Effectiveness of Granular 2,4-D Treatment on Hybrid Watermilfoil (*Myriophyllum sibiricum* x *spicatum*) in Oconomowoc Lake, Wisconsin

Wisconsin Lutheran College, Biology Dept.
Technical Bulletin 008, March 2006
Prepared by
Angela L. Ortenblad, Allison M. Zappa,
Abby R. Kroken Robert C. Anderson, PhD

Funded by WDNR Aquatic Invasive Species Control Grant, the Village of Oconomowoc Lake, and the Southeastern Wisconsin Regional Planning Commission

Executive Summary

The Wisconsin Department of Natural Resources identified a hybrid form of northern x Eurasian watermilfoil (*Myriophyllum sibiricum* x *spicatum*) at six locations within Oconomowoc Lake, Waukesha County, Wisconsin, in 2004. Between June and September 2005, an evaluation of three treatment levels was carried out. Monthly aquatic macrophyte surveys were conducted to identify the density and frequency of occurrence of all macrophyte species occurring in four study plots. Three of these plots were treated with granular 2,4-dichlorophenoxyacetic acid (2,4-D) at varying dosages (80, 100, and 120 lbs/acre) after the first survey in early June to evaluate the response of native and invasive watermilfoil. The fourth study plot was not treated and served as a control. Additional biweekly qualitative sampling occurred for 4 weeks after 2,4-D treatment. We observed a decrease in density of native watermilfoil as well as coontail (*Ceratophyllum demersum*) in treated study plots. Hybrid watermilfoil decreased in density and frequency between June and September in both treated and the control plots; however, hybrid watermilfoil collected from the treated areas appeared less healthy than watermilfoil collected from the untreated plot. Annual monitoring could detect trends in hybrid watermilfoil growth patterns in Oconomowoc Lake, which would allow for a better determination of how this plant responds to treatment. Additionally, water depth may have influenced the effectiveness of 2,4-D treatment and more than one year of study is needed to fully evaluate how hybrid watermilfoil responds to 2,4-D.

Acknowledgements

We would like to thank Heidi Bunk and Maureen McBroom of the Wisconsin Department of Natural Resources for coordinating this project. We thank Donald Wiemer, Chief of Police and Village Administrator, Village of Oconomowoc for providing local support. We thank Dr. Jeffery A. Thornton, principal planner of the Southeast Wisconsin Regional Planning Commission for contributions in planning this study. We thank Brian Suffern and Marine Biochemists for applying the herbicide. We thank Dr. Michael L. Moody at Indiana University for providing the genetic analysis.

Introduction

Nonindigenous plant species have been introduced to North America as a consequence of accidental releases or intentional importation as food, fiber, and ornamentals. Although most exotic plants are innocuous and persist only through intensive cultivation, nearly 15% of nonindigenous species become invasive and cause severe ecological disruption of native plant communities (Moody and Les 2002, Pimentel et al. 2000). Eurasian watermilfoil (*Myriophyllum spicatum*) is an exotic, highly invasive submersed aquatic plant native to Eurasia (Whyte and Francko 2001). This exotic species may have been introduced to the United States as early as the 1800s (Haber 1997, Madsen 1997, Madsen et al. 1991), but Couch and Nelson (1985, cited in Madsen 1997) provide evidence that it was first observed as late as the 1940s. Since its introduction into U.S. water bodies, Eurasian watermilfoil has spread throughout North America and is now the dominate species in many temperate lake macrophyte communities (Cheruvelil et al. 2001).

Eurasian watermilfoil is found in littoral regions of lake ecosystems, the most productive area of a lake (Adams and McCracken 1974). Macrophytes play a central role in aquatic ecosystem food web interactions, and nuisance species may alter these interactions (Cheruvelil et al. 2001, Madsen et al. 1991). Non-indigenous canopy-forming species, such as Eurasian watermilfoil, alter natural habitats by creating vertical gradients in temperature, light, dissolved oxygen, and pH. As a result, macroinvertebrate and zooplankton communities shift, effecting abundance and growth of littoral fish (Valley and Bremigan 2002). For example, the shoots of Eurasian watermilfoil support periphyton and collect detritus, which are food resources for macroinvertebrates. Benthic cladocerans are attracted to the leaves and the sediment beneath the plant may support a large population of tubificid worms (Engel 1995). An established population of Eurasian watermilfoil can be beneficial through proper management techniques. For example, mechanical harvesting of this plant effectively prevents formation of the canopy, which encourages growth of native macrophytes while improving the quality of the littoral fish community (Unmuth 2001).

Invasive species, including Eurasian watermilfoil, not only alter community structure and ecosystem functions, but directly impact lake residents (Ellstrand and Schierenbeck 2000). The negative effects of watermilfoil infestation are most evident when high biomass and matting on the surface occur. Many recreational activities such as swimming, boating, fishing, and water skiing are inhibited by watermilfoil growth (Crowell et al. 1994). Eurasian watermilfoil also impacts power generation and irrigation by clogging dam trash racks and intake pipes (WAPMS 2004).

Eurasian watermilfoil is characterized by its rapid growth, unique methods of reproduction, and highly competitive nature (Whyte and Francko 2001). Eurasian watermilfoil is highly adventive and productive, resulting in rapid spread and monospecific growths (Smith and Barko 1990). Eurasian watermilfoil can spread by seed production, stolon production, and fragmentation. Seeds serve as a means of long term reproduction, enabling the species to survive during long periods of dormancy. Localized expansion is provided by stolon growth. Stems which form adventitious roots may establish new plants in the immediate area of the parent. Stolons, located in the upper few centimeters of the sediment, extend outward from the parent plant and produce new plants in the immediate area (Madsen and Smith 1997).

Fragmentation or vegetative spread is considered the major and more important method of reproduction, allowing the plant to invade new habitats (Whyte and Francko 2001). Eurasian watermilfoil displays two methods of fragmentation that allow for long distance dispersal: autofragmentation and allofragmentation (Madsen and Smith 1997). During autofragmentation, abscising fragments develop roots at the nodes before separating from the parent plant. Allofragments are produced by wind, wave activity, and boating activities. Each fragment has the potential to develop into a new plant (WAPMS 2004). In addition to its unique methods of reproduction, Eurasian watermilfoil uses its competitive nature to increase its abundance. According to Valley and Newman (1998), the native northern watermilfoil (*Myriophyllum sibiricum*) is closely related to Eurasian and prefers a similar habitat. However, coexistence is rare and Eurasian tends to displace northern because of Eurasian's ability to form dense canopies (Valley and Newman 1998).

A variety of methods have been used in attempts to control the spread of watermilfoil. Control methods include mechanical harvesting, underwater harvesting, diver-operated dredges, bottom fabrics and barriers, lowering water levels to expose plants to freezing temperatures, and chemical herbicides (Haber 1997). The most commonly used method of control is the use of the herbicide 2,4-dichlorophenoxyacetic acid (2,4-D). This chemical has been used throughout the United States to help treat small patches of Eurasian watermilfoil; approximately 10,000 acres per year are treated with 2,4-D to control Eurasian watermilfoil (Parsons et al. 2001). The chemical 2,4-D destroys the shoots and attached roots but leaves fragments and root crowns at the lake bottom that may develop to create new beds after treatment (Helsel et al. 1996). A selective systematic herbicide, 2,4-D eradicates broadleaf plants, like Eurasian watermilfoil, within a relatively short contact time. It generally does not harm pondweeds or water celery, and it is not damaging to elodea or hydrilla (Madsen 2000).

Many factors contribute to the effectiveness of 2,4-D treatment. The effect of 2,4-D on aquatic plants is determined by the applied concentration of the herbicide and the duration of exposure. Factors that can reduce the exposure of the plants to 2,4-D herbicide include water depth, water movement, convection or advection, and the amount of calcium present in lake water in the form of marl (Crowell 1999).

Oconomowoc Lake (45.089722° N, 88.460556° W) is located in Waukesha County, in southeastern Wisconsin, approximately 30 miles (50 km) west of Milwaukee. Oconomowoc Lake is 767 square acres with a maximum depth of 62 feet and a mean depth of 32 feet. Renowned for its fisheries, Oconomowoc Lake support populations of walleye, northern pike, small and largemouth bass, and bluegill (WDNR 2005a). Many species of macrophytes are native to Oconomowoc Lake, including coontail (*Ceratophyllum demersum*), eel grass (*Vallisneria americana*), several pondweeds (*Potamogeton* spp.), and several species of watermilfoil including northern (*Myriophyllum sibiricum*) and Farwell's (*Myriophyllum farwellii*). The non-native Eurasian watermilfoil, first identified in Wisconsin during the 1960s, was common in 39 Wisconsin counties, including Waukesha County, by 1993(WNDR 2004). In May 1994, the Wisconsin State Herbarium at the University of Wisconsin-Madison received the first specimen of Eurasian watermilfoil collected from Oconomowoc Lake (WBIS 2005).

During the summer of 2004, the Wisconsin Department of Natural Resource (WDNR) identified a hybrid form of northern x Eurasian watermilfoil (*Myriophyllum sibiricum* x *spicatum*), hereafter referred to as hybrid watermilfoil, in Oconomowoc Lake. Genetic analysis by Dr. Michael L. Moody at Indiana University confirmed the hybridization of the two species. In the field, the difference in leaf-segment numbers is primarily used to differentiate between the Eurasian and hybrid watermilfoil. While both species have pinnately compounded leaves, Eurasian watermilfoil leaves typically have 14-21 segment pairs, while hybrid watermilfoil leaves has only 10-12 leaflet pairs (Moody and Les 2002).

Molecular data demonstrates that invasive watermilfoil populations in North America have resulted from hybridization between nonindigenous and native species. It is known that hybridization between introduced and native species can lead to recombinants with superior competitive phenotypes, which can result in hybrid vigor (Moody and Les 2002). Hybridization between populations having very different genotypes may lead to new adaptive strategies allowing the new hybrid to displace a parent or spread to a new community or become a noxious weed (Ellstrand and Schierenbeck 2000). Although hybridization in watermilfoil does not confirm invasiveness is due to hybrid vigor, it does provide a reasonable explanation for why these plants are becoming invasive (Moody and Les 2002).

Surveying 4 study plots on Oconomowoc Lake using transect and sample point methods prior to treatment with 2,4-D herbicide provided baseline data regarding the composition of aquatic macrophytes. Surveys conducted after treatment of 3 study plots with varied dosages of 2,4-D, in comparison with one control plot which was left untreated, allowed for the assessment of the effectiveness of the treatment. Annual monitoring would allow for a long-term evaluation of 2,4-D treatment and illustrate the spread and vigor of hybrid watermilfoil.

Methods

During the summer of 2004, the Wisconsin DNR identified six areas in Oconomowoc Lake containing hybrid watermilfoil. These areas were revisited in late May 2005 and macrophyte beds were observed. The study plots were realigned based on plant density, and four plots were selected for evaluation (Figures 1 & 2).

