State of Michigan's

Status and Strategy for Flowering Rush (*Butomus umbellatus* L.) Management

Scope

Invasive flowering rush (*Butomus umbellatus* L., hereafter FR) has invaded the shores of Michigan waterways since the early 1900's (Core 1941; Stuckey 1968; Anderson et al. 1974). 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 FR.
- Summarizing current management options for FR in Michigan.
- Identifying possible future directions of FR 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

Flowering rush is an emergent aquatic perennial plant with linear, sword-like leaves, triangular in cross-section, and a showy umble of pink flowers (Figure 1). Rhizomes (i.e. horizonal root-like stems) are fleshy, and leaves have parallel veination and can be submersed or emergent. Submersed leaves are linear and limp, unlike sword-like emergent leaves. Flowering rush blooms from June to August. Flowers are arranged in terminal umbels. Flower parts are found in multiples of three (e.g. six tepals, nine stamen, six carpels) with pink to purple tepals 0.25 – 0.5 in (6 - 11.5 mm) long (eFloras 2008). Each flower produces up to six beaked fruits. Flowering rush also produces bulbils (i.e. small bulb-like structure that may produce a new

Figure 1. Flowering umbel of flowering rush (*Butomus umbellatus*). Photograph by R W Smith, courtesy of Michigan Flora Online (Reznecik et al. 2011)

plant) at the base of the flowers and along the rhizomes.

Species that are often mistaken for FR include: *Sparangium* spp. and species of *Schoenoplectus* with triangular stems. The large, terminal umbel of pink flowers differentiates FR from other Michigan plant species. If no flowers are present, the leaves may resemble bur-reed (*Sparganium* spp.) or three-angled bulrush (*Schoenoplectus* spp.). The leaves of FR are spongier and rebound when pressed, unlike that of the triangular-stemmed *Schoenoplectus* spp. Flowers of *Schoenoplectus* spp. are small, scaled, brown spikelets, and those of *Sparganium* spp. are a jagged spike of small spiked balls.

II. Detection

It is easiest to differentiate FR when it is blooming. In Michigan, FR has been collected in bloom as early as mid-June but only a few flowers were seen until the last days of June (University of Michigan Herbarium - MICH). Flowering rush has been collected as late as September 29 (Monroe County; MICH, Michigan State University Herbarium - MSC), but most collections of flowering individuals were made in July or August (MICH, MSC, Eastern Michigan University Herbarium - EMC).

Remote sensing technology at this time is unable to distinguish submerged aquatic vegetation at water depths greater than 15.7 in (40 cm; Visser et al. 2013), but may be used to detect emergent or floating vegetation under certain circumstances. The resolution of remote sensing imagery is reaching a size where it is feasible to distinguish larger floating and emergent vegetation. There is still the difficulty of background absorption by the water, but some image processing techniques are being developed to account for such obstacles.

Only two studies have attempted to detect FR with remote sensing (Rice et al. 2010; Gorsevski 2013), and one study had very particular imagery gathering procedures and errors in their processing techniques (Rice et al. 2010). One study in Ohio has used remote sensing imagery with a spatial resolution less than 20cm to detect FR with an accuracy of 69.6 – 77.7% (Gorsevski 2013). At least one attempt was made to detect monoculture stands of aquatic vegetation including stands of FR with high resolution aerial photographs, but the study used supervised classification by one expert with unknown training, which puts the repeatability of the study in question (Husson et al. 2013).

At this time, gathering imagery of that scale can only be done with unmanned aerial systems and the area that can be captured is limited to the capabilities of that system (e.g. flight time, sensor capabilities, weight). It is unrealistic to gather imagery of the entire state at that spatial scale, but it could be gathered on a site-by-site basis. Image processing requires time as well. At this time, it may be more cost and time effective to manually inspect lakes of high-risk of infestation for FR.

III. Life History and Spread/Dispersal

Flowering rush is a perennial. Its shoots emerge in late March or early April and are well established by May, when most native species begin to sprout. Flowers bloom from June to August. It is vegetative throughout the season, and frost collapses the leaves for the winter.

Figure 2. Rhizomes and rhizome bulbils of flowering rush (*Butomus umbellatus*). Photograph by Ben Legler

Flowering rush reproduces both asexually and sexually, but in the North American populations, asexual reproduction is the primary method of distribution (Eckert et al. 2003; Kliber and Eckert 2005). Asexually, FR expands colonies via rhizome fragmentation, and bulbils produced at the base of the flowers and on rhizomes (Figure 2). Each bulbil may grow into a clone of the parent plant.

Flowering rush populations in North America are sexually fertile and diploid or infertile and triploid (Eckert et al. 2000; Eckert et al. 2003; Kliber and Eckert 2005). Flowering rush is pollinated by insects; the most common pollinator is the European honey bee, but other general pollinators like other bees, flies, and wasps have also been witnessed on FR (Bhardwaj and Eckert 2001). Flowering rush is capable of self-fertilization, but a physiological mechanism in the flower development prevents the male and female parts of the same flower from being ripe at the same time (Bhardwaj and Eckert 2001).

There is a school of thought that invasive species that have an extremely productive asexual reproduction strategy have less sexual reproduction as a trade-off. This is not the case with FR; studies found that there was no negative correlation between flower production and bulbil production, and in fact, many flowering fertile (diploid) specimens had more bulbils than infertile (triploid) specimens (Eckert et al. 2000; Lui et al. 2005). Infertile (triploid) populations in North America are believed to reproduce almost exclusively by rhizome fragmentation and rhizome bulbils (Eckert et al. 2003; Kliber and Eckert 2005).

Seeds, rhizome fragments, and bulbils may be transported via waterways to form new colonies. Seed germination of European populations need cold-stratification (i.e. over-winter), very shallow waters, little competing vegetation, and germination temperatures of 68° – 86°F (20° - 30°C; Hroudová et al. 1996; Hroudová and Zákravský 2003). Germination experiments on North American populations imitating these conditions have been successful (e.g. Eckert et al. 2000; Thompson and Eckert 2004). Decreases in the water level in nature have been associated with burst of invasive growth in North America (Delisle et al. 2003).

IV. Habitat

The native range of FR extends throughout Eurasia from Spain, Great Britain, and the Scandinavian Peninsula to Russia to northern China and Japan (Figure 3; Hultén and Fries 1986). It is a common plant for water gardens and easily obtained in the horticulture trade (e.g. Gray 1821; Withering 1858; Prior 1879; Maki and Galatowitsch 2004). The roots have been used in bread (Norway) and roasted and eaten (north Asia); the seeds are bitter but have been eaten as well (New York Department of Agriculture 1919).

