LPL-467

Are No-Wake Zones Effective Means of Protecting and Enhancing Submerged Macrophyte Communities?

Results of a Macrophyte Study on Long Lake, Fond du Lac County, WI

Wisconsin Department of Natural Resources
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CONTENTS

SUMMARY

The aquatic macrophyte community in Long Lake, Fond du Lac Co., is relatively diverse and abundant and provides an important benefit to the fishery and to reducing sediment resuspension. Aerial photographs taken in 1995 indicated that large areas of the shallow littoral zone were becoming devoid of plants and that scour from boat propellers may have been contributing to their decline. The Wisconsin Department of Natural Resources, in partnership with the Long Lake Fishing Club, undertook a study in the summer of 1997 to see if an extended no-wake zone along the eastern shoreline could help reduce damage to the aquatic plant community.

A significant part of the littoral zone on the east side of the lake was marked with Slow-No-Wake buoys at the edge of the drop-off. The buoys were placed well beyond the existing 200 ft. no-wake restriction, up to 400 feet (120 m) off-shore. Two non-contiguous areas within this no-wake zone were marked with buoys that read "No-Motor". Boats were allowed in these areas, but operators were asked to tilt their motors and use only electric trolling motors or manual means of propulsion. Plant surveys and aerial photos were used to compare plant growth and species composition in No-Wake, No-Motor, and "Open" plots (outside the study area).

Major findings:

- No-wake zones appeared to be effective at reducing boat activity along the shallow eastern shoreline.

- Boat scour was much reduced in the lake in 1997 compared with low-water year 1995, especially along the underwater peninsulas within the study area.

- No differences were detected in the plant community between the No-Motor and the No-Wake plots; however, boat tracks were found only in the No-Wake plots.

- Milfoil and chara were slightly taller in some areas of the No-Wake and No-Motor plots as compared to the Open plots; however, the differences were small and it was not clear that the differences were related to boating intensity.

The immediate and most significant impact of the extended no-wake zone was the reduced scouring of the sediments and fewer boat tracks, not greatly increased height or density of the existing plant species. Chara is low growing and forms dense mats, while milfoil tended to grow in scattered clumps or in a narrow band along the outside edge of the littoral area. The relatively low species diversity and domination by chara in the study area is likely due to the intense boating that has occurred in this area for many years. Longer term protection from boating may help to increase the spread of milfoil relative to chara and increase the abundance of less resistant species, such as large-leaf pondweed and water lilies. A more diverse and balanced plant community would be beneficial to the lake and would promote a healthier fish community.

RECOMMENDED ACTIONS

1. A no-wake zone extending out to the edge of the plant bed should be established to prevent high speed boating impacts along the shallow eastern shelf of Long Lake.

   - No-wake zones in other areas of the lake would be beneficial to the plant community, but need to be balanced against lake use. The eastern shoreline is undeveloped, with a healthy emergent plant community close to shore. Designating this one area of the lake as no-wake achieves protection of a significant portion of the littoral zone habitat without impairing the use of the lake by riparians or boaters. In addition, anglers will have some refuge from high speed boats.

2. Buoy placement should follow the edge of the drop-off as closely as possible. However, in some cases it may be more appropriate to keep the buoys in a straight line to reduce confusion and to address concerns of boaters that the buoys were restricting their use of the lake.

3. The current no-wake zones out to 200 ft. should be maintained in other areas of the lake to prevent shoreline erosion and ensure safety.

4. Steps should be taken to reduce use of motors and anchors within the no-wake zones.

   - Scour can still occur even at no-wake speeds. A no-motor zone would be effective at preventing boat "tracks" from propeller disturbance and anchor lines; however, such a designation would be too restrictive and difficult to enforce. A greater effort at educating boaters and anglers about the benefits of aquatic plants may help to reduce this impact.

5. If permanent no-wake zones are established along the eastern shoreline out to the edge of the plant bed, periodic monitoring of the plant community as well as aerial photography should be employed to evaluate their long term effectiveness.

I. BACKGROUND

Long Lake is a highly used recreational lake in the Northern Unit of the Kettle Moraine State Forest. The lake is popular for both fishing and boating, by both visitors and local residents. A 1989 survey found that Long Lake had 7088 boating days annually (sum of daily boat numbers), which corresponds to 16.6 boating days per acre per year. Peak boating activity occurs in July, with as many 60 boats present on some weekends (Woodward-Clyde Consultants 1994.).

Macrophyte surveys performed in 1988 and 1995 indicate that plants cover over 85% of the littoral zone and occur as deep as 18 ft. (5.5 m; Hoodie 1995). The plant community is moderately diverse, dominated by chara (*Chara sp.*), coontail (*Ceratophyllum demersum*), and native water milfoil (*Myriophyllum sibericum* and *M. verticillatum*). Eurasian water milfoil (*M. spicatum*) has not been found on the lake to date, although it is present on a number of neighboring lakes (Mark Sesing, pers. comm.). There is currently a lake-wide no-wake zone extending 200 ft. (61 m) from shore. However, aerial photos taken in 1995 show several large areas of the littoral zone which are barren of plants and many other areas crisscrossed by boat tracks. In addition, large-leaf and Illinois pondweed declined significantly between 1988 and 1995. Thus while the plant community on Long Lake is currently relatively healthy, there are signs that boating activity may be having an impact on the lake and may be detrimental in the future.

Recent research on Lake Ripley, Jefferson Co. suggests that motor boat activity can have a detrimental effect on submerged aquatic plants (Asplund and Cook 1997). Plant beds isolated from boat activity in experimental enclosures had greater biomass, taller canopies, and greater areal coverage than exposed control plots. Since artificial enclosures are impractical on a lake wide basis, the next best method of protection is to establish no-wake zones in areas with existing plant communities. Presumably, boat activity is much less common in a no-wake zone than in an area without one, affording some protection to the plant community. However, no-wake zones have some limitations, which may reduce their effectiveness:

1) No-wake zones do not prevent boat access. Boats may still enter a no-wake zone and impact the plant community in shallow depths.
2) It is difficult to enforce no-wake ordinances. Even if most people comply with the ordinance, a few violations of the ordinance may have a significant impact on the plant community.
3) No-wake zones do not prevent impacts from boat wake or turbidity generated in the middle of the lake.

Very little research has been done to see whether these are valid concerns and whether no-wake zones are truly effective.

II. OBJECTIVES

We initiated a study on Long Lake in the summer of 1997 to address some of these issues and to evaluate the effectiveness of no-wake zones as a means of protecting native aquatic plant communities. We established an extended no-wake zone along the eastern shore of the lake which followed the edge of the littoral zone (approximately 120 m (400 ft.) into the lake). Within this extended no-wake zone, two "no-motor" zones were marked off with buoys. Boats were allowed in this no-motor zone as long as they were powered manually or with an electric trolling motor. Over the course of the study, we compared the development of the plant community between the no-wake zones and the no-motor zones, as well as between these areas and areas with the normal 200 ft. no-wake restriction. This study design would allow us to address some of the limitations of no-wake zones as compared to areas where motors are restricted completely.

Thus, the objectives of the study can be summarized as follows:

1) To determine if no-wake zones result in increased plant biomass, taller canopies, or greater coverage, as compared to unregulated areas;

2) To compare plant communities in no-wake zones to no-motor zones;

3) To compare evidence of boat scour from aerial photos from 1995 and 1997

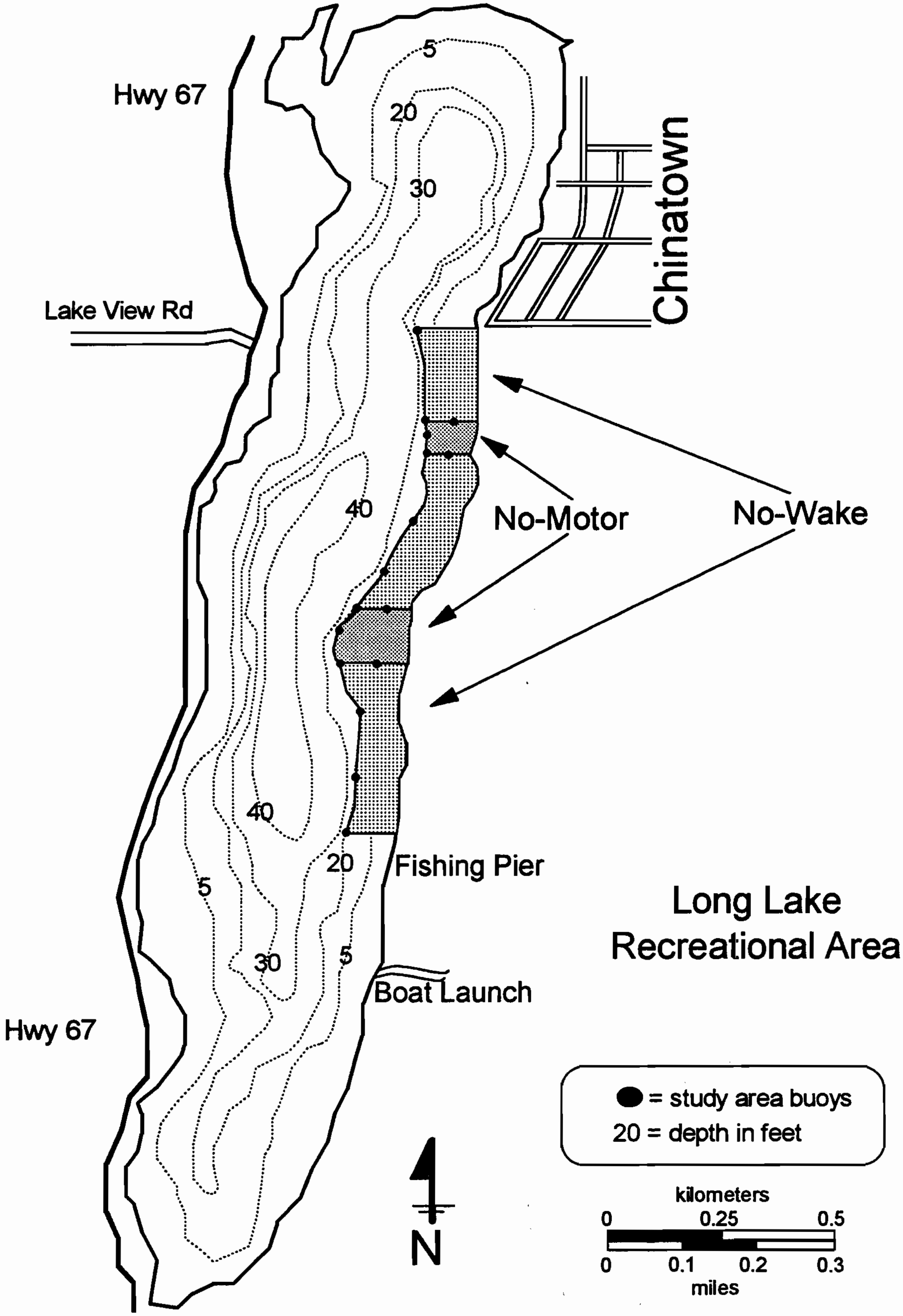
4) To evaluate whether no-wake zones or no-motor zones are feasible or useful means of protecting sensitive plant communities or beds.

III. METHODS

A. Experimental Design

Long Lake is a 169 ha (417 ac) lake located in Fond du Lac County, Wisconsin. Maximum depth is 14.3 m (47 ft) with a mean depth of 6.7 m (22 ft). As suggested by the name, Long Lake is long and narrow, with the primary axis running from north to south. A small 17 acre lobe at the north end of the lake is known as Tittle Lake. Long Lake is a drainage lake with Watercress Creek entering the lake from the north via Tittle Lake and another small creek also entering from the north. The outlet from the south end of the lake is the headwaters for the East Branch of the Milwaukee River. Long Lake is a natural lake formed by glacial activity. A dam was installed on the outlet in 1855 and the water level was raised approximately 5 feet. This created an extensive shallow shelf that rings the lake and extends approximately 120 m (400 ft) out from shore. The west shore of the lake is developed and the east shore is largely undeveloped Kettle Moraine State Forest land. East shore development is primarily in the northeast corner in an area known as Chinatown.