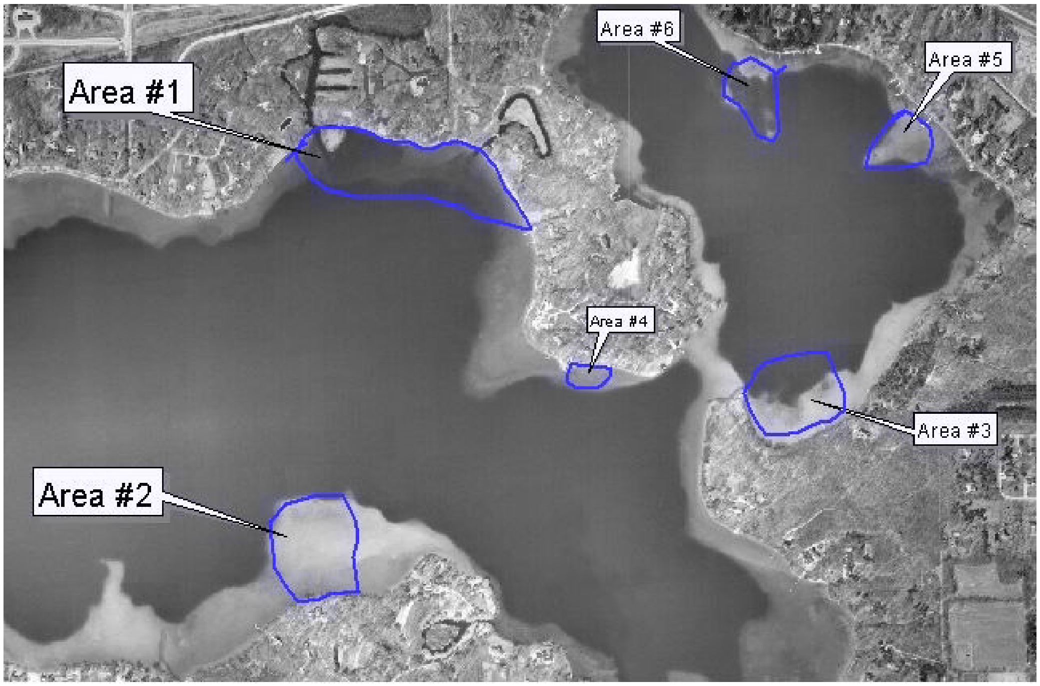


Figure 1. The six areas in Oconomowoc Lake containing hybrid watermilfoil as identified by the WDNR during 2004.

Figure 2. Four areas in Oconomowoc Lake included in the study. Areas 1, 4, and 6 received granular 2,4-D treatment in June 2005, while area 2 received no treatment and was used as the control plot.

Areas 1, 4, and 6 were treated on June 13, 2005 with granular 2,4-dichlorophenoxyacetic acid herbicide (2,4-D). In order to evaluate the effectiveness of 2,4-D treatment on hybrid watermilfoil, the dosage of 2,4-D applied to each study plot varied. Area 1 was treated at 100 lbs/acre, area 4 was treated at 120 lbs/acre, and area 6 was treated at 80 lbs/acre. Area 2 was left untreated and served as a control (Figure 2).

The macrophyte community was assessed one week before treatment (June 6, 2005), four weeks post-treatment (July 5, 2005), nine weeks post-treatment (August 8, 2005), and fourteen weeks post-treatment (September 5, 2005). Line and point intercept methods were used in determining macrophyte presence, frequency, and density (Deppe and Lathrop 1992, Jessen and Lound 1962, Madsen 1999). The line intersect method was utilized in area 1, the largest study plot. Transects ran perpendicular to shore and were spaced roughly 200 feet apart, creating a total of 10 transects. The attempt was made to collect at sample points along each transect; however, due to wind and drift, sampling points occasionally deviated from the proposed transect lines (Figure 3).

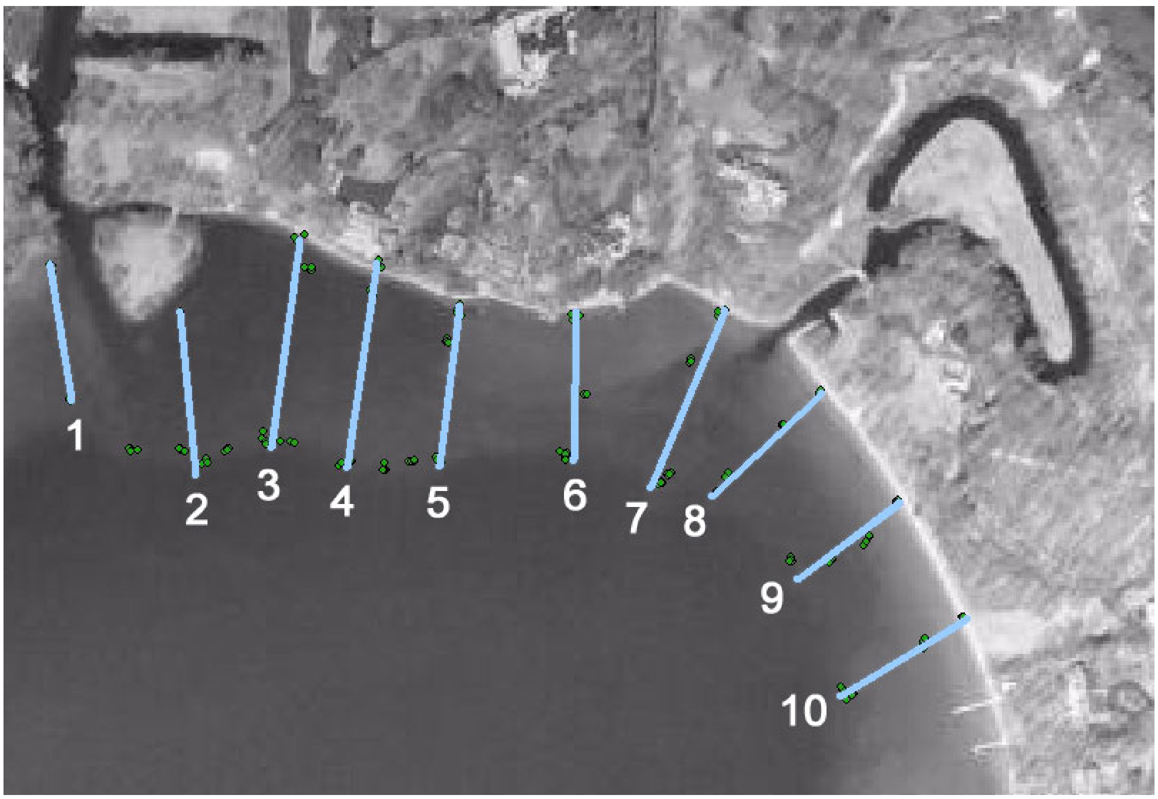


Figure 3. Transects located in sample area 1 of Oconomowoc Lake, Waukesha County, Wisconsin.

Four samples were taken at depths of 1.5, 5, 9, and 11 feet. At each depth, four rake casts were made in a circular pattern with a rake consisting of a 16-foot pole with an attached garden rake head. The head is made of a 1/8-inch thick butt plate with 14 2.5-inch long teeth set along the butt plate lengthwise that allow for the recovery of submerged vegetation (Jessen and Lound 1962). The combination of the rake head and pole is used to determine water depth and substrate at each sampling site.

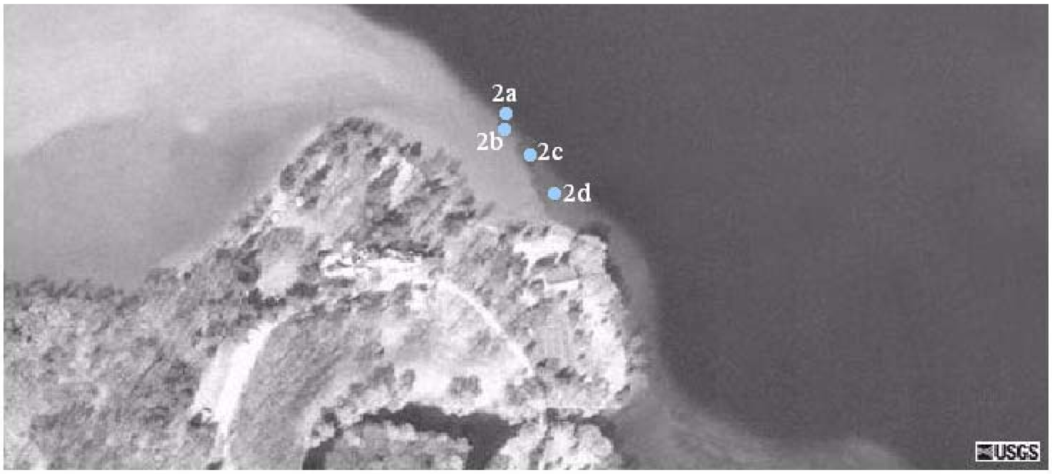
Each species was identified using identification keys (Borman et al. 1997, Fassett 1967). Samples of all species and plants unable to be identified in the field were taken back to the laboratory at Wisconsin Lutheran College. In the laboratory, a representative of each plant species was photographed, pressed, and mounted for documentation.

Density ratings were assigned using the rake coverage technique defined by Deppe and Lathrop (1992) (Table 1). The density rating for individual species at each sampling point was determined by averaging the density ratings assigned to a species collected from the 4 rake hauls.

Table 1. Criteria used to assign density ratings for a plant species collected during a rake haul (Deppe and Lathrop 1992).

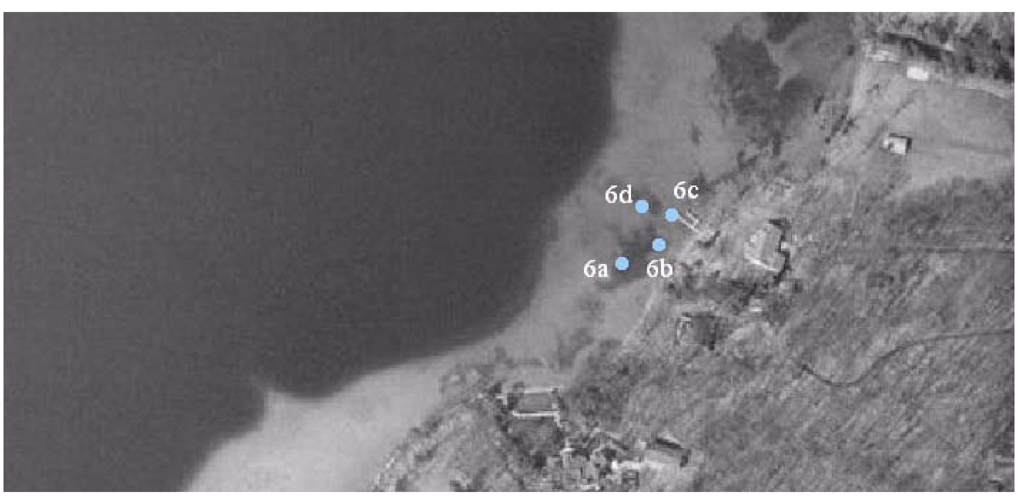
Rake coverage (% of rake head covered by a species)	Density rating
81 – 100	5
61 – 80	4
41 – 60	3
21 – 40	2
1 – 20	1
0	0

The point intercept method was used to sample macrophyte abundance and density in areas 2, 4, and 6. Four points were located in the macrophyte beds at each sample plot (Figure 4). Four rake hauls were cast at each point in a circular pattern and species collected on each haul were identified and assigned a density rating. From this information the average density rating for each species was calculated.



a.

b.



c.

