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Whole Lake Fluridone Treatments For Selective Control of Eurasian Watermilfoil: II. Impacts on Submersed Plant Communities

John D. Madsen

Biological Sciences Department
S-242 Trafton Science Center
Minnesota State University
Mankato, MN 56001

Kurt D. Getsinger, R. Michael Stewart

U.S. Army Engineer Research and Development Center
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Chetta S. Owens

ASI Corporation
U.S. Army Engineer Research and Development Center
Lewisville Aquatic Ecosystem Research Facility
RR #3, Box 446
Lewisville, TX 75056-9720

ABSTRACT

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The aquatic herbicide fluridone is being used in northern tier states to selectively control the submersed exotic species Eurasian watermilfoil (*Myriophyllum spicatum* L.) growing in lakes and reservoirs. Reliable quantitative information linking changes in the submersed plant community following fluridone applications is limited, particularly with respect to water residue records. Therefore, a study was conducted to investigate the effect of low-dose fluridone treatments on the submersed plant communities in four lakes in Michigan. The overall study objective was to determine whether submersed plant species diversity and frequency were impacted by low-dose fluridone applications in the year of treatment, when targeting a whole lake for Eurasian watermilfoil control. The primary objectives of this portion (part II) of the overall study was to determine fluridone effectiveness on the exotic submersed species Eurasian watermilfoil (*Myriophyllum spicatum* L.) and to evaluate shifts in plant species diversity at one year posttreatment. Secondary objectives included determining fluridone effectiveness on the exotic submersed species curlyleaf pondweed (*Potamogeton crispus* L.) and verifying laboratory-derived results of fluridone concentration and exposure time relationships with respect to efficacy against Eurasian watermilfoil. Quantitative sampling of vegetation was performed using point-based frequency of species occurrence to evaluate whole-lake distribution and diversity of the submersed plant community of all eight study lakes. The technique was implemented using global positioning and geographic information systems, with a minimum grid resolution of 50 m by 50 m. Plant surveys were conducted in early to mid May and in mid August in 1997 (year of treatment) and 1998 (12 and 15 months posttreatment). The fluridone concentration and exposure time (CET) relationship resulted in good to excellent control of Eurasian watermilfoil through 15 months posttreatment on three of the treated lakes (Big Crooked, Camp, and Lobdell). On a fourth lake, Wolverine, the required CET relationship was not maintained and poor control of Eurasian water milfoil was observed. There was no strong evidence of long-term curlyleaf pondweed control in any of the fluridone-treated lakes. The herbicide application strategy used in this study did not significantly impact the native plant species diversity or cover in the year of treatment, or through 15 months posttreatment, in any of the fluridone-treated lakes. Native plant cover was maintained at levels >70% in the year of treatment and at one year posttreatment; a level above the range (20 to 40%) recommended for healthy fish and wildlife habitat. The selective control of Eurasian watermilfoil achieved in this study verified results from previously conducted laboratory and outdoor mesocosm evaluations.

Key Words: Sonar AS, aquatic plant control, invasive species, low-dose herbicide, non-target plants.

Limiting the growth of the submersed species Eurasian watermilfoil (*Myriophyllum spicatum* L.) in its introduced range is important because the morphology and physiology of this plant enable it to form large dense stands that out compete and displace native plant communities (Grace and Wetzel 1978, Aiken et al. 1979, Madsen et al. 1988, 1991, Smith and Barko 1990). These weedy Eurasian watermilfoil infestations also negatively impact fish and wildlife habitat, water quality, and recreational uses of water bodies (Hansen et al. 1983, Newroth 1985, Ross and Lembi 1985, Nichols and Shaw 1986).

There is some debate among the lake management community concerning the selective plant control properties of the aquatic herbicide fluridone when used in whole-lake treatment scenarios (Kenaga 1993, 1995). Although cover and diversity of native species has usually recovered by one to three years post-treatment following a whole-lake fluridone application, even at rates ≥ 20 $\mu g \cdot L^{-1}$ (Getsinger 1993, Smith and Pullman 1997), much of the concern has focused on potential impacts to fish populations and overall lake ecology following the removal of a portion of vegetation throughout the lake in the year of treatment. Field observations and reports indicate that when fluridone is applied at water concentrations ≥ 10 $\mu g \cdot L^{-1}$, some non-target plant species may survive the year of treatment while others do not (Kenaga 1993, 1995; Welling et al. 1997; Smith and Pullman 1997). Uncertainties, however, in the aqueous fluridone concentrations achieved and maintained in these situations, have left the issue of defining optimal treatment rates for selective plant control unresolved. In addition, methods used in these studies to determine selectivity were subjective and data were not subjected to statistical analysis.

Since reliable quantitative information linking changes in submersed plant species diversity with fluridone treatments is limited, particularly with respect to water residue records, a 2-year study was conducted in which prescription low-dose fluridone treatments were applied to selected lakes in Michigan. The overall study objective was to determine whether submersed plant diversity and frequency of occurrence are affected by whole-lake, low-dose fluridone applications in the year of treatment when targeting for control of Eurasian watermilfoil. Additional objectives of the study were to: a) provide a fluridone application strategy that would maintain a threshold dose of fluridone in the treated lakes to selectively control Eurasian watermilfoil; b) determine herbicide effects on the exotic submersed species curlyleaf pondweed (*Potamogeton crispus* L.); c) measure the effect of thermal stratification on water column distribution of fluridone; d) verify laboratory results of fluridone concentration and exposure time relationships with respect to plant control; and e) correlate a new immunoassay fluridone water residue technique with the conventional high performance liquid chromatography (HPLC) method.

