Control of Invasive Aquatic Plants **on a Small Scale**

Michelle Nault, Susan Knight, Scott Van Egeren, Eddie Heath,
John Skogerboe, Martha Barton, and Scott Provost

Wisconsin has a diversity of landscapes, including a rich array of natural lakes. Especially prized for their recreational opportunities, residents and visitors enjoy fishing, swimming, and boating on these abundant and diverse waterbodies. Unfortunately, these lakes are increasingly threatened by aquatic invasive species – exotic plants and animals, as well as viruses and other pathogens, which can change the ecology of the lake. Some invasive aquatic plants such as Eurasian watermilfoil (*Myriophyllum spicatum*; EWM) hold much of their biomass near the waters' surface where it is often perceived as a nuisance, interfering with recreational activities and aesthetic appeal (Figure 1). Although there have been a variety of management techniques investigated for EWM control (mechanical harvesting, biocontrol, hand-removal, bottom barriers, etc.), lake organizations and managers in Wisconsin have primarily relied on auxin herbicides, especially 2,4-D, which are viewed as a cost effective management tool. At the same time, it is widely acknowledged that appropriate herbicide selection and application is essential, as managers need to balance the desired effects of the herbicides on target plants, while concurrently minimizing any unintended harm to native communities.

In an attempt to accomplish this selective control, one strategy has been to target EWM with herbicides early in the growing season. Treating in early spring has several advantages in northern temperate lakes. First, cooler water temperatures result in slower microbial degradation of many herbicides, which may increase the effectiveness of control. Second, EWM is actively growing and vulnerable to chemicals, while a majority of native plants are still largely dormant, and are less likely to be affected by the herbicide. Third, although EWM is actively growing, plants have not yet amassed much biomass, which minimizes oxygen depletion when they decompose, and reduces excess nutrient inputs that may stimulate algal growth.

*Figure 1. Colony of surface matted Eurasian watermilfoil (*Myriophyllum spicatum*) in a northeastern Wisconsin seepage lake.*

Along with this strategic seasonal timing, managers often attempt to target isolated invasive plant colonies rather than treating at a larger scale. Several situations may warrant a small-scale treatment; a discovery of a small pioneer colony of EWM, an effort to keep small populations of EWM from rebounding following a larger control effort, or a need to control a specific colony causing a navigational impairment. Wisconsin state administrative code defines small-scale treatments as those less than 10 acres or less than 10% of the littoral zone. From an ecological standpoint, small-scale treatments are those in which the total quantity of applied herbicide is anticipated to have an effect on plants at a localized, not lake-wide, scale.

Treating aquatic invasive plants at a small-scale with auxin herbicides in early spring has been well integrated into Wisconsin's aquatic plant management program. However, the efficacy and observed longevity of invasive control, as well as impacts on native species has not been well documented. The Wisconsin Department of Natural Resources (WDNR), in conjunction with the U.S. Army Corps of Engineers and private lake management consultants, is conducting an ongoing study monitoring the fate of 2,4-D used in small-scale treatments. Here we review some efforts to evaluate these treatments, with specific objectives of monitoring the observed concentration and exposure times of the applied herbicide, evaluating the dissipation patterns of different formulations of herbicides, and assessing efficacy and selectivity of the treatments for small-scale colonies of EWM. While this article focuses on EWM, findings regarding small-scale treatments can likely be applied to other aquatic invasive plants as well.

Herbicide Dissipation Studies

The effectiveness of a chemical herbicide is dependent on the observed concentration (C), as well as the time (T) of exposure (E) of the target plants to the herbicide, creating CET relationships for many chemicals utilized in aquatic environments (Green and Westerdahl 1990; Netherland et al. 1991; Netherland and Getsinger 1992). These laboratory studies linking efficacy and CET show a strong relationship, where higher concentrations require shorter exposure times for effective control, and lower concentrations require longer contact times for similar control (Figure 2).

Although CET relationships have been studied under controlled settings, predicting actual CET in a lake can be challenging. Herbicide concentrations within the treatment areas begin to decline immediately after application. Water flow and wind combine to dissipate the chemical so that actual concentrations within the treatment area may not meet target concentrations. Not surprisingly, herbicides applied to sites exposed to wind and wave action often do not reach target concentrations and dissipate more quickly than treatments in protected areas such as channels or bays (Figure 3).

