State of Michigan's

Status and Strategy for Carolina Fanwort (*Cabomba caroliniana* A. Gray) Management

Scope

Invasive Carolina fanwort (*Cabomba caroliniana* A. Gray, hereafter CFW) is considered a noxious weed in the Australia, China, Netherlands, and the United States, but has only recently been recognized as a management concern in Michigan. 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 CFW.
- Summarizing current management options for CFW in Michigan.
- Identifying possible future directions of CFW 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. Carolina fanwort (*Cabomba caroliniana*) in bloom. Photograph by Sheldon Naive

Carolina fanwort is a perennial aquatic plant with two types of leaves and singular white emergent flowers (Figure 1; Ørgaard 1991). It gets its name from its submerged, fan-like leaves. These leaves have an opposite, sometimes whorled arrangement, 0.75 – 2 in (2 – 5 cm) wide, and finely subdivided with the first division from a single point (Figure 2; eFloras 2014; Godfrey and Wooten 1981). The floating leaves, if present, are linear with a notched base and alternate arrangement, 0.2 – 1.2 in (0.4 – 3 cm) long, 0.04 – 0.2 in (1 – 4 mm) wide, and entire (eFloras 2014). It blooms from May to September. Flowers bloom above water, have six white to purplish sepals and petals, and are 0.25 – 0.6 in (6 – 15 mm) across. Fruits contain three seeds and are less than 0.25 in (7mm) long.

Species that are often mistaken for CFW include: watermilfoil (*Myriophyllum* spp.), coontail (*Ceratophyllum demersum* L.), water-marigold (*Bidens beckii* Torr. Ex Spreng.), and white water crowfoot (*Ranunculus* spp. with white flowers including *R. longirostris* Godr. and *R.*

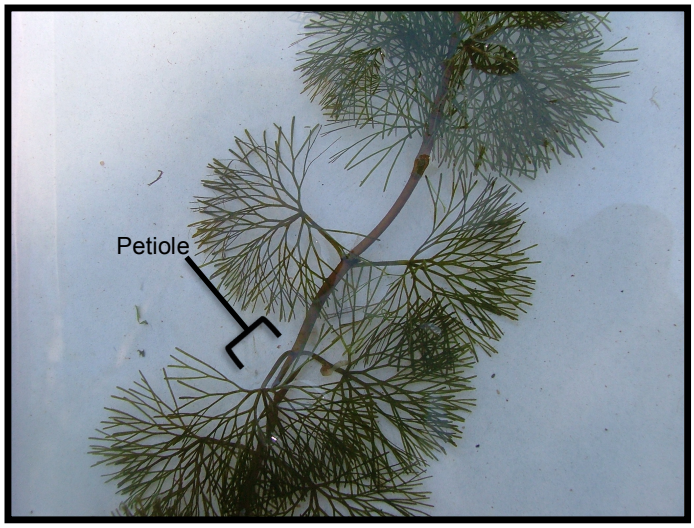

Figure 2. The leaves of Carolina fanwort (*Cabomba caroliniana*) are opposite and have a fan-like shape from a several centimeter long petiole. Photograph by Sheldon Naive

trichophyllus Chaix). Without flowers, submerged CFW may resemble watermilfoil, coontail, or water-marigolds since they all have finely divided submerged leaves. The leaves of watermilfoil branch from a central stem, unlike the fan-like division of CFW (Figure 2). Coontail's submerged leaves are arranged in whorls of five or more and have teeth on their leaves. Coontail is also stiff and brittle and holds its shape out of water, unlike CFW. The submerged leaves of water-marigold are opposite like CFW, but they branch at the stem, lacking the petiole of CFW, and the emerged leaves of water-marigold have an opposite arrangement, while the floating leaves of CFW have an alternate arrangement.

The flowers of white water crowfoot resemble that of CFW and both have finely divided leaves. White water crowfoot has 5 petals, unlike the 6 sepals and petals of CFW, and the finely divided leaves of white water crowfoot have an alternate arrangement.

