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Effects of a Low-dose Fluridone Treatment on Submersed Aquatic Vegetation in a Eutrophic Minnesota Lake Dominated by Eurasian Watermilfoil and Coontail

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ABSTRACT

Whole-lake, low-dose applications of fluridone herbicide are often used to control infestations of Eurasian watermilfoil (*Myriophyllum spicatum* L.). Studies in mesotrophic lakes have documented temporary reductions in Eurasian watermilfoil with little effect on native macrophytes and water quality. Less is known regarding the effects of low-dose fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1*H*)-pyridinone) applications in eutrophic lakes. Therefore, we studied the effects of a low-dose fluridone treatment (approx. 6 ppb) on macrophytes and water clarity in a eutrophic Minnesota lake dominated by Eurasian watermilfoil and coontail (*Ceratophyllum demersum* L.). We estimated the frequency of occurrence of macrophyte species in the treatment lake and one untreated reference lake one year before, the year of, and for two years following treatment. We also mapped vegetation biovolume (percent of water column occupied by vegetation) with hydroacoustics just prior to and for two years following the fluridone treatment. Shortly after the treatment, the frequency of Eurasian watermilfoil declined to zero and remained at zero through the last survey. Nevertheless, Eurasian watermilfoil returned at 12% frequency during surveys one year after our study was completed (three years post-treatment). Mean percent biovolume also declined dramatically following treatment and remained low through the last survey. Secchi transparencies in Schutz Lake declined modestly following treatment. Plant frequency and percent biovolume varied over a smaller range in the reference lake. We conclude low-dose fluridone applications in infested, species-depauperate eutrophic lakes can kill large amounts of submersed vegetation that in turn, may negatively affect water clarity and recovery of native plants.

Key words: cover, abundance, management, nonnative, exotic, Sonar A.S.®

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INTRODUCTION

Non-native Eurasian watermilfoil is now widespread across the United States and Canada (Madsen 1997). In Minnesota, as of the end of 2004, Eurasian watermilfoil was established in 160 lakes, rivers, and streams (Invasive Species Programs 2005). Many of these lakes occur in highly developed watersheds within the Twin Cities metropolitan area, are eutrophic, and support high levels of recreational activity (Invasive Species Programs 2005). Given the ability of Eurasian watermilfoil to displace native macrophytes (Boylen et al. 1999), impede recreation by forming canopies at the water surface (Smith and Barko 1990), and affect fish populations (Lillie and Budd 1992, Valley and Bremigan 2002a), pressure to manage infestations is strong. In recent years, the systemic herbicide fluridone has received great attention due its low toxicity to fish and invertebrates (Hamelink et al. 1986), and its potential to selectively kill Eurasian watermilfoil at low doses (5 to 7 ppb; Netherland et al. 1997).

At whole-lake concentrations greater than 10 ppb, experiments in eutrophic Minnesota lakes documented a decline in native macrophytes, reduced littoral cover of vegetation, decreased water clarity, and a disappearance of some non-game fish species (Pothoven 1996, Welling et al. 1997). Temporary increases in largemouth bass and bluegill growth were also documented following treatment (Pothoven et al. 1999).

In contrast, whole-lake experiments in mesotrophic Michigan lakes (Trophic State Index—TSI range = 40-47; Carlson 1977) with low fluridone concentrations (5 to 7 ppb) produced results that were quite different than those observed in Minnesota (Madsen et al. 2002, Bremigan et al. 2005). In multiple lakes, Eurasian watermilfoil was suppressed to low levels for one to three years without significant declines in water quality (Bremigan et al. 2005), native plant cover (Madsen et al. 2002, Bremigan et al. 2005), macroinvertebrates (Cheruvelil et al. 2001), or largemouth bass populations (Valley and Bremigan 2002b, Bremigan et al. 2005).

The goal of our study was to determine whether low-dose fluridone treatments in species-depauperate eutrophic Minnesota lakes could produce results similar to those observed in species-rich mesotrophic Michigan Lakes. To do so, we compared macrophyte species frequencies and biovolume (traditionally referred to as percent volume infested; Canfield et al. 1984) one year before, the year of, and for two years following a low-dose fluridone treatment in a eutrophic lake, and compare results with an untreated reference lake. Water clarity also was monitored before and after treatment in each study lake.

