State of Michigan's
Status and Strategy for Eurasian Watermilfoil Management
March 30, 2018

Scope

Invasive Eurasian watermilfoil (*Myriophyllum spicatum;* hereafter EWM) has severely affected the waters of the State of Michigan. The goals of this document are to summarize the:

- Current level of understanding on the biology and ecology of EWM.
- Present management options for EWM in Michigan.
- Identify possible future directions of EWM management in Michigan.

I. Biology and Ecology

A. Identification

FIGURE 1 EURASIAN WATERMILFOIL (*MYRIOPHYLLUM SPICATUM*)

EWM is a submerged aquatic perennial plant with finely divided leaves. Leaves are in whorls of 4 to 5 at the stem nodes and have more than 12 pairs of leaflets (Borman et al., 1997). Leaves are usually limp when pulled out of the water. Later in the summer season, these whorls may be several inches apart. The plant's long thin stems can reach up to 21 feet in length and branch repeatedly near the surface of the water to create a dense canopy. Flower stalks are above the water surface and range from 2 to 8 inches long. Flowers are small, located in the axils of the stalk, and whorled in small bracts. EWM does not have winter buds (turions).

Native species that are often mistaken for EWM include: Northern watermilfoil (*Myriophyllum sibiricum*), coontail (*Ceratophyllum demersum*), and common bladderwort (*Utricularia utriculus*). Northern watermilfoil is often distinguished from EWM by the number of leaflets (Northern usually has less than 12 pairs) and the presence of winter buds; however, hybridization has made this distinction more difficult (see “Hybridization” section below). Coontail has small teeth on the midrib and, as a consequence, has a much rougher feel than EWM (Parkinson et al., 2010). Common bladderwort has finely divided leaf-like branches with young bladders that trap prey (Borman et al., 1997).

B. Life History and Spread/Dispersal

EWM overwinters, and in the spring as water temperatures increase, begins to grow rapidly and typically earlier than any native vegetation. The shoots branch copiously near the surface, which results in a dense canopy. The lack of light penetration induces EWM leaves below the surface to slough and fall to the sediment. Many environmental factors influence growth and morphology of EWM (Smith and Barko, 1990). For example, an increase in water clarity allows for growth at greater depths, whereas a decrease in water clarity promotes nearshore growth and canopy formation (Smith and Barko, 1990). Flowers emerge from the water when the plant reaches the water surface. In addition to seed production, EWM also releases plant fragments as a means of asexual reproduction. This characteristic is unique to EWM since native milfoil does not disperse by self-fragmentation. By the end of the growing season, EWM can have a large amount of biomass that survives through the winter, resulting in a rapid and early spring growth.

Historically, fragmentation of EWM was thought to be the predominant mode of spread between and within lakes which can occur from wave action, wind, water currents, self-initiation, or human activities (Madsen and Boylen, 1989; Madsen, 1998; Smith and Barko, 1990). However, there is new evidence that suggests sexual reproduction plays a much larger role in EWM expansion into new water bodies, as well as repopulation after management efforts (Zuelling and Thum, 2012). Despite this new information on the importance of seed reproduction, recreational vessels and equipment are still thought to be the main pathways for the spread of EWM between water bodies.

C. Habitat

EWM’s native range is Europe, Asia, and Northern Africa (Cook, 1985; Smith and Barko, 1990). It can inhabit streams, rivers, lakes, and reservoirs. EWM flourishes in mesotrophic to moderately eutrophic water bodies (Madsen, 1998). EWM is usually found in depths from 3 to 13 feet, but if a lake is particularly clear, then EWM can be found at depths up to 24 feet. While capable of surviving in most sediment types, the most vigorous growth typically occurs in fine textured inorganic sediments (Smith and Barko, 1990).

D. Negative Effects from EWM

EWM invasion and establishment can reduce the distribution and abundance of native aquatic plant species (Madsen et al., 1991), inhibit recreational activities such as boating and swimming, and can lower lakefront property values (Zhang and Boyle, 2010). Dense EWM mats can increase prey fish cover and therefore survival of larval fish; however, these dense mats can also reduce habitat suitable for foraging or spawning fish (Madsen et al., 1991). Reduced levels of dissolved oxygen and increased pH and temperature are also associated with dense mats of EWM.

In Michigan, approximately $24 million is spent each year on the chemical control of aquatic nuisance plants, a large proportion of which is for the management of EWM (Michigan Department of Environmental Quality [MDEQ], 2013). Nationally, EWM is the most managed invasive aquatic plant across the United States (Moody and Les, 2002).