For these reasons, CET targets are difficult to achieve and maintain in small-scale treatments. Current strategies to improve CET are to increase the herbicide concentration and/or increase the size of the treatment area to provide longer exposure times. Many commonly used 2,4-D product labels suggest using a higher concentration in "difficult conditions" such as small areas in large waterbodies than for more "typical conditions" or larger treatments areas. The manufacturer's recommendation of higher use rates recognizes that the chemical will likely dissipate quickly off of small sites after application, especially in areas of high water exchange. The foundational laboratory CET study of 2,4-D (Green and Westerdahl 1990) found that EWM must be exposed to concentrations of 2 ppm for at least 24 hours to be effective. Lake management consultants often add a buffer zone around small-scale treatment areas to increase likelihood of control.

In a study of 98 small (0.1-10 acres) treatment areas across 22 lakes, we monitored the water column concentration

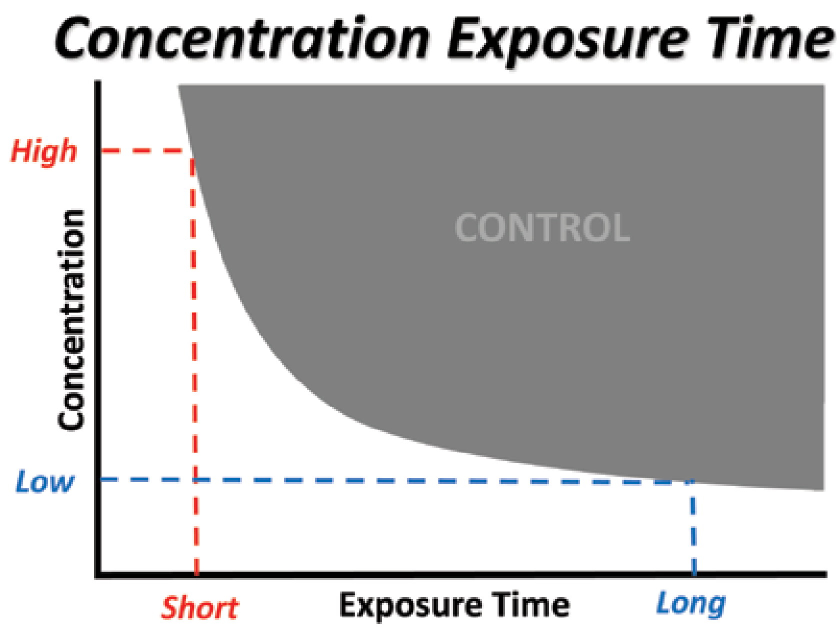

Figure 2. Generalized concentration/exposure time graph. Small-scale "spot" treatments use high concentrations due to short anticipated exposures times, while large-scale treatments use lower levels of herbicides and have longer exposure times.