II. Detection

The finely dissected leaves are distinguishable from similar species, but identification might be difficult for untrained eyes. When in flower, the white, 6-part flower, with finely dissected leaves is more easily distinguishable. Carolina fanwort has a long general blooming period from May to September. Flowering specimens in Michigan have been collected for herbaria from late-June to the end of September (University of Michigan Herbarium - MICH, Western Michigan University Herbarium - WMU). Visitation of ponds in New Jersey established prime flowering time as July to September with seeds appearing soon after flowering begins (Reimer 1968).

Remote sensing technology at this time is unable to distinguish submerged aquatic vegetation at water depths greater than 15.7 in (40 cm) even when processed with object-based image analysis (Visser et al. 2013). Water absorbs the wavelengths commonly used to remotely sense vegetation (i.e. visible and near infrared). Aerial photographs have been used with plant or local experts to distinguish submerged aquatic vegetation, but these studies did not use multiple interpreters with different backgrounds (e.g. botany, remote sensing, none) with identical training, thus, did not have repeatable procedures (e.g. Husson et al. 2013).

III. Life History and Spread/Dispersal

Carolina fanwort is perennial; it overwinters as surviving stems and produces single, white, emergent flowers from May to September (eFloras 2014). In late fall the lower portions of stems defoliate, become brittle, and break apart, facilitating spread (Reimer 1968).

Carolina fanwort can reproduce both sexually and asexually, but there is evidence that it reproduces almost exclusively asexually throughout its invasive range (Ørgaard 1991; Xiaofeng et al. 2005). Southern populations of CFW produce viable seeds, but seeds produced in northern invasive populations rarely, if ever, germinate (Reimer 1968; Gangstad 1992). Asexual reproduction is facilitated through rhizome-like stem growth and stems that readily fragment (Ørgaard 1991; Reimer 1968). Each fragment needs only a single pair of functional leaves to regenerate a new plant. Fragments can spread through normal water flow in connected water bodies, but it is likely that recreational activity in North America has facilitated spread between unconnected water bodies (McCracken et al. 2013).

CFW is a popular aquarium plant and was marketed throughout the 20th century (Les and Mehrhoff 1999). It has been hypothesized that improperly disposed aquarium waste is a vector of introduction. Instances of aquarium waste introduction are difficult to verify without first-hand accounts or molecular data from past commercial sources (McCracken et al. 2013).

Three phenotypes of Carolina Fanwort are documented, distinguishable only by foliage color. Several sources support the existence of a purple foliaged and green foliaged phenotype (Wain et al. 1983; Mackey and Swarbrick 1997; Godfrey and Wooten 1981) and are thought to be the result of differential light and temperature conditions. Purple CFW was thought to grow under warmer water and higher light conditions while green CFW was thought to grow under cooler water and lower light conditions. A recent study supported the separation of these two groups and posited the existence of a third intermediate phenotype based on wide ranging differential herbicide response. Bultemeier et al (2009) found that all three phenotypes (green, purple/red, and intermediate) exhibited differential response to a wide range of aquatic herbicides, and posited that such results may point to a lack of understanding of the genetics of native and invasive CFW populations worldwide. In all cases the red/purple phenotype was most susceptible to herbicide treatment while the green phenotype was least susceptible.

