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Comparison of Three Physical Management Techniques for Controlling Variable-leaf Milfoil in Maine Lakes

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ABSTRACT

Variable-leaf watermilfoil (*Myriophyllum heterophyllum*) is a nuisance aquatic plant in the northeastern United States. It grows in thick mats, often out-competing native vegetation, clogging boat motors, and deterring people from swimming and other water-related activities. We implemented three physical management techniques—hand removal, cutting, and benthic mats—on eight infested lakes in Maine to determine the most effective method to control this aquatic invasive. All three treatments resulted in significantly lower plant regrowth than the control. No significant differences were found among the three treatments in plant regrowth or among lakes in percent regrowth of variable-leaf watermilfoil. The costs of hand removal and cutting were roughly one-third the cost of installing benthic mats, although mat installation required less time to implement than the other two methods. Cutting was found to be unrealistic in practice because of difficulties in implementation. In conclusion, determining the most effective management technique for an area depends on the extent and density of the infestation. Our results suggest benthic mats provide a cost-effective option for thick, extensive infestations, whereas hand removal is more efficient in areas with small, high-density infestations or for selective removal in sparsely infested stands of mostly native macrophytes. Hand removal would also be useful during management surveys when individual plants or small clusters of variable-leaf watermilfoil are detected. Based on our study we suggest that benthic barrier and hand-removal methods are the most effective nonmechanical management techniques for lake associations and governmental agencies to incorporate into their management plans.

Key words: benthic barrier, exotic species, hand removal, invasive aquatic plants, milfoil, *Myriophyllum heterophyllum*, nuisance species.

INTRODUCTION

Variable-leaf watermilfoil (*Myriophyllum heterophyllum* Michx.) is an invasive aquatic plant of concern in New England lakes (Moody and Les 2002). In the battle against invasive aquatic plant species, eradication is the ultimate goal, yet it is rarely achieved (Madsen 2000). Once an introduced plant has invaded a lake, an ongoing management effort is necessary. Even in areas where plant removal is achieved, managers must monitor the water body for recurring infestations. In the United States, research on management techniques for aquatic invasive plants has been conducted on an array of invasive aquatic species including hydrilla (*Hydrilla verticillata* L.f. Royle) (Shearer and Jackson 2006), water hyacinth (*Eichornia crassipes* [Martius]; Holm et al. 1969), water chestnut (*Trapa natans* L.; Madsen 1993), and Eurasian watermilfoil (*Myriophyllum spicatum* L.; Boylen et al. 1996). Techniques widely used to control invasive aquatic plants, including those mentioned above, include herbicide application, biological controls, and physical management techniques. Herbicides are often used in conjunction with other management techniques such as hand removal (Helsel et al. 1996). Use of herbicides often causes public concern due to the potential of bio-magnification, environmental persistence, and minimal understanding of long-term effects (Charudattan 2001, Shepard et al. 2004, Tatum 2004). Furthermore, some plants (including hydrilla) develop herbicide resistance (Albrecht et al. 2004, Michel et al. 2004). For example, in Florida, despite an extensive herbicide management program, hydrilla continues to spread to more waterbodies every year due to herbicide resistance (Koschnick et al. 2006).

Biological controls, using either introduced or naturalized organisms, require extensive research and time to find an appropriate biocontrol agent for a given plant and to ensure that the control will not become invasive or adversely influence native species (Holm et al. 1969). For aquatic plant control, fish and invertebrates are often the key species studied as potential biocontrol agents (Madsen et al. 2000, Pipalova 2006) and are often used in conjunction with other control methods (Nelson and Shearer 2005). This method raises concerns given the number of organisms needed to achieve control, the amount of time required for control to be achieved, and the potential for introduction of new pathogens to local invertebrate populations (Madsen et al. 2000).

Physical management techniques include a variety of mechanical and nonmechanical methods. Nonmechanical methods are usually more economical than herbicides and biocontrol agents and can be put into action without rigorous controls; however, they are time and labor intensive (Madsen 2000). Mechanical methods can spread plant frag-

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ments and have negative effects on aquatic ecosystems, including sediment disturbance, resuspension of chemicals from the substrate, and injury to organisms (Madsen 2000).

