Herbicide Treatments in **Wisconsin Lakes**

Michelle Nault, Alison Mikulyuk, Jennifer Hauxwell, John Skogerboe, Tim Asplund, Martha Barton, Kelly Wagner, Tim Hoyman, and Eddie Heath

Building a Framework for Scientific Evaluation of Large-scale Herbicide Treatments in Wisconsin Lakes

Wisconsin's 15,000 lakes provide rich recreational, ecological, and economic benefits. However, Wisconsin lakes are facing a growing number of threats, including excess nutrient runoff from agricultural and urban development, contamination from mercury and other pollutants, modification of ecologically important nearshore habitats, and the invasion and spread of non-native invasive aquatic species.

Eurasian watermilfoil (*Myriophyllum spicatum* L.) is a non-native aquatic plant that was introduced to Wisconsin in the 1960s and is currently known to be present in approximately 600 lakes and rivers (Figure 1). While landscape-scale patterns of Eurasian watermilfoil (EWM) abundance look similar to those of natives, EWM may have more negative impacts at higher densities. In some of these waterbodies, EWM interferes with recreation and may displace native species (Figures 2 and 3). The Wisconsin Department of Natural Resources (WDNR) has been working to develop and implement plans for strategic and efficient control of EWM, and to prevent its further spread in the state.

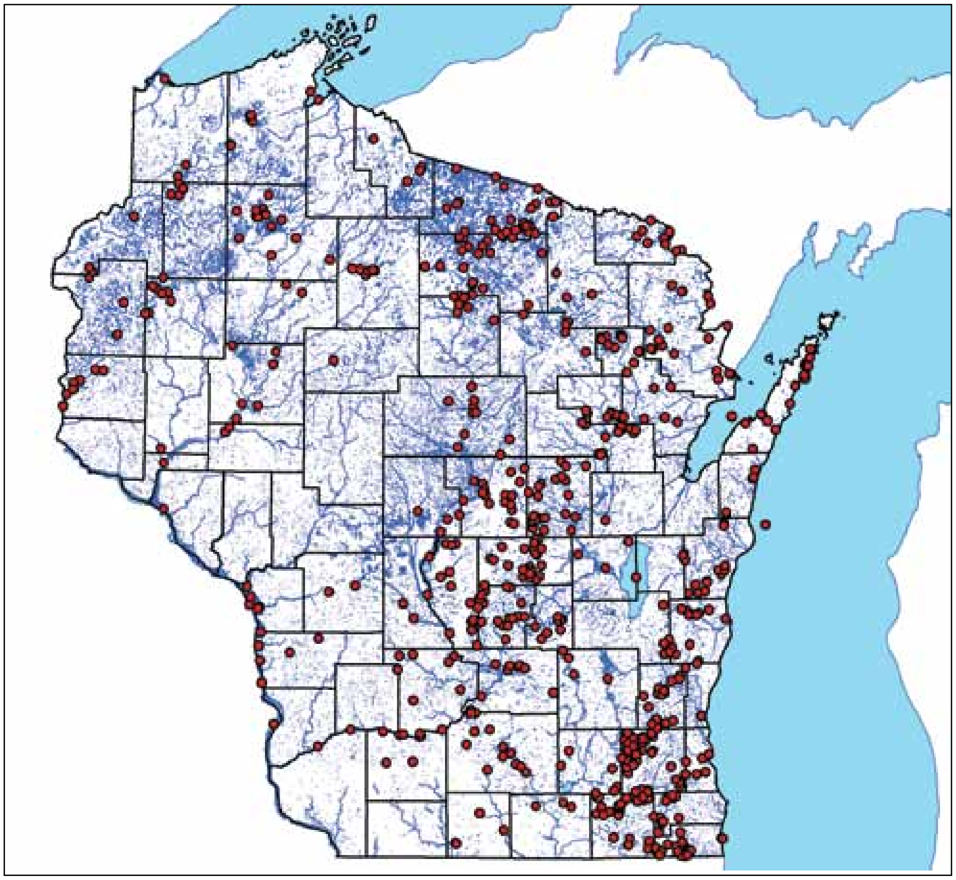

Figure 1. Statewide map of known distribution of Eurasian watermilfoil in Wisconsin.

