State of Michigan's

Status and Strategy for European frog-bit (*Hydrocharis morsus-ranae* L.) Management

Scope

Invasive European frog-bit (*Hydrocharis morsus-ranae* L., hereafter EFB) was first verified in Michigan in 1996 along the Great Lakes waterways in southeastern Michigan and has since been found in more locations in or near Lake Huron (Midwest Invasive Species Information Network, MISIN). This document was developed by Central Michigan University and reviewed by Michigan Departments of Environmental Quality and Natural Resources for the purposes of:

- Summarizing the current level of understanding on the biology and ecology of EFB.
- Summarizing current management options for EFB in Michigan.
- Identifying possible future directions of EFB management in Michigan.

This document used the current information available in journals, publications, presentations, and experiences of leading researchers and managers to meet its goals. Any chemical, company, or organization that is mentioned was included for its involvement in published, presented, or publically shared information, not to imply endorsement of the chemical, company, or organization.

Biology and Ecology

I. Identification

Figure 1. European frog-bit (*Hydrocharis morsus-ranae*) in bloom. Photograph by R.W. Smith, courtesy of Michigan Flora Online (Reznicek et al. 2011)

European frog-bit is a perennial, free-floating aquatic species with heart-shaped leaves that resemble small water lillies (Figure 1). The leaves range from 0.5 – 2.5 in (1 – 6 cm) in diameter and are arranged in clusters, connected by strong cord-like stems or stolons. The underside of the leaves are a purplish-red color and feature a spongy coating along the middle vein that permit floatation (O'Neill 2007). European frog-bit has two stipules at each leaf (Catling et al. 2003). The roots of EFB are numerous and unbranched, reaching lengths up to 10 in (50 cm). They do not anchor in the substrate and develop many root hairs. Colonies form quickly and their long stolons become tangled, producing dense, floating mats (Figure 2). The EFB is dioecious, but one sex usually controls a population. Flowers are produced in early-summer, consisting of a whorl of greenish sepals, three white petals, and a yellow center (Scribailo and Posluszny 1984). Flowering is eratic; the smallest fluctuations in temperature and sunlight conditions can influence the bloom time from mid-July to mid August in North America (Catling et al. 2003). Flowers are short-lived, and in some colonies fail to bloom in a given year.

Species that are often mistaken for EFB include: American frog-bit (*Limnobium spongia* (Bosc) Rich. ex Steud.), white water lily (*Nymphaea odorata* Aiton), and the water-shield (*Brasenia schreberi* J.F. Gmel.). American frog-bit is not found in Michigan and features only one stipule compared to the two that the EFB possess, pictured in Figure 3 (Gardner 2008). The entire underside of the American-frog-bit is covered with a spongy coating, whereas it occurs only along the middle vein of the EFB (OMON 2012). White water lilies can be distinguished from EFB by its significantly greater leaf size (6 – 12 in, 15 – 30 cm). The leaves of the water-shield are oval as opposed to the heart-shape of the EFB.

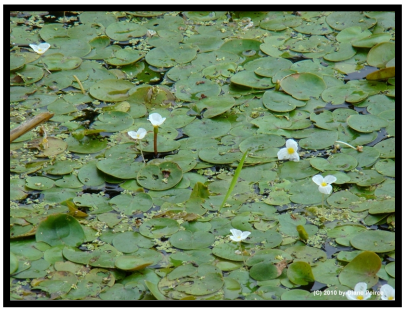

Figure 2. The dense mats of European frog-bit (*Hydrocharis morsus-ranae*). Photograph by Diane Peirce, michwildflowers.com

II. Detection

June, July, and August are the ideal times to look for EFB populations. This is the time when the plant is fully grown and is easily distinguishable. The average eye can identify EFB by its distinct small (0.5 – 2.5 in, 1 – 6 cm), floating lily-pad-like leaves in primarily shallow and calm waters. The flowering window for a colony is brief (one to several days between July and August), so relying on flowers for identification is difficult (Catling et al. 2003). Most Michigan herbaria collections of EFB that contain flowers were collected in early August (University of Michigan Herbarium - MICH, Michigan State University Herbarium - MSC), but one in bud was collected in mid-September (MICH).