Figure 4. Oconomowoc Lake sample plots 2 (**a**), 4 (**b**), and 6 (**c**) depicting the 4 point sample locations. At each sample point, 4 rake hauls were cast to determine average density of each aquatic macrophyte species.

A Trimble GeoXM Global Positioning System field unit was used to note the locations of each transect and sampling point during the June survey. The same locations were revisited and sampled during the July, August, and September surveys.

Water samples were collected the day of treatment and once a week for three weeks thereafter. Samples were collected in each sampling plot with a 6-1/2 foot, one-inch interior diameter PVC pipe. Inside the pipe was a ball that fits into a reduced adaptor connector (Herman 2000). An integrated water sample was collected by lowering the pipe into a minimum of 6 feet of water and as the water fills up the pipe, the ball falls back to the bottom and prevents the sample from leaking out. The pipe was emptied into a 2 quart collection container with a rod inserted through the neck of the jug. This collection method eliminates contact with the sample and prevents potential contamination. The sample was poured into 3 water sample containers and sent to the State Lab of Hygiene in Madison, WI, for analysis of chlorophyll a, total phosphorous, and available phosphorous (PO_4). After the samples were collected and separated, the PVC pipe and modified collection container were rinsed with de-ionized water. The location where water samples were collected was noted on a Trimble GeoXM field unit. These locations were revisited for every water sample collection (Figure 5).

Biweekly qualitative sampling occurred for 4 weeks after 2,4-D treatment. Qualitative sampling included field observation of watermilfoil beds and collection of hybrid watermilfoil in all four areas. Digital photographs of the representative samples were taken upon return to the lab. Samples of hybrid watermilfoil were collected on June 13 and 27, 2005, for DNA verification by Dr. Michael L. Moody at Indiana University.

Water parameter readings were measured in the four sample areas using a Hydrolab DataSonde4 multiprobe unit. Measured parameters included water temperature, pH, dissolved oxygen, and conductivity levels. Readings were taken at the surface and at the maximum depth at each locale. Hydrolab readings occurred at the same location as water sampling and during macrophyte surveys (Figure 5).

.

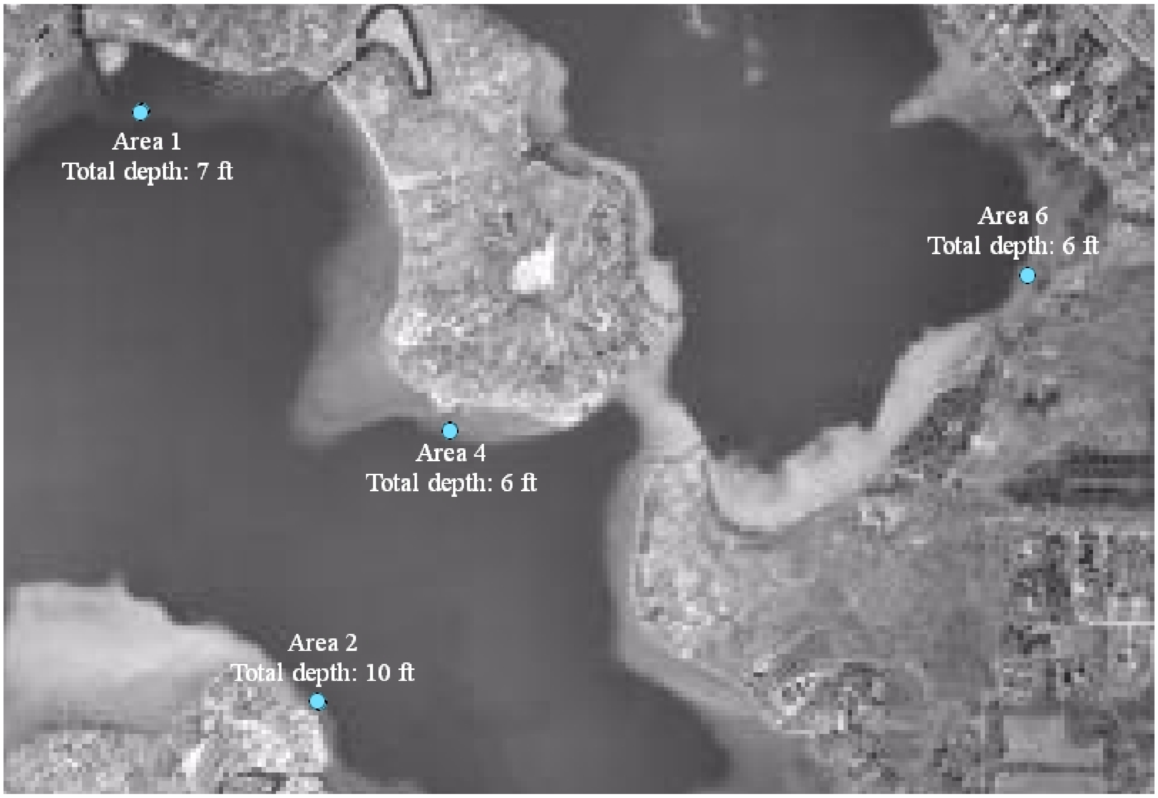


Figure 5. Locations were water samples were collected and environmental variables were measured using a Hydrolab DataSonde4.

Water clarity was measured and recorded when water sampling or macrophyte surveys occurred. On the shady side of the boat, a secchi disk was lowered until it was no longer visible. Upon reappearance, the rope was marked and then measured from the secchi disk to the marked position.

Results

A total of seventeen aquatic plant species were found in Oconomowoc Lake, Wisconsin, during the months of June, July, August, and September of 2005 (Table 2). Macrophytes were surveyed at depths of 1.5, 5.0, 9.0 and 11.0 feet at each transect in area 1; in areas 2, 4, and 6, macrophytes were surveyed at each of the four points. Muskgrass (*Chara* sp.) was the most abundant species collected within the four study plots during the course of the study. Hybird watermilfoil (*Myriophyllum sibircum* x *spicatum*) was frequently encountered at 3 of the 4 study plots (Appendix A).

Table 2. Relative abundance of aquatic plant species found in Oconomowoc Lake, Wisconsin, during the months of June, July, August, and September of 2005.

Plant Species	Relative Abundance
Coontail (*Ceratophyllum demersum*)	Moderate
Muskgrass (*Chara* sp.)	Very abundant
Farwell's watermilfoil (*Myriophyllum farwelli*)	Sparse
Hybrid watermilfoil (*Myriophyllum sibircum* x *spicatum*)	Abundant
Northern watermilfoil (*Myriophyllum sibircum*)	Very sparse
Eurasian watermilfoil (*Myriophyllum spicatum*)	Moderate
Bushy pondweed (*Najas flexis*)	Very sparse
Southern waternymph (*Najas guadalupensis*)	Very sparse
Spiny naiad (*Najas marina*)	Very sparse
Curlyleaf pondweed (*Potamogeton crispus*)	Very sparse
Waterthread pondweed (*Potamogeton diversifolius*)	Very sparse
Leafy pondweed (*Potamogeton foliosus*)	Very sparse
Illinois pondweed (*Potamogeton illinoensis*)	Sparse
Sago pondweed (*Potamogeton pectinatus*)	Very sparse
Flatstem pondweed (*Potamogeton zosteriformus*)	Very sparse
Bladderwort (*Utricularia* sp.)	Moderate
Wild celery (*Vallisneria americana*)	Moderate

A total of twelve species were found during the June survey, twelve during July, eleven during August and twelve during September (Table 3).

Table 3. Macrophyte species found each month (June, July, August, and September 2005) in Oconomowoc Lake, Wisconsin (X: found at least once at transect or point).

	June	July	August	September
Coontail	X	X	X	X
Muskgrass	X	X	X	X
Farwell's milfoil	X			X
Hybrid milfoil	X	X	X	X
Northern watermilfoil	X		X	X
Eurasian watermilfoil	X	X	X	X
Bushy pondweed		X		X
Southern waternymph		X		
Spiny naiad		X	X	X
Curlyleaf pondweed	X			
Waterthread pondweed	X			
Leafy pondweed	X			
Illinois pondweed	X	X	X	X
Sago pondweed		X	X	X
Flatstem pondweed		X	X	
Bladderwort	X	X	X	X
Wild celery	X	X	X	X

In Area 1, the average density of hybrid watermilfoil (treated with 100 lbs/acre of 2,4-D) increased during June, July, and August (Figures 6 & 8), despite a slight decrease in frequency of occurrence (Figure 7). Therefore, hybrid watermilfoil was found in denser concentrations as the summer progressed but was found at fewer points within each transect. Both density and frequency of hybrid watermilfoil were lower in September than the pre-treatment levels in June. Eurasian watermilfoil occurred in sparse patches and was found only in August and September (Figures 6 & 7). Native watermilfoil (Farwell's and northern) were not found after treatment in June, but reappeared in September (Figures 6 & 7). Native macrophytes (including curly leaf pondweed, *Potamogeton crispus*) density and frequency significantly increased from June to August (Figures 6 & 7). Eel grass and muskgrass were the dominant native species found in Area 1 (Appendix A, Figures 1A & 5A).

The average density and frequency of hybrid watermilfoil in Area 2 (the control plot) declined throughout June and July, until no hybrid watermilfoil was found in August or September (Figures 6 - 8). Farwell's watermilfoil was only found in June and no other watermilfoil were collected. Native plant density and frequency in Area 2 increased significantly from June to September (Figures 6 & 7). Muskgrass, bladderwort (*Utricularia* sp.), and eel grass were the dominant native species (Appendix A, Figures 2A & 6A).

In Area 4 (treated with 120 lbs/acre of 2,4-D), hybrid watermilfoil increased in density and frequency following treatment in June but decreased in density and frequency from June to September (Figures 6-8) Eurasian watermilfoil followed a similar pattern in density however did not increase in frequency after treatment (figures 6 & 7). Native watermilfoil were only found before the June treatment (Figures 6 & 7). Native macrophyte density and frequency increased significantly from June to September (Figures 6 & 7); eel grass and muskgrass were the predominant species (Appendix A, Figures 3A & 7A).

Hybrid watermilfoil progressively decreased in density and frequency (Figures 6 - 8) throughout the summer in Area 6 (treated with 80 lbs/acre). Eurasian watermilfoil was present pre-treatment and only reappeared in August at a lower density and frequency (Figure 6 &7). Farwell's and northern watermilfoil were not collected from Area 6. Coontail also responded to 2,4-D herbicide treatment; it was found during the pre-treatment survey and reappeared at a lower density and frequency in September. Muskgrass composed the majority of native plant density and occurrence (Appendix A, Figures 4A & 8A). The density and frequency of native plants fluctuated little between June and September (Figures 6 & 7).