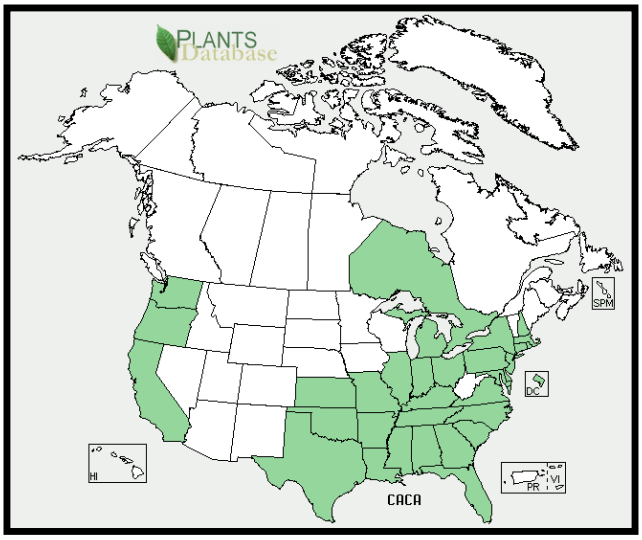

Figure 3. Distribution of Carolina fanwort (*Cabomba caroliniana*) in North America. It is considered adventive or noxious in most states north of the Ohio River and on the west coast of North America. Map provided by USDA PLANTS Database (2014)

IV. Habitat

Carolina fanwort is considered native to the southeastern United States and parts of South America (Figure 3; Ørgaard 1991) but has colonized a diverse collection of habitats far outside of this range including Australia, China, Malaysia, and Canada. It has been rapidly expanding its range in the Netherlands (Matthews et al. 2013), and it is so problematic in Australia that it was ranked as one of the twenty species on the inaugural weeds of national significance list (Thorp and Lynch 2000). These two countries have produced a large percentage of the recent CFW research.

Carolina fanwort is a freshwater macrophyte primarily found in lakes, ponds, and slow moving streams with soft sediment. In its native range CFW often occupies water depths from 6 – 12 ft (2 – 4 m) and does not impede the growth of other native plants. In its invasive range it can effectively colonize the 3 – 18 ft (1 – 6 m) zone and excludes many native species. This difference is thought to be a result of predatory species present in its native range but absent in its invasive range (Schooler et al. 2006).

Water pH is the most powerful predictor of CFW colonization potential (Jacobs and Macisaac 2009). CFW grows best in soft water systems with low alkalinity and acidic pH (4-6; Gangstad 1992; James 2011; Riemer 1965) but can also colonize pH levels as high as 8.8 if other environmental conditions are favorable (Matthews et al. 2013).

V. Effects from CFW

a. Ecological effects

In habitats with suitable growing conditions, CFW has the ability to produce dense mats that outcompete and exclude native vegetation (Lyon 2006). Along with excluding native flora, these mats reduce the amount of sunlight reaching the sediment, increase epiphytic algal biomass, and alter the macro-invertebrate assemblage (Hogsden 2007). Carolina fanwort is not an important food plant for waterfowl, but has been consumed occasionally (McAtee 1939).

b. Economic effects

No studies were found directly relating CFW colonization to fish populations or assemblage, but dense mats of CFW discourage swimming and boating and have reduced angler success in heavily infested areas. This has prompted the movement of these recreational pursuits to more desirable locations (Gangstad 1992).

When growing in drinking water reservoirs, CFW gives an unpleasant flavor and discoloration to the water, increasing the cost of treatment up to $50 per cubic meter (Australian Department of the Environment and Heritage 2003). Removal of CFW has been found to improve water quality by reducing dissolved nitrogen, dissolved phosphorus, and turbidity (Anderson et al 1996).

Current Status and Distribution in Michigan

Considered native to the Southeastern United States and parts of South America, CFW has established invasive populations in regions of the United States, Canada, Australia, Europe, and China. In the United States, CFW has established invasive populations in the Northeast, Midwest, and parts of the Pacific Northwest.

The first population in Ontario, Canada, was discovered in Kasshabog Lake in 1991 (MacDonald 2002). The genetics of select North American populations indicate that the population in Ontario is likely the result of invasion from the northern United States as opposed to novel introduction. It is thought that there have been at least 3 separate introductions in the northeastern United States (McCracken et al. 2013).

