Big Lake Protection Grant LPT-67:
Big Lake Macrophyte Management Plan Implementation

Volume 1: Report

Prepared for:
Church Pine, Round, and Big Lake Protection and Rehabilitation District

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Executive Summary

Following a long history of nuisance macrophyte (aquatic plant) growth, macrophyte surveys were completed in Big Lake during 1996. The surveys evaluated plant coverage, density, and species composition during June and August. The results indicate macrophyte density in the lake's littoral region is bothersome throughout the summer period. The dense coverage results from the concurrent growth of a large number of species. The undesirable exotic (non-native) species *Potamogeton crispus* (curlyleaf pondweed) was the dominant species during the June sample period.

A macrophyte management plan was completed in 1997. The goals of the *Big Lake Macrophyte Management Plan* (Barr, 1997) were:

- Reduce plant density throughout the littoral region from the existing high density to a moderate plant density. A moderate density is defined as approximately 111 stems per square meter and corresponds to the optimum plant density for fisheries growth as determined by Crowder and Cooper (1979).
- Reduce the exotic, curlyleaf pondweed to the greatest extent possible from Big Lake, while maintaining a healthy native aquatic plant community.

The **management plan** included five parts:

1. Education of Lake Homeowners
2. Pilot Treatment Program
3. Large-Scale Treatment Program
4. Control Introduction of Exotic Species to the Lake Evaluation Program
5. Evaluation Program

The **pilot treatment program** was conducted from 1998 through 2000. The methodology and results of the pilot treatment program are discussed in this report. The program involved the evaluation of three treatment options:

1. Early-Summer Lime Slurry Treatment
2. Spring Herbicide Treatment
3. Spring Harvesting

Eight 1-acre treatment plots were selected, four on the north half of the lake and four on the south half of the lake. The north and south groups of plots were comprised of replicate control plots and replicate treatment plots representing the above three treatments. Treatments of the north and south groups of treated plots occurred during 1998 and 1999. The eight plots were sampled during 1998 through 2000 to evaluate treatment effects.

Results of the pilot treatment program (See Table EX-1) confirmed Big Lake needed a reduction in stem density to achieve the lake's goal of a moderate stem density. A moderate stem density is defined as 111 stems per square meter (Crowder and Cooper, 1979). Pre-treatment stem densities ranged from 184 to 621 stems per square meter.

Although treatment of experimental plots resulted in significant decreases in stem density, none of the treatments achieved the goal of 111 stems per square meter. Densities following treatment, during late-June 1998 through August 2000 ranged from 126 to 473 stems per square meter. Hence, it is unknown whether goal achievement with treatment is or is not feasible. Treatment, however, is expected to reduce stem densities from present levels to a density that is nearer the desired moderate level.

Results of the pilot program indicate *Potamogeton crispus* (curlyleaf pondweed) was rarely dominant and rarely occurred in problematic growths within the eight treatment plots. Prior to treatment in May through early-June of 1998, curlyleaf pondweed comprised 0-3 percent of the plant mass (i.e., dry weight) in treatment plots. During 1998 through 2000, curlyleaf pondweed rarely exceeded 5 percent of the plant mass in treatment plots. Curlyleaf pondweed was the dominant species in two plots during June of 2000, but was not dominant in other plots or at other times. The pilot program results differed from expectations based upon 1996 survey results. Survey results in 1996 indicated curlyleaf pondweed was present at 77 percent of sample points and was the most frequently occurring species in the lake. The 1996 survey results indicated curlyleaf pondweed was problematic and that its management would be beneficial to the lake. However, pilot program results indicate the lake's problematic high stem density is generally caused by other species. Therefore, a management program to reduce stem density, regardless of species, is needed to achieve the lake's goal of achieving a moderate stem density.

Treatment effects during the 1998 through 2000 period varied from year to year. In the first year of treatment, it appears that all three treatments were effective and that harvesting was the most effective treatment. During the second year of treatment, harvesting did not appear to be an effective treatment. During the third year of the study, 2000, residual effects were not noted for harvesting. The data indicate lime slurry and herbicide were more effective treatments than harvesting.

Table EX-1Summary of Pilot Program Results

Sample Date	Significant Differences (p-values 0-0.20)					
	Stem Density			Dry Weight		
	Treatment	Location	Individual Plots	Treatment	Location	Individual Plots
May 4-6, 1998	Harvesting & Herbicide > Control	South > North	3 > 2,4,6,7,8 4,8 >6,7	None	None	None
June 8-9, 1998	Lime Slurry > Control	None	1 > 2,5,6	None	None	2,5 <1,6
June 24-26, 1998	None	None	None	None	None	None
July 29-30, 1998	Lime Slurry > Control	South > North	1 > 2,5,6	Lime Slurry < Control	South < North	None
Aug 17-20, 1998	Harvesting < Herbicide & Control; Lime Slurry & Herbicide > Control	None	7 < All; 8 > all	Control > All	None	ANOVA:7 <1 < 3 < 4 < 2 < 8 < 5 < 6; Kruskal-Wallis: 4 < 1 < 3 < 6 < 2 < 7 < 8 < 5
1998 Growing Season	All three effective; Harvesting Most Effective Herbicide Least Effective	None	Most Effective in 1 & 3; More effective in 1,3,4, & 5 than others; Increasing in 6 and 8; Least effective in 8	All 3 Effective; Harvesting & Lime Slurry More Effective than Herbicide: Only Lime Slurry Significant Difference.	South < North	1 < All
June 22-25, 1999	None	South> North	4 <All	None	South < North	4 < All 8 > All
July 27-29, 1999	Lime Slurry < Control	South < North	1<All	Lime Slurry < Control	None	None
Aug. 24-27, 1999	Herbicide<All; Harvesting>All; Control>Herbicide & Lime Slurry	None	None	None	None	4 < All; 8 > All

Table EX-1Summary of Pilot Program Results Continued)

Sample Date	Significant Differences (p-values 0-0.20)					
	Stem Density			Dry Weight		
	Treatment	Location	Individual Plots	Treatment	Location	Individual Plots
1999 Growing Season Means	Herbicide & Lime Slurry Effective; Herbicide More Effective than Lime Slurry; Harvesting Not Effective	None	Decreasing Stem Density in Plots 4,5,&8; 1< 2,3,5,6,&7; Increasing Stem Density in 3 & 7.	None	North < South	Comparison of 2,3,4,6,7, & 8:4 lowest and 8 highest; Comparison of 1,2,5,&6: 1 lowest; 5 second lowest in July & highest in August
June 20-22, 2000	Harvesting > Herbicide & Control	North > South	3,7 > 2,4,6,8; 7 > All	Herbicide most effective; harvesting > control	None	4 < 7; 2 < 7; 3 < 7
July 24-25, 2000	None	North < South	5 < 1,2,6	None	None	None
Aug. 28-30, 2000	Harvesting > All; Herbicide < All	None	4,5,6,8 < All; 3 > All	South lime slurry reduced mass; north lime slurry higher mass than control or south line slurry.	North-South + treatment indicate low mass at south and high mass at north & significant difference.	Plot 1 < 2,5,6 Plot 5 > 1,2,6
2000 Growing Season	No residual effects for harvesting; Herbicide and Lime Slurry noted residual effects.	None	7 > All; 5 < All	Inconsistent results so no evidence of treatments	Residual effect in north herbicide plot and south lime slurry plot; Higher plant mass in south herbicide plot and north line slurry plot:	Plot 1 < 2, 5, 6; Plot 4 < 2,3,6,7,8

Lime slurry and herbicide treatments were effective during the 3-year study. Lime slurry appeared to be more effective than herbicide during 1998. Herbicide appeared to be more effective than lime slurry during 1999. Residual effects from both treatments were evident in 2000. Stem density and dry weight data were in agreement that both treatments were effective.

Analyses of species indicated lime slurry was a more effective management tool for concurrently reducing stem density and minimizing curlyleaf pondweed growth in Big Lake. During 2000, curlyleaf pondweed was dominant in the two herbicide treatment plots. It appears that curlyleaf pondweed dominance in herbicide plots was facilitated by previous years' plant removal. The data indicate that herbicide treatment prevented curlyleaf pondweed from becoming dominant during treatment years. However, treatment may have created uncolonized areas and, thus, provided an opportunity for curlyleaf pondweed colonization of plots during a year in which treatment did not occur. Curlyleaf pondweed did not become dominant in lime slurry plots during treatment years or in 2000, a year in which no treatment occurred. Because curlyleaf pondweed was never dominant in lime slurry plots, lime slurry appears to be more effective in minimizing curlyleaf pondweed growth while reducing overall stem density.

Dominant species in lime slurry plots indicate the treatment encouraged the growth of species considered valuable habitat for the lake's fisheries. Dominant species based on stem density generally differed from dominant species based on dry weights. The most frequently occurring dominant species in the lime slurry plots were:

- **Plot 1 (south lime slurry)**—*Valisneria americana* (stem density) and *Potamogeton amplifolius* (dry weight)
- **Plot 5 (north lime slurry)**—*Elodea canadensis* and *Valisneria americana* (stem density) and *Ceratophyllum demersum* (dry weight)

Changes in dominant species occurred in the study plots, including lime slurry plots, throughout the monitoring period. Other dominant species in the lime slurry plots following treatment include: *Potamogeton richardsonii, Potamogeton pectinatus, Zosterella dubia, Potamogeton zosteriformis, Lemna minor,* and *Myriophyllum exalbescens.*

Lime slurry treatment results were somewhat inconsistent. Plot 1 generally noted lower stem densities and dry weights than Plot 5. The non-uniform effects are believed due to increased water movement in Plot 5. Sampling staff observed large numbers of springs within Plot 5. Staff applying the lime slurry to the plot noted that water movement caused some lime slurry to flow from the plot prior to settling to the lake's bottom. Riparian residents observed that while both plots received the same dose of lime slurry, the north plot appeared to have a lighter dose, presumably because some of the lime slurry drifted out of the plot.

An evaluation of lime slurry pros and cons indicates the treatment appears effective, but its experimental status should also be considered. Lime slurry treatment is a little-used experimental treatment and, consequently, less is known about its effects. It is expected to treat the cause of the lake's excess stem density problems by binding phosphorus in the sediments and interstitial porewaters. Hence, the treatment is expected to limit the number of stems that can grow per square meter of lake sediment. The treatment is not expected to be species-selective and is, therefore, expected to impartially impact all species.

Lime slurry, as a management technique for aquatic plants, was developed by the University of Alberta in conjunction with Engineering Services, Alberta Agriculture. Treatment of farm dugouts appeared to effectively control plant growth for a minimum of 2 years. Results of mesocosm experiments indicated lime slurry treatment (i.e., dose of 400 mg/L $Ca(OH)_2$) caused a reduction in porewater soluble reactive phosphorus concentrations. Samples were collected 1 month and 1 year after treatment. Experiment results indicated application of lime to immature plants caused a 30 to 46 percent decrease in biomass of *Myriophyllum exalbescens* and *Potamogeton pectinatus* (i.e., dose of 200 mg/L $Ca(OH)_2$). Immature *Potamogeton richardsonii* and *Lemna trisulcus* were little affected by the treatment. Experiment results indicated application of lime to mature plants (i.e., plants that have reached the water surface) affected all plants and caused a 64 to 100 percent decrease in biomass as compared with untreated controls (i.e., dose of 200 mg/L $Ca(OH)_2$). The experiment results indicate lime inhibits aquatic plant growth in the short term as a result of changes in open-water pH and carbon availability and, in the long-term, by decreasing phosphorus availability in the sediments. Calcium added by lime treatment binds phosphorus in the sediments, thereby rendering it unavailable for plant growth (Prepas et.al. 1992).

Recommendations

Large-scale treatment of Big Lake with lime slurry is recommended to reduce stem density to the moderate level (i.e., 111 stems per square meter) or to a level as close as possible to the moderate level. Treatment of a navigation channel approximately 80 feet wide, extending from the dock ends outward to the open water areas, during mid-June of 2 consecutive years is recommended for most of the lake's littoral area. A 20-foot wide navigation channel is recommended through two areas designated by the WDNR as aquatic plant management sensitive areas. A treatment area of approximately 21 acres is expected. A calcium hydroxide dose rate of 300 mg/m^2 lake surface area is recommended. Treatment cost is expected to range from $16,000 to $28,000 per year, depending upon the contractor selected for the treatment.

As discussed in the preceding paragraph, some areas within Big Lake were designated by the Wisconsin Department of Natural Resources as aquatic plant management sensitive areas. The lake contains four sensitive areas, two within the recommended treatment area and two that are not included in the recommended treatment area. Aquatic vegetation in these areas provide valuable spawning, feeding, and nursery areas for fish populations. Although lime slurry is not expected to harm the vegetation in these areas, a conservative approach is recommended to insure protection of these areas. It should be noted that one of the aquatic plant management sensitive areas was Plot 5 in the pilot program and was treated with lime slurry during 1998 and 1999. As discussed previously, the data indicate no adverse changes following lime slurry treatment. However, it is recommended that only 20-foot wide channels be harvested until an evaluation of the large-scale treatment program is completed. An evaluation of the treatment program will provide information regarding the impact of a large-scale treatment program on sensitive areas (e.g., Plot 5). The feasibility of treating 80-foot wide navigation channels through the aquatic plant management sensitive areas should then be determined. If a study of the large-scale treatment program indicates additional treatment within the sensitive areas would not be detrimental, then treatment of an 80-foot wide navigation channel through the sensitive areas is recommended. Treatment dose (300 mg/m^2), frequency (2 consecutive years), and application time (mid-June) should be the same as the large-scale treatment program, unless study results indicate a need for modification of one or more parameters.

Treatment of four selected areas within Church Pine and Round Lake is recommended as a part of the large-scale treatment program. The areas recommended for treatment are 3 navigation channels and a small bay currently harvested annually per recommendations in the lakes' macrophyte management plan. The navigation channels and bay provide lake access to lake-users living adjacent to very dense plant growths. Because the Big Lake pilot program determined that lime slurry is a more effective management technique than harvesting, treatment of Round and Church Pine lakes with lime slurry is recommended. Lime slurry treatment of the navigation channels and bay is expected to effectively reduce stem density, thus enabling navigation of these areas. Lime slurry treatment of a small bay and one 80-foot wide navigation channel is recommended. A 20-foot wide navigation channel is recommended for two areas designated by the WDNR as aquatic plant management sensitive areas. As discussed in the preceding paragraph, a conservative treatment approach of sensitive areas is recommended until results of a study of the large-scale treatment program are available. If study results of the large-scale treatment program indicate additional treatment within the sensitive areas would not be detrimental, then treatment of an 80-foot wide navigation channel through the sensitive areas is recommended. Treatment dose (300 mg/m^2), frequency (2 consecutive years), and application time (mid-June) should be the same as the large-scale treatment program, unless study results indicate a need for modification of one or more parameters. Treatment of navigation channels within Church Pine and Round Lake is expected to cost approximately $1,600 to $3,200 per year depending upon the contractor selected for the treatment.

Evaluation Program

An evaluation program is recommended to determine impacts of the large-scale treatment program on Big Lake, Church Pine Lake, and Round Lake. A sample plot should be selected within each of the two treatment areas of Church Pine Lake and within each of the two treatment areas of Round Lake. Sampling in Church Pine and Round Lake plots should occur at the same times as Big Lake sampling and the same methodology should be followed. The Big Lake evaluation program should duplicate the pre-treatment and 2000 sample programs. Sampling in Big, Church Pine and Round lakes should occur during May and early-June, prior to the mid-June lime slurry treatment. The lakes will receive a mid-June lime slurry treatment for two consecutive years. A post-treatment sampling program, like the 2000 sample program, will occur in the third year.

Sampling in Big Lake should occur at the eight experimental plots used in the pilot program. Sample dates should be as close as possible to the pre-treatment and year 2000 sample dates. Sampling in Church Pine and Round Lake should occur at four 1-acre plots (i.e., two in Church Pine Lake and two in Round Lake, located within the lakes' treatment areas). Sample collection, sample analysis, and data analysis methodology should be as described in the methods section of this report. Big Lake data collected from the large-scale treatment program should be compared with pre-treatment data and data collected during 2000 to determine changes resulting from large-scale lime slurry treatment of the lake. Pre-treatment and post-treatment data collected from Church Pine and Round lakes should be compared to determine the effectiveness of lime slurry treatment of the lakes.

Funding Sources

Lime slurry treatment is an experimental management method that has likely not been used in Wisconsin prior to the Big Lake pilot program. Hence, a large-scale treatment has likely not yet occurred in Wisconsin. Because the management technique appears to concurrently accomplish the goals of enhanced recreational use and improved fisheries habitat, it is considered a promising and desirable management technique. Hence, it is recommended that WDNR Lake Protection funding be obtained to fund the lime slurry treatment and the evaluation program to determine treatment effects on Big, Church Pine, and Round Lakes. The project will provide the WDNR with a unique opportunity to evaluate a promising new macrophyte management tool. The Lake Protection grant program provides the opportunity to obtain up to $200,000 of grant funding. The Church Pine, Round, and Big Lake Protection and Rehabilitation District would be required to pay 25 percent of the project cost. The local share of payment can be in the form of cash or volunteer labor, valued at $5 per hour. Lake Protection grant applications must be submitted by May 1 of each year. Grant awards generally occur around October 1 of each year.

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Big Lake Macrophyte Management Plan Implementation

Volume 1: Report

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1.0 Introduction

Big Lake is located in the Church Pine, Round, and Big Lakes chain in Polk County, Wisconsin. The chain is valued by riparian owners, area residents, Polk County, and the WDNR for its fisheries and for recreational use (see Figure 1). However, all three lakes have experienced problems with aquatic plant beds and Big Lake has experienced problems with algal blooms for more than 30 years. Concern for the lakes resulted in the formation of a lake association during the 1960s, and the Church Pine, Round, and Big Lake Protection and Rehabilitation District in the 1970s.

The District, with assistance from a consultant, completed a lake and watershed analysis of the chain during 1987. The study concluded that all three lakes exhibited aquatic plant growth throughout their littoral areas. Species identified in the lakes included *Potamogeton crispus*, a nuisance exotic species. The study further concluded that Church Pine and Round Lakes exhibited good water quality, while Big Lake exhibited irritating summer algal blooms. Excessive phosphorus loading from North Creek, a tributary to Big Lake, was considered the primary cause of Big Lake's summer algal blooms (Lim Tech Consultants 1987).

From 1986 through the present, volunteers have collected water transparency data through the WDNR "Self-Help" program. The data corroborate the 1987 study results. Each year, Big Lake has noted declining water transparency throughout the summer months because of algal blooms. Church Pine Lake exhibited good water transparency throughout the period of record, while Round Lake exhibited a water transparency midway between that of Church Pine and Big Lakes.

During 1995, representatives from the Church Pine, Round, and Big Lake Protection and Rehabilitation District approached the WDNR to discuss management of the lakes' problematic macrophyte (aquatic plant) growth. The WDNR recommended that the District complete macrophyte surveys and a macrophyte management plan for the three lakes. Consequently, macrophyte surveys of Big Lake were completed in 1996 and a macrophyte management plan completed in 1997. Macrophyte surveys of Church Pine and Round lakes were completed in 1997 and a macrophyte management plan completed in 1998 (*Church Pine and Round Macrophyte Surveys and Management Plan*, Barr, 1998).