E. Hybridization

Crossbreeding has been documented between EWM and the native Northern watermilfoil, hereafter hybrid milfoil (*M. spicatum* x *M. sibiricum*), on numerous occasions and locations (Moody and Les, 2002 and 2007; Poovey et al., 2007; Glomski and Netherland, 2010; Zuelling and Thum, 2012). Furthermore, hybrid milfoils have numerous genetic lineages resulting in a high variation of genetic diversity (Zuelling and Thum, 2012). Sexual and asexual reproduction has also been verified in hybrid milfoil in Michigan (LaRue et al., 2012). In some genotypes, hybrid milfoil has been shown to grow faster and exhibit reduced sensitivity to the aquatic herbicides, 2,4-dichlorophenoxy acetic acid (2,4-D), dimethylamine salt, and fluridone compared to EWM (LaRue et al., 2012; Thum et al., 2012). However, reduced sensitivity in previous experiments showed no statistical differences between hybrid milfoil and EWM (Poovey et al., 2007; Glomski and Netherland, 2010). The differing results support the concept that there is high genetic variation within hybrid milfoils. Currently, there is little understanding on the genetic architecture of decreased sensitivity to herbicides. In order to better manage hybrids, additional research is needed to understand the specific mechanisms in which reduced sensitivity occurs.

As a consequence of hybridization, distinguishing physical characteristics between EWM and Northern watermilfoil are no longer reliable. Genetic analyses using specific DNA markers to determine which biotype of milfoil is present could aid in determining best management practices (Moody and Les, 2007; Poovey et al., 2007; Moody et al., 2008; and LaRue et al., 2012). Knowing whether a lake has beneficial native Northern watermilfoil, EWM, and/or hybrid milfoil could prevent unnecessary management efforts or enable a rapid response to a new occurrence (Moody et al., 2008). Lastly, it could provide essential baseline data to evaluate future biotypes of watermilfoil populations for herbicide sensitivity.

II. Current Distribution in Michigan

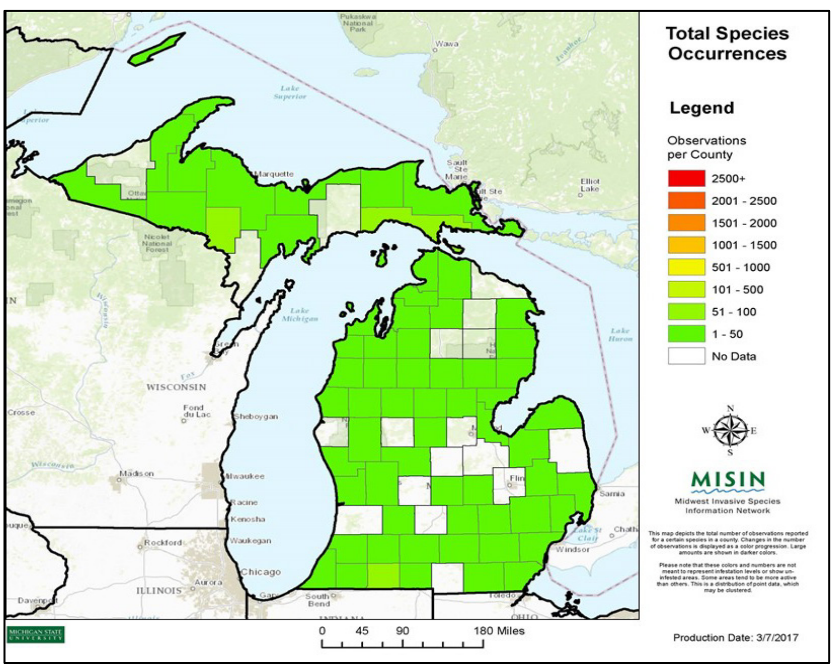

Figure 2. EWM locations reported in MISIN, March 2017 (Ziegler, 2017)

EWM was first collected in 1961 and recognized in Michigan waters in 1970 (Reznicek et al., 2011). Today, observations reported to the Midwest Invasive Species Information Network (MISIN) show 65 of the 83 counties in Michigan have EWM populations (Figure 2). However, it is likely there are additional locations in both reported and unreported counties. Not all of these observations have been verified and it is not clear how many of these observations may be hybrid milfoil, or pure EWM.

On a national scale, EWM is found in 45 of the 50 states, including all 8 Great Lakes states. It has also been recorded in 3 Canadian provinces (British Columbia, Ontario, and Quebec).

III. Management of EWM

There are several Michigan laws related to EWM possession and management. First and foremost, EWM and hybrid milfoil are listed in Michigan as a “restricted species” per Part 413, Transgenic and Nonnative Organisms, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (NREPA). As a restricted species, it is unlawful to possess, introduce, import, sell, or offer EWM for sale as a live organism, except under certain circumstances. Other Michigan laws, which relate to regulatory requirements for EWM management and control, are presented in the specific management sections that follow.