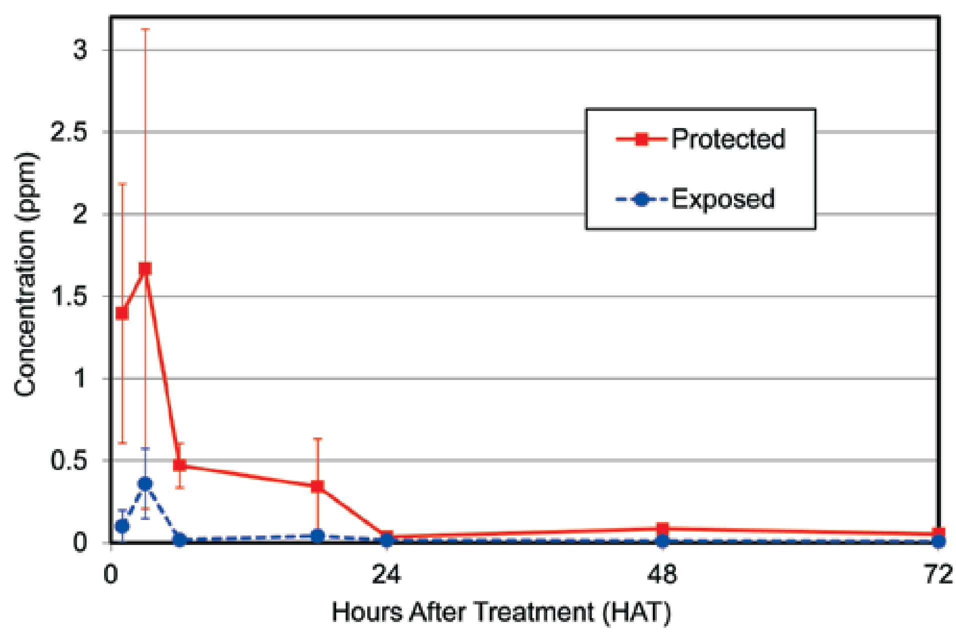

Figure 3. Comparison of average herbicide concentrations observed in treatment sites located in areas exposed or protected from wind and water currents. Concentrations in protected treatment areas were initially higher than those in exposed areas, although concentrations quickly dissipated to below detectable limits by 24 hours after treatment (HAT) regardless of spatial location.

of 2,4-D (target concentration 2-4 ppm) from 1 to 192 hours after treatment (HAT). In the majority of cases, initial observed concentrations within treatment areas were far below the target concentration, and then dropped below detectable limits within a few hours (Figure 4). These results indicate the water column concentrations in the treatment areas were lower than those recommended by previous CET studies for effective EWM control. Data from these small-scale treatments suggests that rapid dispersion is the main factor influencing the decline of herbicide concentrations. Although microbial activity will ultimately degrade 2,4-D, data from other studies indicate this occurs over a period of weeks.

The corollary to the dissipation problem is that the chemical may drift away from the intended treatment area into other non-targeted areas. Depending on the quantity of chemical, this dispersed herbicide might have no measurable effect on plants in the lake, or it could affect plants outside of the intended target area (if concentrations are sustained with a long enough exposure time). If the area of all the small-scale treatments sums to more than 5-10% of the epilimnetic lake volume, there may be sufficient herbicide to disperse throughout the lake and function as a lower concentration whole-lake treatment, potentially impacting plants on a lake-wide scale (Nault et al. 2012) (Figure 5).

Different Formulations

2,4-D for aquatic use is marketed under a variety of product names, and there is belief that differences between these products may play a role in the success of small-scale treatments. There are both liquid and granular forms, and while the liquid form is an amine, there are both ester and amine formulations of the granular products. Once in contact with water, both the ester and amine formulations dissociate to the acid form of 2,4-D. The rate of ester dissociation is influenced by the pH of the water, with a faster dissociation to acid under more alkaline conditions. While the ester formulation has been shown to be much more active than the amine on variable-leaf milfoil *(Myriophyllum heterophyllum)* in low alkalinity water (Netherland and Glomski 2007), this relationship has not been established for EWM in higher alkalinity waters. Nonetheless, the granular and liquid forms of 2,4-D are commonly believed to perform differently in terms of controlling EWM. It may seem reasonable to expect a granular application to be more effective in small areas; in theory the granules drop and stay put, releasing the chemical as they dissolve to maintain a steady concentration. However, comparisons between granular and liquid forms reveal they dissipated similarly when applied at small-scale sites. Initially, liquid forms had higher water column concentrations than the granular, but in the majority of cases concentrations of both forms decreased rapidly to below detection limits within 24 HAT (Figure 6).

