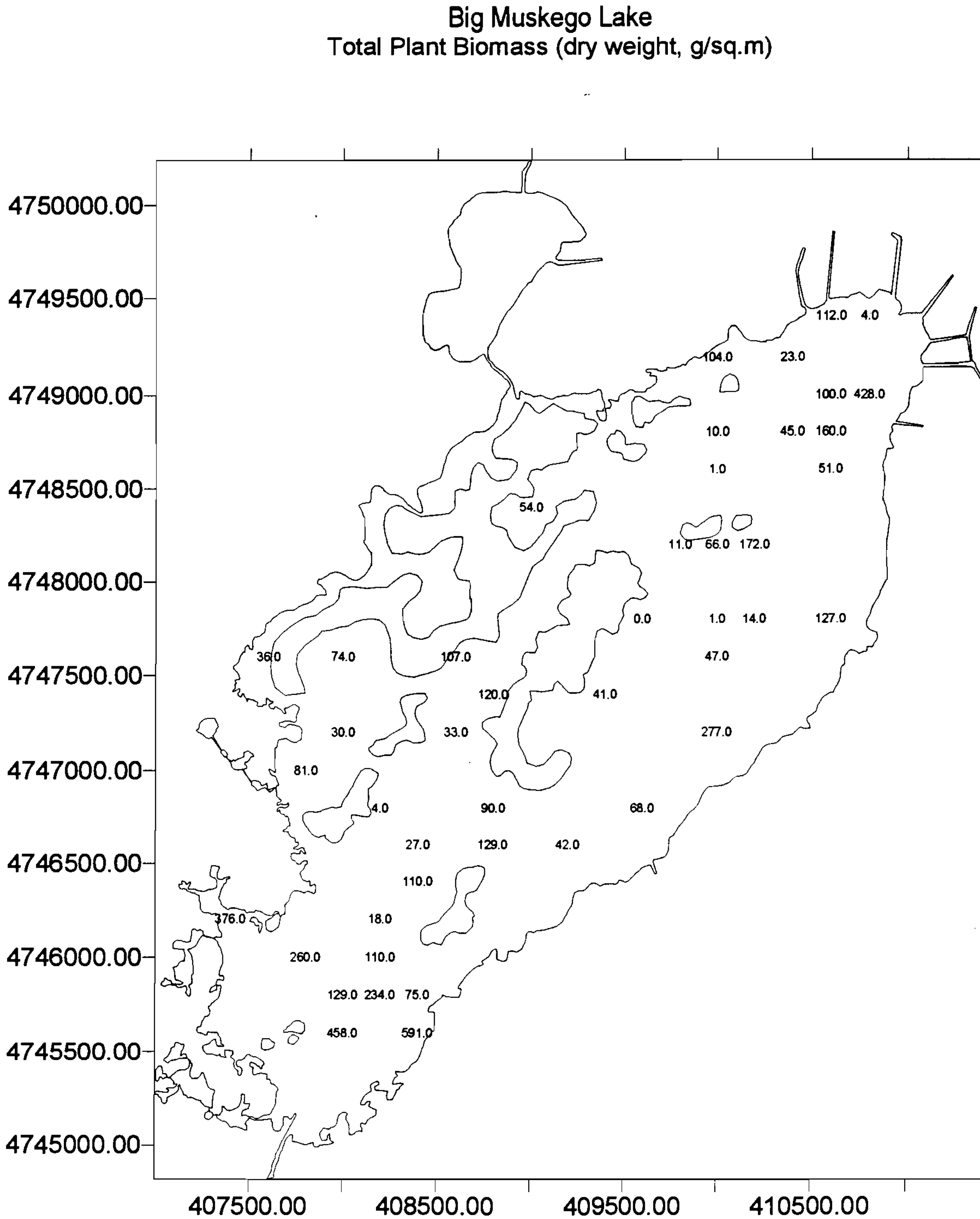


Figure 5. Distribution of actual values of total plant biomass (g m^{-2}) at each sample point in Big Muskego Lake.

Big Muskego Lake
Total Plant Biomass (dry weight, g/sq.m)

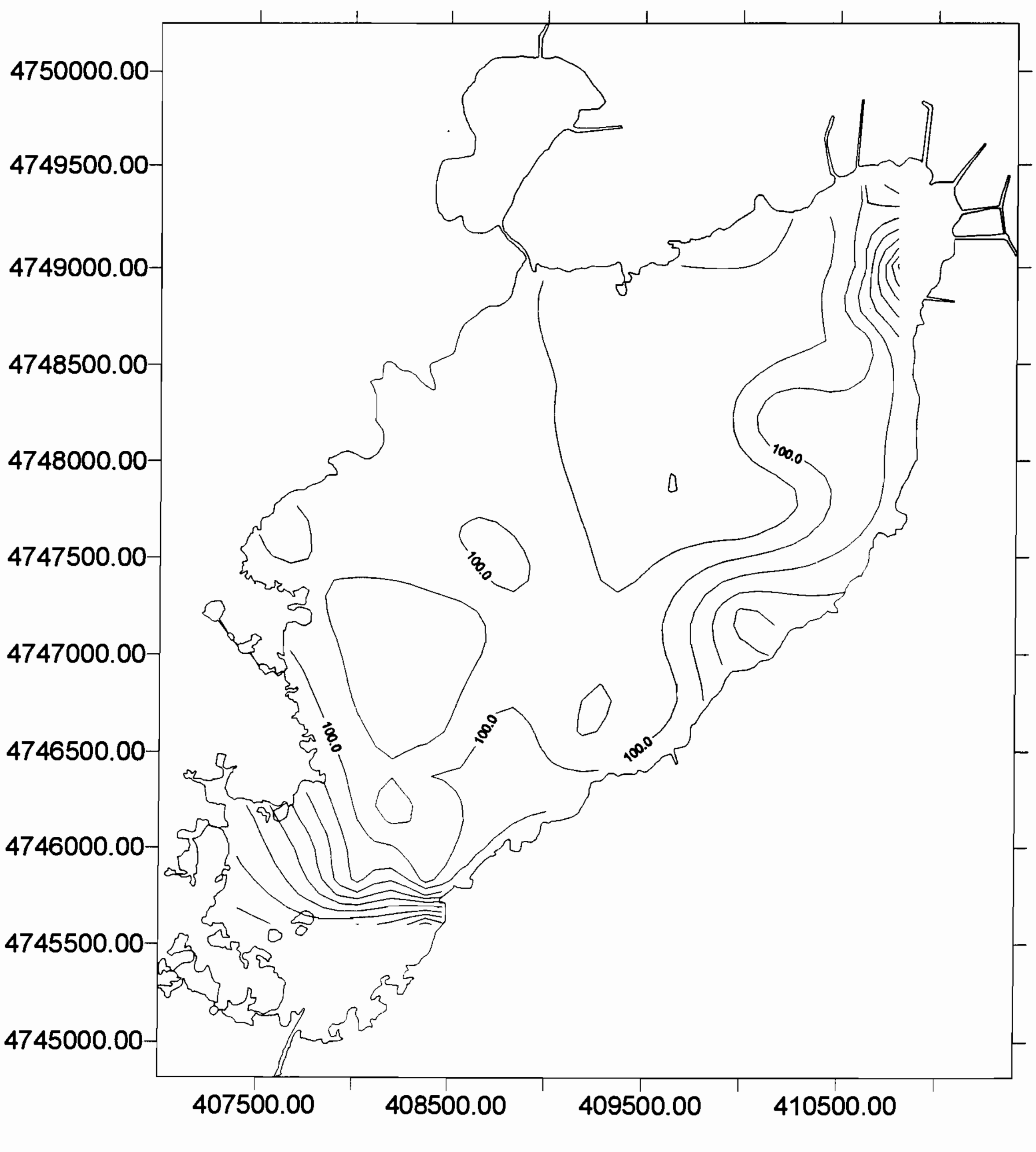


Figure 6. Contour plot of total plant biomass (g m^{-2}) distribution in Big Muskego Lake.

