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Management in Practice

Field application of florpyrauxifen-benzyl to treat hybrid Eurasian watermilfoil: initial effects on native and invasive aquatic vegetation

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Abstract

One of the most widespread and common invasive aquatic plant species in North America is *Myriophyllum spicatum* L. (Eurasian watermilfoil). Given the variety of impacts it has on ecological and recreational values, identifying an effective treatment strategy for Eurasian and hybrid watermilfoil is a priority for invasive aquatic plant management agencies. Unfortunately, traditional control efforts using herbicides have not only been variably effective, but they have also resulted in non-target impacts. The herbicide florpyrauxifen-benzyl (trade name ProcellaCOR®) has recently been approved but understanding of effectiveness is mostly limited to mesocosm studies. Our study reports the outcome of using florpyrauxifen-benzyl to treat a strain of hybrid watermilfoil in an inland lake in the Laurentian Great Lakes region. Mean abundance in treatment areas decreased at all points sampled (or stayed the same where initial cover was zero). Percent cover in the two quadrats declined from 50% to 5% in area 1, and 20% to 0% in area 2. Of the nine native plant species present, frequency of occurrence increased (six species) or stayed the same (three species) after treatment. Mean species richness at each transect increased pre- to post-treatment. The substantial decreases in this strain of hybrid watermilfoil abundance and increases in presence of native aquatic vegetation in this field study provide initial evidence that florpyrauxifen-benzyl is effective in partial-lake treatments of this strain of hybrid watermilfoil at an application rate of 12.68 oz/ac ft, with limited non-target impacts to native species. Our study balances observational studies with logistical management concerns to benefit researchers and lake stakeholders, alike. Study outcomes support recent advances in milfoil management that could lead to improved control, which translates to reduced ecological and recreational impacts of milfoil, as well as reduced non-target impacts and long-term management costs.

Key words: invasive aquatic plants, aquatic plant management, Great Lakes, adaptive management, citizen science, non-target impacts

Introduction

Invasive aquatic plant (IAP) management is a broad field with a variety of species and treatment options. One of the most widespread and common IAP species in North America is *Myriophyllum spicatum* L., Eurasian watermilfoil (hereafter "EWM"). Native to Europe, Asia and north Africa, EWM was first identified outside its native range in eastern United States and is currently present in 48 U.S. states and three Canadian provinces (Moody et al. 2016). This species grows at depths of 1–10 m in freshwater or brackish lakes, ponds, shallow reservoirs and slow-flowing rivers and streams. While EWM does produce seeds, vegetative reproduction is the primary form of spread. Impacts of EWM result from its dense stands: it excludes native aquatic vegetation and potentially wildlife, impedes recreational activities, and decreases lakeshore property values (Boylen et al. 1999; Horsch and Lewis 2009; Zhang and Boyle 2010). This species can also hybridize with native *Myriophyllum sibiricum* Komarov (northern watermilfoil) to produce hybrid strains of watermilfoil (LaRue et al. 2013). While these hybrid strains are generally described as more invasive and resistant to herbicide treatment than EWM, significant variation in growth patterns and response to herbicides exists between strains, and even within pure EWM. While many hybrid strains are more aggressive than native strains, and more resistant to control efforts such as chemical control, overlap exists (Hoff and Thum 2022). Given the variety of impacts from both EWM and/or hybrid watermilfoil, these plants are a common target of IAP management efforts. Identifying an effective treatment strategy is a priority for IAP management agencies.

Management strategies include biocontrol, manual removal, benthic barriers, and chemical treatment. Biocontrol with the milfoil weevil (*Euhrychiopsis lecontei* Dietz, 1896) has been used with variable success; it avoids impacts to native species but is expensive and weevils can be difficult to source (White et al. 2022). Manual removal and benthic barriers have been used for very small populations but are not feasible for larger patches. Chemical herbicides such as 2,4-D, triclopyr, and fluridone are the most widely used approach to EWM management. Unfortunately, these herbicides have not only been variably effective, but they have also resulted in non-target impacts (Kujawa et al. 2017; Nault et al. 2018). Mikulyuk et al. (2020) compared the ecological effects of EWM with the effects of lake-wide 2,4-D treatments used for EWM control. They found that lake-wide 2,4-D treatments aimed at controlling EWM led to larger decreases in the number of native plant species, and abundance of native plant populations, than did the presence of EWM itself.