By our earlier reasoning, we might expect the granular forms to have a lower concentration just after application due to slow dissolution and diffusion off of the granule. However, rather than maintaining a steady concentration over time, the observed concentration in the water column continues to rapidly decrease due to dissipation. Possibly, the granule sinks into the bottom sediment and is no longer exposed enough to diffuse into the overlying water column. There have been preliminary investigations into the concentration of herbicides in the water-saturated sediments, or pore-water. Initial results suggest the concentration of herbicide in the pore-water varies widely from site to site following a chemical treatment, although in some locations, the concentration in the pore-water was 2-3 times greater than the application rate (Jim Kreitlow, personal communication). Vassios (2014) found that following a granular herbicide application, more herbicide accumulated in the roots of EWM when compared to liquid herbicide, suggesting this might result in a more effective control than treating the foliage. However, recent mesocosm data revealed that high rates of 2,4-D (4 to 20 mg/Kg of sediment) applied to the sediment resulted in very limited visual symptoms and no control of the treated plants. These results suggested very limited root uptake of the herbicide from the sediment or pore-water (M. Netherland, personal communication).

Effectiveness of Small-Scale Treatments

Assessment of multiple small-scale treatment areas across a large number of lakes proved a difficult logistical challenge. Determination of an adequate sampling regime (number of samples,

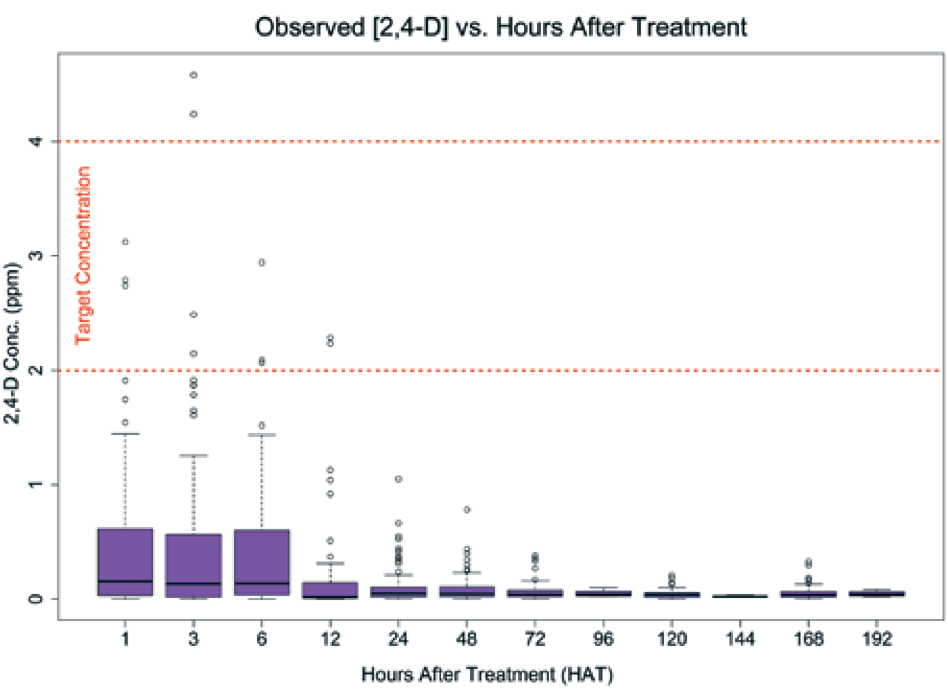

Figure 4. Boxplot graph of 2,4-D water column concentrations observed across 22 study lakes compared to hours after treatment. Initial observed herbicide concentrations were well below target application rates, and herbicide moved quickly off site within a few hours after treatment.