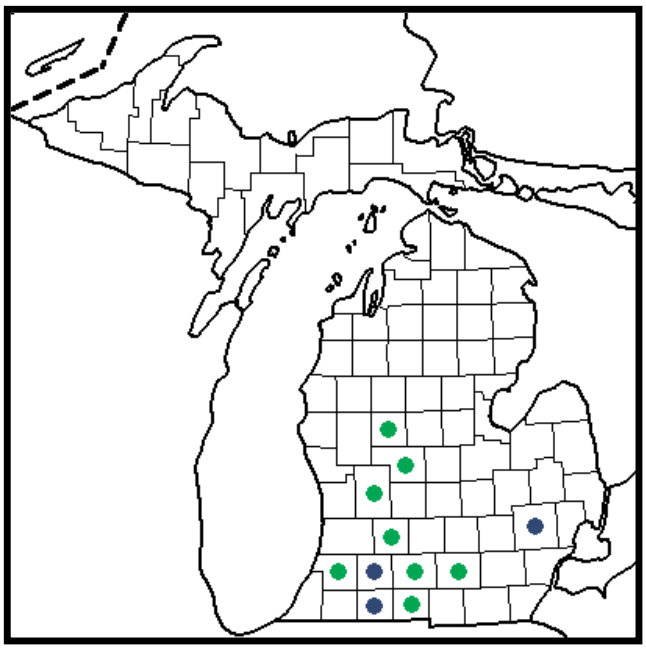

Figure 4. Blue dots indicate counties in Michigan where a specimen of CFW has been collected and included in Michigan Flora. Green dots indicate counties where CFW was documented by Midwest Invasive Species Information Network, but not by Michigan Flora. County map developed by Michigan Flora online (Reznicek et al. 2011)

W.J. Beal planted CFW in the Michigan State University botanic garden pond circa 1890 (Beal 1900). It is not known whether invasive populations in Michigan are a result of that introduction or later ones. Carolina fanwort was first collected from the wild in Michigan in June 1935 from Kimble Lake and Portage Creek in Kalamazoo County (Reznicek et. al. 2011; WMU), and has been collected in two additional counties since: Oakland and St. Joseph (Figure 4). The Midwest Invasive Species Information Network (MISIN 2014) reported populations of CFW in eight additional counties in western Lower Peninsula.

The only populations of CFW reported in southeastern Michigan are in Oakland County. It has been found in lake Wau-Me-Gah and Lake Sherwood (MISIN 2014).

On the western side of the Lower Peninsula there is a large concentration of reported sightings in lakes within Kalamazoo County and the counties surrounding it. A smaller group of sightings have been reported in the Kent County area. CFW has been found in Reeds and Fisk Lakes near Grand Rapids and Brower Lake near Rockford.

The northernmost reported sightings are in Indian Lake near Howard City and Mecosta Lake in Mecosta County. The isolation of these populations from larger groupings may indicate that CFW is spreading northward in the state from the first collected populations in Kalamazoo and St. Joseph Counties.

Management of CFW

I. Prevention

Carolina fanwort becomes very difficult and expensive to control once it is established upstream; the single year management cost at a particularly infested site in the Netherlands was over €350,000 (US$480,000; Matthews et al. 2013). Protecting uninfected waters is more practical than managing it post colonization.

Carolina fanwort is a "Prohibited species" in Michigan under Natural Resources and Environmental Protection act 451 of 1994. Under this act it may neither be sold nor grown in the state. Building a coalition of local and regional partners with this same designation for CFW may help improve enforcement of this act. Studies at the Great Lakes Commission and University of Notre Dame are underway to examine trade of aquatic invasive species. The following actions may prevent and limit the dispersal of CFW:

- Build a coalition of local, statewide, and Great Lakes regional partners to monitor for CFW and other aquatic invasive species
- Build a coalition of states that have classified CFW as a restricted or prohibited species
- Expand existing coalitions to include organizations that may soon encounter CFW as an aquatic invasive species
- Improve monitoring and enforcement of distribution and sale of CFW among states that restrict or prevent its distribution (Maki and Galatowitsche 2004)
- Educate aquarium owners and industry on the hazards associated with dumpling aquatic tanks into natural bodies of water and the spread of invasive species
- Provide boat washing stations for high-traffic public lake accesses
- Develop and sustain a sustainable water recreation vehicles and trailers inspection program
- Identify water bodies with high-risk of infestation using known distribution and dispersal knowledge

II. Management/Control

Removal of CFW is difficult once a population is established. 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.