MATERIALS AND METHODS

Study Area

Both study lakes are located within the Twin City metropolitan area of Minnesota (Table 1). In terms of lake morphometry, timing of Eurasian watermilfoil infestation and plant communities prior to infestation, our study lakes are very similar. Our treatment lake, Schutz Lake, is a 43-ha moderately deep eutrophic lake with no major waterway connections. Total Phosphorus (TP) evaluated between the periods of 1989 and 1998 was 30 ppb (MPCA 2005). Eurasian watermilfoil was discovered in Schutz Lake in 1990 (MN DNR unpublished survey data). In 1986, the macrophyte community (and hence, the potential seed/propagule bank) of Schutz Lake was primarily composed of northern watermilfoil (*M. sibiricum* Komarov), coontail (*Ceratophyllum demersum* L.), sago pondweed (*Stuckenia pectinata* (L.) Boerner), water stargrass (*Zosterella dubia* (Jacq.) Small), white waterlily (*Nymphaea odorata* Aiton), and yellow waterlily (*Nuphar* sp.; MN DNR unpublished survey data).

Our reference lake, West Auburn Lake, is also a moderately deep 58-ha. eutrophic lake. Total Phosphorus evaluated between the periods of 1989 and 1998 was 28 ppb (MPCA 2005). Relatively high nutrient loads enter West Auburn Lake through upstream waterways that drain developing municipalities and feedlots (J. Barten, Three Rivers Park District, pers. comm.). Eurasian watermilfoil was discovered in West Auburn Lake in 1989 (MN DNR unpublished survey data). Lake managers were permitted to remove 1.2 ha of aquatic vegetation each year for access to a public boat launch, fishing pier, and swimming beach. No other plant management activities occurred in this lake during the study. Both Schutz and West Auburn lakes contain populations of common carp (*Cyprinus carpio* L.), which are known to negatively impact water clarity through sediment resuspension (Breukelaar et al. 1994).

Procedure

In both lakes, point-intercept species surveys (Madsen 1999) were conducted in June and August one year prior (2001), the year of (2002), and for two years following (2003 and 2004) treatment with fluridone in each lake. Species presence on a double-sided rake, and species visually observed in a 1-m^2 area where the rake was thrown, were recorded from 100 to 150 uniformly spaced points over the surface of the littoral zone. The littoral zone was defined by the area containing macrophytes prior to treatment, which extended to approximately 3.7 meters in both lakes prior to the fluridone treatment.

To measure submersed vegetation biovolume, we used hydroacoustics (Valley et al. 2005). Hydroacoustic surveys followed the same seasonal sampling frequency as species surveys, although we could not begin sampling these lakes until just prior to the fluridone treatments in 2002. Our hydroacoustic methods are described in detail by Valley et al. (2005). We used a Biosonics DE-6000 echosounder equipped with a 6-degree transducer. We collected hydroacoustic data over parallel transects spaced 10 m apart and arranged perpendicular to the longest shoreline. Given ping rates of 5 pulses per second, differentially corrected GPS rates of approximately 2 seconds, and a boat speed of 3 to 5 knots, we were able to achieve high hydroacoustic point densities over the entire littoral surface of each lake. Redundant points were recorded where the boat was slowed to make turns. To filter redundant points, a systematic sampling procedure was performed in GIS to select points from a 20-m by 20-m grid. Hydroacoustic points closest to the input sampling points were selected and all others were disregarded in all subsequent statistical analyses.

Acoustic signals from echosounder data files were processed by Biosonics *EcoSAV*® vegetation analysis software (version 1.2; Biosonics, Inc. 2002). We used a custom built version of this software (1.2.5.2; Biosonics, Inc.) that allowed us greater flexibility in classifying plants in environments where vegetation was growing to the surface (Valley et al. 2005). Ground-truth tests demonstrated relatively high accuracy and precision of plant height and water depth estimations with this software's algorithm (Sabol and Johnston 2001, Sabol et al. 2002). We combined *EcoSAV* estimates of plant height, water depth, and percent cover to estimate the proportion of the water column occupied by vegetation (biovolume).