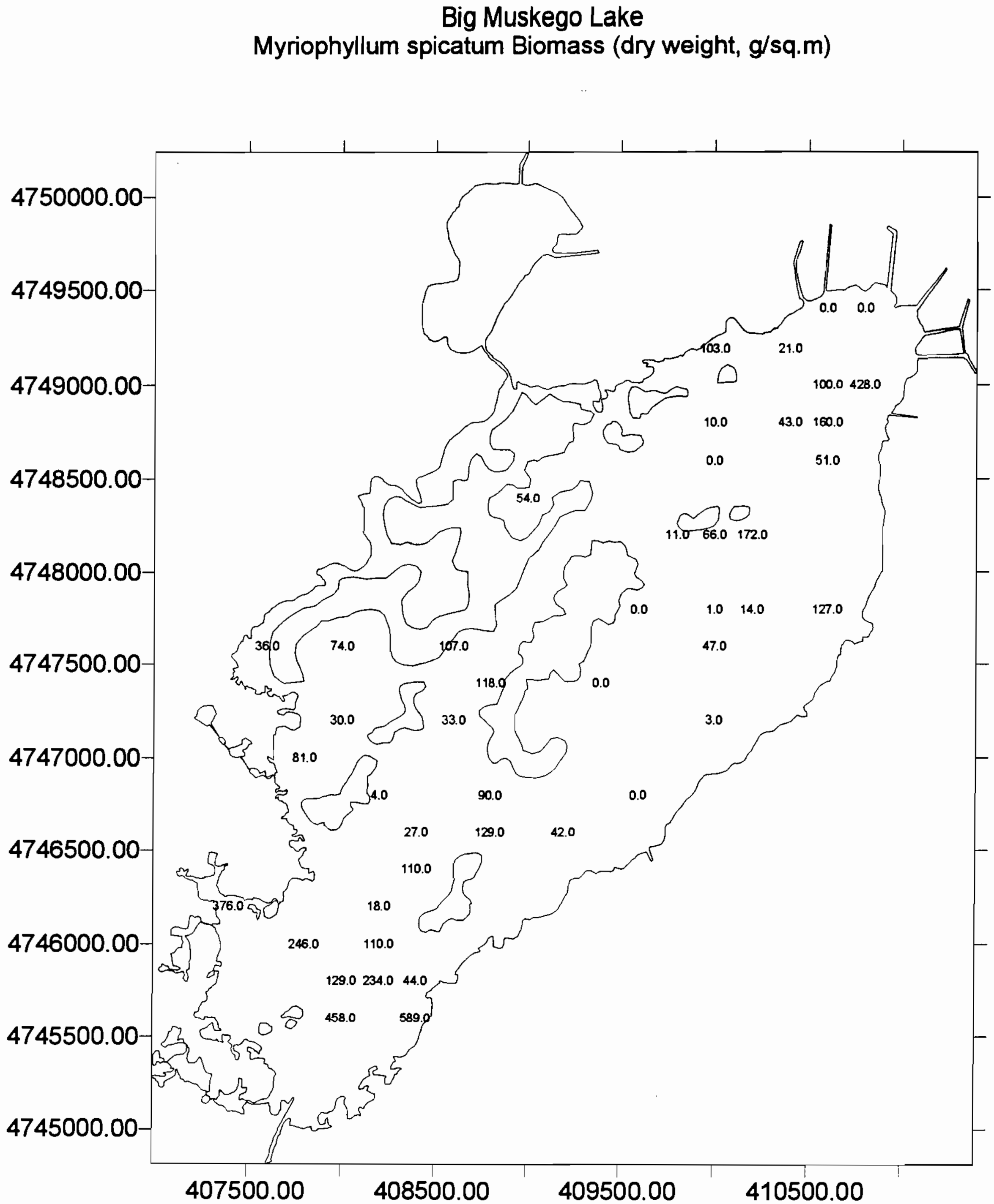


Figure 7. Actual value at each sample point of *M. spicatum* biomass (g m^{-2}) in Big Muskego Lake.

Big Muskego Lake
Myriophyllum spicatum Biomass (dry weight, g/sq.m)

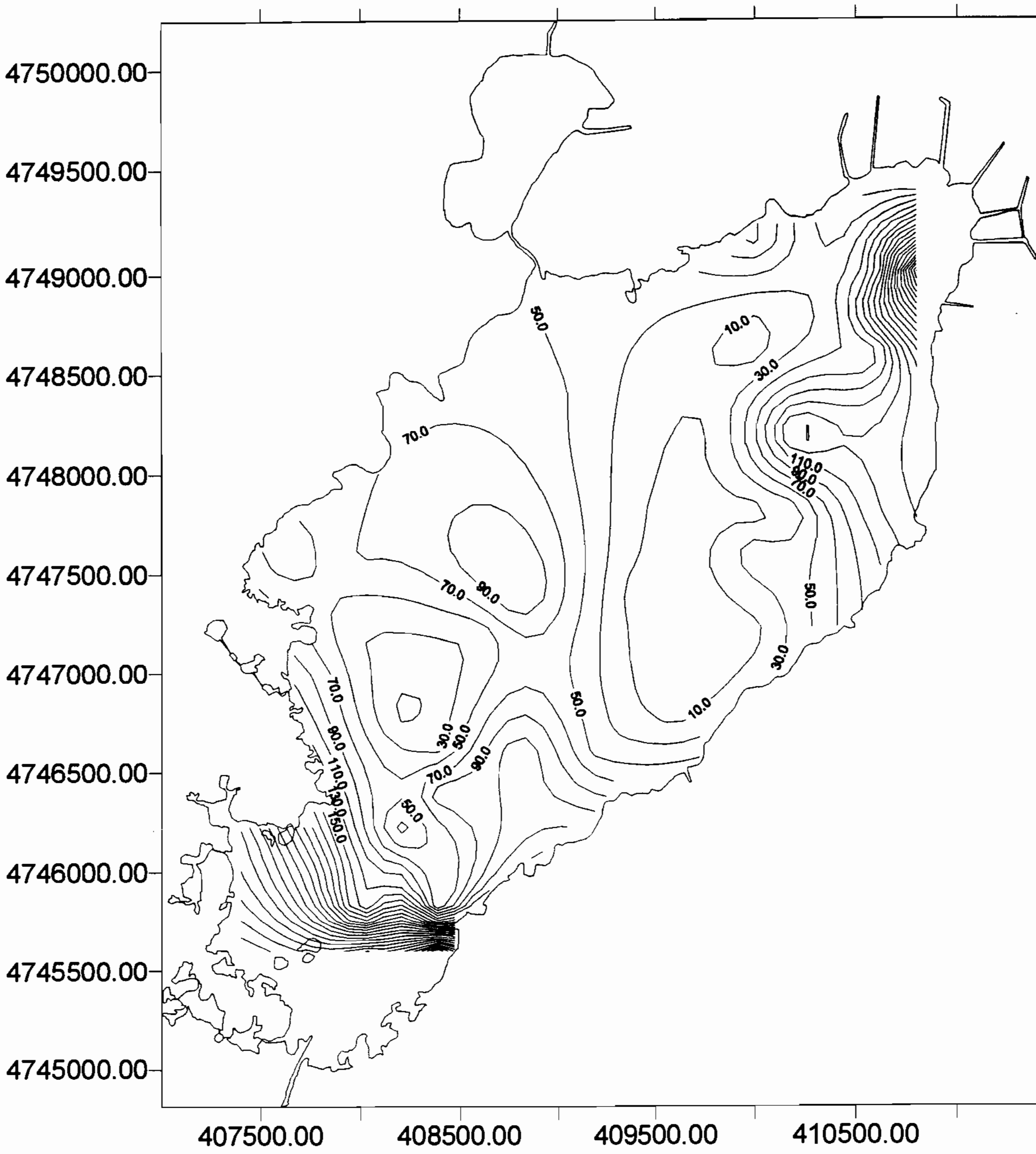


Figure 8. Contour plot of *M. spicatum* biomass (g m^{-2}) of in Big Muskego Lake.