The fragmentary nature of stems makes physical removal of the species challenging without facilitating further spread. Environmental controls (e.g. downdraw of water) may avoid the issue of fragmentation, but can do equal or greater damage to native macrophytes as well as CFW. Chemical treatments of CFW have resulted in both differential response to herbicides and unusual herbicide resistance, making chemical treatment an uncertain solution to infestation (Buletmeier 2009).

In Australia CFW is included on the “weeds of national significance” list, which includes species of special importance for management. The weed of national significance program has provided a country-scale model for addressing invasive species. Methods have been published on both the determination of species and the actions taken to address each (Thorp 1999). The following is a summary of control methods to date and their results.

a. Chemical

No studies were found regarding the effectiveness of herbicide treatments in the field. Herbicide treatments of CFW in the laboratory had mixed results regarding the susceptibility to standard treatments. Some studies have found CFW susceptible to standard herbicide treatments; others have found it to be highly resilient. One study found that three different CFW color phenotypes responded significantly differently to various herbicide treatments (Bultemeier et al. 2009). This could explain the conflicting study results and complicate management plans that include chemical treatment.

Herbicides recommended for use against CFW include triclopyr, penoxsulam, fluridone, diquat, flumioxazin, and endothall (Table 1; DiTomaso et al 2013). Dyes can also be used as a non-herbicidal treatment limiting photosynthesis.

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.

Effective in the laboratory – Flumioxazin and endothall (amine salt) were found effective against CFW in a laboratory setting. Three CFW phenotypes were exposed to a 24-hour treatment period and 144 hour post-treatment waiting period. After this time photosynthesis of all three phenotypes was reduced to below 50% of untreated controls. Flumioxazin was most effective, reducing photosynthesis of all three phenotypes to zero (Bultemeier et al. 2009).

Fluridone at 20 ppb reduced CFW biomass by 80% in a growth chamber study, but that concentration of fluridone also severely limited water marigold (*Megalodonta beckii*), which was used as a representative of native macrophytes (Nelson et al. 2002). It is unusual to be issued a permit in Michigan to apply fluridone at concentrations more than 6 ppb.

James (2011) found lime addition to be an effective means of CFW treatment in a laboratory setting. In soft water experimental tanks lime additions of 55 and 160 μM

resulted in an increase in pH (9, 10) and a 36% and 8% reduction of shoot biomass, respectively. No analysis was performed on how this increase in pH would affect native macrophytes. Lime addition would be most effective in areas where maintenance of current native flora is not a primary concern and a large increase in pH is feasible.

Effective in the field – Flumioxazin was field-tested at 200 ppb on an eleven-acre canal infested with CFW in July 2008 by Cygnet Enterprises. It provided 100% control (Valent 2009). These results were encouraging, but more thorough field-testing and examination of regrowth should be performed to confirm efficacy.

Table 1. Summary of effective herbicide treatments on Carolina fanwort (*Cabomba caroliniana*) 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. 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 MNFI (2012). Much of the information below is summarized from Ditomaso et al 2013