A. Prevention

Once EWM becomes established in an ecosystem, eradication becomes nearly impossible and long-term management and control is often needed. Millions of dollars are spent statewide each year to manage the impacts of EWM infestations. Therefore, preventing new introductions is the most economical approach for invasive species management. Prevention is the first goal of Michigan’s Aquatic Invasive Species State Management Plan (MDEQ, 2013). To prevent and limit the dispersal of EWM and hybrid milfoil, the following actions are recommended:

- Effective education and outreach to raise awareness of the importance of preventing EWM spread by removing plants and mud from boats, trailers, and gear prior to leaving or entering a water body (e.g., Clean, Drain, Dry or Stop Aquatic Hitchhikers).
- Increase monitoring and reporting of existing populations to inform prevention efforts.
- Coordination and collaboration among multiple partners at local and regional levels.
- Encouraging research and development of new techniques for monitoring and preventing the spread of EWM and hybrid watermilfoil.

B. Management/Control

There are a variety of methods being used today to control EWM, all with the intent of decreasing EWM populations. Efforts to increase the native plant population and diversity are less often addressed but may play an important role in managing EWM. State or federal permits may be required depending on the control method and the size of the area being treated. The goal of the permits is to reduce potential nontarget impacts. Monitoring is essential before, during, and after control efforts in order to determine management effectiveness, guide future control efforts, and implement best management practices.

Table 1 (attached) provides a list of potential management options, legal or permitting requirements, and some pros and cons for each method. It should also be recognized that many of these options can be used in conjunction with one another as an integrated management approach.

a. Chemical

Research over the past two decades has greatly improved the chemical management of invasive species, specifically in species selectivity and a reduction of chemical use rates (Getsinger et al., 2008; Cason and Roost, 2011). There are two types of herbicides in use for EWM control: systemic and contact. Systemic herbicides are absorbed through the leaves, which negatively affect the plant's vascular tissue (Menninger, 2011). Systemic herbicides are transported throughout the plant and can kill the entire plant, including the roots. Contact herbicides kill only the plant tissues exposed to the chemical. Herbicides can also be either selective or nonselective. Nonselective herbicides can impact nontarget species, while selective herbicides target specific species without harming desirable species. Two common lawn and garden herbicides are good examples of target selectivity. Glyphosate (the active ingredient in Roundup™) is nonselective, while 2,4-D (commonly found in "weed and feed" products) is selective because it can kill broad-leafed nuisance weeds without harming the turf grass.

In Michigan, an Aquatic Nuisance Control Permit (http://www.michigan.gov/anc) is required for chemical treatment of surface waters pursuant to Part 33, Aquatic Nuisance Control, of the NREPA. Current chemical control options for EWM in Michigan must be approved for aquatic use and include the following active ingredients: chelated copper, Diquat, Endothall, Flumioxazin, Fluridone (use may be subject to lake management plan), granular 2,4-D, and Triclopyr. When used properly, herbicide use can reduce EWM biomass without damage to native plants and animals.

There are some downsides regarding herbicide treatment of EWM. Chemical control is usually at the cost of the landowner or lake association and may need to be repeated every 1-3 years for systemic herbicides (due to seed reproduction and growth and spread of any plants not treated earlier) and multiple times in a single season for contact herbicides. Over time, this can be a costly form of management and repeated applications using a similar treatment protocol could potentially induce a strain of chemically resistant EWM that could be comparable to Florida's fluridone-resistant hydrilla (Michel et al., 2004).

Another challenge associated with chemical treatment is ensuring that the herbicide reaches sufficient concentration to treat EWM while minimizing exposure and/or effects to nontarget species. A recent study examined whole-lake EWM treatments on two Wisconsin lakes using 2 different target concentrations of liquid 2,4-D: 500 and 275 micrograms per liter (µg/L). Please note that liquid 2,4-D is not approved for use in Michigan waters due to its toxicity to nontarget organisms. The study concluded that both treatments were effective in reducing EWM; however, the lake treated with the higher dose resulted in a 62 percent reduction in native plant biomass at the conclusion of the study (Nault et al., 2014). Conversely, the impacts to the native plant community for the lower dose treatment were minimal. Additionally, the herbicide concentrations in both lakes did not reach the threshold level recommended to allow irrigation of terrestrial plants until 50-93 days after treatment. Lastly, 2,4-D has been shown to be less effective in treatment of some strains of hybrid milfoil (La Rue et al., 2012). The results of these studies highlight the challenges many managers and lake associations must face when considering treatment options.