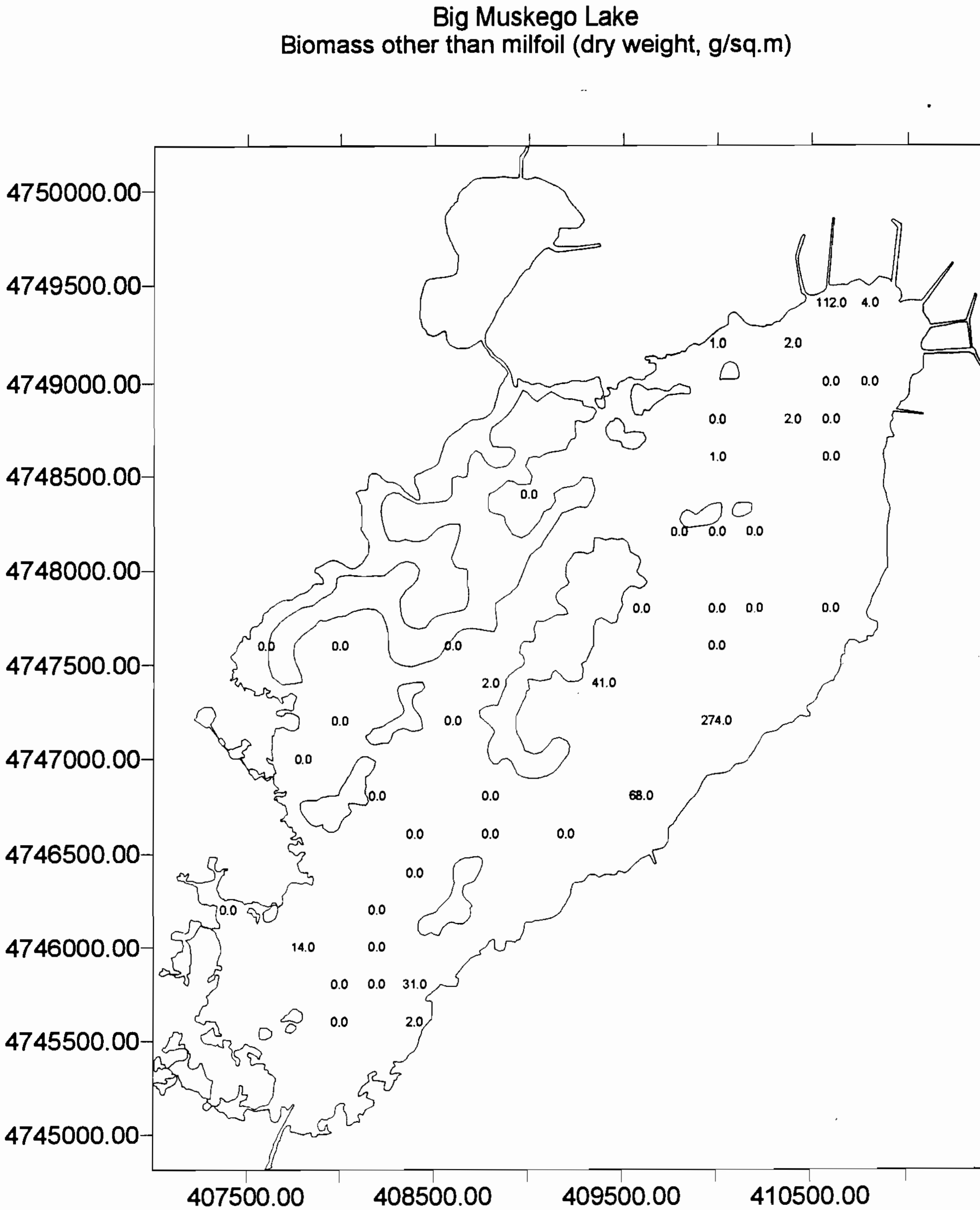


Figure 9. Actual biomass (g m^{-2}) values at each sample location of species other than *M. spicatum* in Big Muskego Lake.

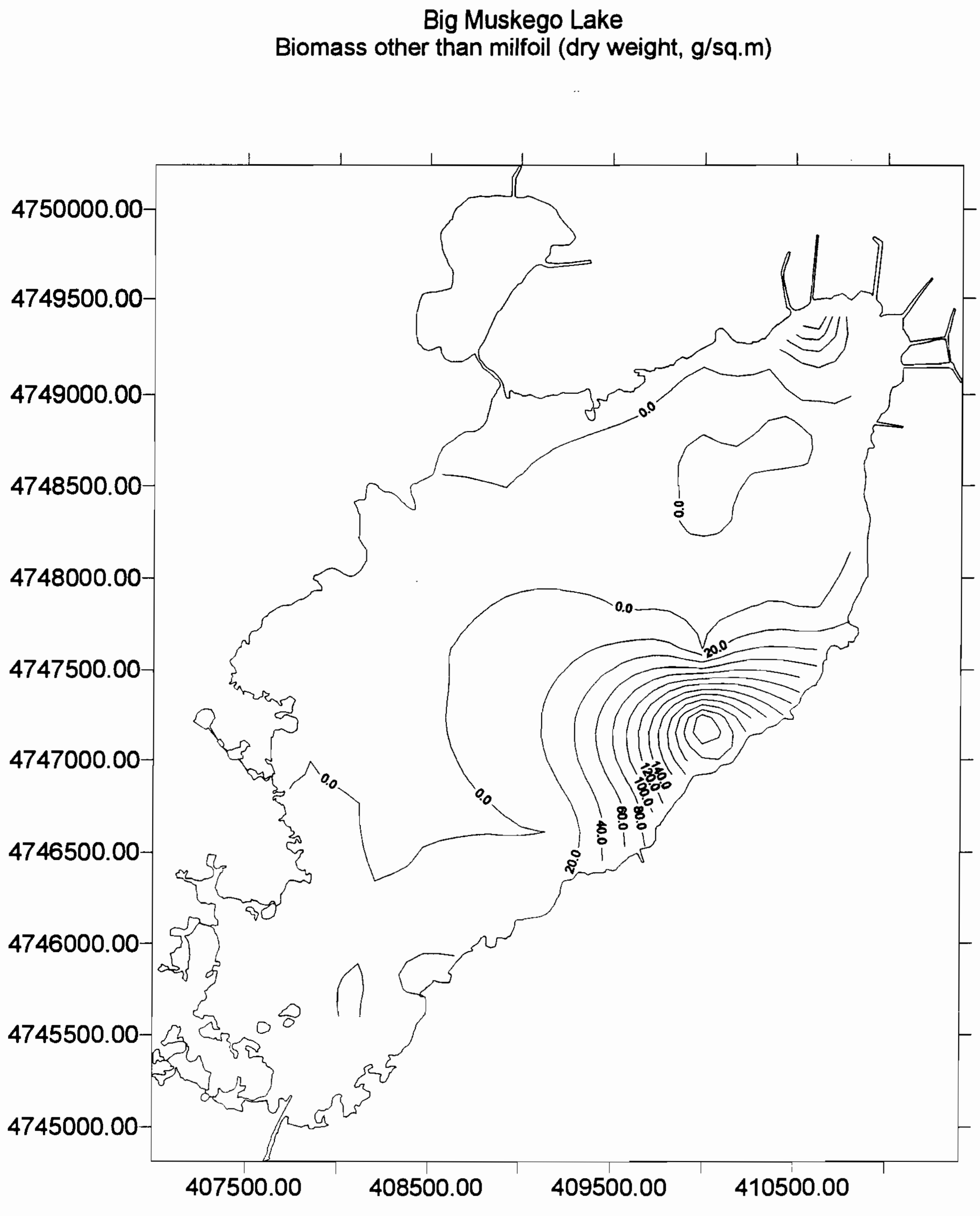


Figure 10. Contour plot of biomass (g m^{-2}) of species other than *M. spicatum* in Big Muskego Lake.