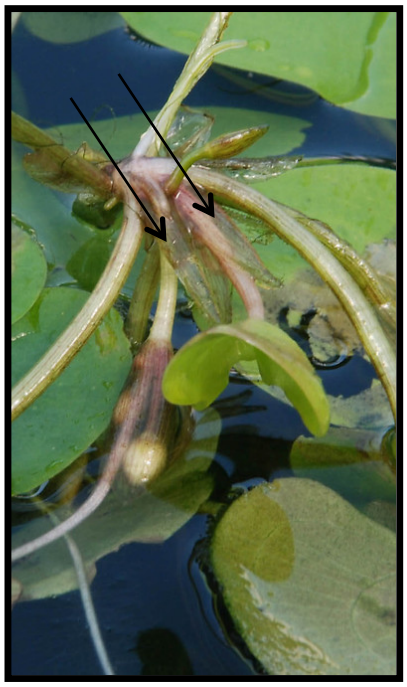

Figure 3. The two arrows point to the two transparent leaf-like stipules at the base of the leaf of European frog-bit (*Hydrocharis morsus-ranae*). American frog-bit (*Limnobium spongia*) has only one stipule. Photograph by Paul Busselen, courtesy of Go Botany, New England Wildflower Society

Remote sensing technology has been used to distinguish EFB mats from other vegetation at one lake in Ontario, Canada, at a overall accuracy of 72.8% (Kappa 66.0%) for unsupervised fuzzy and object-based image analysis (Proctor 2011). The unsupervised analyses occasionally mistook EFB for other floating macrophytes (i.e. *Nymphaea odorata, Lemna minor* L.*, Nuphar lutea* (L.) Sm.*, Ceratophyllum demersum* L.*, Potamogeton natans* L.) and sometimes for mixed forest along the water's edge. Supervised processing performed better (overall accuracy 87.4%; Kappa 84.3%), but required image processing experts to develop classification rules at every step. Proctor (2011) did not report the time required for supervised or unsupervised processing of imagery.

Proctor (2011) used hyperspectral imagery of the visual and near infrared spectrum gathered by satellite QuickBird at 2.4 m resolution. At 2.4 m resolution, EFB mats less than 10m across would be difficult to detect, because it is difficult to distinguish objects less than 5 pixels across in imagery. Populations that

did not form dense mats may go undetected because the plant is smaller than the resolution of the imagery. To gather imagery at a smaller resolution, unmanned aerial systems would have to be utilized, most likely on a site by site basis given limited capabilities of unmanned aerial systems (e.g. FAA flight restrictions, flight time, sensor capabilities, weight).

Figure 4. A turion of European frog-bit (*Hydrocharis morsus-ranae*). Photograph by Christopher Fischer

III. Life History and Spread/Dispersal

The EFB reproduces both sexually and asexually, though sexual reproduction is rare. Its primary means of reproduction is asexual through overwintering turions and stolon fragmentation. Turions are vegetative winter buds that develop near the nodes of the stolon at the end of summer (Figure 4). In the fall these turions break free from the plant and sink to the substrate to overwinter. In the spring when temperatures increase, the turions rise to the surface and begin to germinate. Turions range from 0.2 – 0.3 in (5 – 7 mm) in length and are oval in shape. They initially they develop into a solitary root, then a small rosette. By the end of spring they are mature rosettes (Catling et al. 2003). Once mature, the long, durable stolons entangle with one another, creating dense mats (Figure 2). One turion can give rise to over 10 ramets (i.e. clones), and each of which can produce 10 turions of their own. A single turion can grow to and spread to cover an area of 1 m^2 in just one season (Catling et al. 2003).

The flower of the EFB gives rise to a round berry that contains 26 - 42 seeds per berry, but can contain up to 74 seeds. When ripe internal pressure causes the sides of the berry to split, releasing the seeds into the water (Scribailo and Posluszny 1985). However, information involving seed germination is unclear since very few have been found in the wild (Catling et al. 2003).

The ease of spread and dispersal of EFB is just one factor that makes it such a problematic species. Dispersal primarily occurs via wind and water currents, but can also occur from assorted waterfowl such as ducks and herons that have portions of the plant attached to their feet or bills. Human activities are also largely to blame for the rapid spread of EFB. Plant fragments and turions can easily become attached to a boat's hull, anchor, rope, trailer, or prop and transported to another water body (O'Neill 2007). Dispersal has also occurred through horticulture efforts for the plant's decorative qualities in water gardens.