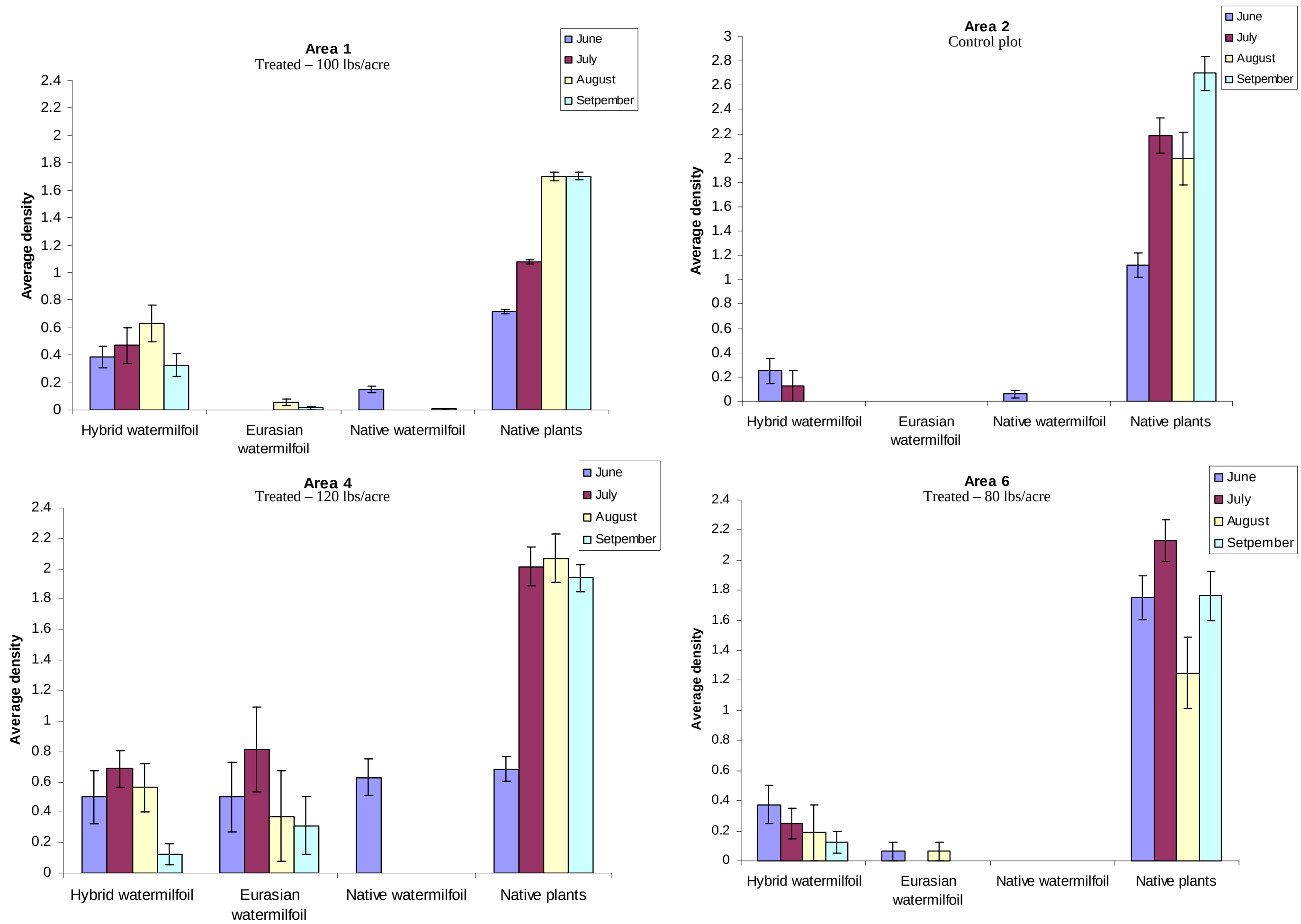


Figure 6. Average density of hybrid, Eurasian, and native (Farwell's and Northern) watermilfoil and native macrophyte species found in Oconomowoc Lake during June, July, August, and September surveys.

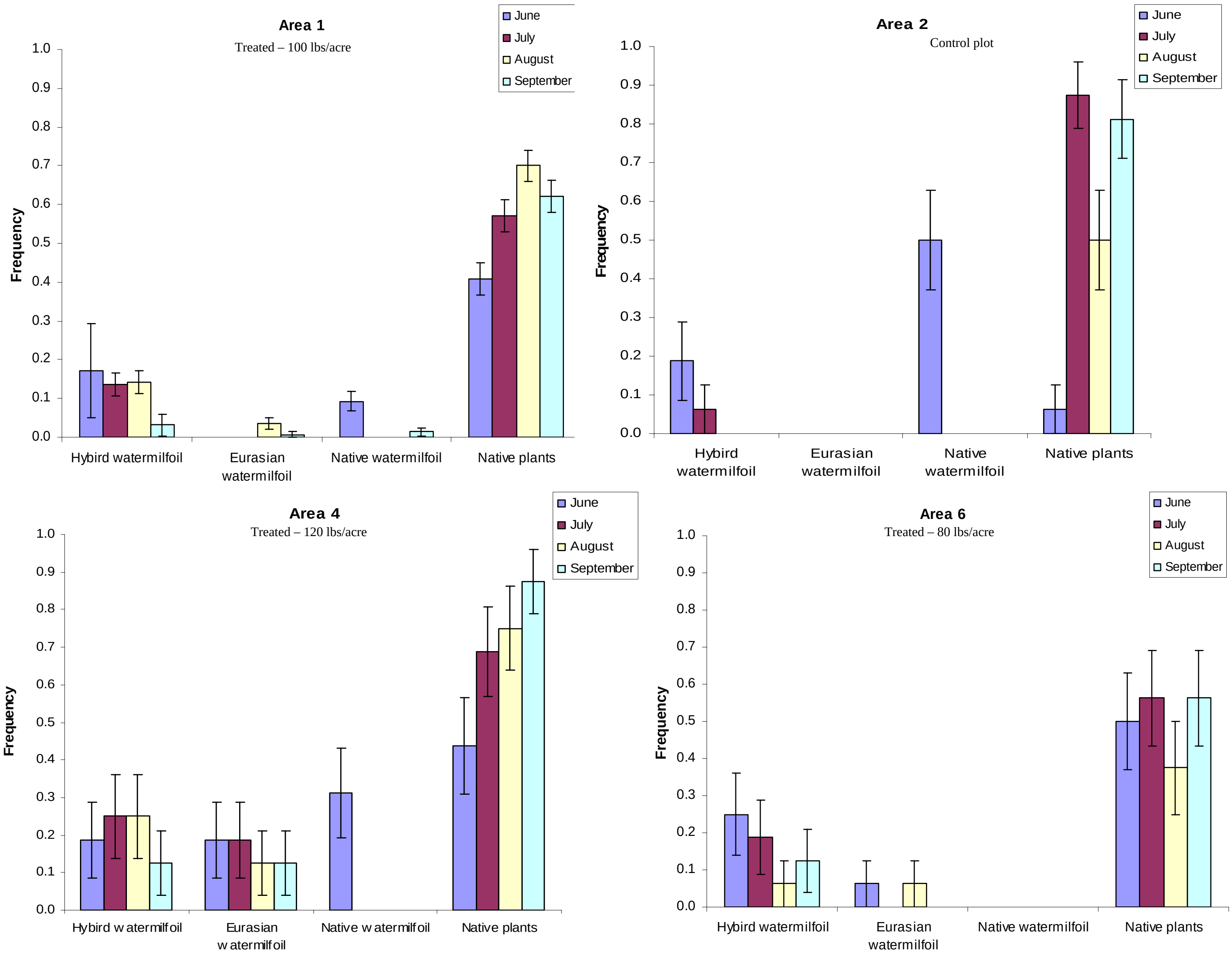


Figure 7. Frequency of occurrence of hybrid, Eurasian, and native (Farwell's and Northern) watermilfoil and native macrophyte species found in Oconomowoc Lake during June, July, August, and September surveys.

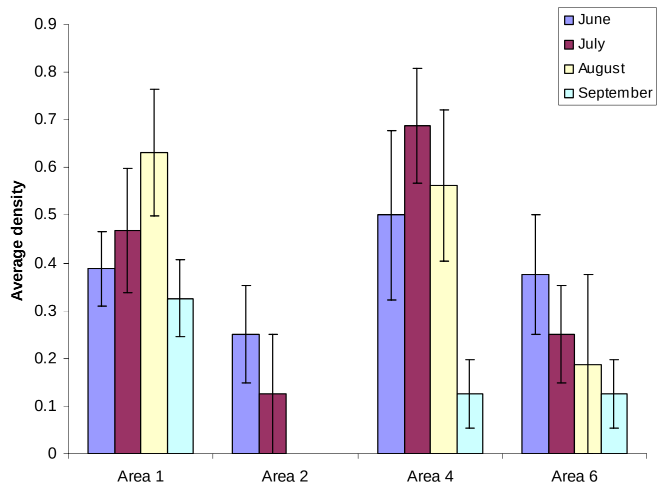


Figure 8. Average density of hybrid watermilfoil during June, July, August, and September 2005 in the 4 study plots of Oconomowoc Lake, Wisconsin. After the June survey, treatment of granular 2,4-D was applied to Area 1 (100 lbs/acre), Area 4 (120 lbs/acre), and Area 6 (80 lbs/acre). Area 2 remained untreated and served as a control.

When comparing average density of macrophytes in the treated regions (Areas 1, 4, & 6) to the untreated region (Area 2), no significant difference was detected for hybrid watermilfoil. In the treated regions, hybrid watermilfoil decreased in density from June to September, thought not significantly. Eurasian watermfoil was only found in the treated regions and did not show a significant decrease in density following 2,4-D treatment. Farwell's and northern watermilfoil (native watermilfoil) in the treated regions were found in June and reappeared in very low densities in September (not shown in Figure). In the untreated region, native watermilfoil was only found in June at a low density. Native macrophyte species were unaffected by 2,4-D treatment and significantly increased in density from June to September. Native plant denisty peaked in August in the untreated region, and did not show a significant change in density throughout the summer.

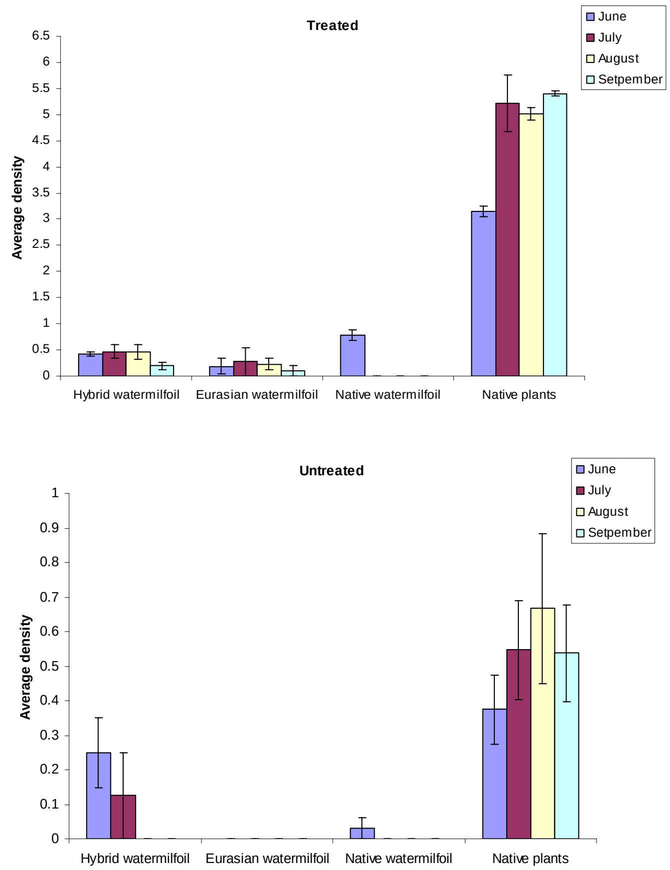


Figure 9. Comparison of average density of aquatic macrophytes in regions treated with 2,4-D (Areas 1, 4, & 6) and the control plot (Area 2) during the summer of 2005 in Oconomowoc Lake, Wisconsin.