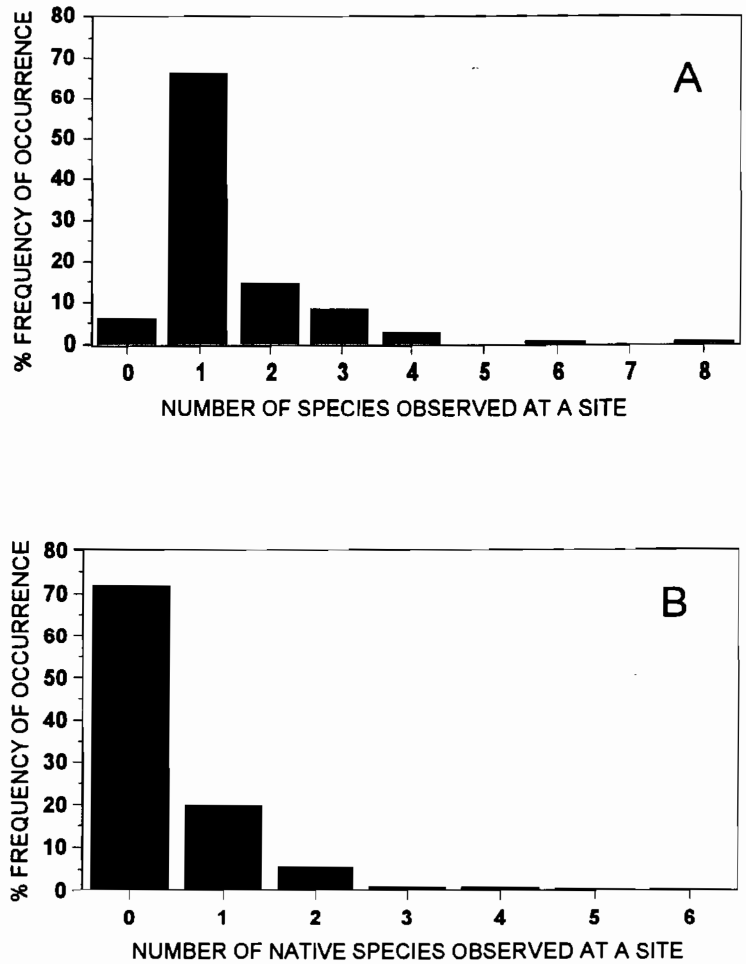
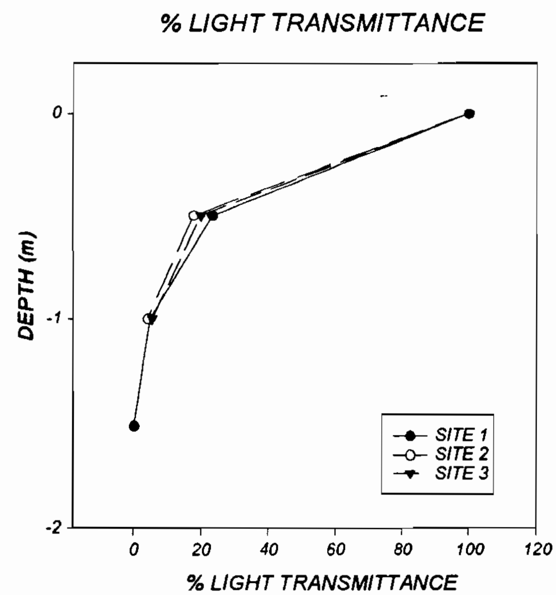


Figure 11. Frequency distribution of species richness at 214 point sample sites in Big Muskego Lake. A. Histogram of all species observed, B. Histogram of native species observed.

A.



B.

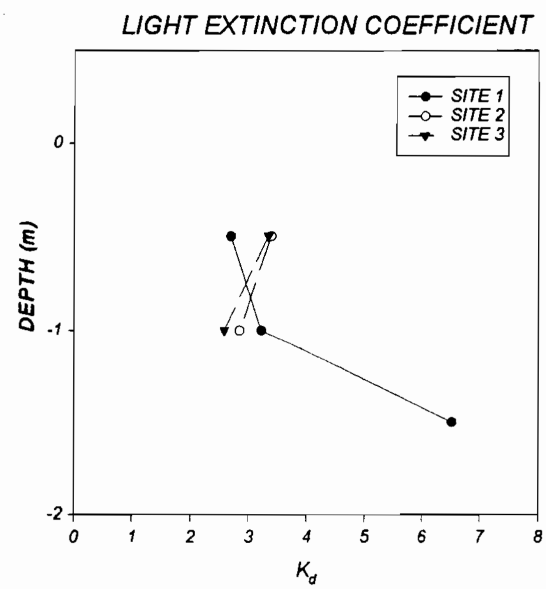


Figure 12. A. Percent light transmittance and B. light extinction coefficient (K_d) versus depth (m) at three sample sites in Big Muskego Lake.

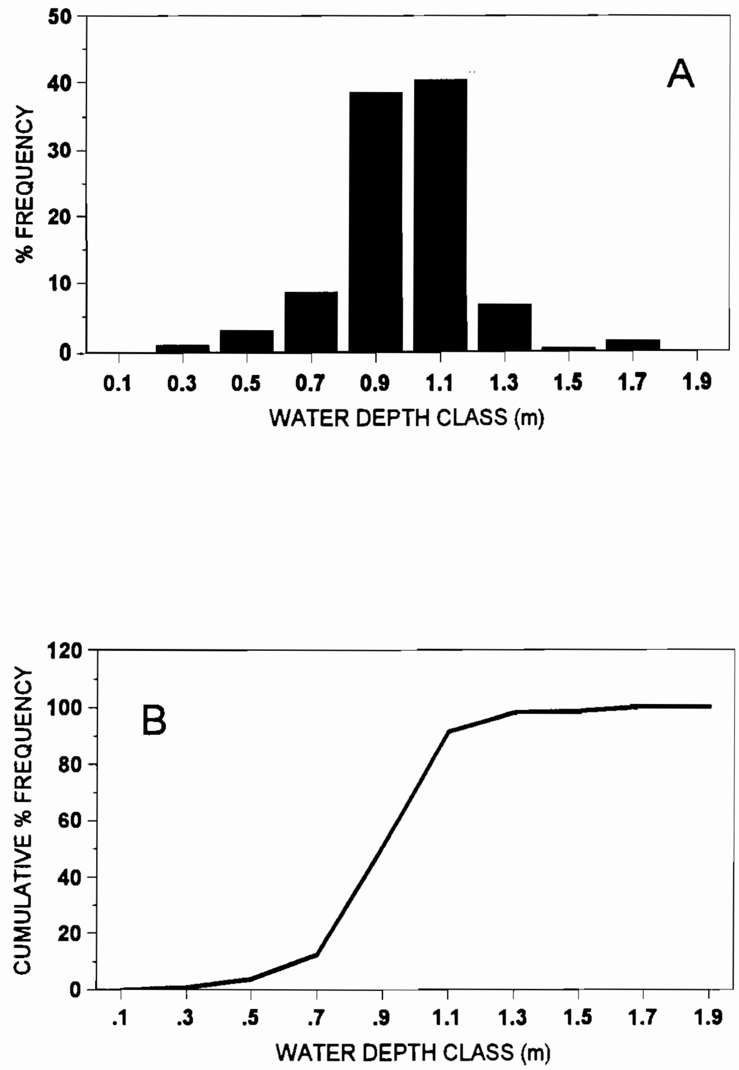


Figure 13. Water depth frequency distribution (A) and percent cumulative distribution (B) for 0.2 m depth classes. X-axis value is median point of the 0.2 m depth class.

