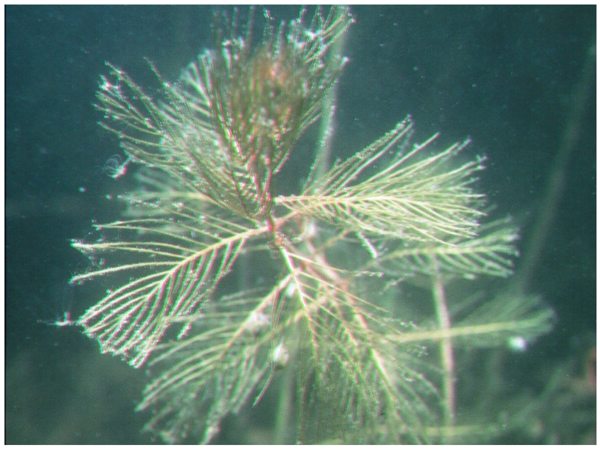
RAPID RESPONSE PLAN FOR EURASIAN WATERMILFOIL (*Myriophyllum spicatum*) IN MASSACHUSETTS



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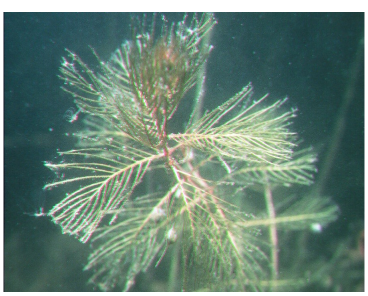
Species Identification and Taxonomy

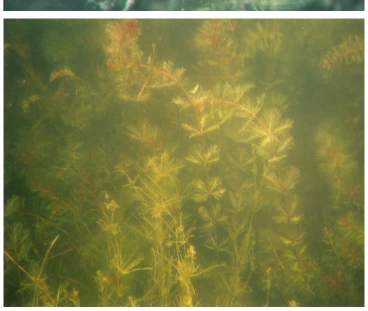
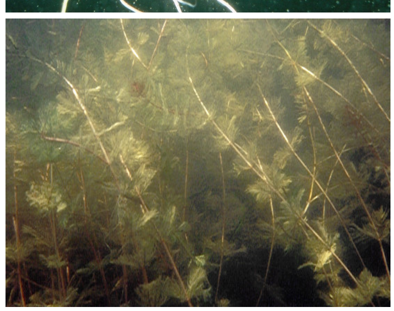
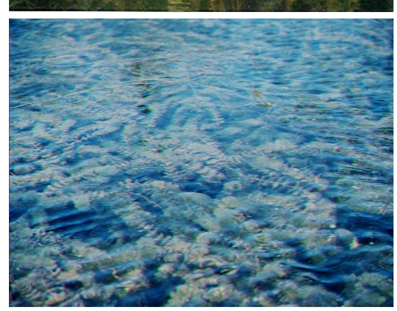
Eurasian watermilfoil (*Myriophyllum spicatum*, or EWM) is a submersed perennial herb that attaches to the substrate with fibrous roots. The stems of EWM are slender, reddish-brown, and can reach 20 feet in length, typically branching near the surface of the water. The leaves are green, less than 2 inches in length, and contain at least 12 segments. When removed from the water, the leaves of EWM tend to collapse around the stem. Mature leaves are typically arranged in whorls of 4 around the stem, ranging from 3 to 6 on rare occasions. Flowers of EWM are located on a spike protruding from the water. Flowers are reddish to pink in color, each containing four petals, and are most often observed in August and September. The fruit of EWM is four-lobed and splits into four separate one -seeded nutlets. Pigment or DNA analysis is sometimes needed for species identification as a consequence of morphological variability and possible hybridization. EWM is sometimes confused with other species of milfoils, most notably the native northern watermilfoil (*Myriophyllum sibiricum*).

According to Crow and Hellquist (2000), the following taxonomic characteristics are used to identify EWM to species:

1. Leaves pinnately divided, with filiform segments; vegetative stems elongate
2. Leaves whorled
3. Bracts usually twice as long as pistillate flowers
4. Bracts of upper portion of inflorescence lanceolate, entire to denticulate, not glaucous; rhizomes not whitish; lowermost nodes of young shoots lacking entire leaves
5. Middle leaves with 12 or more segments on each side of rachis; many of the uppermost leaves truncate at apex; stem diameter below inflorescence greater, up to twice the diameter of lower stem; stem tips usually reddish; winter buds not formed

Other milfoils share some of these characteristics. Reproductive parts are the most definitive character. In the absence of flowers and/or seeds, the most distinctive characteristics are the normally reddish stem tips, the 12 or more filaments on each side of the central axis of each leaf, and the truncated leaf tips. This latter feature gives leaf ends the appearance of having been trimmed with scissors.



Species Origin and Geography

Eurasian watermilfoil is native to Europe, Asia and northern Africa. First believed to have been introduced to the Chesapeake Bay area in the 1880's (Aiken et al. 1979), the first known sample of EWM was collected in a Washington, DC, waterbody in 1942 (Couch and Nelson 1985). By 2002, EWM had been reported in 45 of the 50 United States, and in the southern portions of Canada from Quebec to British Columbia (Madsen and Welling 2002). EWM has been found in nearly all Massachusetts drainage basins (Figure 1), although it is most common in the less acidic, better buffered waters of the Berkshire region and central through northeastern Massachusetts. EWM has great potential for expansion due to an adaptive life history strategy, rapid vegetative growth, and carbohydrate storage in the root crowns, allowing for overwintering in cold climates (Adams and Prentki 1982; Madsen 1991; Madsen and Welling 2002). Plant fragments are easily transported to new waterbodies by boats, trailers, fishing gear, wind, animals and currents (Aiken et al. 1979). In one study, Minnesota authorities found aquatic plants on 23% of all boats inspected (Bratager et al. 1996). Plant fragments transported to new waterbodies can become rooted and form new shoots.