Flowering rush grows best in shallow, slow moving ditches, streams, rivers, and lakeshores in temperate regions. It can grow in water up to 10 ft (3 m) deep as emergent plants and submersed plants may grow as deep as 20 ft (6.1 m) in clear waters (Jacobs et al. 2011). European specimens grew in stable or fluctuating water levels, but were outcompeted by other plants when water levels were stable (Hroudová et al. 1996). Some studies have found that FR does not grow well in high nutrient conditions (Hroudová and Zákravský 1993a; Trebitz and Taylor 2007).

Figure 3. The native range of flowering rush (*Butomus umbelatus*) in Eurasia. Map from Hultén and Fries (1986)

V. Effects from FR

Little scientific research has been completed on the specific ecological or economic effects of FR, but as an aquatic invasive species that forms large mono- or oligoculture stands along rivers and lakeshore it has the potential to:

- Impede irrigation
- Promote deposition of sediment
- Impact recreation activity
- Promote habitat of the intermediate host of the swimmer's itch parasite (e.g. great pond snail – *Lymnaea stagnalis* L.)
- Decrease open spawning habitat
- Decrease abundance and diversity of native plant species

Companies that provide surface water irrigation for agricultural, municipalities, and others in FR invaded areas can spend over $60,000 per year battling FR, not including the costs of chemical treatment. This cost was an 8% rate increase for shareholders of the Aberdeen-Springfield Canal Company (Rice 2009). Although surface water irrigation is not as prevalent in Michigan due to the abundance of available and potable groundwater, this example illustrates possible costs for stream and river recreation.

The preliminary results of an ongoing study in Montana show that FR increased habitat for fish that spawn in vegetative habitat and decreased the habitat of open water spawners. The effects of FR habitat alteration on the fish and macroinvertebrate community has not been fully investigated (Rice et al. 2014). Although, Michigan and Montana have different desired fish communities, habitat alteration is the primary threat to salmoniods and native fish in the Great Lakes (Roseman et al. 2009; Mandrak and Cudmore 2010). Great Lakes fish and macroinvertebrate communities have yet to be investigated for effects of FR invasions.

Many invasive species will crowd out native species given time (Madsen 2009; Higman and Campbell 2009). The relatively early sprouting time of FR lends weight to that belief, but there were no documented studies illustrating a decrease in native species after FR was introduced at the time of this report. In infertile (triploid) populations in Minnesota, FR was reported to be growing with 31 native and non-native species; it was often growing with hardstem bulrush (*Schoenoplectus acutus* (Muhl. ex J.M.Bigelow) Á.Löve & D.Löve), a native species (Madsen et al. 2012).

Current Status and Distribution in Michigan

The range of FR in North America extends from Nova Scotia and New England to British Columbia and Washington, in mostly border states between Canada and the USA, and states in the Great Lakes basin (Figure 4; USDA 2014; Parsons et al. 2014). In North America there have been several introductions, the first of which in the St. Lawrence Seaway near Montreal, Quebec, Canada, in 1897 (Core 1941). Flowering rush was first collected in Michigan in August 1930 from Brownstown Township and in September from the Rouge River in Wayne County near Detroit (Cranbrook Institute of Science Herbarium - BLH). The population was described by the collector to have existed since the days of the explorer Antonie de Cadillac in the 1700s, but most estimate the introduction to be around the turn of the century, shortly after it was introduced on the St. Lawrence Seaway near Montreal (Core 1941; Delisle et al. 2003).

Over the last century it was hypothesized that the Detroit and Montreal populations came from two separate origins based on physiological differences of stem length, stem width, flower stalk length, petal length, and flower number (Anderson et al. 1974).

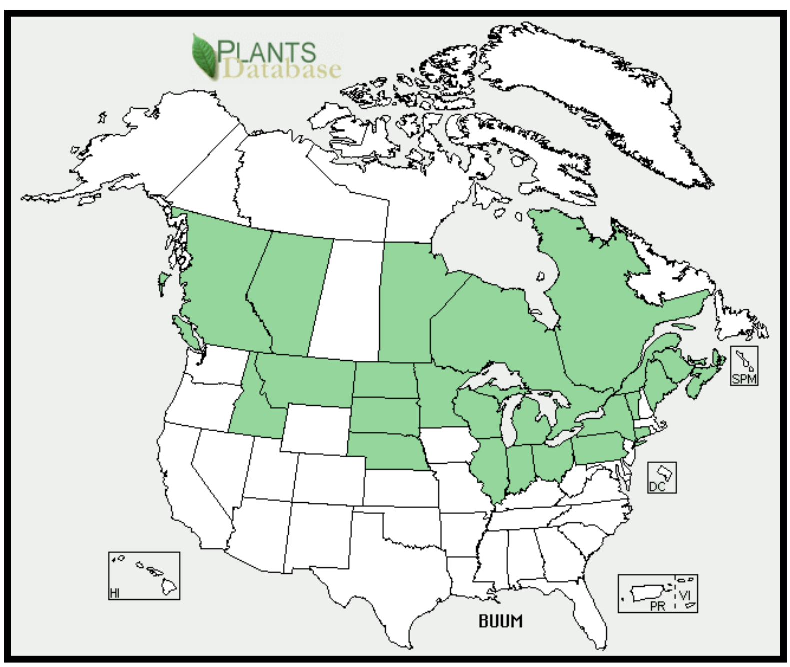

Figure 4. Distribution of flowering rush (*Butomus umbellatus*) in North America. Populations have recently been reported in Washington state (Parsons et al. 2014). Map provided by USDA PLANTS Database (2014)

In the last decade, population genetic studies have disproved this hypothesis. Kliber and Eckert (2005) uncovered that the two populations were genetically related (possibly from the same origin) and fertile (diploid) populations, but they were unable to narrow the country of origin. It was believed that FR was planted in both locations, as it was a common plant for water gardens in Europe, and its planting was encouraged in early North American horticulture books (Gray 1821; Withering 1858; e.g. Prior 1879; Henderson 1910).

There have been several other introductions of FR into central and western North America (Staniforth and Frego 1980; Scotter 1991; USDA 2014; Parsons et al. 2014). Many of these introductions have been attributed to infertile specimens with origins in the Scandinavian Peninsula and northern Germany, likely acquired from the horticulture trade (Maki and Galatowitsch 2004; Kliber and Eckert 2005).