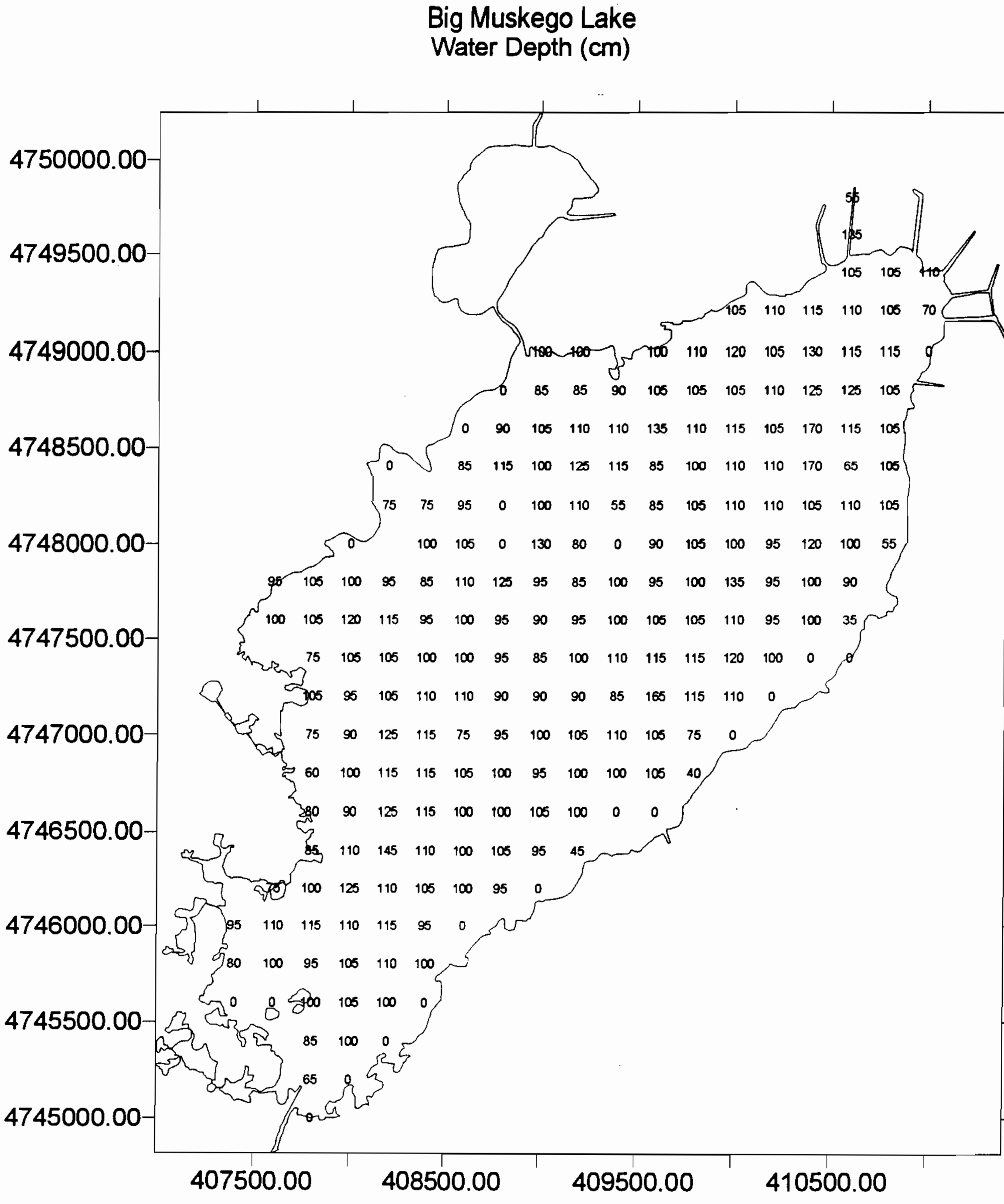


Figure 14. Actual values of water depth (cm) at each site in Big Muskego Lake.

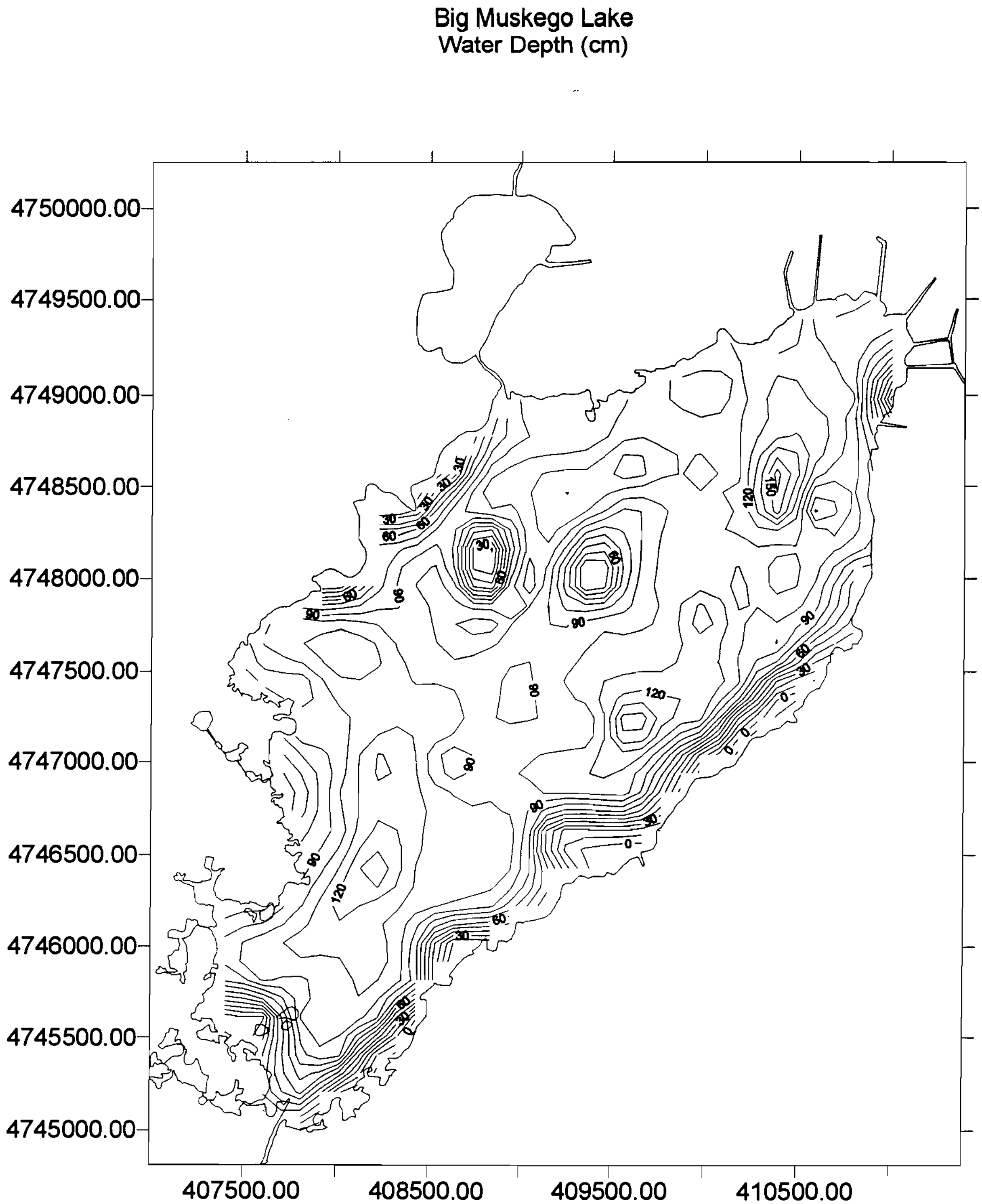


Figure 15. Contour plot of water depth (cm) in Big Muskego Lake.