Church Pine and Round lakes noted healthy aquatic plant communities. A few areas, however, required management to provide navigation channels for area residents. Hence, the macrophyte management plan for Church Pine and Round lakes included a harvesting plan to provide navigation channels through areas of dense growth.

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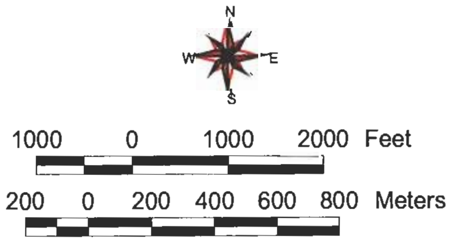


Figure 1

SITE MAP
Big Lake

Big Lake noted extensive areas of dense aquatic plant growth. Hence, extensive management is needed to support the lake's beneficial uses. The lake's management plan included a recommendation to complete a pilot treatment program in advance of a large-scale treatment program. The intent of the pilot treatment program was to determine which of three treatment approaches would be most effective in accomplishing the lake's management goals. A pilot treatment program was completed during 1998 through 2000. The methodology and the results of the pilot treatment program are discussed in this report.

This report discusses:

- Project Goals
- Pilot Treatment Program Methods
- Results and Discussion
- Recommendations

2.0 Project Goals

The primary goal of the pilot treatment program was to determine the most effective treatment method to reduce plant density within Big Lake to a moderate level. A moderate plant density is defined as approximately 111 stems per square meter and corresponds to the optimum plant density for fisheries growth as determined by Crowder and Cooper (1979).

A secondary goal was to determine the most effective treatment method to reduce curlyleaf pondweed to the greatest extent possible, while maintaining a healthy native aquatic plant community. Curlyleaf pondweed is an undesirable exotic (non-native) species noted in 77 percent of Big Lake sample locations during the 1996 survey.

3.0 Pilot Treatment Program Methods

The pilot treatment program included:

1. Early-Summer Lime Slurry Treatment
2. Spring Herbicide Treatment
3. Spring Harvesting

Following is a detailed description of the pilot program.

3.1 Lime Slurry Treatment

During 1998 through 2000 a pilot program was completed to investigate the feasibility of reducing aquatic plant density in Big Lake via a mid-June application of lime slurry. Two test plots and two control plots, approximately one acre in size, were selected (See Figure 2). One test plot and one control plot were located in the north half of the lake. The second test plot and control plot were located in the southern half of the lake. Application of the lime slurry occurred during June 19, 1998 and June 18, 1999. Calcium hydroxide was applied as a slurry. A 17-foot boat with deep application booms was used for the subsurface application. A dose of 150 grams/square meter was applied to each test plot during June of 1998. During June of 1999, the dose was doubled. Lime slurry treatment did not require a permit. A study was completed to determine the effectiveness of the pilot treatment program (i.e., described in 3.5 of this report under Evaluation Program).

3.2 Spring Herbicide Treatment

During 1998 through 2000 a pilot program was completed to investigate the feasibility of reducing aquatic plant density in Big Lake via a spring application of the herbicide Reward (diquat). Reward is a contact herbicide that effectively treats *Potamogeton crispus* (curlyleaf pondweed), *Potamogeton pectinatus* (sago pondweed), *Ceratophyllum demersum* (coontail), and *Myriophyllum sibiricum* (formerly *exalbescens,* northern milfoil). Hence, four of the five most frequently sited species in the 1996 Big Lake macrophyte survey are effectively treated by Reward. Two test plots, approximately 1 acre in size, were selected for the pilot program (See Figure 2). The control plots described in the lime slurry discussion were also used as controls for the herbicide study. One test plot and one control plot were located in the north half of the lake. The second test plot and control plot were located in the southern half of the lake. Herbicide permits were obtained from WDNR prior to treatment during 1998 and 1999 (Permit #12). Application of the herbicide occurred during May 11, 1998 and May 24 (Plot 4) and May 29 (Plot 8), 1999. A 17-foot boat with deep application booms

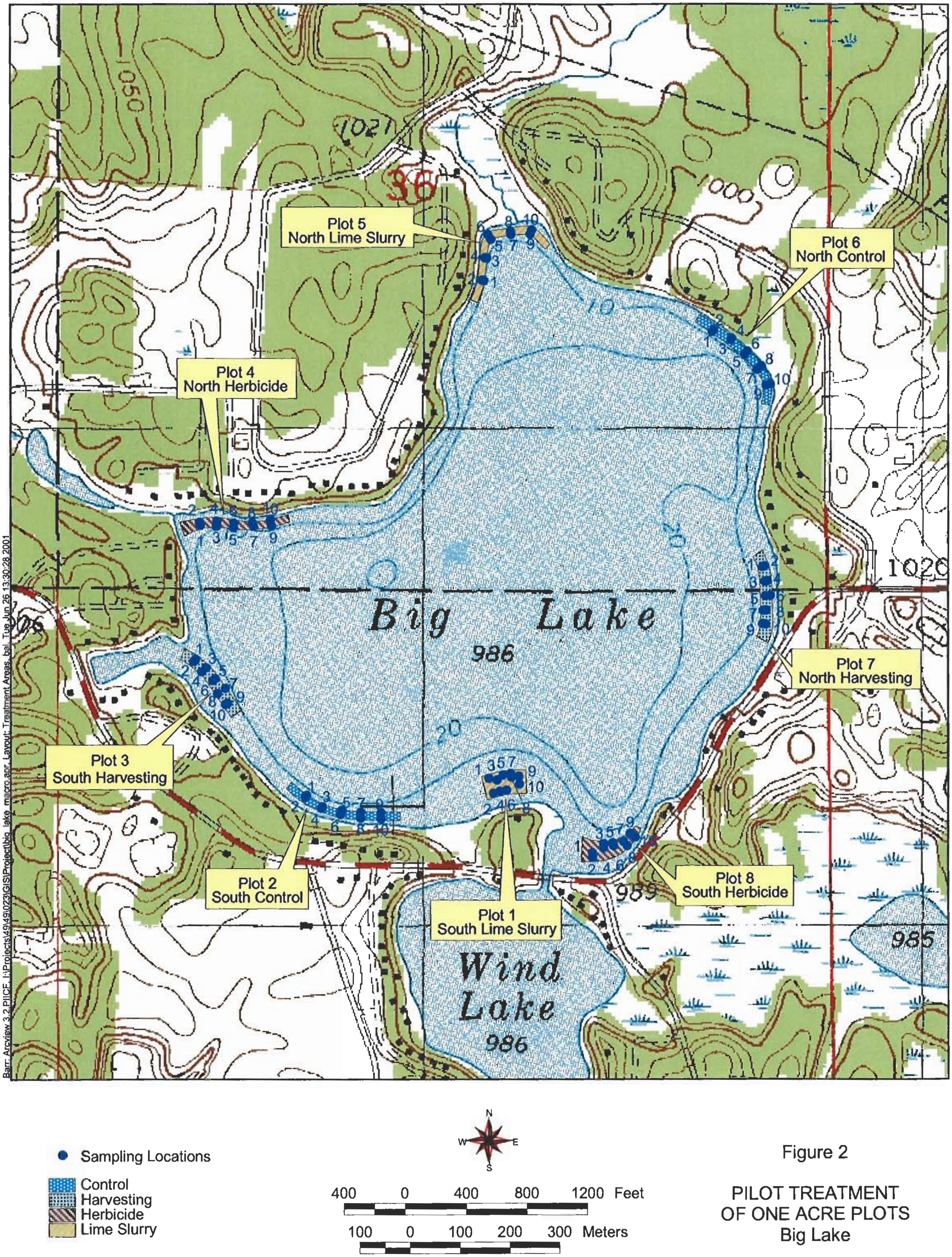


Figure 2

PILOT TREATMENT
OF ONE ACRE PLOTS
Big Lake

was used for the subsurface application. The herbicide Reward was applied at a rate of 2 gallons per acre. A study was completed to determine the effectiveness of the pilot treatment program (i.e., described in 3.5 of this report under Evaluation Program).

3.3 Spring Harvesting

During 1998 through 2000 a pilot program was completed to investigate the feasibility of reducing aquatic plant density in Big Lake via spring harvesting. Two test plots, approximately 1-acre in size, were selected (See Figure 2). The control plots described in the lime slurry and herbicide discussions were also used as controls for the harvesting study. One test plot and one control plot were located in the north half of the lake. The second test plot and control plot were located in the southern half of the lake. Harvesting occurred during May 12, 1998 and May 24 and June 5, 1999. Harvesting consisted of cutting and removing plants from within each treatment plot. Treatment plots were harvested twice in 1999 because windy conditions resulted in missed areas during the first harvesting attempt. A study was completed to determine the effectiveness of the pilot treatment program (i.e., described in 3.5 of this report under Evaluation Program).

3.4 Plot and Station Selection

Big Lake was divided into a northern and southern half and replicate test plots were selected within each half. Hence, replicate harvesting, control, lime slurry, and herbicide plots were located on opposite sides of the lake. Within each plot, 10 sample stations were selected using a stratified random approach. Using Arcview GIS, the plots were divided into a grid pattern. Using a random number table, two points were selected in each of the 5 rows of the grid. The 10 selected points within each plot became the 10 sample stations. A map showing the selected sample stations within each plot was then prepared using Arcview GIS (See Figure 2). Using Arcview GIS, latitude and longitude measurements for each sample location were estimated. Staff used the estimated latitude and longitude measurements, the map, and a Global Positioning System (GPS) to select the plot boundaries and station locations in the field. A marker buoy attached to an anchor was placed at the four corners of each plot and at each station location. Prior to installation, Big Lake volunteers labeled each marker buoy with the following information: project name, plot number, sample station number or plot information, and a Do Not Disturb—Experiment in Progress notice. Prior to installation of the marker buoys, a formal request was made to the area warden and the WDNR Law Enforcement Safety Specialist for permission to install the marker buoys. At the request of the WDNR, the Church Pine, Round, and Big Lake Protection and Rehabilitation District requested that the township pass an ordinance to provide statutory authority for the use of marker buoys during the pilot project. As requested, the ordinance was passed.

3.5 Evaluation Program

An evaluation program was completed to determine the effectiveness of the pilot treatment program in accomplishing the lake's goals. A description of the program follows.

Each sample location was sampled:

- **Before treatment during 1998**: (i.e., May 4-6 for control, herbicide, and harvesting plots; June 8-9 for control and lime slurry plots)
- **After treatment during 1998:** (i.e., June 24-26 for control, herbicide, and harvesting plots; July 29-30 for control and lime slurry plots; and August 17-20 for all plots)
- **After treatment during 1999:** (i.e., June 22-25 for control, herbicide, and harvesting plots; July 27-29 for control and lime slurry plots; and August 24-27 for all plots)
- **During 2000:** (June 20-22 for control, herbicide, and harvesting plots; July 24-25 for control and lime slurry plots; and August 28-30 for all plots).

Sample collection involved the collection of all stem/shoot material found within a 0.1 square meter quadrat at each sample location by a scuba diver. All stem/shoot material within the sampler were placed in a bag and labeled as to plot, sample location, and sample date. Samples from each station were sorted by volunteers. Plant material was separated by species. The number of stems of each species was counted and recorded. Plants of each species were placed in a labeled ziplock bag (labeled as to plot, sample location, species, and sample date). Samples and the data sheet with stem counts were then sent to Barr Engineering Co. for confirmation of species identification. Sorted plant material from each sample location was placed in paper bags (i.e., each species in a separate paper bag). Each bag was labeled as to treatment plot, sample location, species, and collection date. Samples were analyzed by the University of Minnesota Limnological Research Center Core Laboratory. Samples were oven dried at 105°C (degrees Celsius) for approximately 24 hours. The weight (i.e., biovolume) of each sample was recorded. Approximately 10 percent of the samples were returned to the oven and dried for an additional 24 hours and reweighed. The two weights were compared to insure that a constant weight had been obtained.

During the August sample event during 1998, 1999, and 2000, samples were collected to evaluate curlyleaf pondweed turion densities at each sample location. A turion is the reproductive structure of curlyleaf pondweed. An Eckman dredge was used to collect sediment samples at each sample location. Once collected, each sediment sample was washed through a ¼-inch mesh sieve to remove the turions. The number of turions were then counted and recorded. Turion density was determined by converting the numbers to an areal density (# per square meter) based on the area sampled by the dredge (150 mm by 150 mm).

3.6 Data Analyses

An analysis of unmodified data indicated the data were not normally distributed. Hence, several data transformations were evaluated to determine the most appropriate transformation to achieve normal distribution. Data transformations included Log 10, Ln, square root, third root, and fourth root. Square root transformation achieved normal distribution and was used for subsequent analyses of transformed data.

Three types of data analyses were completed:

1. Analyses of stem count data
2. Analyses of dry weight data
3. Analyses of species using stem count and dry weight data

3.6.1 Analyses of Stem Count Data

Stem count data were analyzed to determine the impact of the three treatments on stem density. Analysis of Variance (ANOVA) of stem count data were completed for each sample date. Untransformed data and square root transformed data were analyzed separately. Non-parametric analyses of data were completed using Kruskall-Wallis. The dependent variable for each analysis was stem count. Independent variables included plots (1 through 8), location (north or south), and treatment (control, herbicide, harvesting, and lime slurry). The program, Systat 9, an SPSS program, was used for all analyses.

Stem count data from all dates were concurrently analyzed to determine whether changes in stem counts between sample dates were significant. The dependent variable for each analysis was stem count and the independent variable for each analysis was sample date. Each treatment type was analyzed separately. Analyses included ANOVA of untransformed data, ANOVA of square root transformed data, and Kruskal-Wallis non-parametric tests.

3.6.2 Analyses of Dry Weight Data

Dry weight data were analyzed to determine the impact of the three treatments on total plant mass. Analysis of Variance (ANOVA) of dry weight data were completed for each sample date. Untransformed data and square root transformed data were analyzed separately. A paired (i.e. repeated) ANOVA was completed to evaluate the changes in dry weight between sample dates. Square root transformed data were used for this evaluation. Non-parametric analyses of data were completed using Kruskall-Wallis when n >2 and Mann-Whitney when n=2. The dependent variable for each analysis was dry weight. Independent variables included plots (1 through 8), location (north or south), and treatment (control, herbicide, harvesting, and lime slurry). A variance test, the F-test, was completed to determine whether within plot variance differed significantly between plots. The F-test was performed on square root transformed dry weight data from each sample date. The F-test compares the variances of data sets to yield the F-statistic, a measure of the significance of the differences between the samples. All analyses were completed using Statview, a SAS program.

3.6.3 Analyses of Species Data

Species data were analyzed to determine the impact of the three treatments on individual species. Analysis of Variance (ANOVA) of species data were completed for each sample date. Untransformed data and square root transformed data were analyzed separately. Dependent variables were stem count and dry weight. Independent variables were species and plots (1 through 8). The program, Systat 9, an SPSS program, was used for all analyses.

4.0 Results and Discussion

Plant data collected during 1998 through 2000 are summarized in tabular and graphic format in Appendices A through C. Results of the statistical analyses of the plant data are found in Appendices D through F. A summary of the turion data is found in Appendix G. A sensitive areas report completed by the WDNR is found in Appendix H. A discussion of results includes:

- Results of Stem Count Analyses
- Results of Dry Weight Analyses
- Results of Species Analyses
- Pilot Program Results

4.1 Results of Stem Count Analyses

Analysis of stem counts completed during 1998 through 2000 indicate all sample stations noted dense plant growth (i.e., greater than 111 stems/m^2). Stem densities ranged from 126 to 621 stems/m^2 during the sample period (See Figures 3 and 4). Pre-treatment densities ranged from 184 to 621 stems/ m^2. Densities in treated plots ranged from 216 to 434 stems/ m^2 during 1998 and 138 to 396 stems/ m^2 during 1999. Control plots noted densities ranged from 126 to 463 stems/ m^2 during 1998 through 1999. Densities in the eight plots ranged from 188 to 473 stems/ m^2 during 2000 . The data indicate treatments did not reduce plant densities to the desired moderate level defined as approximately 111 stems/ m^2.

The results stems analyses are presented in Appendix D.

4.1.1 1998 Pre-treatment Data Analyses

4.1.1.1 May 4-6

Analyses of pre-treatment data indicate significant differences in stem density occurred during early-May. Differences between plots, between north and south groups of plots and between treatment and control plots were significant. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non parametric analyses are in agreement that:

- The density at Plot 3 (south harvesting) was greater than all other plots;

- The densities at Plot 4 (north herbicide) and Plot 8 (south herbicide) were greater than the densities at Plot 6 (north control plot) and Plot 7 (north harvesting plot).

The three analyses were in agreement that these differences were significant at the 95 percent confidence level.

The three analyses were also in agreement that the stem densities in the south group of plots were greater than the stem densities in the north group of plots. ANOVA of square root transformed data indicated the stem density differences were significant at the 95 percent confidence level. ANOVA of untransformed data and Kruskal-Wallis analyses were in agreement that the differences were significant at the 90 percent confidence level.

The three analyses were in agreement that stem densities in harvesting and herbicide plots were greater than stem densities in the control plots. However, this difference was not significant at the 90 percent or 95 percent confidence level. ANOVA of untransformed data indicates the difference was significant at the 80 percent confidence level. ANOVA of square root transformed data and Kruskal-Wallis non-parametric analyses indicate the difference was not significant at the 80 percent confidence level (p-values of 0.218 and 0.426, respectively).