In 2007, a study of exotic and invasive species in Great Lakes coastal wetlands found FR along Lake Erie and Lake Ontario shores but not in the other three lakes (Trebitz and Taylor 2007). Michigan Flora documented FR in nine Michigan counties, all in the Lower Peninsula: Macomb, Monroe, Oakland, Washtenaw, and Wayne Counties in southeastern Michigan, Cheboygan and Emmet Counties in the northern Lower Peninsula Michigan, and Newaygo and Ottawa Counties in western Lower Peninsula Michigan (Reznicek et al. 2011). The Midwest Invasive Species Information Network (MISIN) reported occurrences of FR in additional counties of Livingston, Saginaw, and St. Clair Counties in southeast Michigan and Calhoun and Van Buren Counties in southwest Michigan (MISIN 2014).

In southeast Michigan, populations were reported by MISIN to be sparse to forming monocultures. The western shore of Lake Erie (e.g. Point Mouillee State Game Area, Maumee Bay) was reported as having patchy to dense populations. Most populations were reported as sparse in Lake St. Clair, except for dense populations of FR at Metro Beach MetroParks. There were also reports of FR in the St. Clair River connecting Lake St. Clair and Lake Huron (MISIN 2014).

More inland in southeast Michigan, Oakland County populations were reported in lakes in Pontiac Lake State Recreation area (i.e. Pontiac Lake, Maceday Lake, Lotus Lake) and in nearby neighborhoods. Highland State Recreation Area has FR in Lower Pettibone Lake. Oakland County also contained reported populations in Lakeville Lake (MICH), Orchard Lake, and near Island Lake and Lower Long Lake (MISIN 2014). Rivers in the southeast that were recorded as having populations of FR were Clinton River (University of Notre Dame Herbarium - ND), Detroit River (New York Botanical Garden Herbarium - NY), Rouge River (BLH, MICH), and the mouth of the River Raisin (MICH, MSC).

Sparse and patchy populations were reported in Washtenaw County near Pinckney State Recreation Area in Portage and Base Line Lakes. There are also populations reported in the city of Ann Arbor on the Huron River (MISIN 2014).

Reported populations in Saginaw County were concentrated along rivers and tributaries from the Shiawassee River State Game Preserve to the Shiawassee National Wildlife Refuge as well as in the Cass River (MISIN 2014).

In the two northern Lower Peninsula counties, populations were first collected in Emmet County in 1938 and in Cheboygan County in 1954 (University of Michigan Biological Station Herbarium - UMBS, MICH). The first specimen collected in Cheboygan County admitted to FR being an escaped cultivar planted in 1946 that established itself on both sides of the road (UMBS).

In western Michigan, a specimen was collected just north of White River in Denver Township, Newaygo County (MICH). The reported population in Calhoun County was on Lane Lake near Battle Creek and were described as sparse.

Sparse populations were reported on Reynolds Lake in Van Buren County (MISIN 2014).

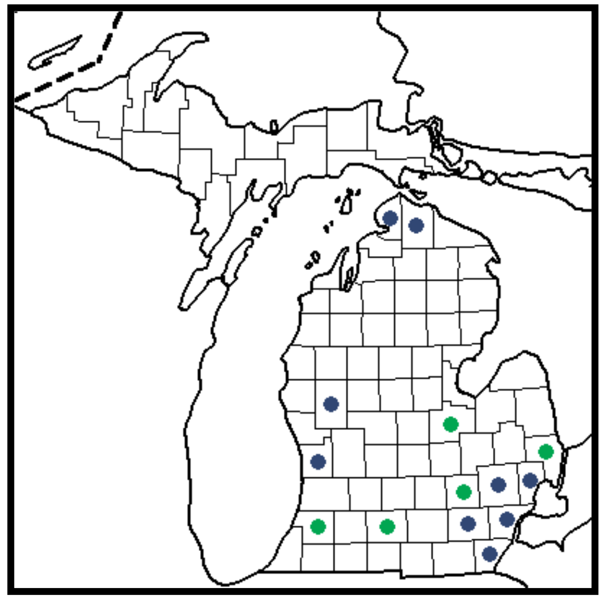

Figure 5. Blue dots indicate counties in Michigan where a specimen of FR has been collected and included in Michigan Flora. Green dots indicate counties where FR was documented by Midwest Invasive Species Information Network, but not by Michigan Flora. County map developed by Michigan Flora online (Reznicek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

In Ottawa County, FR was collected in 2012 from Grand River Park. This population was in a former gravel pit and contained white flowers. The white flowers are a polymorph found in China and had also been observed in Wisconsin (Huang and Tang 2008). There were some physical differences between the two polymorphs, and the pink phenotype has shown to have greater seed production (Huang and Tang 2008). No genetic work has been performed at the time of this report.

Reported out of state populations of concern for distribution into Michigan or the Great Lakes are the Elkhart River in Indiana and Oconto River, Wisconsin. The Elkhart River is a tributary of the St. Joseph River that flows through Michigan and discharges into Lake Michigan. Populations of FR in the Elkhart River have been noted since 1952, but local observations place FR in the Elkhart River since 1940 (Witmer 1964). Populations have been reported on the Oconto River in Wisconsin since the 1980's and were reported in Green Bay near Oconto, Wisconsin, in 1991 (MISIN 2014).

Management of FR

I. Prevention

Flowering rush is difficult to remove entirely once established. It is considered a "Restricted Species" in the Natural Resources and Environmental Protection Act 451 of 1994. Under this act, FR may not be grown or sold without permit in the state. Studies headed by Erika Jensen at the Great Lakes Commission and at University of Notre Dame are underway to examine trade of aquatic invasive species.

Aside from restricting the purposeful human distribution of FR, other methods to reduce its dispersal are to wash equipment and remove plant matter before transporting between locations and dispose of the plant fragments so that it does not runoff back into the lake or stream. The following actions may prevent and limit the dispersal of FR:

- Build a coalition of local, statewide, and Great Lakes regional partners to monitor for FR and other aquatic invasive species
- Build a coalition of states that have classified FR as a restricted or prohibited species
- Expand existing coalitions to include organizations that may soon encounter FR as an aquatic invasive species
- Improve monitoring and enforcement of distribution and sale of FR among states that restrict or prevent its distribution (Maki and Galatowitsch 2004)
- Educate citizens, focusing on waterfront property owners and horticulture industry, about AIS including FR
- Promote the benefits of native lakescaping
- Provide boat washing stations for high-traffic public lake accesses
- Develop and enforce a sustainable water recreation vehicles and trailers inspection program
- Encourage research and development of for monitoring, measuring the ecological and economic effects, and controlling FR
- Identify water bodies of high-risk of infestation using known distribution and dispersal knowledge

II. Management/Control

There were few effective methods found to control FR and most research has been conducted on the infertile (triploid) populations, whereas fertile (diploid) populations are found more frequently in the Great Lakes basin. It is possible that the control methods for infertile populations may not be as effective with fertile populations.