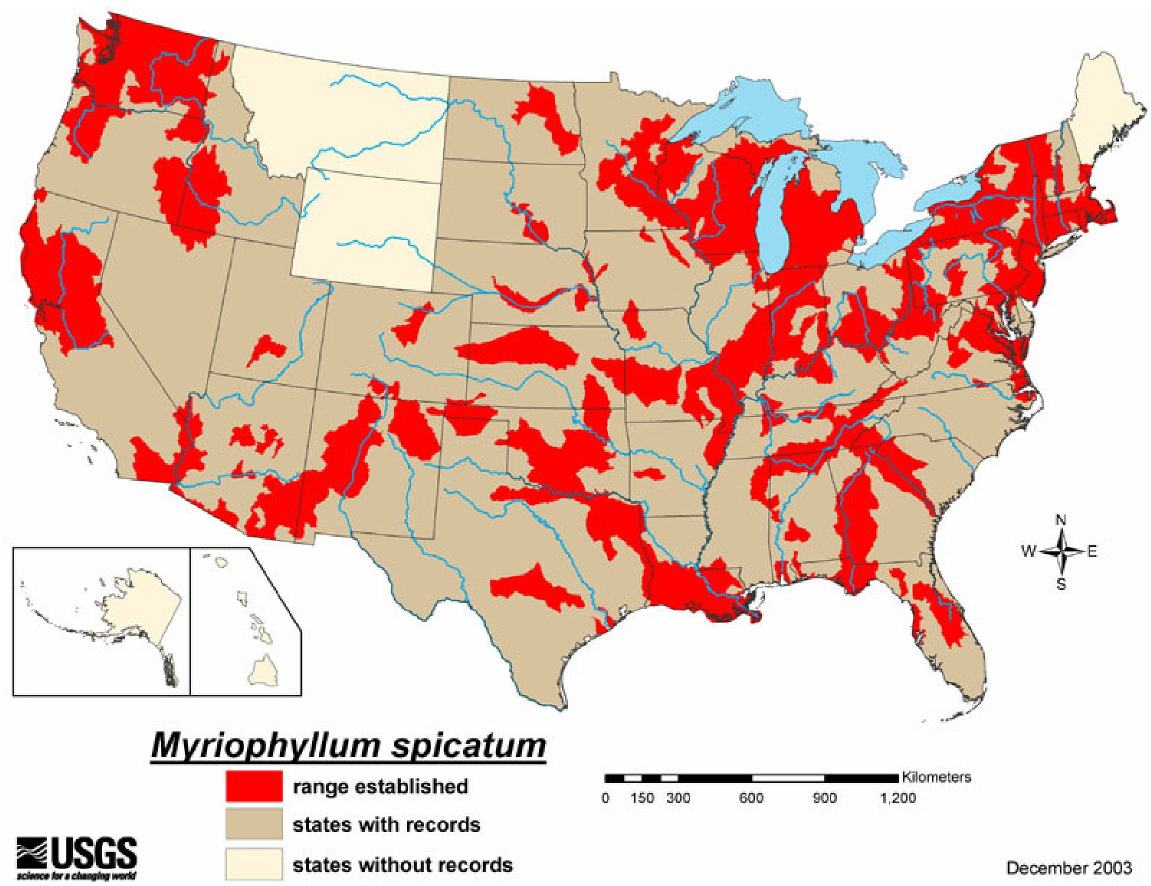


Figure 1. A map indicating the present range of *Myriophyllum spicatum*. Red indicates that *M. spicatum* has been located in at least one waterbody within the drainage basin.

Species Ecology

Eurasian watermilfoil is a hearty plant with the ability to survive a wide range of environmental conditions. EWM prefers alkaline waters, but occasionally grows in acidic waters of lakes, ponds and rivers (Crow and Hellquist 2000). Specimens have been reported in waters ranging in pH from 5.4 to 11 (Crow and Hellquist 2000; www.ecy.wa.gov 2004), and can tolerate salinities up to 10 or 15 ppt (www.ecy.wa.gov 2004). The preferred depth range for EWM is 0.5 to 3.5 meters (Aiken et al. 1979), but plants grow to depths up to 10 meters. Fine-textured, inorganic sediments appear to be the most suitable for EWM, as growth on highly organic sediments is relatively poor (Barko 1983; Barko and Smith 1986; Smith and Barko 1990, www.ecy.wa.gov 2004). EWM inhabits lakes and ponds of all trophic states, from oligotrophic to eutrophic, but achieves dominance most often in mesotrophic to moderately eutrophic lakes (Madsen 1998). EWM can survive in lakes and rivers that are too turbid for many native species (Engel 1995). The life history characteristics of EWM can lead to rapid distribution and infestation. Open substrates can be colonized at a high density within two years, while EWM can become the dominant species in an existing plant community in as little as five years. However, very dense, healthy, native plant assemblages have resisted colonization for more than a decade.