In this paper, the authors report on the efficacy of the whole lake treatments on Eurasian watermilfoil and curlyleaf pondweed, and on impacts to the non-target submersed plant communities. A companion paper (Getsinger et al. 2002) reports on the whole lake application strategy, and the dissipation and distribution of fluridone residues in the treated lakes. While a third paper (Netherland et al. 2002) reports on the correlation of the immunoassay and HPLC analytical methods for measuring aqueous levels of fluridone.

Materials and Methods

Eight lakes, approximately 55 to 220 ha in size and located in the eastern and western portions of southern Michigan, were selected for the study. County location, surface area, depth, and littoral zone information for each lake are presented in Table 1. These lakes represented typical water bodies in the southern region of the state managed for the control of Eurasian watermilfoil and curlyleaf pondweed using herbicides. Although all of these lakes were infested with Eurasian watermilfoil, and most with curlyleaf pondweed, they also contained a total of 23 species (average per lake = 7 species) of non-target native submersed plants at the initiation of the study. The most common native species included coontail (*Ceratophyllum demersum* L.), muskgrass (*Chara* spp.), water stargrass (*Heteranthera dubia* (Jacq.) MacM.), large-leaved pondweed (*Potamogeton amplifolius* Tuckerm.), Illinois pondweed (*P. illinoensis* Morong), sago pondweed (*P. pectinatus* L.), small pondweed (*P. praelongus Wulf.*), Robbins pondweed (*P. robbinsii* Oakes), flatstem pondweed (*P. zosteriformis* Fern.), and wild celery (*Vallisneria americana* Michx.). A complete list of the submersed plants and their frequency of occurrence on all of the study lakes can be found in Getsinger et al. 2001a.

Four of the lakes, Lobdell (221 ha), Wolverine (98 ha), Big Crooked (65 ha), and Camp (55 ha), were chosen for fluridone treatments, and an equal number, Bass (75 ha), Big Seven (68 ha), Clear (75 ha), and Heron (53 ha) were used as untreated reference lakes. The four fluridone-treated lakes were chosen from a pool of lakes that qualified under the Michigan Department of Environmental Quality's (MDEQ) permit procedures to apply fluridone on a whole lake basis in 1997. The untreated reference lakes were selected from a pool of lakes that would not experience

Table 1.–Location, morphometry, and extent of littoral zone for the eight study lakes in Michigan, 1997-1998.

Lake	County	Surface Area (ha)	Mean Depth (m)	Max Depth (m)	Max Plant Depth[1] (m)
Fluridone Treated					
Big Crooked	Kent	65	4.4	18.5	5.5
Camp	Kent	65	7.5	16.7	6.1
Lobdell	Genesee/Livingston	221	3.2	24.4	5.8
Wolverine	Oakland	98	2.9	17.9	3.6
Untreated Reference					
Bass	Kent	75	3.0	10.4	7.6
Big Seven	Oakland	68	2.9	16.7	5.5
Clear	Barry	75	2.3	7.3	6.1
Heron	Oakland	53	3.5	20.1	6.4

[1]Estimate of littoral zone.

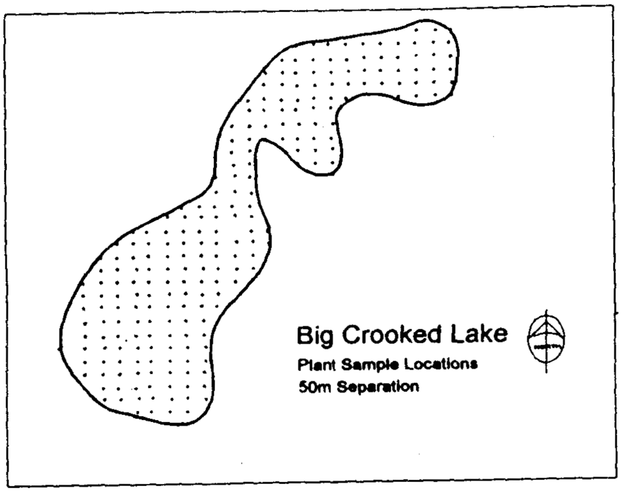
major aquatic plant management activities in 1997 or 1998.

A low-dose whole-lake fluridone treatment strategy was used which was intended to provide control of Eurasian watermilfoil while minimizing injury to non-target plant populations during the year of treatment. This application strategy was utilized on each herbicide-treated lake (12 May 1997 on Lobdell and Wolverine, and on 14 May 1997 on Big Crooked and Camp), employing an initial application method designed to evenly distribute fluridone (formulated as Sonar® AS, at a concentration of 5 $\mu g \cdot L^{-1}$ within the top 3.05 m (10 ft) of the water column over the entire lake. This initial application was followed in two to three weeks by a second, booster application (30 May on Wolverine, Big Crooked, and Camp, and 2 June on Lobdell), designed to re-establish a whole-lake fluridone concentration of 5 $\mu g \cdot L^{-1}$. The purpose of this initial and booster application strategy was two fold: a) to provide maximum control of Eurasian watermilfoil, and b) to compensate for any low initial fluridone residues, while extending the overall fluridone exposure period in the lakes for ≥ 60 d. Details of the fluridone application techniques are provided in a companion paper (Getsinger et al. 2002).