In 2017, however, the U.S. Environmental Protection Agency approved the herbicide florpyrauxifen-benzyl (trade name ProcellaCOR®; hereafter, FPB) for management of freshwater aquatic vegetation in slow-moving or still waters. Research on non-target impacts is forthcoming, but lab studies have shown minimal effects on seven aquatic plants native to North America (Beets et al. 2019), specifically *Elodea canadensis* Michx. (Howell et al. 2022), and *Pontederia cordata* L. (Beets and Netherland 2018), as well as freshwater mussels (Buczek et al. 2020). Overall, non-target impacts appear favorable compared to alternative herbicides (Washington Department of Ecology 2017). Given its recent approval, detailed information on effectiveness in field applications on EWM is very limited. In the laboratory, Mudge et al. (2021b) found that FPB at 3, 6, or 9 μg active ingredient L^{-1} resulted in 100% decrease in EWM biomass by 5 weeks post treatment in growth chambers, whereas 2,4-D and triclopyr required ≥ 270 µg acid equivalent L^{-1} to reduce shoot biomass 95–100%. Similar results were found in mesocosm studies of pure and hybrid strains (Beets et al. 2019; Mudge et al. 2021a). Haug et al. (2021) found lower absorption of FPB in the hybrid strain tested, as compared to pure EWM, which likely explains the lower sensitivity found in tests of hybrid vs. pure EWM strains (Beets and Netherland 2018). Cattoor et al. (2022) evaluated FPB in a small lake in Minnesota. They found few to no declines in native aquatic plant species, and a significant decrease in the strain of hybrid watermilfoil present (72% to 1% and 58% to 8%).

Given the improved efficacy of FPB relative to traditional herbicides, some citizen organizations such as lake associations have started, and will likely continue, to use FPB. While this change has the potential to yield benefits in terms of fewer non-target impacts, these lake user-driven treatments often lack a pre- and post-treatment evaluation of treatment outcomes. Many experts have called for increased field monitoring of the efficacy of IAP treatment strategies to better support management decisions. Unfortunately, state agencies do not have the resources to complete treatment surveys for the vast majority of lakes undertaking IAP control, and lake users often lack the funds to hire private consultants and/or lack the expertise and volunteers to complete extensive surveys themselves. However, with training, citizens can better understand management considerations and provide data adequate to inform science and management (Hoyer and Canfield 2021; Weber et al. 2022). As an alternative to agency or consultant surveys, our study provides a preliminary model that lake associations or similar groups could use to monitor the effectiveness of IAP control efforts on their own lake.

Our study expands the limited published literature related to field trials of FPB by reporting the outcomes of using FPB to treat a strain of hybrid watermilfoil in an inland lake in the U.S. Great Lakes region. Although the study size is small, it demonstrates the feasibility of lake users conducting pre- and post-treatment monitoring of both the target and native species, in a manner that requires neither extensive funding nor personnel. This will provide multiple stakeholder groups (state agencies, industry, and citizen groups) with a better "on the ground" understanding of an IAP treatment strategy that has the potential to provide better management and control while limiting impacts to native species.

Methods

Mickey Lake is a 61-acre lake located in Grand Traverse County, Michigan, USA (44.730°N; −85.765°W). Mickey Lake eventually outflows into Lake Michigan and has a 14,435-acre watershed. It contains a range of bottom substrates (fine sediment, sand, gravel, and rock) and significant lakeshore development and recreational (primarily angling) activity. Mickey Lake has