EWM produces seeds in the late summer, but seeds are not a significant source of reproduction for the species (Coble and Vance 1987), and seeds may not be viable in many cases. The majority of reproduction is through the spread of vegetative fragments. In late summer, EWM becomes brittle and plant fragments are easily broken off through physical contact with boat props or currents. Root formation often occurs at the nodes of fragments prior to abscising (www.ecy.wa.gov 2004). The adventitious roots allow rapid establishment upon settling. Fragments drift, settle, root, survive the winter, and begin growing in the spring (Madsen and Welling 2002). Along with plant fragments, basal shoots and roots of the EWM plant survive the winter, aided by carbohydrates formed in spring and summer (Madsen 1991; Madsen and Welling 2002). Root crowns are the primary means of local expansion, while fragments facilitate relocation to more distant areas (Madsen and Smith 1997).

Species Threat Summary

New shoots grow rapidly in the spring and branch repeatedly as they approach the surface of the water. Leaf canopies created by fast growing shoots shade out the germinating seeds or vegetative propagules of understory plants. This reduces growth by other plants and potentially eliminates native plants, reducing species diversity (Smith and Barko 1990; Madsen et al. 1991; Madsen 1994). Monospecific stands of EWM negatively affect wildlife, and can alter the predator/prey relationship as well as the overall ecology of an aquatic ecosystem (Aiken et al. 1979; Engel 1990; Engel 1995; Madsen et al. 1995; Madsen and Welling 2002). Small amounts of EWM may be consumed by aquatic waterfowl, but is not considered a valuable food source (Aiken et al. 1979).

Aquatic macrophytes can provide food, shelter and spawning habitat for a wide variety of fishes (Lillie and Bud 1992). Intermediate densities of aquatic macrophytes, even including EWM, enhance fish diversity, feeding, growth and reproduction (Dibble et al. 1996). However, dominance by EWM tends to replace native macrophytes, altering the food web and creating food shortages for many fishes (Engel 1995). Beds of EWM can also impede predation, shelter overly dense assemblages of panfishes, and cover spawning areas, leading to potential decreases in sportfish abundance (Engel 1995). Large piscivorous fishes spend more time foraging for prey as plant density increases, thus reducing growth rates through unfavorable energetics (Savino and Stein 1982). EWM beds have been shown to decrease fish abundance compared to native vegetation, and Keast (1983) found that beds of native vegetation supported up to four times as many fish and up to seven times as many macroinvertebrates. Decreases in macroinvertebrate abundance were observed as EWM coverage increased in a Michigan study examining six lakes (Cheruvelil et al. 2001). In another Michigan study involving 13 laskes (Schneider 2000), EWM was implicated in undesirable population features for centrarchid fishes (bass and sunfish). The depletion of oxygen in waterbodies with dense milfoil coverage can also result in fish avoidance, and, in extreme, cases fish kills (Holland and Huston 1984, Lillie and Bud 1992, Engel 1995).

Dense mats of EWM limit human uses of the waterbody and can lead to decreased water quality. Dense mats choke channels, clog water intakes, and restrict aquatic activities such as fishing, swimming and boating. The mass of large mats can cause flooding in some waterbodies (www.ecy.wa.gov 2004), and increase sedimentation by trapping sediment and detritus (Adams and Prentki 1982). Oxygen levels can be reduced underneath large EWM mats due to a decrease in wind mixing, and decaying mats decrease oxygen and increase the internal nutrient load to the waterbody (Honnell 1992; Engel 1995; www.ecy.wa.gov 2004).

Detection of Invasion

As EWM enters lakes with flow, boats and birds in the vast majority of cases, the logical places to look first are the mouths of tributaries, boat ramps and areas of higher bird concentrations. While mature EWM growths will usually "top out", reaching the surface and forming a canopy, new infestations may be less obvious and often require underwater examination for early detection. Although EWM can grow in water as deep as 20-30 ft, it typically gets its start in shallow waters (<10 ft deep) and is likely to be visible from a boat with a viewing tube or by snorkeling. Use of an underwater video system (Aqua-Vu or equivalent) can be very helpful in scanning large areas of variable depth, but is more expensive and not usually necessary for detecting early invasion.

Sources may not be obvious, but the pattern of occurrence observed during early detection may provide useful clues. Appearance near boat ramps suggests boats as vectors, while appearance in more remote areas with no direct access or inflows suggests birds as the source. Where growths are detected near the mouth of a tributary, it would be appropriate to check the next upstream waterbody or the stream bed itself if conditions are suitable for rooted plant growth.

Quantifying the Extent of Invasion

Gaining effective control of EWM depends on detecting all growths, as this species can expand rapidly. The initial discovery may be made during a routine mapping exercise, but mapping approaches suitable for overall plant assemblage characterization (e.g., point intercepts on a grid or transects) are not appropriate for thorough coverage of recent invasions. Where a growth is detected, it is likely that expansion in the first growing season will be by root crowns, so viewing each discovered growth in concentric circles moving outward from the apparent center will best facilitate mapping of the growth. Detection of additional growths is best accomplished by a thorough visual inspection of the newly infested area, either using tightly spaced transects radiating out from the first discovered growth or focused in the direction of likely current or wind transport. If the discovered growth is in a definable cove, examine the entire cove, or at least that portion with a water depth <10 ft.