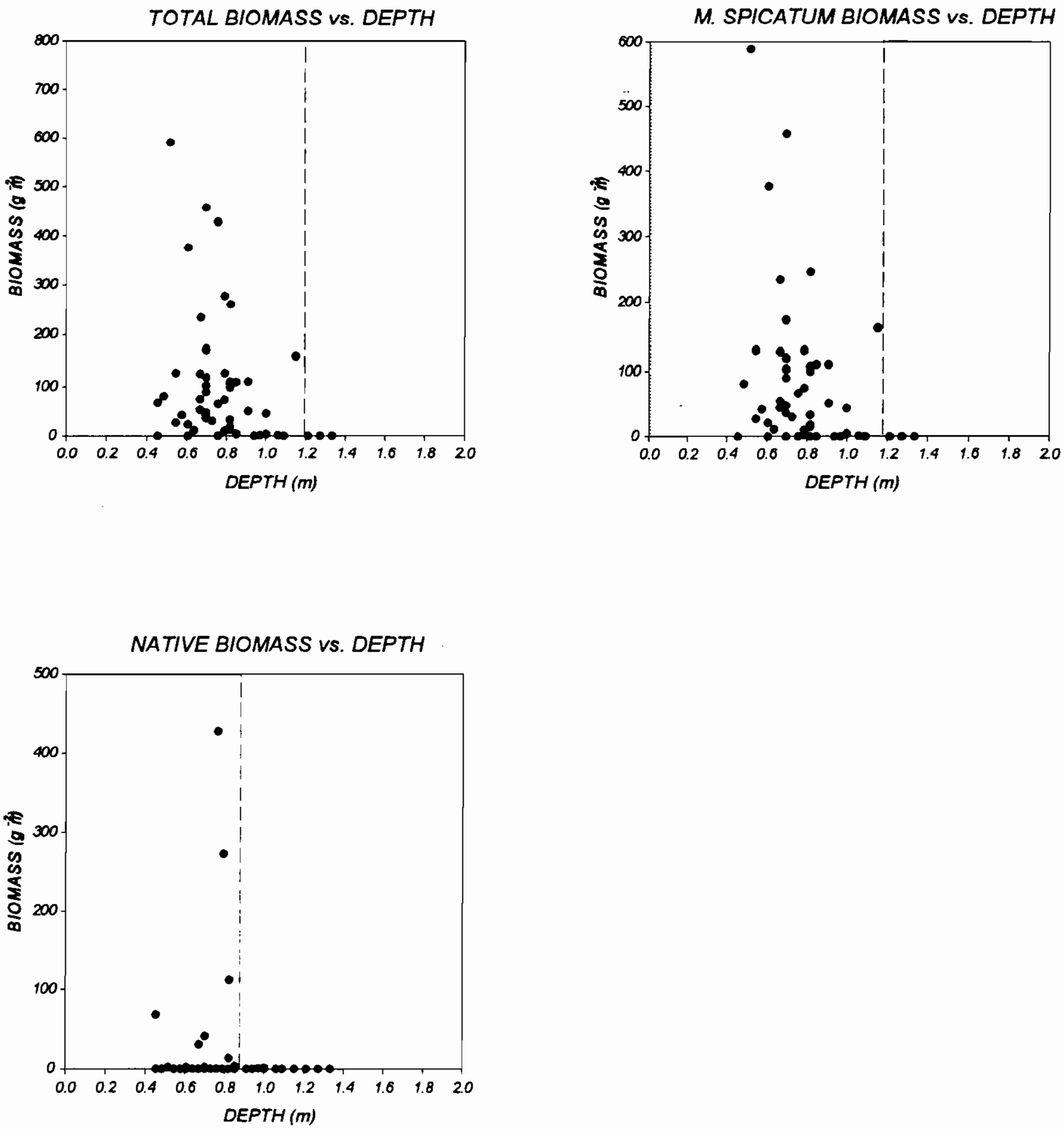


Figure 16. Relationship between plant biomass (g m^{-2}) and depth (m) for total plant biomass (top left), *M. spicatum* biomass (top right), and native plant biomass (bottom left).

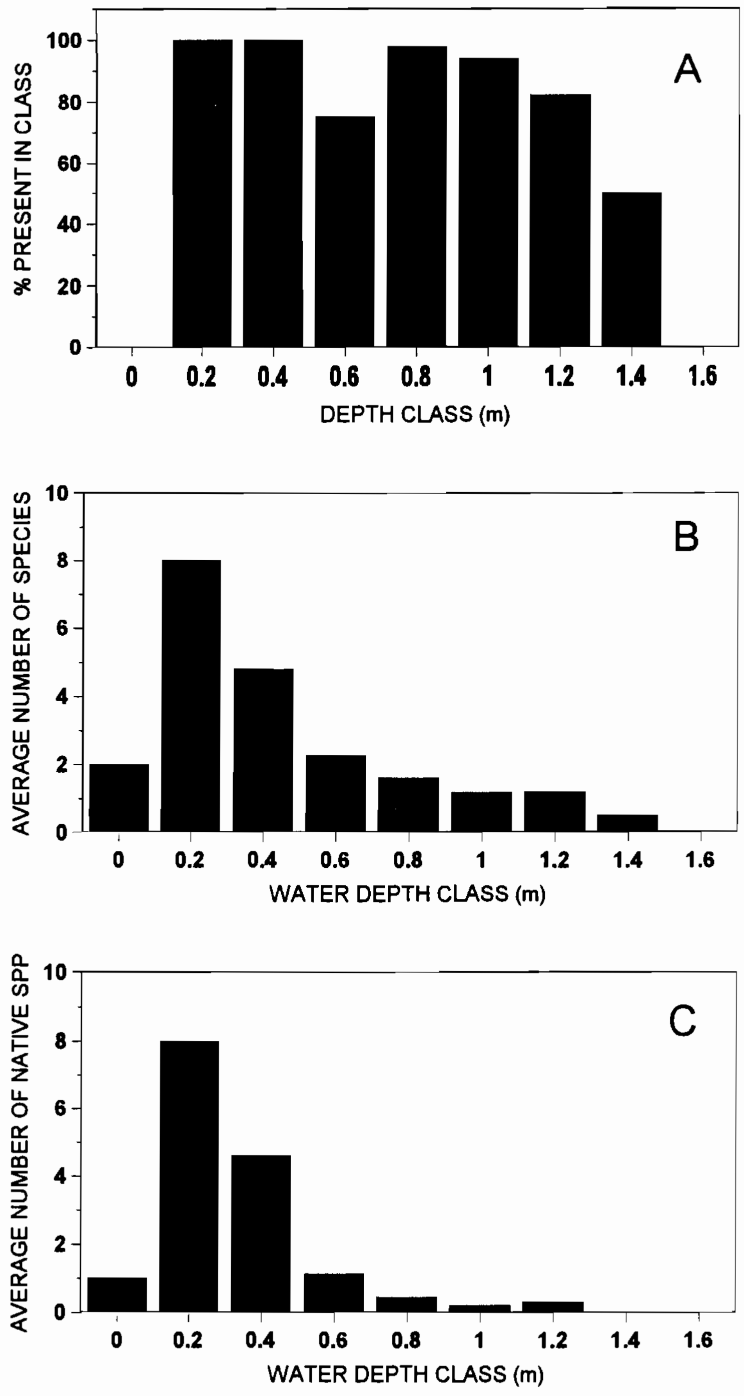


Figure 17. Relationship of plant distribution to depth. A. Water depth class (m) versus percent of sites with M. spicatum present, B. Water depth class (m) versus average number of species present per site, and C. Water depth class (m) versus average number of native species present per site.