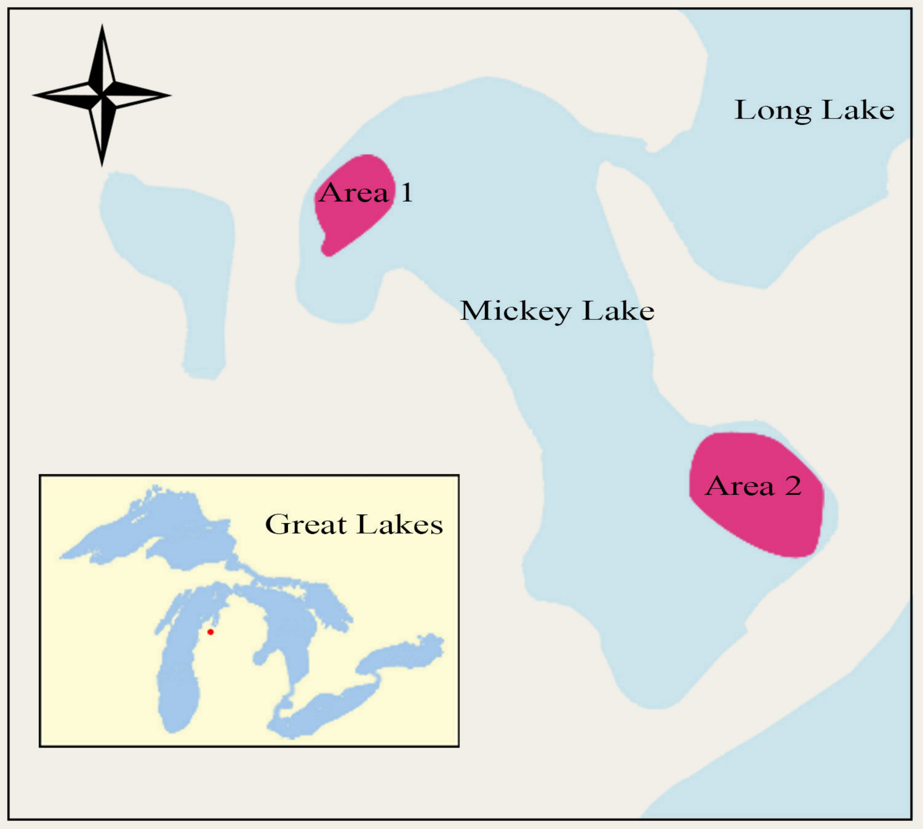

Figure 1. Treatment areas in Mickey Lake (indicated by dot in inset map). Area 1, 1.9 acres; Area 2, 4.1 acres.

had watermilfoil since 1995, which was assumed by lake managers to be EWM. However, it is difficult to correctly identify EWM vs. hybrid watermilfoil strains without genetic analysis (for this section the generic term "milfoil" is used for the Mickey Lake population). To determine the genetic identification of the milfoil, twenty plants were collected randomly from rake tosses within the two treatment areas. The top 15 cm with meristem were preserved by drying with silica gel and processed using microsatellite genotyping (genotyping by the Thum lab; see Thum et al. 2020).

Mickey Lake has two primary areas of milfoil growth, which were treated with liquid FPB by a licensed applicator on June 22, 2022 (Area 1 and 2; Figure 1). These areas were treated using a spray application rate of 38.04 oz/ac m over 6 acres, at an average depth of 1 m). Shoreline transect vegetation surveys were conducted on June 16, 2022 (pre-treatment) and July 14, 2022 (post-treatment). Two transect lines were sampled in each area (four total). Each transect line was sampled at depths of 0.3 m, 1.2 m, and 2.4 m (due to obstructions caused by the presence of dock/boat hoists at depths 0.3 m and 1.2 m in transects three and four in treatment area 2, only the 2.4 m sampling point was available for these transects). Four rake tosses, two from each side of the boat, were performed at each depth (sensu Thum et al. 2017). Thus, each of the eight transect points had four samples. The rake was a double headed 14-tine rake attached to approximately 15 m of 1 cm braided polypropylene rope. Abundance was used to assess changes

Table 1. Mean abundance of hybrid watermilfoil at 2.4m depth, derived from rake tosses.

Transect	Mean percent cover before (SE)	Mean percent cover after (SE)
1	48% (± 16%)	4% (± 1%)
2	14% (± 10%)	1% (± 1%)
3	19% (± 10%)	1% (± 1%)
4	1% (± 1%)	0% (± 0%)

in milfoil populations. Milfoil abundance was measured using the percentage of rake tines covered by milfoil in each double-sided rake toss. The mean milfoil abundance measure from the four rake tosses was used to estimate the abundance at each transect point. In addition, a 3 m^2 quadrat was placed in the center of each treatment area, and a visual assessment of milfoil percent cover was completed in each quadrat before and after treatment.

Frequency of occurrence (hereafter, "frequency") was used to assess changes in native plant species richness for the treatment areas and on a per-transect basis. The frequency for the treated areas summed species data across all sample points (four tosses at each of the eight sample points) to present a total species richness pre- and post-treatment. The frequency for each transect used the mean species richness pre- and post-treatment (total number of species in each transect sampling point, divided by the number of sampling points (three points per transect)).

Results

Genetic analysis showed that the milfoil strain present in Mickey Lake is a novel hybrid watermilfoil strain (Ryan Thum *pers. comm*). After treatment, watermilfoil abundance decreased at all points sampled (or stayed the same where initial cover was zero). The milfoil had the greatest abundance at the 2.4 m depth (Table 1). Except for the 4% abundance measure in transect 1, mean abundance for all sampled points was 0–1% post-treatment. Percent cover from visual assessment in the two quadrats declined from 50% to 5% in area 1, and 20% to 0% in area 2.