The study area consisted of about 1 mile of shoreline along the east side of Long Lake, extending out to the edge of a shallow shelf (Map 1). Water depth was relatively uniform within the shallow shelf (between 1-2 m), although it dropped off rapidly at the edge. Sixteen buoys were placed at the edge of this shelf in about 3-4 m of water, approximately 100-120 m out from shore. The entire area was designated “Slow No-Wake”, meaning that boats inside the buoys should operate at speeds that do not produce a wake. Within this area were two non-contiguous plots marked off as “No-Motor” plots. Each of these measured approximately 120-150 m along shore, with the outside edge at the drop-off. Boaters were allowed inside of the no-motor zones, but were asked to tilt their motors out of the water and use electric trolling motors or manual means of propulsion. Buoys were placed in mid-May, 1997, and removed in late September.



Map 1. Long Lake, Fond du Lac Co. The approximate location of the No-Wake and No-Motor Areas are indicated .

Special permission was obtained to designate no-wake and no-motor zones in the lake for purposes of this study. The restrictions were technically voluntary and marked with informational buoys rather than regulatory buoys. As a result, this study depended on cooperation between WDNR personnel, the Long Lake Fishing Club (LLFC), and the Town of Osceola Boat Patrol to encourage compliance with the boat use restrictions. A concerted effort was made to educate local citizens as well as non-resident lake users about the study and the importance of respecting the special boat-use zones. We placed large signs throughout the State Recreation Area (SRA) and at all boat access points with a map of the study area and an explanation of the buoys. Brochures describing the study were made available at local businesses and the SRA. A press release was issued and published in several area newspapers. Finally, the LLFC publicized the study in their newsletter and at a social gathering in mid-June.

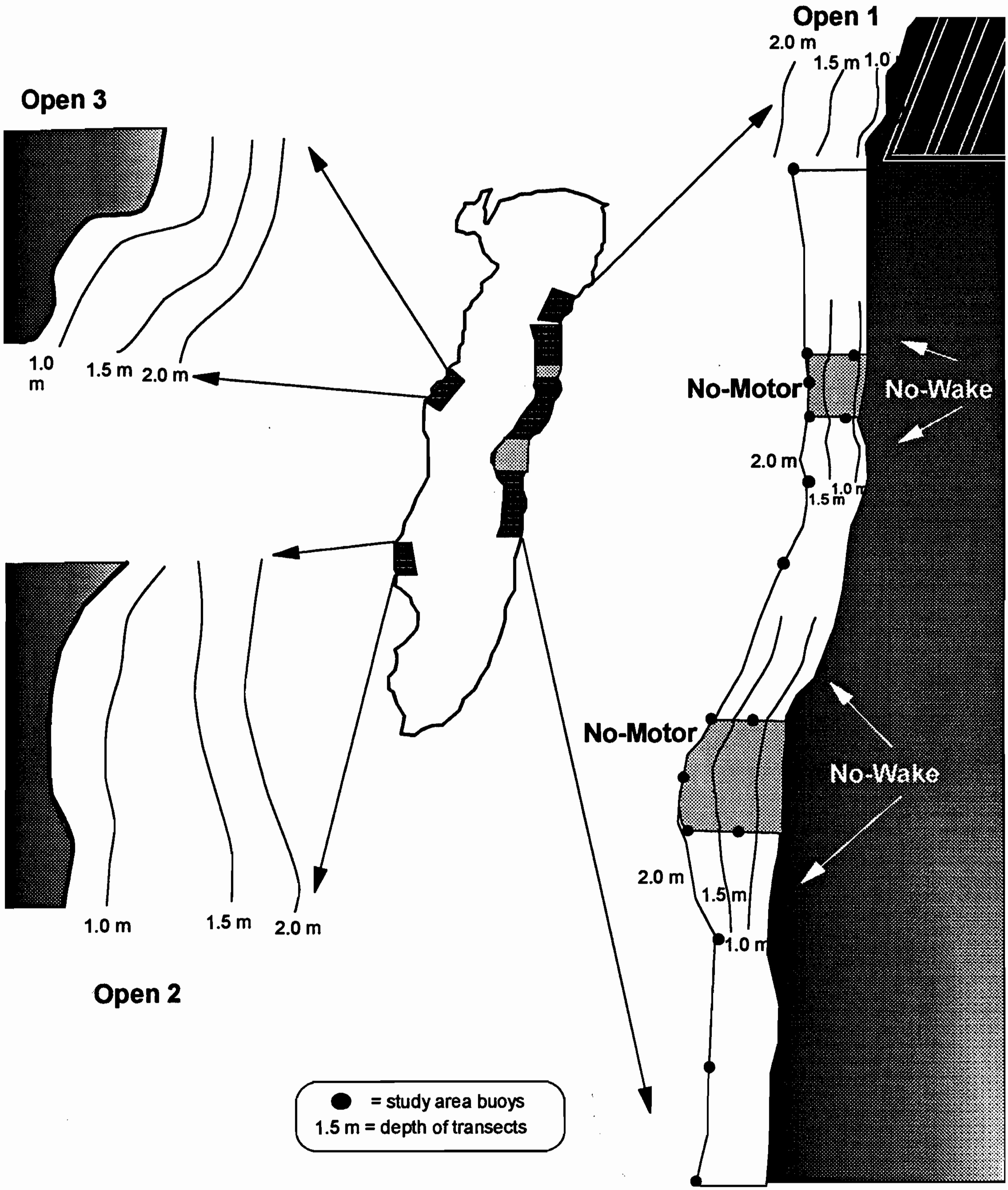
B. Plant Assessment Methods

Macrophytes were assessed in the two replicate No-Motor plots, four replicate No-Wake plots, and two control ("Open") plots on June 16-19 and on August 25-28 and Sept. 3, 1997 (Map 2). Open plots were subject to normal boating activity and guidelines and were not specially marked. An additional Open plot on the west side of the lake was sampled during the later period. Only the August data will be presented in this report as we have more complete data and plant growth and boating impacts would be maximized. No major differences in the plant community were observed between June and August, aside from slightly taller plants and some differences in plant species composition. Complete plant data for both dates can be found in Appendix 1.

We used a stratified random approach with transects oriented parallel to shore and following depth contours as closely as possible. We set up transects at 1.0 m, 1.5 m, and 2.0 m water depths. No-Wake transects started at the edge of each No-Motor plot and proceeded to the north and south (Map 2). Open transects were laid out with a random starting point in June, and roughly repeated in August. Transects were approximately 110 m long and divided into equal 10 m intervals. Within each interval, a sampling point was selected randomly using a random number chart. At each sampling point, a diver or snorkeler collected the following information on the plant community within a 0.2 m^2 quadrat:

- Presence/absence of individual species
- Density rating for each species:
    - 1=sparse (a few specimens)
    - 2=moderate (about 33-66% of the quadrat)
    - 3=dense (covering most of the quadrat)
- Overall stand density rating
- Height of tallest plant of each species
- Water depth

For analysis, measures of the plant community were summed or averaged for each transect. In addition to the parameters listed above, species richness (number of species), and species



Map 2. Location and arrangement of transects used to assess the aquatic plant community. The Open plots were not marked on the lake.

frequency of occurrence (number of occurrences of a species/total sites surveyed) were calculated for each transect. Canopy height was determined by averaging the height of the tallest plants at each site.

We assessed plant responses to boating separately for the three different depths due to differences observed in the plant community and in potential for impacts. The one-meter transects were closest in to shore and as a result likely would have minimal impacts from high speed boating. These transects were well within the no-wake zone in the Open plots. At 1.5 m, boating impacts would be expected to be more pronounced than at 1 m. These transects were located close to the edge of the no-wake zone in the Open plots and would be more accessible to anglers in the study area. The two meter transects were generally at the edge of the shelf in the middle of dense milfoil beds. These transects were well outside of the no-wake area in the Open plots and were at the buoy line in the study area. We would expect boating impacts to be greatest here, as they are closest to high-speed traffic.

Biomass samples were collected from each transect during the August sampling period only. Samples were collected at every other random sample point using a 0.1 m^2 quadrat. The quadrat was laid onto the bottom and all plants inside were harvested by hand and bagged. Samples were kept in coolers until analysis. In the lab, each sample was separated by species, placed in paper bags, and dried at 105° C for at least 24 hours. The bags and their contents were then weighed to obtain a dry mass. The weight of an empty dry bag was subtracted to correct to a true dry mass for the plants.

Since chara often is encrusted with calcium carbonate (marl), we performed an additional step to obtain an ash-free dry mass. A representative dried sub-sample from each major plant species was crushed and re-dried in crucibles at 105° C and weighed. These were then placed into the oven at 550° C to remove the organic fraction of the plant matter. After weighing, we returned the crucibles to the oven and baked at 900°C to remove the carbonate fraction. Based on multiple replicates, we then calculated average percent organic matter, calcium carbonate, and inorganic matter for each species (Table 1). The resulting organic matter percentage for each species was multiplied by the dry mass values obtained earlier to arrive at an ash-free dry mass value.

C. Sediment Assessment Methods

Sediment samples were collected from each of the 9 study plots (2 No-Motor plots, 4 No-Wake plots, 3 Open plots) on 24 September 1997. Three replicates from each plot were collected using an Ekman sampler. These samples (27 total) were analyzed to determine the percentage of moisture, organic matter (APHA 1992), and particle size (ASA 1965).

D. Aerial Photography and Digital Image Analysis

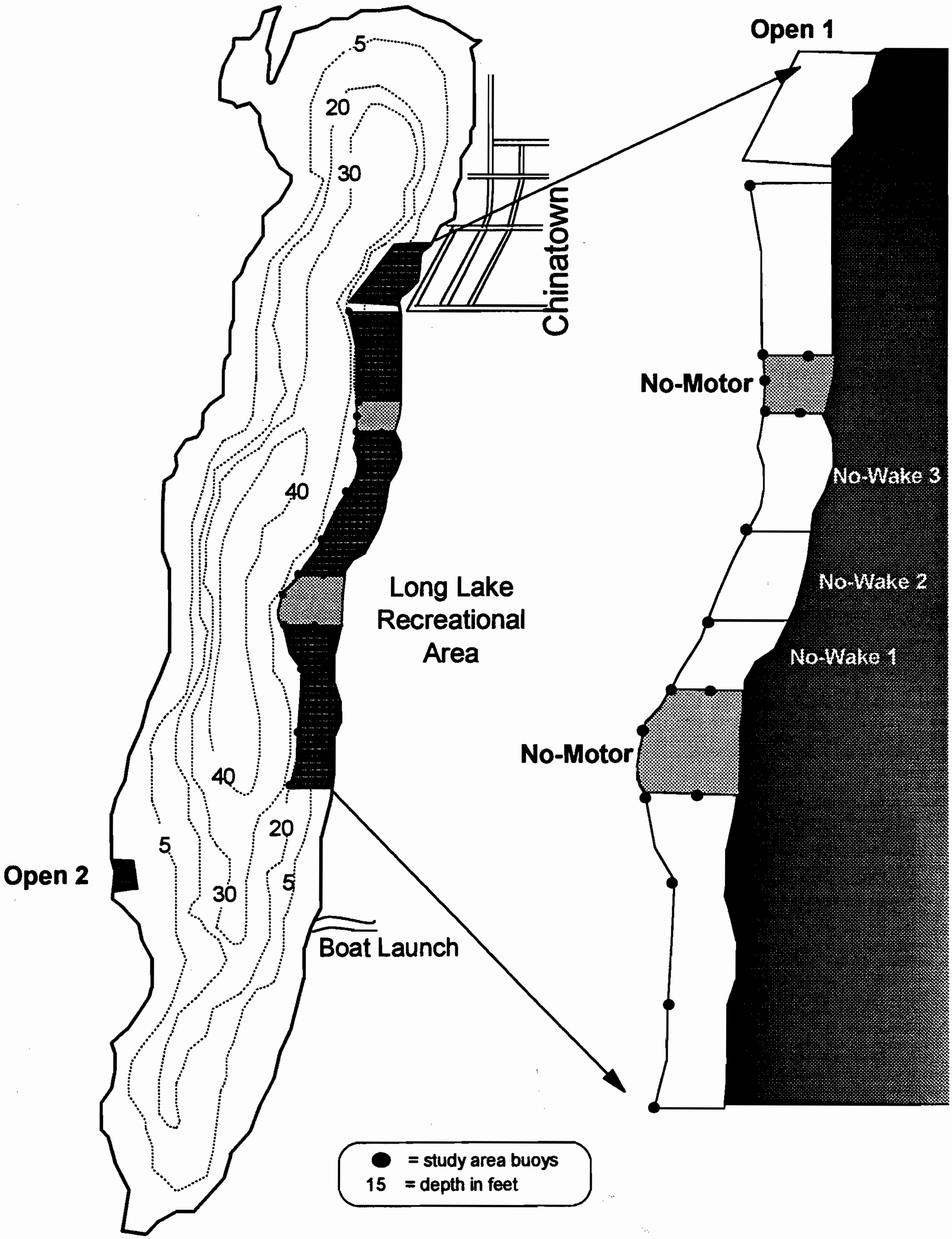
Aerial photos of Long Lake were taken on 27 June, 7 August, and 12 September 1997. Vertical photos of the lake were taken from an altitude of 3500 feet (1067 m) and pieced together to form

Table 1. Percent organic and $CaCO_3$ composition of plant material collected from Long Lake in August, 1997. Values represent average composition from at least 3 subsamples of ground, dry plant material.