Defining the Questions

There are many considerations when forming and implementing an aquatic plant management (APM) control plan, including different management tools and approaches (e.g., harvesting, drawdowns, herbicides, and biological controls), and in the case of herbicides – timing, formulations and application rates, water flow, lake type, and target and non-target species. Wisconsin aquatic plant management administrative rules (NR 107 Wis. Adm. Code) state the guidance and procedures for utilizing chemical herbicides for the management of aquatic plants. The rule emphasizes a balanced and healthy aquatic ecosystem, and specifically states that *Chemical management shall be allowed in a manner consistent with sound ecosystem management and shall minimize the loss of ecological values in the water body.* Historically, resource managers have applied a "do-no-harm" philosophy for public waters when permitting measures to provide nuisance vegetation relief over the short-term, as opposed to setting concrete restoration goals achievable over the long term – for example, to strategically reduce populations of an invasive, or to restore or protect the native plant community. Whether achievement of these long-term goals is possible or feasible in Wisconsin lakes is yet to be

Figure 2. Photograph of Eurasian watermilfoil in Bear Paw Lake (Oconto County, WI). Photo: M. Nault.

Figure 3. Photograph of Eurasian watermilfoil in Eagle Lake (Racine County, WI) raked into piles by lake residents after being cut by a mechanical harvester. Photo: J. Hauxwell.

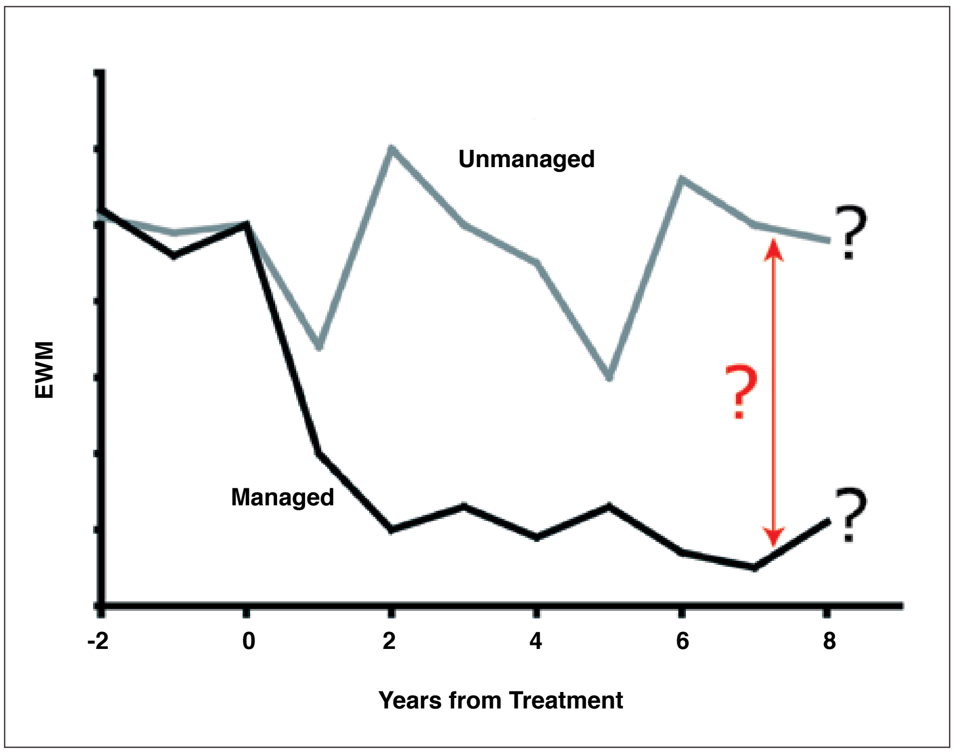

Figure 4. Conceptual figure showing the relationship between the abundance of Eurasian watermilfoil over time, subject to management or not.

determined. It is similarly unclear whether long-term strategic management versus the "do nothing" approach results in different outcomes over broad temporal and spatial scales (Figure 4).