We report here the results of our study evaluating the effectiveness of three physical management techniques: hand removal, cutting (leaving roots below ground), and benthic barriers on variable-leaf watermilfoil in lakes in southwestern Maine, USA. The Maine Department of Environmental Protection (MDEP) has taken a conservative approach to herbicide use in Maine lakes, and currently there are only three lakes in which herbicides have been used for other plant species. Hand removal and benthic mat techniques are commonly used physical management methods for many invasive aquatic plants, including milfoil. Benthic mats block sunlight for all the plant material, including native plants (Madsen 2000). Once the mat is removed, native species may recolonize the area. We additionally evaluated the effectiveness of cutting the variable-leaf watermilfoil plant at the water-substrate line, leaving the roots intact. Cutting using large mechanical mowing apparatus is commonly used for aquatic weed management (Madsen 2000), but it fragments and distributes plant material. We were interested in developing a hand-cutting technique that could be easily implemented by SCUBA divers and would minimize substrate disturbance while speeding up the removal process. Methods for managing variable-leaf watermilfoil, native to the southeastern United States (Les and Mehrhoff 1999), include herbicides and nonmechanical techniques. Although not as widespread as Eurasian watermilfoil, variable-leaf watermilfoil is known to be aggressive locally (Crowe and Hellquist 2000). Eurasian watermilfoil has been studied extensively for invasive traits (Grace and Wetzel 1978, Galatowitsch et al. 1999), dispersal capacity (Madsen and Smith 1997), and management and eradication techniques (Nichols 1972, Helsel et al. 1996, Madsen et al. 2000). Management technique effectiveness on variable-leaf milfoil has not been studied extensively (Bugbee et al. 2003). To our knowledge, there is currently is no research evaluating the effectiveness of nonmechanical physical management techniques for this species.

Management techniques for this study were chosen for evaluation based on their ease of implementation for resource managers and lake associations, as well as their minimal impact to the surrounding lake system (Nicholson 1981). Our objectives were to determine which physical management technique was most effective in controlling variable-leaf watermilfoil, most cost and time effective, and most suitable for dense infestations versus patchy infestations.

MATERIALS AND METHODS

Study Area

We selected eight lakes (Table 1) in Maine, USA, from the MDEP list of lakes with confirmed invasions of variable-leaf watermilfoil (http://www.maine.gov/dep/blwq/topic/invasives/doc.htm) to evaluate the efficacy of three nonmechanical control techniques. Maine has 29 lakes that have been invaded by four species of invasive aquatic plants. Variable-leaf milfoil has been found in 26 waterbodies, and the remaining three aquatic invaders (hydrilla, curly-leaf pondweed [*Potamogeton crispus* L.] and Eurasian watermilfoil) were each found in only one waterbody (Figure 1). Affected lakes are located in southwestern Maine where tourist activity and boating traffic is high. Our eight research lakes represent the northern and southern extent of the invaded lakes in Maine and vary in substrate composition, surface area, and number of boat access points (Table 1). Lakes were chosen that could accommodate the experimental plots and which had no history of prior management or current management near or in the plots.

Experimental plots were established on each lake based on accessibility to the plots, minimizing boating traffic around the plots, having an infestation of at least 60% variable-leaf milfoil in each plot, and uniformity of growth of variable-leaf watermilfoil in each plot. On each lake we established four 3 by 4 m plots along a perpendicular transect extending 20 m from the shoreline, in 2 to 3 m of water (Figure 2). We marked the corners of each plot with 0.6 m orange stakes so we could visually identify plot boundaries while SCUBA diving. A red buoy marked the lower right corner of each plot at the water surface. We established a 3-m buffer between each plot. The three treatments (cutting, hand removal, and benthic mat) and control were randomly assigned to each experimental plot.

Control Methods

We set up our experimental plots in summer and fall 2004, implemented the three management techniques in spring and early summer 2005, and collected all plant matter in late summer 2006. We monitored our plots biweekly during summer and fall 2005 and spring and summer 2006. We canoed or kayaked over each plot and used an Aquascope™ viewer to check the plots for any disturbance from swimmers or boaters.

Table 1. Comparison of eight research lakes infested with variable-leaf milfoil in southwestern Maine, USA.

Research lake	Lake surface area (hectares)	Public launches	Observed substrate composition
Lake Arrowhead	407	2	uncharacterized
Lake Auburn	928	3	sandy/rocky
Hogan Pond	72	0	sand
Little Sebago Lake	768	2	sand/organic
Messalonskee Lake	1,420	3	clay/sand
Pleasant Pond	302	2	sand
Shagg Pond	26	1	leaf litter
Thompson Lake	1,791	3	organic