Vegetation grew to the surface (i.e., biovolume = 100%) over most littoral areas in West Auburn Lake and required supplemental manual sampling with a DGPS and a survey rod (i.e., hydroacoustics does not function effectively when plants grow to the surface; Valley et al. 2005). To collect these data, we navigated to survey points on a 30-m by 30-m sampling grid and recorded data on plant height and water depth, thus providing a means by which to manually calcu-

TABLE 1. LOCATION AND MORPHOMETRY OF THE TWO STUDY LAKES IN CARVER COUNTY, MINNESOTA.

Lake	Latitude-Longitude	Treatment[a]/Reference	Lake size (ha)	Total Phosphorus (ppb)[c]	Percent littoral[b]	Mean depth (m)
Schutz	44°52'N -93°38'W	Trt	43	30	40	6.6
W. Auburn	44°52'N -93°41'W	Ref	58	28	47	7.9

[a]Schutz Lake was treated with 5.4 ppb Sonar A.S.® on 30 May 2002, and boosted to 6.4 ppb 33 days after initial application.
[b]Littoral zone was defined by area within the depth contour that plants frequently occurred.
[c]Data collected by MPCA (2005) and includes seasonal averages pooled between 1989 and 1998.

late data on biovolume. These data were later appended to hydroacoustic data files for all subsequent analyses. Water transparency was measured with a Secchi disk bi-weekly from June through September in each lake by DNR, local county, local citizen, and watershed district personnel.

On 30 May 2002, 15.44 L of fluridone (tradename Sonar A.S.®) was applied to Schutz Lake to achieve a target concentration of 5.0 ppb. Water samples were collected for determination of fluridone concentrations at 1, 4, 8, 14, 21 and 28 days after the initial treatment (DAT) from 5 littoral sites at a depth of 0.3 m. Samples were analyzed using an enzyme-linked immunosorbent assay to determine concentration of fluridone (Netherland et al. 2002). The initial application of Sonar A.S.® produced a concentration of 9.5 ppb fluridone on the day of treatment, and then dropped to 5.4 ppb at four days post-treatment (Figure 1). After 28 days, whole-lake concentration fell to 2.5 ppb, prompting a second application of 7.42 L of Sonar A.S.® so the proper concentration (>2 ppb) and exposure time (>60 DAT) could be achieved (Madsen et al. 2002; Figure 1). Concentration after the second application peaked at 6.3 ppb the first day after application, and steadily declined to 2.3 ppb at 91 DAT (Figure 1).

RESULTS AND DISCUSSION

In 2001, prior to the fluridone treatment, Secchi depths averaged 1.78 ± 0.13 m in Schutz Lake. Eurasian watermilfoil and coontail together dominated the submersed species in both Schutz and West Auburn lakes prior to the fluridone treatment (Table 2). In the two surveys prior to the fluridone treatment in Schutz Lake, Eurasian watermilfoil and/or coontail was present at 87% of the sample sites. During this same time period in West Auburn Lake, Eurasian watermilfoil and/or coontail was present at 98% of the sample sites.

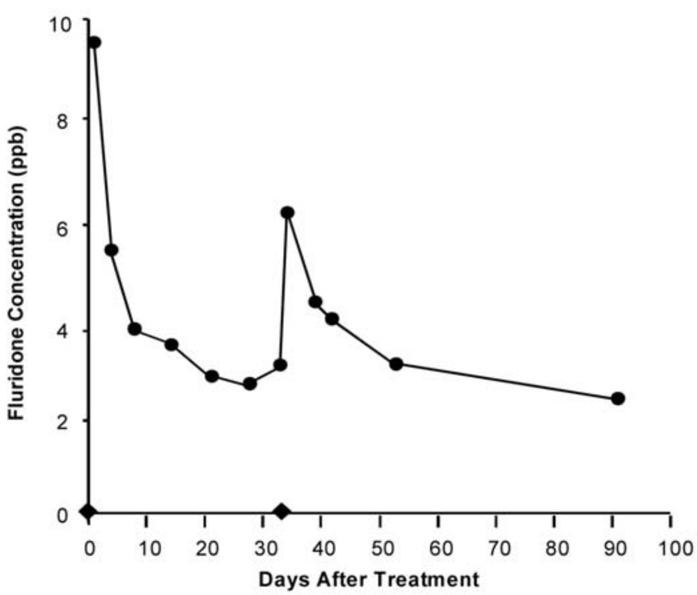

Figure 1. Concentrations of fluridone following the first application of Sonar herbicide on 30 May 2002 and a second application on 2 July in Schutz Lake, Carver County, Minnesota. Treatment on days 0 and 33 are indicated by ◆.