Herbicide	Target Dosage/ Rate	Adjuvant	Timing	Pros	Cons	References
Diquat (e.g. Reward®)	0.1 to 0.25 ppm		Late spring to early summer	• Approved for aquatic use in Michigan (permit and licensing required)	• Ineffective in turbid water or conditions with a lot of wave action • May harm non-target species (Broad-spectrum, contact herbicide) • Toxic to aquatic invertebrates	(Syngenta 2007; Bultemeier et al 2009)
Endothall (e.g. Aquathol®)	1-2 ppm		Spring to early summer. 48 hour exposure	• Shows symptoms within 3-7 days • Approved for aquatic use in Michigan (permit and licensing required)	• May harm non-target species (Broad-spectrum, contact herbicide) • Prohibited for use in water bodies <600 ft. from a potable water intake	(Bultemeier et al 2009; United Phosphorus, Inc. 2011)
Flumioxazin (e.g. Clipper®)	0.4 ppm		Spring to early summer. 24 hour exposure	• Reduces photosynthesis to zero 144 hours after treatment in laboratory study • Approved for aquatic use in Michigan (permit and licensing required)	• May harm non-target species (Broad-spectrum, contact herbicide) • Toxic to aquatic invertebrates	(Bultemeier et al 2009; Valent 2012)
Fluridone (e.g. Sonar®)	6-15 ppb		Early spring. 5-7 weeks	• Reduces biomass by >80% after 84 days at 0.02ppm • Approved for aquatic use in Michigan (permit and licensing required)	• May harm non-target species (Broad-spectrum, systemic herbicide) • Restricted concentrations near potable water intakes	(Nelson et al 2002; SePRO 2013a)
Penoxsulam (e.g. Galleon®)	0.1-0.2 ppm for 4-6 weeks		Spring to early summer	• Less harm to non-target species (Selective, systemic herbicide)	• Not on either the aquatic approved or not approved list for Michigan	(DiTomaso et al 2013; SePRO 2013b)
Triclopyr (e.g. Renovate®)	0.5 to 2 ppm		Spring to early summer	• Does not affect many monocot species • Less harm to non-target species (Selective, systemic herbicide) • Approved for aquatic use in Michigan (permit and licensing required)	• Restricted concentrations near potable water intakes	(DiTomaso et al 2013; SePRO 2013c)

b. Physical or Mechanical Control

Physical removal by divers or suction can be effective, but it is time consuming and expensive (Wilson et al. 2007). Mechanical control is not encouraged in areas where further spread is a concern. Escaping stem fragments can rapidly spread and repopulate.

In the Netherlands the Hydro-venturi system is a new experimental control. The system uses water pressure to dislodge whole plants from the sediment and then collect them when they float to the surface (Matthews et al. 2013). This avoids most fragmentation and is less intrusive than conventional dredging. The Hydro-venturi system did not work well near shores and displaced sediment into the water, reducing clarity and increasing turbidity. Its use is most appropriate in artificial channels or canals with large infestations (Matthews et al. 2013).

Lake or reservoir drawdown can reduce or eliminate CFW population dependent on weather conditions (Dugdale et al. 2013). Effectiveness of drawdown is also dependent on the harshness of weather conditions during the time the sediment is exposed. Carolina fanwort can survive and repopulate if established in dense enough mats. Drawdown is not practical for many aquatic habitats, and CFW may be less affected than desirable species.

Shading with tarps can effectively eliminate CFW in small confined areas such as ponds or dams (Schooler 2008). This is an inexpensive option that doesn't result in fragments that could recolonize or move to other water bodies. It is not a species-specific solution and will also impede other species in the shaded area.

c. Biological

There are two insect species that have been identified as possible biological control agents of CFW: *Hydrotimetes natans* Kolbe, an aquatic weevil, and *Paracles spp.,* a pyralid moth (Schooler et al. 2006; Schooler and Julien 2008; Cabrera-Walsh et al. 2011). Both species prey on CFW in its native South American range. Host specificity, effectiveness, and captive rearing of the species have yet to be fully investigated for any species.

The aquatic weevil completes its entire life cycle on CFW. Larva feed primarily on the basal stems and adults on upper leaves and stems. It has not colonized any other aquatic macrophytes during tests and appears to be host specific (Cabrera-Walsh et al. 2011). Predation from the weevil is thought to weaken CFW stems, reducing competitiveness in the deeper part of its growth range.