If the initial discovery is associated with a boat ramp, check other ramps if present. Where growths occur near a tributary mouth, check area maps for upstream ponds or impoundments on the offending stream and any other tributary and investigate where possible EWM sources seem most likely. When the new growth appears associated with areas of bird congregation, check all such areas in the lake. If the lake is large, effort may have to be limited to the most likely locations for invasion. In this regard, examination of any existing plant maps may be helpful. Look for areas of suitable depth (<20 ft, with emphasis on areas 2-10 ft deep) and substrate (moderately organic to sandy bottom), known plant and bottom disturbance (marinas, boating lanes, windswept shallows), and plant assemblages of lower density and/or lesser canopy formation.

Evaluation of recent EWM growths should focus on extent of coverage and degree of dominance. Biovolume or biomass measures are useful but time consuming and are not critical to combating new infestations. Stem counts are helpful in assessing the efficacy of hand harvesting, but are also time consuming; an estimate of stems per unit area and more careful assessment of the area covered is more valuable in assessing potential controls for new growths. With regard to dominance, it is important that the other species present be noted, as the presence of protected species and the relative abundance of seed producers vs. vegetative propagators are important to planning management actions. A list of plant species with an approximation of the percent of the community each represents is appropriate.

Assessing the rate of expansion may not be necessary if the invasion is detected early and prompt control actions are implemented. However, where EWM has been present for more than a single growing season, information on the rate of expansion may be helpful in planning a control strategy and in garnering support for rapid action. Note which areas have seemingly established beds vs. scattered plants vs. a single plant or just a few stems. Where EWM is discovered in multiple locations, look for spatial patterns that suggest either transport from the earliest infestation or invasion from multiple sources. Isolated plants are likely to signal the first year of growth, while scattered plants are likely to represent the second year of growth and well established beds will normally be more than two growing seasons old.

Communication and Education

Unless the invasion is discovered by individuals trained in plant taxonomy, samples should be sent to competent taxonomists for confirmation. In Massachusetts, the Department of Conservation (DCR), the Department of Environmental Protection (DEP), and the University of Massachusetts at Amherst (UMASS) have the expertise to assist in plant identification. Many consulting and lake management firms also possess this expertise. It is suggested that the DCR at 617-626-1411 be the first point of contact.

Once the presence of EWM has been confirmed, the Town(s) in which the lake is situated should be notified, usually through the Conservation Commission, which will have a chairperson or an agent who is reachable through Town Hall. It would also be appropriate to notify all relevant stakeholder groups, but these need to be identified and many will not have a central clearinghouse contact for notification. Groups who should be informed about the infestation include any active lake association, shoreline property owners, boaters, anglers, swimmers, birdwatchers, and water suppliers. Notification through individual contacts is desirable but may be inefficient. Posting a notice in the local paper will help publicize the problem, but the notice may not receive widespread attention. Posting the lake at access points is perhaps the most effective approach, as it is the actual users that should be informed and warned to avoid spreading EWM.

It is desirable to post access points with warning signs even before an invasion, displaying a picture or drawing of EWM and asking lake users to be on the lookout for this invasive plant. Users, particularly boaters, should be asked to inspect their boats and any trailers prior to launching, and to remove any discovered plants with proper disposal in a manner that prevents the plant from reaching the lake. A local contact (name and phone number) for notification should be given, typically either a representative of the lake association or the town's Conservation Commission, or both. Users should be advised to mark the location where the plant was observed if at all possible, but not to pull it out unless they can get the whole plant, including the roots. As most users will not be diving or snorkeling, immediate, effective hand harvesting is probably not a realistic expectation.

After an invasion has been discovered, access points should be posted with a warning to users to avoid any action that could spread EWM. Again, a picture or drawing of EWM should be provided, and any known locations of the plant should be shown on a map of the lake. Users should be asked to notify a local contact if EWM is found in other areas not shown on the map, and to avoid motorized boating in areas with EWM. All boats, trailers, fishing equipment, bait buckets or other possible means of transport should be inspected and cleaned prior to leaving the lake.

Responsibility for control of EWM does not rest with any one entity under the laws of the Commonwealth of Massachusetts. Approval for control actions is governed by the Wetlands

Protection Act, which always involves the town Conservation Commission and the Commonwealth's DEP. Approval for control actions may also involve the Division of Fisheries and Wildlife and/or the Natural Heritage and Endangered Species Program, both agencies of the Commonwealth, depending upon the resources in the lake (particularly if protected species are known from the lake). Other agencies and approval programs may apply, depending upon the features of the lake (naturally large enough to be a statutory Great Pond), the location of the lake (e.g., in an Area of Critical Environmental Concern), or the uses of the lake (e.g., as a water supply). However, none of these agencies is charged with controlling invasive species, and there is no legislation in Massachusetts that mandates control of EWM. The DCR has taken the lead in Massachusetts with regard to encouraging control of invasive species, and supports control efforts as its budget allows, but it has no statutory responsibility for the lakes and ponds of the Commonwealth outside of those on Commonwealth land (e.g., state parks and forests). Control is therefore largely a function of local desire to protect and maintain the resource.

Quarantine Options

Both natural processes and human activities can spread EWM, both within an invaded lake and to other area lakes. Minimizing the spread of EWM may require some form of quarantine. Making the lake off limits to all users is an extreme action not typically justified for new growths that are likely to be limited in areal coverage. However, keeping people out of infested areas may be a valid option. This may be done by signage, buoys, or an actual sequestration curtain, with cost increasing dramatically in the listed progression.