The use of fluridone in Michigan has shown positive results in managing EWM populations (Lisa Huberty, MDEQ, personal communication). Liquid fluridone is used as a whole lake spring treatment to control EWM with target lake water concentrations of six parts per billion. Lake management plans, including aquatic vegetation surveys to document the number and distribution of both native and nonnative species, are required prior to treatment. The permit may authorize an additional "bump" treatment 2-3 weeks following initial treatment if average fluridone concentrations fall below five parts per billion. While the use of fluridone has been shown to be successful at lowering EWM population levels, often for a number of years after treatment, additional information is needed to further refine the fluridone treatment protocol (Aquatic Nuisance Control Program staff, MDEQ, personal communication).

Laws and Regulations for Chemical Treatment:
Part 33 defines permitted actions and procedures for the treatment of aquatic nuisance species.

b. Physical

Physical control refers to either manually removing EWM biomass from a lake or altering the lake environment so that the habitat is less suitable for plant growth. Examples include: hand raking, weed harvesting boats, and lowering lake water levels. Most physical control options are time-consuming and labor-intensive, need to be repeated during the growing season, and removal is often not species-specific (Idaho Invasive Species Council, 2008), which means other native plant species may be unintentionally removed along with EWM. The removal of native plant species can have negative impacts to the lake ecosystem, as these native species provide food and important habitat for fish, invertebrates, and other wildlife.

A relatively common method is to use large boats equipped with cutting blades to mechanically cut and collect the plant material. Once collected, the plants are off-loaded to shore. This method provides some flexibility on the timing of control and provides immediate results. However, mechanical harvesting is not selective and may damage native plants that provide valuable fish and wildlife habitat and food sources. Furthermore, removal of the upper portion of the plant is only effective in the short-term and can be challenging as a long-term management solution. Over time, harvesting can exacerbate the problem if any plant fragments are dropped during the process; as noted earlier, EWM can spread via fragments.

EWM may be removed by hand using a method called diver assisted suction harvesting (DASH) where scuba divers hand pull plants from the lake bottom and a boat with a vacuum-like pump collects the plants. The DASH method can work in areas of early infestation; however, this method is highly labor-intensive, requires specialized plant identification skills, and can increase turbidity in a water body. DASH works well around structures such as docks or piers and is moderately selective, thus minimizing impacts to native plant species; however, there are still risks of dropped plant fragments, increased turbidity, and potential for negative impacts on native fish and wildlife (Idaho Invasive Species Council, 2008).

Water bodies that have a dam, augmentation well, or other control structure used to regulate the lake levels may consider water level manipulation an option for EWM management. Generally, the water is lowered for the winter, which exposes the lake bottom and kills EMW by drying and freezing. However, there are negative effects of using this method, as manipulation of water levels affects all fish, wildlife, and vegetation in the system. In addition, EWM is capable of surviving in deeper waters than most native aquatic plants, which means that lowering water levels to treat EWM could result in a disproportional negative impact on the shallower growing native plant species compared to the deeper growing EWM.

Lastly, benthic barriers refer to the placement of natural or synthetic materials on the lake bottom to shade out plants. Traditional benthic barriers are impermeable mats made of synthetic materials (e.g., plastic sheets). Benthic barriers have been shown to be effective at reducing EWM biomass over several seasons; however, this method is neither permanent nor species-specific. Benthic barriers can degrade or eliminate important shallow habitat areas and food sources; can inhibit the movement, spawning, nesting, and rearing of native species; may encourage macroalgae growth (e.g., invasive Starry stonewort, *Nitellopsis obtusa*); and may require significant maintenance (Eichler et al., 1995). However, benthic barriers may be appropriate for small infestations or in areas where they will have minimal negative impacts (e.g., around docks). More recently, natural fiber benthic barriers, which degrade over time, have been deployed to test in several lakes. Natural fiber benthic barriers are gas permeable and may provide an opportunity to control EWM, reduce the maintenance needs, and allow for native plant recolonization (Hofstra and Clayton, 2012). Synthetic or natural benthic barriers are susceptible to damage from boat props when employed in water depth less than three feet.

Laws and Regulations for Physical Control:

Most physical or mechanical control efforts require a permit in Michigan waters, under Part 301, Inland Lakes and Streams, or Part 303, Wetlands Protection, of the NREPA. Aquatic plant harvesting or mechanical vegetation removal efforts require a permit when it leads to disturbance of the soil or substrate, such as soil rutting from equipment or vehicles, or disturbance of soil when roots are pulled. DASH, water level manipulation, and benthic barriers also typically require permits from the MDEQ and sometimes local governments.