Species richness was relatively low in both lakes in 2001 (Table 3).

Direct Effects of Low-dose Fluridone on Plants

Fluridone had a large direct effect on the macrophyte community in Schutz Lake. Frequencies of Eurasian watermilfoil declined from 64% in June to 0% in August during the year of treatment and remained at 0% for the first two years after treatment (Table 2). Eurasian watermilfoil was rediscovered in Schutz Lake three years after treatment and was present at 12% of the sample sites (MN DNR Eurasian watermilfoil program, unpubl. data). Coontail, which is susceptible to a wide range of fluridone concentrations (SePRO Corp. Carmel, IN; Smith and Pullman 1997), declined from 80% in June to 55% in August during the year of treatment. We observed pink discoloration on the apices of coontail plants during the year of treatment, indicating fluridone was affecting metabolic processes in coontail plants. In addition, we observed a large decline in biovolume in Schutz Lake two months following treatment (Figure 2). White and yellow waterlilies apparently were not affected by the treatment because their frequencies remained similar throughout the study (Table 2).

Indirect Effects of Low-dose Fluridone on Plants

During the first and second years after treatment, we assumed that fluridone was no longer having a direct effect on the vegetation because concentration of the herbicide reached a low level of 2.3 ppb at 91 DAT on 29 August 2002 (Figure 1). Consequently, changes in the vegetation after this time are considered indirect effects. The invasive, non-native curly-leaf pondweed (*Potamogeton crispus* L.) increased in frequency during June of the years following treatment (Table 2). Nevertheless, curly-leaf pondweed colonies were not dense (Figure 2). The native sago pondweed also increased in frequency during June of the first year after treatment, but declined in the next year (Table 2). These two species produce propagules that remain dormant in the substrate until conditions become suitable for germination (Bolduan et al. 1994, Kantrud 1990). Apparently, conditions were more favorable for curly-leaf pondweed than sago pondweed. Over the course of the study, percent frequency of all submersed plants within the 3.7-m vegetated zone declined from 90% during August of 2001 to 28% by August 2004. Percent frequency of native submersed plants declined from 88% during August 2001 to 26% by August 2004 (Table 2). Most areas of the littoral zone remained denuded of submersed vegetation throughout the study (Figure 3).

Average water clarity declined in Schutz Lake following the fluridone treatment (Figure 4). This change may have been due to a combination of high ambient levels of phosphorus, an increase in curly-leaf pondweed following treatment (early season senescence of this species often is followed by algal blooms; Bolduan et al. 1994), and resuspension of denuded sediments by carp (Breukelaar et al. 1994).

For reasons uncertain, percent frequency of all plants in untreated West Auburn Lake declined modestly in 2003 (Table 2). In 2004, vegetation biovolume was higher than in

Table 2. Percent frequency of commonly occurring taxa (with at least one occurrence of 20% or greater in at least one lake on one sampling date) within the littoral zones of Schutz and West Auburn lakes, Carver County, Minnesota before (above dashed line) and after (below dashed line) a low-dose fluridone treatment in Schutz Lake. *Chara* sp., *Fontinalis* sp., *Potamogeton nodosus* Poiret, *P. pusillus* L., *Zannichellia palustris* L., and *Zosterella dubia* (Jacq.) Small, and *Nitella* sp. were also sampled in Schutz Lake throughout the study, all at less than 8% frequency. In West Auburn Lake, *Brasenia shreberi* Gmel., *Elodea* sp., *P. illinoensis* Morong, *Myriophyllum sibiricum* Komorov, *Najas* sp., *P. amplifolious* Tuckerman, *P. natans* L., *P. nodosus* Poiret, *Ranunculus* sp., *Zannichellia palustris* L., and *Zosterella dubia* (Jacq.) Small were also sampled throughout the study, all at less than 4% frequency.