Where the invasion is occurring at a boat ramp, closure of the ramp may be justified; this will both limit the spread of EWM and generate public awareness of the problem and a desire to take action against the EWM. A town may take such an action where the public welfare is deemed to be at stake for a boat ramp owned by the town, but it is not clear that such action is legal for private boat ramps and towns do not have the authority to close ramps owned by the Commonwealth. Consult with private owners or the Fishery Access Board of Massachusetts when considering closure of a ramp not owned by the town.

Where the invasion is occurring in a swimming area, closure of that area will have much the same effect and limitations as for boat ramps. If the EWM growths are localized, it may be possible to partition off the infested area by moving the buoyed ropes that usually delimit swimming areas. If the growths are extensive, it may be appropriate to close the swimming area on the basis of public safety; people can get tangled in EWM and drown.

The use of sequestering curtains or screens can both restrict access to an infested area and limit the spread of EWM by vegetative fragmentation. This approach, while often expensive, has been very effective in a number of cases, especially for small areas or coves with a narrow connection to the main body of the lake.

Possible expansion routes should be considered and addressed to the extent possible. Sequestration, as noted above, can be highly effective if the infested area is localized and amenable to curtains or screens. Outlets from the lake should also be screened to minimize the export of EWM fragments with outflow. This may be problematic where leaves or other debris are abundant enough to clog such screens, necessitating frequent cleaning. Rotating screens or other automated outflow restrictors are effective but expensive. It may be advisable to implement bird controls to limit bird contact with infested areas; scare tactics (e.g., flags or pinwheels on buoys, noisemakers) can be effective for short time periods, which may be all that is necessary for lakes with migratory populations. Greater effort may be needed for lakes with substantial resident bird populations. If boating is allowed, it is advisable to set up a temporary wash station at any ramp; it may be necessary to staff it to maximize use compliance. At the very least, boats and trailers leaving the lake should be inspected and cleaned.

Early Eradication Options

Timelines for necessary action with regard to EWM invasions hinge on stopping the spread of this plant. Root crown expansion occurs throughout the growing season, so the sooner controls are implemented, the smaller the area that must be addressed. As plants fragment in the late summer and early autumn, emphasis should be placed on removing plants before the end of August to limit dispersal of propagules by that mechanism. Once the growing season is over (about October), plants are largely dormant and many collapse or otherwise be reduced in biovolume until the following spring. Detecting and effectively removing EWM plants by physical means will therefore be more difficult outside the growing season.

Management options are covered in The Practical Guide to Lake Management in Massachusetts (Wagner, 2004), a companion guide to the GEIR on Lake Management, available on-line at http://www.mass.gov/dcr/waterSupply/lakepond/lakepond.htm and supplied to all towns in the Commonwealth by the DCR in 2004. A summary of control approaches with the potential to eradicate EWM during the early stages of an invasion is provided below.

Hand Harvesting

Mode of action: Plants are removed by divers by hand; removal includes root crowns.

Probability of successful control: Where density is <500 plants per acre over a small number of acres, control can be complete. At higher densities or area of coverage, risk of incomplete harvest or spread by fragment escape increases dramatically.

Potential non-target impacts: Limited; with training, divers recognize EWM and avoid other plants; risk to non-target plants increases as density of plant community increases. Temporary turbidity increases are expected.

Permitting needs: Can be approved without Order of Conditions under the Wetlands Protection Act through a Negative Determination of Applicability (WPA regulations deemed not to apply, as only the invasive plant is removed).

Monitoring needs: Critical to delineate target area and provide means for divers to stay on course with complete coverage. Monitoring during harvesting to detect and collect fragments is also very important to successful elimination of EWM.

Range of costs: Often done by volunteers, but estimates from professional operations range from $100 to $500 per acre.

Suction Harvesting

Mode of action: Plants can be pulled directly into the suction apparatus, but for best effect this is a suction aided hand harvesting operation, whereby hand harvested plants are fed into the suction tube and filtered out in an above-water chamber. This speeds up the operation and limits fragment dispersal.

Probability of successful control: High potential for eradication at low to moderate densities of EWM; complete removal probability declines at higher densities.

Potential non-target impacts: May pull in non-target plants and plankton by suction, but effects localized and limited. Turbidity plume at surface from filtering chamber may be substantial.

Permitting needs: Generally requires an Order of Conditions under the Wetlands Protection Act, but may be issued a Negative Determination of Applicability where risk to other species and turbidity are expected to be low.

Monitoring needs: Critical to delineate target area and provide means for divers to stay on course with complete coverage.

Range of costs: $5,000 to $15,000 per acre, depending upon equipment features, contractor mobilization, EWM density, and total area to be harvested.

Benthic Barriers

Mode of action: Covers target area with a porous or non-porous blanket, limiting light and physically stressing plants.

Probability of successful control: Usually completely eliminates live vegetation from covered area in 30 to 60 days.

Potential non-target impacts: All plants under the barrier will be killed. Some invertebrates are also killed, but many relocate. Fish find the barriers attractive for cover and foraging area, mainly a function of "edge effect" (creation of edges between plants and open water).

Permitting needs: Often approved through a Negative Determination of Applicability (provisions of WPA do not apply) where EWM is the main plant affected. Otherwise permitted with and Order of Conditions with possible restrictions where other species are at significant risk.

Monitoring needs: Careful delineation of areas to be covered is needed. Condition of plant community, especially root crowns of EWM, should be assessed prior to removal.