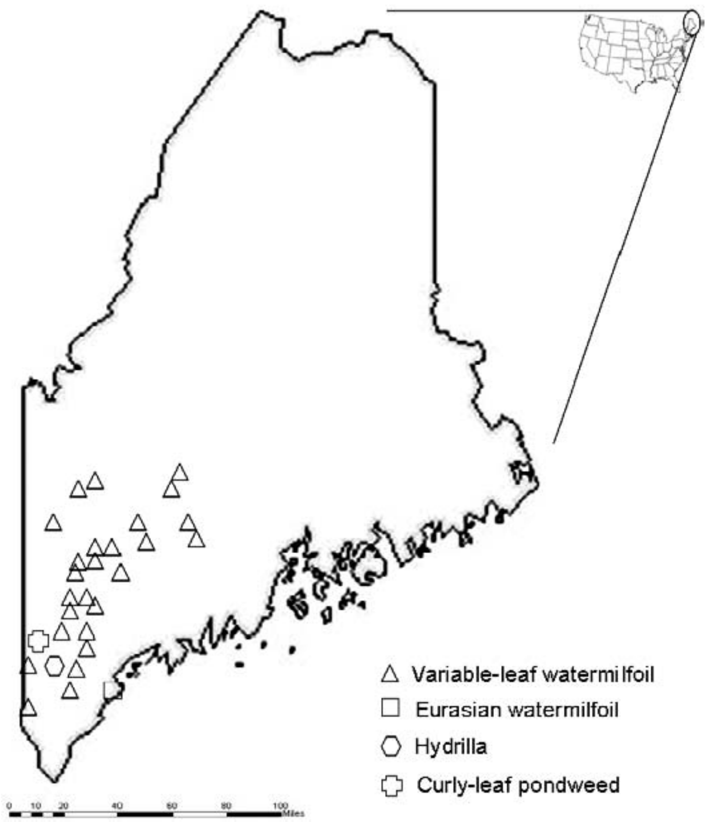

Figure 1. Location of invasive aquatic plant species infestations in Maine lakes.

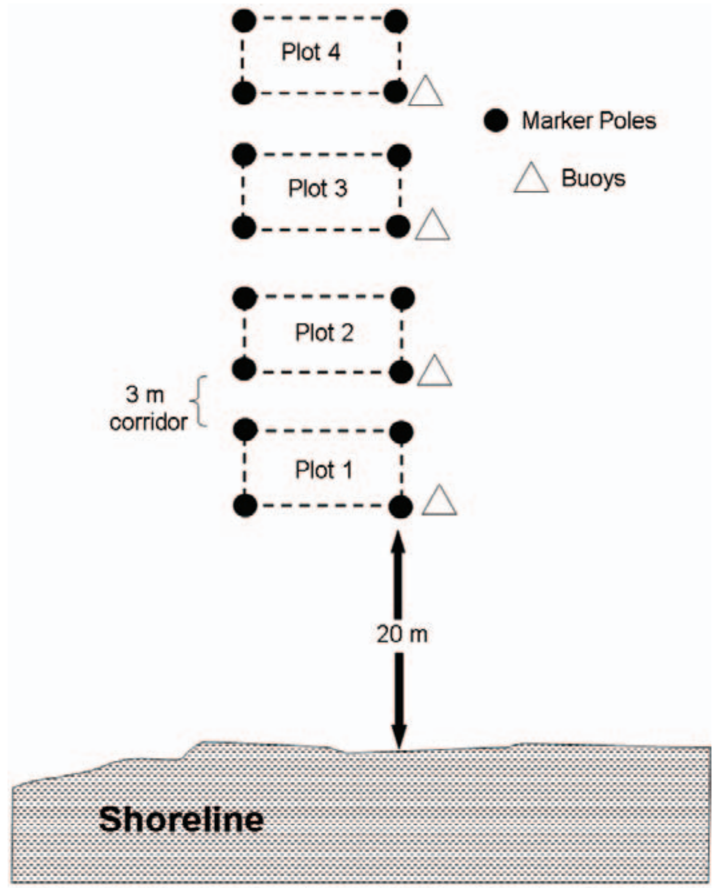

Figure 2. Schematic of 3 by 4 m experimental plots for variable-leaf milfoil used in eight Maine lakes.

Hand Removal and Cutting

We removed variable-leaf watermilfoil plants by hand, including roots, from plots by SCUBA diving to the lake-bottom. In the cutting treatments, we cut the vegetative portion of each plant at the sediment-water interface with anvil pruners. The cutting method was repeated (two to three times depending on the lake) throughout the management season (summer/fall 2005) whenever any regrowth was identified. For both treatments, we waited approximately 30 min for the sediment to settle after the initial removal and then conducted a sweep to locate any plants that may have been missed. Plant matter (for all removal methods) was collected in mesh bags and transported to the laboratory for drying and weighing. Plant matter was dried on screens in the sun for 30 days then placed on racks in a drying room at 30 C for an additional 30 days to provide adequate time for complete drying prior to weighing. Native species were not removed from the experimental plots. This process was continued until every milfoil plant was removed from the treatment plots.