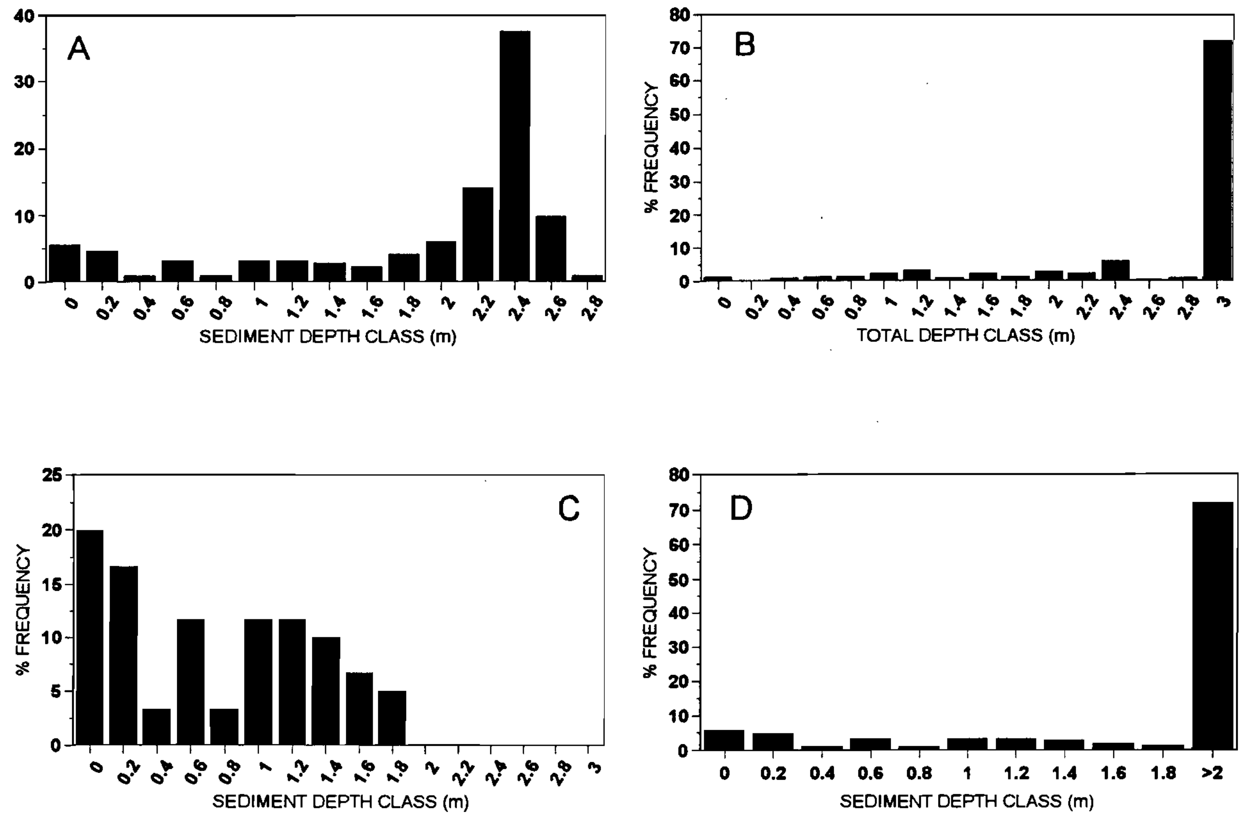


Figure 18. Frequency distributions of sediment depth (m) from 214 sites in Big Muskego Lake. A. Sediment depth calculated as total probe depth minus water depth; B. Total probe depth, with all total depths greater than 3 m combined; C. Sediment depth distributions for all sites with total depths less than 3 m; D. Sediment depth classes with all sites with total depths greater than 3 m reported as a sediment depth of greater than 2 m.

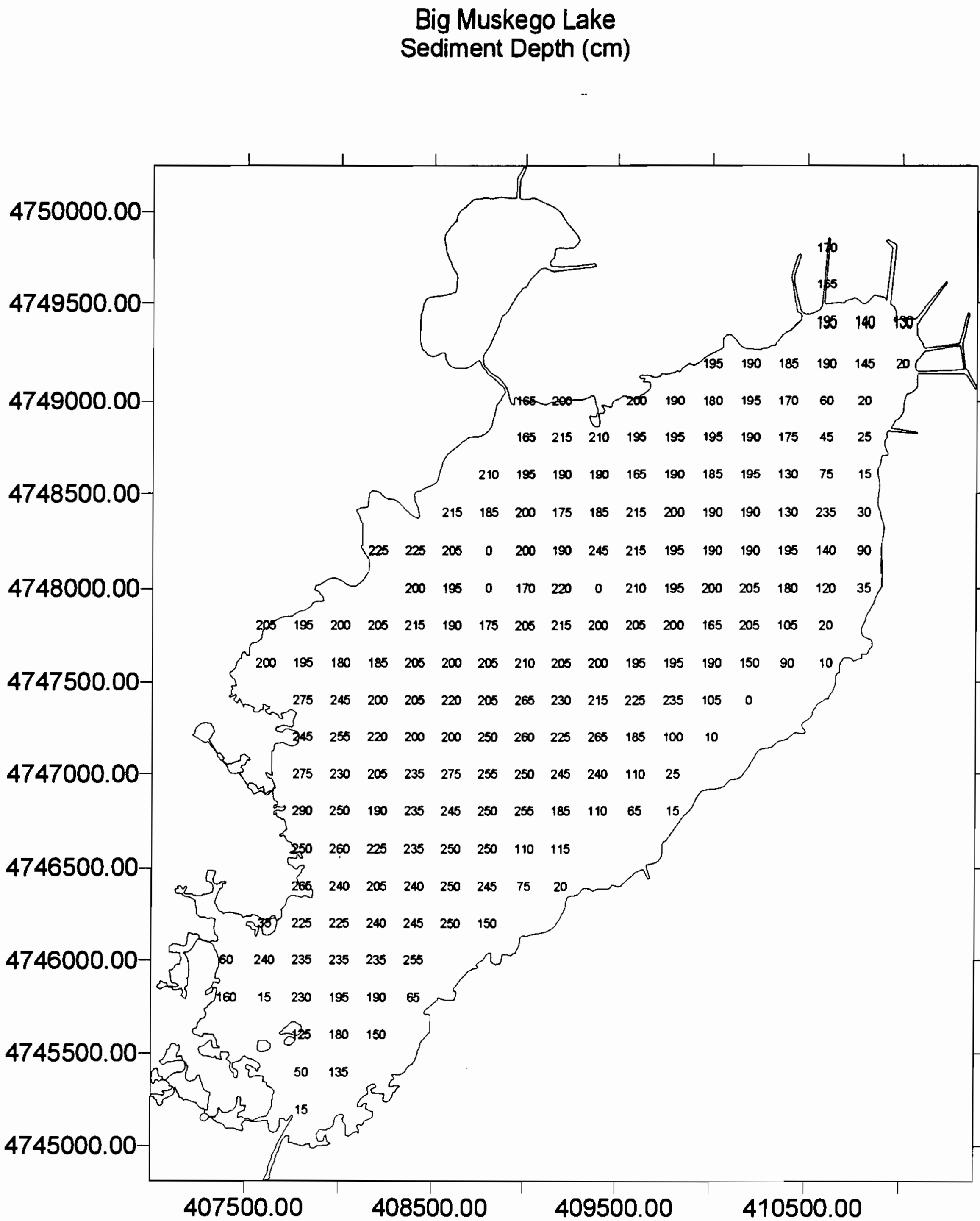


Figure 19. Sediment depths (cm) calculated as the difference between total probe depth and water depth for 214 sites in Big Muskego Lake.