1998-2001 Big Lake Pilot Project
Stem Densities

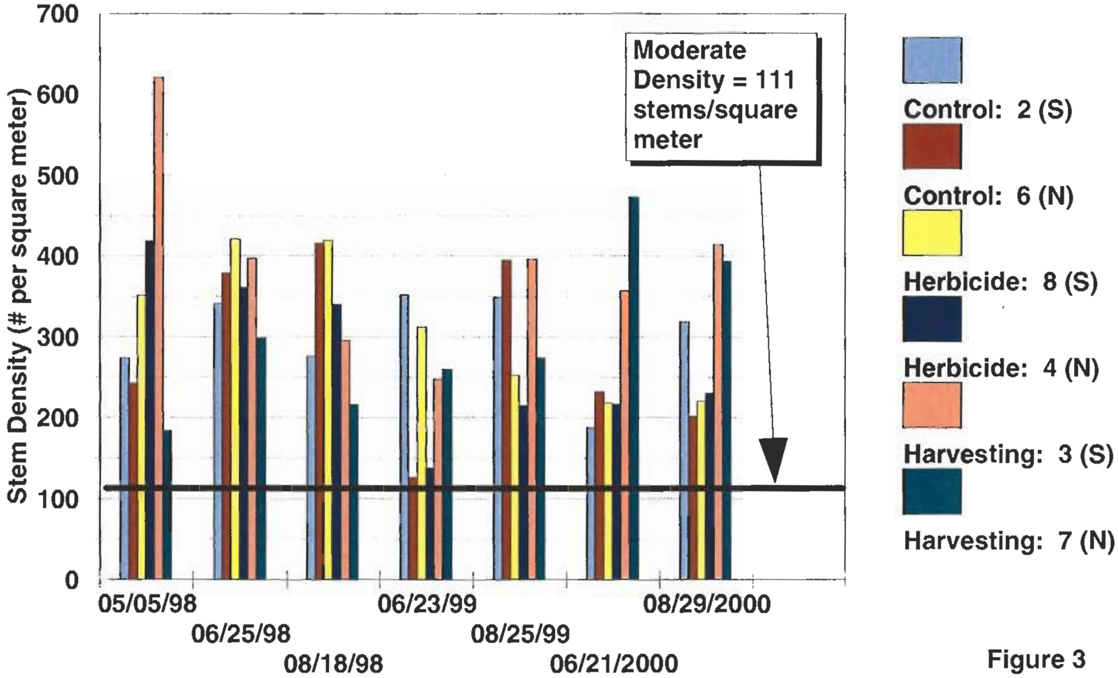


Figure 3

1998-2001 Big Lake Pilot Project
Stem Densities

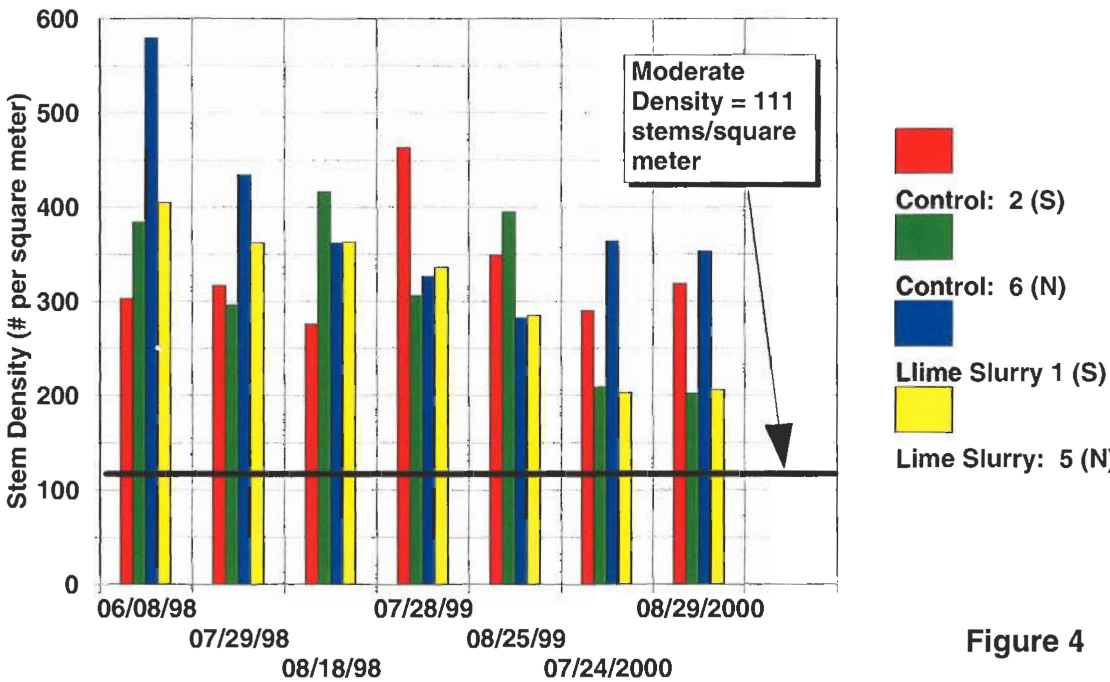


Figure 4

4.1.1.2 June 8-9

Analyses of pre-treatment data collected in early-June indicate the stem density in the lime slurry plots was significantly higher than the stem density in the control plots. ANOVA of untransformed and square root transformed data were in agreement that the difference was significant at the 95 percent confidence level. Kruskal-Wallis results indicate the differences were significant at the 94 percent confidence level.

Stem density in Plot 1 (south lime slurry) was significantly higher than stem density in the other plots during early-June. The three analyses are in agreement that the differences are significant at the 95 percent confidence level.

No significant differences between north and south plots were observed during early-June.

4.1.2 1998 Treatment Results

4.1.2.1 June 24-26

June data indicate a stem density reduction occurred in harvesting and herbicide plots following treatment. Pre-treatment data indicated:

- Harvesting and herbicide plots noted higher stem densities than control plots;
- Some individual harvesting and herbicide plots differed significantly from other individual plots;
- The south group of plots noted higher stem densities than the north group of plots.

Stem density reductions resulting from treatment eliminated these differences. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that no significant differences between plots, between treatments, or between north and south groups of plots occurred in late-June.

4.1.2.2 July 29-30

July data indicate treatment did not remove differences in stem density between lime slurry and control plots noted in pre-treatment sample results. Hence, stem density was significantly higher in lime slurry plots than control plots during early-June and again during late-July. ANOVA of untransformed and transformed July data indicate the difference between lime slurry and control plots was significant at the 95 percent confidence level. Non-parametric analyses (i.e., Kruskal-Wallis) of July data indicate the difference was significant at the 94 percent confidence level.

July data indicate treatment did not remove differences in stem density between Plot 1 and the other plots. Hence, stem density in Plot 1 (south lime slurry) was greater than stem densities in the other plots during early-June and again during late-July. ANOVA of untransformed and transformed data indicate the difference was significant at the 90 percent confidence level. Kruskal-Wallis non-parametric analysis indicates the difference was significant at the 88 percent confidence level.

Although north and south groups of plots noted similar stem densities during early-June, differences were detected in July. Stem densities in the south plots were greater than the stem densities in the north plots. The Kruskal-Wallis non-parametric analysis indicates the difference was significant at the 84 percent confidence level. ANOVA of untransformed and transformed data indicate the difference was not significant at the 80 percent confidence level (p-values of 0.259 and 0.304, respectively).

4.1.2.3 August 17-20

August data indicate the harvesting treatment was more effective than the other treatments. Hence, stem densities in harvesting plots were lower than stem densities in the control, herbicide, and lime slurry plots.

Pre-treatment data indicated that all treatment plots noted stem densities greater than the control plots. Therefore, it appears that the harvesting treatment successfully lowered stem densities resulting in densities less than the control plots. Lime slurry and herbicide, treatments, however, did not lower stem densities to a level less than the control plots. Hence, stem densities in lime slurry and herbicide plots were greater than control plots during August. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that the differences in stem densities between the harvesting, herbicide, lime slurry, and control plots during August were significant at the 95 percent confidence level.

An analysis of individual plot data indicates results of the harvesting and herbicide treatments were not consistent. August data indicate the harvesting treatment was most effective in the north plot (i.e., Plot 7). Harvesting did not appear to be effective in the south plot (i.e. Plot 3). Similarly, herbicide was more effective in the north plot than the south plot. Hence, August data indicate the lowest stem density occurred in Plot 7 (north harvesting). Plot 3 (south harvesting) noted a similar density as the adjacent control plot (i.e., #2). The highest stem density occurred in Plot 8 (south herbicide). Plot 4 (north herbicide) noted a similar density as the north control plot (i.e., #6), and a lower density than Plot 8. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that the differences in stem densities between Plot 7 and all other plots and the differences between Plot 8 and all other plots were significant at the 95 percent confidence level.

ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that differences between the north and south groups of plots were not significant at the 95 percent confidence level.

4.1.3 1998 Growing Season Changes

During 1998, all three treatments were effective. Harvesting was most effective and herbicide was least effective. Stem density increased in the control plots and decreased in the treatment plots during the growing season. Harvesting resulted in a greater decrease in stem density than the other treatments. Herbicide treatment resulted in a lower decrease in stem density than the other treatments. ANOVA of untransformed data and square root transformed data indicate the differences between treatments were significant at the 95 percent confidence level.

During 1998, treatment effects were not uniform. Hence, differences in treatment effectiveness were noted in individual treatment plots. Greatest treatment effectiveness was noted in plots exhibiting decreasing stem density during the growing season. Decreasing stem density was noted in Plots 1 (south lime slurry), 3 (south harvesting), 4 (north herbicide), and 5 (north lime slurry). Plot 1 (south lime slurry) and Plot 3 (south harvesting) noted greater decreases in stem density than the other plots. Treated plots that failed to exhibit stem density decreases noted the lowest treatment effectiveness. Control plots did not exhibit consistent stem density decreases, further confirming the effectiveness of treatments that caused the occurrence of season long stem density decreases. Stem density increases were noted in Plot 6 (north control) and Plot 8 (south herbicide). Plots noting increasing stem density during May through late-June and decreasing stem density from late-June through August include Plot 2 (south control) and Plot 7 (north harvesting). ANOVA of untransformed data and square root transformed data indicate the differences between plots were significant at the 95 percent confidence level.

4.1.4 1999 Treatment Results

4.1.4.1 June 22-25

June data indicate stem densities were similar in control and treatment plots. No significant differences in stem density were noted. Hence, the data are similar to June 1998 data. The stem density reductions resulting from treatments in 1998 were maintained during 1999. However, new reductions in density were not observed. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses of June data are in agreement that differences between treatments (control, herbicide, and harvesting) were not significant at the 80 percent confidence level (p-values of 0.900, 0.879, and 0.376, respectively).

June data indicate treatment resulted in a greater reduction in stem density in Plot 3 (south harvesting) and Plot 4 (north herbicide) than other plots. These plots noted significantly higher stem densities than other plots prior to treatment in 1998. The first year of treatment reduced stem densities in Plot 3 (south harvesting) from 60 to 40 stems per 0.1 square meter (least squares means for May and June of 1998). Stem densities in Plot 4 (north herbicide) were reduced from 42 to 36 stems per 0.1 square meter (least squares means for May and June of 1998). During June 1999, stem densities in Plots 3 and 4 were further reduced to 24 stems per 0.1 square meter (least squares means for June 1999). Kruskal-Wallis non-parametric analysis of June 1999 data indicates stem density in Plot 4 (north herbicide) was significantly less than stem densities in the other plots. The difference was significant at the 95 percent confidence level. The stem density in Plot 3 did not differ significantly from the other plots. ANOVA of untransformed and square root transformed data indicate the differences between plots were not significant at the 80 percent confidence level (p-values of 0.490 and 0.287, respectively).

An analysis of individual plot data indicate herbicide treatment results were not consistent. June data indicate lowest stem density was found at Plot 4 (north herbicide) and highest stem density was found at Plot 8 (south herbicide). The Kruskal-Wallis analysis indicates the differences were significant at the 95 percent confidence level. The ANOVA of untransformed and square root transformed data, however, indicate the differences were not significant at the 80 percent confidence level (p-values of 0.490 and 0.287, respectively).

1999 treatments did not remove the stem density differences between north and south plots observed during pre-treatment in 1998. As discussed previously, 1998 treatments removed the difference. Hence, stem densities in the south plots were greater than stem densities in the north plots during

June of 1999. ANOVA of square root transformed data indicate the June 1999 stem density differences between north and south plots were significant at the 95 percent confidence level. Kruskal-Wallis non-parametric analysis indicates the differences were significant at the 90 percent confidence level. ANOVA of untransformed data indicate the differences were significant at the 85 percent confidence level.

4.1.4.2 July 27-29

July data indicate lime slurry treatment resulted in decreased stem density. The increased effectiveness in 1999 as compared with 1998 results may be attributed to the doubling of the lime slurry treatment dose during 1999. The Kruskal-Wallis analysis indicates differences between control and lime slurry plots were significant at the 95 percent confidence level. ANOVA of square root transformed data indicates the differences were significant at the 89 percent confidence level. ANOVA of untransformed data indicates the differences were not significant at the 80 percent confidence level (p-value of 0.394). The statistical results confirm visual observations during sample collection. The scuba diver collecting samples indicated patches of vegetation within the lime slurry plots were "lying down", similar to patches of wheat that are pushed down by a windstorm. During 1998, the plants remained upright and the only evidence of the lime slurry treatment was white encrustation of the plants.

July data indicate lime slurry treatment of Plot 1 (south lime slurry) was more effective than treatment of Plot 5 (north lime slurry). The three analyses agree that stem density at Plot 1 was significantly lower than the other plots on July 27, 1999. ANOVA of square root transformed data and Kruskal-Wallis non-parametric analysis indicated the differences between Plot 1 and the other plots were significant at the 95 percent confidence level. ANOVA of untransformed data indicated the differences were significant at the 87 percent confidence level. The differences between the plots are of interest because Plot 1 noted a stem density significantly greater than the other plots prior to treatment in 1998.

July data indicate lime slurry was an effective treatment, but its results were not consistent. Hence, differences in stem density were noted in north and south plots. The significant reduction in stem density occurring at Plot 1 (south lime slurry plot) following 1999 treatment resulted in differences in stem density between the north and south. The difference is of interest because the south plots noted significantly higher stem densities than the north plots during July of 1998 and significantly lower stem densities than the north plots in July of 1999. Kruskal-Wallis analysis of July 1999 data indicates north and south stem density differences were significant at the 95 percent level. ANOVA of square root transformed data indicates the differences were significant at the 80 percent confidence level. ANOVA of untransformed data indicates the differences were not significant at the 80 percent confidence level (p-value of 0.255).

4.1.4.3 August 24-27

August data indicate herbicide was the most effective treatment and harvesting was the least effective treatment. The results are of interest because August 1998 results were the reverse of August 1999 results. August 1999 data indicate the highest stem densities occurred in the harvested plots. Lowest stem densities occurred in herbicide plots. Lime slurry was an effective treatment, but its stem densities were higher than herbicide plots. Hence, both herbicide and lime slurry appear to be effective treatments. Harvesting does not appear to be an effective treatment. The stem density differences between treatments were significant at the 79 to 88 percent confidence levels. P-values were 0.122 (Kruskal-Wallis non-parametric test), 0.133 (ANOVA square root transformed data), and 0.209 (ANOVA of untransformed data).

Individual plot data confirm that herbicide was the most effective treatment and that lime slurry was also an effective treatment. August data indicate Plots 1 (south lime slurry), 4 (north herbicide), and 8 (south herbicide) noted a lower stem density than other plots. The results are of interest because these plots noted significantly higher stem densities than other plots during 1998. Pre-treatment data indicate Plot 1 noted higher densities than Plots 2, 5, and 6; Plot 4 noted higher densities than Plots 6 and 7. Plot 8 noted the highest stem density during August 1998. The reduced stem density noted during August of 1999 indicates lime slurry and herbicide treatments appear to be effective in reducing stem density. However, the differences between plots were not significant at the 80 percent confidence level. The three analyses indicated p levels of 0.382 (ANOVA of untransformed data), 0.210 (ANOVA of transformed data), and 0.420 (Kruskal-Wallis non-parametric analysis).

August data from individual plots indicate harvesting was less effective in 1999 than 1998. In 1999, Plots 3 and 7 noted stem densities higher than most other plots. Kruskall-Wallis non-parametric analysis of August 1999 data indicates the rank sums of Plots 3 and 7 were 482 and 462, respectively. Rank sums of the other plots ranged from 289 to 471.5. In 1998, Plots 3 and 7 noted stem densities lower than most other plots. Kruskall-Wallis non-parametric analysis of August 1998 data indicates the rank sums of Plots 3 and 7 were 363 and 199, respectively. Rank sums of the other plots ranged from 349 to 531.

4.1.5 1999 Growing Season Changes

During 1999, two of the three treatments were effective. Growing season data indicate:

- Herbicide and lime slurry were effective treatments
- Herbicide was a more effective treatment than lime slurry
- Harvesting was not an effective treatment.

Stem density increases and decreases during the growing season were evaluated to determine treatment effectiveness. A consistent increase in stem density throughout the growing season indicated no treatment had occurred (control plots) or indicated a treatment was ineffective. Stem density increased in the control and harvesting plots throughout the growing season. Density increases in the harvesting plots were greater than increases in the control plots, confirming the ineffectiveness of the harvesting treatment. Consistent decreases in stem density throughout the growing season indicated a treatment was effective. Stem densities decreased consistently in the herbicide and lime slurry plots. The herbicide plots noted lower stem densities than the lime slurry plots, indicating herbicide treatment was a more effective treatment than lime slurry. ANOVA of square root transformed data indicate the differences between treatments are significant at the 95 percent confidence level. ANOVA of untransformed data indicate the treatments are significant at the 86 percent confidence level.

1999 data from individual plots provide further confirmation that herbicide and lime slurry were effective treatments and that herbicide was more effective than lime slurry. The data provide additional confirmation that harvesting was not an effective treatment. During 1999, decreasing stem density was noted in Plots 4 (north herbicide), 5 (north lime slurry), and 8 (south herbicide). Plot 1 noted a relatively stable stem density. Its stem density, however, was lower than all plots except the two herbicide treated plots (Plots 4 and 8). Stem density increases were noted in Plots 3 (north harvesting) and 7 (south harvesting). Control plots noted increasing stem density during June through July and decreasing stem density from July through August (Plot 2—south control and Plot 6—north control). ANOVA of untransformed data and square root transformed data indicate the differences between plots are significant at the 95 percent confidence level.

4.1.6 2000 Treatment Results

4.1.6.1 June 20-22

June data indicate herbicide treatment during 1998 and 1999 resulted in a residual effect of decreased stem density in 2000. Harvesting, however, did not exhibit a residual effect from treatment in previous years. June data indicate stem density in harvested plots was greater than stem density in herbicide and control plots, which had stem densities similar to one another. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses of June data are in agreement that differences between the harvesting plot and the other plots were significant at the 95 percent confidence level. The difference is of interest because both herbicide and harvesting plots noted significantly higher stem densities than control plots prior to 1998 treatment. During June 2000, density in harvesting plots was higher than pre-treatment levels, while herbicide stem densities were approximately half of pre-treatment levels and similar to control levels.

Individual plot data confirm the ineffectiveness of the harvesting treatment and the effectiveness of the herbicide treatment in yielding a residual effect. Harvesting plots (i.e., Plots 3 and 7) noted a higher stem density than control (i.e., Plots 2 and 6) and herbicide plots (i.e., 4 and 8), which had stem densities similar to one another. Plot 7 (north harvesting) noted a higher stem density than all other plots. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses of June data are in agreement that differences between Plot 7 and the other plots are significant at the 99 percent confidence level. The difference is of interest because pre-treatment data indicated Plot 7 had the lowest stem density, around 18 stems per 0.1 square meter. Plot 7 also noted the lowest stem density throughout 1998, ranging from 22 to 33 stems per 0.1 square meter. June 2000 data indicate Plot 7 noted the highest stem density, around 60 stems per 0.1 square meter. Other plots noted a lower stem density than had been observed during pre-treatment. The decline in stem density in herbicide plots to control plot stem density levels indicates herbicide treatment resulted in a residual effect evident from June 2000 data. The data indicate harvesting may have resulted in increased stem density in Plot 7.

The high stem density at Plot 7 during June caused the north group of plots to have a higher stem density than the south group of plots. ANOVA of untransformed data indicate the difference was significant at the 80 percent confidence level. However, ANOVA of square root transformed and Kruskal-Wallis non-parametric analysis indicate the difference was not significant at the 80 percent confidence level (0.282 and 0.403). The data confirm the residual effect of herbicide treatment and the higher stem density resulting from harvesting treatment in Plot 7. Pre-treatment data indicated the south group of plots noted a significantly higher stem density than the north group of plots. Effects of 1998 and 1999 treatments reversed stem density differences between north and south plot groups.