The physical response of hybrid watermilfoil to 2,4-D treatment is apparent through qualitative analysis of photographs taken nine-weeks after treatment (August 9, 2005). Hybrid watermilfoil collected from areas 1 and 4 were less vigorous than the untreated milfoil from area 2. Hybrid watermilfoil in area 6 was slightly discolored but less affected by 2,4-D treatment. Area 6 received the lowest concentration of 2,4-D treatment, which may have resulted in a healthier appearance (Figure 16).

a.

b.

c.

Figure 16. Comparison between hybrid watermilfoil samples collected on August 9, 2005, in area 1 (treated 100 lbs/acre), area 4 (treated 120 lbs/acre), and area 6 (treated 80 lbs/acre) with area 2 (untreated) in Oconomowoc Lake, Wisconsin.

The physical parameters of Oconomowoc Lake were relatively stable throughout the summer. Temperature and dissolved oxygen levels were similar throughout the summer at all study areas (Figure 10). Mean water temperatures were slightly higher at the surface. Mean dissolved oxygen levels were highest in Area 6; this may be related to the presence of filamentous algae, which was only found in this study plot.

Throughout summer, pH fluctuated little within and between study plots (Figure 11). Variations in pH values may be the result of precipitation events and changes in alkalinity. Total phosphorus, a limiting nutrient in aquatic systems, ranged from 0.007 mg/L to 0.019 mg/L throughout the summer (Figure 12). Excess phosphorus fueled a midsummer algal bloom, evident in increased in chlorophyll a values (Figure 13) and secchi disk readings (Figure 15).

Specific conductivity, a measure of the resistance of an aqueous solution to electrical flow and dependent on the concentration of dissolved ions (Wetzel 2001), decreased as summer progress (Figure 14).

Water clarity, based on secchi disk transparency, decreased from June to August, then increased in September (Figure 15). This decrease coincided with the chlorophyll a values, which increased from the beginning of June to July.

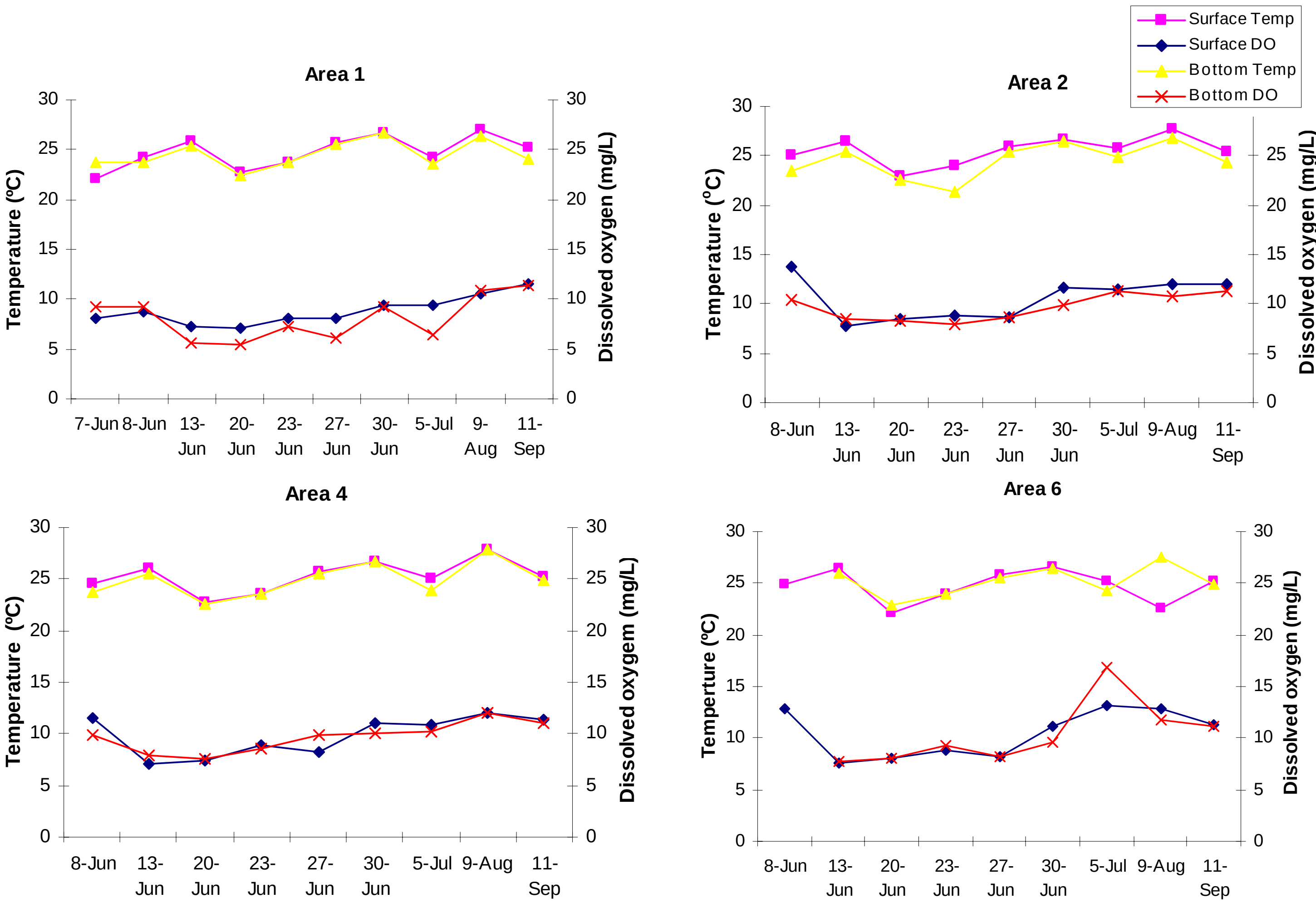


Figure 10. Temperature (^{o}C) and dissolved oxygen (mg/L) in Oconomowoc Lake, Wisconsin, during summer 2005.

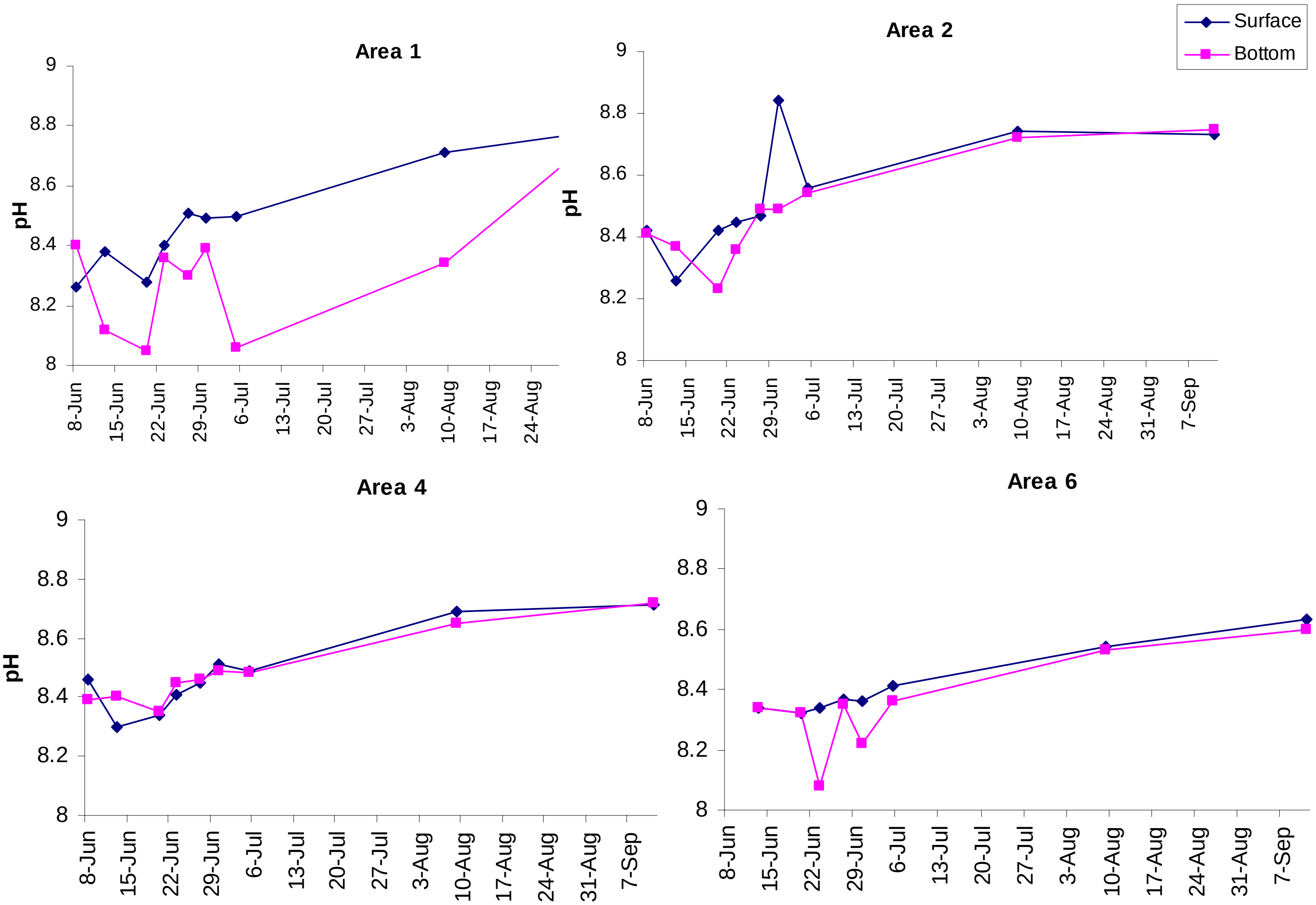


Figure 11. Values for pH in Oconomowoc Lake, Wisconsin, during summer 2005.

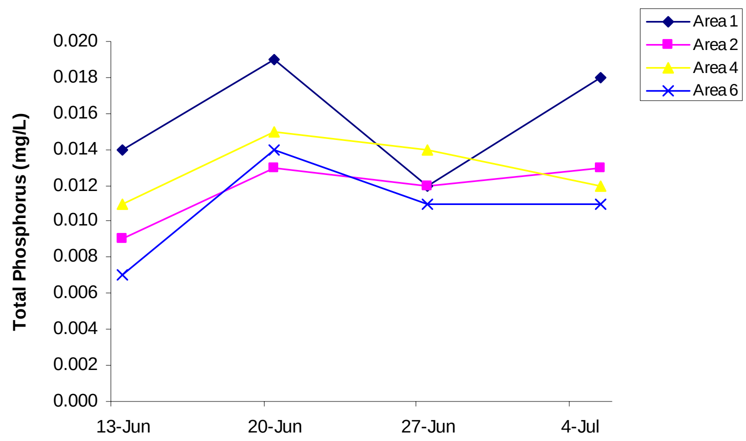


Figure 12. Total phosphorus concentrations (mg/L) at the 4 study plots in Oconomowoc Lake, Wisconsin, during June and early June 2005.