To address some of these gaps in knowledge, we have developed an adaptive, science-based monitoring framework designed to help us weigh the costs of invasion against the costs and benefits of management. Working in partnership with stakeholders (lake groups and private lake management professionals), as well as academic and agency scientists and resource managers, we have begun to assess a long-term, ecosystem-wide strategic management approach that employs large-scale, early-season herbicide applications to reduce the distribution and density of EWM and restore native plant communities.

Opportunity for Success Using Early Spring Low-dose Treatments?

The efficacy of aquatic herbicides is dependent on both application concentration and exposure time, and these factors are influenced by two separate but interconnected processes – dissipation and degradation. Dissipation is the physical movement of the active herbicide within the water column both vertically and horizontally. Dissipation rates are affected by wind, water flow, treatment area relative to untreated area, and water depths. Degradation is the physical breakdown of the herbicide into inert components. Depending on the herbicide utilized, degradation occurs over time either through microbial or photolytic processes.

Laboratory studies have shown 2,4-D (2,4-dichlorophenoxy acetic acid, dimethylamine salt) concentrations well below current recommended label rates of 2000-4000 µg/L acid equivalent (ae) coupled with extended exposure times can result in effective control of EWM. Green and Westerdahl (1990) documented good EWM control after a 24-hour exposure to 2000 µg/L ae 2,4-D. They then tripled the exposure time and quartered the concentration to produce similarly effective control with a 72-hour exposure to 500 µg/L ae. Subsequent research by Glomski and Netherland (2010) demonstrated that long-term exposures (>14 days) to concentrations as low as 100 µg/L ae can result in effective EWM control. It is our goal to evaluate the operational applications of these laboratory findings in the field.

There may be several advantages to conducting low-dose herbicide treatments in early spring. Water temperatures are cooler in the spring, resulting in slower microbial degradation and longer exposure times. In addition, early emerging exotic plant species are still small and most vulnerable to herbicides, while many native plant species remain dormant and are therefore less susceptible to treatment. In addition, performing treatments while plant biomass is relatively low prevents the decomposition of large volumes of plant material, which in turn minimizes the risk of dissolved oxygen crashes, nutrient pulses, and algal blooms.

Building the Framework

To evaluate the efficacy, selectivity, and potential changes in water quality associated with large- to whole-lake scale early season herbicide treatments for the management of EWM, WDNR has been working under a cooperative research agreement with the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) for the last four years. The objective is to systematically measure in-lake herbicide concentration and exposure times under varying operational conditions and develop recommendations for improving control of invasive aquatic plants and reducing damage to native plant populations. Most projects involve detailed aquatic plant surveys (Hauxwell et al. 2010; Mikulyuk et al. 2010), early spring and late summer mapping of the target species, residual herbicide monitoring and analyses (ERDC Waterways Experiment Station, Vicksburg, MS; Center for Invasive Aquatic Plants, Gainesville, FL), and water quality monitoring. Citizen volunteers and private consulting firms are active participants in a number of these projects, contributing to the effort by collecting water samples and taking water quality measurements. Many of these projects received funding from state aquatic invasive species (AIS) control grants that are available through the WDNR to cover some of the costs.

Whole-lake scale herbicide treatments result from herbicide application and then dissipation throughout the water column that achieves an effective overall lake-wide concentration. This can be accomplished by applying 2,4-D over the entire lake surface at a constant rate to achieve the lake-wide target concentration, or by applying at higher rates only to EWM areas, allowing dissipation to move the chemical off-site and reach a lower lake-wide concentration that is acting on a whole-lake scale.

To date, we have developed nine case studies of whole-lake liquid 2,4-D treatments in northern and eastern Wisconsin (Figure 5). We have analyzed herbicide residual concentrations and evaluated the selectivity of aquatic plant control. Target treatment area concentrations of 2,4-D in our experimental case study lakes ranged from 250-2500 µg/L ae, and were applied to 8-100 percent of the lake area resulting in whole-lake target concentrations of 73-500 µg/L ae (Table 1). While we are still in the process of compiling and analyzing data and treatment details across all the projects, some patterns are beginning to emerge.

Preliminary Findings

Liquid 2,4-D dissipates quickly

2,4-D can quickly dissipate throughout a lake in as little as one to three days after treatment, even if applied only to EWM high-density areas (Table 1). Mean lake-wide 2,4-D concentrations from zero to three days after treatment (DAT) ranged from 122-613 µg/L ae and 122-575 µg/L ae 0-7 DAT. This rapid dissipation of herbicide off of targeted treatment sites can result in a whole-lake treatment if the scale of the treatment area is large compared to the overall lake volume.