4.1.6.2 July 24-25

The July data indicate residual effects from lime slurry treatment eliminated the differences between lime slurry and control plots noted prior to treatment in 1998. Lime slurry plots noted a significantly higher plant density during 1998. No significant differences in plant density were noted during July 2000. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses of July data are in agreement that differences between lime slurry and control plots were not significant at the 80 percent confidence level (p-values of 0.775, 0.890, and 0.935).

July data indicate stem density in Plot 5 (north lime slurry) was less than stem densities in other plots. The Kruskall-Wallis non-parametric analysis indicated the difference was significant at the 85 percent confidence level. ANOVA of untransformed and square root transformed data indicate the difference was not significant at the 80 percent confidence level (p-values of 0.469 and 0.269). The data indicate the lime slurry treatment of Plot 5 was effective and that a residual effect is evident. The data further indicate that the statistically significant higher stem densities noted in Plot 1 prior to treatment were eliminated by the lime slurry treatments and its residual effects. Hence, a residual effect was evident at Plot 1.

July data indicate stem density in the north group of plots was less than stem density in the south group of plots. Kruskall-Wallis non-parametric analysis indicates the difference was significant at the 95 percent confidence level. ANOVA of square root transformed data indicates the difference was significant at the 90 percent confidence level. ANOVA of untransformed data indicates the difference was significant at the 80 percent confidence level. Pre-treatment data indicate no significant difference between north and south plots. The data indicate provide further confirmation of the residual effect of the lime slurry treatment in the north plot (i.e., Plot 5).

4.1.6.3 August 28-30

The August data indicate herbicide had the highest residual treatment effect and harvesting the lowest residual treatment effect. The harvesting plots noted the highest stem density and the herbicide plots noted the lowest stem density. The Kruskal-Wallis non-parametric analysis indicated the stem rank sums of the four groups of plots were 700 (herbicide), 717 (control), 789 (lime slurry), and 1,034 (harvesting). The Kruskal-Wallis non-parametric analysis indicated the differences were significant at the 93 percent confidence level. ANOVA of square root transformed data indicated the differences were significant at the 85 percent confidence level. ANOVA of untransformed data indicated the differences were not significant at the 80 percent confidence level (i.e., p-value of 0.324). Prior to treatment in 1998, lime slurry, herbicide, and harvesting noted higher stem densities than the control plots. It appears that residual effects from lime slurry and herbicide treatments eliminated their differences from the control plots. Harvesting treatment, however, did not exhibit a similar residual effect.

Individual plot data provide further evidence of the residual effects from lime slurry and herbicide treatments. The data also provide further evidence of the lack of residual effects from harvesting. The data indicate stem densities at Plots 4 (north herbicide), 5 (north lime slurry), 6 (north control), and 8 (south herbicide) were lower than stem densities at the other plots. The data indicate stem density at Plot 3 (south harvesting) was greater than the other plots. ANOVA of untransformed data and Kruskal-Wallis non-parametric analyses were in agreement that the differences were significant at the 95 percent confidence level. ANOVA of square root transformed data indicated the differences were significant at the 89 percent confidence level.

August data indicated the residual effects from herbicide and lime slurry treatments were insufficient to overcome differences in stem density between north and south groups of plots identified by May 1998 pre-treatment sampling. Stem density in the north group of plots was lower than the stem density in the south group of plots during August 2000. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that the differences are significant at the 95 percent confidence level. Pre-treatment data indicated the north group of plots noted significantly lower stem densities than the south group of plots during May of 1998.

4.1.7 2000 Growing Season Changes

2000 growing season data indicate herbicide and lime slurry were effective treatments that lowered stem density and maintained a lower density during a year in which no treatment occurred. No residual effects were noted for the harvesting treatment. Harvesting stem densities were higher than densities in control plots and other treatment plots throughout the growing season. The four groups of plots noted the following 2000 stem density ranges (i.e., least squares means):

- **Harvesting**—from 38 to 46 stems per 0.1 square meter
- **Herbicide**—from 20 to 28 stems per 0.1 square meter

- **Lime Slurry**—from 25 to 35 stems per 0.1 square meter
- **Control**—from 20 to 38 stems per 0.1 square meter.

ANOVA of square root transformed data indicate the differences between the four groups of plots were significant at the 95 percent confidence level. ANOVA of untransformed data indicate the differences between the four groups of plots were significant at the 90 percent confidence level.

A comparison of 1998 and 2000 growing season stem densities provides further evidence that herbicide and lime slurry noted residual effects, while harvesting failed to exhibit residual effects. 2000 harvesting stem densities were higher than 1998 densities. In contrast, 2000 herbicide and lime slurry stem densities were lower than 1998 densities. Control stem densities were relatively similar during 1998 and 2000. The four groups of plots noted the following 1998 stem density ranges (i.e., least squares means):

- **Harvesting**—from 21 to 38 stems per 0.1 square meter
- **Herbicide**—from 36 to 37 stems per 0.1 square meter
- **Lime Slurry**—from 35 to 48 stems per 0.1 square meter
- **Control**—from 23 to 30 stems per 0.1 square meter.

Data from individual plots provide further evidence that herbicide and lime slurry treatments yielded residual effects. Evidence that harvesting failed to yield a residual effect is also indicated by 2000 data from individual plots. Data indicate highest plant density was noted in Plot 7 (north harvesting) and lowest stem densities were noted in Plot 5 (north lime slurry) and Plot 8 (south herbicide). ANOVA of square root transformed data indicate the differences are significant at the 95 percent confidence level. ANOVA of untransformed data indicate the differences are significant at the 90 percent confidence level.

4.2 Results of Dry Weight Analyses

Dry weight analyses were completed to determine changes in plant mass during 1998 through 2000. Results of the dry weight analyses are presented in Appendix E.

4.2.1 1998 Pre-Treatment Data Analyses

4.2.1.1 May 4-6

Analyses of pre-treatment data indicate there were no significant differences between north and south groups of plots, treatment groups of plots, and between individual plots. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that the differences were not significant at the 80 percent confidence level. P-values during May 4-6 ranged from 0.398 to 0.994. The data indicate a relatively uniform plant mass occurred in the 8 plots.

4.2.1.2 June 8-9

Analyses of pre-treatment data indicate there were no significant differences between north and south groups of plots and between treatment groups of plots. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that the differences were not significant at the 80 percent confidence level. P-values ranged from 0.309 to 0.978.

An analysis of individual plot data indicated lower dry weights occurred in Plot 2 (south control) and Plot 5 (north lime slurry) than Plot 1 (south lime slurry) and Plot 6 (north control). ANOVA of square root transformed data indicate the differences were significant at the 90 percent confidence level. Kruskal-Wallis non-parametric analysis indicates the differences were significant at the 89 percent confidence level. ANOVA of untransformed data indicate the differences were significant at the 84 percent confidence level. The data indicate some differences in plant mass occurred among individual plots.

4.2.2 1998 Treatment Results

4.2.2.1 June 24-26

June data indicate treatment failed to significantly reduce plant mass. There were no significant differences between north and south groups of plots, between treatment groups of plots, and between individual plots. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analyses are in agreement that the differences are not significant at the 80 percent confidence level. P-values ranged from 0.458 to 0.831. Hence, the relatively uniform plant mass observed in May was again observed during late-June.

4.2.2.2 July 29-30

July data indicate lime slurry treatment effectively reduced plant mass. ANOVA of untransformed and square root transformed data indicate differences between lime slurry plots and control plots were significant at the 80 percent confidence level. Kruskal-Wallis analysis indicated the differences were not significant at the 80 percent confidence level (p-value of 0.245).

July data indicate a lower plant mass occurred in the south plots than the north plots. ANOVA of untransformed and square root transformed data and Kruskal-Wallis analysis indicate the differences in dry weight were significant at the 80 percent confidence level. The difference is of interest because significant differences did not occur prior to treatment with lime slurry.

Plant mass differences in individual plots were not significant in July. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate differences between individual plots were not significant at the 80 percent confidence level (p-values of 0.251, 0.300, and 0.352, respectively). Kruskal-Wallis analysis indicates the sum ranks for the individual plots were:

Plot 1 (south lime slurry)—156 grams per square meter
Plot 2 (south control)—203 grams per square meter
Plot 5 (north lime slurry)—211 grams per square meter
Plot 6 (north control)—250 grams per square meter

4.2.2.3 August 17-20

August data indicate herbicide, harvesting, and lime slurry were effective treatments. Harvesting appears to be the most effective treatment and herbicide appears to be the least effective treatment. ANOVA of untransformed and square root transformed data indicate the differences between treatment plots were significant at the 85 percent confidence level. Kruskal-Wallis analysis indicates the differences were not significant at the 80 percent confidence level (p-value of 0.206).

North and south groups of plots did not differ significantly in plant mass. Hence, differences between plots appear to result from treatment rather than location within the northern or southern half of the lake. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate differences between north and south groups of plots are not significant at the 80 percent confidence level (p-values of 0.340, 0.325, and 0.317, respectively).

Analysis of individual plots indicated treatment effects resulted in plant mass differences between plots. The differences indicate treatment effects are not uniform. ANOVA of untransformed and square root transformed data indicate the following ranking of plots, from lowest to highest plant mass: Plot 7 (north harvesting), Plot 1 (lime slurry), Plot 3 (south harvesting), Plot 4 (north herbicide), Plot 2 (south control), Plot 8 (south herbicide), Plot 5 (north lime slurry), and Plot 6 (north control). Kruskal-Wallis non-parametric analysis indicates the following sum ranks of plots, from lowest plant mass to highest plant mass:

Plot 4 (north herbicide)—191 grams per square meter
Plot 1 (south lime slurry)—251 grams per square meter
Plot 3 (south harvesting)—415 grams per square meter
Plot 6 (north control)—452 grams per square meter
Plot 2 (south control)—460 grams per square meter
Plot 7 (north harvesting)—468 grams per square meter
Plot 8 (south herbicide)—494 grams per square meter
Plot 5 (north lime slurry)—509 grams per square meter

ANOVA of untransformed and square root transformed data indicate the differences between plots are significant at the 90 percent confidence level. Kruskal-Wallis analysis indicate the differences between individual plots are significant at the 85 percent confidence level.

4.2.3 1998 Growing Season Changes

An analysis of 1998 seasonal changes indicates plant mass increased in all plots. A repeated ANOVA of square root transformed data indicates the differences in plant mass during the growing season are significant at the 99.9 percent confidence level. The data indicate that lowest plant mass was found in the spring and highest plant mass was found in late-summer.

1998 data indicate harvesting, herbicide, and lime slurry were effective when compared to controls (lower increase in biomass than controls). Seasonal data indicate lime slurry and harvesting were more effective treatments than herbicide. However, only lime slurry exhibited statistically significant differences. A repeated ANOVA of square root transformed June, July, and August control and lime slurry data indicate treatment differences were significant at the 80 percent confidence level (p-value of 0.175). A comparable repeated ANOVA of square root transformed May, June, and August control, herbicide, and harvesting data indicate treatment differences were not significant at the 80 percent confidence level (p-value of 0.542).

1998 data indicate lime slurry effectiveness differed between the north and south plots during the growing season. A comparable difference was not observed for herbicide and harvesting treatments. Lime slurry treatment was more effective in the south treatment plot than the north treatment plot. The south plot noted a higher plant mass than the north plot prior to treatment. Treatment caused a greater reduction in plant mass in the south plot than the north plot, reversing the plot with the lowest plant mass from north to south. Hence, the south plot noted a lower plant mass than the north plot in August. A repeated ANOVA of square root transformed data for the variables time, treatment, and north-south indicates differences were significant at the 95 percent confidence level. A comparable repeated ANOVA of square root transformed data for the variables of time, treatment, and north-south of herbicide, harvesting, and control plots indicates the differences were not significant at the 80 percent confidence level (p-value of 0.694).

Seasonal individual plot data indicate lime slurry treatment of the south plot was the most effective treatment. Lowest plant mass was found in Plot 1 (south lime slurry) following treatment. A repeated ANOVA of square root transformed data for the variables time and plot (i.e., lime slurry and control plots) indicates differences were significant at the 90 percent confidence level. A comparable repeated ANOVA of square root transformed data for the variables time and plot for herbicide, harvesting, and control plots indicates the differences were not significant at the 80 percent confidence level (p-value of 0.669).

4.2.4 1999 Treatment Results

4.2.4.1 June 22-25

June data indicate herbicide was the most effective treatment, but its effects were not consistent between replicate plots. The lowest plant mass was found in Plot 4 (north herbicide) and the highest plant mass was found in Plot 8 (south herbicide). ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate the differences between plots were significant at the 95 percent confidence level. Games Howell analysis of untransformed and square root transformed data indicate differences between Plot 4 (north herbicide) and Plot 2 (control) are significant at the 95 percent confidence level.

The large difference between the north and south herbicide plots resulted in differences between the north and south groups of plots. ANOVA of untransformed and square root transformed data indicate differences between north and south groups of plots were significant at the 95 percent confidence level. However, the Kruskal-Wallis non-parametric analysis indicates the differences were not significant at the 80 percent confidence level (p-value of 0.460).

Analysis of treatment groups indicates herbicide was the most effective treatment. However, the inconsistent response between replicate herbicide plots minimized the difference between herbicide treatment and the other treatments (i.e., control and harvesting). ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate differences between treatments were not significant at the 80 percent confidence level (p-values of 0.913, 0.651, and 0.574, respectively).

4.2.4.2 July 27-29

Analyses of July data indicated lime slurry was an effective treatment. ANOVA of square root transformed data and Kruskal-Wallis analysis indicated the differences between lime slurry treated plots and control plots were significant at the 80 and 90 percent confidence levels, respectively. ANOVA of untransformed data indicated differences between treated and control plots were not significant at the 80 percent confidence level (p-value of 0.240).

Analyses of replicate plots indicate a relatively uniform plant mass occurred in the north and south locations. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicated differences between north and south groups of plots were not significant at the 80 percent confidence level (p-values of 0.929, 0.869, and 0.860, respectively).

Analyses of individual plot data indicate lowest plant mass was found in the south lime slurry plot. However, ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate differences between plots were not significant at the 80 percent confidence level. It appears that the relatively small differences between plots and large variation within plots resulted in p-values ranging from 0.412 to 0.610.

4.2.4.3 August 24-27

August data indicate herbicide was the most effective treatment, but its effects were not consistent between replicate plots. The lowest plant mass was found in Plot 4 (north herbicide) and the highest plant mass was found in Plot 8 (south herbicide). ANOVA of untransformed and square root transformed data indicate the differences between plots were significant at the 95 percent confidence level. Games Howell analysis of untransformed data indicate differences between Plot 4 (north herbicide) and Plot 2 (control) are significant at the 95 percent confidence level. Games Howell analysis of square root transformed data indicate differences between Plot 4 (north herbicide) and Plot 5 (north lime slurry) were significant at the 95 percent confidence level. Kruskall-Wallis non-parametric analysis indicates the differences between individual plots were not significant at the 80 percent confidence level (p-value of 0.371).

August data indicate herbicide was the most effective treatment and harvesting was the least effective treatment. However, inconsistent effects of herbicide and lime slurry treatments in replicate plots minimized differences between treatments. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate the differences between treatments were not significant at the 80 percent confidence level (p-values of 0.779, 0.590, and 0.371, respectively).

North and south replicate plots noted opposing responses to lime slurry and herbicide treatments. The north herbicide plot (#4) noted the lowest plant mass and the south herbicide plot (#8) noted the highest plant mass. The south lime slurry plot (#1) noted the second lowest plant mass and the north lime slurry plot (#5) noted the second highest plant mass. The remaining plots noted a relatively uniform plant mass. Hence, the north and south groups of plots differed little in plant mass. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate the differences between the north and south groups of plots were not significant at the 80 percent confidence level (p-values of 0.963, 0.740, and >0.9999, respectively).

4.2.5 1999 Growing Season Changes

An analysis of 1999 seasonal changes indicates plant mass increased in all plots. A repeated ANOVA of square root transformed data from control, harvesting, and herbicide plots indicates the differences in plant mass during the June through August period are significant at the 99.9 percent confidence level. A repeated ANOVA of lime slurry and control plots indicates the differences in plant mass during the July through August period are significant at the 87 percent confidence level. The data indicate that lowest plant mass was found in the spring and highest plant mass was found in late summer.

Herbicide treatment was the most effective treatment during the 1999 growing season. However, herbicide effects were inconsistent in replicate plots. Plot 4 (north herbicide) noted the lowest plant mass throughout the growing season and Plot 8 (south herbicide) noted the highest plant mass throughout the growing season. A repeated ANOVA of square root transformed data indicates:

- Differences between individual plots are significant at the 95 percent confidence level.

- Differences between north and south groups of plots are significant at the 95 percent confidence level
- Using north-south and treatment as variable, differences are significant at the 95 percent confidence level.

Lime slurry treatment was effective, but its effects were also inconsistent in replicate plots. In a comparison between the lime slurry and control replicate plots:

- Plot 1 (south lime slurry) noted the lowest plant mass during July and August.
- Plot 5 noted the second lowest plant mass in July and the highest plant mass in August.
- A repeated ANOVA of square root transformed data using time and north-south as variables indicates differences were significant at the 90 percent confidence level.
- A repeated ANOVA of square root transformed data using north-south and treatment as variables indicates differences were significant at the 85 percent confidence level.

4.2.6 2000 Treatment Results

4.2.6.1 June 20-22

June data indicated herbicide was the most effective treatment, but its effects were not consistent between replicate plots. The lowest plant mass was found in Plot 4 (north herbicide) and the highest plant mass was found in Plot 8 (south herbicide). The data indicate 1998 and 1999 treatments resulted in reduced plant mass in the north herbicide plot but not in the south herbicide plot during 2000. Both harvesting plots noted more plant mass than the control plots in 2000, indicating no evidence of plant mass reductions from 1998 and 1999 treatments. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate the differences between plots were significant at the 85 percent, 90 percent, and 95 percent confidence levels, respectively. ANOVA of untransformed and square root transformed data for variables north-south and treatment indicate differences were significant at the 95 percent confidence level.

Analyses of individual plots provides further evidence for the plant mass reductions from 1998 and 1999 treatments in Plot 4 (north herbicide). The data further confirm no evidence of plant mass reductions from 1998 and 1999 treatments in harvesting plots. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate differences between individual plots were significant at the 95 percent confidence level. Increased plant mass in Plot 7 (north harvesting) during 2000 indicates the previous years' harvesting may have caused increased plant growth. Games Howell analysis of untransformed and square root transformed data indicate differences between:

- Plot 2 (control) and Plot 7 (north harvesting)
- Plot 4 (north herbicide) and Plot 7 (north harvesting)

are significant at the 95 percent confidence level. Games Howell analysis indicates harvesting effects were inconsistent between replicate plots. A lower plant mass was observed in Plot 3 (south harvesting) than Plot 7 (north harvesting). Games Howell analysis of square root transformed data indicates differences between Plot 3 (south harvesting) and Plot 7 (north harvesting) were significant at the 95 percent confidence level.