A permit is generally not required from the MDEQ to control aquatic submerged vegetation in inland lakes by mechanical harvesting (i.e., cutting plants above the lake bottom with no soil disturbance). Inconsequential or insignificant (“de minimis”) vegetation removal done by hand (e.g., hand-pulling or raking a few plants) does not require a permit. Small-scale removal of plants that are an aquatic nuisance as defined in Part 33 does not require a permit if the removal is accomplished by hand-pulling and all plant fragments are removed from the water and properly disposed of on land. A permit is not required for hand-raking of lake bottomlands where vegetation is not present before raking and that are predominantly composed of sand or pebbles. Large-scale removal of plants requires a permit from the MDEQ.

Other physical control measures, such as benthic barriers, DASH, weed rollers, or lake drawdown, always require a permit from the MDEQ. A use permit or authorization may be necessary from the Michigan Department of Natural Resources to use a state-operated access site for physical/mechanical control. In addition, cutting vegetation, including mechanical harvesting and mowing, on Great Lakes bottomlands in the St. Clair Flats requires a permit from the MDEQ. Disposal of harvested material within inland lakes, on Great Lakes bottomlands, or in wetlands is not allowed without prior written approval from the MDEQ. For information on how to obtain a permit from the MDEQ for these types of physical and mechanical control measures, visit www.michigan.gov/jointpermit.

c. Biological

Biological approaches to EWM management offer a unique suppression option, particularly because, used appropriately, they minimize or avoid altogether the negative impacts to native plant species. Many organisms have been tested (e.g., weevils, fungi, moths, carp, and midges) for potential EWM biocontrol and some have shown promise. For example, the native milfoil weevil (*Euhrychiopsis lecontei*) has shown preference for EWM as food compared to the native Northern watermilfoil, so nontarget impacts are uncommon. The main drawback to biological control is that it is not a quick fix, but rather a long-term and sometimes continual effort. A recent study in Washington did not see an active and established weevil population until five years into augmentation (Parsons et al., 2011). However, in the study, EWM frequency of occurrence decreased by 37 percent, which was eventually attributed to the presence of midges (another biocontrol potential) and the weevil. In addition to taking time to impart control, successful biocontrol will not eliminate EWM but will reduce the population and reduce negative impacts.

The weevil has shown to have an intermediate food preference for hybrid milfoil when compared to Northern milfoil (low preference) and EWM (high preference) (Roley and Newman, 2006).

The success of weevil biocontrol has been variable from lake to lake and currently there is little understanding of what makes some weevil populations more successful than others. Research has shown weevils can control EWM, but further study is required to determine if success is density-dependent (for both weevils and EWM) and/or influenced by a variety of environmental factors.

A number of states have restrictions regarding weevil stocking and the movement of weevils between water bodies. Michigan does not currently regulate activities regarding movement of the native milfoil weevils. However, there is currently not a commercial source for weevils in Michigan, which limits the accessibility of this technique throughout the state.

A potential biopesticide that has been studied but is not commercially available is the plant fungal pathogen, *Mycoleptodiscus terrestris* (Mt). There have been several formulations that have proved successful in the laboratory but ultimately failed in the field trials (Shearer and Jackson, 2006). The exact mechanisms that aid in successful EWM suppression are not understood at this time. Mt is currently not federally approved for use in the nation's surface waters. Obtaining an Experimental Use Permit from the federal government is required if this method is to be employed. Table 1 (attached) has a link to the United States Environmental Protection Agency (USEPA) experimental use permit Web site.

A biological control that is not an option in Michigan is the use of nonnative grass carp (*Ctenopharyngodon idella*). Grass carp consume large amounts of aquatic vegetation, but prefer native plants over EWM (Lewis, 1999). The potential negative impacts grass carp pose is that they are a prohibited species in Michigan, which means they are illegal to buy, sell, or possess.

Laws and Regulations for Biological Control:

Information on laws and regulations were presented in the individual potential biological control species information above.

d. Indirect Management

The maintenance and restoration of a native plant community may improve EWM management and control efforts. Native aquatic vegetation is an integral component to a healthy ecosystem in many lakes. Native plants provide diverse habitat to aquatic insects, mollusks, crustaceans, larval and adult fish, and wildlife. Lakes with a healthy native vegetation community are less likely to experience algal blooms, and native plants compete directly with EWM for space, nutrients, and light, thereby helping to slow the establishment, growth, and spread of EWM within a lake. Native plant restoration is often overlooked when EWM management/control efforts are planned or conducted but when included, it may improve success. Further research efforts to better understand the role native aquatic vegetation can play in the prevention and long-term management and control of EWM are needed.