Species	% Organic	% $CaCO_3$	% Inorganic
Chara sp.	33.9	47.4	19.2
Vallisneria americana	71.7	11.5	16.8
Zosterella dubia	72.8	14.1	13.2
Potamogeton illinioensis	80.2	10.4	9.3
Ceratophyllum demersum	81.7	6.7	11.6
Ranunculus sp.	81.9	5.5	12.7
Myriophyllum sp.	82.5	5.1	12.4
Mix	79.3	8.9	11.8

a composite image of Long Lake for each date. Photos from late summer 1995 were also obtained (Mark Sesing, pers. comm.) for comparison purposes. The September 1997 composite was compared to the 1995 composite using digital image analysis (Optimas Imaging software reference). Each image was broken into smaller portions (region of interest or ROI) corresponding to our No-Motor, No-Wake, and Open plots (Map 3). Three No-Wake ROI's were defined using the two no-wake buoys between the No-Motor plots. This resulted in a continuous region from the south No-Motor plot to the north No-Motor plot being described by the three No-Wake ROI's (No-Wake 1, 2, and 3).

The software allowed the user to selectively highlight areas of the image based on light wavelength characteristics. By manipulating ratios of red, green, and blue wavelengths it was possible to isolate milfoil growth, chara growth, and scoured areas. These areas were reported as a percentage of the ROI. Where photos overlapped, slight differences in photo-finishing made it difficult to accurately select milfoil, chara, and scour areas. In these cases, two separate ROI were created and the results merged. Since the image from 1995 did not show our study buoys, the ROI had to be created by visually matching the areas. This undoubtedly introduced some error, but was unavoidable. The entire procedure (image acquisition, ROI definition, and wavelength selection) was repeated twice on one ROI from each image to quantify the error in the technique. The spread of percentages for each area (chara, milfoil, and scour) are reported below (Table 2).



Map 3. Location of Regions of Interest used for digital image analysis.

Table 2. Maximum difference in percent coverage estimates among replicate imaging tries.

	1997	1995	Average
Chara	5.0	5.4	5.2
Milfoil	3.1	4.5	3.8
Scour	-----	3.9	3.9

E. Newsletter Survey

An informal survey was sent out to about 500 members of the Long Lake Fishing Club in late September. Responses were received from 67 members. The survey asked lake users about their experiences boating or fishing on the lake during 1997, whether they adhered to the buoy restrictions, and their opinion about the effectiveness of the buoys for improving the lake. The survey questions and results can be found in Appendix 2. The purpose of the survey was two-fold. First we wanted to find out whether people generally used the no-wake and no-motor zones as intended. Second, we wanted to get feedback on the utility or feasibility of designating an extended no-wake zone in this area in the future. The survey was not intended to be a scientific representation of all Long Lake users, but rather a way to informally poll people about their activities to help us interpret our results.

IV. RESULTS AND DISCUSSION

A. Lake and Study Area Use

We did not attempt to quantify the number of boats using the lake or systematically monitor lake or study area use. However, we noticed that boats were present inside the No-Wake buoys on several occasions, particularly during visual observations made on several weekend days and during aerial photography flights. Occasionally we noted boats inside the No-Motor zones, but most often boats were observed at the edge of the plant bed or just outside the buoyed area. At no time did we observe boats traveling at speeds above no-wake in the study area. It appeared that the boats that were inside the buoys were being used by anglers and were either anchored or moving to another location within the No-Wake zone. Discussions with local residents, Long Lake Recreation Area personnel, and boat safety patrol also indicated that people generally respected the No-Wake buoys and stayed out of the No-Motor areas.

Survey results generally supported the anecdotal information (FIG. 1; Appendix 2). Most of the respondents used the lake for both fishing and boating, while about 41% identified themselves as either anglers or boaters. Sixty-four percent of respondents stayed at the edge of the buoys, while only 11% entered the No-Motor zones. Ninety percent of the respondents thought that the public

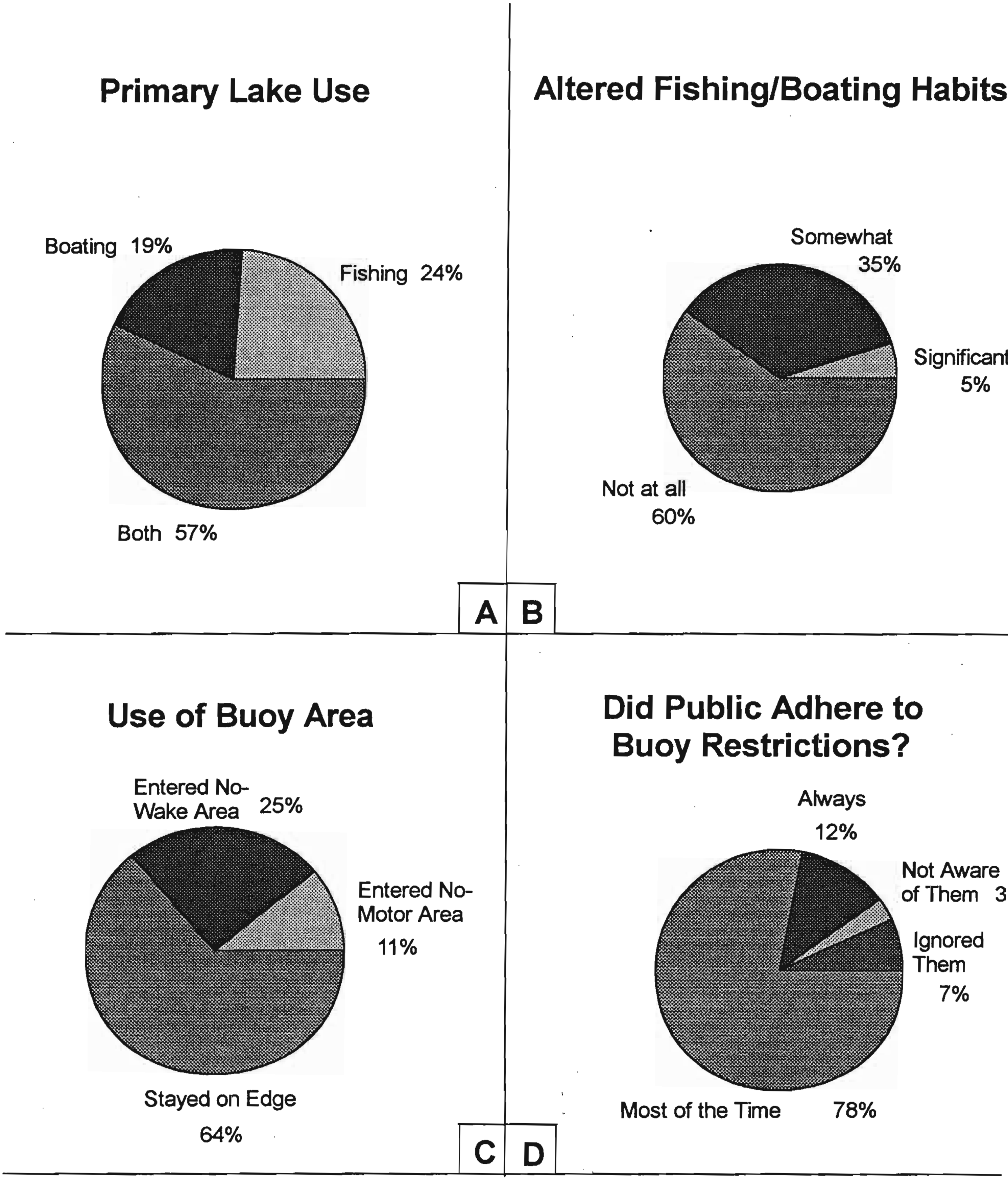


Figure 1. Results from a survey of Long Lake Fishing Club members. All respon included (n = 67). Original questions can be found in Appendix 2.

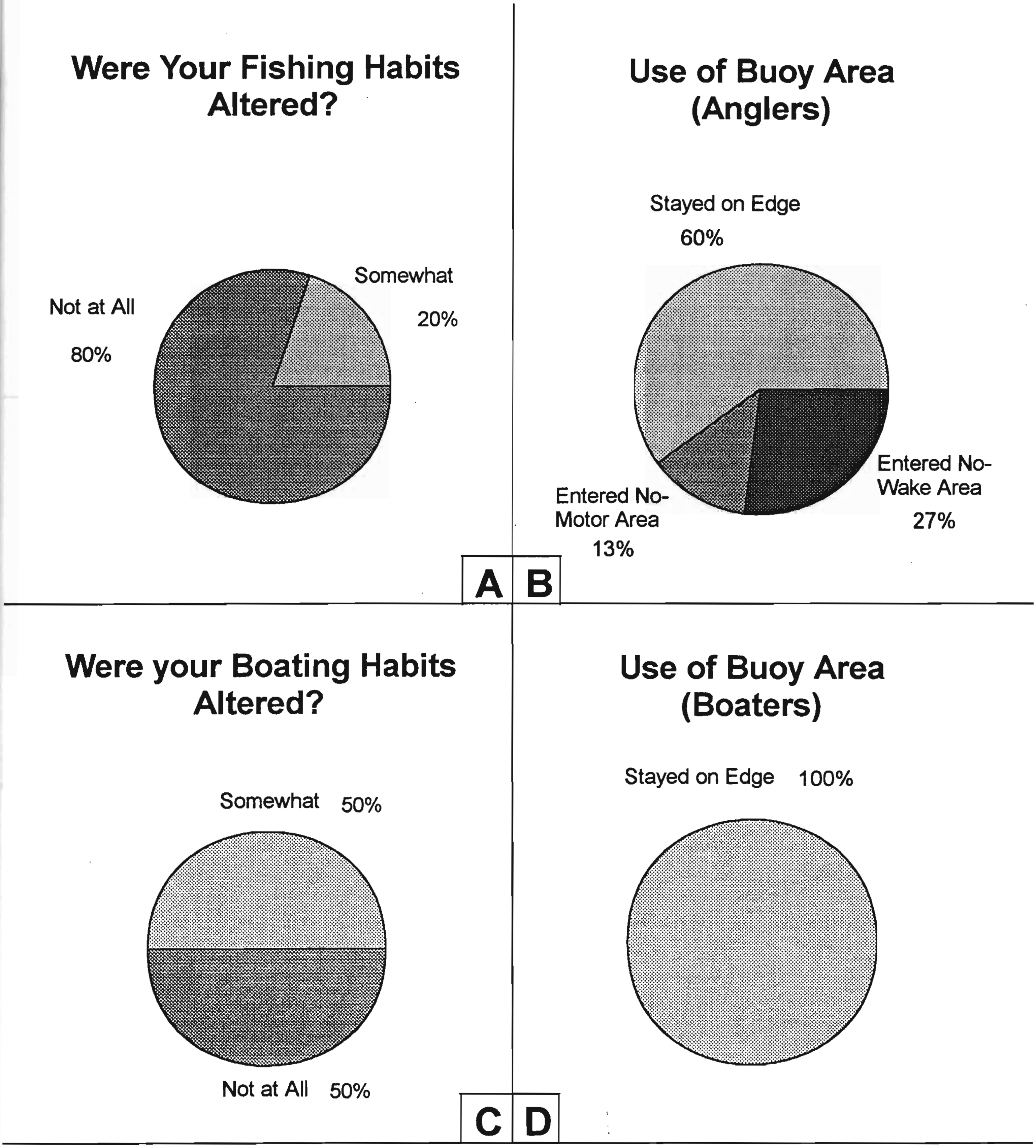
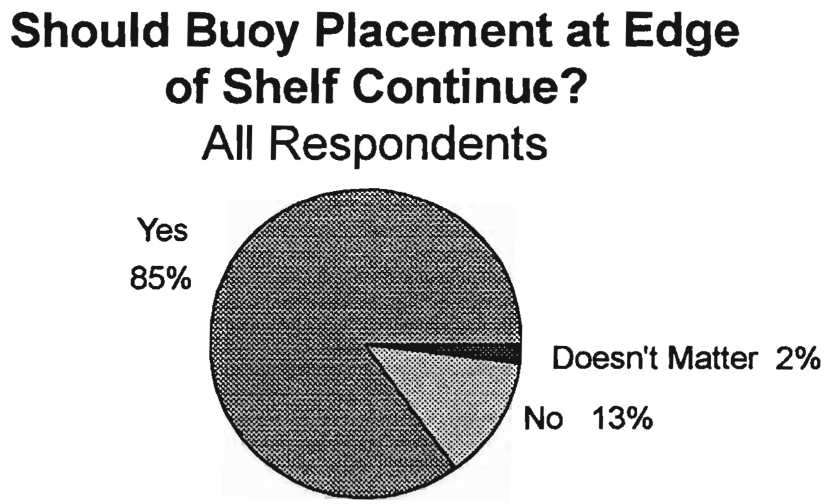