4.2.6.2 July 24-25

July data provide no evidence of plant mass reductions from 1998 and 1999 treatments. ANOVA of untransformed and square root transformed data and Kruskal-Wallis non-parametric analysis indicate differences between treatment, individual plots, and north-south groups of plots are not significant at the 80 percent confidence level. P-values ranged from 0.279 to 0.943.

4.2.6.3 August 28-30

August data indicate 1998 through 1999 lime slurry treatments resulted in a reduced plant mass in the south treatment plot. The treatment effects, however, were not consistent between replicate plots. Highest plant mass was found in the north lime slurry plot. ANOVA of untransformed and square root transformed data for the variables north-south and treatment indicate differences were significant at the 96 and 94 percent confidence levels, respectively.

Further evidence that 1998 and 1999 lime slurry treatments resulted in reduced plant mass in Plot 1 (south lime slurry) was indicated by an analysis of individual plots. The analysis provided additional evidence for the inconsistent treatment response of the replicate lime slurry plots. Analysis results indicate lowest plant mass was found in Plot 1 (south lime slurry) and highest plant mass was found in Plot 5 (north lime slurry). ANOVA of untransformed and square root transformed data and Kruskal Wallis non-parametric analysis indicate the differences were significant at the 84, 78, and 76 percent confidence levels, respectively.

The analysis indicates 1998 and 1999 herbicide and harvesting treatments failed to reduce plant mass below the level of both control plots during August of 2000. Kruskal-Wallis non-parametric analysis indicates the following sum ranks of plots, from lowest plant mass to highest plant mass:

Plot 1 (south lime slurry)—268 grams per square meter
Plot 2 (south control)—322 grams per square meter
Plot 7 (north harvesting)—388 grams per square meter
Plot 4 (north herbicide)—389 grams per square meter
Plot 6 (north control)—406 grams per square meter
Plot 8 (south harvesting)—489 grams per square meter
Plot 5 (north lime slurry)—523 grams per square meter

4.2.7 2000 Growing Season Changes

An analysis of 2000 seasonal changes indicates plant mass increased in all plots. A repeated ANOVA of square root transformed data from control, harvesting, and herbicide plots indicates the differences in plant mass during the June through August period are significant at the 99.9 percent confidence level. A repeated ANOVA of lime slurry and control plots indicates the differences in plant mass during the July through August period are significant at the 89 percent confidence level. The data indicate that lowest plant mass was found in the spring and highest plant mass was found in late summer.

Inconsistent effects of replicate harvesting and herbicide plots were noted during 2000. Hence, a concurrent analysis of replicate plots indicated no evidence of residual effects of harvesting and herbicide treatments. The data indicate plant mass at harvesting and herbicide plots was greater than control plots during 2000. Repeated ANOVA analysis of square root transformed harvesting, herbicide, and control data using the variables treatment and time indicate differences were significant at the 80 percent confidence level (p-value of 0.189).

Analyses involving separation of the north and south replicate plots, however, indicate the occurrence of an apparent residual effect of treatment in the north herbicide plot. The north herbicide plot noted a lower plant mass than the other plots. However, the south herbicide plot noted a higher plant mass than the other plots. Repeated ANOVA of square root transformed herbicide, harvesting, and control data using the variables north-south and treatment indicated the differences were significant at the 95 percent confidence level. Analysis using the variables north-south and time indicates the differences were significant at the 90 percent confidence level. Analysis using the variables time, north-south, and treatment indicates the differences were significant at the 95 percent confidence level.

Inconsistent effects in replicate lime slurry treatment plots prevented the detection of residual treatment effects during 2000 from a concurrent analysis of replicate plot data. The south lime slurry plot noted a lower plant mass than the north lime slurry and both control plots. The north lime slurry plot noted a higher plant mass than the south lime slurry plot and both control plots. Repeated ANOVA analysis of square root transformed lime slurry and control data using the variables treatment and time indicate differences were not significant at the 80 percent confidence level. (p-value of 0.276). However, repeated ANOVA of square root transformed data using the variables north-south and treatment indicated differences were significant at the 80 percent confidence level. Repeated ANOVA of square root transformed data using the variables time, north-south, and treatment indicate differences were significant at the 90 percent confidence level.

Individual plot analyses indicate the south lime slurry and the north herbicide plots noted a lower plant mass than other plots during 2000. The data provide evidence of a residual effect from 1998 and 1999 treatments. Repeated ANOVA of herbicide, harvesting, and control plots for the variables time and plot indicate differences were significant at the 95 percent confidence level. Repeated ANOVA of lime slurry and control plots for the variables time and plot indicate differences were significant at the 90 percent confidence level.

4.3 Results of Species Analyses

Analyses of species included :

- Determination of the number of species at each plot
- Analyses to determine the dominant species at each plot during each sample event using stem density and dry weight as deterministic variables
- Dominant species were further analyzed to determine the percent of sample events each species was dominant.

The results of the species analyses are presented in Appendix F.

4.3.1 Number of Species

A species analysis of 1998 through 2000 data indicates treatment and control plots both noted fluctuations in the average number of species (See Figure 5), including:

Control Plots 2 and 6—both noted a decline in number of species during 1999 and an increase in number of species during 2000;

Lime Slurry Plots 1 and 5—both noted a decline in number of species following treatment in 1998 and 1999 and an increase in number of species during 2000;

Harvesting Plot 3—noted a decline in number of species following treatment during 1998 and an increase in number of species during 1999 and 2000;

Harvesting Plot 7—noted increases in numbers of species following treatment during 1998 and 1999 and a decline to pre-treatment levels during 2000.

Herbicide Plot 4—noted increases in numbers of species following treatment in 1998 and during 1999 and 2000.

Herbicide Plot 8—noted increases in numbers of species following treatment in 1998 and during 2000. Although a decrease in numbers of species was noted during 1999, the number of species remained above the pre-treatment level.

1998-2000 Big Lake Pilot Treatment Project

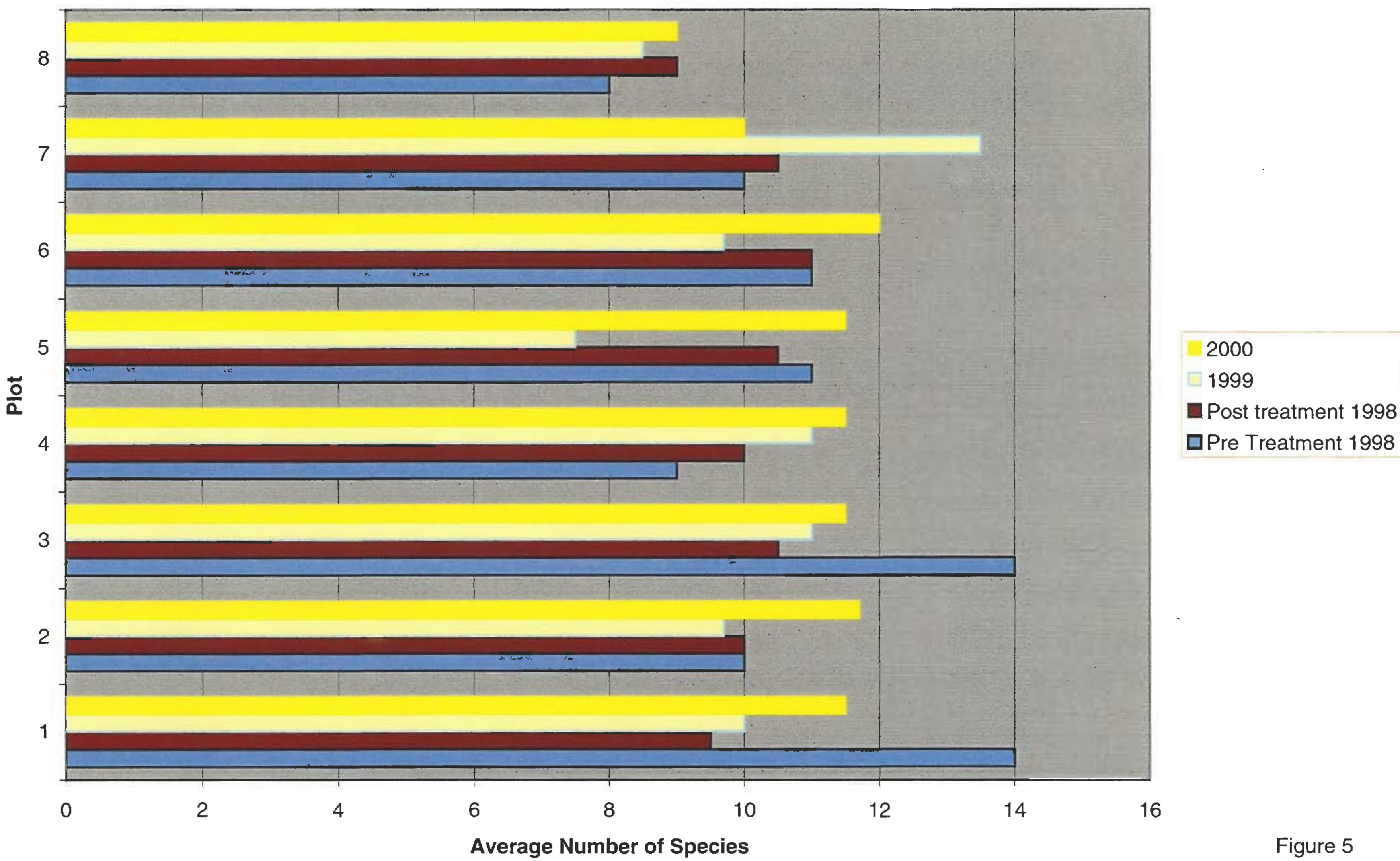


Figure 5

4.3.2 Dominant Species

All plots noted changes in dominant species during 1998 through 2000, both from a stem density and a dry weight perspective. Hence, 20 different species were dominant during the 1998 through 2000 period. Dominant species based on stem density generally differed from dominant species based on dry weights. The data indicate species with high numbers of stems comprise less plant mass than other species within the plots. The data also indicate that species comprising the highest plant mass do not have the highest numbers of stems within the plots.

Pre-treatment data indicate *Ceratophyllum demersum* was dominant, on a dry weight basis, at all plots except Plot 1 (south lime slurry), which noted a dominance by *Potamogeton amplifolius* on a dry weight basis. During other sampling dates, individual plots differed in dominant species. Dominant species are shown in Figures 6 through 13. The most frequently occurring dominant species in the eight plots were:

Plot 1 (south lime slurry)—*Valisneria americana* (stem density) and *Potamogeton amplifolius* (dry weight)

Plot 2 (south control)—*Valisneria americana* (stem density) and *Potamogeton amplifolius* (dry weight)

Plot 3 (south harvesting)—*Valisneria americana* (stem density) and *Ceratophyllum demersum* and *Potamogeton richardsonii* (dry weight)

Plot 4 (north herbicide)—*Zosterella dubia* and *Potamogeton zosteriformis* (stem density) and *Ceratophyllum demersum* (dry weight)

Plot 5 (north lime slurry)—*Elodea canadensis* and *Valisneria americana* (stem density) and *Ceratophyllum demersum* (dry weight)

Plot 6 (north control)—*Elodea canadensis* (stem density) and *Ceratophyllum demersum* (dry weight)

Plot 7 (north harvesting)—*Elodea canadensis* and *Valisneria americana* (stem density) and *Potamogeton zosteriformis* and *Ceratophyllum demersum* (dry weight)

Plot 8 (south harvesting)—*Potamogeton spp.* and *Potamogeton richardsonii* (stem density) and *Ceratophyllum demersum* (dry weight)