Benthic Mats

We placed a 4 by 3 m fabric mat over the assigned plot of variable-leaf milfoil on each research lake. The mat was constructed of a 6-oz nonwoven geotextile with six 2.4-m sections of rebar placed at 0.76-m intervals to add weight. The rebar was held in place using zip ties. We cut small (3 to 5 cm) holes into every meter section to allow gases from degrading plant material to escape. The benthic mats were installed during fall 2005 and removed in spring 2006.

During spring and early summer 2006 experimental plots were not manipulated. Any regrowth of variable-leaf milfoil that occurred was collected during the final collection phase in summer 2006.

Assessment of Management Technique Effectiveness

We analyzed our data using SAS® 9.1 with ANOVA followed by mean separation tests (LSD, $\alpha = 0.05$) to determine plant weight differences among the four treatments, percent of variable-leaf milfoil regrowth differences among the study lakes and observed substrate type, and plant weight differences among plots based on the distance from shore. Percent regrowth was estimated using plant dry weight. For each lake, the control plot plant dry weight was the baseline of 100% growth, and each management technique plot dry weight was calculated for percent regrowth based on the control plot plant dry weight.

Average time of management technique per site was based on the amount of time it took two divers to implement the method. Cost per site was based on the cost of materials added to the average wage for invasive watermilfoil SCUBA divers in Maine ($35/hour/diver) multiplied by the time required to implement the management technique. Dive time was computed based on average time for implementation of management techniques, including 30 min for gear set-up/break-down. Equipment costs are based on the prices of two dive bags for plant material collection ($12/bag), two anvil pruners ($3/pruner), rebar ($6/2.4-m section), and benthic mat material ($10/12 m^2).

RESULTS AND DISCUSSION

Plant dry weight was lower in all three treatments compared to the control ($p < 0.01$) (Figure 3). However, plant dry weight among the three treatments did not differ ($p = 0.62$). During final plant collection, some regrowth of milfoil was found in the interior portions of the experimental plots, but the majority (>60%) of plant matter was collected along the edges. Milfoil plants immediately outside the plots likely influenced the regrowth along the edges of the experimental plots. Because the study lakes varied in observed substrate type and plant composition, we looked at percentage of regrowth in experimental plots to see if the substrate differences influenced the amount of regrowth; however, they did not differ ($p = 0.79$). There was also no difference in plant dry weight ($p = 0.77$) or percentage of regrowth ($p = 0.91$) among plots based on distance from the shore. Comparison of percent regrowth among lakes was also not significantly different ($p = 0.57$).

Hand removal had a similar site per hour cost ($97) as the cutting ($96) technique, but was considerably lower than benthic mats ($314). Although removal by hand is a fairly inexpensive technique to implement, it is time and labor intensive (2 hr 10 min/site). Different options for implementing this technique include wading into shallow areas, SCUBA diving in deeper areas, and diver-assisted suction devices. Each of these methods adds a degree of expense to the process.

The removal of invasive plants by hand is a fairly low impact management technique (Nicholson 1981). There is some disturbance to the substrate causing resuspension of sediments, but not to the same degree as mechanical methods (Madsen 2000). Note that during the hand removal process it is important to remove the entire root system below the substrate. Based on our field observations, an incompletely removed root system may be able to regenerate a plant. Removal by hand is an effective management technique for waterbodies with small, high density stands of variable-leaf milfoil or for selective removal in stands of mostly native macrophytes with sparse numbers of milfoil plants interspersed among the natives. This method would also be useful during follow up surveys of management areas when individual or small clusters of variable-leaf watermilfoil are detected. Immediate removal would decrease the opportunities for further spread of the plant.

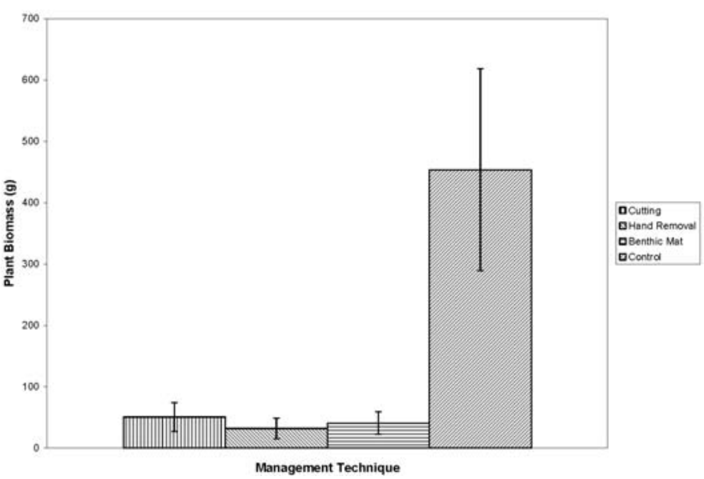

Figure 3. Comparison of plant dry weight for hand removal, cutting, benthic mats, and control experimental plots.