The moth species has not been investigated for host specificity, but caterpillars feed on CFW foliage and are thought to directly limit productivity at all depth zones through damaging photosynthetic parts of the plant (Schooler et al. 2006).

While both species are thought to limit CFW growth in its native range, their effectiveness as control agents for CFW remains uncertain. Neither species is known to survive in temperate climates, nor have they been field-tested. Introducing any species to a new area requires caution, and more investigation is necessary to determine whether the weevil or moth could effectively reduce CFW competitiveness without becoming problematic invasive species themselves.

III. Indirect Management

No indirect management techniques have been investigated for the control of CFW at the time of this report. Maintenance of a healthy native ecosystem of flora is the best method for preventing the colonization of invasive species, but it is no guarantee of exclusion.

Research Needs

In order to better understand CFW ecology, monitoring, and management in Michigan, the following research areas could be addressed: genetic analysis for the presence of different ecotypes and genotypes, population genetics, seed viability studies, determination of ecological and economic impacts, field testing of laboratory effective herbicides, long-term chemical and integrated management studies, effectiveness of biodegradable bottom barriers (e.g. hemp mats), and continued biological control studies.

I. Genetics

Understanding the genetics of invasive fanwort populations will inform future monitoring and management strategies. A useful distribution or control plan cannot be created without knowledge of different ecotypes and genotypes, especially considering the differing susceptibilities of CFW ecotypes to herbicide treatment (Bultemier et al. 2009). The CFW ecotype research was conducted over 30 years ago and used gel electrophoresis to determine allele frequencies at 12 loci (Wain et al. 1983). Given the advancements of genetics in the last 30 years, further research on the different ecotypes of CFW may reveal different conclusions.

Analysis of the population genetics of Michigan populations may be able to pinpoint pathways of dispersal (e.g. aquarium waste, fragments from unconnected water bodies). This testing will contribute to better understanding of origin, dispersal, and ecotype of Michigan populations. Without population genetic analysis, it is unknown if the more isolated populations of CFW were established by human or animal dispersal from existing populations or improper disposal from the aquaria trade. This knowledge would allow for the development of more efficient tactics to prevent the dispersal of the species.

II. Biology and Ecology

While northern invasive CFW populations are not known to produce viable seeds, a seed germination study could be done to confirm this in Michigan populations. Without viable seed production, eradication appears to be possible in small water bodies if informed

management choices are made. Viable seeds with a high longevity would require the development of longer-term management plans.

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.

Additional research to assess the ecological and socioeconomic impacts of different CFW ecotypes, genotypes, as well as asexually and sexually reproducing populations will inform future monitoring and management efforts. Understanding the effects of CFW both ecologically and socioeconomically could be vital in developing strategies to impede the spread of CFW. Two leaf shapes, narrow- and spatula-shaped, have been observed to have different degrees of ecological impact, but it has yet to be investigated.

III. Management

Due to the fragmentary nature of stems and conflicting literature regarding chemical treatment, there is currently no standard management regime for CFW. Continued research into the viability and longevity of chemical, biological, and integrated management techniques may develop successful long-term integrated management plans.

Reexamination of chemical treatments for the differing susceptibilities of the CFW ecotypes may provide a better understanding of the causes (Bultemier et al. 2009) and effects of herbicide temperature on susceptibility.

Biofilms, communities of bacteria, algae, fungi, and protozoan that accumulate on surfaces in aquatic environments, and their relationship to herbicide effectiveness has not been investigated thoroughly. 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).

The use of biodegradable hemp mats to eradicate CFW could be investigated for dense localized patches. The new biodegradable bottom barrier requires less maintenance and has less installation problems than the traditional bottom 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 for individual on a species by species basis and has not yet been performed for CFW (Hofstra and Clayton 2012).

Future Directions for Michigan and CFW Management

Carolina fanwort is an aquatic macrophyte that was first introduced into Michigan in the 1890s (Beal 1900). For almost a century it existed in the state without being considered a significant threat to native flora. CFW has developed invasive populations in the Northeastern, Midwestern, and Pacific-Northwestern United States, Australia, China, Malaysia, India, and parts of Europe. It has invaded climates with a wide range in temperature and aquatic conditions, prompting governments in many parts of the world to invest in research.