Quantitative sampling of vegetation was performed using point-based frequency of species occurrence to evaluate whole-lake distribution and diversity of the submersed plant community of all eight study lakes. This technique was implemented using grid locations determined by a geographic information system (GIS), and located on each lake using a GPS mounted on a survey boat (Madsen 1999). This type of sampling protocol allowed for a rigorous statistical analysis of the data. Point-based frequency of sampling required up to two days per lake to complete, and was conducted in the spring (early to mid-May) and in summer (mid-August) on each lake, in 1997 (year of herbicide treatment) and in 1998 (12 and 15 months posttreatment). This bimodal, two-year sampling schedule allowed for changes in submersed plant communities to be compared within the year of treatment, and across two successive growing seasons.

For each study lake, a grid of sample points was developed using MapInfo (MapInfo Corp., Troy, NY), a desktop mapping program similar to a GIS. An example of the grid points established on a treated and untreated lake is provided in Fig. 1. The minimum grid resolution was 50 m by 50 m. At least 200 points were visited on each lake, with a maximum of 500 points evaluated dependent upon lake size. Map lake boundaries were taken from digital county highway map database provided by MapInfo. Once on a lake, a GeoExplorer II GPS (Trimble Corp., Santa Rosa, CA) was used to accurately locate sampling points. At each point, water depth was measured, and each species present (in an area approximately one meter square) was identified and recorded. An aquascope was used to aid in underwater viewing of plants. If plants could not be clearly identified from the surface, or if plants at the bottom could not be seen, a rake-type sampling device was lowered through the water column and plants were brought to the surface for species verification. Voucher specimens representing all submersed plant species observed on the study lakes were collected and archived at the U.S. Army Engineer Research and Development Center's Lewisville Aquatic Ecosystem Restoration Facility herbarium. Any unknown or questionable species were sent to a taxonomic expert,

[1]Sonar® is a registered trademark of SePRO Corporation, Carmel, IN. Mention of trade names is not intended to recommend the use of one product over another.



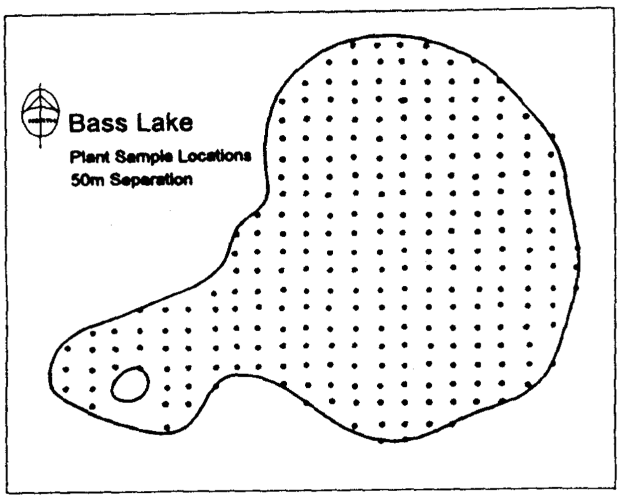


Figure 1.–Plant sampling points grid for a fluridone-treated lake (Big Crooked) and an untreated lake (Bass) in Michigan, 1997-98.

C. Barre Hellquist (North Adams State College, North Adams, MA), for verification.

During the 2-year study period, the contact herbicide diquat [6, 7-dihydrodipyrido(1,2-a:2',1'-c) pyrazinediium dibromide], formulated as Reward®[2], and several types of chelated copper algaecides were used to control nuisance levels of native plants and algae in limited near-shore areas in some of the study lakes. This level of management was required to alleviate problems associated with excessive amounts of vegetation along the near shore areas of lakeside residents and property owners. Since these treatments typically comprised less than 10 percent of the surface area of a lake, were in waters less than 1.3 m in depth, and only controlled some of the shoot mass of the treated vascular plants (due to the mode of action of the herbicides), they had a negligible affect on the whole-lake plant assessment results.

The maximum depth of aquatic vegetation in each lake was used to define the extent of the littoral zones (Table 1). Change in species distribution, or frequency, was evaluated using a Chi-square analysis on 2 by 2 by X tables of frequency in the littoral zone only. Change in diversity as measured by average number of species per sample site were statistically analyzed using a T-test or ANOVA.

Results and Discussion

Eurasian watermilfoil was controlled in all fluridone-treated lakes, except for Wolverine (Fig. 2). Control was excellent in Big Crooked, with a 100% reduction in frequency measured in the year of treatment (1997), and only a 7% frequency of occurrence measured by August 1998, at 15 months posttreatment. Control in Camp was also very good, with a 95% reduction in frequency in the year of treatment, and slight recovery (14% frequency of occurrence) observed by August 1998. Fluridone provided a 93% reduction in frequency of Eurasian watermilfoil in the year of treatment in Lobdell, but growth of that plant had recovered to 10% frequency of occurrence by August 1998.