Lake	Month	Year	*M. spicatum*	*Ceratophyllum demersum*	*P. crispus*	*P. zosteriformis*	*Stuckenia pectinatua*	*Nymphaea* sp.	*Nuphar* sp.	Submersed spp. frequency (%)	Native submersed spp. frequency (%)
Schutz	June	2001	57	70	16	0	16	31	18	92	77
Treated 5/30/02	August	—	56	86	2	0	11	42	20	90	88
	22 June	2002	64	80	4	0	4	35	18	94	82
	August	—	0	55	0	0	0	26	22	57	57
	June	2003	0	6	33	0	17	31	19	47	26
	August	—	0	11	2	0	26	41	20	41	41
	June	2004	0	8	40	0	13	28	19	53	27
	August	—	0	17	5	0	11	39	25	28	26
W. Auburn	June	2001	93	98	10	20	12	20	5	100	98
	August		83	93	0	15	9	28	3	96	93
	June	2002	97	96	5	13	0	17	3	100	97
	August		95	92	0	8	3	35	5	99	92
	June	2003	87	96	9	10	2	22	3	97	97
	August		75	89	0	3	3	33	2	72	69
	June	2004	86	88	16	3	3	22	2	95	89
	August		89	95	0	7	16	35	6	100	95

TABLE 3. SPECIES RICHNESS AND AVERAGE RICHNESS PER SITE IN SCHUTZ AND WEST AUBURN LAKES, CARVER COUNTY, MINNESOTA BEFORE (ABOVE DASHED LINE) AND AFTER (BELOW DASHED LINE) A LOW-DOSE FLURIDONE TREATMENT IN SCHUTZ LAKE.

Lake	Month	Year	Submersed species richness	Avg. no. submersed spp. per site
Schutz	June	2001	8	1.7
Treated 5/30/02	August		7	1.6
	22 June	2002	6	1.5
	August	2002	4	0.6
	June	2003	6	0.6
	August		6	0.5
	June	2004	4	0.7
	August		4	0.3
W. Auburn	June	2001	7	2.4
	August		6	2.0
	June	2002	8	2.2
	August		11	2.1
	June	2003	10	2.1
	August		7	1.2
	June	2004	8	2.0
	August		7	2.1

2003, but still lower than 2002. In 2004, percent frequency of plants returned to levels similar to those observed in 2001 and 2002 (Table 2). This slight decline and recovery in West Auburn Lake contrasts with substantial and continual decline in Schutz Lake. In West Auburn Lake, water clarity was lower in 2002 than in other years (Figure 4B), presumably because of high levels of precipitation during summer (J. Barten, Three Rivers Park District, pers. comm.).

The initial large reductions in the distribution and abundance of submersed plants following treatment of fluridone were expected since Eurasian watermilfoil dominated the plant community in Schutz Lake. We had anticipated at least some increase in native submersed plants within a year after treatment, based on results in Michigan (Madsen et al. 2002, Schneider 2000). Similar to the outcome in Schutz Lake, Schneider (2000) documented large reductions in plant cover in mesotrophic Michigan lakes using high rates of application, but observed recovery of chara (*Chara* sp.) and water celery (*Vallisneria americana* L.) in most lakes within a year following treatment. Rapid recovery of native plants has been observed in mesotrophic Minnesota lakes treated with fluridone as well (Welling et al. 1997, Crowell 2004, Crowell and Proulx 2004).