Natural vegetation zones along the shoreline may also slow EWM growth. Inputs of sediment and nutrients, in particular phosphorus, results in increased aquatic plant growth, including EWM. Natural shoreline buffers around a lake can intercept and uptake excess nutrients, etc. moving across the landscape due to human related activities (e.g., farming, lawn fertilizers). In addition, native vegetation provides shoreline stabilization, thereby preventing or limiting erosion (USEPA, 2016). Further research on connecting the increase of natural shorelines to a decrease in EWM would be beneficial.

A combination of laminar flow (a.k.a. lake aeration) and bacterial augmentation has been suggested as a management option for EWM control. Several principles have been put forward as to how aeration of the bottom sediments, in concert with the addition of bacteria and enzymes, can result in EWM population reduction. The general concept is that increasing the aerobic bacterial activity will reduce nutrient rich sediments and slow EWM growth. However, there are concerns that this method has the potential to have detrimental impacts to native vegetation, fish and wildlife habitat, and overall stability of the lake ecosystem. There are no known peer reviewed studies that corroborate the mechanism behind or the efficacy of this method for controlling higher plants or address the impacts of this technique. Anecdotal evidence from lakes where this has been done range from successful reduction of EWM to increases in EWM. A study by Cowell et al. (1987) found cyanobacteria levels were reduced in a hypereutrophic Florida lake following aeration. However, the same study observed a significant decline in zooplankton populations (an important food source for fish) after aeration began. More information on the efficacy and impacts of laminar flow and bacterial augmentation are warranted and further research is needed.

Laws and Regulations for Indirect Management:

Many activities conducted on an inland lake or in wetlands are regulated under Part 301 by the MDEQ's Inland Lakes and Streams Program (www.michigan.gov/deqinlandlakes) or Part 303 by the MDEQ's Wetlands Protection Program (www.michigan.gov/wetlands). Some examples include:

- Laminar Flow (http://www.michigan.gov/deq/0,4561,7-135-3313_3681_28734---,00.html).
- Bacterial augmentation requires use of an MDEQ-authorized product and submittal of a notice of intent under Part 31, Water Resources Protection, of the NREPA (http://www.michigan.gov/deq/0,4561,7-135-3313_46123_46124---,00.html).

- Disruption of soils within 500 feet of a lake or stream also requires a Part 91, Soil Erosion and Sedimentation Control, of the NREPA, permit from the county soil inspector (https://www.michigan.gov/statelicensesearch/0,4671,7-180-24786-245158--,00.html).

IV. Future Directions for Michigan and EWM Management

Since the 1970s Michigan has been challenged with managing EWM. Residents, nongovernment organizations, and government agencies have spent countless hours and resources to manage EWM, with little long-term success. It is, therefore, beneficial to evaluate current management practices and identify knowledge gaps preventing successful long-term EWM management. Specifically, a targeted management approach towards prevention, monitoring, reporting, restoration, and addressing research gaps is recommended (Table 2, attached).

Prevention is the most cost-effective approach in management and should be a top priority in any lake management plan. A prevention strategy that identifies and targets areas that are most at risk to invasion (e.g., water bodies with high boater traffic) should be the first goal in EWM management. However, new infestations are often inevitable and, therefore, a cohesive lake monitoring system needs to be established. If EWM is found, it is important to report the finding. Reports should be made through the MISIN Web site (misin.msu.edu). This will increase regional knowledge of EWM locations and possibly enable early detection responses to new occurrences.

EWM management techniques, whether indirect, chemical, biological, physical, or an integrated approach, have the potential to be effective tools to manage EWM populations. However, there are some critical knowledge gaps in which scientific research is warranted. Broadening the universe of understanding for all techniques involved in EWM management will provide managers with the best tools and may result in new tools becoming available to manage EWM populations. Table 2 provides more details on research needs for EWM control.

The overarching goal of EWM management in Michigan should be to have ecologically stable lake communities that require minimal chemical, physical, or biological manipulation. Any type of control should always be supported by lake management plans that consider all physical, biological, and social factors affecting long-term ecological stability of a water body.