Range of costs: Materials typically cost $0.50 top $1.00 per square foot. With application and maintenance costs, expect $30,000 to $50,000 per acre. However, material can be re-used indefinitely, so costs are greatly reduced for subsequent applications.

Water Level Drawdown

Mode of action: Lowered water level exposes plants and substrate to drying and freezing action. Ice damage may also be a factor. Where plants can be dried, frozen, or ripped up by ice action, EWM can be greatly reduced in abundance or eliminated. With many years of repeated drawdown, exposed substrate tends to be dominated by coarse sediment less hospitable to EWM invasion.

Probability of successful control: Very high where drying, freezing and/or ice damage occurs. As this is a function of the weather pattern, uncertainty is high; about one out of three years provides effective drawdown conditions in Massachusetts. Where thick organic sediments, spring activity, or other factors limit freezing and drying, success will be lower.

Potential non-target impacts: Other plants that overwinter in vegetative forms are also likely to be harmed. Seed-producing plants may be stimulated. Some invertebrates (especially mollusks), amphibians (most likely frogs), reptiles (particularly wood turtles) and mammals (most probably beaver and muskrat) could be negatively affected. Effects on fish vary, depending upon timing and duration of drawdown and the interaction with feeding and reproduction. Direct water supply and water level in wells may be affected.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act, usually entailing a detailed review of the potential for non-target impacts.

Monitoring needs: Can be extensive. Pre- and post-implementation surveys are needed. Aside from effects on the plant community, effects on susceptible fauna may be required. Water supply must be monitored and a contingency plan is needed if supply is impaired. It should be assumed that at least three years of implementation will be needed to conduct a valid assessment of success and non-target impacts.

Range of costs: Where drawdown is facilitated by existing structures, costs are limited to permitting and monitoring, with potential for mitigation costs if impacts are unacceptable.

Application of 2,4-D

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, killing susceptible plants by disrupting cellular growth. Uptake is fairly rapid, limiting necessary exposure time.

Probability of successful control: EWM is highly susceptible to 2,4-D. With adequate dose (around 1 ppm active ingredient) and contact time (1-3 days), EWM can be completely eliminated. Where dilution, flushing or other factors compromise dose and exposure, success declines.

Potential non-target impacts: Many other plants are susceptible to 2,4-D at doses and exposure times applied for EWM control. Rapid die off may reduce oxygen levels through decay. Most fauna are not affected at those doses, although toxicity has been observed in lab studies. It is considered a health risk to humans if consumed at applied doses.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP. Application to waters used for drinking water supply, including surface waters with potential interaction with wells, is prohibited.

Monitoring needs: Normally the plant community is monitored before and after treatment. Special studies of other populations may be required by permit, depending upon the resources present.
Range of costs: Typically $300 to $800 per acre.

Application of Fluridone

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, inhibiting the synthesis of carotenoid pigments. Lack of these auxiliary (protective) photosynthetic pigments causes susceptible plants to die slowly through reduced food production and damage by sunlight. Uptake must be nearly continuous over an extended period (>60 days preferred), necessitating extended exposure time.
Probability of successful control: Where adequate dose (>6 ppb, preferably >10 ppb) and exposure time (60-120 days) are maintained, EWM can be eradicated. This has proven difficult to achieve, however, particularly in partial lake treatments. Use of slow release pellet formulations or sequestration of the target area with impervious curtains maximizes exposure time and limits dilution of the dose. Follow up actions, such as hand harvesting, are often necessary.
Potential non-target impacts: Susceptibility of other plants to fluridone varies widely, and lowering of the dose can maintain much of the native community. However, doses <6 ppb are unlikely to control EWM, and complete control is not typically achieved at <10 ppb, if then. Slow die-off of affected plants limits oxygen reduction. No impacts to fauna or humans are expected at applied doses.
Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP.
Monitoring needs: Normally the plant community is monitored before and after treatment. The concentration of fluridone is also commonly tracked on a weekly to monthly basis with an Enzyme Limited Immuno-Sorbent Assay (ELISA).
Range of costs: Costs range from $500 to $2,000 per acre, depending upon the form of fluridone applied, any necessary re-treatment to maintain dose, and any sequestration of the target area.

Application of Triclopyr

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, inhibiting synthesis of key enzymes while stimulating growth, resulting in plant death. Uptake is rapid and exposure time can be less than one day. Plants sink from the surface within a week and die within three weeks.
Probability of successful control: Where adequate dose (0.75 to 2.5 ppm, usually about 1.5 ppm) and exposure time (6-12 hours) are maintained, EWM can be eradicated. As this herbicide was approved in November of 2004, however, there is only limited experience under experimental use permits to guide treatment.

Potential non-target impacts: Dicotyledonous plants, including EWM, are susceptible to triclopyr, while monocotyledonous species, such as naiad and pondweed, are minimally affected at label doses. Impacts to fauna or humans have not been observed at applied doses.
Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP.
Monitoring needs: Normally the plant community is monitored before and after treatment.
Range of costs: Costs are expected to range from $600 to $800 per acre, but there have been too few treatments to date to generalize.