In addition to wind and water flow, lake stratification can also play an important role in vertical dissipation, preventing mixing of herbicide into deeper lake waters, and presents an

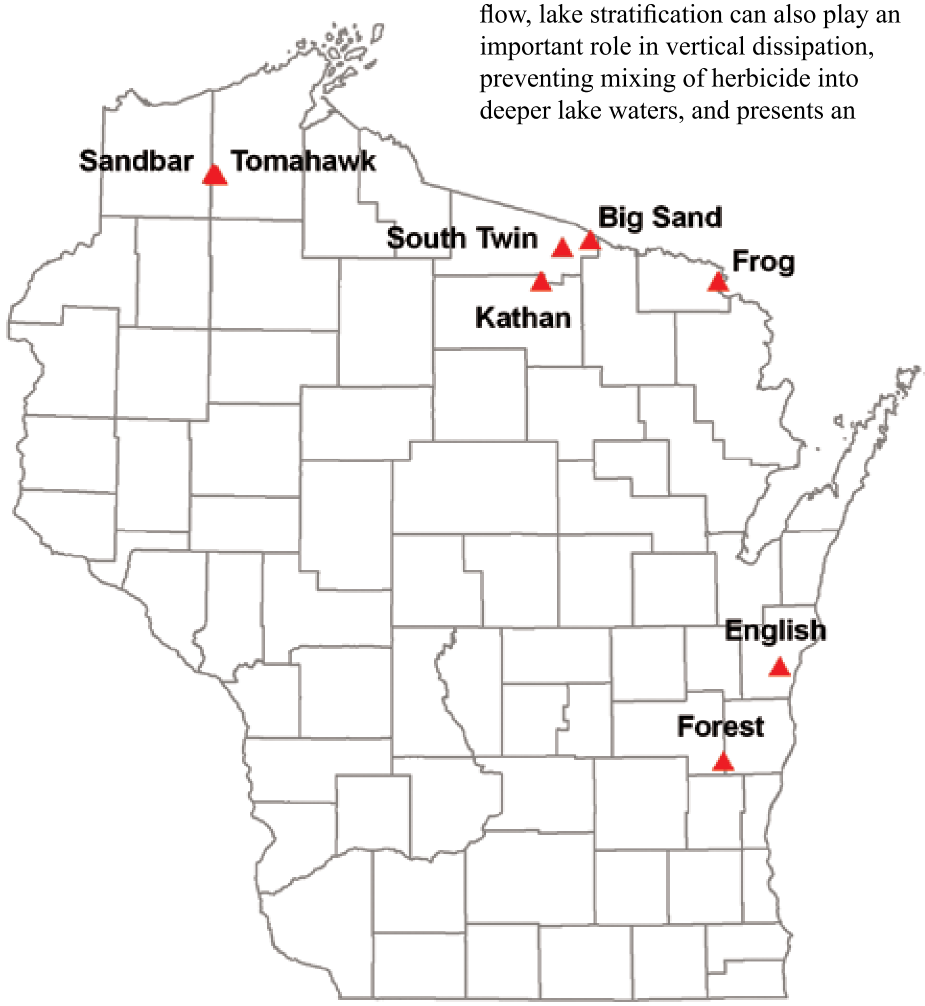

Figure 5. Location of Wisconsin case study lakes involved with early spring, whole-lake treatments and herbicide residual monitoring. South Twin Lake was treated in both 2009 and 2010.

Table 1. Summary table of nine case studies in Wisconsin managed with a whole-lake, early spring 2,4-D treatment for control of EWM. Residual herbicide data represents water samples collected at mid-depth at multiple sites. Only native plants with at least a 5 percent littoral frequency of occurrence at any sampling event were tested for significant differences pre- and post-treatment using Pearson's chi-square test. (‡) 0-4 DAT mean, (‡‡) 0-2 DAT mean, (*) 0-8 DAT mean, (**) 0-9 DAT mean, and (***) 0-6 DAT mean. n/a indicates situations in which pre- and post-treatment native plant data was not available.