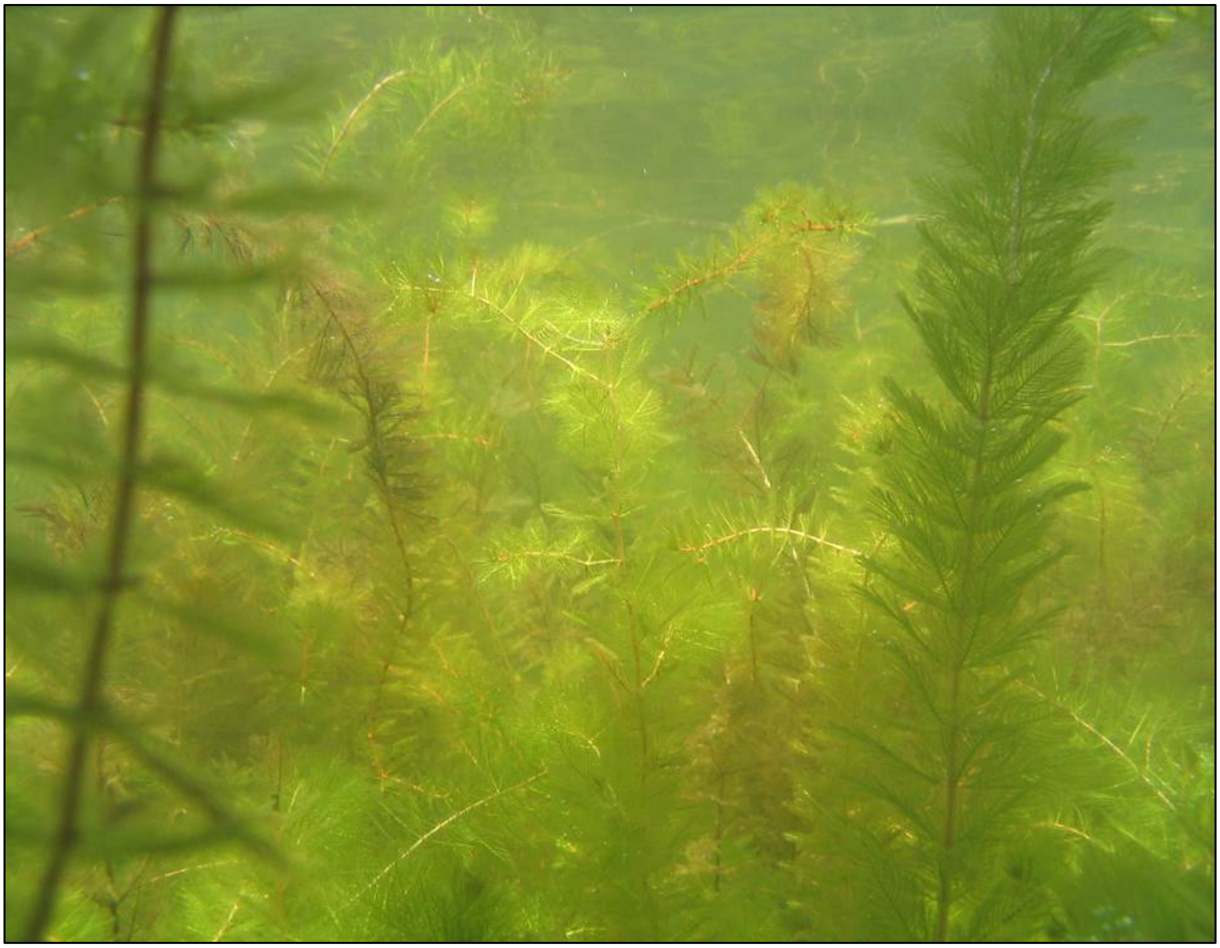

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Table 1: Comparison of control and management methods for Eurasian watermilfoil. To date no method has successfully eradicated an established EWM population. Multiple methods can be combined in an integrated plant management program. Information on cost have been omitted. [1] Local regulations are not presented here.