In these three lakes, removal of Eurasian watermilfoil from upper levels of the water column did not take place until 8 to 12 weeks after initial herbicide application. This slow "knock-down" and collapse of the canopy was most likely caused by the low fluridone rates administered in these treatments, and by the advanced growth stage of the plants at the time of treatment. An application earlier in the plant's growth cycle might have provided a more rapid knock-down. Field observations in other Michigan lakes, and in other states, have indicated that higher rates of fluridone ($>10\ \mu g \cdot L^{-1}$) can knock-down standing beds of the plant in less than 6 weeks posttreatment. This low-dose, boost treatment regime, however, was considered an operational success on Big Crooked, Camp, and Lobdell, since the plant was effectively removed as a nuisance species in the lakes for two growing seasons. As predicted from earlier growth chamber and mesocosm studies (Netherland et al. 1993; Netherland and Getsinger 1995a, 1995b), water residues in these lakes reached a high enough level, and remained in contact with the plant for a long enough period of time to provide effective control.

In Wolverine, the treatment regime was considered

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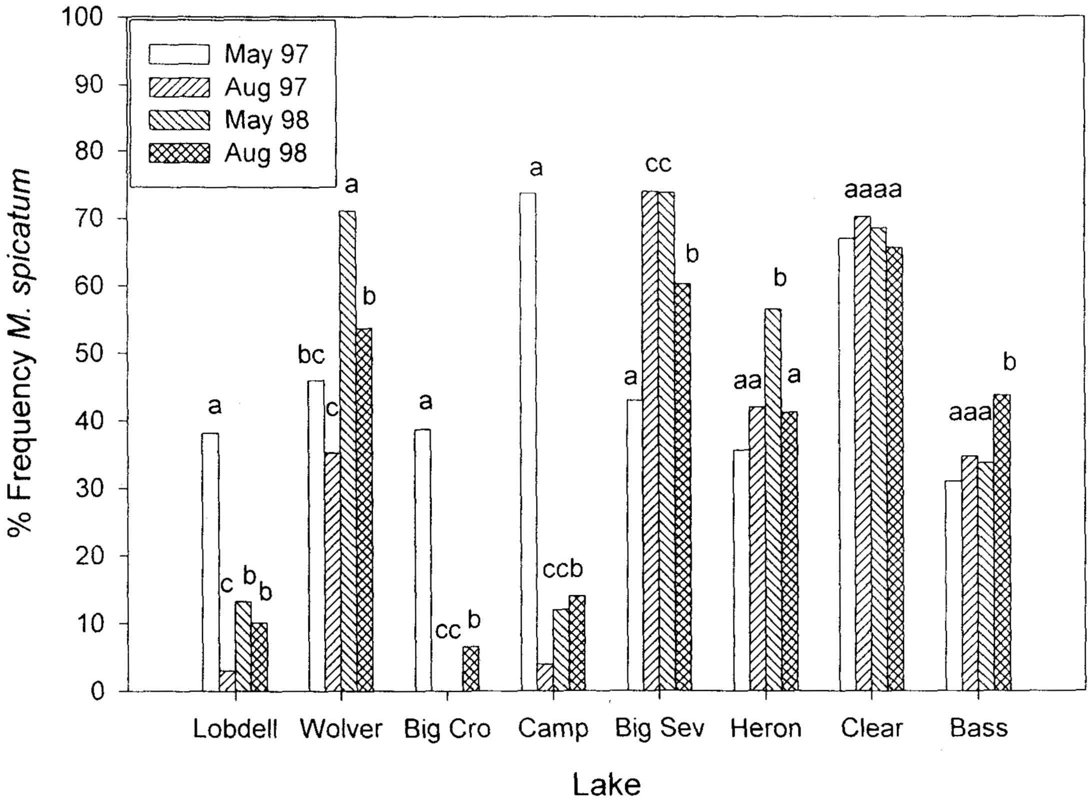

Figure 2.–Percent frequency of Eurasian watermilfoil (*Myriophyllum spicatum*) in fluridone- and untreated lakes in Michigan, 1997-1998.

an operational failure per adequately controlling Eurasian watermilfoil. In that lake, the frequency of the plant was only reduced by 27% in the year of treatment. And by August 1998 the frequency of occurrence was measured at 54%, which was 8% greater than that recorded at the pretreatment evaluation period the previous spring. The low residue levels measured in that lake through the posttreatment period, indicate that lethal levels of fluridone and adequate exposure periods of those levels were never achieved. Although the plant was not controlled, some opening-up of the plant canopy and smaller, stunted shoots were observed in most of the lake, particularly during the year of treatment.

In contrast to the treated lakes, frequency of Eurasian watermilfoil significantly increased in two of the untreated reference lakes, Big Seven and Bass, while levels of the plant remained essentially unchanged in the other two water bodies, Heron and Clear (Fig. 2). The stable or increased growth of Eurasian watermilfoil in these reference lakes provided strong evidence that the decline of the plant in the treated lakes was a direct result of the herbicide application, and was not a consequence of any natural or seasonal phenomena.

The unique life cycle of curlyleaf pondweed allows this plant to grow rapidly in the early spring, form a dense canopy by May, and then decline naturally by late June (Nichols 1999). Moreover, in May and June, curlyleaf pondweed produces numerous compact axillary turions that serve as the source of growth and reinfestation the following spring. Therefore, fluridone applications in mid-May 1997 were likely conducted during peak biomass and just prior to a natural senescence of curlyleaf pondweed. However, under this scenario the timing of treatments would not have prevented production of turions. As expected for a plant that senesces in early summer, posttreatment evaluations in August 1997 showed a significant reduction in curlyleaf pondweed for both treated and untreated lakes.