Lake	Year	Target [2,4-D] in treated area (µg/L ae)	% Lake Area Treated	Mean 0-3 DAT Lake-wide [2,4-D]	Mean 0-7 DAT Lake-wide [2,4-D]	Days [2,4-D] > 100 µg/L ae	EWM Seasonal Control	Confirmed Hybrid	% Native Species with Decrease
South Twin	2010	2500	26	613 ± 139	575 ± 112*	23	Complete	No	57
Tomahawk	2008	500	100	563 ± 44	539 ± 25*	110	Complete	No	78
Sandbar	2011	275	100	370 ± 17	357 ± 14	44	Partial	No	27
English	2010	2000	27	306 ± 64‡	286 ± 48**	38	Partial	Yes	n/a
Frog	2010	250	100	297 ± 22	289 ± 14	22	Partial	Yes	38
Forest	2011	600	37	286 ± 13	289 ± 10***	31	Partial	Yes	n/a
Big Sand	2010	2100	8	194 ± 61‡‡	167 ± 31	14	Partial	No	n/a
Kathan	2010	500	54	149 ± 30	131 ± 21	14	Partial	No	43
South Twin	2009	1750	26	122 ± 12‡‡	122 ± 7	17	Partial	No	47

operational challenge for calculating treatment volume. Absence of a thermocline when one is expected may result in no observable whole-lake effects of treatment due to diluted concentrations. Conversely, the presence of a thermocline when not accounted for has the potential to unintentionally turn a spot treatment into a whole-lake treatment if the volume of water that the herbicide is able to mix with is significantly less than the overall lake volume.

Liquid 2,4-D degradation was slower than predicted

2,4-D degradation occurred at a slower than expected rate, especially in situations with cool spring water temperatures. 2,4-D specimen labels impose irrigation restrictions for treated waters based on a 21-day waiting period and/or a measured concentration of less than 100 µg/L ae. Lake-wide residual concentrations exceeded the irrigation standard of 100 µg/L ae for 14 to 110 DAT, and concentrations remained high after the 21-day waiting period in six of the nine case study lakes. We are evaluating the impact of trophic status, alkalinity, and history of prior herbicide use as factors that may influence the rate of 2,4-D degradation.

Eurasian watermilfoil control varied

Treatment efficacy varied over the nine case study projects, ranging from 40-100 percent reduction in seasonal EWM occurrence. Complete seasonal control of EWM was achieved in lakes with the highest 0-7 DAT lake-wide concentration of 2,4-D. At mid- to low-treatment concentrations, variation was high – while a particular target concentration achieved good seasonal control of EWM in one system (nearing detection limits), it resulted in less than a 50-percent reduction in EWM in another. Lower-than-expected efficacy was also associated with the occurrence of hybrid watermilfoil (*M. spicatum* X *sibiricum*), and further analysis on hybrid susceptibility is currently underway.

Effects on native plants and other observations

Year of treatment effects on native plants were mostly negative, and on aggregate, 34 of the total 38 significant differences between species frequency of occurrence pre- and post-treatment were reductions, affecting 38 percent to 78 percent of the number of native species within a lake (Table 1). Short-term reductions in native littoral frequency of occurrence occurred even at low concentrations of 2,4-D if exposure times were long. Native dicots such as the watermilfoils (esp. northern watermilfoil), water marigold, and bladderworts are known to be susceptible to 2,4-D, and displayed statistically-significant decreases in some of the case studies. At long-term exposures (across a range of concentrations) we also observed adverse impacts to relatively tolerant monocots such as naiads, several narrow leaf pondweeds, wild celery, and elodea.

Water quality may also be affected by large-scale treatments. For example, in two lakes for which we collected Secchi data pre- and post-treatment (Sandbar and Tomahawk), we observed a 40-percent reduction in water clarity when comparing pre-treatment averages to year-of treatment averages. In another Wisconsin lake not part of this study (Bridge Lake), dissolved oxygen levels declined following a large-scale treatment that occurred relatively late in the season when water temperatures were higher. We will continue to monitor these variables over the long term to better understand whether treatment-related impacts on native plants and water quality are persistent and how they relate to dosage and timing of treatments.