Cutting was more time-consuming (2 hr 50 min) to implement, and sediments were resuspended in the water column causing decreased visibility and making it difficult for divers to find the substrate-water line to cut the plants. Once the initial disturbance occurred there was a 15- to 20-cm layer of disturbed sediment hovering over the substrate (Jacolyn Bailey, pers. observ.). This disturbed sediment layer made it difficult for divers to see any shorter stems that were above the substrate. This technique was initially tested because we hypothesized that by not removing the rooted material of the variable-leaf watermilfoil plant the substrate would be less disturbed and divers would be able to more efficiently remove the upper vegetation. There is no advantage to using this method over hand-removal techniques because sediment disturbance does occur.

Benthic mats were the most costly technique, although they took the least amount of time to implement (20 min/mat installation). The mats can be put in place relatively quickly, even with just two divers. Some recolonization by milfoil occurred, but these plants were individuals that were easily removed by hand. During final milfoil collection, we observed that native species had also recovered in the benthic mat sites.

Typically, a benthic mat is left over an infested area for 45 to 60 days during the macrophyte growing season (Madsen 2000). We left the benthic mats in place over one winter (fall 2005 to spring 2006) to determine if this timing was effective. In areas where the number of times benthic mats can be moved and placed over new variable-leaf watermilfoil areas is limited due to winter freeze of lakes, this could be a useful way to extend the benthic mat placement season. By being able to add another round of benthic mat installation in the fall and removing them the following spring, more area can be managed annually. Because there was a difference between the benthic mat experimental plots and the control plots, we believe leaving mats in place over winter is an effective tool, although we cannot assess whether growing season usage would have been more effective.

Gases accumulating under benthic mats may be problematic (Madsen 2000). Rebar and sand bags are often used to counter the effect of the gases. Typically, a woven geotextile is used as benthic mat material (Eakin 1990, Eichler et al. 1995). We chose a comparably priced nonwoven material because it had a higher water flow-through rate (110 gpm/ft^2) than the woven material (6 gpm/ft^2), which might also facilitate release of gases through the fabric. Even so, some lifting still occurred with the nonwoven mat material. We also observed native and variable-leaf milfoil plants that settled and rooted into the nonwoven fabric of benthic mats, making cleaning the mats after removal difficult, if not impossible. Material for benthic mats is fairly expensive, and the ability to reuse the material helps lower that cost. The lifespan of the mat is dependent on the type of material used. Using a material that could easily be cleaned when removed and reused for a number of installations would be much more cost effective.

Management Recommendations

We found that removal by hand and benthic barriers are the most effective techniques (Table 2) for managing milfoil in situations where mechanical techniques may not be feasible. For example, in shallow areas of lakes, these nonmechanical methods may be more desirable. Hand removal is recommended for use in sparsely infested sites of limited area where selective removal is needed to minimize impacts to native plants. In areas with dense populations of invasive plants, benthic barriers are the most effective choice, given limited financial resources.

Although eradication is seldom achieved, we believe variable-leaf milfoil infestations can be managed effectively by incorporating the use of hand removal and benthic barriers in management plans. In more sensitive areas of lakes, it may be desirable to supplement mechanical techniques with hand removal and benthic barriers. We observed reduced variable-leaf watermilfoil plant numbers both in the current study and in Maine lakes that implemented these methods (Jacolyn Bailey, pers. observ.). A longer-term study to monitor recolonization of the experimental plots by variable-leaf watermilfoil and native macrophytes would provide managers with a better idea of the efficacy of these three management techniques over a longer time-frame.

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TABLE 2. ADVANTAGES AND DISADVANTAGES OF HAND REMOVAL, CUTTING, AND BENTHIC MATS MANAGEMENT TECHNIQUES.

	Advantages	Disadvantages
Hand Removal	• Relatively inexpensive • Quick implementation • Low tech • Selective removal	• Resuspension of sediment • Time intensive • Labor intensive • Effective at smaller scales
Cutting	• Relatively inexpensive • Low tech • Selective removal	• Difficult to implement • Resuspension of sediment • Time intensive • Labor intensive
Benthic Barrier	• Quick installation • Effective for dense infestations • Low tech	• Cost • Nonselective

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