Figure 2. Survey results from questions 2 and 3. A and B use only those surveys that listed "fishing" as primary lake activity (n = 15). C and D use only those surveys that listed "boating" as primary lake activity (n = 12).

A



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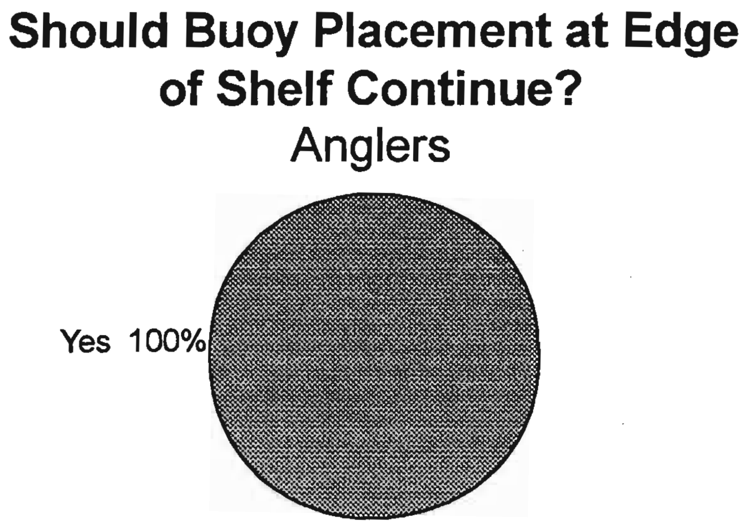

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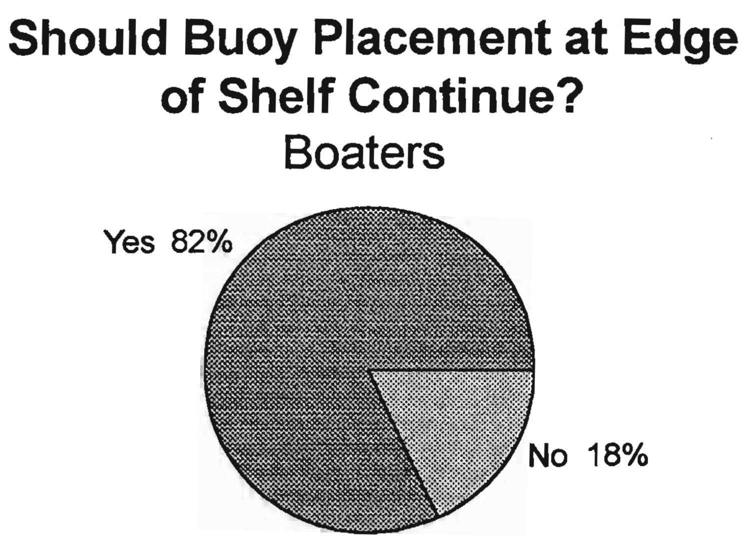


Figure 3. Survey results for question # 6. All respondents (A), people who indicated fishing as primary lake use (B), and those who indicated boatin as primary lake use (C).

adhered to the boating restrictions most of the time, if not always. Only 5% said that the buoys affected their activities significantly. Anglers were more likely to enter the buoyed area than boaters; however, boaters were more likely to have problems with the buoys than anglers (FIG. 2). Eighty percent of anglers responded that their fishing habits were not at all altered, while 50% of boaters indicated that their habits were somewhat altered. Unfortunately, we have no way of knowing whether boat use actually differed in the No-Motor plots as compared to the No-Wake plots.

The overwhelming majority (85%) of survey respondents were supportive of the buoys and thought that their continued presence would "protect the lake's aquatic environment and water clarity" (FIG. 3). All of the anglers favored the presence of the buoys, while 80% of boaters agreed. Comments received from the respondents indicated a wide range of opinion about the effectiveness of the buoys and the need for regulating boat traffic (see Appendix 2 for a complete listing of comments). Several people expressed concern about the placement of some of the buoys and the future of boating on the lake if negative impacts were found. Many people indicated that they thought that boat traffic was a problem, while others expressed concern about the "weeds". It is clear that any future actions on Long Lake need to address the concerns of all lake users and to balance the various uses of the lake, whether it be fishing, boating, swimming, or aesthetic enjoyment.

B. Aquatic Plants

1. Species composition and distribution

a. Lakewide distribution and community composition.

Species composition across all our study areas is listed in Table 3, as well as rake survey data from 1988 and 1995. Chara and native water milfoil were the dominant species found in our study areas, both occurring in 53% of the samples in August. These were also two of the dominant species in the previous rake surveys, although Illinois pondweed and coontail were much more prevalent in the earlier surveys. Many of the same species were found in all three surveys; however, the 1997 distribution was less diverse than the whole-lake surveys from 1988 and 1995. In fact the other 10 species found in 1997 occurred in less than 5% of the sites. Much of the diversity found in previous surveys came from areas in the northern and southern ends of the lake, while our study area was limited to the eastern and western shorelines. Our study also incorporated only about half of the littoral zone, with the deepest sampling point at 2.0 m. Thus the percent frequency data should not be considered to be a change in plant community composition, rather it is included as a comparison of our study area in relation to whole lake plant community.

b. Depth differences

Plant distributions were somewhat different among depths, as indicated by FIG. 4A. Chara was the dominant species in both the 1.0 m and 1.5 m transects, while milfoil was dominant in the 2.0 m transects. In fact, the 2.0 m transect consisted almost entirely of milfoil. This transect tended

Table 3. Frequency of occurrence as a measure of plant cover in the littoral zone in 1988, 1995, and 1997[1]

Common name	Scientific name	1988[2]	1995[2]	1997
Bladderwort	*Utricularia purpurea*	1	3	1
Buttercup	*Ranunculus sp.*	-	-	2
Chara	*Chara sp*	32	35	53
Coontail	*Ceratophyllum demersum*	19	48	2
Elodea	*Elodea canadensis*	3	5	-
Naiad	*Najas guadalupensis*	17	6	-
Nitella	*Nitella sp.*	-	1	-
Pond lily, yellow	*Nuphar varigatum*	12	5	-
Pondweed, flatstem	*Potamogeton zosteriformis*	19	22	1
Pondweed, floating leaf	*Potamogeton natans*	-	1	4
Pondweed, Illinois	*Potamogeton illinoensis*	37[3]	6	3[3]
Pondweed, large leaf	*Potamogeton amplifolius*	-	12	-
Pondweed, Richardson's	*Potamogeton richardsoni*	5	12	3
Pondweed, sago	*Potamogeton pectinatus*	11	22	1
Water celery	*Vallisneria americana*	4	3	-
Water lily, white	*Nymphea odorata*	-	8	-
Water marigold	*Bidens beckii*	-	9	1
Water milfoil	*Myriophyllum sibericum*	71	77	53
Water stargrass	*Zosterella dubia*	-	9	-
All species	--	89	95	100

[1]1988 and 1995 data are from 25 rake transects around the entire lake; 1997 data are diver collected from study area transects only. Frequency of occurrence is calculated as the number of sites where species occurred at least once divided by the total number of sites.

[2] 1988 and 1995 data are reported in Hoodie 1995.

[3] includes *P. amplifolius.*

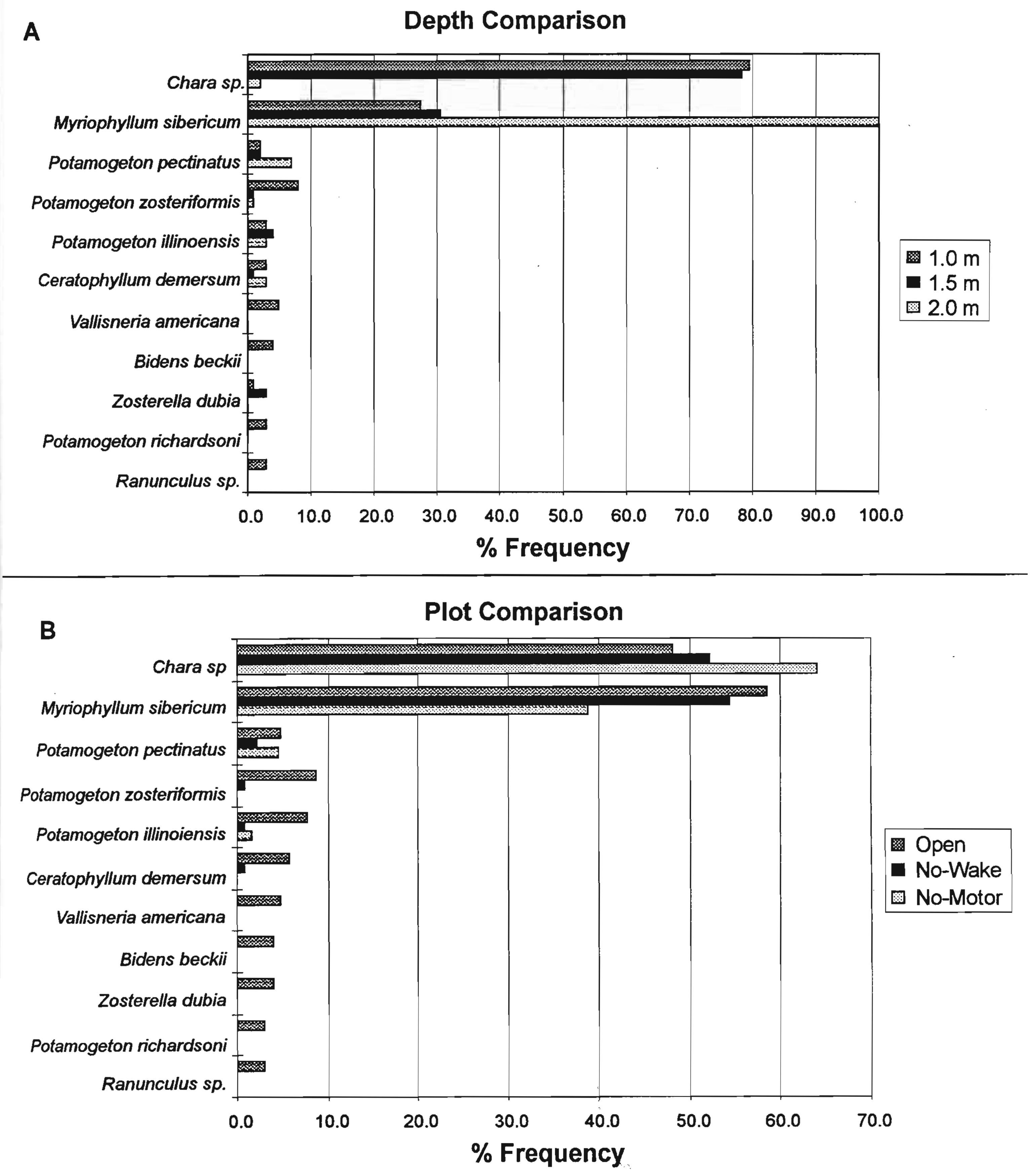


Figure 4. Frequency of occurrence of plant species by depth (A) and by type of plot (B) in August 1997. % Frequency is the number of occurrences of a species divided by the total number of sample sites.

to follow the edge of the littoral shelf and was characterized by a narrow band of water milfoil all around the lake. The 1.0 m transects were the most diverse, with several species only found at this depth. The 1.5 meter transects were somewhat less diverse than 1.0 m, but had a similar distribution of chara and milfoil.

c. Differences among study plots

Chara and milfoil again were the dominant species in all plots (FIG. 4B). Milfoil followed a decreasing trend from Open, to No-Wake, to No-Motor plots, while chara showed the opposite trend. Milfoil was slightly more frequent than chara in the Open and No-Wake plots, but chara was dominant in the No-Motor plots. The Open plots had the most diversity or species richness. In fact, 5 species were only found in the Open plots. It should be noted that most of the diversity in the Open plots occurred in the 1.0 m transects (FIG. 5A). It is possible that our 1.0 m transects in the Open plots were closer to shore than in the protected plots and that our sampling design missed the diversity in the protected plots. We observed that areas closer to shore in the No-Wake and No-Motor plots were more diverse and dominated by emergent grasses and floating leaf species such as water lily.