Other management options are not listed for one or more of the following reasons:

- impractical on a small scale
- not able to eradicate EWM
- could cause EWM to spread
- not approved for use in Massachusetts

The most recommended early actions are hand harvesting and bottom barriers, each of which has a high potential for success, low cost on a localized basis, and limited permitting needs. Where growths are too dense for effective hand harvesting and too extensive for cost-effective bottom barrier placement, suction harvesting should be considered. Drawdown, where applicable, is perhaps the most effective preventive control in cases where repeated invasion is expected or documented. On a localized basis, the herbicide triclopyr has great potential for control of EWM where exposure times are limited and with limited impacts on other native species; more experience is needed to make a more definitive recommendation, however. The herbicides 2,4-D and fluridone are very effective but difficult to use on a small scale. However, where EWM growths are too widespread, dense or deep for other methods, or where detection and removal of all growths in an area is impeded by low light or other vegetation, 2,4-D or fluridone may represent the preferred approach.

Control of Established Infestations

This document deals mainly with early invasion and the new infestations that result, but it is important to note that older infestations, where the EWM has moved throughout the lake into all suitable habitats and probably become the dominant plant, can and should be addressed if continued invasion in the region is to be curtailed. The Practical Guide to Lake Management in Massachusetts (Wagner, 2004), a companion guide to the GEIR on Lake Management, provides a review of all available techniques for combating EWM infestation. On a whole lake basis, herbicide treatment is the most cost-effective means for reducing EWM coverage and density to levels that can be controlled by physical techniques like hand harvesting or bottom barriers. Drawdown will reduce EWM in the drawdown zone, but it is rare that a lake can be drawn down enough to eliminate EWM without unacceptable impacts to non-target species. Techniques suitable for combating new growths are seldom practical or effective on a whole lake scale (e.g., hand harvesting, bottom barriers).

Maintenance techniques that limit the impact of EWM on lake uses, but do not typically result in elimination of EWM, include mechanical harvesting, hydroraking, rotovation, and the contact herbicides diquat and endothall. The physical methods may actually spread EWM if it is not already everywhere in the lake, in which case these are analogous to mowing a lawn. The contact herbicides do not kill the root crowns of EWM, allowing regrowth within two growing seasons.

Dredging can remove EWM along with all other plants and any remaining seeds or other propagules associated with the dredged sediment. The cost is extremely high, however, and resulting substrate conditions are usually still hospitable to EWM growth. With much bare area to be colonized, invasive species such as EWM are likely to become dominant it more desirable species are not actively introduced. Only if dredging results in a water depth too great for effective colonization by EWM is it likely to be the only method needed to control EWM in the target area.

The introduction of the herbivorous insects, including the milfoil weevil, moth and midge, has the potential to reduce EWM growths, but is unlikely to eliminate them as a function of classic predator-prey interactions, which usually result in cycles of abundance and scarcity. As fish eat the insects but few herbivores eat the EWM, constant inputs of herbivorous insects appear necessary to bolster populations to a level at which they can control EWM. Grass carp, which at sufficient density can eliminate EWM (and indeed all other submersed plants), are also not approved for use in Massachusetts at this time.

Prevention of Re-Infestation

Once an invasion has been repulsed through any of the above methods, it should be apparent that the lake is susceptible to EWM. As the cost of prevention is much less than the cost of rehabilitation of an infested lake, steps should be taken to reduce the risk of re-introduction of EWM. As EWM most often comes from a local source, control activity is encouraged on a watershed, multi-municipal or regional level. Working across political boundaries with limited funding is difficult, but represents the most sweeping opportunity to limit future invasions. Alternatively, and almost essential as a back-up, steps need to be taken at the individual lake to reduce the risk of re-introduction. Key steps may include:

- Posting of all access points with signs warning of the threat, showing how to identify EWM, and urging that boats, fishing gear and other recreational equipment be cleaned before and after use in the lake.
- Provision of a wash station at boat ramps, and/or staffing of ramps with inspectors.
- Education through the lake association or town for all users about the threat of EWM, how to avoid introducing it to the lake, how to identify it, and who to contact if it is found.
- Drawdown where applicable and permitted to minimize overwintering of introduced EWM.
- Monitoring of the plant community to detect EWM, with a focus on boat ramps and inlets.

Summary

1. Eurasian watermilfoil (*Myriophyllum spicatum* or EWM) is a highly invasive plant normally identified by reddish stem tips and whorled leaves in sets of 4, with >12 thread-like segments on each side of the central leaf axis and truncated leaf ends, giving the appearance of having been trimmed even. More definitive identification requires flowers and/or seeds. Hybridization is possible, necessitating genetic identification in some cases.
2. EWM is native to Europe, Asia and northern Africa. It has been in the USA since at least 1942. It is now found in 45 of 50 states, and in every drainage basin in Massachusetts. It is most often transported on boats or trailers, by birds, and with water flow.
3. Seeds are of minimal importance in dispersal. EWM is transported great distances by fragments that can root and grow. It becomes locally abundant by root crown expansion.
4. EWM creates canopies that shade out other plant species. At high density it provides poor habitat for most water-dependent fauna, impairs recreational uses, and can have negative impacts on water supply and flood control.
5. EWM is most often detected in the early stages of infestation in water 2-10 ft deep by visual examination (viewing tube from boat or mask and snorkel). Look first in the vicinity of boat ramps, inlets, and areas of bird congregation.
6. When detected, map EWM coverage with notation of density as beds, scattered plants, or solitary stems. Be thorough with visual coverage of potentially infested areas. Record all other species present and their relative abundance.
7. Educate lake users by whatever means practical about the threat and presence of EWM. Posting of access points is useful in all cases. Signs should show how to identify EWM, urge that all boats, trailers and other recreational equipment be cleaned before and after use in the lake, and provide a contact name and phone number for reporting or correspondence.
8. It is advantageous to quarantine infested areas until removal can be attempted. Closing beaches and boat ramps can be problematic, legally and practically, but can promote greater awareness and support for prompt action. Use of curtains or screens both to keep people out of an infested area and to keep EWM inside is desirable but expensive.
9. Eradication of EWM detected early in an invasion can be accomplished with hand harvesting, suction harvesting, benthic barriers, drawdown, or the herbicides 2,4-D, fluridone or triclopyr. Hand harvesting and benthic barriers are often allowable without an Order of Conditions under the WPA, and can therefore be implemented most rapidly. Each method has benefits and drawbacks, and the specific circumstances will affect which option(s) can be applied.
10. A range of additional options are available to combat later stage invasions. Those not mentioned as eradication options for new infestations have some feature that prevents effective, rapid use.
11. Drawdown, where feasible, can act as a deterrent to invasion on an annual basis at a relatively low cost, but has many possible impacts on aquatic resources and requires a thorough evaluation in each case.
12. Once EWM has been removed after an invasion event, steps are necessary to prevent re-infestation. Education of lake users, with a focus on boating, and ongoing monitoring to detect new EWM plants, are critical components.