Quantifying the Trade-offs

We are beginning to define a conceptual framework within which to assess management actions (Figure 6). A successful treatment will minimize unintended impacts while maximizing the level of control of the target species. While high target impact and no collateral

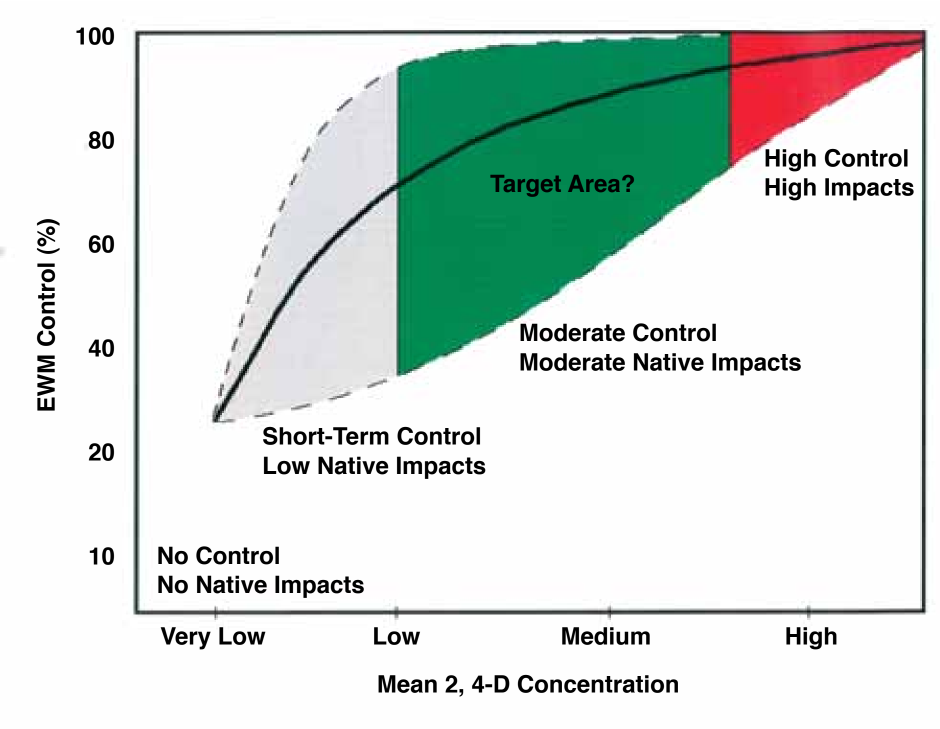

Figure 6. Conceptual figure relating whole-lake 2,4-D concentrations to Eurasian watermilfoil seasonal control and non-target negative impacts on native plants. The range of whole-lake concentrations depicted on the graph is from 0-600 µg/L ae, assuming an exposure time ≥14 days. Dashed lines show the range of outcomes of treatment at a given concentration, but are hypothetical and not intended to encompass all possible outcomes.

damage is the goal of any treatment, our forthcoming analysis shows this expectation may be unrealistic. It is therefore a matter of policy to define an acceptable tradeoff between costs and benefits. Conceptually, treatment performance can be evaluated by relating benefits (reduction in the negative impacts of invasive species) to simultaneous costs (unwanted collateral impacts). This framework may help guide policy and allow for unbiased evaluation of treatment performance. By continuing a rigorous scientific approach to treatment assessment and evaluation, we hope to continue to refine our understanding of appropriate measures for invasive species control, thereby improving management policy and decisions statewide.

It is important to note that large-scale herbicide treatments in Wisconsin are considered demonstration projects, and occur only as part of an approved APM plan and in conjunction with detailed monitoring and evaluation. We are still evaluating the longevity of the treatment benefits and drawbacks as well as "maintenance" requirements. While multi-year EWM control may be possible in some scenarios, negative impacts to certain native plants and longe-than-expected herbicide residuals demonstrate both the challenges and opportunities facing aquatic plant managers. The WDNR and ERDC have compiled a draft summary report of all the residual monitoring project case studies, and will continue with a final synthesis and published report. Our research shows the importance of residual monitoring both to understand treatment efficacy as well as potential ecological risks, and will help guide future management decisions to protect and restore Wisconsin's lakes.