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. It is difficult to mechanically remove FR without spreading clonally, and repeated treatment of broad-spectrum pesticides is needed which may harm native species and promote invasion by other invasive species. Some research on control methods is being conducted at Concordia College in Minnesota (Michelle Marko), Mississippi State University (John D. Madsen), Salish Kottenai College in Montana (Virgil Dupuis), University of Montanta (Peter Rice) and US Army Engineer of Research and Development Center (Angela Poovey). Research into biological controls is in its infancy (Patrick Häfliger, Centre for Agriculture and Biosciences International – CABI). The following is a summary of control methods tested to date and their results.

a. Chemical

Submerged and emergent FR needed to be controlled with different treatment methods (Duncan 2014). There has been little success in finding a treatment that consistently controls biomass, especially the belowground biomass of either growth form. Reduction in belowground biomass is desired, because FR's primary dispersal methods are rhizome fragmentation and bulbils. A summary of chemical controls that have shown some effectiveness is in Table 1.

1. Submerged FR

Effective in the laboratory - Laboratory experiments on submerged FR have shown some reduction of aboveground biomass with 2, 4-D amine, 2, 4-D ester, endothall, and flumioxazin treatments (Poovey et al. 2012; Poovey et al. 2013). Endothall at 1.5 ppm with 24 hour exposure and flumioxazin at 20 ppb with 5 weeks of exposure to the herbicide also showed reduction in belowground biomass (Poovey et al. 2013).

Effective in the field - Repeat field treatments of diquat at a target concentration of 0.37 ppm were effective at reducing above and belowground biomass of submerged FR (Madsen et al. 2012; Madsen et al. 2013; Fleming 2014). In cases that showed reduction of biomass, two treatments, one in early summer and one in late summer, were used. The Archibald Lake case study showed a decrease in both submerged and emergent leaves with repeated diquat treatments (Fleming 2014).

Madsen et al. (2012) examined changes in frequency of non-target species between diquat treated and reference plots. There was a reduction in percent frequency of common waterweed (*Elodea canadensis* L.), curly-leafed pondweed (*Potamogeton crispus* L.), leafy pondweed (*P. foliosus* Raf.), Richardson's pondweed (*P. richardsonii* (Benn.) Rydb.), longbeak buttercup (*Ranunculus longirostris* Godr.), sago pondweed (*Stuckenia pectinata* (L.) Börner), and common bladderwort (*Utricularia macrorhiza* Leconte) in treatment plots, but no significant reduction was observed for the other 23 co-existing species (Madsen et al. 2012).

Triclopyr with 2, 4-D amine showed submerged leaf control and reduced regrowth but not emergent leaves in a case study in Archibald Lake, Wisconsin. The FR was estimated to have 1 – 2 day exposure to the triclopyr with 2, 4-D amine that was applied with a target rate of 3.5 – 5ppm.

The effectiveness of an initial treatment of fluridone at 90ppb and triclopyr at 2500ppb followed by a reapplication 21 days later of fluridone at 60ppb is being tested in ongoing field experiments in Lake Pend d'Oreille (Skibo 2014). The results of this experiment had not been reported at the time of this report.

Ineffective trials - Laboratory experiments with herbicides triclopyr, fluridone, bispyribac, and imazamox showed no differences in biomass after treatment or had significant regrowth shortly after treatment (Poovey et al. 2013).

Field trials with repeated treatments of endothall (up to three times in one season) did not control submerged FR in above- or belowground biomass (Madsen et al. 2012; Madsen et al. 2013; Fleming 2014). Researchers hypothesized that the exposure time in the field was not long enough (Madsen et al. 2013).

2. Emergent FR

Effective in the laboratory - Preliminary results of laboratory experiments with application of fluridone at 90 ppb, diquat at 370 ppb mixed with fluridone at 90 ppb, and topramezone with MVO at 90.72, 152.02, and 392.32 ppm had greater than 50% reduction of total biomass at the end of the first season of treatment (Skibo 2014). The fluridone and diquat with fluridone treatments were added to the standing water of the emergent FR, while the topramezone mixture was applied to the foliage.

Effective in the field - In field trials, spring applications of imazamox or imazapyr when 5 – 7 in (12.7 – 17.8 cm) of leaves have emerged were initially effective to reduce aboveground biomass of FR, but control one year after treatment ranged from 23.3% – 35.0% (Rice et al. 2009a; Rice et al. 2009b). Repeated treatments were necessary (Rice et al. 2009b). A study by Madison et al. (2013) in Minnesota supported the finding that one treatment of imazapyr was not enough to reduce biomass of emergent FR, particularly belowground biomass.

Repeated treatments of diquat at a target rate 0.37 ppm with 2 – 3 hour exposure showed submerged and emergent leaf control in a case study in Archibald Lake, Wisconsin, but no measurement of regrowth or belowground biomass were made at the time of this report (Fleming 2014).

The effectiveness of glyphosate with 1% DynaAmic surfactant treatment seems to be related to the length of exposed leaf. Glyphosate at 5% active ingredient (ai) had 61% control one year after treatment when at least 2 ft (0.61 m) of leaf was exposed at field trials in Washington state (Parsons et al. 2014). It has less control one year after treatment with a concentration less than 3% ai (44%) or when only one foot was emerged (29%). When glyphosate (at 3 – 4% ai) was mixed with imazapyr (< 1% ai) percent control one year after treatment did increase for 1 ft emergent leaves over glyphosate alone (45 – 50%). Cases in Michigan are testing 2% ai glyphosate with a surfactant with one fall application, but results were not available at the time of this report (Ankney 2012).

Ineffective trials - Preliminary results of laboratory experiments showed no reduction of biomass with herbicides triclopyr, triclopyr with 2,4-D amine, endothall amine salt, diquat with ticlopyr and 2,4-D amine, and topramezone when they were applied to the water of the emergent FR (Skibo 2014).

3. Exposed soil

The water level of some water bodies is artificially controlled for energy or to control flooding. Often the water is lowered in early spring, which gives earlier sprouting species like FR an advantage to colonize. In these cases, herbicide treatment was applied to FR when the soil was exposed in the early spring.