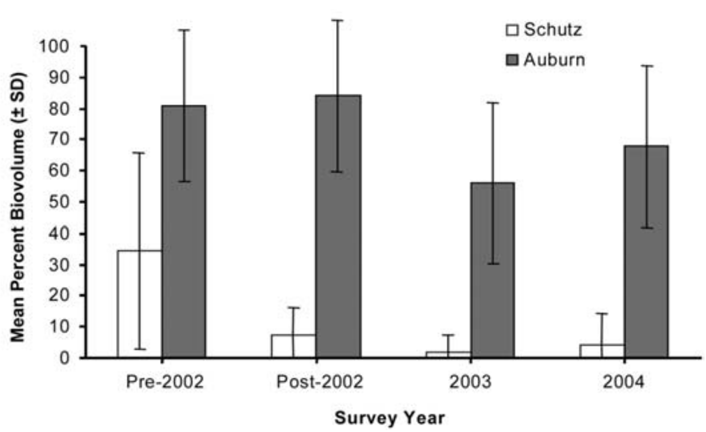

Figure 2. Mean percent submersed vegetation biovolume (± one standard deviation) from hydroacoustic surveys in Schutz and West Auburn lakes (Carver County, Minnesota) before (30 May 2002; Pre-) and after (August; Post-) low-dose fluridone treatment in Schutz Lake. Biovolume data from June and August surveys in 2003 and 2004 were pooled.

The reestablishment of native plants in Schutz Lake after the fluridone treatment may have been prevented by one or more of the following factors: 1) low water clarity caused by algae (Scheffer et al. 1993); 2) resuspension of sediments and nutrients by carp (Breukelaar et al. 1994); 3) burial of native seeds and propagules by accumulated sediments under Eurasian watermilfoil canopies (Carpenter and Lodge 1986, de Winton and Clayton 1996); and 4) a lack of remnant plants to produce new propagules, which might disperse through the lake (Capers 2003).

Predicting the Short-term Effects of Fluridone Applications

Treatment of mesotrophic lakes with low-dose applications of fluridone can selectively control Eurasian watermilfoil without killing native plants or reducing water clarity if the littoral zone is populated with fluridone-tolerant native species prior to treatment (Smith and Pullman 1997; Madsen et al. 2002, Bremigan et al. 2005). Nevertheless, Bremigan et al. (2005) demonstrate Eurasian watermilfoil may return to near nuisance levels 1-3 years following treatment without continual maintenance management. The long-term cumulative effects of multiple treatments on plant communities, water quality, and fish are not known.

Results of the current study, along with those of Welling et al. (1997) and Pothoven (1996), suggest that following treatment of eutrophic lakes with fluridone, increases in native plants may not occur for several years, if at all, especially where declines in water clarity are observed following treatment. Consequently, lake managers contemplating possible treatment of eutrophic lakes with fluridone to control milfoil