References

Adams, M. S., and R. T. Prentki. 1982. Biology, metabolism and functions of littoral submersed weedbeds of Lake Wingra, Wisconsin, U.S.A.: a summary and review. Arch. Hydrobiol./Suppl. 62:333-409.

Aiken, S. G., P. R. Newroth, and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. Canadian Journal of Plant Science 59:201-215.

Barko J. W. 1983. The growth of *Myriophyllum spicatum* in relation to selected characteristics of sediment and solution. Aquatic Botany 15:91-103

Barko, J. W., and R. M. Smart. 1986. Sediment-related mechanisms of growth limitation in Submersed macrophytes. Ecology 67:1328-1340.

Bratager, M., W. Cromwell, S. Enger, G. Montz, D. Perleberg, W. J. Rendall, L. Skinner, C. H. Welling, and D. Wright. 1996. Harmful Exotic Species of Aquatic Plants and Wild Animals in Minnesota. Annual Report. Minnesota Department of Natural Resources, St. Paul. 99 pp.

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

Coble, T. A., and B. D. Vance. 1987. Seed germination in *Myriophyllum spicatum* L. Journal of Aquatic Plant Management 25:8-10.

Couch, R., and E. Nelson. 1985. *Myriophyllum spicatum* in North America. Pp. 8-18 in L.W.J. Anderson (ed.). First International Symposium Watermilfoil and Related Haloragaceae Species. 23-24 July 1985, Vancouver, B.C. Aquatic Plant Management Society, Vicksburg, MS.

Crow, G. E., and C. B. Hellquist. 2000. Aquatic and wetland plants of northeastern North America. Volume One: pteridophytes, gymnosperms, and angiosperms: dicotyledons. University of Wisconsin Press, Wisconsin.

Dibble, E. D., K. J. Killgore, and S. L. Harrel. 1996. Assessment of fish-plant interactions. Transactions of the American Fisheries Society 16:357-372.

Engel, S. 1990. Ecosystem reponses to growth and control of submerged macrophytes: a literature review. Technical Bulletin 170. Wisconsin Department of Natural Resources, Madison.

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

Holland, L. E., and M. L. Huston. 1984. Relationship of young-of-the-year northern pike to aquatic vegetation types in backwaters of the Upper Mississippi River. North American Journal of Fisheries Management 19:18-27.

Honnell, D., J.D. Madsen, and R.M. Smart. 1992. Effects of aquatic plants on water quality in pond ecosystems. Proceedings: 26th Annual Meeting, Aquatic Plant Control Research Program. Report A-92-2. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Keast, A. 1983. The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey, Department of Biology, Queens University, Kingston, Ontario, Canada.

Lillie, R. A., and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. Journal of Freshwater Ecology 7(2):113-125.

Madsen, J. D. 1991. Resource allocation at the individual plant level. Aquatic Botany. 41:67-86.

Madsen, J. D. 1994. Invasions and declines of submersed macrophytes in Lake George and other Adirondack lakes. Lake and Reservoir Management 10(1):19-23.

Madsen, J. D. 1998. Predicting invasion success of Eurasian watermilfoil. J. Aquat. Plant Manage. 36:28-32.

Madsen, J. D., R. M. Smart, G. O. Dick, and D. R. Honnell. 1995. The influence of an exotic submersed aquatic plant, *Myriophyllum spicatum*, on water quality, vegetation, and fish populations of Kirk Pond, Oregon. Proceedings: 29th Annual Meeting, Aquatic Plant Control Research Program. US Army Corps of Engineers Waterways Experiment Station.

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

Madsen, J. D., and C. H. Welling. 2002. Eurasian Watermilfoil (*Myriophyllum spicatum* L.). Lakeline 58:29-30.

Savino, J. F., and R. A. Stein. 1982. Predator-Prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society 11:255-266.

Schneider, J. C. 2000. Evaluation of the Effects of the Herbicide Sonar on Sport Fish Populations in Michigan Lakes. State of Michigan Department of Natural Resources, Fisheries Division Technical Report.

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

Wagner, K.J. 2004. The Practical Guide to Lake Management in Massachusetts. Commonwealth of Massachusetts, Executive Office of Environmental Affairs, Boston, MA.

Washington Department of Ecology website. www.ecy.wa.gov 2004.