Acknowledgments

Special thanks to the numerous citizen volunteers who assisted in collecting water samples and conducting water quality readings. Also thanks to WDNR Science Services field crew and support staff: Meghan Porzky and Scott Van Egeren, and regional WDNR staff: Kevin Gauthier Sr., Pamela Toshner, Mary Gansberg, Jim Kreitlow, and Scott Provost. We thank Dr. Mike Netherland and his staff at the Center for Invasive Aquatic Plants in Gainesville, FL for running our residual analysis samples and for Mike Netherland, Gina LaLiberte, and Scott Van Egeren for reviewing an earlier draft of this article.

References

Glomski, L.M. and M.D. Netherland. 2010. Response of Eurasian and hybrid watermilfoil to low use rates and extended exposures of 2,4-D and Triclopyr. *J. Aquat. Plant. Manage.* 48:12-14.

Green, W.R. and H.E. Westerdahl. 1990. Response of Eurasian watermilfoil to 2,4-D concentrations and exposure times. *J. Aquat. Plant Manage*. 28:27-32.

Hauxwell, J., S. Knight, K.I. Wagner, A. Mikulyuk, M.E. Nault, M. Porzky and S. Chase. 2010. Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry and Analysis, and Applications. Available from the Wisconsin Department of Natural Resources, Madison, WI. PUB SS-1068 2010.

Mikulyuk, A., J. Hauxwell, P. Rasmussen, S. Knight, K.I. Wagner, M. Nault and D. Ridgley. 2010. Testing a methodology for assessing plant communities in temperate inland lakes. *Lake and Reserv. Manage.* 26:54-62.

Michelle Nault is a research scientist for the Wisconsin Department of Natural Resources and conducts research on aquatic plant ecology and invasive species management throughout the state. Reach her at: Michelle.Nault@wisconsin.gov.

Alison Mikulyuk is a research scientist for the Wisconsin Department of Natural Resources, a doctoral student at the University of Wisconsin-Madison's Center for Limnology, and a member of NALMS. She conducts research on aquatic ecology and invasive species ecology and management. She can be reached at: Alison.Mikulyuk@wisconsin.gov.

Jennifer Hauxwell, Ph.D., is chief of the Fisheries and Aquatic Sciences Research program at the Wisconsin Department of Natural Resources. She earned her Ph.D. in aquatic ecology from Boston University's

Marine Program at Marine Biological Laboratory in Woods Hole, MA, and was a postdoctoral associate at the University of Florida. She can be reached at: Jennifer.Hauxwell@wisconsin.gov.

John Skogerboe is a research scientist with the U.S. Army Corps of Engineers Engineer Research and Development Center with 34 years of experience, most recently focused on the management and control of invasive aquatic plants and restoration of native species. He provides Eurasian watermilfoil and curly-leaf pondweed management project guidance throughout Wisconsin, the Midwest, and nationally. He can be reached at: skoger@gte.net.

Tim Asplund is the statewide limnologist for the Wisconsin Department of Natural Resources, and has been a member of NALMS since 1992. He provides technical assistance and statewide leadership for lake protection, improvement, and restoration, including aquatic invasive species control projects and aquatic plant management activities. He can be reached at: Tim.Asplund@wisconsin.gov.

Martha Barton is a research scientist for the Wisconsin Department of Natural Resources, and conducts research on aquatic ecology and invasive species. She can be reached at: Martha.Barton@wisconsin.gov.

Kelly Wagner is a research scientist for the Wisconsin Department of Natural Resources, and conducts research on aquatic ecology and invasive species in Wisconsin lakes. E-mail her at: Kelly.Wagner@wisconsin.gov.

Tim Hoyman is the founder of Onterra, LLC and the firm's lead aquatic ecologist. He has been a member of NALMS since 1991 and can be reached at: thoyman@onterra-eco.com

Eddie Heath is an aquatic ecologist with Onterra, LLC, where he manages numerous projects and oversees all aspects of the firm's aquatic plant work. He can be reached at: eheath@onterra-eco.com.

Left to right: Tim Asplund, John Skogerboe, Michelle Nault, Martha Barton, and Jennifer Hauxwell.