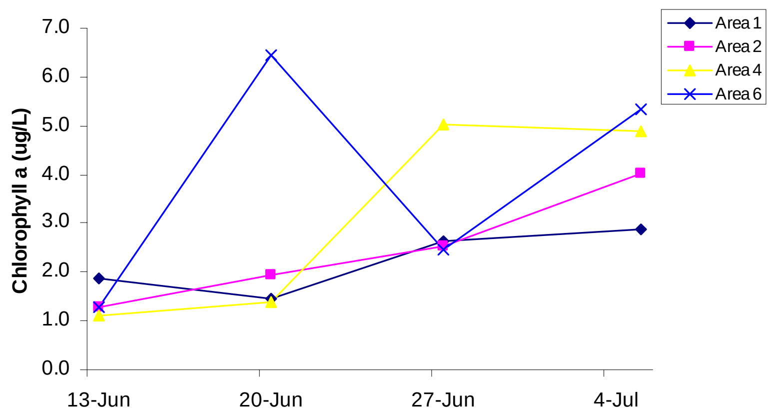


Figure 13. Chlorophyll a values (µg/L) from the 4 study plots in Oconomowoc Lake, Wisconsin, during June and early June 2005.

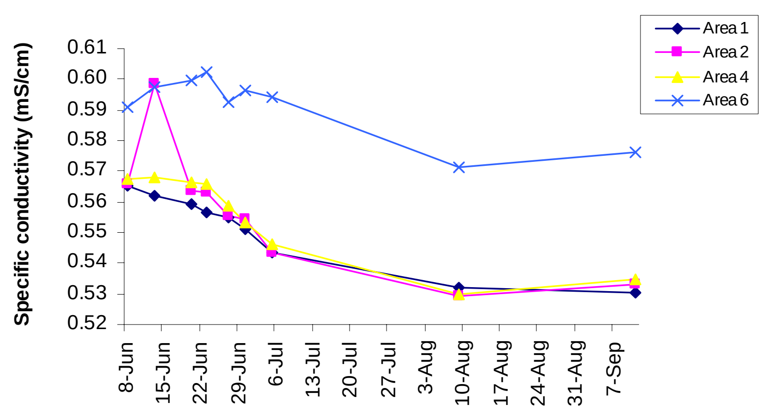


Figure 14. Specific conductivity (mS/cm) measured at the 4 study plots in Oconomowoc Lake, Wisconsin, from June to September 2005.

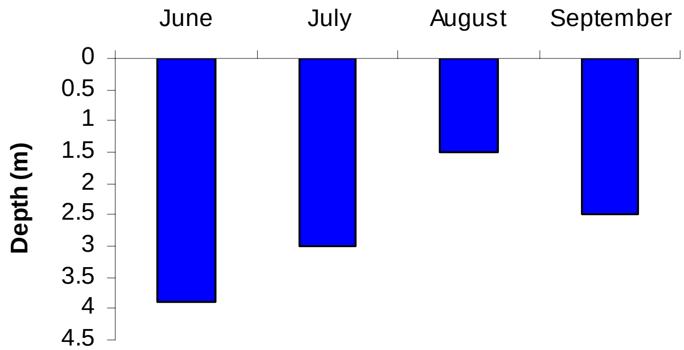


Figure 15. Average secchi disk readings taken in Oconomowoc Lake, Wisconsin, from June to September 2005.

Discussion

The purpose of this study was to determine the current composition of macrophyte communities in selected study plots in Oconomowoc Lake and study the effectiveness of various levels of 2,4-D aquatic herbicide treatment on hybrid milfoil. On June 13, 2005, areas 1, 4, and 6 were treated with 100 lbs/acre, 120 lbs/acre, and 80 lbs/acre of granular 2,4-D aquatic herbicide respectively. To produce the best results, 2,4-D was applied in late spring/early summer while the vegetation was actively growing. The recommended application rates for this product are 100 lbs/acre (APCRP 2002).

There was not a significant difference in the hybrid milfoil density or frequency in response to different treatment levels. It was also not possible to note a difference between treated and untreated areas. Thus the only indication of an effect of treatment resulted from the visual comparison of stems. This visual comparison did indicate a greater impact on hybrid watermilfoil stems at higher concentrations of treatment.

It is possible that the hybrid watermilfoil in Oconomowoc Lake is expressing hybrid vigor, and as a result is more resistant to 2,4-D treatment than Eurasian watermilfoil. Hybrid watermilfoil appeared to be denser and found more frequently than Eurasian or native watermilfoil each month (Figures 6 & 7).

In area 1, which was treated at 100 lbs/acre, statistical analysis indicates that hybrid watermilfoil at the 9 foot depth responded to treatment and significantly decreased in frequency between June and September. However, at the 11 foot depth the frequency of hybrid watermilfoil did not experience a significant change between June and September. Water depth may have an impact on 2,4-D effectiveness. Greater depth increases the volume of water and may influence the amount of 2,4-D absorbed by individual hybrid watermilfoil shoots. In the deeper section of areas 1 and 6, milfoil shoots were taller; thus, less 2,4-D was dispersed to the entire plant relative to surface area.

The herbicide 2,4-D is a somewhat selective, systemic growth regulator. It has been shown to inhibit cell division of new tissue and stimulate cell division of some mature plant tissues, resulting in growth inhibition, necrosis of apical growth, and eventually total cell disruption and plant death. The herbicide acts rapidly; approximately two weeks are needed to control most vegetation. Yet, if the roots are not killed, re-growth can occur 4-5 weeks after treatment (APCRP 2002).

Concentration of the herbicide and the duration of exposure essentially determine the effectiveness of 2,4-D (Crowell 1999). As an extremely water soluble agent, 2,4-D is only persistent in the water for approximately one month. Its biodegradation half-life is equal to 3.9-11 days after application. If longer exposure times are expected, then lower concentration of the herbicide can be applied. For higher exchange rates, higher concentrations of herbicide are needed. Too low of a concentration may even stimulate the growth of Eurasian watermilfoil (Madsen 2000). In addition, several factors can effect the efficacy of 2,4-D. Once 2,4-D is introduced to an environment, it tends to quickly dissipate depending of the degree of water movement, temperature, pH, and substrate. Furthermore, ultraviolet light and microorganisms living in the water and sediments can convert the herbicide into carbon dioxide, water, and chlorine (Parsons et al. 2001).

The 2, 4-D treatment in the study areas on Oconomowoc Lake appeared to have little negative impact on native vegetation. In each area, the density and frequency of native species increased after treatment (Figures 5 & 6). This may have resulted from inhibiting the growth and spreading of milfoil species due to the treatment. Based on the pre-treatment survey, Oconomowoc Lake supports a very diverse community of native species. If the treatment of invasive milfoils is continued, the diversity and abundance of native plants may increase.

Physical attributes of Oconomowoc Lake reflect the lake is balancing between a mesotrophic and eutrophic system (Shaw et al. 2002). Secchi disk depth (Figure 15) decreased as summer progressed as result of an algal bloom. Chlorophyll a concentrations also increased during June and July as a result of the algal bloom. Total phosphorus levels in Oconomowoc Lake varied, but reflect good water quality according to Lillie and Mason (1983) and Shaw et al. (2002).

Appendix A

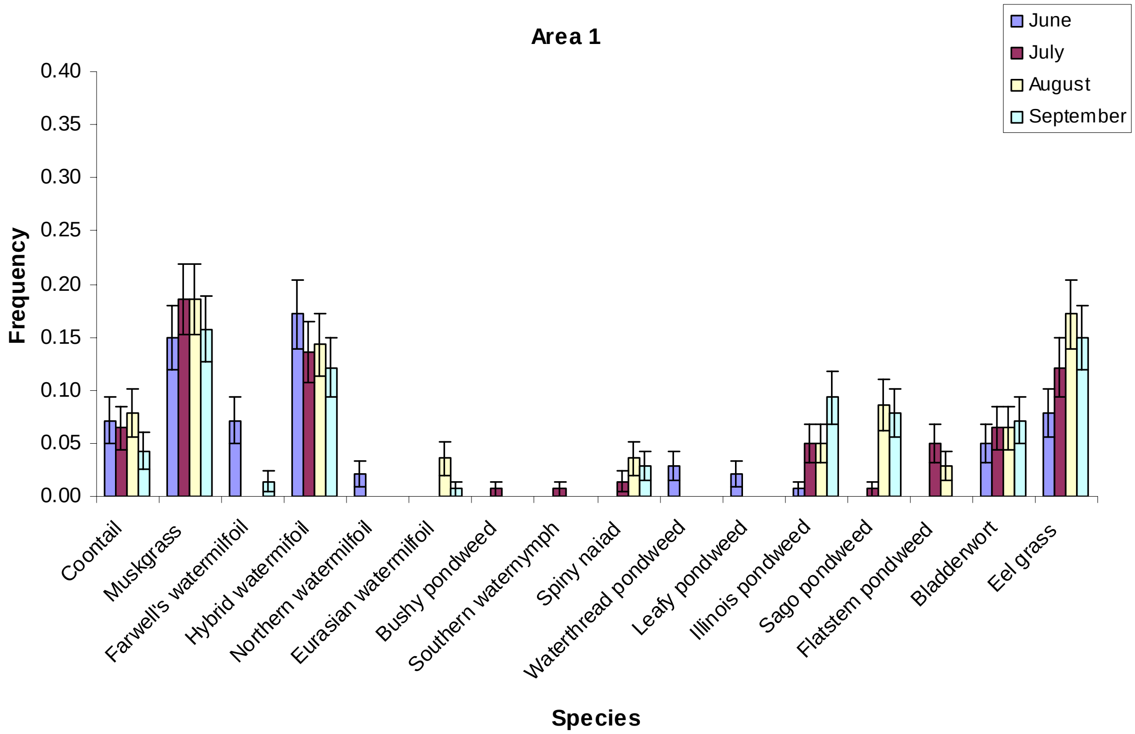


Figure 1A. Average frequency of occurrence of aquatic macrophytes per month in Area 1 (treated with 100 lbs/acre of granular 2,4-D) of Oconomowoc Lake, Wisconsin, during 2005.