Curlyleaf pondweed frequency did increase in all fluridone-treated lakes between May 1997 and May 1998 (Fig. 3). This expanded growth represented 1.3 to 3.5 fold increase in curlyleaf pondweed frequency. Anecdotal evidence has suggested that curlyleaf pondweed growth can be stimulated in lakes that have been treated the previous spring with herbicides, including fluridone, and is probably related to reduced competition via removal of Eurasian watermilfoil, and the condition and abundance of the curlyleaf turion bank on a lake-specific basis. Although this growth release seems to have occurred on the treated lakes in this

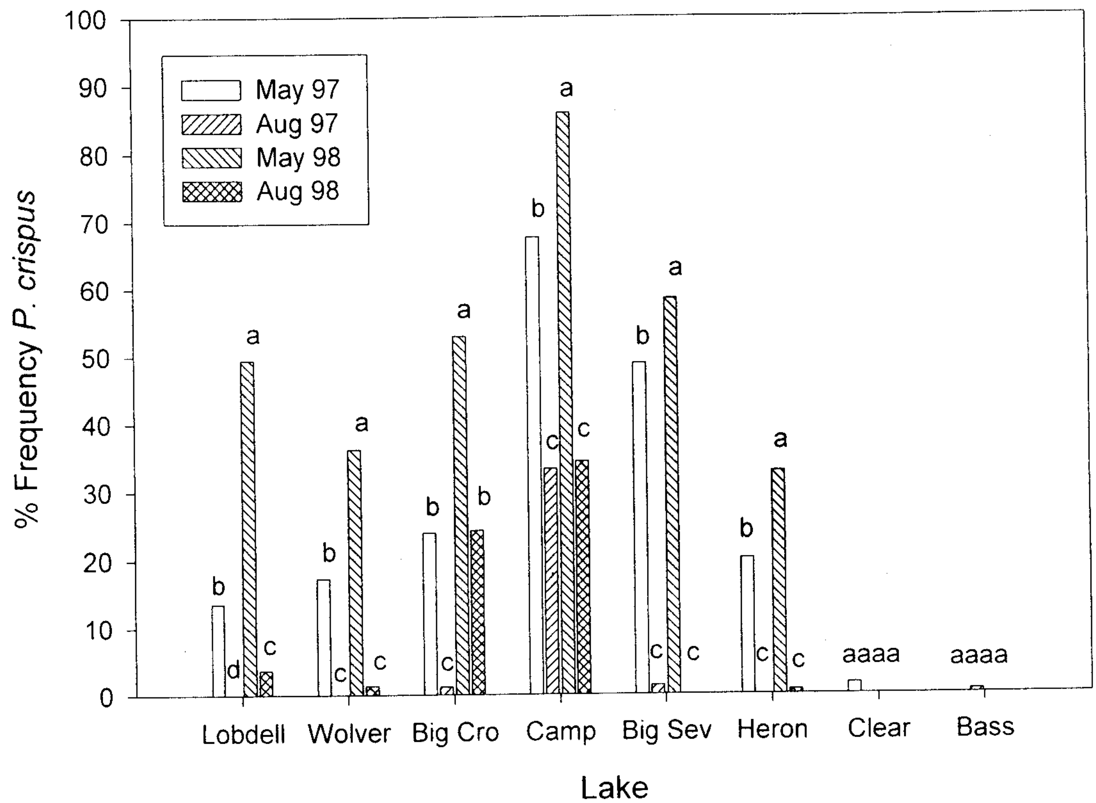

Figure 3.–Percent frequency of curlyleaf pondweed (*Potamogeton crispus*) in fluridone-treated and untreated lakes in Michigan, 1997-1998.

study, it must be noted that an increase, albeit to a lesser extent (1.2 to 1.6 fold), in curlyleaf pondweed frequency also occurred in two of the untreated reference lakes, Big Seven and Heron (Fig. 3). This curlyleaf pondweed growth release was not measured in the other two reference lakes, Bass and Clear, because these lakes had an extremely low proportion of that plant (<1% frequency) in their respective plant communities. The increase in curlyleaf pondweed frequency in untreated reference lakes indicates that some of the expanded growth observed in herbicide-treated lakes may have been related to natural or seasonal events. The warmer than normal temperatures experienced in southern Michigan during winter and spring 1998, for instance, could have contributed to boost growth rates typically exhibited by curlyleaf pondweed.

The increased proliferation of curlyleaf pondweed following fluridone applications suggests that timing of treatments can be critical when managing a lake for the invasive exotics curlyleaf pondweed and Eurasian watermilfoil. Fall fluridone applications and early spring treatments (late March through mid-April), conducted at rates that control Eurasian watermilfoil, can also control curlyleaf pondweed (authors unpubl. data). These early season treatments have the added benefit of controlling curlyleaf pondweed prior to formation of turions. Disrupting the life-cycle of curlyleaf pondweed by preventing production of new turions is currently being investigated as a strategy to provide long-term control of this invasive weed. Data collected from Indiana and Michigan lakes treated with fluridone in the fall and early spring have demonstrated near 100% control of curlyleaf pondweed biomass, as well as a great reduction (60-90%) in viable turions (authors unpubl. data).