	Method	Strengths	Challenges	State and Federal Regulations[1]
Chemical	Contact herbicides	• Selective if early season • Fast uptake and impact • Safe at permitted concentrations	• Not selective if mid- to late season • Only kills what it contacts (roots not impacted) • May require repeat application within season • Some water use restrictions • Tolerance/resistance	• Part 33, Aquatic Nuisance Control
	Systemic herbicides	• Largely selective all season • Potentially kill all above ground biomass • Safe at permitted concentrations	• May not kill root crown • Slower acting than contact herbicides • Some water use restrictions (irrigation, swim) • Tolerance/resistance	• Part 33, Aquatic Nuisance Control
Physical	Harvesting, mechanical	• Immediate visual impact • Safe for human health • No water use restrictions • Removal of cut plant material • Site specific	• Not selective • May increase spread (fragmentation) • May impact water quality (e.g., turbidity) • Regrowth as only top of plants are removed • Disposal	• Not regulated by if soils are not disturbed • If soils are disturbed: • Part 301 Inland Lakes and Streams Permit • Part 303, Wetlands Protection • Part 325, Great Lakes Submerged Lands
	Diver assisted suction harvesting (DASH)	• Selective • Potential to remove root crown • Safe for human health • No water use restrictions • Removal of plant material • Site specific	• Disruption of sediment • May impact water quality (e.g., turbidity) • Impractical for large areas • Regrowth • Disposal	• Part 301 Inland Lakes and Streams Permit
	Weed roller	• Safe for human health • No water use restrictions • Site specific	• Not selective • May impact water quality (e.g., turbidity) • Impractical for large areas	• Part 301 Inland Lakes and Streams Permit
	Benthic barrier	• Safe for human health • No water use restrictions • Site specific	• Not selective • May promote other invasive species • Impractical for large areas • Maintenance (e.g., removal and cleaning)	• Part 301 Inland Lakes and Streams Permit
	Dredging	• Safe for human health • Removal of plant material • Site specific	• Not selective • May impact water quality (e.g., turbidity) • May increase spread (fragmentation)	• Part 301 Inland Lakes and Streams Permit • Part 303, Wetlands Protection • Part 325, Great Lakes Submerged Lands
	Lake drawdown	• Safe for human health • No water use restrictions	• Not selective • May have more impact on native species • Seeds and winter buds may survive • Potential impacts to wetlands	• Part 301 Inland Lakes and Streams Permit • Part 303, Wetlands Protection
Biological	Milfoil weevil	• Native to North America (including Michigan) • Potential long-term solution • Largely selective for EWM • Safe for human health and environment	• Control takes time (years) • Results unpredictable • May not kill root crown • Not commercially available	• Not regulated by the State of Michigan
	Mycoleptodiscus terrestris (fungal pathogen)	• Native to North America (including Michigan) • Potential long-term solution • Potential synergy with herbicides	• Not approved by USEPA • Poor success in field trials • Not commercially available	• EPA Experimental Use Permit
	Grass carp	• Consumes plants	• Consumes native plants	• Prohibited to buy, sell, or own in Michigan
Indirect	Native aquatic plant restoration	• Safe for human health and the environment • Beneficial for native fish and wildlife	• Requires direct management to reduce EWM • Limited research on effectiveness	• Not regulated if soils are not disturbed • If soils are disturbed: • Part 301 Inland Lakes and Streams Permit • Part 303, Wetlands Protection • Part 325, Great Lakes Submerged Lands
	Natural shoreline buffers	• Safe for human health and the environment • Improves overall lake health	• Requires direct management to reduce EWM	• Part 301 Inland Lakes and Streams Permit
	Laminar flow/bacterial augmentation	• Safe for human health • No water use restrictions	• May disrupt natural lake processes • Requires constant electricity • Limited research on effectiveness	• Part 301 Inland Lakes and Streams Permit • Part 31 Bacterial Augmentation Certification

Table 2: Research needs for EWM management

Management Option	Strategic Action	Potential Stakeholders	Expected Outcome
Optimize chemical treatment methods	• Determine optimal herbicide concentration and contact time (esp. fluridone) • Evaluate if fluridone destroys EWM root crowns • Investigate chemical management strategies to lower risk of reduced sensitivity • Examine response of hybrid genotypes to treatment • Ascertain if treatment selects for hybrid genotypes • Document and mitigate any non-target impacts on native species.	• MDEQ ANC Program • Lake consultants and managers • Commercial herbicide applicators • University research	• Improve EWM and hybrid treatment efficacy • Reduce non-target impacts • More cost effective treatment strategies • Reduce long-term treatment costs
Establish biocontrol strategies that will sustain EWM populations below control and minimize negative impacts	• Determine factors that limit success with current biocontrol agents (milfoil weevils and *Mycoleptodiscus terrestris,* Mt) • Evaluate the Mt / herbicide synergy • Determine biocontrol agents efficacy for hybrid milfoil control	• University research	• Better use of public and private funds for biocontrol • Lower long-term management costs • A viable and sustainable management option
Utilize the best physical control methods to mediate the effects of EWM	• Monitor and evaluate EWM and native populations before, during, and after removal	• University research	• Better understand the effects of mechanical management techniques on native and non-native macrophytes • Better use of public and private funds
Increased scientific understanding of the impact of indirect management on EWM populations	• Evaluate the relationship between shoreline buffers and natural shorelines and EWM populations • Investigate the role of native macrophyte beds as both a restoration tool and as a tool to increase resilience from infestation • Determine the efficacy of laminar flow aeration and bacterial augmentation as an EWM management tool • Understand the effectiveness as well as the potential negative impacts of using benthic barriers for EWM control	• University research	• Better use of public and private funds • Provide viable and sustainable supplement to management efforts