The differences seen among the three types of plots (Open, No-Wake, No-Motor) in plant distribution may not be related to the study, but may represent pre-existing differences in plant distribution due to site-specific conditions. For example, sediment moisture and organic matter content in the Open plots were slightly higher than in the buoyed-off plots (see Appendix 3). This may be indicative of more flocculent and nutrient rich sediments, which may support a broader range of species. Particle size distribution was not significantly different among the plots, but the relatively high proportion of sand (45%) suggests that plants may be easily uprooted by disturbance. All three Open plots were located offshore of developed shorelines with numerous piers. In contrast, the No-Wake and No-Motor plots were almost entirely dominated by chara and milfoil and had few pockets of open sediments. Prior to the study, these areas likely did not receive much impacts from boating, as the shoreline is undeveloped and relatively shallow.

Finally, plant species composition would not likely respond to manipulation in one summer. Thus the plant metrics we have focused on in this study are ones that measure growth of the existing species (height, density, frequency, biomass). Longer term study would be necessary to evaluate the effects of boating or boating regulation on the plant species composition.

2. Plant characteristics

Plant community characteristics such as height of the canopy, density, and biomass are directly affected by boating (Wagner 1990; Liddle and Scorgie 1980). Propellers may chop off the tops of plants, affecting the canopy height, while uprooting or scouring of sediments may affect plant density (Asplund and Cook 1997). Both of these effects may result in reduced plant biomass. We compared these parameters among the three types of plots (Open, No-Wake, and No-Motor) for the whole plant community and for the two major species - chara and native water milfoil. Our hypothesis was that plant height, density and biomass would be least in the Open plots and

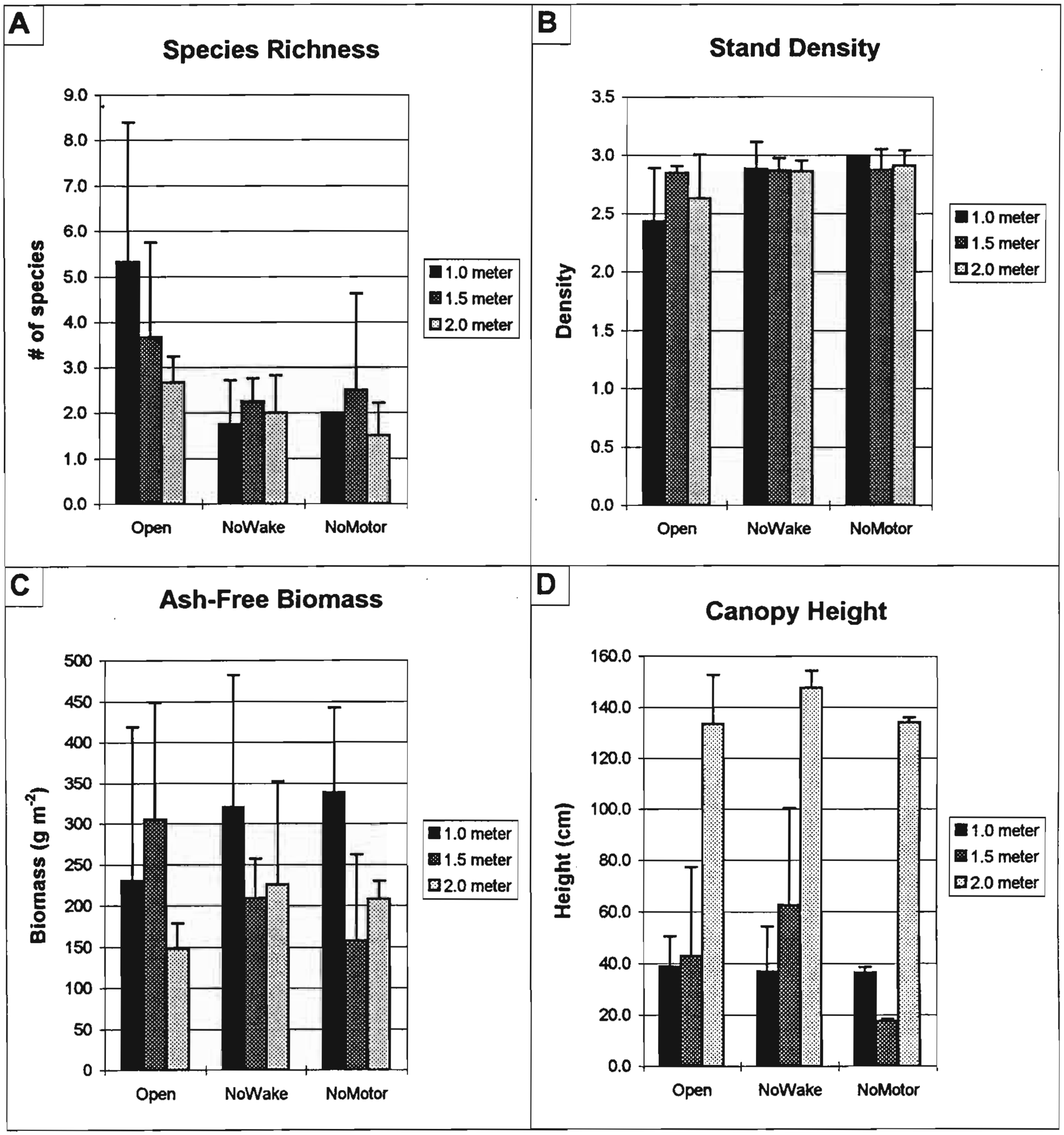


Figure 5. August vegetation characteristics by depth and type of plot. A. Species Richness (number of species along a transect); B. Stand Density (on a scale from 1 to 3); C. Ash-free Biomass (in grams per square meter); and D. Canopy Height (in centimeters).

greatest in the No-Motor plots. We expected the height of the milfoil to be affected more than the chara, since milfoil often reaches the water surface. Conversely, we expected the density or frequency of the chara to be affected more than the milfoil, as chara tended to cover the entire littoral area and appeared to be most affected by scour in the aerial photos. Again, data were analyzed separately for the different depth transects.

a. Stand density

Stand density was relatively uniform and dense across depths with average stand density between 2.4 and 3.0 on a scale of 0 to 3. The Open plots tended to be slightly less dense than the No-Wake or No-Motor plots (FIG. 5B), although the differences were not statistically significant. Milfoil and chara density were directly correlated to the frequency of occurrence along a transect. At any particular sampling site, either chara or milfoil was dominant and fairly dense. In fact, there was an inverse correlation between chara frequency and milfoil frequency among all transects ($R^2 = 0.94$). Thus at 1 m, milfoil occurred more frequently in the Open plots than in the No-Wake and No-Motor plots (FIG. 6A), while chara was less frequent (FIG. 7A). At 1.5 m, milfoil was virtually absent from the No-Motor plots, while chara occurred 100% of the time. The slightly lower stand density in the Open plots may indicate some thinning by boating activity, although it is difficult to discern which species was most affected.

b. Biomass

Plant biomass confirmed the stand density observations with biomass in the Open plots about 30% lower than in the protected plots at both 1.0 m and 2.0 m (FIG. 5C). However, at 1.5 m, plant biomass followed a decreasing trend from Open to No-Wake to No-Motor plots. Biomass varied quite a bit among similar-type plots; thus the differences among plots were not statistically significant. Chara biomass drove the plot differences at 1.0 m (FIG. 7B), while milfoil biomass influenced the differences at 2.0 m (FIG. 6B).

c. Canopy height

The plant canopy was the tallest in the 2.0 m transects (FIG. 5D), as might be expected since milfoil was dominant at this depth. No significant differences in canopy height were observed among plots at 2.0 m or at 1.0 m. At 1.5 m, the canopy was relatively low in the No-Motor plots. Since milfoil tends to grow much taller than chara, the differences among plot canopy heights were driven mostly by milfoil frequency. Milfoil was actually much shorter in the Open plots than in either the No-Wake or No-Motor plots at 1.0 m (FIG. 6C), but because it was more frequently occurring, the average canopy height was similar among heights. At 1.5 m, milfoil was very sparse in the No-Motor plots, so the canopy height was influenced by the chara. Thus it appears that boats may have been limiting the growth of milfoil at 1.0 m depth, but other influences were difficult to detect.

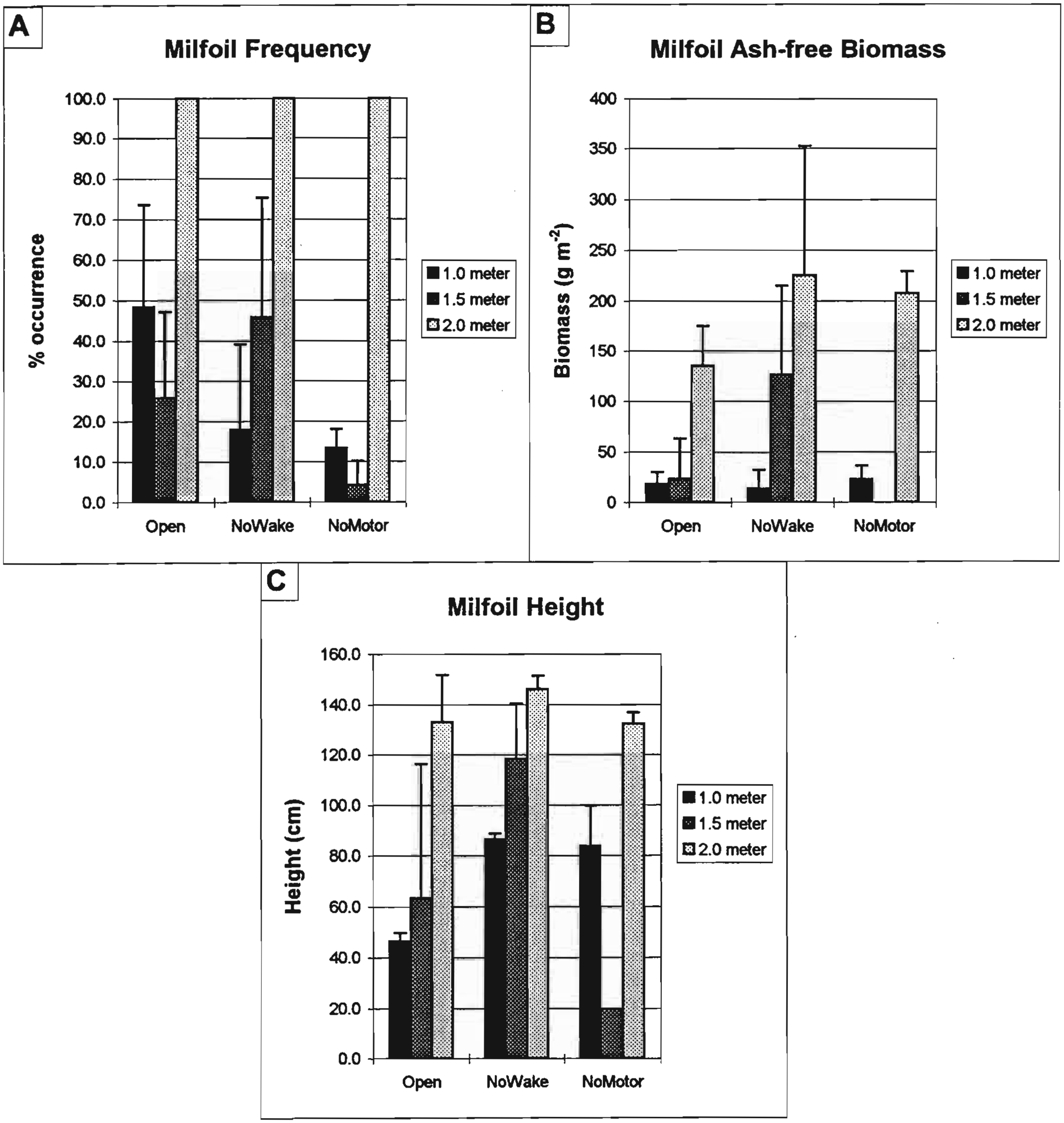


Figure 6. August *Myriophyllum sp.* (milfoil) characteristics by depth and type of plot. A. Frequency of Occurrence (percent of sites with milfoil along a transect); B. Ash-free Biomass (in grams milfoil per square meter); and C. Milfoil Height (in centimeters).