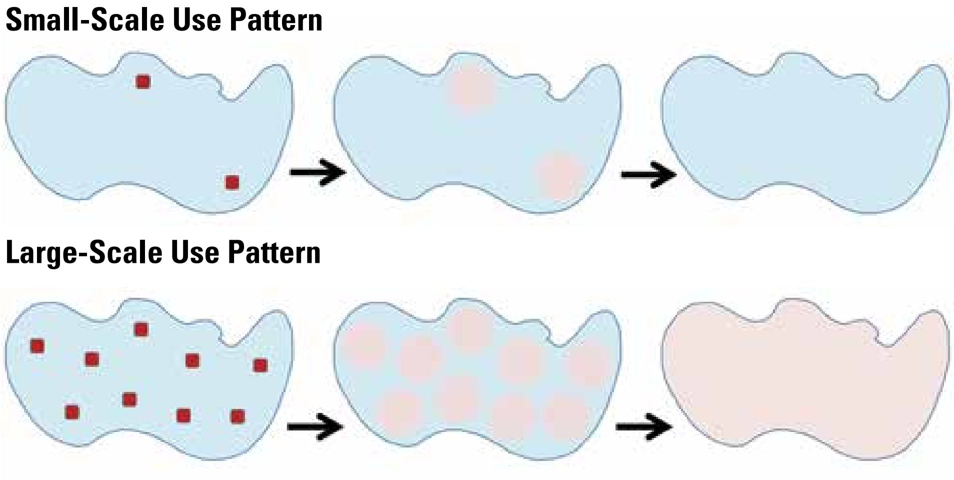

Figure 5. Conceptual diagram comparing dissipation patterns of small-scale versus large-scale chemical treatments. Anticipated impacts with small-scale treatments are localized, while large-scale treatments often result in lake-wide effects.

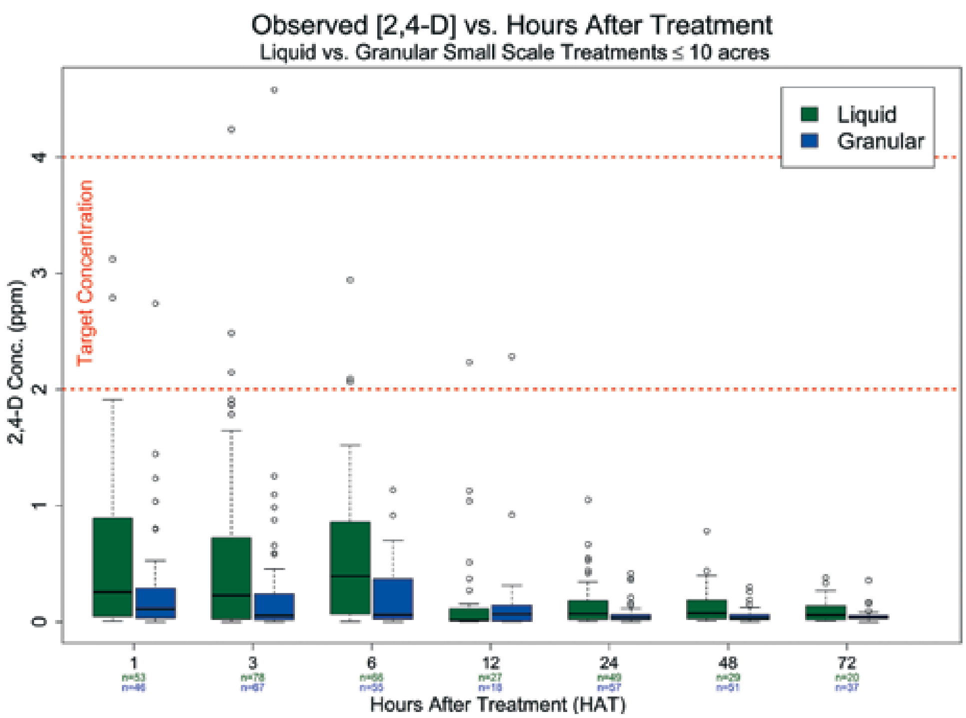

Figure 6. Boxplot graph of 2,4-D water column concentrations observed across 22 study lakes compared to hours after treatment. Initial liquid herbicide concentrations were higher than granular, although both forms were typically below target application rates, and similarly dissipated off site.

number of evaluations, effort vs. data) proved difficult to standardize, yet the efforts produced a body of evidence regarding overall efficacy of small-scale applications with 2,4-D. Surveys of pre- and post-treatment aquatic plant community data were sometimes, though not always collected in conjunction with small-scale treatments to determine treatment outcomes. Using a modified version of the whole lake point-intercept sampling methodology, a grid of sampling locations was laid over the treatment sites, and frequency and semi-quantitative abundance of natives and invasive plants were assessed. Because of their size, small treatment areas typically had few sampling points within their boundaries, and valid statistical comparisons on individual treatment sites were often limited by sample size.