Big Lake Pilot Project
1998-2000 Dominant Species
Plot 1

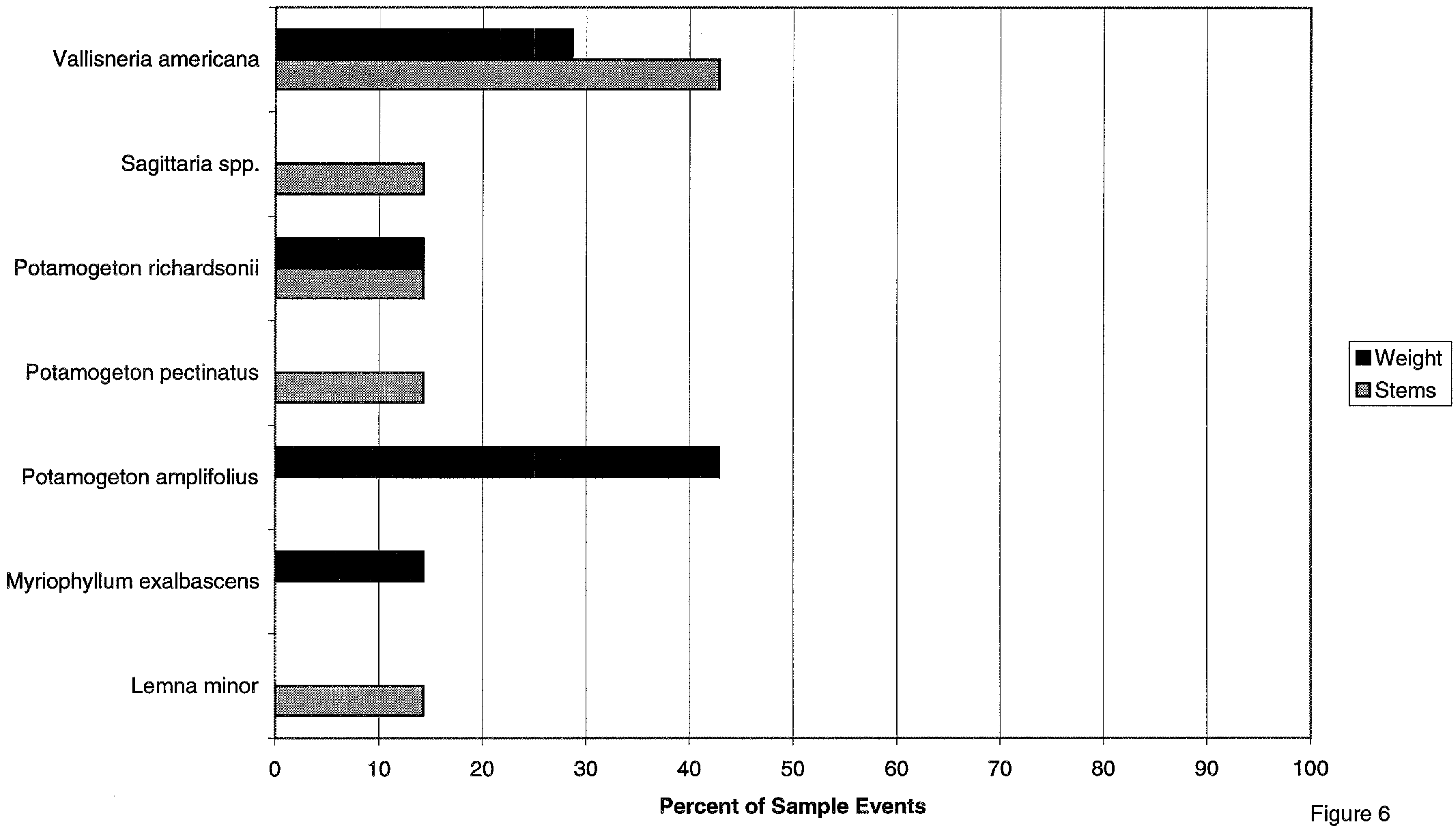


Figure 6

Big Lake Pilot Project
1998-2000 Dominant Species
Plot 2

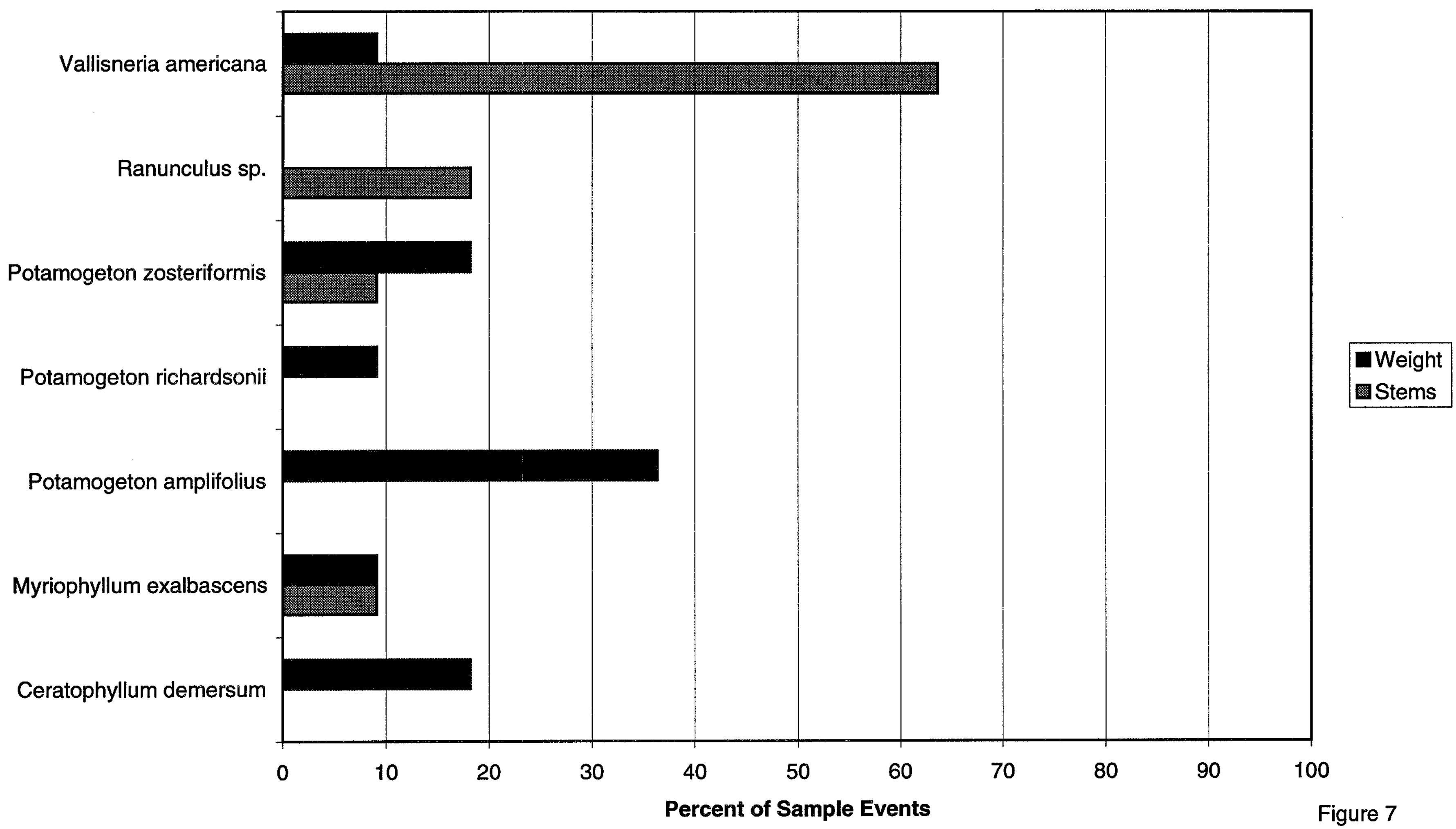


Figure 7

Big Lake Pilot Project
1998-2000 Dominant Species
Plot 3

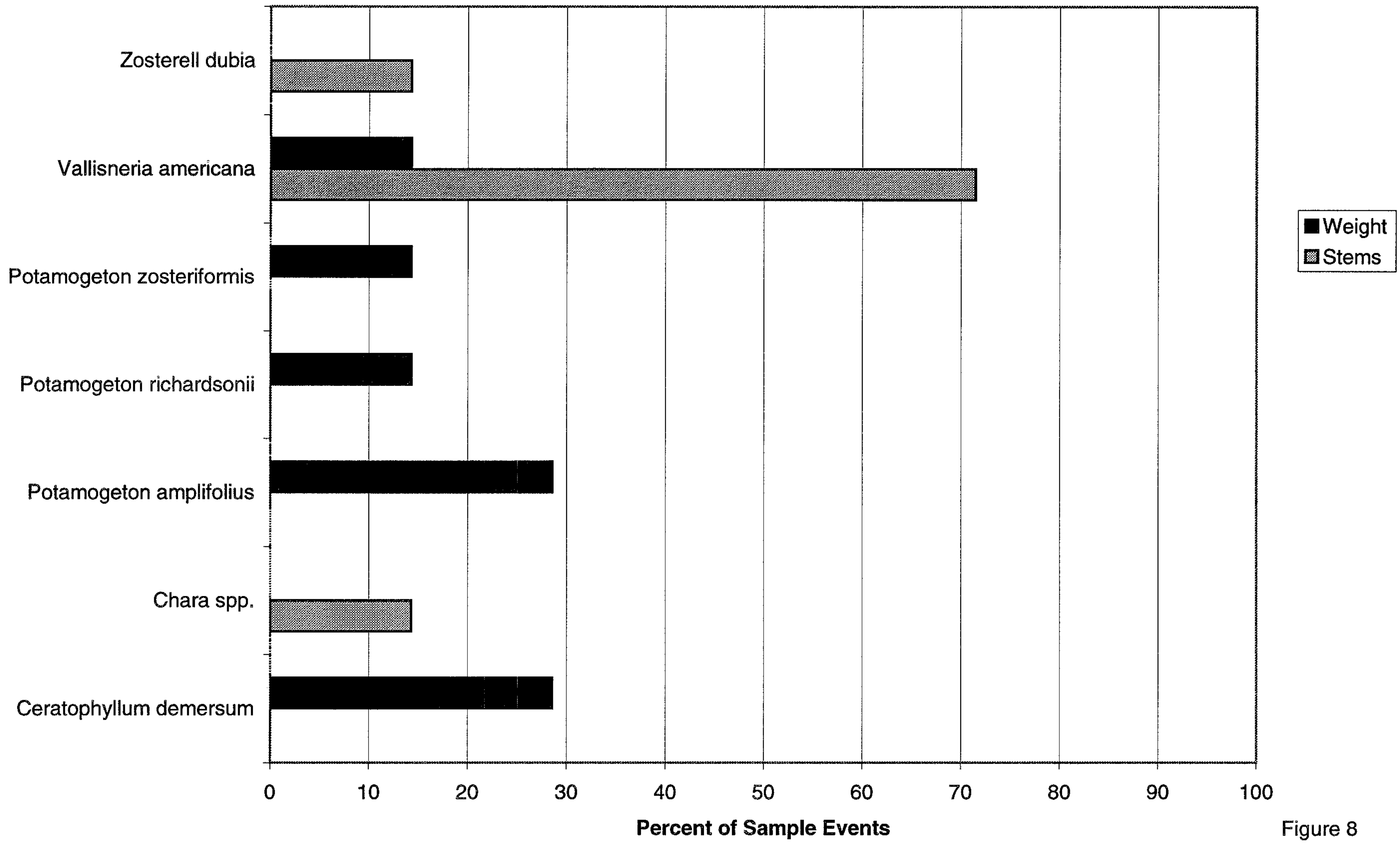


Figure 8

Big Lake Pilot Project
1998-2000 Dominant Species
Plot 4

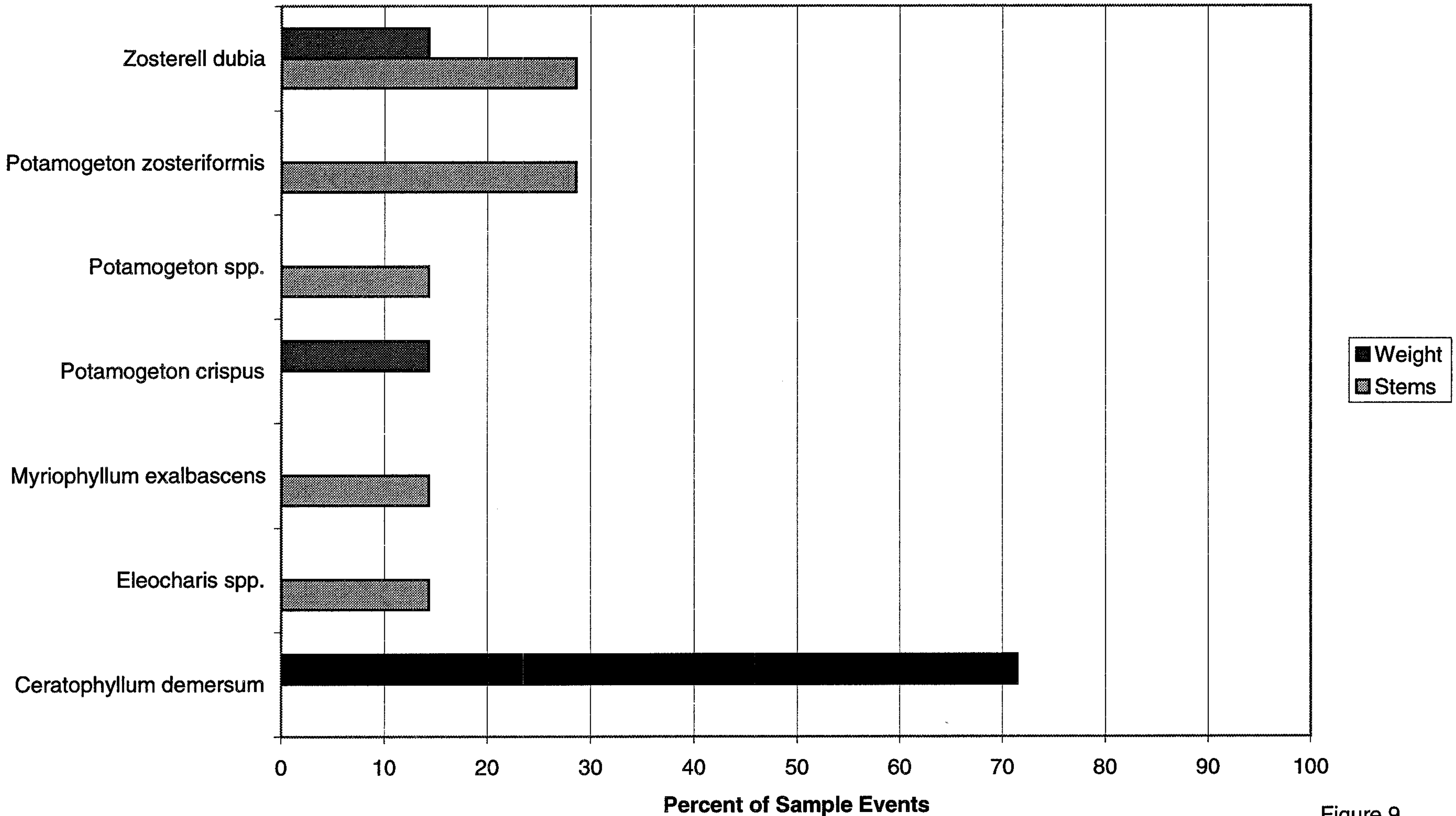
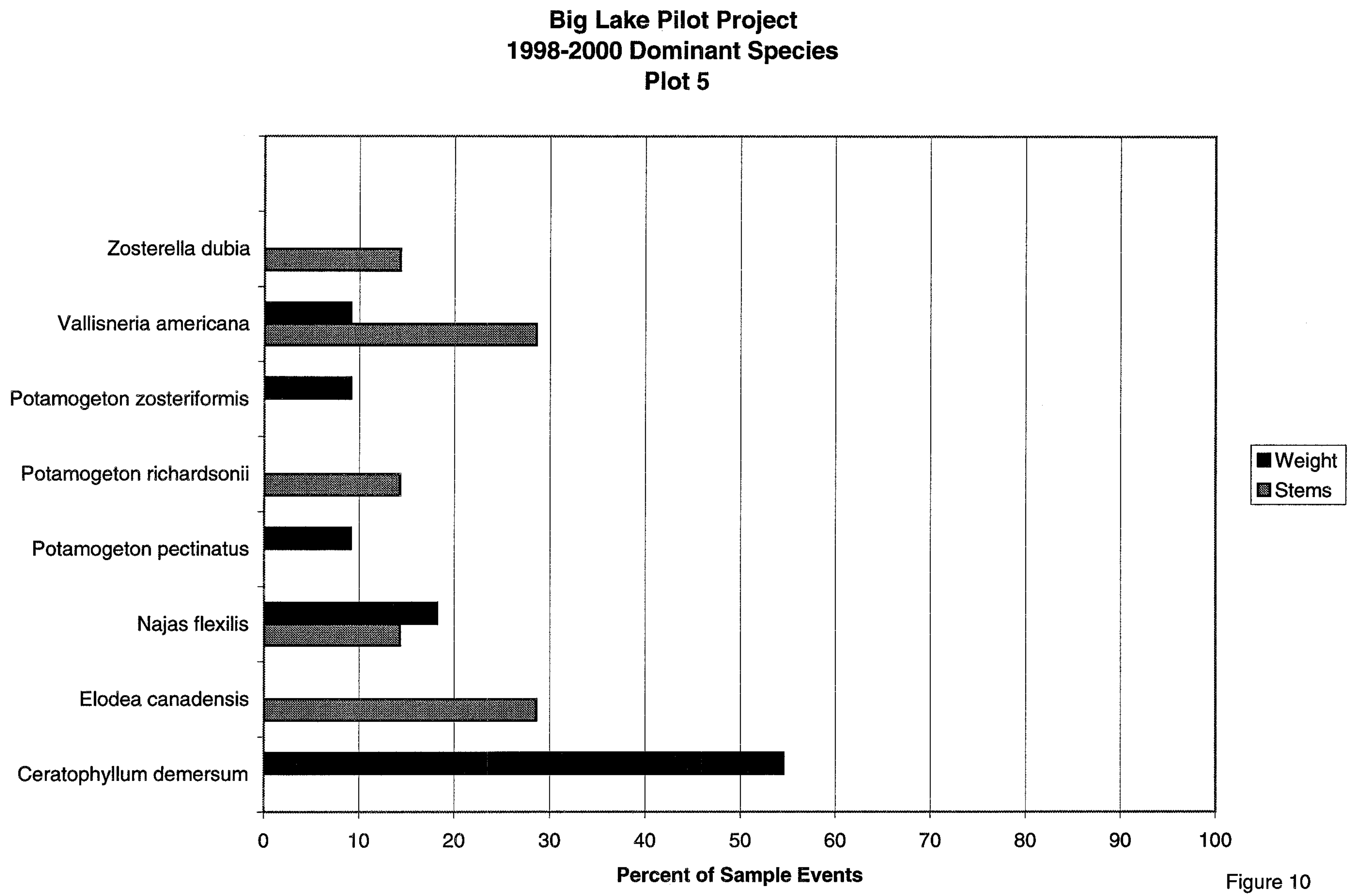


Figure 9



Big Lake Pilot Project
1998-2000 Dominant Species
Plot 5
Zosterella dubia
Vallisneria americana
Potamogeton zosteriformis
Potamogeton richardsonii
Potamogeton pectinatus
Najas flexilis
Elodea canadensis
Ceratophyllum demersum
0
10
20
30
40
50
60
70
80
90
100
Percent of Sample Events
Weight
Stems