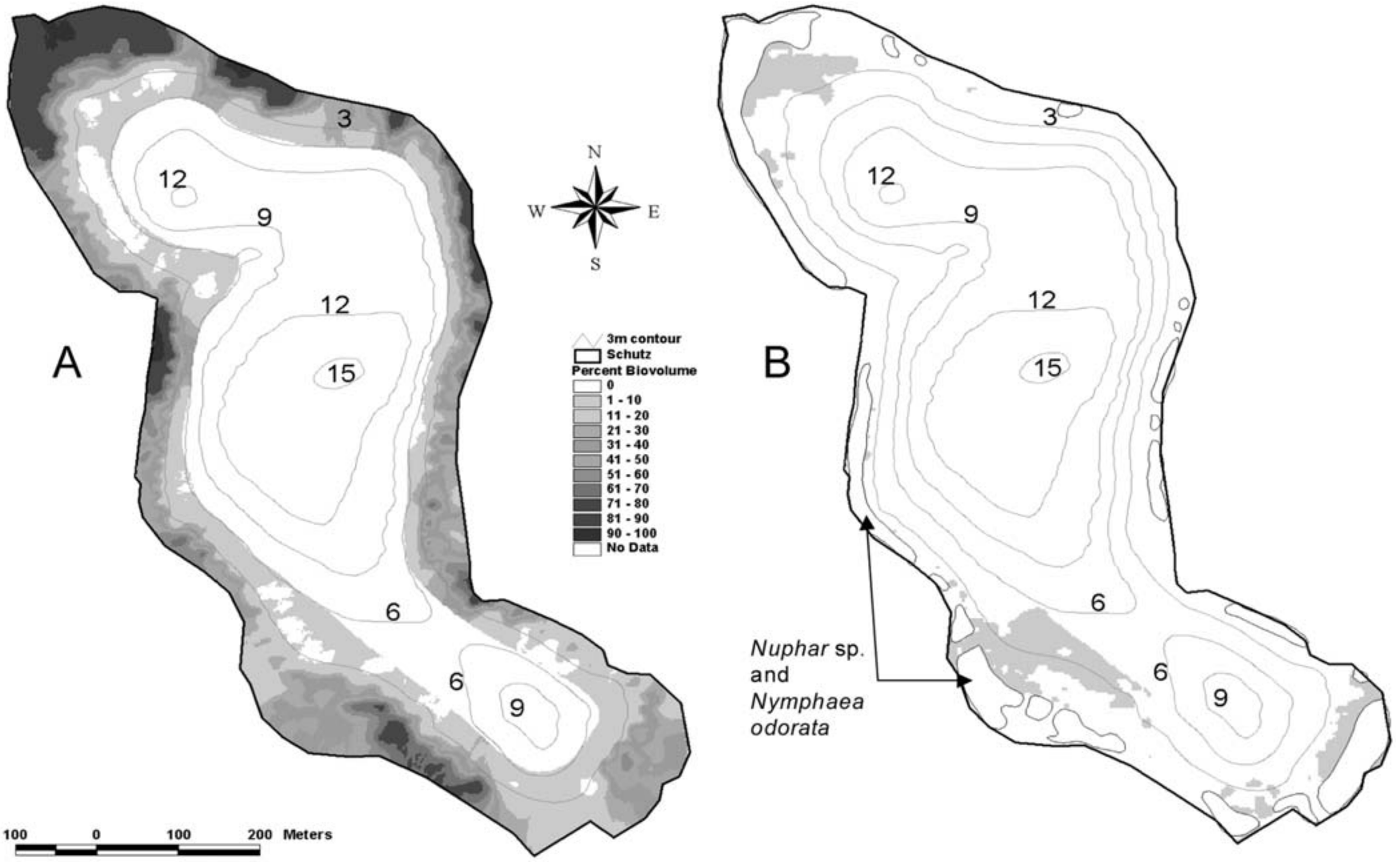

Figure 3. Percent biovolume of aquatic vegetation before (30 May 2002; A) and two years after (Aug. 2004; B) treatment with low-dose fluridone of Schutz Lake, Carver County, Minnesota. Waterlilies (*Nuphar* sp. and *Nymphaea odorata*) were present during the pre-treatment survey, but had not yet germinated. Biovolume data were collected with hydroacoustics and maps were created using kriging interpolation (Valley et al. 2005).

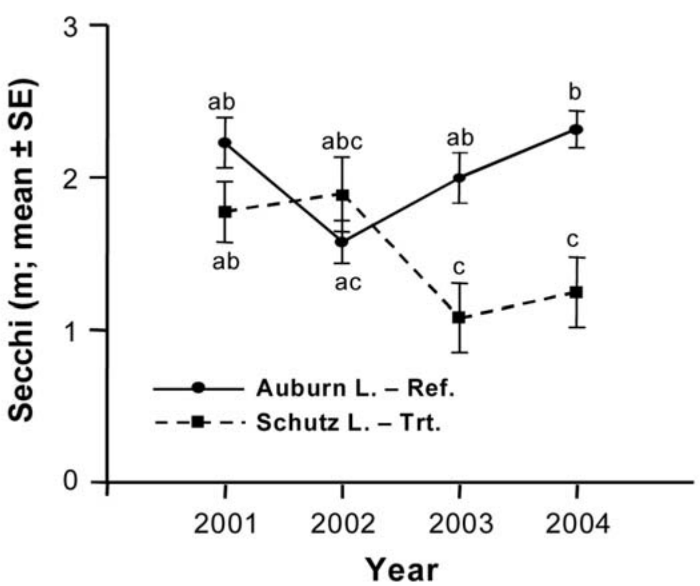

Figure 4. Seasonal mean Secchi depth (± one standard error) based on bi-weekly observations made from June through September in Schutz (A) and West Auburn (B) lakes, Carver County, Minnesota. Low dose applications of fluridone were applied to Schutz Lake on 30 May and 2 July 2002. Different letters indicate 95% confidence intervals around mean Secchi values did not overlap.

should carefully weigh the benefits of reducing Eurasian watermilfoil with the risks of reducing water clarity and decreasing the distribution and abundance of submersed plants.

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