Effective in the laboratory - Mesocosm experiments by Woolf et al. (2011) showed reduction of belowground biomass with fluridone and triclopyr 24 weeks after treatment under such conditions. Imazamox only showed reduction in above ground biomass.

Ineffective trials – In laboratory mesocosm experiments, acetic acid, aminopyralid, flumioxazin, imazapyr, and penoxsulam mixed with methylated seed oil did not affect above or belowground biomass (Rice et al. 2009a; Woolf et al. 2011).

Field trials of imazamox, imazapyr at two different concentrations showed initial effectiveness with aboveground biomass reduction, but had significant regrowth one year after treatment (Rice et al. 2009b). Woolf et al. (2011) had no reduction of biomass with imazamox, imazapyr, fluridone, and acetic acid (Woolf et al. 2011).

Triclopyr performed poorly in the field: 5.0% control 82 days after treatment; 5.9% 451 days after treatment, but researchers believed more testing at lower concentrations and different exposure times were needed (Rice et al. 2009a; Rice et al. 2009b; Woolf et al. 2011).

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.

Table 1. Summary of effective herbicide treatments on flowering rush (*Butomus umbellatus*) to date. For each herbicide, example brand names, target concentration or rate, any recommended adjuvants, treatment timing, advantages, disadvantages, and the cited literature was listed. The first column indicated the type of herbicide application or part of the plant that was treated. Directions on the pesticide label should always be followed and the state Department of Environmental Quality and Department of Natural Resources should be consulted for up to date regulations, restrictions, permitting, licensing, and application information. Table modeled after the MNFI Glossy Buckthorn Factsheet (2012)

	Herbicide	Target Dosage/ Rate	Adjuvant	Timing	Pros	Cons	References
Submersed	**Endothall** (e.g. Aquathol®)	1.5 ppm		24 hour exposure	• Reduces belowground biomass in the laboratory • Lists species name on label • Approved for aquatic use in Michigan (permit and licensing required)	• Not effective in the field • Tests on infertile (triploid) populations only • May harm non-target species (Broad-spectrum, contact herbicide) • Prohibited for use in water bodies < 600 ft from a potable water intake	(United Phosphorus, Inc. 2011; Madsen et al. 2012; Poovey et al. 2013; Madsen et al. 2013; Fleming 2014)
Submersed	**Flumioxazin** (e.g. Clipper®)	0.4 ppm		5 week exposure	• Reduces belowground biomass • Approved for aquatic use in Michigan (permit and licensing required)	• Has not been tested in field • Tests on infertile (triploid) populations only • May harm non-target species (Broad-spectrum, contact herbicide) • Toxic to aquatic invertebrates • Does not list species name on label	(Valent 2012; Poovey et al. 2013)
Submersed	**Triclopyr + 2, 4-D amine** (e.g. Renovate ® Max G)	3.5 – 5 ppm		June or July treatment, repeated yearly; 24 – 48 hour exposure	• Reduces submerged leaves • Reduces regrowth in year two • Less harm to non-target species (Selective, systemic herbicide) • Approved for aquatic use in Michigan (permit and licensing required)	• Affects on belowground biomass were not measured • Not effective on emergent vegetation • Needs yearly repeat treatments • Tests on infertile (triploid) populations only • Restricted concentration when near potable water intakes • Does not list species name on label	(SePRO 2013a; Fleming 2014)

	Herbicide	Target Dosage/ Rate	Adjuvant	Timing	Pros	Cons	References
Submersed & Emergent	**Diquat** (e.g. Tribune®)	0.37 ppm	All in one wetting agent, sticker, activator, and penetrant (e.g.Cide Kick II)	Yearly treatments, twice a year: early and late summer; 2 - 3 hours exposure	• Reduces aboveground biomass • Reduces both submerged and emergent leaves • Reduces only 3 non-target species of 31 non-target species in field testing (preliminary) • Diquat approved for aquatic use in Michigan (permit and licensing required)	• Has mixed results for reduction of belowground biomass • Incomplete experiment (regrowth measurements not yet recorded) • Tests on infertile (triploid) populations only • Do not apply in turbid water or conditions with a lot of wave action • May harm non-target species (Broad-spectrum, contact herbicide) • Toxic to aquatic invertebrates • Does not list species name on label • Cide Kick II not approved for aquatic use in Michigan	(Syngenta 2011; Madsen et al. 2012; Madsen et al. 2013; Fleming 2014; Skibo 2014)
Emergent	**Glyphosate** (e.g. AquaNeat)	5% ai	1% ai DyneAmic	Yearly treatments; late summer	• Controls up to 61% of growth one year after treatment in field trials • Biodegrades and binds to soil faster than many other pesticides • Approved for aquatic use in Michigan (permit and licensing required)	• At least 2 ft (0.61 m) of leaf must be exposed • May need yearly repeated treatments • Prohibited for use in water bodies < ½ mile from a potable water intake • May harm non-target species (Broad-spectrum, systemic herbicide) • Does not list species name on label • DyneAmic surfactant not listed on either the aquatic approved or not approved list for Michigan	(Ankney 2012; Nufarm Americas Inc. 2013; Parsons et al. 2014)

	Herbicide	Target Dosage/ Rate	Adjuvant	Timing	Pros	Cons	References
Emergent	**Imazamox** (e.g. Clearcast®)	0.5 gal $acre^{-1}$		Over 1 foot of leaf must be exposed	• Controls 23.3% cover one year after treatment in field trials • Approved for aquatic use in Michigan (permit and licensing required) • Lists species name on label	• May need several repeat treatments per year • Not effective on submersed FR • Tests on infertile (triploid) populations only • Restricted concentration when near potable water intakes • May harm non-target species (Broad-spectrum, systemic herbicide)	(Rice et al. 2009a; Rice et al. 2009b; Poovey et al. 2013; SePRO 2013b)
Emergent	**Imazapyr** (e.g. Habitat®)	31 gal $acre^{-1}$		One mid-summer treatment with at least 1 ft of above water foilage	• Controls 31.7% - 35.0% cover one year after treatment in field trials • Approved for aquatic use in Michigan (permit and licensing required) • Lists species name on label	• Needs several repeat treatments per year for lasting effectiveness (further testing needed) • Not effective on submersed FR • Tests on infertile (triploid) populations only • Prohibited for use in water bodies < ½ mile from a potable water intake • May harm non-target species (Broad-spectrum, systemic herbicide)	(SPECIMEN 2008; Rice et al. 2009a; Rice et al. 2009b; Poovey et al. 2013)
Emergent	**Fluridone** (e.g. Sonar® ONE)	90 ppb		Over 1 foot of leaf must be exposed	• Controls 50% of total biomass with water application • Approved for aquatic use in Michigan (permit and licensing required)	• Has not been tested in field • Tests on infertile (triploid) populations only • Restricted concentration when near potable water intakes • May harm non-target species (Broad-spectrum, systemic herbicide) • Does not list species name on label	(SePRO 2013c; Skibo 2014)
Emergent	**Topramezone** (e.g. Oasis®)	90.72, 152.02, and 392.32 ppm	MVO (e.g. Com-petitor®)	Over 1 foot of leaf must be exposed	• Controls 50% of total biomass with foliar application • Less harm to non-target species (Selective, systemic herbicide)	• Has not been tested in field • Does not reduce biomass with water application • Tests on infertile (triploid) populations only • Not listed on either the aquatic approved or not approved list for Michigan	(Skibo 2014)