Of the nine native species found, frequency of occurrence increased (six species) or stayed the same (three species) after treatment (Figure 2). Mean species richness increased pre- to post-treatment in transects 1 and 2, and appeared to increase in transects 3 and 4 (Table 2). Although the sample sizes were not sufficient to allow a powerful statistical analysis, six of the eight submerged species increased in frequency, while the single floating species did not change. Only two submerged species did not see any increase (*Potamogeton gramineus* and *Potamogeton illinoensis*). *Chara globularis* and *Najas flexilis* saw the greatest increase in frequency (four-fold).

Discussion

The substantial decreases in the hybrid watermilfoil abundance and increases in presence of native aquatic vegetation in our field study provide initial evidence that FPB reduces milfoil abundance and cover with no apparent

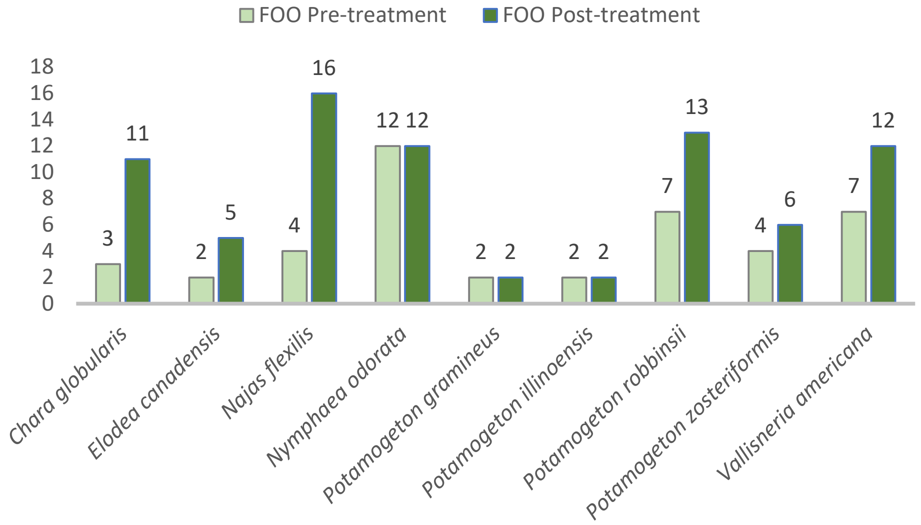

Figure 2. Frequency of occurrence (FOO) of native species (number of sites = 8), pre- and post-treatment.

Table 2. Mean species richness at each transect. *No SE due to single sampling point available for these transects.

Transect (n)	Mean species richness pre-treat (SE)	Mean species richness post-treat (SE)
1 (3)	3.7 (± 0.3)	5 (± 0.6)
2 (3)	3.3 (± 1.2)	3.6 (± 1.5)
3 (1)	1.3*	4*
4 (1)	0*	4*

negative effects on native species richness for at least four weeks post treatment. The large decreases in this hybrid watermilfoil strain (generally 95–100%) compare, for example, to what was considered "good" control (60% reduction) of a hybrid watermilfoil by 2,4-D after a long duration (greater than 31 days) of sustained concentrations (Nault et al. 2018). The increase in native species frequency of occurrence was likely a combination of increased growth and greater access to the native plants due to absence of milfoil. Although milfoil abundance may have interfered with collection of native species pre-treatment, the lack of detection suggests that natives were rare and sparse, because any common or abundant native species would likely have been detected. The removal of a competitor (in this case, hybrid watermilfoil for light) will likely allow improved future growth of native species (Claeson and Bisson 2013).

The availability of an effective tool to manage non-resistant milfoil strains with no apparent non-target impacts has several implications. First, the long-term cost savings to state agencies and other organizations providing treatment that would result from switching to a highly effective herbicide could be significant. These reduced annual costs, however, would depend on characteristics of the area treated and current treatment regimens; FPB is currently more expensive than traditional herbicides, and whether the potential long-term reduction in herbicide volumes would outweigh this increased cost would vary. Second, the non-target impacts of herbicides used to treat milfoil (2,4-D and triclopyr in particular) are gaining recognition (e.g., Mikulyuk et al. 2020; Dehnert et al. 2021); with that understanding comes the impetus for managers and treatment applicators to rethink routine application of traditional herbicides (Mikulyuk et al. 2020). The initial research on FPB (e.g., our study, Beets et al. 2019; Mudge et al. 2021b; Cattoor et al. 2022) suggest it may pose a solution to these issues: large reductions in milfoil with limited impacts to native plants. One caveat to this, however, is that due to genetic variation, milfoil strains may not respond consistently (i.e., large reductions in milfoil may not always be achieved; *sensu* Hoff and Thum 2022).