Figure 10

Big Lake Pilot Project
1998-2000 Dominant Species
Plot 6

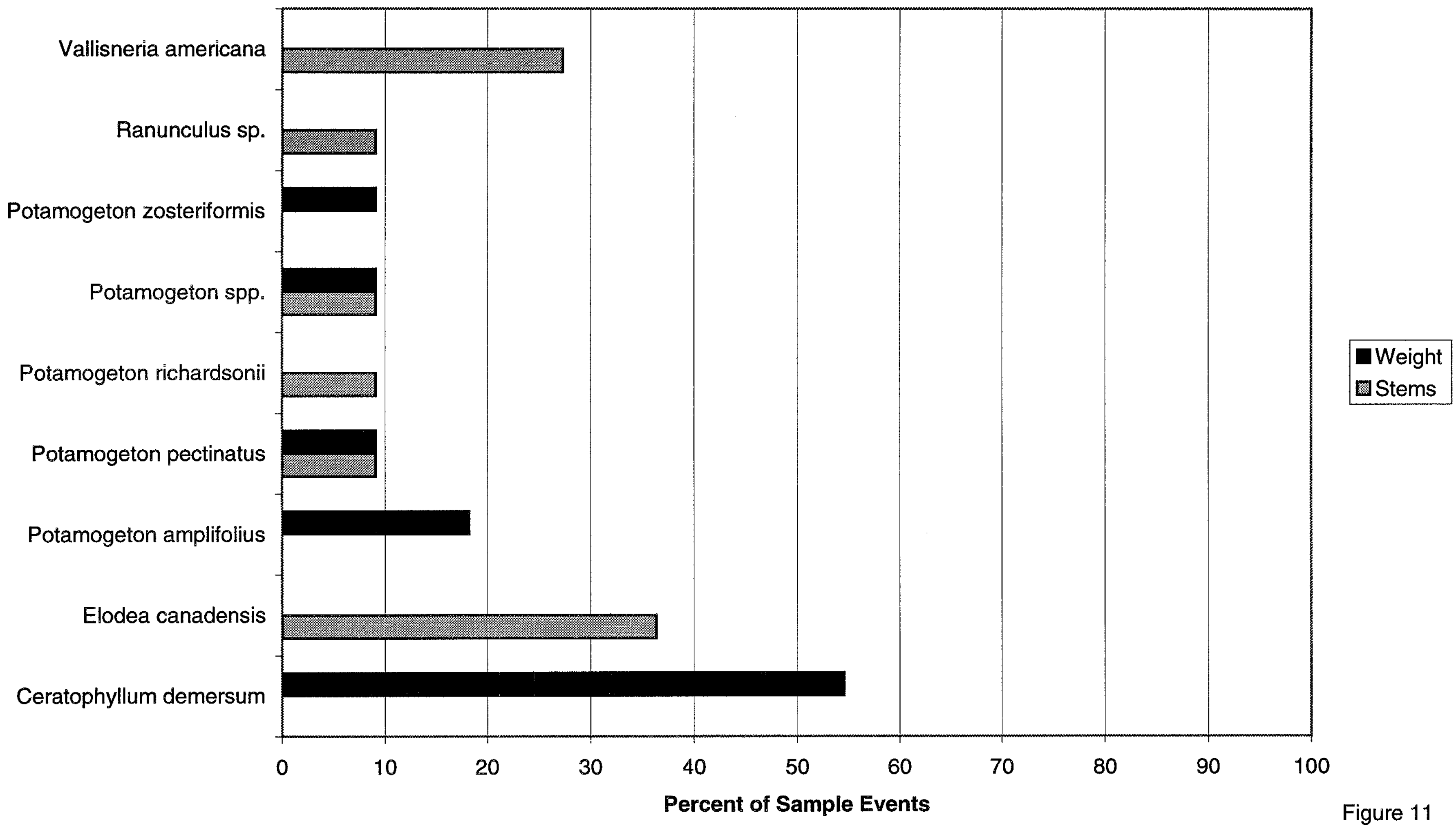


Figure 11

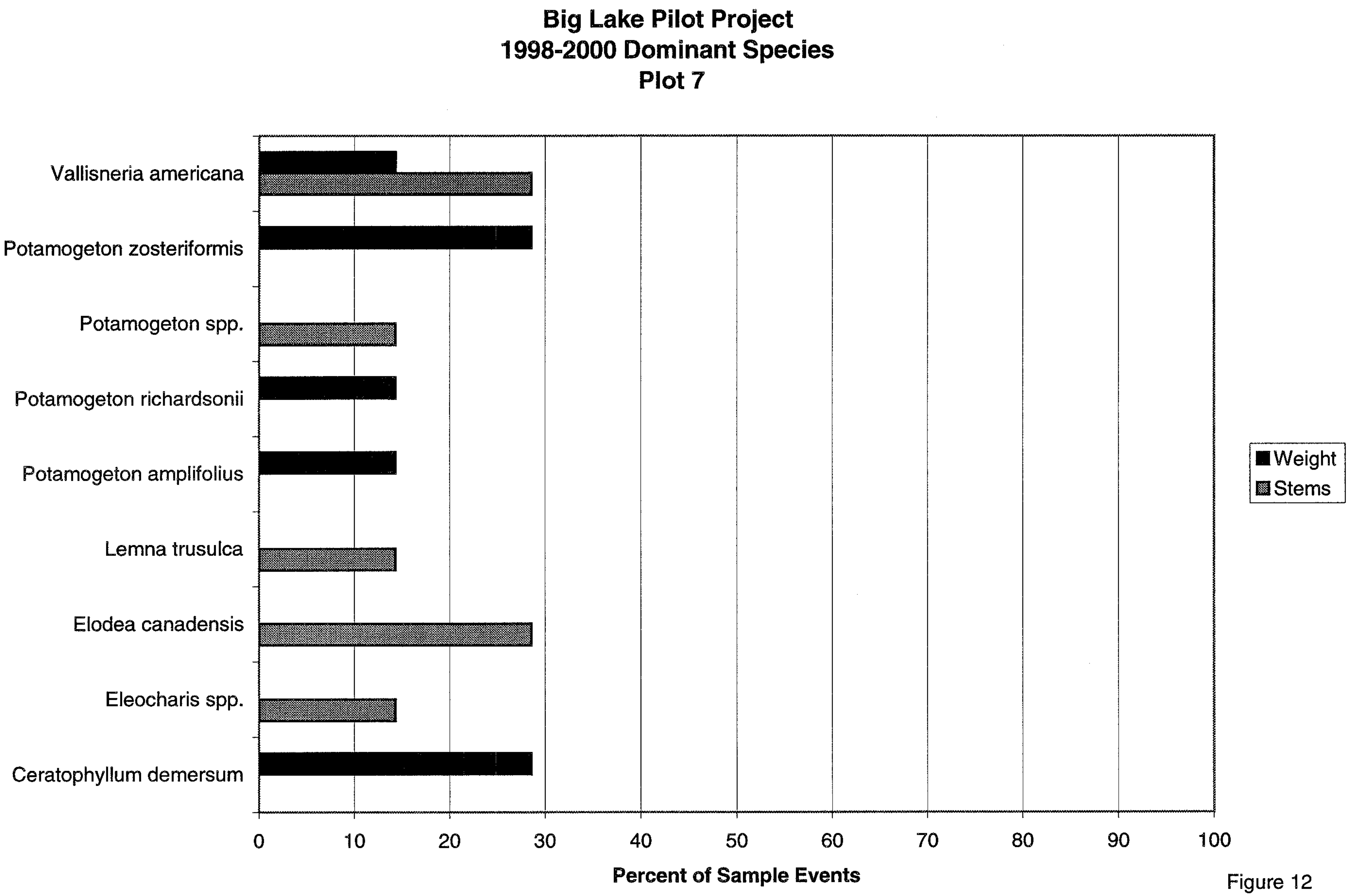
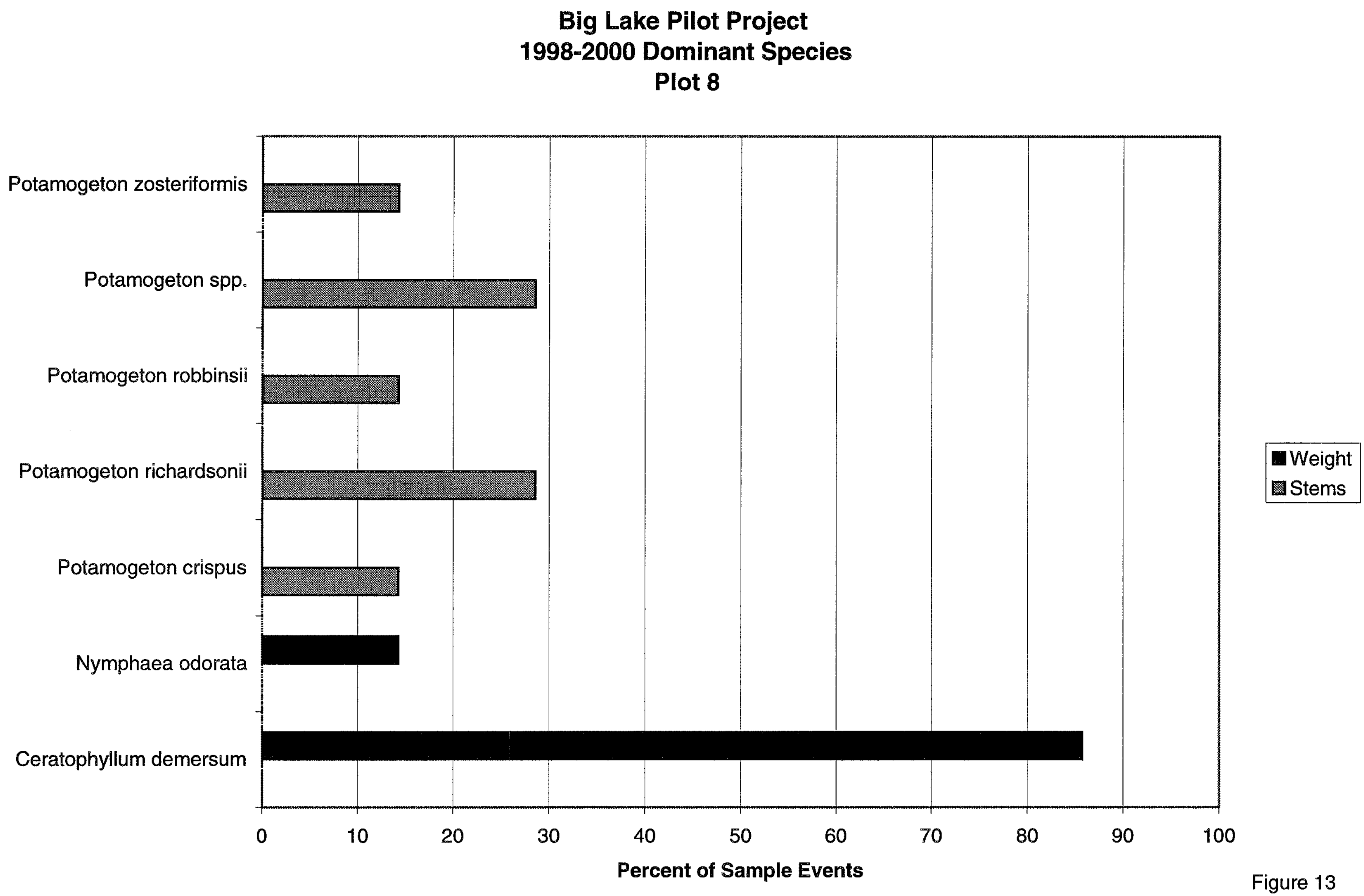

Big Lake Pilot Project
1998-2000 Dominant Species
Plot 7
Vallisneria americana
Potamogeton zosteriformis
Potamogeton spp.
Potamogeton richardsonii
Potamogeton amplifolius
Lemna trusulca
Elodea canadensis
Eleocharis spp.
Ceratophyllum demersum
0
10
20
30
40
50
60
70
80
90
100
Percent of Sample Events
Weight
Stems

Figure 12



Big Lake Pilot Project
1998-2000 Dominant Species
Plot 8
Potamogeton zosteriformis
Potamogeton spp.
Potamogeton robbinsii
Potamogeton richardsonii
Potamogeton crispus
Nymphaea odorata
Ceratophyllum demersum
0
10
20
30
40
50
60
70
80
90
100
Percent of Sample Events
Weight
Stems

Figure 13

Herbicide treatment generally did not change the plots' dominant species. *Ceratophyllum demersum* was the dominant species in Plots 4 (north herbicide) and 8 (south herbicide) on a weight basis during 71 to 86 percent of the sample events, respectively. This species was dominant on a weight basis prior to treatment and remained dominant during all but one or two sample events during the 1998 through 2000 period. Both plots noted dominance by a different species during August of 1998 and Plot 4 was dominated by *Potamogeton crispus* (curlyleaf pondweed) during June of 2000. Hence, the data indicate *Ceratophyllum demersum* maintained its dominance during and following treatment.

The data indicate lime slurry treatment may have changed the north plot's dominant species during the two years of treatment. *Ceratophyllum demersum* was dominant in Plot 5 on a weight basis prior to treatment in 1998 and during both 2000 sample events. P-values were 0 on June 8, 1998, 0.221 on July 24, 2000, and 0.744 on August 28, 2000. The data indicate a stronger dominance by *Ceratophyllum demersum* prior to treatment than after 2 years of treatment. During 1998 and 1999, *Potamogeton* species were dominant following treatment. P-values ranged from 0.027 to 0.400.

Harvesting plots noted a change in species during the second year of treatment and during 2000 (i.e., year of no treatment following two years of treatment). *Ceratophyllum demersum* was the dominant species from a weight perspective at both plots prior to treatment (May 1998) and again during August 1998. During the second year of treatment (1999) and during 2000, *Potamogeton* species and *Vallisneria americana* were dominant. Because *Ceratophyllum demersum* has the ability to grow new plants from fragments, harvesting has the potential of leaving fragments which result in new plant growth. However, the data indicate a decrease in *Ceratophyllum demersum* following harvesting resulting in dominance by other species.

During 2000, it appears that curlyleaf pondweed dominance in herbicide plots was facilitated by previous years' plant removal. *Potamogeton crispus* (curlyleaf pondweed) was the dominant species at Plots 4 (north herbicide) and 8 (south herbicide) during June 2000. Curlyleaf pondweed was dominant from a stem density perspective in Plot 8 and from a dry weight perspective in Plot 4. Curlyleaf pondweed was not a dominant species in these plots prior to herbicide treatment or during a year in which herbicide treatment occurred. The data indicate that herbicide treatment prevented curlyleaf pondweed from becoming dominant during treatment years. However, treatment may have created uncolonized areas and, thus, provided an opportunity for curlyleaf pondweed colonization of plots during a year in which treatment did not occur.

Although lime slurry treatment also effectively reduced stem density in treatment plots, curlyleaf pondweed did not become dominant in lime slurry plots during treatment years or in 2000, a year in which no treatment occurred. Hence, lime slurry is a more effective management tool for concurrently reducing stem density and minimizing curlyleaf pondweed growth in Big Lake.

4.4 Pilot Program Results

Results of the pilot treatment program confirmed Big Lake needed a reduction in stem density to achieve the lake's goal of a moderate stem density. A moderate stem density is defined as 111 stems per square meter (Crowder and Cooper, 1979). Pre-treatment stem densities ranged from 184 to 621 stems/m^2. The data indicate the lake's plant community is dense. Dense plant growth results in problems for recreational users, primarily hampering navigation and interfering with swimming. Dense plant growth also reduces hunting success of fish predators, limiting growth rates of gamefish (e.g., northern pike) and leading to an unhealthy increase of forage species (e.g. sunfish).

Although treatment of experimental plots resulted in significant decreases in stem density, none of the treatments achieved the goal of 111 stems per square meter. During 1998, densities in the six treated plots ranged from 216 to 434 stems/m^2. During 1999, densities in the six treated plots ranged from 138 to 396 stems/m^2. Control plot densities during 1998 through 1999 ranged from 126 to 463 stems/m^2. In 2000, densities ranged from 188 to 473 stems/m^2 in the eight experimental plots. Hence, it is unknown whether goal achievement with treatment is or is not feasible. Treatment, however, is expected to reduce stem densities from present dense levels to a density that is nearer the desired moderate level.

Results of the pilot program indicate *Potamogeton crispus* (curlyleaf pondweed) was rarely dominant and rarely occurred in problematic growths within the eight treatment plots. Prior to treatment in May through early-June of 1998, curlyleaf pondweed comprised 0-3 percent of the plant mass (i.e., dry weight) in treatment plots. During 1998 through 2000, curlyleaf pondweed rarely exceeded 5 percent of the plant mass in treatment plots. Curlyleaf pondweed was the dominant species in two plots during June of 2000, but was not dominant in other plots or at other times. The pilot program results differed from expectations based upon 1996 survey results. Survey results in 1996 indicated curlyleaf pondweed was present at 77 percent of sample points and was the most frequently occurring species in the lake. The 1996 survey results indicated curlyleaf pondweed was problematic and that its management would be beneficial to the lake. However, pilot program results indicate the lake's problematic high stem density is generally caused by other species. Therefore, a management program to reduce stem density, regardless of species, is needed to achieve the lake's goal of achieving a moderate stem density.

Treatment effects during the 1998 through 2000 period varied from year to year. In the first year of treatment, it appears that all three treatments were effective and that harvesting was the most effective treatment. During the second year of treatment, harvesting did not appear to be an effective treatment. During the third year of the study, 2000, residual effects were not noted for harvesting. The data indicate lime slurry and herbicide were more effective treatments than harvesting.

Lime slurry and herbicide treatments were effective during the 3-year study. Lime slurry appeared to be more effective than herbicide during 1998. Herbicide appeared to be more effective than lime slurry during 1999. Residual effects from both treatments were evident in 2000. Stem density and dry weight data were in agreement that both treatments were effective.

Analyses of species indicated lime slurry was a more effective management tool for concurrently reducing stem density and minimizing curlyleaf pondweed growth in Big Lake. During 2000, curlyleaf pondweed was dominant in the two herbicide treatment plots. It appears that curlyleaf pondweed dominance in herbicide plots was facilitated by previous years' plant removal. The data indicate that herbicide treatment prevented curlyleaf pondweed from becoming dominant during treatment years. However, treatment may have created uncolonized areas and, thus, provided an opportunity for curlyleaf pondweed colonization of plots during a year in which treatment did not occur. Curlyleaf pondweed did not become dominant in lime slurry plots during treatment years or in 2000, a year in which no treatment occurred. Because curlyleaf pondweed was never dominant in lime slurry plots, lime slurry appears to be more effective in minimizing curlyleaf pondweed growth while reducing overall stem density.

Dominant species in lime slurry plots indicate the treatment encouraged the growth of species considered valuable habitat for the lake's fisheries. Dominant species based on stem density generally differed from dominant species based on dry weights. The most frequently occurring dominant species in the lime slurry plots were:

- **Plot 1 (south lime slurry)**—*Valisneria americana* (stem density) and *Potamogeton amplifolius* (dry weight)
- **Plot 5 (north lime slurry)**—*Elodea canadensis* and *Valisneria americana* (stem density) and *Ceratophyllum demersum* (dry weight)

Changes in dominant species occurred in the study plots, including lime slurry plots, throughout the monitoring period. Other dominant species in the lime slurry plots following treatment include *Potamogeton richardsonii, Potamogeton pectinatus, Zosterella dubia, Potamogeton zosteriformis, Lemna minor,* and *Myriophyllum exalbescens.*

Lime slurry treatment results were somewhat inconsistent. Plot 1 generally noted lower stem densities and dry weights than Plot 5. The non-uniform effects are believed due to increased water movement in Plot 5. Sampling staff observed large numbers of springs within Plot 5. Staff applying the lime slurry to the plot noted that water movement caused some lime slurry to flow from the plot prior to settling to the lake's bottom. Riparian residents observed that while both plots received the same dose of lime slurry, the north plot appeared to have a lighter dose, presumably because some of the lime slurry drifted out of the plot.

An evaluation of lime slurry pros and cons indicates the treatment appears effective, but its experimental status should also be considered. Lime slurry treatment is a little-used experimental treatment and, consequently, less is known about its effects. It is expected to treat the cause of the lake's excess stem density problems by binding phosphorus in the sediments and interstitial porewaters. Hence, the treatment is expected to limit the number of stems that can grow per square meter of lake sediment. The treatment is not expected to be species-selective and is, therefore, expected to impartially impact all species.

Lime slurry, as a management technique for aquatic plants, was developed by the University of Alberta in conjunction with Engineering Services, Alberta Agriculture. Treatment of farm dugouts appeared to effectively control plant growth for a minimum of 2 years. Results of mesocosm experiments indicated lime slurry treatment (i.e., dose of 400 mg/L $Ca(OH)_2$) caused a reduction in porewater soluble reactive phosphorus concentrations. Samples were collected 1 month and 1 year after treatment. Experiment results indicated application of lime to immature plants caused a 30 to 46 percent decrease in biomass of *Myriophyllum exalbescens* and *Potamogeton pectinatus* (i.e., dose of 200 mg/L $Ca(OH)_2$). Immature *Potamogeton richardsonii* and *Lemna trisulcus* were little affected by the treatment. Experiment results indicated application of lime to mature plants (i.e., plants that have reached the water surface) affected all plants and caused a 64 to 100 percent decrease in biomass as compared with untreated controls (i.e., dose of 200 mg/L $Ca(OH)_2$). The experiment results indicate lime inhibits aquatic plant growth in the short-term as a result of changes in open-water pH and carbon availability and, in the long-term, by decreasing phosphorus availability in the sediments. Calcium added by lime treatment binds phosphorus in the sediments, thereby rendering it unavailable for plant growth (Prepas et.al. 1992).

5.0 Recommendations

Dense plant growths throughout the littoral portion of Big Lake have consistently interfered with the lake's aesthetic quality and recreational value. Dense plant growths can also harm the quality of a lake's fishery (Wiley et al. 1984; Bettoli et al. 1992). Dense macrophytes can cause panfish and game fish to become stunted via two pathways. First, feeding rates generally are reduced in lakes with dense macrophytes (Crowder and Cooper 1982). Although prey abundance (either insect or fish) may increase as macrophyte density increases, macrophytes also reduce predator foraging efficiency by providing a refuge for prey. Therefore, feeding rate (determined by the combination of prey abundance and foraging efficiency) is maximized at intermediate macrophyte densities and reduced as densities increase beyond that point (Heck and Crowder 1991; Savino et al. 1992). Second, dense vegetation generally reduces foraging efficiency of piscivores and lowers predator-induced mortality rates of small fishes (Savino and Stein 1982; Gotceitas and Colgan 1989). This reduction in mortality leads to a greater population density and stronger competitive interactions among small fishes (Mittelbach 1988). A moderate plant density is ideal for optimum aesthetic quality, recreational value, and fisheries growth rates. A moderate plant growth is defined as 111 stems per square meter (Crowder and Cooper 1979) or a coverage of 25 to 50 percent (Newman 2001). The potential for improving growth and size-structure of fishes by reducing macrophyte densities has long been recognized. As early as 1941, Swingle and Smith recommended macrophyte control as a strategy "for correcting conditions that produce impounded waters" (Swingle and Smith 1941). Since that time, the idea has been proposed and tested many times (reviewed in Engel 1995). In 1998, a multi-lake experiment was completed to determine whether removal of macrophytes from approximately 20 percent of the littoral zone would result in improved gamefish growth rates. Experiment results indicate substantially increased growth rates of some age classes of both bluegill and largemouth bass in treatment lakes relative to controls were observed in the first year after manipulation (Olson et al. 1998).

Large-scale treatment of Big Lake with lime slurry is recommended to reduce stem density to a moderate level (i.e., 111 stems per square meter) or to a level as close as possible to the moderate level. Treatment of a navigation channel approximately 80-feet wide, extending from the dock ends outward to the open water areas, during mid-June of 2 consecutive years is recommended for most of the lake's littoral area. A 20-foot wide navigation channel is recommended through two areas designated by the WDNR as aquatic plant management sensitive areas. A treatment area of approximately 21 acres is expected. A calcium hydroxide dose rate of 300 mg/m^2 lake surface area is

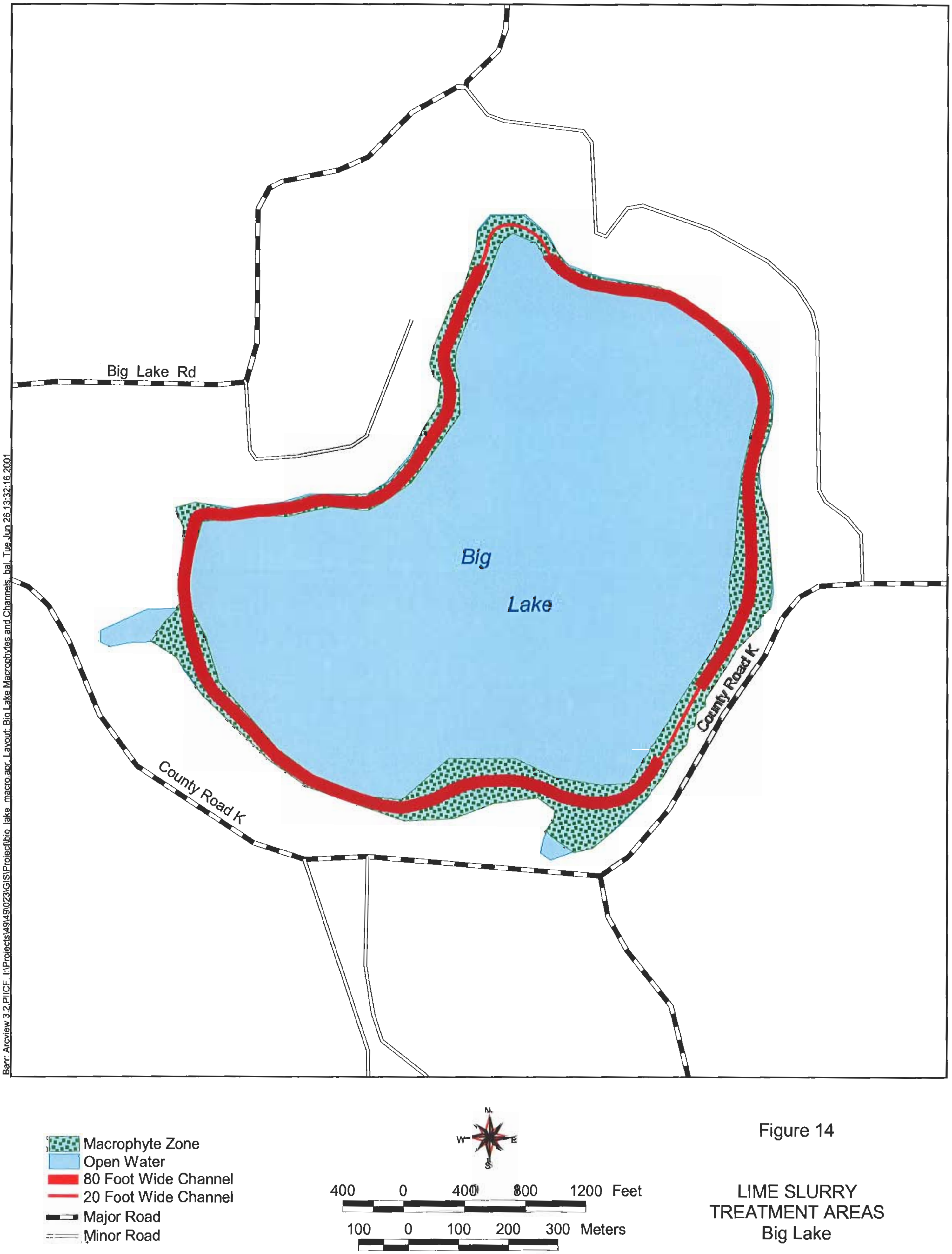


Figure 14

LIME SLURRY TREATMENT AREAS
Big Lake

recommended. Treatment cost is expected to range from $16,000 to $28,000 per year, depending upon the contractor selected for the treatment. The recommended treatment area is shown in Figure 14.