Data presented in Fig. 4 indicate that total submersed plant diversity (with Eurasian watermilfoil and curlyleaf pondweed included in the analyses) was significantly greater in the fluridone-treated lakes, both within the year of treatment, and between pretreatment and one year posttreatment. The greatest change occurred between May 1997 and May 1998, where total diversity increased 1.5 to 2.3 fold. Total species diversity remained above the May 1997 levels through August of 1998. Likewise, a significantly greater total species diversity was measured in the untreated reference lakes during the study period (Fig. 4) Diversity levels increased by factors similar to those measured in the treated lakes. While it is clear that the fluridone treatments did not reduce total plant species diversity, the reference lake data suggests that some of the increase in species diversity measured in the treated

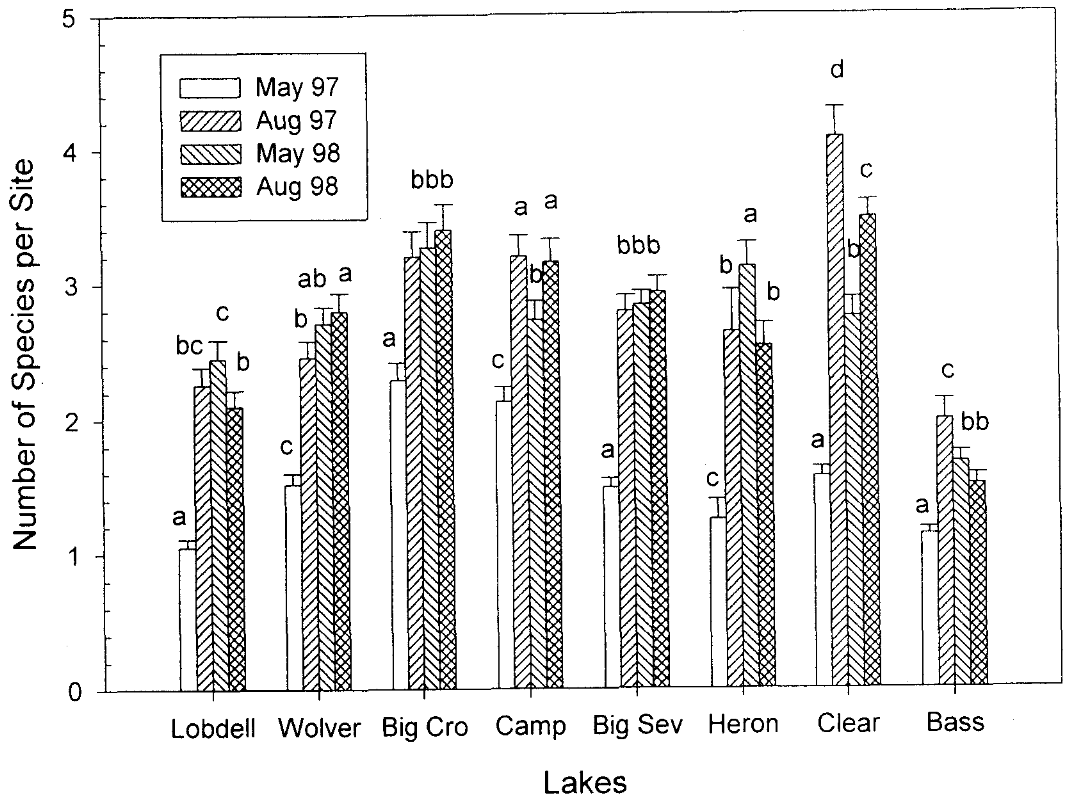

Figure 4.–Number of all submersed plant species per site in fluridone-treated and untreated lakes in Michigan, 1997-1998.

lakes could have been caused by natural or seasonal events.

Native plant species diversity, calculated without the presence of Eurasian watermilfoil and curlyleaf pondweed, was roughly equivalent between the treated and untreated lakes (Fig. 5), and exhibited post-treatment increases very similar to those seen for total species diversity. The greatest increase in species diversity occurred between May 1997 and May 1998, with species numbers still elevated above pretreatment levels in August 1998. Again, this data clearly shows that fluridone treatments did not have a negative impact on species diversity, but the increases observed might have been related to natural events between seasons. Natural shifts in plant community assemblages occur in Northern tier lakes from early spring to late summer, and comparisons within a growing season could be confounded by these seasonal effects.

As an additional method for determining shifts in species diversity, the percent frequency of plant presence (plant cover) for total plant species (including Eurasian watermilfoil and curlyleaf pondweed) and for native plant species (without the inclusion of Eurasian watermilfoil and curlyleaf pondweed) were compared for all lakes within the year of treatment (1997), and between years (1997 and 1998). These analyses indicate that total plant cover, and native plant cover, significantly increased or remained the same in all of the lakes, including those treated with fluridone (Figs. 6 and 7). This data demonstrates that fluridone treatments did not have a negative impact on plant cover, but because of similar shifts in the untreated reference lakes the increases observed might have been related to natural events between seasons. In all cases, posttreatment plant cover was maintained at levels above 60%, which exceeds the plant cover amounts (20 to 40%) in the littoral zone considered optimal for healthy fisheries in Northern tier lakes (Savino and Stein 1982; Wiley et al. 1984, 1987).