IV. Habitat

The native range of EFB is throughout Europe and portions of Africa and Asia. The EFB is considered an endangered species in Switzerland (Sager and Clerc 2006).

European frog-bit prefers to grow in calm, shallow water bodies such as swamps, marshes, inlet bays and coves, stagnant ditches, canals, and the edges of lakes, streams, and rivers (O'Neill 2007). It tends to favor mesotrophic to moderate eutrophic bodies of water that are high in calcium and have an organic substrate.

V. Effects from EFB

The invasion of EFB has had many negative effects on Michigan's aquatic ecosystems and has threatened biodiversity. The rapidly growing, dense mats of EFB can limit the amount of light that penetrates the water column, which can negatively affect the growth of native plants below (O'Neill 2007). In shallow waters the dense mats of EFB can overcrowd native plant species, which can in turn have negative effects on the native wildlife, decreasing overall biodiversity of the area. When large colonies of EFB die in the fall they decompose, reducing levels of dissolved oxygen in the water, which can be critical to fish communities and other aquatic life (Catling et al. 2003). Mats of EFB can also inhibit recreational activities such as boating, swimming, and fishing.

Current Status and Distribution in Michigan

European frog-bit was first introduced in North America in 1932. It was introduced as an ornamental plant in an arboretum in Ottawa, Ontario, Canada. In 1939 it was found in the Rideau Canal and began its spread south through New York and into the lower eastern Great Lakes area. European frog-bit was first established in the United States in New York in 1974 along the St. Lawrence River (Catling and Dore 1982; Roberts et al. 1981).

It was first observed in Michigan at the Ford Yacht Club in Wayne County in 1996 (MICH; Reznicek et al. 2011). At the time of this report, it has been observed in seven counties in Michigan and is expected to appear in more soon: Alpena, Bay, Chippewa, Macomb, Monroe, St. Clair, and Wayne Counties (MISIN 2014).

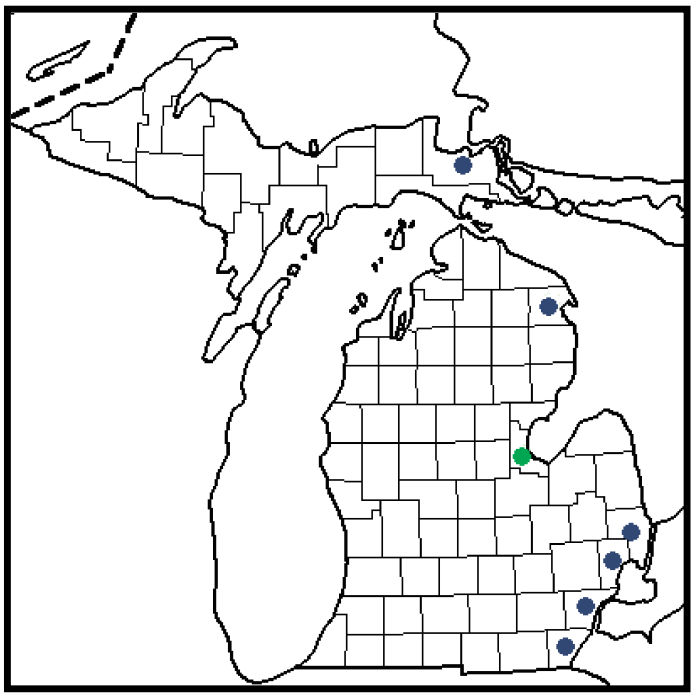

Figure 5. Blue dots indicate counties in Michigan where a specimen of EFB has been collected and included in Michigan Flora. Green dots indicate counties where EFB was documented by Midwest Invasive Species Information Network, but not by Michigan Flora. County map developed by Michigan Flora Online (Reznicek et al. 2011)

Most known populations are in southeastern Michigan along the Lake Huron, Lake St. Clair, and Lake Erie coasts. Most of these populations are patchy, except those found near Lake St. Clair, which are dense (MISIN 2014).