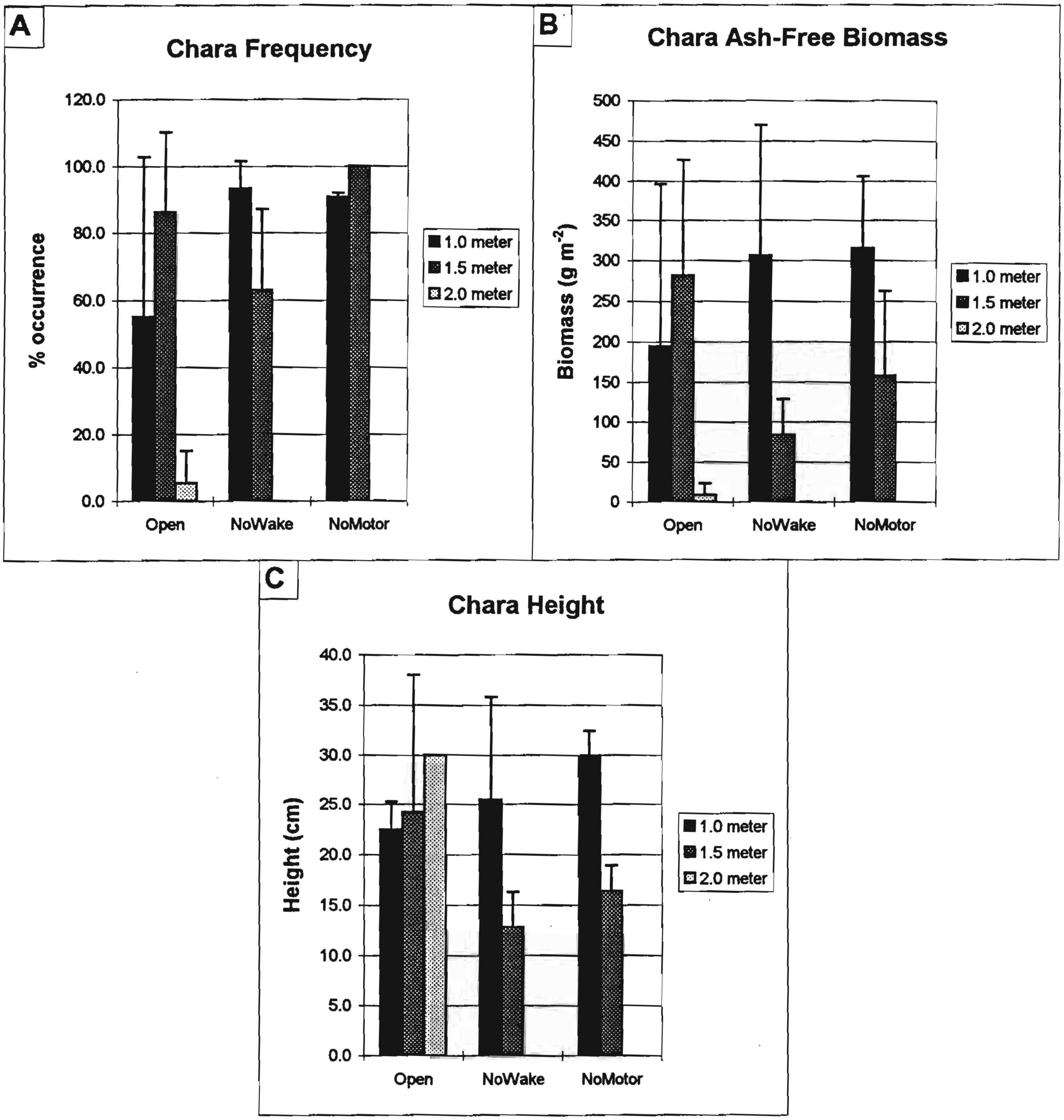


Figure 7. August *Chara* sp. characteristics by depth and type of plot. A. Frequency of Occurrence (percent of sites with *Chara* along a transect); B. Ash-free Biomass (in grams *Chara* per square meter); and C. *Chara* Height (in centimeters).

3. Summary of differences among study plots

The following observations summarize the results of the plot comparisons:

- Species richness was greater in the Open plots at 1 m as compared to either No-Wake or No-Motor plots;
- Canopy height tended to be similar among all plots;
- Milfoil and chara were slightly taller in the No-Wake and No-Motor plots at 1.0 m;
- Stand density was slightly greater in the No-Wake and No-Motor plots at 1.0 and 2.0 m;
- Chara and milfoil were slightly more abundant in the No-Wake plots at 1.0 and 2.0 m.

Thus it appears that the no-wake zones may have had a small influence on height and biomass of plants, but that there was little difference between No-Motor and No-Wake plots. In addition, the plant parameters were somewhat variable among similar-type plots and were not significantly different in a statistical framework. The fact that no differences were seen at 1.5 m suggests that the effect of the no-wake zone may have been limited in terms of plant growth characteristics.

There were some limitations to comparing plant parameters in the study areas to other areas in the lake. First, the Open plots may not have been true "controls". That is, the Open plots may not have received the same level or intensity of boating as our study plots would have had without the buoys. Second, we do not have a clear understanding of how boating in these Open plots compared to boating inside the study area. Finally, pre-existing differences in the various study plots may have masked differences due to boating. These pre-existing differences may explain the higher diversity in the Open plots. Without baseline plant data, it is difficult to attribute differences seen among plots to one particular factor.

C. Aerial Photography and Digital Image Analysis

Given the limitations of comparing diverse sites with no baseline pre-manipulation data, we decided to use aerial photography to help assess whether the no-wake and no-motor zones effectively reduced boating impacts. The composite photograph from 1995 clearly shows areas completely void of plant growth and other areas streaked by boat scour all around the lake. Scour may be caused by continuous operation of boats in a shallow area which uproots or chops off the vegetation or even by the passage of a single boat which creates a boat track. Scoured areas are lighter color than areas with chara, and milfoil beds are clearly visible as dark circles or bands. In 1997, this scouring is much reduced throughout the lake, especially in the area we designated as no-wake for the study. The large underwater point halfway along the eastern shore had virtually no plants in 1995, yet was covered by plants in 1997 (FIG. 8). This site was a designated no-motor zone in 1997. Similarly, to the north, the shallow area was crisscrossed by boat tracks in

1995. In 1997, the boat tracks were visible only in the no-wake portion of the shoreline and absent in the No-Motor plot (FIG. 9).

We quantified these visual observations using digital image analysis, the results of which are summarized in Table 4. Scoured areas represented a smaller percentage of lakebed coverage in all sites in 1997 than in 1995, but the most pronounced drop was in the southern No-Motor plot and in the No-Wake area adjacent to it. Approximately 50% of the area was scoured in 1995 and covered with chara in 1997, while milfoil stayed roughly the same. The northern No-Motor plot had about 10% less scour in 1997 than in 1995. The other No-Wake plots had only slightly less scour in 1997, as did the Open-2 plot. Open-1 had 12% less scour; however this plot was adjacent to the No-Wake area and may have had less boating activity than in 1995. The No-Wake 3 plot had increased milfoil coverage, while the rest of the plots had negligible changes in milfoil coverage.

Reduced boating activity due to the presence of the buoys along the eastern shoreline appeared to be the main factor contributing to the more extensive plant cover. Boat tracks were also much reduced in the No-Wake area and absent in the No-Motor plots indicating reduced boating in these areas. However, some areas still had boat tracks, resulting in only small differences between the two years. Boat tracks continued to be observed in other parts of the lake, though at reduced levels.

Water levels may have played a role in the reduced boat scour in 1997. While lake stage data are not available, precipitation records for Plymouth, WI, show that precipitation was 11 inches below normal in 1995 and 1994 (State Climatology Office 1998). Complaints by lake residents and boaters in 1995 that water levels were too low prompted the dam operator to raise the dam by 1.5 inches in 1996 (Dave Dins, pers. comm.). In 1997, precipitation was near normal; however, precipitation for June was the highest on record (4.7 inches above normal). This rainfall resulted in lake levels higher than usual for much of the summer (Dick Edwards, pers. comm.).

Thus, reduced water levels in 1995 may have resulted in more contact between boats and the lakebed in shallow areas and contributed to the severe levels of scour seen in 1995. Aerial photos obtained from the Fond du Lac Co. NRCS from the past 10 years show variable levels of scour at the underwater points, although the high altitude of the photographs and varying time of year make direct comparison difficult. Year to year variability in the extent of scour may thus be partially due to water levels. However, the lack of any scour in the No-Motor plots indicates that the buoys were effective as well.