	Herbicide	Target Dosage/ Rate	Adjuvant	Timing	Pros	Cons	References
Exposed sediment	**Fluridone** (e.g. Sonar® ONE)	32 or 64 oz $acre^{-1}$		Early spring; two weeks before water level rises	• Reduces belowground biomass 24 weeks after treatment • Approved for aquatic use in Michigan (permit and licensing required)	• Was not effective in field trials • Tests on infertile (triploid) populations only • Restricted concentration when near potable water intakes • May harm non-target species (Broad-spectrum, systemic herbicide) • Does not list species name on label	(Woolf et al. 2011; SePRO 2013c)
Exposed sediment	**Imazamox** (e.g. Clearcast®)	0.75 gal $acre^{-1}$		Early spring; two weeks before water level rises	• Reduces aboveground biomass initially • Approved for aquatic use in Michigan (permit and licensing required) • Lists species name on label	• Regrows 1 year or less after treatment • Needs several repeat treatments per year • Tests on infertile (triploid) populations only • Restricted concentration when near potable water intakes • May harm non-target species (Broad-spectrum, systemic herbicide)	(Rice et al. 2009a; Rice et al. 2009b; Woolf et al. 2011; SePRO 2013b)
Exposed sediment	**Imazapyr** (e.g. Habitat®)	0.5 gal $acre^{-1}$		Early spring; two weeks before water level rises	• Reduces aboveground biomass initially • Approved for aquatic use in Michigan (permit and licensing required) • Lists species name on label	• Regrows 1 year or less after treatment • Needs several repeat treatments per year • Ineffective on submersed FR • Tests on infertile (triploid) populations only • Prohibited for use in water bodies < ½ mile from a potable water intake • May harm non-target species (Broad-spectrum, systemic herbicide)	(SPECIMEN 2008; Rice et al. 2009a; Rice et al. 2009b; Woolf et al. 2011)

	Herbicide	Target Dosage/ Rate	Adjuvant	Timing	Pros	Cons	References
Exposed sediment	**Penoxsulam** (e.g. Galleon® SC)	5.6 oz $acre^{-1}$		Early spring; two weeks before water level rises	• Reduces belowground biomass 24 weeks after treatment • Less harm to non-target species (Selective, systemic herbicide)	• Has not been tested in field • Tests on infertile (triploid) populations only • Does not control when applied to emergent foliage at maximum concentration in another mesocosm experiment • Does not list species name on label • Not listed on either the aquatic approved or not approved list for Michigan	(Rice et al. 2009a; Woolf et al. 2011; SePRO 2013d)
Exposed sediment	**Triclopyr** (e.g. Renovate ®)	256 oz $acre^{-1}$		Early spring; two weeks before water level rises	• Reduces belowground biomass 24 weeks after treatment • Less harm to non-target species (Selective, systemic herbicide) • Approved for aquatic use in Michigan (permit and licensing required)	• Was not effective in field trials • Tests on infertile (triploid) populations only	(Woolf et al. 2011; SePRO 2013a)

b. Physical or Mechanical Control

It is difficult to mechanically remove FR without spreading it clonally (Duncan 2014). Raking and cutting FR below the water surface are not recommended. Small infestations of FR may be removed by hand-digging during low water levels, but it must be done carefully to prevent plant breakage. Hand-digging may need to be repeated if fragments are left to colonialize (Johnson et al. 2008; Jacobs et al. 2011; Woolf et al. 2011; Parsons et al. 2014).

Some case studies and anecdotal reports have shown effective treatment with using bottom barriers to reduce spread of aquatic species growth including FR (Rice et al. 2009c; Jacobs et al. 2011; Woolf et al. 2011). They are best used in areas of frequent recreational use and are not practical for a lake-wide solution. Traditional bottom barriers must be installed properly, regularly maintained, and occasionally replaced to work effectively and be safe for swimmers and boats. Barriers also inhibit native species and cause a disturbance in the natural shoreline. If removed without replacement, new infestations of aquatic invasive species are likely.

The Aberdeen-Springfield Canal Company recently reported the development of an effective treatment with a mechanical method of removal, but the project was in its infancy at the time of this report. Peter Rice of University of Montana will conduct scientific examination of the method beginning 2014 (Steve Howser, Aberdeen-Springfield Canal Company, *personal communication*).

c. Biological

There are several published studies related to the development of many parts and reproduction of FR (Wilder 1974; Fernando and Cass 1994; Fernando and Cass 1996a; Fernando and Cass 1997a; Fernando and Cass 1997b; Bhardwaj and Eckert 2001; Thompson and Eckert 2004; Li et al. 2012), and to the populations genetics and genetic diversity of North American and European populations (Fernando and Cass 1996b; Eckert et al. 2003; Kirschner et al. 2004; Kliber and Eckert 2005; Brown and Eckert 2005; Cuenca et al. 2013). The low genetic diversity of North American populations may make FR more susceptible to diseases and pests. The phylogeny of FR as the single member of the Butomaceae family and *Butomus* genus was considered an advantage to finding a viable biological control, because it was unlikely that a host specific pest on FR would adapt and damage a non-target species (Häfliger et al. 2014).