In the eastern Upper Peninsula, several large EFB populations were found near the mouth of the Munuscong River connecting to Lake Huron. Some of these colonies were dense and over an acre in size (MISIN 2014). Colonies in Alpena and Munuscong Bays in Chippewa County

were hand-harvested by the Michigan Department of Natural Resources, but the effectiveness of this control has not been evaluated.

In Alpena County in the northeastern Lower Peninsula, colonies were reported throughout the Thunder Bay River basin in 2013. The spread can be traced upstream to Fletcher Pond, 27 miles southwest of where the Thunder Bay River meets Lake Huron. Populations were documented from Fletcher Pond to Lake Huron including Lake Besser, Alpena Wildlife Sanctuary, and Lake Winyah (MISIN 2014).

Colonies in the Nayanguing Point Wildlife Area in the Saginaw Bay in Bay County were also reported in 2013 (Vaughn and Ankney 2013; MISIN 2014). Michigan Department of Natural Resources attempted to hand-harvest the dense colonies in the fall of 2013 (Vaughn and Ankney 2013). The effectiveness of this control has not yet been evaluated.

Management of EFB

I. Prevention

Since EFB spreads quickly once it's established, it is imperative to take the proper measures toward prevention, which is one of the primary goals of Michigan's Aquatic Invasive Species Management Plan (MDEQ 2013). In Michigan, EFB is considered a "Prohibited species" in the Natural Resources and Environmental Protection Act 413 of 1994. Under this act the growing and selling of EFB is not permitted within the state. Studies at the Great Lakes Commission and University of Notre Dame are underway to examine trade of aquatic invasive species which is still a common pathway for aquatic invasive species (Maki and Galatowitsch 2004; O'Neill 2007).

The EFB is an aquatic hitchhiker, so boaters, anglers, hunters, and water gardeners are unintentionally one of the biggest culprits of its dispersal. Fragments and even turions attach to boats, trailers, or boots and can be transferred to uninfested waters. Methods to reduce its dispersal are to wash equipment and remove plant matter before transporting between locations and dispose of plant matter away from shore. The following actions may prevent and limit the dispersal of EFB:

- Build a coalition of local, statewide, and Great Lakes regional partners to monitor for EFB and other aquatic invasive species
- Build a coalition of states that have classified EFB as a restricted or prohibited species
- Expand existing coalitions to include organizations that may soon encounter EFB as an aquatic invasive species
- Improve monitoring and enforcement of distribution and sale of EFB among states that restrict or prevent its distribution
- Educate citizens, focusing on waterfront property owners and horticulture industry, about AIS including EFB
- Promote the benefits of native lakescaping

- Develop and enforce a sustainable water recreation vehicles and trailers inspection program
- Identify water bodies of high-risk of infestation using known distribution and dispersal knowledge

II. Management/Control

Early detection and rapid response of an EFB colony is crucial. Removal of EFB is difficult after establishment, because of its rapid growth and the ease of turion dispersal. Although presented separately here, a management plan developed by integrating ecological knowledge, several management techniques, monitoring, and plan adaptation over time – called integrated pest management – is the most effective approach to controlling invasive species.

There have been a variety of methods used over the years to control EFB, but unfortunately none have been proven effective. Physical harvesting (by hand or mechanical) and use of herbicides are the most commonly used methods. Other methods require more research before widespread implementation. The following is a summary of control methods tested to date and their results.

a. Chemical

Diquat, paraquat, chlorthiamid, terbutryne, and dichlobenil, were shown to effectively control EFB for one year (Newbold 1975). European frog-bit was also susceptible to cyanatryn (Newbold 1977). Diquat is the only one of these approved for aquatic use by the Department of Environmental Quality under the Aquatic Nuisance Control Standard Permits in the state of Michigan. More field research could determine effective concentrations and repetitions of diquat treatments, other effective herbicides, and effects that chemical treatments may have on non-target species.

Many herbicides effect the growth of closely related American frog-bit (*Limnobium spongia*), but it is uncertain if EFB is equally susceptible. The most common herbicides used to control American frog-bit are triclopyr, diquat, and imazamox.