Results from this portion of the overall study showed that the low-dose, 5 $\mu g \cdot L^{-1}$ boost to 5 $\mu g \cdot L^{-1}$ whole lake fluridone treatment strategy, can provide control of Eurasian watermilfoil approaching 100% in the year of treatment, and near 90% control through 15 months posttreatment. However, these results can be obtained provided that adequate aqueous fluridone concentration/exposure time (CET) relationship is maintained (i.e.,5 $\mu g \cdot L^{-1}$ fluridone during the initial 2 to 3 weeks of a treatment, followed by an exposure of ≥ 2 $\mu g \cdot L^{-1}$ for a period of at least 60 consecutive days). If the required fluridone CET relationship is not maintained, failure to control Eurasian watermilfoil

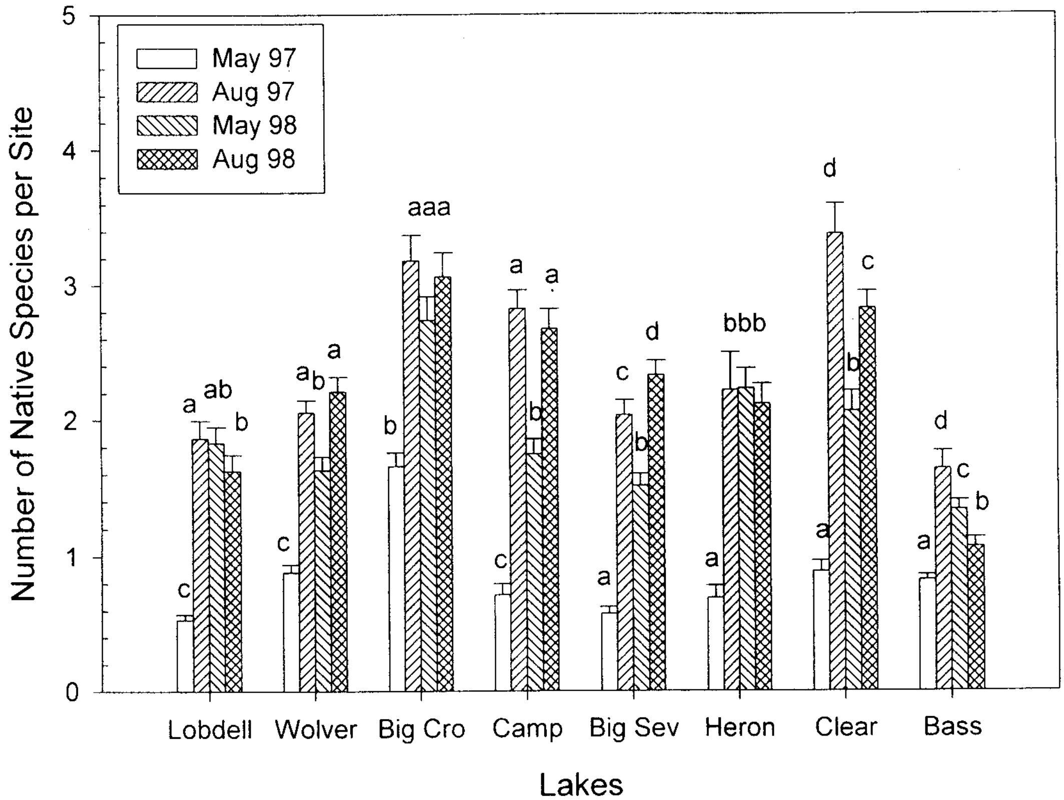

Figure 5.–Number of native submersed plant species per site in fluridone-treated and untreated lakes in Michigan, 1997-1998.