There has been no research published on biological controls of FR at this time. Hariet Hinz of CABI Switzerland gave a presentation in February 2014 on her team's progress in the search, collection, and evaluation of possible insect biological control agents (Häfliger et al. 2014). Six insect species were found that feed exclusively on FR: *Bagous nodulosus* Gyllenhal (weevil), *B. validus* Ros. (weevil), *Donacia tomentosa* Ahrens (leaf beetle), *Phytoliriomyza ornata* Meigen (agromyzid fly), *Hydrellia concolor* Stenhammar (ephydrid fly), and *Glyptotendipes viridis* Macquart (Chironomid fly). The two *Bagous* species, *H. concolor*, and *G. viridis* were targeted by the group for future study, but the

Bagous species were more promising based on the rhizome damage to FR. Examination of these species for captive breeding, non-target species damage, and impact on FR will determine their practically as a biological control.

Three fungus species were reported to develop on FR (Häfliger et al. 2014). At least one species *Physoderma butomi* J. Schröt. was reported as exclusive on FR and found in Michigan populations of FR since the 1950's (Sparrow 1956; Sparrow 1974). *P. butomi* infected FR on a cellular level, but scientists studying the fungus observed "*B. umbellatus* seems little affected," (Sparrow 1956; Sparrow 1974). Genetic engineering of a pest such as this may produce a more effective, host-specific biological agent.

III. Indirect Management

Promotion and maintenance of natural shorelines and native vegetation may reduce FR establishment. In greenhouse experiments, FR required more than eight hours of direct light for a successful percentage of seed germination (Hroudová and Zákravský 2003), which established vegetation reduces. There are many other benefits to a natural shoreline with native vegetation including essential habitat for animal species, flood control, shore stabilization, and nutrient filtration.

Research Needs

In order to better understand FR ecology, monitoring, and management in Michigan, the following research areas could be addressed: population genetics, ecological and economic impacts of fertile (diploid) compared to infertile (triploid) populations, ecological and economic impacts of submersed compared to emergent FR, seed viability, chemical control testing on fertile individuals, effects of microbial biofilm on herbicide effectiveness, and long-term integrated management studies.

I. Genetics

The fertile infestations in southeastern Michigan were established over 100 years ago, but no population genetic research has investigated FR in the northern and western Lower Peninsula (Eckert et al. 2003; Kliber and Eckert 2005; Lui et al. 2005). Genetic testing will contribute to documenting and better understanding of origin, dispersal, and ploidy-level of Michigan populations. Without genetic testing it is unknown if the more isolated populations of FR in western Michigan were established by human or animal dispersal from existing populations, separate horticultural plantings, or some other means.

II. Biology and Ecology

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.

Almost all research of ecological impacts of FR to date has been on infertile populations (e.g. Jacobs et al. 2011; Madsen et al. 2012; Rice et al. 2014). The reason fertile populations are understudied is unknown. It is possible that those states with infertile populations have more developed management plans, there are other AIS are of higher concern in areas with fertile population, or that the infertile populations are more aggressive than fertile populations. Studies in Europe have shown habitat and reproductive differences between fertile and infertile populations, but the reproductive differences between fertile and infertile populations in North America were different from European results (Hroudová and Zákravský 1993b; Hroudová and Zákravský 1993a; Krahulcova and Jarolimova 1993; Eckert et al. 2003; Kirschner et al. 2004; Brown and Eckert 2005; Lui et al. 2005). Research of negative impacts of fertile populations as well as a comparison of the fertile, infertile, submerged, and emergent FR may reveal different level of control or priority for FR management among the populations.

The Great Lakes have different fish and macroinvertebrate communities than those where ecological effects studies of FR are being conducted. Studies in the Great Lakes region would evaluate the specific effects of FR on Great Lakes communities

Asexual reproduction is the primary dispersal method for FR populations, but fertile populations do produce viable seeds (Krahulcova and Jarolimova 1993; Eckert et al. 2000; Hroudová and Zákravský 2003; Brown and Eckert 2005; Lui et al. 2005). It is possible that the control of the current population may produce the conditions needed for FR seeds to sprout (Hroudová and Zákravský 1993b; Hroudová and Zákravský 2003). Long-term integrated management plans will benefit from the knowledge of seed longevity for regrowth and likelihood of germination post-treatment.

III. Monitoring

In addition, the genetics of fertile, infertile, submerged, and emergent FR populations has not yet been documented, described, and analyzed in Michigan. The type of population may influence management techniques, so designation is important for developing an effective plan. Once populations are identified, the construction of site maps or site spatial analyses could improve understanding of within lake dispersal and be used to develop more efficient monitoring plans.

IV. Management

Long-term management studies will help develop effective long-term integrated management plans. Current research is being conducted in other states on the ecological effects and management options for FR (e.g. Concordia College in Minnesota (Michelle Marko), Mississippi State University (John D. Madsen), and University of Montanta (Peter Rice), but so far chemical and mechanical controls have not been very successful at reducing belowground biomass and preventing reestablishment after treatment (Duncan 2014). Current researchers and managers of FR see biological controls as the most promising method of control in conjunction with other treatments, and would benefit from further investigation (Duncan 2014).

Many different chemicals have been tested for immediate effectiveness on FR. Few studies have examined long-term effects on non-target species, adding adjuvants, effectiveness of repeat treatments, effects of herbicide temperature, and testing on fertile populations at the time of this report.

The foliage of flowering rush provides habitat for microbial biofilm, which some believe to impact the effectiveness of herbicide treatment. Biofilms are communities of bacteria, algae, fungi, and protozoan that accumulate on surfaces in aquatic environments. There is research on the role biofilm communities play in remediation and toxic clean-ups (Singh et al. 2006) and the effects of certain herbicides on biofilms (e.g. Kosinski 1984; Wolfaardt et al. 1995; Lawrence et al. 2001; Gustavson et al. 2003; Schmitt-Jansen and Altenburger 2005), but little directly addressing the relationship between biofilm and herbicide effectiveness, and the effects of killing the biofilm prior to herbicide application. There could also be ecological impacts of killing biofilm prior to herbicide application for non-target species or duration of the herbicide in the system (e.g. Kosinski 1984; Wolfaardt et al. 1995; Lawrence et al. 2001). Examination of the impacts of the biofilm and possible treatment regiments can improve herbicide absorption and be used to develop more effective treatments.

As of this report, chemical treatment studies have been performed on only infertile FR (e.g. Poovey et al. 2012; Poovey et al. 2013; Madsen et al. 2013). It is unknown if fertile FR will respond to chemical treatment in the same manner as infertile FR.