Adjuvants are additives that are added to herbicides that, in some instances, will improve herbicide effectiveness; there are some aquatic herbicides that include adjuvants in the mixture. There are only four adjuvants approved at this time for aquatic use in Michigan: agri-dex, cygnet plus, polyan, and topfilm. All four are drift/sink adjuvants; all but topfilm are nonionic surfactants and topfilm is a grain-based emulsifier. Aquatic herbicides will list possible adjuvants to mix with on their label, but whether or not adjuvants cause a significant difference in herbicide performance is dependent on the herbicide, herbicide concentration, environmental conditions, and target species.

Three adjuvants are not approved for aquatic use in Michigan for their adverse effects on fish and macroinvertebrates: cide-kick II, subcide, and sure-fact.

b. Physical or Mechanical Control

Hand harvesting is thought to be the most effective means of physical control for EFB. The best time for hand harvesting is in the spring or early summer after the overwintering turions have germinated on top of the water, but before new turions have developed. This usually occurs in late April to early May when temperatures are between 59° – 77°F (15° – 25°C; Catling et al. 2003). Hand harvesting has been shown to provide only temporary relief, thus monitoring and repeated treatments occur every year for effective control. The process is also quite costly, requiring multiple workers and many hours of hard work to control even the smallest of areas. It is easy for fragmentation to occur during this process, distributing EFB throughout the area. For optimal effectiveness, tools for hand harvesting are constructed to capture the small turions as well as the rest of the plant. An ongoing study on the effectiveness of hand harvesting as a control strategy has been conducted in Adirondack Park, New York, beginning in June 2007, but results of the study have yet to be published (Langdon et al. 2008, Langdon et al. 2009).

Mechanical harvesting has become a popular control method for several other invasive aquatic plant species, but it is not effective against EFB. The primary disadvantage with mechanical harvesting, like the hand harvesting, is that it leaves behind many fragments and turions that can promote spread.

Controlling EFB through water drawdown has shown to be effective in small ponds, but it is only possible for water bodies with artificially controlled water levels. This method is usually done overwinter, or in the spring after the turions have germinated (Catling et al. 2003). Uncertainties on the length of time needed for the drawdown to be effective have arisen. Water drawdown can have many negative effects on the ecosystem, primarily the loss of native flora and fauna diversity.

Shading with tarps can be effective to manage EFB in small areas. Shading at 100% has shown to be effective, resulting in nearly no growth, but had a large negative impact on non-target species abundance and diversity. Shading at 70% was also effective in controlling EFB with only minor impacts on the ecosystem: 25 times less biomass accumulation, an improvement in dissolved oxygen conditions, and no drastic changes on submerged vegetation (Zhu et al. 2014). Shading can be costly and requires time to design, construct, and maintain (Bashaw and Brown 2009).

c. Biological

Some biological controls of EFB have been studied, but they have had little success. It has been shown to be a food source for a variety of animals, but most have shown only leaf damage: moth larvae (i.e. *Munroessa icciusalis* Walker and *Synclita occidentalis* Lange), frogs, and snails (Catling et al. 2003). The turions of EFB have been found in

the gullets of black ducks (*Anas rubripes* Brewster*),* but more studies are needed to determine any significance (Catling et al. 2003).

Invasive grass carp has shown to be an effective biological option for EFB control. They are capable of consuming large quantities of the plant and the cost of doing so is quite reasonable, but the introduction of carp into an ecosystem has dire consequences to native fauna, reducing diversity.

No bacteria, viruses, or plant parasites have been recorded on EFB. The plant does however host a variety of rusts, smuts, and molds, but their effects on EFB colonies have not been studied as of the date of this report (Catling et al. 2003).

III. Indirect Management

Reducing nutrient loading of water bodies may impair EFB establishment, because EFB prefers meso- and eutrophic environments. Promotion and maintenance of natural shorelines and native vegetation on water front property can reduce nutrient loading in water bodies. Native grasses and wildflowers feature deep and extensive root systems that stabilize the soil, prevent erosion, and reduce nutrient run-off. The use of native plants is preferred in shoreline landscaping because they are well adapted to the climate and soil conditions of that ecosystem and require very little maintenance once established (Henderson et al. 1998). The root systems take time to established, sometimes even years, and there are local government regulations that must be followed before planting (Henderson et al. 1998).