As discussed in the preceding paragraph, some areas within Big Lake were designated by the Wisconsin Department of Natural Resources as aquatic plant management sensitive areas (See Figure 15). The lake contains four sensitive areas, two within the recommended treatment area and two that are not included in the recommended treatment area. Aquatic vegetation in these areas provides valuable spawning , feeding, and nursery areas for fish populations. Although lime slurry is not expected to harm the vegetation in these areas, a conservative approach is recommended to insure protection of these areas. It should be noted that one of the aquatic plant management sensitive areas was Plot 5 in the pilot program and was treated with lime slurry during 1998 and 1999. As discussed previously, the data indicate no adverse changes following lime slurry treatment. However, it is recommended that only 20-foot wide channels be treated until an evaluation of the large-scale treatment program is completed. An evaluation of the treatment program will provide information regarding the impact of a large-scale treatment program on sensitive areas (e.g., Plot 5). The feasibility of treating 80-foot wide navigation channels through the aquatic plant management sensitive areas should then be determined. If a study of the large-scale treatment program indicates additional treatment within the sensitive areas would not be detrimental, then treatment of an 80-foot wide navigation channel through the sensitive areas is recommended. Treatment dose (300 mg/m^2), frequency (2 consecutive years), and application time (mid-June) should be the same as the large-scale treatment program, unless study results indicate a need for modification of one or more parameters.

Treatment of four areas within Church Pine and Round Lake is recommended as a part of the large-scale treatment program. The areas recommended for treatment are one small bay and three navigation channels currently harvested annually per recommendations in the lakes' macrophyte management plan. The bay area and navigation channels provide lake access to lake-users living adjacent to very dense plant growths. Because the Big Lake pilot program determined that lime slurry is a more effective management technique than harvesting, treatment of Round and Church Pine lakes with lime slurry is recommended. Lime slurry treatment of the bay area and navigation channels is expected to effectively reduce stem density, thus enabling navigation of these areas. Lime slurry treatment of a small bay area and one 80-foot navigation channels is recommended. A 20-foot wide navigation channel is recommended within two aquatic plant management sensitive areas (See Figure 15). As discussed in the preceding paragraph, a conservative treatment approach of sensitive areas is recommended until results of a study of the large-scale treatment program are available. If study results of the large-scale treatment program indicate additional treatment within the sensitive areas would not be detrimental, then treatment of an 80-foot wide navigation channel through the two sensitive areas is recommended. Treatment dose (300 mg/m^2), frequency (2 consecutive years), and application time (mid-June) should be the same as the large-scale treatment program, unless study results indicate a need for modification of one or more parameters. Treatment of a small bay area and three navigation channels within Church Pine and Round Lake is expected to cost approximately $1,600 to $3,200 depending upon the contractor selected for treatment. The recommended treatment areas are shown in Figures 16 and 17.

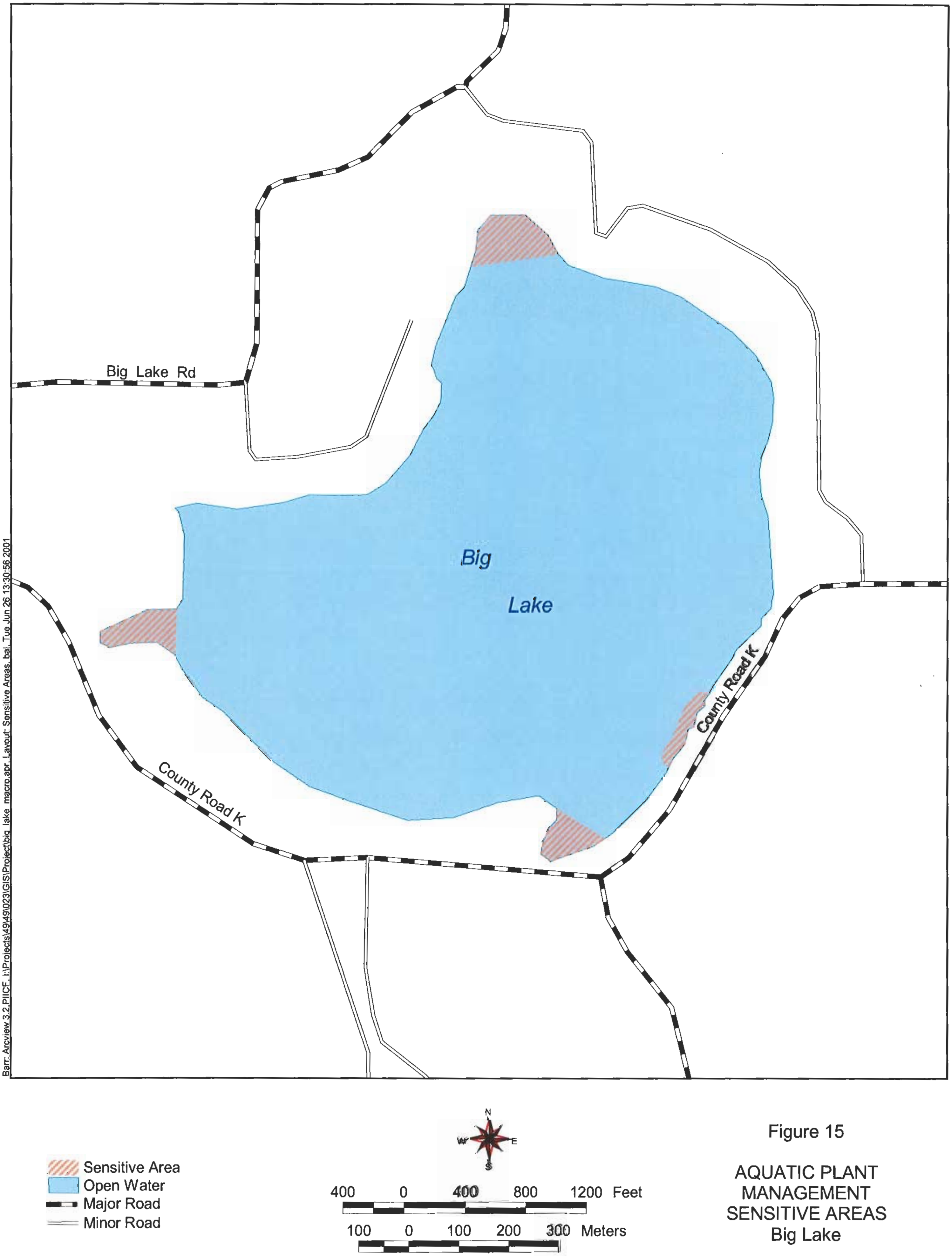


Figure 15

AQUATIC PLANT MANAGEMENT SENSITIVE AREAS
Big Lake

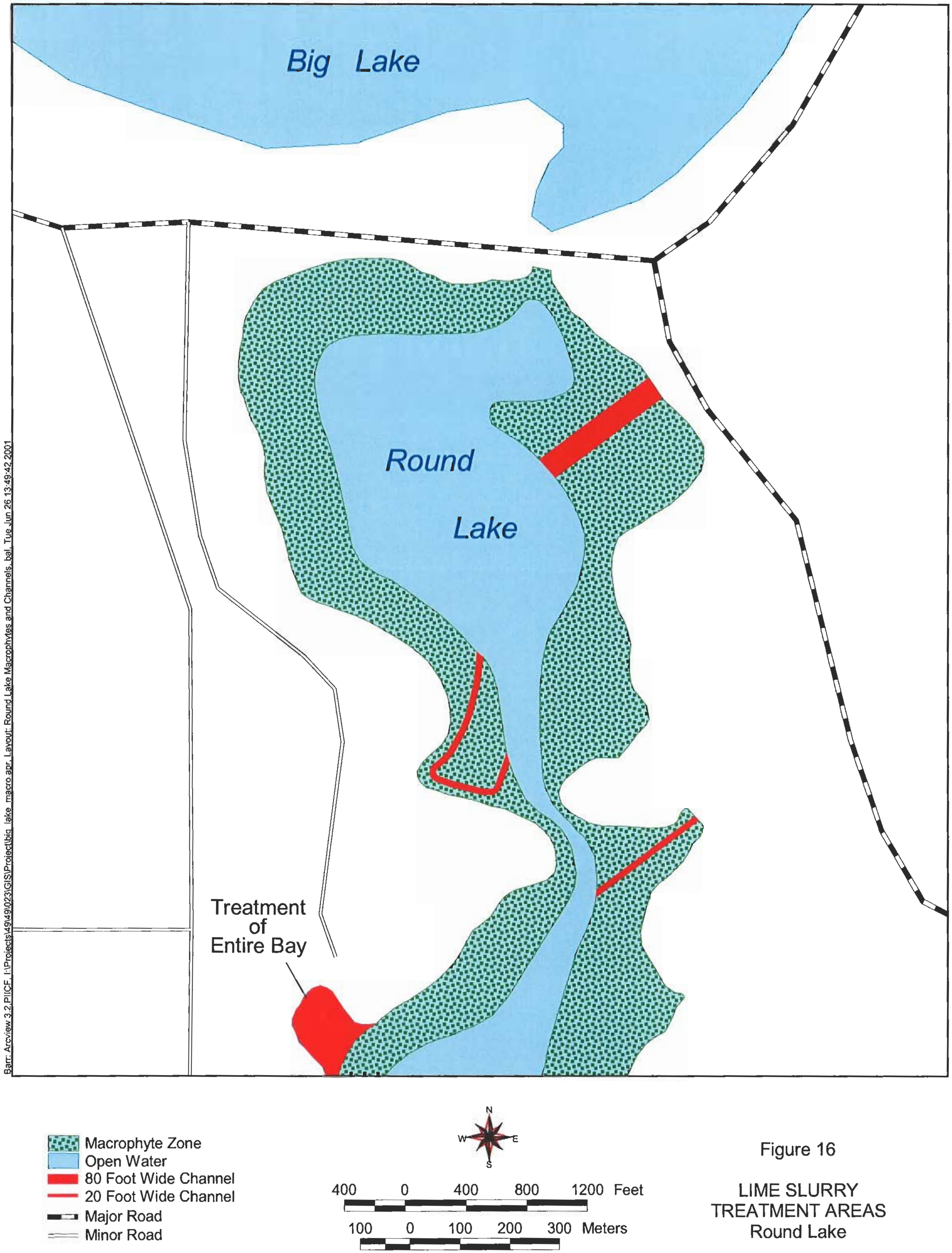
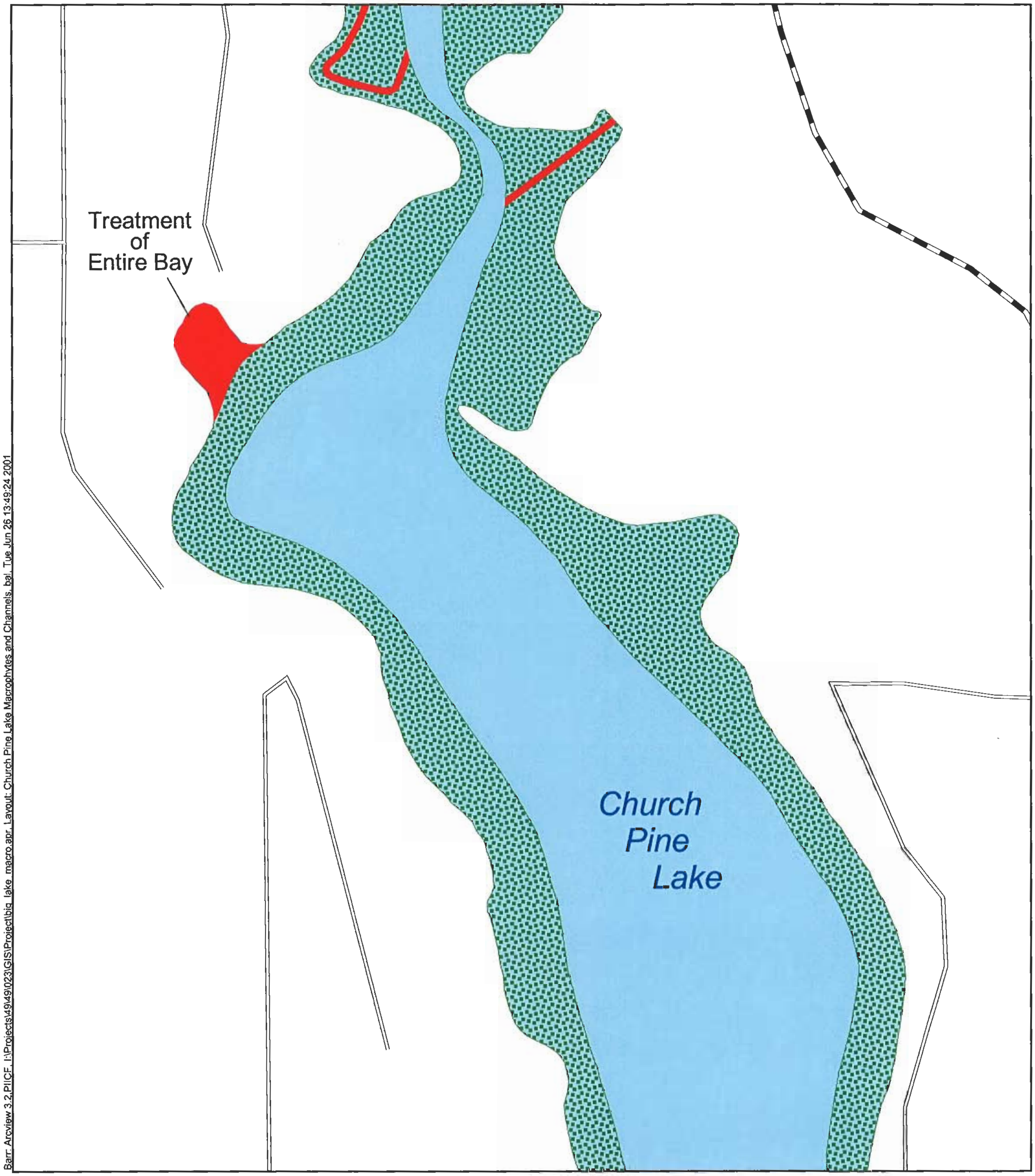


Figure 16

LIME SLURRY TREATMENT AREAS
Round Lake



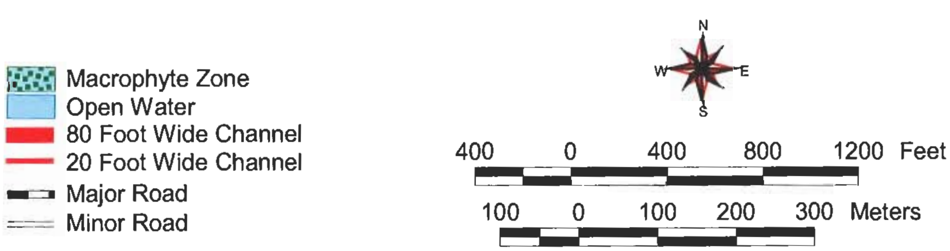


Figure 17

LIME SLURRY
TREATMENT AREAS
Church Pine Lake

5.1 Evaluation Program

An evaluation program is recommended to determine impacts of the large-scale treatment program on Big Lake, Church Pine Lake, and Round Lake. A sample plot should be selected within each of the two treatment areas of Church Pine Lake and within each of the two treatment areas of Round Lake. Sampling in Church Pine and Round Lake plots should occur at the same times as Big Lake sampling and the same methodology should be followed. The Big Lake evaluation program should duplicate the pre-treatment and 2000 sample programs. Sampling in Big, Church Pine and Round lakes should occur during May and June of the first year of treatment and again during the year subsequent to the second year of treatment. Sampling in Big Lake should occur at the eight experimental plots used in the pilot program. Sample dates should be as close as possible to the pre-treatment and year 2000 sample dates. Sampling in Church Pine and Round Lake should occur at four 1-acre plots (i.e., 2 in Church Pine Lake and 2 in Round Lake, located within the lakes' treatment areas). Sample collection, sample analysis, and data analysis methodology should be as described in the methods section of this report. Big Lake data collected from the large-scale treatment program should be compared with pre-treatment data and data collected during 2000 to determine changes resulting from large-scale lime slurry treatment of the lake. Pre-treatment and post-treatment data collected from Church Pine and Round lakes should be compared to determine the effectiveness of lime slurry treatment of the lakes.

5.2 Funding Sources

Lime slurry treatment is an experimental management method that has likely not been used in Wisconsin prior to the Big Lake pilot program. Hence, a large-scale treatment has likely not yet occurred in Wisconsin. Because the management technique appears to concurrently accomplish the goals of enhanced recreational use and improved fisheries habitat, it is considered a promising and desirable management technique. Hence, it is recommended that WDNR Lake Protection funding be obtained to fund the lime slurry treatment and the evaluation program to determine treatment effects on Big, Church Pine, and Round Lakes. The project will provide the WDNR with a unique opportunity to evaluate a promising new macrophyte management tool. The Lake Protection grant program provides the opportunity to obtain up to $200,000 of grant funding. The Church Pine, Round, and Big Lake Protection and Rehabilitation District would be required to pay 25 percent of the project cost. The local share of payment can be in the form of cash or volunteer labor, valued at $5 per hour. Lake Protection grant applications must be submitted by May 1 of each year. Grant awards generally occur around October 1 of each year.

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