A. 1995

B. 1997

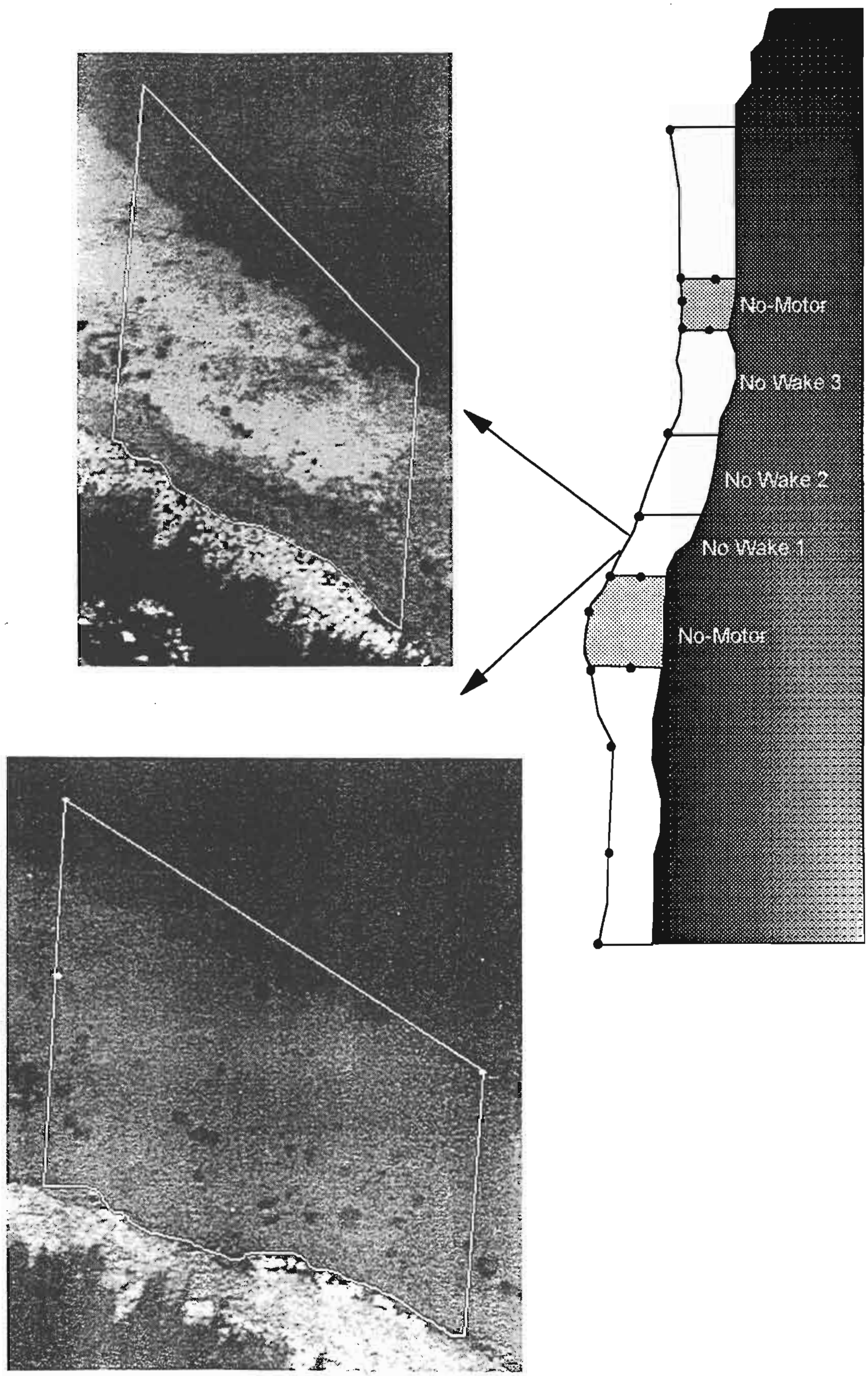
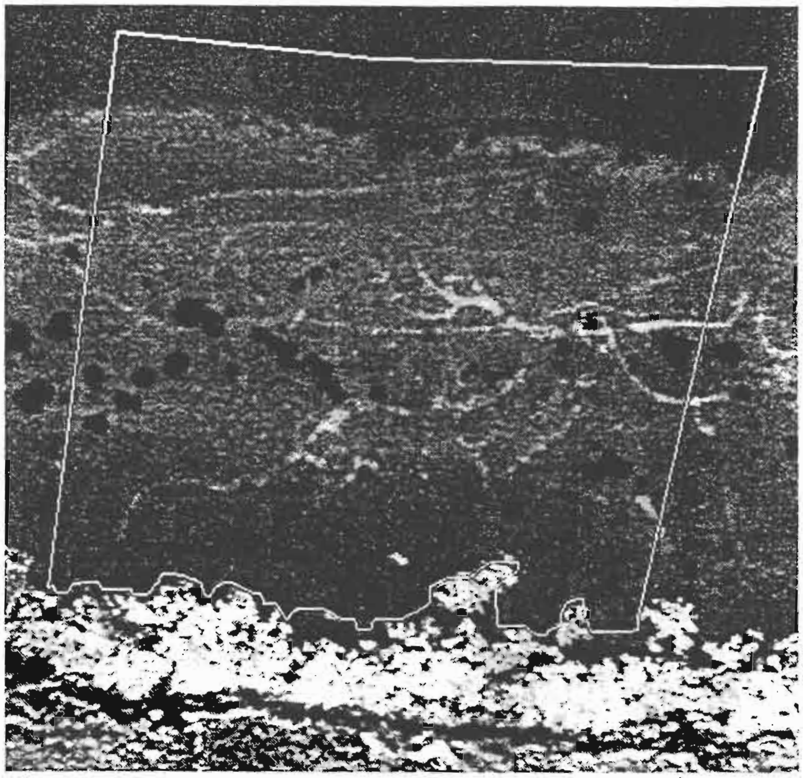
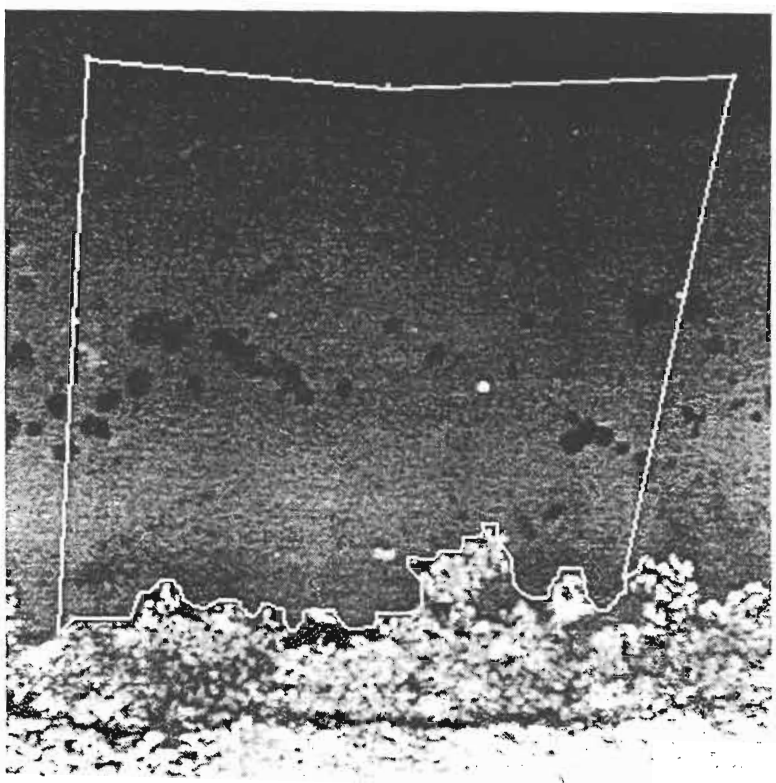


Figure 8. Comparison of No Wake 1 site from 1995 (A) and 1997 (B). Note area of scour in 1995 photo and absence of scour in 1997 photo.

A. 1995



B. 1997



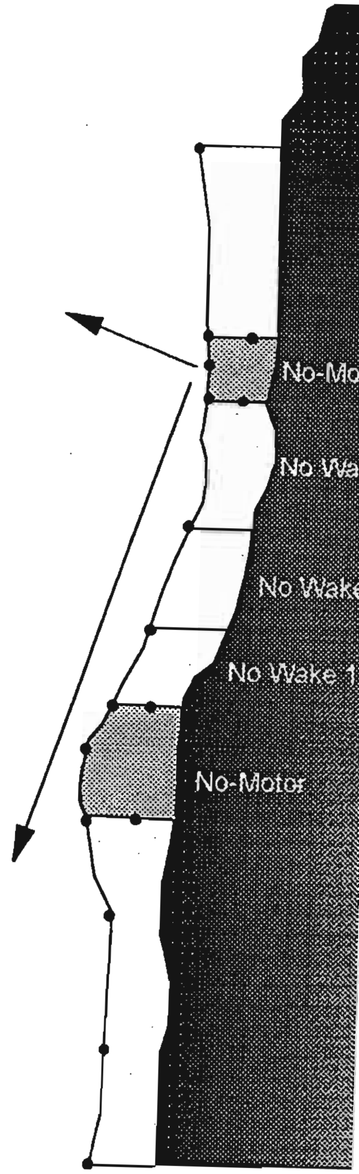


Figure 9. Comparison of No Motor site from 1995 (A) and 1997 (B). Note boa tracks in 1995 photo and absence in 1997 photo.

Table 4. Percentage of littoral area covered by Chara, Milfoil, or Scour as determined by digital image analysis of aerial photographs taken in 1995 and 1997. Sites correspond to areas indicated on Map 3.

	1997			1995		
	Chara	**Milfoil**	**Scour**	**Chara**	**Milfoil**	**Scour**
No-Motor S	75.1	17.2	2.5	25.5	19.0	49.1
No-Motor N	76.7	15.7	0.4	70.1	20.3	10.2
No-Wake 1	77.8	14.4	0.0	34.0	17.4	38.1
No-Wake 2	67.8	23.9	1.3	62.2	26.6	6.9
No-Wake 3	64.0	26.1	4.8	75.9	16.0	7.3
Open 1	64.7	27.2	0.3	58.6	23.7	13.1
Open 2	66.4	16.3	4.1	69.5	13.1	10.8

V. CONCLUSIONS

The no-wake zones appeared to be effective at reducing boat activity along the shallow eastern shoreline. The survey results and anecdotal reports indicated that people generally followed the no-wake and no-motor designations. However, the no-motor zones were somewhat confusing to people and were generally avoided. In addition, some of the Open plots were also avoided because of their proximity to the study area. Thus while boat traffic was limited in our study area, we are uncertain how it compared among the No-Motor, No-Wake, and Open plots.

We had expected plants in the No-Wake and No-Motor plots to be taller, more dense, and more diverse than in the Open plots, and the No-Motor plots to contain the least evidence of disturbance. We did observe slightly taller and more dense plants in some areas of the protected plots; however, we did not detect any differences in the plant community between the No-Motor and the No-Wake plots. More species diversity in the Open plots could be a function of the historically high boating disturbance in these areas; however, other factors related to wave exposure or sediment quality could also play a role. For the most part, the plant growth characteristics were highly variable or similar among the plots.

The reason for the small differences in plant characteristics among our study plots may be that the dominant species was chara, a plant that tends to form a thick low-growing mat. This plant thrived in all parts of the lake, but especially along littoral areas which have been subject to intense boating for many years. Where these plants occurred, they grew dense and relatively uniform in height. Similarly, the other dominant species, native water milfoil, occurred mostly in a narrow band along the outside of the littoral zone and in dense clumps scattered within the littoral zone. The milfoil tended to reach the lake surface in both the open plots and the no-wake area. One year of protection by the no-wake zone did not appear to be adequate to cause this species to expand its areal coverage relative to the chara.

The strongest evidence for the effects of boat activity on aquatic plants comes from the aerial photographs taken in 1995 and 1997. Large areas of the littoral zone which were devoid of plants in 1995 were plant-covered in 1997, largely as a result of the buoys being present. Boat tracks were much less evident in the areas that were marked off as "No-Motor". Boat tracks were observed in other areas of the lake, however, suggesting that the buoys prevented this type of disturbance. The photos from 1995 indicated that scour was much reduced in 1997 in all areas of the lake. The worst scoured area was the large underwater point on the east side of the lake; this area was almost completely covered by plants in 1997. Thus, while plant parameters were not significantly different among the study plots, boat scour appeared to be most reduced in the No-Motor plots, and somewhat reduced in the No-Wake areas compared to other areas of the lake.

We can conclude that the No-Wake areas were effective at reducing scour caused by high-speed boating, but that boat tracks may still occur in No-Wake areas. Water levels appear to play a role in the extent of the disturbance; however, keeping water levels high may cause other problems with the emergent plant community, wetland areas, and boat docks. A combination of no-wake designation in critical plant areas and educational efforts aimed at reducing the use of anchors and deep-propeller motors in these areas would likely be most beneficial to the macrophytes in Long Lake.

VI. ACKNOWLEDGMENTS

Thank you to Dick Edwards and members of the Long Lake Fishing Club for their efforts in designing and placing the buoys on the lake. Thanks also to Dick for his help in getting the survey out and publicizing the study. Thanks are due to Jerry Leiterman and Doug Bilgo and the rest of the DNR staff stationed at the Kettle Moraine State Forest (Northern Unit) Headquarters for help in placing signs and getting information out to the public about the study. Thanks to Greg Quinn, Paul Garrison, Janel Pike, Kim Hartwig, and Pat Gorski for their assistance in the field. This study was funded by a Wisconsin DNR Lake Planning Grant matched by funds from the Long Lake Fishing Club.

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Appendix 1.

Table A. Aquatic macrophyte characteristics for each transect sampled in late August, 1997. See Map 2 for location of transects. Values represent the average of several subsamples for density and height (n = 10-12), and biomass (n = 5-6). Species richness and frequency of occurrence are calculated by transect.