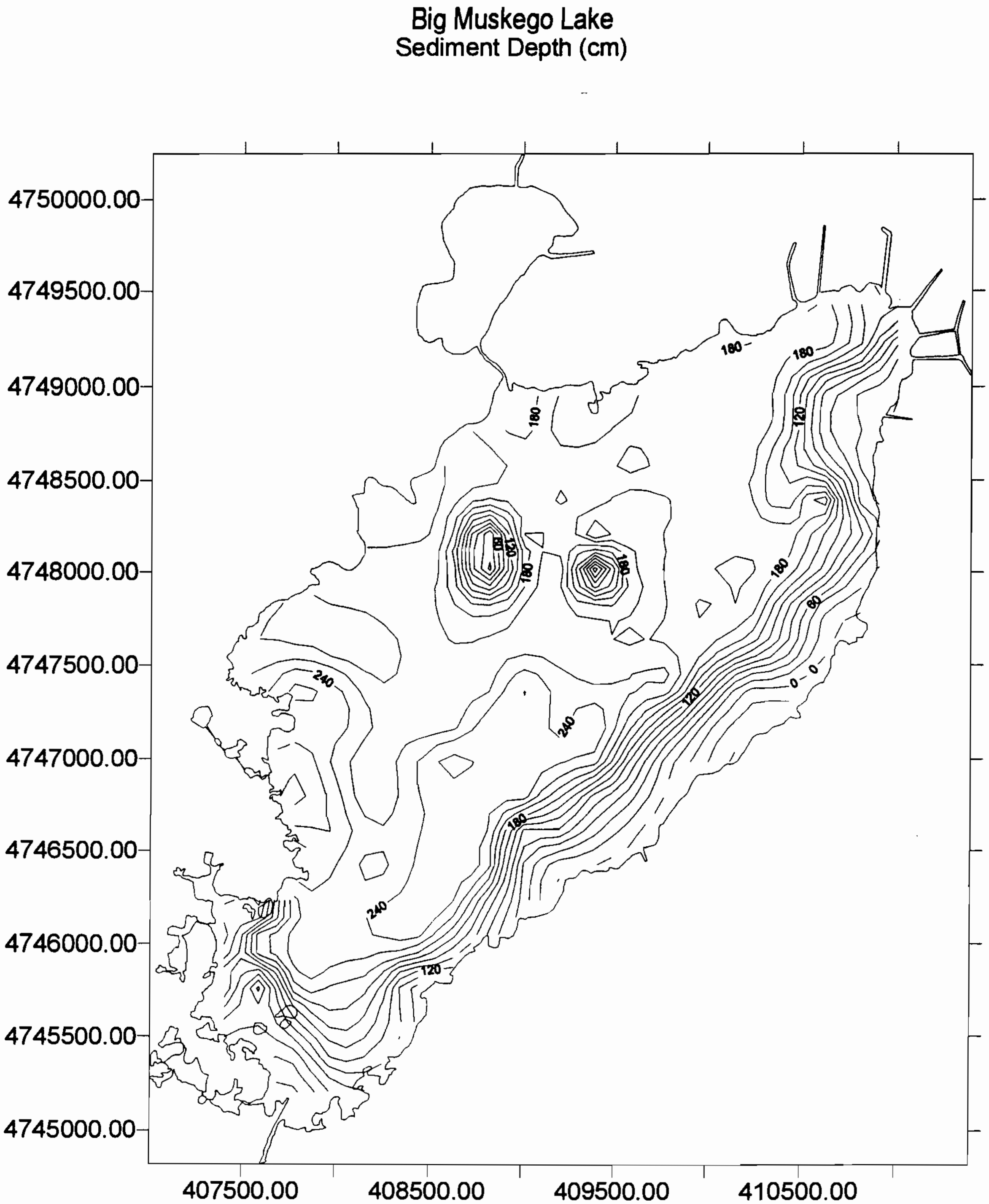


Figure 20. Sediment depth (cm) contour map for Big Muskego Lake.

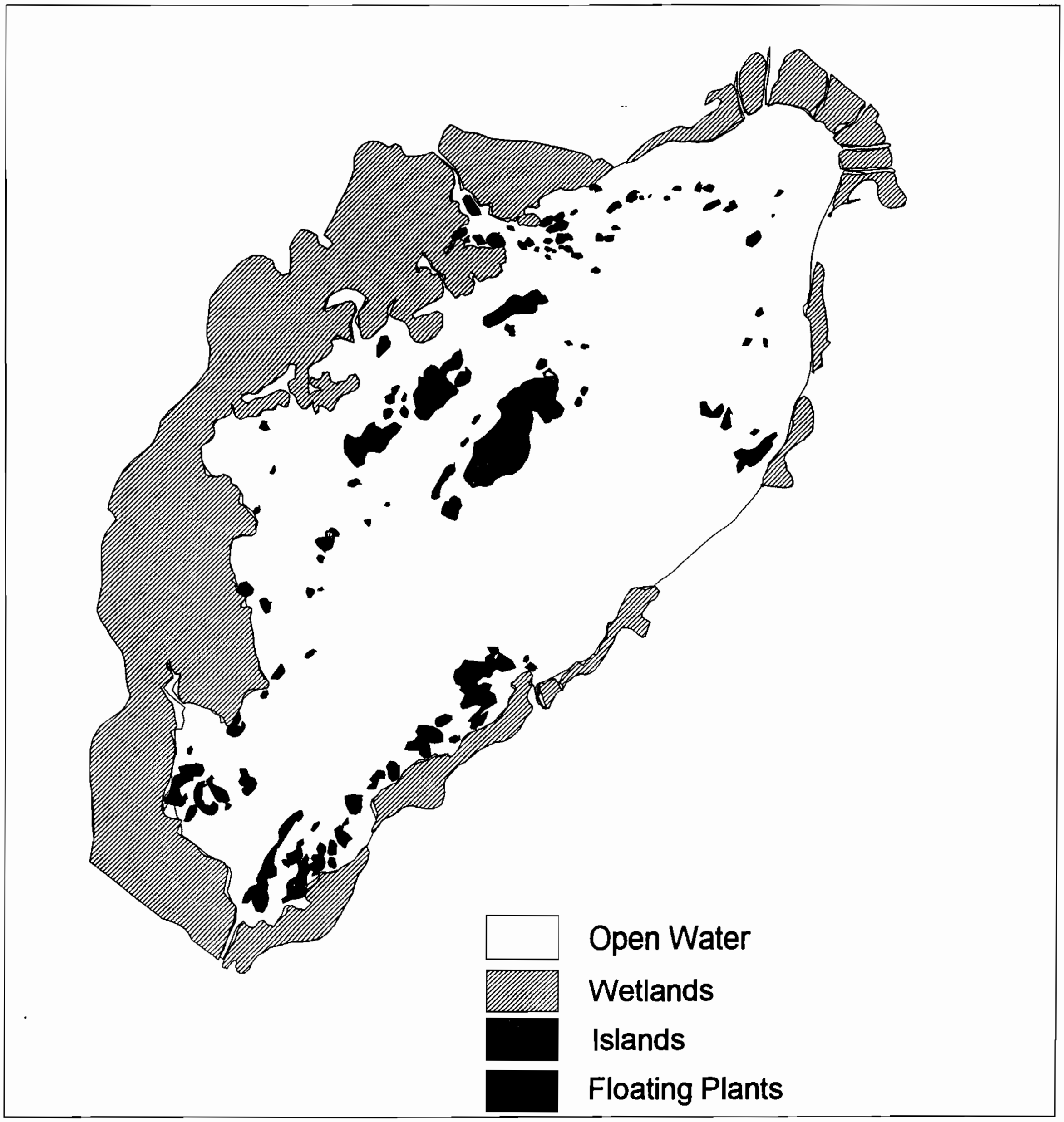


Figure 21. Photo interpretation of aerial photography of Big Muskego Lake, with each category digitized manually from aerial photographs.