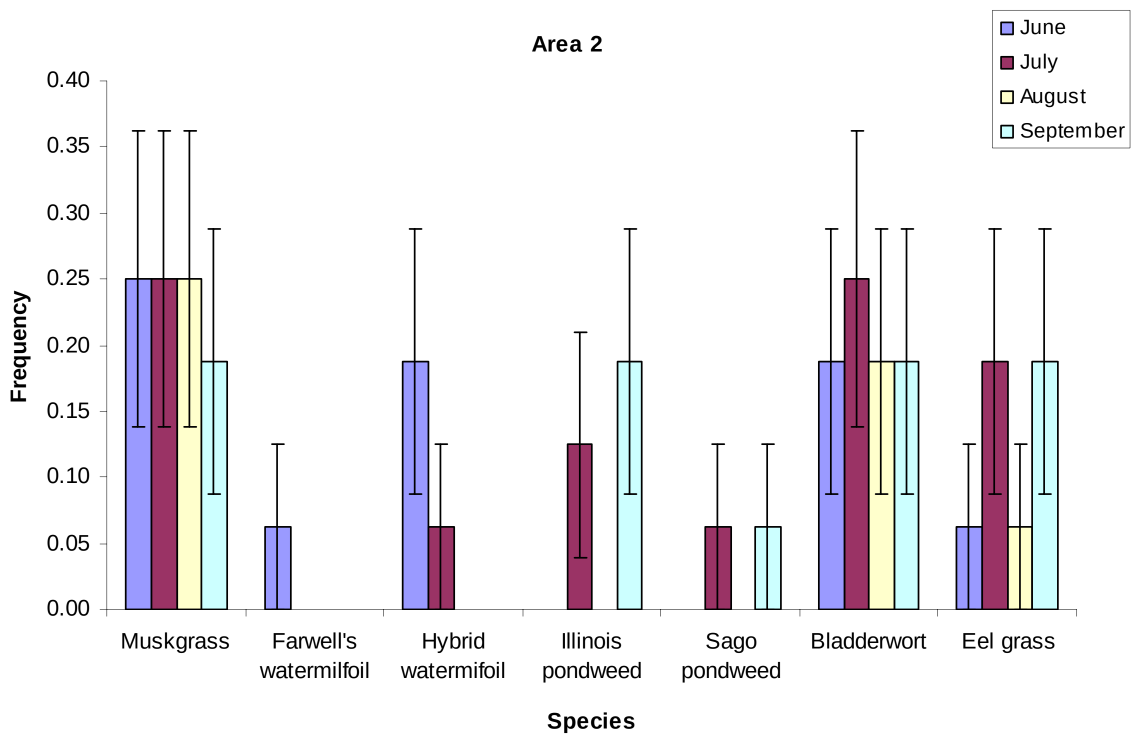


Figure 2A. Average frequency of occurrence of aquatic macrophytes per month in Area 2 (control plot) of Oconomowoc Lake, Wisconsin, during 2005.

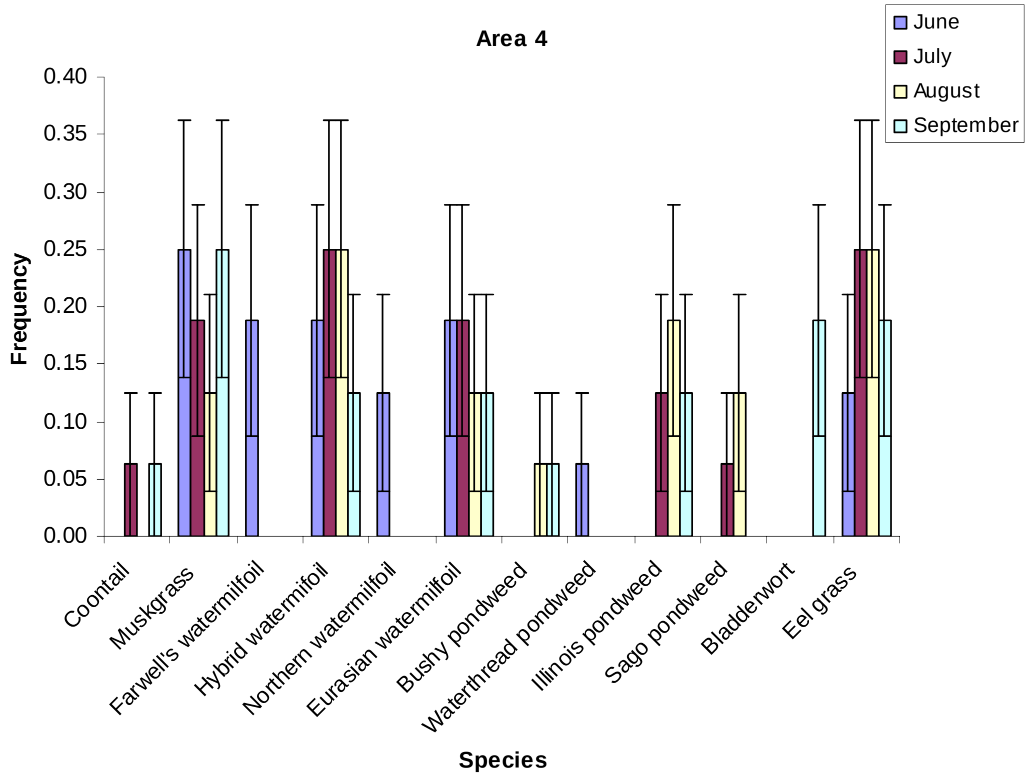


Figure 3A. Average frequency of occurrence of aquatic macrophytes per month in Area 1 (treated with 120 lbs/acre of granular 2,4-D) of Oconomowoc Lake, Wisconsin, during 2005.

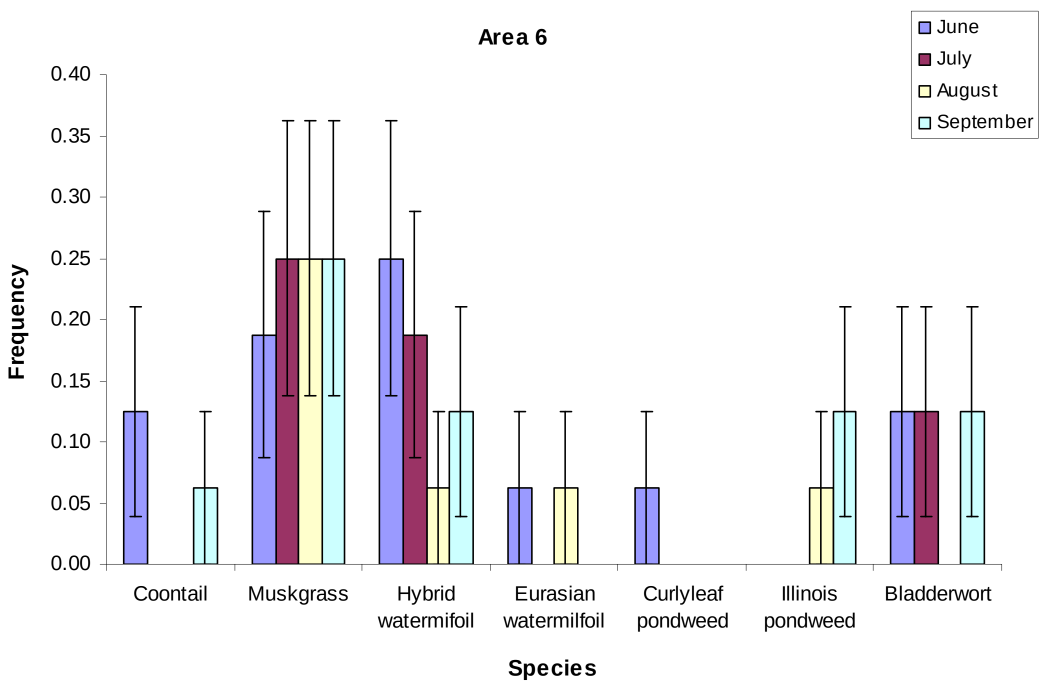


Figure 4A. Average frequency of occurrence of aquatic macrophytes per month in Area 1 (treated with 80 lbs/acre of granular 2,4-D) of Oconomowoc Lake, Wisconsin, during 2005.

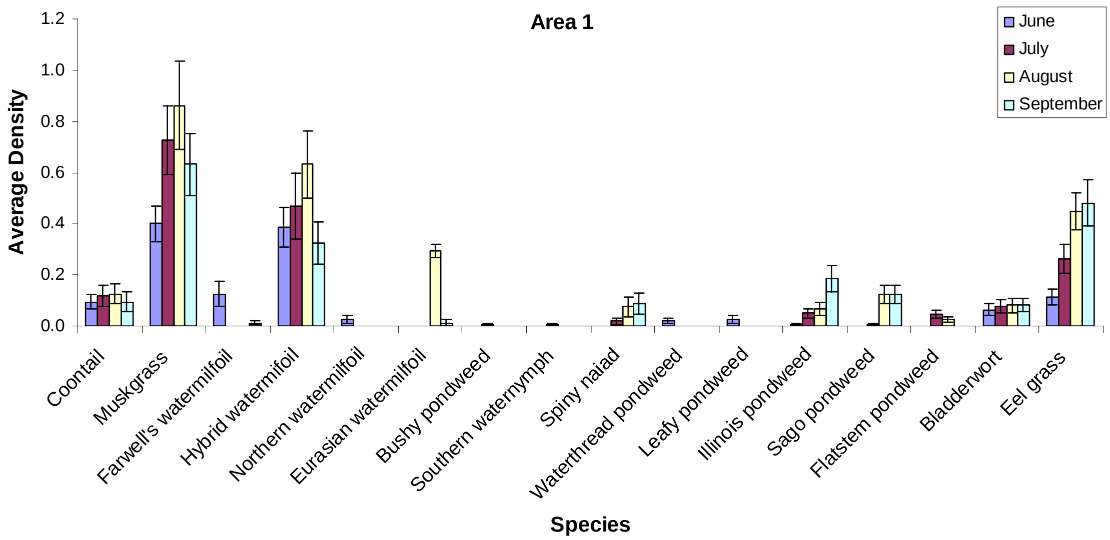


Figure 5A: Average density of aquatic macrophytes per month in Area 1 (treated with 100 lbs/acre of granular 2,4-D) of Oconomowoc Lake, Wisconsin, during 2005.

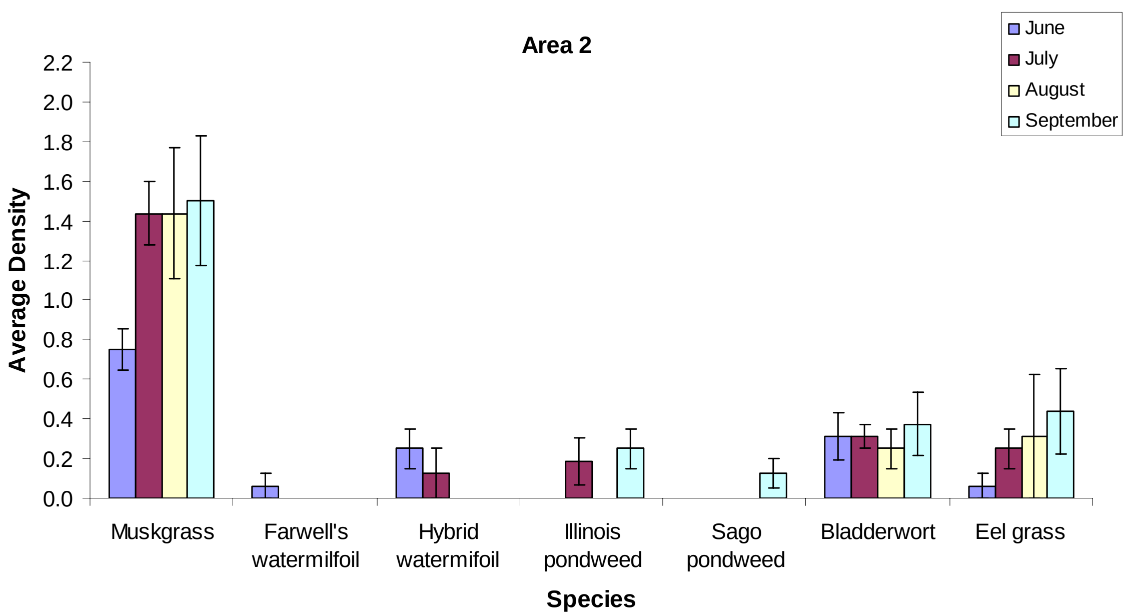


Figure 6A: Average density of aquatic macrophytes per month in Area 2 (control plot) of Oconomowoc Lake, Wisconsin, during 2005.