The lake used for our study has two characteristics that are relevant to improved milfoil management: first, moderate water movement that reduces actual exposure times (Mickey Lake flows into Long Lake, which flows into the Laurentian Great Lakes). Mesocosm studies have suggested that FPB requires short exposure times (0.5–4 hours exposure, depending on concentration) (Mudge et al. 2021b). Although the in-water concentrations of FPB over time were not measured, the rapid reduction in milfoil suggests they were sufficient. Second, despite the evidence that pure and hybrid watermilfoil strains are variably resistant to treatment (Hoff and Thum 2022), many lake managers do not determine the genetic identification before treatment (LaRue et al. 2013), which hinders the ability to understand how treatment impacts a specific strain and make appropriate treatment decisions in the future. Our study, in combination with other studies that evaluated different milfoil strains (Mudge et al. 2021a; Cattoor et al. 2022) indicates at least several hybrid genotypes are susceptible to FPB.

Since milfoil was discovered in 1995, management strategies for Mickey Lake milfoil have included treatment with 2,4-D, triclopyr, and, from 2002–2009, milfoil weevils. Despite these efforts, the populations of EWM and/or hybrid watermilfoil have spread in Mickey Lake, as well as the adjoining Long Lake. As in this case, the costs of this milfoil “maintenance management” are often covered by the local lake association, which generally have limited funds that compete for other ecological or recreational improvements. The absence of vegetation surveys prevents a better understanding of actual effectiveness of conventional herbicide treatment that would inform these community efforts (Thum et al. 2017). While citizen science has been used primarily for monitoring and surveillance of invasive species (Dehnen-Schmutz and Novoa 2022; Kousteni et al. 2022), our study demonstrates the potential for another application of citizen science, i.e., improving the understanding of invasive species control measures. Many states have programs to support volunteer water quality monitoring efforts, including aquatic plant surveys (e.g., Latimore and Steen 2014). These programs could potentially develop and house an invasive aquatic plant treatment monitoring component. This novel application of citizen science could be a foundation for more widespread efforts to collect information on IAP control strategies such as herbicide efficacy. This increased involvement in monitoring efforts may also lead to increased engagement in general lake management (Storey et al. 2016).

Our study has several limitations. Our small sample size and lack of reference areas prevents a powered statistical analysis, and most conclusions are based on observations. However, observational studies have value, particularly if they include tests of hypotheses about patterns (Underwood et al. 2000). Future survey designs for citizen-driven surveys should include more sampling points, over a longer temporal scale, and include reference sites. Given that EWM and hybrid milfoil strains commonly resprout after herbicide treatment (e.g., Thum et al. 2017), the incorporation of an herbicide treatment survey component into a long-term, citizen-based water quality monitoring program would provide robust evidence of the long-term efficacy of an herbicide. The study also failed to include reference (untreated) sites to compare to treated sites, to observe any background changes in milfoil or native plant abundance. Although it is possible the reported declines in milfoil were lake-wide changes not due to the herbicide, informal observations of significant milfoil biomass present in the lake for the remainder of the season suggest this was not the case. Finally, residue samples taken after herbicide application to confirm field concentrations would have been optimal.

Despite these limitations, our study provides value to the aquatic plant management community by documenting the outcomes of a successful, short-term treatment strategy that is similar to the treatment strategies used by thousands of lakes treating EWM and/or hybrid watermilfoil (i.e., a partial lake treatment designed to restore ecological and recreational values to treatment areas). The importance of this “ecology in situ” that balances observational studies with logistical management actions benefits researchers and lake stakeholders, alike (Kujawa et al. 2017). In conclusion, our study supports recent advances in EWM management that could lead to improved control, which translates to reduced ecological and recreational impacts of EWM, as well as reduced non-target impacts and long-term management costs.

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Author’s contribution

AD: research conceptualization; sample design and methodology; investigation and data collection; data analysis and interpretation; funding provision; and writing of original draft and editing.

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