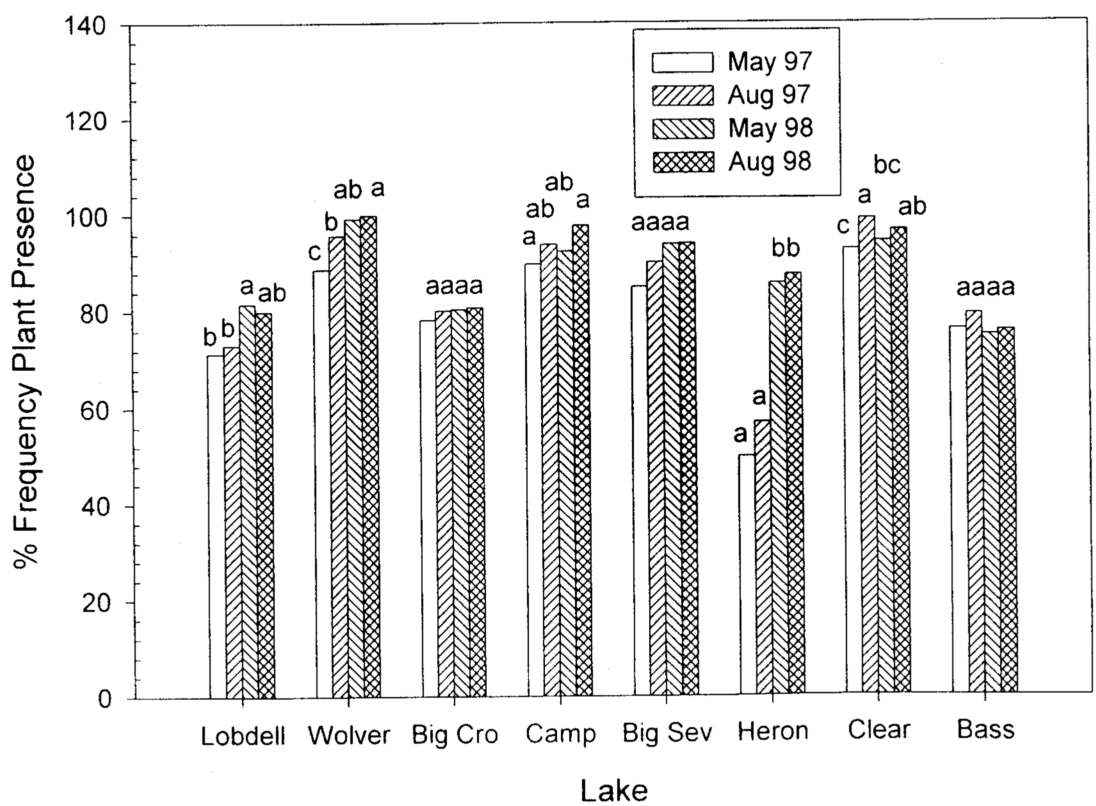

Figure 6.–Percent frequency of all submersed plant species presence in fluridone-treated and untreated lakes in Michigan, 1997-1998.

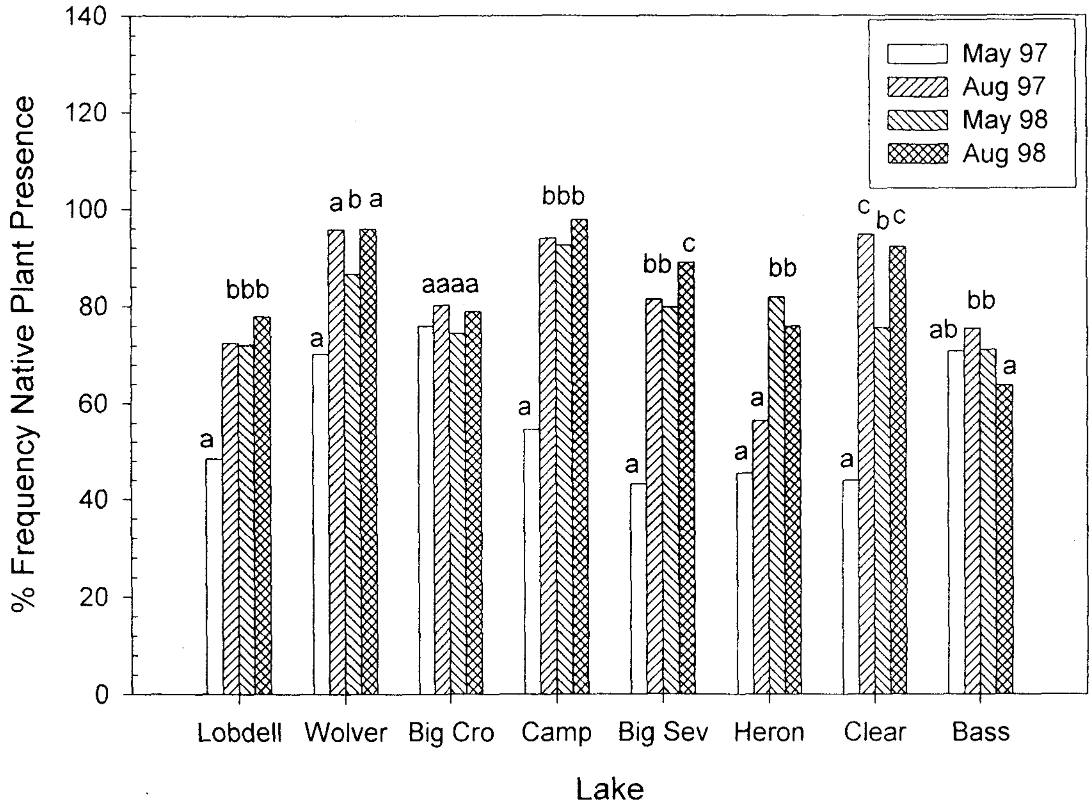

Figure 7.–Percent frequency of native submersed plant species presence in fluridone-treated and untreated lakes in Michigan, 1997-1998.

can also occur under the treatment strategy employed in this study. This was observed on Wolverine Lake where limited control of Eurasian watermilfoil occurred in the year of treatment (27%) and increased in abundance (54%) by 1 year posttreatment.

It was also demonstrated that the treatment strategy used in this study did not significantly impact the native plant species diversity or cover in the year of treatment, or through 15 months posttreatment, following selective control of Eurasian watermilfoil. Moreover, these results provided a field-verification for laboratory-derived CET relationships developed to selectively control Eurasian watermilfoil (Netherland et al. 1993; Netherland and Getsinger 1995a, 1995b; Netherland et al. 1997). Finally, the timing of the fluridone applications in this study were not conducive for long-term control of curlyleaf pondweed. The increase in abundance of that plant (which occurred in both treated and untreated lakes) was most likely related to several factors including plant competition, curlyleaf phenology, and environmental conditions.

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