Prevention – Prevention of new colony establishment is the most cost effective approach to CFW management. The aquarium industry is believed to have been the original pathway for CFW introduction, thus should be targeted for education and enforcement of current state regulations of prohibited plant species. Increased enforcement of current restrictions placed on the distribution and sale of CFW could prevent new introductions (Maki and Galatowitsch 2004). Collaborations between states with similar regulations of CFW and other aquatic invasive species could prove beneficial. Expanding existing coalitions to include organizations that may soon face CFW as an invasive species may also prevent spread. Results of the Great Lakes Commission studies on aquatic invasive species trade could provide avenues of approach to the aquaculture and internet trade to reduce introductions.

Carolina fanwort 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 CFW could aid the reduction of spread of this species.

Monitoring – Early detection would make eradication a more realistic option. Adding CFW to existing monitoring programs will assist in early detection and increase the potential of eradication of CFW. 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 CFW locations and enable early detection responses to new colonies. Connecting waterfront property owners with resources such as MISIN may improve early detection efforts. Education programs in west Michigan water bodies where CFW appears to be spreading would be beneficial.

Carolina fanwort 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 CFW in Michigan. To develop a targeted monitoring strategy, the current known distribution 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 CFW, 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 CFW, water bodies could be prioritized based on the distance (Euclidean and upstream/downstream distance) from infested water bodies, density of CFW in nearby infested water bodies, environmental habitat conditions of CFW, level of recreational activity, number of public access points, vicinity to a store selling aquaria plants, 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 CFW 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 CFW 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 – When managing CFW, it is important to delimit the current extent of infestation, contain already established populations and protect high-value sites. When determining the best integrated pest management plan, factors such as phenotypes, ecotypes, and whether or not the population reproduces sexually or asexually should be taken into consideration. Population genetics, as well as chemical and mechanical control research could help develop more effective management plans.

Flumioxazin shows promise as a chemical treatment, but its effectiveness has yet to be tested thoroughly. Other alternatives for controlling or eradicating CFW include water drawdown of sparse populations and the Netherlands Hydro-venturi system in canals.

Measuring effective control – Following the treatment of CFW, the effectiveness of treatment can be quantitatively assessed through documenting any year-to-year regrowth and reduction in CFW percent cover.

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 the 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 CFW Management

Guidance and Outreach for Carolina fanwort 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 CFW • Increase the frequency and use of boat washing programs • Contain established populations
Prevent other new introductions of CFW	• Educate local and regional aquaria about AIS	• MDARD • Great Lakes Commission	• Reduce sale of invasive CFW in Michigan • Elimination of purposeful and accidental sale of CWF
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 CFW management	• Creation of a CFW technical guide and CFW prioritization tool.		• Increase management efforts
CFW 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 of CFW • 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 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 CFW Management			
Chemical: Develop chemical treatments that will increase management success and minimize the ecological and economical effects	• Resolve contradictions regarding the existence/response of different phenotypes to chemical treatment • Investigate impacts of microbial biofilm on herbicide effectiveness		• More effective treatment options for already established populations • Decrease management effects on non-target species
Biological: Establish biological control methods that will increase control and minimize effects of CFW	• Investigate viability of *Hydrotimetes natans* and *Paracles* spp. as biological controls • Search for biological control species that can be effective in temperate climates		• More effective treatment options for already established populations • Decrease management effects on non-target species
Mechanical: Determine the most effective and economical mechanical methods to mediate the effects of CFW	• Explore methods that limit spread through stem fragmentation • Investigate the effectiveness of hemp bottom barriers on CFW		• Reduce unnecessary dispersal of CFW for colonies too large for effective mechanical removal • Determine a less maintenance approach to bottom barriers for high traffic areas

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