Plot type	Location	Transect	Water Depth (cm)	Species Richness	Stand Density	Canopy Height (cm)	Chara Height (cm)	Milfoil Height (cm)	Chara Freq. Occur. (%)	Milfoil Freq. Occur. (%)	All Plants Ash-Free Biomass (g/m^2)	Chara Ash-Free Biomass (g/m^2)	Milfoil Ash-Free Biomass (g/m^2)
NoMotor	North	1.0 m	90.0	2	3.0	38.0	31.7	95.0	90.0	10.0	264.36	251.13	13.23
		1.5 m	130.0	1	3.0	18.2	18.2	–	100.0	0.0	231.50	231.50	0.00
		2.0 m	198.6	1	2.8	135.5	–	135.5	0.0	100.0	223.13	0.00	223.13
	South	1.0 m	97.1	2	3.0	35.0	28.2	72.5	91.7	16.7	411.70	379.58	32.12
		1.5 m	138.8	4	2.8	17.1	14.6	20.0	100.0	8.3	83.81	83.81	0.00
		2.0 m	196.8	2	3.0	132.7	–	129.1	0.0	100.0	192.63	0.00	192.63
NoWake	North A	1.0 m	87.0	3	3.0	46.0	25.0	85.0	90.0	30.0	212.56	194.49	18.07
		1.5 m	137.5	2	2.9	23.0	11.1	130.0	90.0	10.0	195.96	122.18	73.78
		2.0 m	198.2	2	2.8	138.6	–	138.6	0.0	100.0	159.34	0.00	159.34
	North B	1.0 m	97.3	1	2.5	12.3	12.3	–	100.0	0.0	173.29	173.29	0.00
		1.5 m	148.2	2	3.0	111.4	8.8	133.9	36.4	81.8	249.08	24.90	228.33
		2.0 m	196.8	1	3.0	147.3	–	147.3	0.0	100.0	148.10	0.00	148.10
	South A	1.0 m	92.9	2	3.0	51.7	27.0	88.0	83.3	41.7	367.07	329.32	37.75
		1.5 m	128.8	2	2.8	45.4	15.6	86.0	75.0	41.7	147.50	114.47	33.03
		2.0 m	194.5	2	2.8	153.6	–	150.9	0.0	100.0	414.93	0.00	414.93
	South B	1.0 m	98.6	1	3.0	37.5	37.5	–	100.0	0.0	528.25	528.25	0.00
		1.5 m	150.8	3	2.8	70.4	15.8	123.3	50.0	50.0	245.01	75.25	169.76
		2.0 m	198.2	3	2.8	151.4	–	147.3	0.0	100.0	179.20	0.00	179.20
Open	1	1.0 m	101.4	6	2.7	39.1	24.4	43.0	81.8	45.5	437.98	402.47	24.66
		1.5 m	138.2	3	2.8	21.4	14.5	15.0	100.0	9.1	437.51	437.51	0.00
		2.0 m	197.3	3	2.6	111.4	–	111.4	0.0	100.0	154.85	0.00	154.85
	2	1.0 m	88.3	2	2.7	27.1	20.5	48.3	83.3	25.0	183.28	180.00	4.59
		1.5 m	151.4	2	2.8	25.0	18.2	55.0	100.0	18.2	151.90	151.90	0.00
		2.0 m	200.0	2	3.0	145.8	–	145.8	0.0	100.0	174.21	0.00	161.10
	3	1.0 m	115.8	8	1.9	50.4	–	48.3	0.0	75.0	68.45	0.00	25.44
		1.5 m	148.3	6	2.9	82.5	40.0	120.0	58.3	50.0	325.17	256.09	69.08
		2.0 m	200.0	3	2.3	143.3	30.0	141.7	16.7	100.0	114.83	25.80	89.03

Table B. Aquatic macrophyte characteristics for each transect sampled in mid-June, 1997. See Map 2 for location of transects. Values represent the average of several subsamples for density and height (n = 10-12). Species richness and frequency of occurrence are calculated by transect.

Plot type	Location	Transect	Water Depth (cm)	Species Richness	Stand Density	Canopy Height (cm)	Chara Height (cm)	Milfoil Height (cm)	Chara Freq. Occur. (%)	Milfoil Freq. Occur. (%)	All Plants Ash-Free Biomass (g/m^2)	Chara Ash-Free Biomass (g/m^2)	Milfoil Ash-Free Biomass (g/m^2)
NoMotor	North	1.0 m	108.2	2	3.0	32.3	31.8	30.0	100.0	9.1	--	--	--
		1.5 m	149.5	4	2.9	59.6	16.4	58.7	63.6	100.0	--	--	--
		2.0 m[1]	--	--	--	--	--	--	--	--	--	--	--
	South	1.0 m	102.4	3	3.0	30.0	16.7	29.3	100.0	58.3	--	--	--
		1.5 m	147.9	3	2.7	68.8	10.7	114.0	58.3	41.7	--	--	--
		2.0 m[1]	--	--	--	--	--	--	--	--	--	--	--
NoWake	North A	1.0 m	104.4	2	3.0	35.5	26.8	110.0	100.0	9.1	--	--	--
		1.5 m	149.1	3	3.0	63.6	12.5	92.0	72.7	45.5	--	--	--
		2.0 m[1]	--	--	--	--	--	--	--	--	--	--	--
	North B	1.0 m	110.0	2	3.0	36.4	35.9	35.0	100.0	9.1	--	--	--
		1.5 m	152.7	3	3.0	116.8	20.0	116.8	18.2	100.0	--	--	--
		2.0 m[1]	--	--	--	--	--	--	--	--	--	--	--
	South A	1.0 m	93.4	4	2.8	38.3	18.2	44.0	91.7	41.7	--	--	--
		1.5 m	151.3	4	3.0	126.7	10.0	126.7	16.7	100.0	--	--	--
		2.0 m[1]	--	--	--	--	--	--	--	--	--	--	--
	South B	1.0 m	104.1	2	3.0	25.0	22.5	40.0	100.0	16.7	--	--	--
		1.5 m	138.1	3	2.3	26.3	9.5	57.5	83.3	33.3	--	--	--
		2.0 m[1]	--	--	--	--	--	--	--	--	--	--	--
Protected[1]	North	2.0 m	200.0	1	3.0	100.9	--	100.9	0.0	100.0	--	--	--
	South	2.0 m	200.0	2	3.0	128.7	--	128.7	0.0	100.0	--	--	--
Open	1	1.0 m	105.5	10	2.8	51.4	15.0	45.6	63.6	72.7	--	--	--
		1.5 m	143.9	4	2.6	16.4	11.4	21.7	100.0	27.3	--	--	--
		2.0 m	200.0	2	3.0	123.6	--	123.6	0.0	100.0	--	--	--
	2	1.0 m	98.2	5	2.8	52.3	34.5	43.3	90.9	27.3	--	--	--
		1.5 m	152.5	1	3.0	30.9	30.9	--	55.0	0.0	--	--	--
		2.0 m	200.0	2	3.0	128.6	--	128.6	0.0	100.0	--	--	--

[1] Transects at 2.0 m in the No-Wake and No-Motor plots were combined into two "Protected" transects.

[2] Biomass was not collected in June.

Appendix 2. Questionnaire sent to Long Lake Fishing Club members in September, 1997, as part of a regular newsletter mailing. A total of 67 responses were received.

Long Lake Buoy Project Fishing/Boating Survey

To complete the buoy project, a survey of lake users and how they viewed the project would be very helpful. The final report needs to include response from people who use the lake. Did the buoy placement benefit or hinder their activities in any way? Did those who use the lake see the value in protecting the aquatic plant communities along the east shore?

1. Please indicate whether you use the lake primarily for

	Fishing	Boating	Both
Number	15	12	35
Percent	24%	19%	56%

2. Were your fishing/boating habits altered by the buoys being farther out from shore?

	Not at all	Somewhat	Significantly
Number	38	22	3
Percent	60%	35%	5%

3. Did you enter the marked areas or did you stay on the edge?

	Stayed on edge	Entered No-Wake Area	Entered No-Motor Area
Number	45	18	8
Percent	63%	25%	11%

4. Do you think the fishing/boating public adhered to the buoy restrictions?

	Always	Most of the Time	Ignored Them	Were not aware of them
Number	7	46	4	2
Percent	12%	78%	7%	3%

5. How did the fishing/boating compare with past years?

	Better	About the Same	Worse
Number	16	25	25
Percent	24%	38%	38%

6. Do you think it would help protect the lake's aquatic environment and water clarity to continue the placement of the buoys at the edge of the shelf? This is just your opinion, not a vote!

	Yes	No	Doesn't Matter
Number	52	8	1
Percent	85%	13%	2%

7. Comments on the project, buoy placement, fishing or boating or whatever:

No-wake Sundays. Expand buoy placement.
Good idea!
Increased control of weed growth and floating weeds is needed.
Weed cutting program floating.
I think lake should be checked for pollution.
Too much boat traffic, too many ski jets, need more restrictions!!!!! Comments-The fishing sucks! You can't fish until Wed. until the lake settles down--the boats "fast" and jet skis have wrecked the lake!!!!!!!!!!
Some of buoys on point to far out, restrict boating traffic. Add some buoys on south west side (last point on southwest point)
Great project-continue
Fishing will get better when the weather does.
They should be continued for 3-5 years to test them
We were surprised that aerial photos showed disappearing of weeds. The east side of lake is so thick with weeds, it seems out of control. It is difficult to even use a paddleboat.
Buoy great idea!! But worst panfishing I ever had!! Where are the perch and bluegills??
Too many big boats on lake. Restrict motor size.
1. If the project appears to help, it should be continued. 2. I would like to see restrictions on jet skis and overpowered boats on lake.
One season will not reveal a difference!
It is a good thing. <u>But</u>, boaters are concerned about the bottom line. Will boating be continued if adverse conditions are found? I've heard that question from a few of the players on the lake.
We need to limit weekend boat traffic particularly large boats that don't belong on the lake.
Water clarity is the result of heavy week-end boat traffic. One only needs to look at the difference mid-week.
Its to difficult to turn with a skier because of traffic & less width. <u>Makes lake dangerous</u>.
Needs more enforcement.
Too many weeds all over lake! Bad!
Too many ski-jets.
Too many weeds & algae-appears the lake is dying quickly. We need to control weeds immediately.
Weed control program.
I'm concerned-if this project works-will more areas be restricted?
Caused congestion in lake--too narrow for safe boating.

Please continue--helps keep boats from weeds & disturbing fish.
Good job.
What happened to the perch and crappie.
Many more reg's needed for jet skis--they cause many dangerous times on the lake.
Buoy placement narrowed an already narrow lake making water skiing even more dangerous.
Good job this year.
Where are the fish? Also to many boats on the lake.
Very good.
Needs a little better outside lineup.
Fishing stinks.
Good job.
Waiting for evaluation later this year.
We had a lot of little fish by shore. Buoys helped.
Too many ski-jets.

Please circle your answers. This is an anonymous survey, so please be honest and please return it in a timely fashion. Please return surveys to Long Lake Fishing Club, N4155 Boy Scout, Campbellsport, WI. 53010.

Thank you for your help. If you have any questions, please call Tim Asplund, DNR Research Specialist, at 608-221-6357.

Appendix 3: Sediment Analysis Results

- Statistical analysis showed differences among sites in % moisture and % organic. ANOVA, alpha= 0.05. Further, t-tests determined that significant differences were between Open/No-Wake and Open/No-Motor and not between No-Wake/No-Motor at alpha = 0.05.
- Percent sand, silt, clay did not show any significant differences in ANOVA analysis.

Site	% Moisture	% Organic[1]	% Sand[1]	% Silt[1]	% Clay[1]
No-Motor N	61.4	5.8	49.0	45.3	5.7
No-Motor S	62.2	5.6	54.7	39.0	6.7
No-Wake 1	62.1	6.7	37.7	54.7	8.0
No-Wake 2	66.6	7.6	43.3	49.7	7.3
No-Wake 3	65.0	7.6	41.0	50.0	9.0
No-Wake 4	59.7	5.4	55.0	37.3	8.3
Open 1	71.0	10.4	38.0	49.0	13.0
Open 2	67.5	8.4	42.0	49.0	9.3
Open 3	70.8	10.0	51.3	41.7	7.0

1. Note that % sand, silt, and clay add up to 100%, but that % organic is independent of these parameters. All of these parameters are expressed as a percentage of dry sediment.