Research needs

In order to better understand EFB ecology, monitoring, and management in Michigan, the following research areas should be addressed: population genetics, turion viability and triggers, delineation and investigation of flowering and non-flowering populations, chemical controls, biological controls, and recolonization post-treatment.

I. Genetics

Population genetics research will contribute to understanding the origin and dispersal of EFB. Understanding the origin and dispersal of EFB will allow for the development of more efficient education, prevention, and monitoring programs. Aside from the Thunder Bay River populations, EFB has been restricted to the Lake Huron, Lake St. Clair, and Lake Erie coasts. Genetic relationships between these populations and those seeming isolated colonies elsewhere in Michigan may provide clues to dispersal pathways. Delineation and comprehension of flowering and non-flowering populations will also provide clues to dispersal of EFB.

II. Biology and Ecology

No research was found at the time of this report as to the viability of turions pre- and post-consumption or turion sprouting and maturity triggers. Research in these areas can provide insight in determining the best time and strategy methods for controlling EFB.

In general, there is a lack of literature on specific ecological and economic impacts of a specific aquatic invasive plant species. Most impacts are grouped by growth forms of the species, but the impacts are not quantitatively measured. It is more difficult to justify management of an invasive species when quantitative impact data is lacking.

III. Management

Further research is needed on EFB management options. Repeated treatment, long-term, and integrated management strategies have not been fully investigated. There is little known about what chemicals are being used to control EFB, their effectiveness, and the impacts they have on non-target species. Research evaluating the effectiveness of herbicide treatments used on *Limnobium spongia* (American frog-bit; e.g. triclopyr, diquat, and imazamox) on EFB could be useful for control.

Hand harvesting is labor intensive and needs to be continued indefinitely, but mechanical harvesting promotes dispersal of EFB. Research into more efficient method or device for physical or mechanical extraction could be beneficial. Post-mechanical regrowth is also an area worth further investigating. Continued research into shading techniques could strengthen the findings of previous studies.

Further research exploring potential biological methods of control could provide a long-term control option. EFB serves as a food plant for a variety of insects, snails, and fish, but they have shown to create minimal damage to the leaves only. There have been no bacteria, viruses, or plant parasites recorded on EFB, but it does host a variety of rusts, smuts, and mold that may be worth further investigation (Catling et al. 2003).

Future Directions for Michigan and EFB Management

The European Frog-bit was first reported in Michigan in 1996 in Macomb County along Lake St. Clair and is currently established in seven counties throughout the state (MISIN 2014). It has quickly become a problematic species and a definitive management strategy is required to slow the rapid and aggressive spread of this invasive. To advance the front against EFB invasion, recognize all possible vectors for spread, initiate or continue monitoring programs, enforce current regulations, and address research needs.

Prevention – Prevention is the most effective and economically feasible method of managing EFB. The first occurrence of EFB in North America was an aquaculture escapee, and it is still possible to acquire prohibited and restricted species via aquaculture and internet sales (Maki and Galatowitsch 2004). Increased enforcement of current restrictions may reduce new introductions. Collaborations between states with similar regulations of EFB and other aquatic invasive species could be beneficial. Expanding existing coalitions to include organizations that

may soon face EFB as an invasive species may also prevent spread. Results of the Great Lakes Commission studies on aquatic invasive species trade should provide avenues of approach to the aquaculture and internet trade.

European frog-bit can easily attach to boats, trailers, or boots, and can be transferred to uninfested waters. The instigation of a sustainable boat washing or inspection program from waters infested with EFB can aid the prevention of the spread of this species.

Monitoring – Early detection would make eradication a more realistic option. Adding EFB to existing monitoring programs will assist in early detection and increase the potential of eradication of EFB. A cohesive monitoring and reporting system involving local municipalities, non-profit organizations, lake associations, recreation clubs and organizations, and waterfront property owners, would increased the knowledge of EFB locations and enable early detection responses to new colonies. Connecting waterfront property owners with resources such as MISIN may increase early detection efforts. The Thunder Bay River watershed and areas bordering Lake Huron and Lake Erie would benefit most from a targeted education program for monitoring EFB.