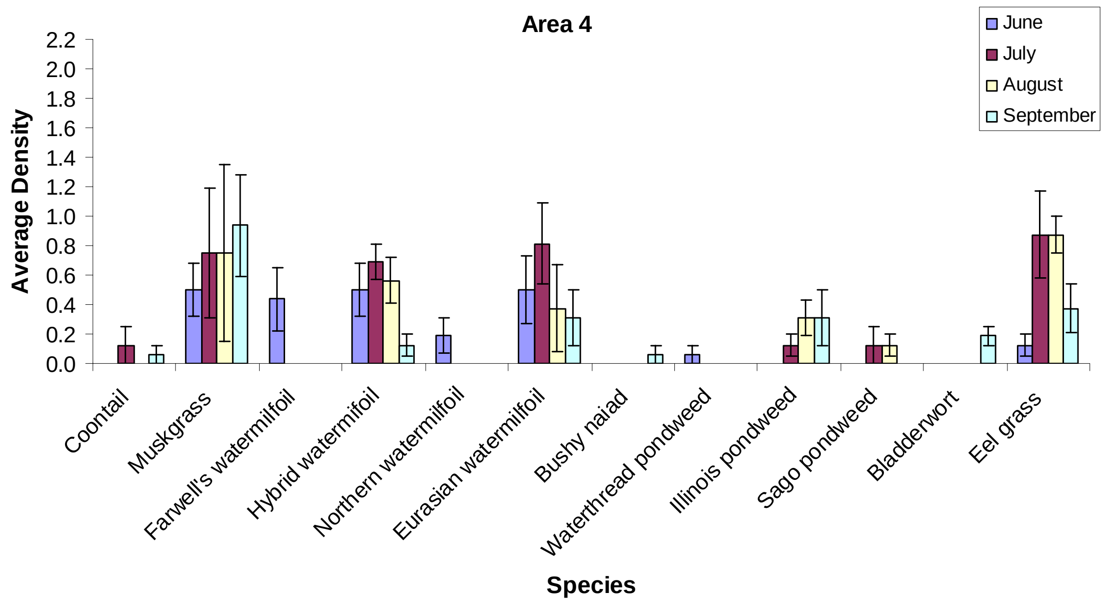


Figure 7A: Average density of aquatic macrophytes per month in Area 4 (treated with 120 lbs/acre of granular 2,4-D) of Oconomowoc Lake, Wisconsin, during 2005.

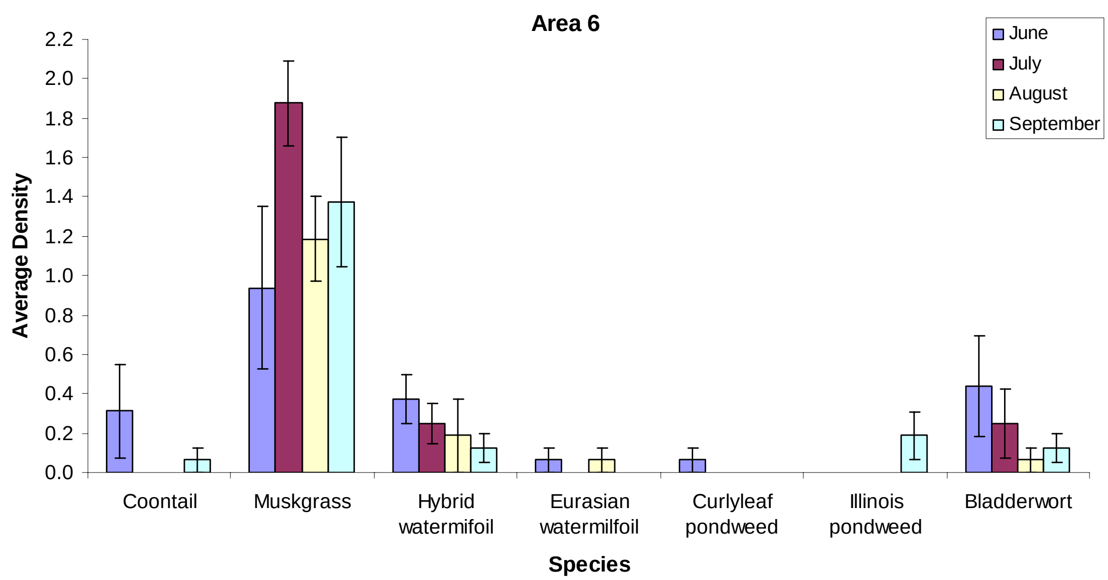


Figure 8A: Average density of aquatic macrophytes per month in Area 4 (treated with 120 lbs/acre of granular 2,4-D) of Oconomowoc Lake, Wisconsin, during 2005.

References

Adams, M. S., and M. D. McCracken. 1974. Seasonal production of the *Myriophyllum* component of the littoral of Lake Wingra, Wisconsin. Journal of Ecology 62: 457-465.

APCRP (Aquatic Plant Control Research Program). 2002. Aquatic plant information systems. U.S. Army Corps of Engineers. *Available at* http://el.erdc.usace.army.mil/aqua/. *Accessed in* August 2005.

Borman, S., R. Korth, and J. Temte. 1997. Through the looking glass: a field guide to aquatic plants. DNR Publication FH-207-97. Reindl Printing, Inc., Merrill, WI.

Britton, J. E. 2003. 2003 Peppermill Lake District aquatic plant management technical report. Aquatic Enginnering, Inc.

Cheruvelil, K. S., P. A. Soranno, and J. D. Madsen. 2001. Epiphytic marcoinvertabrates along a gradient of Eruasian watermilfoil cover. Journal of Aquatic Plant Management 39: 67-72.

Crowell, W. J. 1999. Minnesota DNR tests the use of 2,4-D in managing Eurasian watermilfoil. Aquatic Nuisance Species Digest 3: 42-43.

Crowell, W., N. Troelstrup Jr., L. Queen, and J. Perry. 1994. Effects of harvesting on plant communities dominated by Eurasian watermilfoil in Lake Minnetonka, MN. Journal of Aquatic Plant Management 32: 56-60.

Deppe, E. R., and R. C. Lathrop. 1992. A comparison of two rake sampling techniques for sampling aquatic macrophytes. Research Management Findings 32: 1-4.

Ellstrand, N. C., and K. A. Schierenbeck. 2000. Hybridization as a stimulus for the evolution of invasiveness in plants. Proceedings of the National Academy of Sciences of the United States of America 97: 7043-7050.

Engel, S. 1995. Eurasian watermilfoil as a fishery management tool. Fisheries 20(3): 20-27.

Fassett, N. C. 1967. A manual of aquatic plants. The University of Wisconsin Press, Madison, WI.

Haber, E. 1997. Eurasian watermilfoil fact sheet. Invasive Exotic Plants of Canada Fact Sheet No. 10. National Botanical Services, Ottowa, Ontario, Canada.

Helsel, D. R., D.T. Gerber and S. Engel. 1996. Comparing spring treatments of 2,4-D with bottom fabrics to control a new infestation of Eurasian watermilfoil. Journal of Aquatic Plant Management 34: 68-71.

Jessen, R., and R. Lound. 1962. An evaluation of a survey technique for submerged aquatic plants. Game Investigational Report No. 6. Minnesota Department of Conservation.

Lillie, R. A. and J. W. Mason. 1983. Limnological characteristics of Wisconsin lakes. Wisconsin Department of Natural Resources Technical. Bulletin 138, Madison.

Madsen, J. D. 2000. Advantages and disadvantages of aquatic plant management techniques. LakeLine 20: 20-34.

Madsen, J. 1999. Point intercept and line intercept methods for aquatic plant management. Aquatic Plant Control Technical Note MI-02, February 1999.

Madsen, J. D., and D. H. Smith. 1997. Vegetative spread of Eurasian watermilfoil colonies. Journal of Aquatic Plant Management 35: 63-68.

Madsen, J. D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. Journal of Aquatic Plant Management 29: 94-99.

Moody, M. L., and D. H. Les. 2002. Evidence of hybridity in invasive watermilfoil (*Myriophyllum*) populations. Proceedings of the National Academy of Sciences of the United States of America 99: 14867-14871.

Parsons, J. K., K. S. Hamel, J. D. Madsen and K. D. Getsinger. 2001. The use of 2,4-D for selective control of an early infestation of Eurasian watermilfoil in Loon Lake, Washington. Journal of Aquatic Plant Management 39: 117-125.

Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50: 53-65.

Shaw, B., C. Mechenich, and L. Klessig. 2002 Understanding lake data. University of Wisconsin Cooperative Extension Publishing, Madison, Wisconsin. Publication (G3582) SR-02/2002-1M-525.

Smith, C.S., and J.W. Barko. 1990. Ecology of Eurasian watermilfoil. Journal of Aquatic Plant Management. 28: 55-64.

Unmuth, J. M. L., M. J. Hansen, P. W. Rasmussen, and T. D. Pellett. 2001. Effects of mechanical harvesting of Eurasian watermilfoil on angling for bluegills in Fish Lake, Wisconsin. North American Journal of Fisheries Management 21: 448-454.

Valley, R. D., and R. M. Newman. 1998. Competitive interactions between Eurasian watermilfoil and northern watermilfoil in experimental tanks. Journal of Aquatic Plant Management 36: 121-126.

Valley, R. D., and M. T. Bremigan. 2002. Effects of macrophyte bed architecture on largemouth bass foraging: implications of exotic macrophyte invasions. Transactions of the American Fisheries Society 131: 234-244.

WAAPMS (The Western Aquatic Plant Management Society). 2004. Eurasian watermilfoil (*Myriophyllum spicatum*). *Available at* http://www.wamps.org. *Accessed in* May 2005.

WBIS (Wisconsin Botanical Information System). 2005. Wisconsin State Herbarium. *Available at* http://www.botany.wisc.edu/herbarium. *Accessed in* June 2005.

WDNR (Wisconsin Department of Natural Resources). 2005a. Wisconsin lakes. Wisconsin Department of Natural Resource PUB-FH-800.

WNDR (Wisconsin Department of Natural Resources). 2005b. Eurasian watermilfoil Infestation may have been there for years. *Available at* http:// dnr.wi.gov./org/caer/ce/news/on/2005/on050111.htm. *Accessed in* September 2005.

WDNR (Wisconsin Department of Natural Resources). 2004. Eurasian watermilfoil (*Myriophyllum spicatum*). *Available at* http://dnr.wi.gov/org/land/er/invasive/factsheets/milfoil.htm. *Accessed in* June 2005.

Wetzel, R. G. 2001. Limnology: lake and river ecosystems, third edition. Academic Press, San Diego.

Whyte, R. S., and D. A. Francko. 2001. Dynamics of a pioneer population of Eurasian watermilfoil (*Myriophyllum spicatum* L.) in a shallow Lake Erie wetland. Journal of Aquatic Management 39: 136-139.