Bottom barriers have shown some local control of FR, but a hemp or burlap biodegradable barrier has not yet been tested for effectiveness. The new biodegradable bottom barrier constructed of hemp or burlap requires less maintenance and has fewer installation problems than the traditional barrier. It has shown success with some rooted aquatic invasive species (Hofstra and Clayton 2012). The results were mixed for some species, so testing of this barrier must be completed on a species by species basis and has not yet been performed for FR (Hofstra and Clayton 2012).

Future Directions for Michigan and FR Management

Flowering rush has been reported in Michigan since the beginning of the 20th century in Wayne County near Detroit (Core 1941; Stuckey 1968; Anderson et al. 1974). With new, separate colonies being reported in the Lower Peninsula and inland counties (Newaygo County; Reznicek et al. 2011), it is important that vectors are identified, prevention and monitoring programs initiated or continued, current regulations enforced, and research needs addressed.

Prevention - Given the current distribution and difficultness in eradicating FR after establishment, prevention of new colony establishment is the most cost effective approach to FR management. Plantings and horticulture escapees is a common pathway for newly established populations (Core 1941; Anderson et al. 1974; Eckert et al. 2003; Maki and Galatowitsch 2004; Kliber and Eckert 2005). Increased enforcement of current restrictions placed on the distribution and sale of FR could prevent new populations from establishing (Maki and Galatowitsch 2004). A collaboration among states with prohibited or restricted status on FR and other aquatic invasive species may be beneficial to educate the horticultural industry and monitor activity. Expanding existing coalitions to include organizations that may soon face FR as an invasive species may also prevent spread. A boat inspection program initiated at public access points following other states may impede the spread of FR.

Monitoring – Early detection would make eradication a more realistic option. Adding FR to existing monitoring programs will assist in early detection and increase the potential of eradication of FR in valued areas. A cohesive monitoring and reporting system involving local municipalities, non-profit organizations, lake associations, recreation clubs and organizations, and waterfront property owners, would increase knowledge of FR locations and enable early detection responses to new colonies. Connecting waterfront property owners with resources such as MISIN may improve early detection efforts.

The implementation of a strategic-random, stratified-random, or targeted monitoring strategy could establish a more accurate statewide distribution of FR. A targeted strategy would involve the most preparation, but may be the most efficient in the field. To develop a targeted monitoring strategy, the current known distribution 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 FR, 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 FR, water bodies could be prioritized based on the distance (Euclidean and upstream/downstream distance) from infested water bodies, density of FR in nearby infested water bodies, environmental habitat specifications, level of recreational activity, number of public access points, and property owner types. Each potential pathway is ranked and weighted for spatial analysis. Those water bodies that score in the highest tier are prioritized for monitoring.

In addition, the confirmation of historic populations of FR in Emmet and Cheboygan counties will inform distribution and monitoring efforts in Michigan.

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 – When managing FR, it is important to contain already established populations and protect high-value sites. When determining the best integrated pest management plan, it may be beneficial to consider factors such as whether or not the population is fertile (diploid), infertile (triploid), submersed, or emergent. Research is still needed in this area regarding population genetics, as well as chemical and mechanical control treatments. Population genetics, chemical control, and mechanical control research could also inform management plans.

Activities to prevent dispersal from established populations could reduce new infestations. New and relatively isolated infestations may be contained and possibly eradicated the infestation while small. Populations in southeastern Michigan have been established for approximately 100 years, and controlling the spread from those areas could reduce spread to uninfested water bodies should be the focus.

Measuring effective control – Following the treatment of FR, the effectiveness of the treatment can be quantitatively assessed through documenting any year-to-year regrowth, reduction of FR percent cover, reduction in belowground biomass, as well as any reduction in seed production.

The goal of aquatic invasive species management strategies is to preserve or restore ecologically stable aquatic communities. Minimal chemical, biological, and physical controls should be required to maintain these communities. Any management plan should involve integration of prevention and control methods that consider factors affecting the long-term ecological stability of an aquatic community.

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Table 2. Objectives, Strategic Actions, Leads, and Expected Outcomes of FR Management

Guidance and Outreach for Flowering Rush 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	• Increase public awareness of FR • Reduce the number of new introductions • Increase the frequency and use of boat washing programs
Prevent other new introductions of FR	• Educate local and regional horticulture, aquaculture, and gardening groups about AIS	• MDARD • Great Lakes Commission	• Reduce sale of FR in horticulture industry in Michigan • Elimination of purposeful and accidental sale of FR
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
Provide technical guidance to those interested in FR management	• Creation of a FR technical guide and FR prioritization tool.		• Increase management efforts
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 Water Corps	• Develop a more thorough and up-to-date statewide distribution • Predict dispersal trends • Delimit the extent of current infestations
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 Water Corps • Lake associations • Management agencies	• Increase public awareness of AIS • Identify water bodies that need professional confirmation of AIS • Delimit the extent of current infestations

Research Needs for Management			
<u>Chemical:</u> Develop chemical treatments that will increase management success and minimize the ecological and economical effects	• Continue research into effective herbicide treatments focusing on decrease of belowground biomass • Investigate more targeted chemical methods such as systemic herbicides • Investigate impacts of microbial biofilm on herbicide effectiveness • Genetic testing on FR populations in western and northern Lower Peninsula to determine ploidy, origin, and dispersal in case of differing susceptibilities to herbicides • Begin trials on fertile (diploid) FR populations		• Analyze pathways for dispersal • Understand dispersal methods to improve target monitoring • More effective treatment options for already established populations • Decrease management effects on non-target species •
<u>Biological:</u> Establish biological control methods that will increase control and minimize effects of FR	• Evaluate the validity of using *Bagous* spp. as a biological control including effectiveness, captive breeding, and non-target effects • Investigate diseases or fungus for applicability as management options		• More effective treatment options for already established populations • Decrease management effects on non-target species
<u>Mechanical:</u> Determine the most effective and economical mechanical methods to mediate the effects of FR	• Determine threshold for colony size for effective mechanical removal including reestablishment probability • Scientifically evaluate a new mechanical removal method (Steve Howser, Aberdeen-Springfield Canal Company, *personal communication*)		• Reduced unnecessary dispersal of FR for colonies too large for effective mechanical removal • Determine long-term effects and effectiveness of new mechanical removal method
<u>Indirect Management:</u> Increase understanding of the impact of natural shoreline management and aquatic invasive species establishment	• Investigate relationships between natural shoreline maintenance, disturbance, and FR and other aquatic invasive species establishment		• Provide better understanding of preventative measures of FR establishment • More economical use of public and private funds • Support a viable and sustainable supplement to other management efforts

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