European frog-bit monitoring would benefit from a direct and targeted monitoring strategy. A targeted monitoring strategy would involve preparation and research, but may be the most efficient strategy in the field considering the limited known distribution of EFB in Michigan. To develop a targeted monitoring strategy, the current known distribution and predictive modeling would be used to extrapolate sites that have a high-likelihood of infestation. The likelihood of infestation of sites would be determined by evaluating potential pathways and dispersal trends of EFB, like that Abigail Fursaro and Alisha Dahlstrom Davidson (Wayne State University) are currently applying as a part of the Great Lakes Restoration Initiative to identify hot spots for new aquatic invasive species to be introduced. For EFB, water bodies could be prioritized based on the distance (Euclidean and upstream/downstream distance) from infested water bodies, density of EFB in nearby infested water bodies, environmental habitat conditions, level of recreational activity, number of public access points, vicinity to a store selling aquaculture plants, migration routes, and property owner types. Each potential pathway is ranked and weighted for spatial analysis. Those water bodies that score in the highest tier have a high-likelihood of infestation.

If EFB is found at a site, its population can be recorded, added to the current distribution, and surveyed. Wisconsin has a site-surveying method that is effective and provides the understanding as to where EFB may occur and where controls are needed.

Networking data – Statewide monitoring methods would benefit from creating or participating in systems that centralize and provide open access to diversity data (e.g. MISIN, Weed Map – Cooperative Weed Management Area, MiCorps Data Exchange Network – Great Lakes Commission, VertNet, Nonindigenous Aquatic Species Database - USGS, Biodiversity Information Serving Our Nation (BISON), and Global Biodiversity Information Facility (GBIF)). These databases house biological specimen or observation data including species location, verification, photographs, density, and even links to genetic data. Preliminary efforts within the state of Michigan have agencies contributing to regional databases (e.g. MISIN, Cooperative

Weed Management Area, Nonindigenous Aquatic Species Database), but participation is not consistent or standard throughout programs. In addition, state databases are not always networked within an agency, across the state, throughout the region or relative to national efforts.

Participation in a national or global information network will standardize data collecting practices, produce comparable data across projects, ease data acquisition, avoid data redundancies, and promote projects with a larger scope of study than the original project for which the data was collected. Information networks that are continually linked to other resources and updated can be used to develop effective and efficient monitoring and management plans. In turn, monitoring plans can inform the resources on their findings and create an adaptive strategy to combat invasive species. When information networks are not linked or periodically synched, a person collecting information must independently identify, locate and consolidate data from separate and often difficult to access sources. The result is information is not accessed and data collection becomes redundant and inefficient.

Networking with and contributing to state, regional, national and internationals databases will advance research in areas that could improve the way aquatic invasive species are managed. Researchers can easily access the data and use it to model suitable habitat, model distribution, research population genetics across many spatial scales, predict new introductions, study changes due to climate change, or locate areas most beneficial for new projects or collections. The public could also use this data to know what species they may be exposed to when recreating specific water bodies.

Rapid response – The ability to rapidly respond to reports in new or high-value locations submitted by the public or through a regular monitoring strategy is essential to battling invasive species. Invasive species are easier to treat if the infestation is small. If the procedure to manage an infestation takes several years to achieve action, the infestation may have grown beyond realistic management. Maine Department of Environmental Protection has developed a rapid response protocol that attempts to treat infestations of certain aquatic invasive species within 30 days of a newly detected aquatic invasion (MDEP 2006). The workflow begins at confirmation of report, and then delineation of infestation, containment, and primary evaluation. Next steps are treatment selection, plan refinement, and implementation. The infestation should be monitored and evaluated regularly for several seasons to evaluate the treatment and control any reemerging growth. Although it is called a rapid response, it may not end rapidly.

Management – Early detection is critical to the eradication of EFB. When managing EFB colonies, it is important to delimit the current extent of the infestation, contain already established populations, and protect high-value sites. One management method has not proved successful alone, so an integrated pest management plan is essential.

The optimal time for physical control is in the spring or early summer after the reproductive turions have germinated, but before the new ones have developed (Catling et al. 2003). To date, hand harvesting has shown to be the most efficient means of eradicating the plant, but it is not economical for larger colonies. If a plant colony is detected early, the small colonies can be

harvested by hand with minimal labor effort. For large populations, this method provides only temporary relief and needs to be repeated annually.

Chemical treatment with diquat may be effective, but further field-testing is needed. Biological controls had not been thoroughly investigated at the time of this report.