Preliminary analysis of 2,4-D treatments from small (<10 acres) treatment sites across multiple study lakes revealed that EWM control was highly variable following use of either liquid or granular treatments. In order to qualify overall efficacy of control across multiple sites and lakes, we pooled data from a number of studies and found that in general, approximately half of small-scale treatments were effective (>50% reduction) when assessed a few months following the treatment. This efficacy is lower than that observed with large or whole lake treatments, where there is typically 80-100% control of EWM, and the CET are better understood (Nault, in preparation). Although some small-scale treatments can be effective, they are also difficult to evaluate and the variables that drive their efficacy are complex. The uncertainty of achieving control with small-scale treatments needs to be understood by lake organizations and funding sources that allocate large amounts of money towards management efforts.

Research Summary

Applications of 2,4-D to small-scale areas rarely reached target concentration or the CET that laboratory studies have shown necessary to effectively control EWM. Plants may experience injury symptoms and reductions in growth, but may not be completely killed if the herbicide was not in contact with the plant for a sufficient period of time. Data collected following small-scale herbicide treatments with both liquid and granular 2,4-D products in Wisconsin show mixed efficacy in controlling EWM and were much less predictable than whole-lake treatments. In addition, the quick herbicide dissipation from treatment areas was similar between granular and liquid forms of 2,4-D. While there is some evidence that granular herbicide forms can initially concentrate in sediment pore-water, any connection between this and efficacy has not yet been documented.

Future Research Direction – Integrated Pest Management

Recent aquatic plant management in Wisconsin has primarily relied on the use of 2,4-D to control EWM. However, this management tool for aquatic invasive plant control may not be appropriate in all circumstances. It appears that there are more questions than answers using 2,4-D for control of aquatic invasive plants. As more data are collected on the fate of target and non-target effects we will be able to better evaluate the effectiveness of herbicide treatments. Further, there is natural inter-annual variability in EWM populations, with populations expanding or shrinking even in the absence of any targeted control, making the evaluation of active management more difficult. Monitoring of untreated reference areas would aid in our understanding of the natural factors that influence EWM from year to year and to determine if a "monitor and wait" management strategy has merit.

It is essential to recognize that eradication of EWM is likely unrealistic, and that an up-to-date lake management plan with clearly outlined goals will help guide management decisions. Management plans and future research should embed integrated pest management within the options implemented and evaluated. Contact herbicides (with shorter CET requirements), manual hand-removal, scuba diver assisted suction removal, benthic barriers, and biocontrol weevils all deserve additional research so that the costs, efficacy, and non-target impacts can be compared. In addition, the installation of a barrier curtain around small invasive plant colonies could be used to increase exposure time where systemic herbicides are used. In all cases, collecting quality data over both the short- and long-term is essential to evaluate and potentially revise management techniques.

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Left to right: Michelle Nault, Martha Barton, Scott Van Egeren, Scott Provost, and Susan Knight. Not pictured: Eddie Heath and John Skogerboe.

Michelle Nault is a water resources management specialist for the Wisconsin Department of Natural Resources, and conducts monitoring and research on aquatic plant ecology and invasive species management. She can be reached at: Michelle.Nault@wisconsin.gov.

Susan Knight is an associate scientist with the University of Wisconsin-Madison Center for Limnology, specializing in aquatic plant ecology and taxonomy. She can be reached at: seknight@wisc.edu.

Scott Van Egeren is the statewide lakes and reservoir ecologist for the Wisconsin Department of Natural Resources. He can be reached at: Scott.VanEgeren@wisconsin.gov.

Eddie Heath is an aquatic ecologist with Onterra, LLC, where he oversees numerous aquatic invasive species monitoring and control projects. He can be reached at: EHeath@onterra-eco.com.

John Skogerboe is a retired research scientist, previously working with the U.S. Army Corps of Engineers, Engineer Research and Development Center. He can be reached at: jskogerboe@comcast.net.

Martha Barton is a research scientist for the Wisconsin Department of Natural Resources, Bureau of Science Services. She can be reached at: Martha.Barton@wisconsin.gov.

Scott Provost is the statewide aquatic plant management coordinator for the Wisconsin Department of Natural Resources. He can be reached at: Scott.Provost@wisconsin.gov.