Measuring effective control – Following the treatment of EFB, the effectiveness of the treatment can be quantitatively assessed by documenting year-to-year regrowth, reduction of EFB percent cover, as well as reduction of turion growth.

The primary goal of EFB management is to develop a strategy that prevents its spread and eradicates current populations without compromising the ecological stability of the water bodies. The ideal strategy should be effective, but implement minimal chemical, biological, and physical control methods in the process, preserving the stability and biodiversity of the ecosystem.

Document citation

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Table 1. Objectives, Strategic Actions, Leads, and Expected Outcomes of EFB Management

Guidance and Outreach for European Frog-bit Management			
Objective	**Strategic Action**	**Who is leading effort in Michigan?**	**Expected Outcome**
Increase public awareness of prevention methods	• Coordinate and collaborate with local and regional partners of water bodies with an infestation or high likelihood of infestation • Educate public of identification, early-detection, and prevention	• AIS Core Team • Lake associations • Michigan Inland Lakes Partnerships • MSU extension	• Increase public awareness of EFB • Increase the frequency and use of boat washing programs • Contain established populations
Prevent other new introductions of EFB	• Educate local and regional aquaculture industry	• MDARD • Great Lakes Commission	• Reduce sale of invasive EFB • Elimination of purposeful and accidental sale of EFB
Increase public awareness of the benefits of natural shoreline development	• Provide informational material on the benefits of natural shoreline	• Michigan Natural Shoreline Partnership • Michigan Inland Lakes Partnership	• Increase in natural shoreline development • Lower nutrient inputs into lakes
Provide technical guidance to those interested in EFB management	• Creation of EFB technical guide and EFB prioritization tool.		• Increase management efforts
EFB Monitoring and Data Management			
Develop a mechanism for monitoring and reporting AIS species	• Develop a system of identifying water bodies with high likelihood of infestation • Survey water bodies with high likelihood of infestation	• AIS Core Team • MISIN • BISON • Michigan Clean Water Corps	• Develop a more thorough and up-to-date statewide distribution of EFB • Evaluate dispersal pathways and vectors
Contribute regularly to regional, national, and global diversity information networks	• Consolidate Michigan biological and abiotic data • Standardize resources • Standardize data collection • Network existing data • Regularly synchronize data	• MISIN • Weed Map - CWMA • MiCorps • VertNet • NAS - USGS • BISON • GBIF	• Develop adaptive monitoring strategy that responds to up-to-date distribution • Promote AIS research of regional, national, and global extents • Prevent data redundancies
Educate public on identification and reporting of AIS in Michigan	• Target users of water bodies that are infested and high-likelihood of infestation	• MISIN • Michigan Clean Water Corps • Lake associations • Management agencies	• Increase public awareness of AIS • Increase early detection of AIS • Identify water bodies that need professional confirmation of AIS

Research Needs for EFB Management			
Chemical: Develop chemical treatments that will increase management success and minimize the ecological and economical effects	• Test herbicides that are effective on American frog-bit on EFB • Investigate the effects of varying concentrations and repeated treatment of diquat on EFB growth and non-target effects • Investigate systemic herbicides on turion development • Test herbicides in combination with mechanical controls		• Find more effective and long-term treatment options for established populations • Decrease management effects on non-target species
Biological: Investigate possible biological controls	• Survey native range for host-specific organisms that cause disease or affect turion development in EFB • Investigate the relationship between waterfowl and dispersal of EFB		• Develop more effective treatment options for established populations • Decrease management effects on non-target species • Improve preventative measures by targeting likely dispersal vectors
Mechanical: Determine the most effective and economical mechanical methods to mediate the effects of EFB	• Test herbicides in combination with mechanical controls • Determine turion viability and maturation triggers • Survey maturation time for the turions in Michigan • Further investigate use of shading as a long-term control method	• DNR	• Reduce unnecessary dispersal of colonies of EFB during mechanical control • Determine long-term effects and effectiveness of EFB treatment
Indirect Management: Increase understanding of the impact of natural shoreline management and aquatic invasive species management	• Investigate relationships between natural shoreline development, nutrient loading, and EFB establishment	• DNR • MSU extension	• Provide better understanding of preventative measures of EFB establishment

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